Feasibility Analysis for Petroleum Distribution Centers

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Submitted to:

The Florida Legislature's Office of Program Policy Analysis and Government Accountability (OPPAGA)

Submitted by:

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Table of Contents

Acronyms

Acronym	Definition
AIS	Abbreviated Injury Score
AST	Aboveground Storage Tank
BCR	Benefit-to-Cost Ratio
BEBR	Bureau of Economic and Business Research
BOD/EOD	Beginning of Day/End of Day
CBOB	Conventional Blendstock for Oxygenate Blending into 87 octane gasoline
CDC	Centers for Disease Control and Prevention
E0	Gasoline containing no ethanol
E10	Gasoline containing 10% ethanol
EOC	Emergency Operations Center
ER	Emergency Room
FI&H	Fuel Inventory and Handling Costs
FDEM	Florida Department of Emergency Management
FEMA	Federal Emergency Management Administration
FHP	Florida Highway Patrol
FPHLM	Florida Public Hurricane Loss Model
FPL	Florida Power & Light
GasBuddy	Website (www.gasbuddy.com) that reports service station prices and fuel availability through crowd-sourced data
GIS	Geographic Information System
gal/d	gallons per day
gpm	gallons per minute
HURDAT	HURDAT is a large database of historical hurricane information
MMgal/d	millions of gallons per day
MPH	miles per hour
O&M	Operations and Maintenance
PDC	Petroleum Distribution Center
ROM	Rough Order of Magnitude
SRES	Statewide Regional Evacuation Study
TWIC	Transportation Worker Identification Credential required by the U.S. Department of Homeland Security at ports
UST	Underground Storage Tank
VRU	Vapor Recovery Unit, which captures gasoline vapors that are emitted when a fuel terminal or truck is loaded

Executive Summary

In July 2018, pursuant to proviso language found in Ch. 2018-9, *Laws of Florida*, the Florida Legislature's Office of Program Policy Analysis and Government Accountability (OPPAGA) commissioned ICF to study the feasibility of establishing strategically located petroleum distribution centers (PDCs) in Florida to alleviate storm-related impacts on fuel supply and distribution throughout the state. This study analyzes the challenges that Florida's gasoline supply and distribution network faced during the evacuation that preceded Hurricane Irma and develops strategies for enhancing the system to perform better during future evacuations.

ES-1. Review of Hurricane Irma Fuel Distribution Issues

In early September 2017, evacuation orders were issued for nearly seven million people in Florida ahead of Hurricane Irma, which was barreling toward the state as one of the strongest storms on record, with an uncertain forecast that put both the state's eastern and western coasts in the path of potential danger. This mass evacuation—the largest in the state's history—led to a surge in gasoline demand from evacuees and was further buoyed by residents who decided to shelter-in-place but sought to fill up their vehicles before the storm in the event that fuel was not available in the storm's aftermath. Overall, ICF estimates that Florida statewide retail gasoline sales nearly doubled over the four-day Irma evacuation.

The unprecedented surge in demand led to widespread fuel shortages at retail gas stations—approximately half of the state's gas stations were without gasoline, with nearly every region of the state (except the Western Panhandle) reporting significant outages. Although there was sufficient gasoline supply available at primary storage terminals in Florida to meet the needs of evacuees, the fuel distribution network simply could not deliver fuel from the terminals to retail stations fast enough to meet the demand.

The most important factor limiting the fuel distribution network during the Irma evacuation was that petroleum terminals did not have sufficient excess truck-loading capacity to handle a doubling of normal demands. This led to long lines and long waits for tanker trucks at Florida's petroleum terminals. Heavy traffic on the state's major roadways was another key limiting factor, particularly for markets far from primary terminals where the long distances compounded traffic issues exponentially.

ES-2. Potential Fuel Distribution Network Enhancements

To alleviate retail fuel availability issues during future Florida evacuations, ICF evaluated a two-pronged strategy aimed at enhancing the state's gasoline deliverability—the capacity of primary terminals to out-load fuel and deliver it to retail stations. The two strategies are:

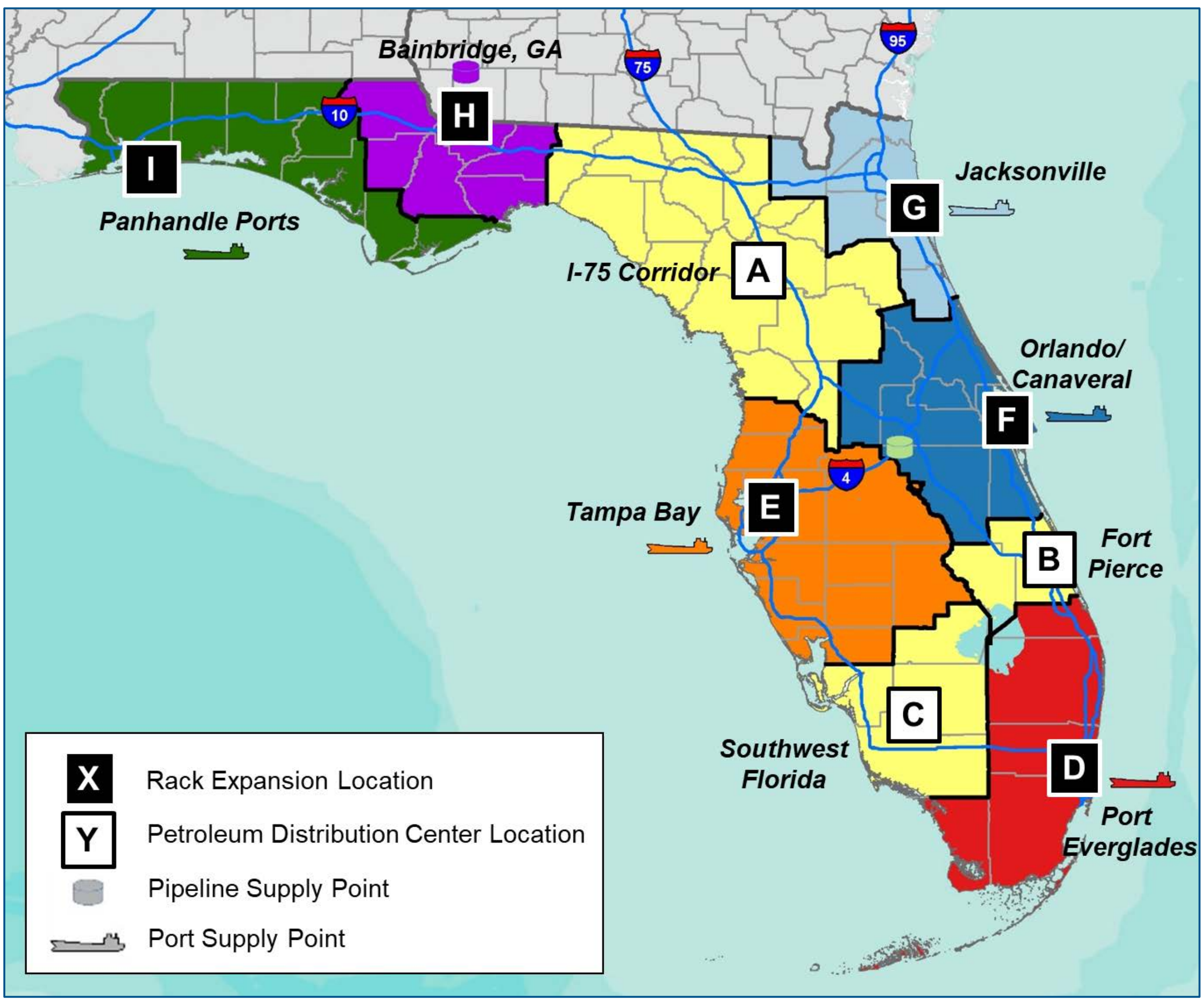
1. **Debottlenecking Fuel Distribution at Existing Terminals (Rack Expansions):** In areas of the state close to (less than 100 miles from) major supply sources, truck-loading (rack) capacity could be expanded at existing terminals that have sufficient storage inventories to support increased demand. This can be done either by building new truck-loading bays and associated pumps, or by increasing maximum loading rates at existing loading bays. In addition, other actions can be taken to streamline deliveries from existing terminals, such as providing guides at terminals to expedite truck loading, providing additional police escorts to help move trucks through traffic to areas

experiencing shortages, and providing methods to bring additional trucks and drivers into the state to provide additional fuel transportation service during emergencies. Debottlenecking would be the optimal strategy for Florida fuel markets close to Port Everglades, Tampa, Orlando, Port Canaveral, Jacksonville, the Panhandle ports, and the Bainbridge, GA, terminal that supplies the Eastern Panhandle.

2. **Establish Petroleum Distribution Centers:** In areas of the state that are remote from primary terminals, it may be beneficial to establish PDCs—state-owned facilities that consist of both gasoline storage and truck-loading capability. PDCs can either be configured as small terminals—consisting of aboveground storage tanks, truck-loading rack facilities, and associated infrastructure—or as rail-to-truck transloading facilities that utilize rail tank cars to hold inventory and mobile pump carts to load fuel directly from the railcars into tanker trucks. Potential PDC sites include the I-75 Corridor from Wildwood to the Georgia border, the Fort Pierce area near where I-95 and the Florida Turnpike intersect, and Southwest Florida, including the cities Naples, Cape Coral, and Fort Myers.

Exhibit 1 maps out the proposed locations of each of the system enhancements described above.

Exhibit 1. Potential Fuel Distribution Network Enhancements



The fuel network enhancement strategies evaluated in this study add value by adding excess deliverability to the gasoline distribution system (beyond the system's current capacity). This capacity would be reserved for use at the state's direction to enable more fuel to reach consumers during high-demand evacuation periods. To implement either strategy, the state would need to contract with private companies to build, operate, and manage the infrastructure. Considerations for how to structure the arrangements between the state and the infrastructure operators are discussed later in this report, as are technical considerations with operating the PDCs, such as the need to manage fuel inventories, fuel supply, and fuel sales and distributions.

ES-3. Optimal Size of Potential Fuel Distribution Network Enhancements

To estimate the optimal size and configuration of the potential fuel distribution network enhancements, ICF conducted a cost-benefit analysis on several size and infrastructure combinations. For each option evaluated, the analysis compared the potential benefits—defined as lives saved and injuries avoided due to greater fuel availability, allowing faster and more complete evacuations—against the costs of building, operating, and managing the required infrastructure. These potential future costs and benefits were estimated using a Monte Carlo simulation that modeled future hurricane landfalls, sizes, intensities, and the resulting evacuation fuel demands across a 20-year period. Using this approach, ICF identified the configuration that delivered the highest level of total benefits while also providing a benefit-to-cost ratio strong enough to withstand potential unfavorable changes in key model inputs. This configuration (detailed in Exhibit 2) provides a total deliverability of approximately 8.2 million gallons per day (MMgal/d), with 6.9 MMgal/d provided through rack expansions at existing terminals and 1.3 MMgal/d provided through the development of two PDC sites in the I-75 Corridor and the Fort Pierce regions. ICF estimates that the upfront cost of developing this infrastructure would total approximately $29.2 million, with annual operating costs of about $1.7 million per year.

Exhibit 2. Fuel Network Enhancements – Optimal Size and Configuration

Location	Working Storage Volume (gal)	Deliverability (gal/d)
PDCs		
A) I-75 Corridor	2,600,000	860,000
B) Fort Pierce	1,300,000	430,000
C) Southwest	–	–
PDC Total	**3,900,000**	**1,290,000**
Rack Expansions		
D) Port Everglades	–	2,580,000
E) Tampa Bay	–	2,150,000
F) Orlando/Canaveral	–	1,290,000
G) Jacksonville	–	860,000
H) Bainbridge	–	–
I) Panhandle Ports	–	–
Rack Expansion Total	**–**	**6,880,000**
Total	**3,900,000**	**8,170,000**

1. Introduction

In early September 2017, Hurricane Irma threatened South Florida as a massive Category 5 storm. As Irma approached the state, its projected track shifted several times, first threatening Miami and the state's Atlantic Coast before shifting west, where it eventually moved through the Florida Keys and up the state's western coast, affecting Southwest Florida, Tampa, and the Eastern Panhandle. The size and intensity of the storm and the large swath of population threatened by the changing path resulted in evacuation orders being issued for nearly 7 million Floridians—the largest mass evacuation in the state's history. The Irma evacuation resulted in traffic jams on the state's main northbound highways and a surge in demand for gasoline from evacuating motorists. Residents with plans to ride out the storm further boosted demand as they stocked up on gasoline to ensure that they had adequate supply, if needed, in the aftermath of the storm.

Florida's fuel distribution network worked around the clock to keep fuel supply moving; however, the unprecedented surge in demand exceeded the network's capabilities, leading to widespread outages at retail gas stations. Although there was plenty of gasoline supply at the state's bulk storage facilities, primarily located at the ports, that supply could not be distributed to retail stations fast enough to keep up with the demand. By the time the storm made landfall, approximately half of the state's gas stations were out of supply, with virtually every region of the state experiencing shortages.

In July 2018, pursuant to proviso language found in Ch. 2018-9, *Laws of Florida*, the Florida Office of Program Policy Analysis and Government Accountability (OPPAGA) commissioned ICF to study the feasibility of establishing strategically located petroleum distribution centers (PDCs) in Florida to alleviate storm-related impacts on fuel supply and distribution throughout the state. The following report presents the results of this study. The report includes:

- A description of Florida's fuel supply and distribution infrastructure (Chapter 2);
- A review of how supply and demand behaved during the Irma evacuation, including an analysis of wholesale gasoline deliveries and retail station outages (Chapter 3);
- An evaluation of potential solutions to strengthen the ability of Florida's fuel distribution network to meet evacuation demands during future storms (Chapter 4);
- A cost-benefit analysis of the potential solutions identified (Chapter 5); and
- A summary of the study's findings and a discussion of next steps in the development of the identified solutions (Chapter 6).

This study focuses on actions to strengthen gasoline availability for motorists during mass evacuations in the State of Florida. Although diesel and jet fuel are important transportation fuels for the state, the stakeholders interviewed for this study did not identify major shortages of those fuels during the Irma evacuation. This study also focuses only on the evacuation period prior to a storm's landfall—a period when fuel supply is critical for people seeking to quickly get out of harm's way. In the aftermath of a hurricane, storm damage, power outages, and port closures can have a major impact on fuel supply and availability in the state. While post-storm fuel availability is critical for emergency responders and for backup power resources, the state effectively manages these issues through other means, and post-storm fuel availability is outside the scope of this study.

To inform the results of this study, ICF analyzed data from multiple sources, including the Florida Department of Emergency Management, Florida Department of Revenue, Florida Department of Environmental Protection, Florida Department of Transportation, U.S. Energy Information Administration, U.S. Army Corps of Engineers, National Hurricane Center, and GasBuddy.com, among others. In addition, ICF spoke with major stakeholders, including state officials and emergency managers, representatives from Florida industry associations, trucking companies, retail station owners, and operators and managers of Florida's petroleum infrastructure.

The end goal of this study is to help Florida policymakers better understand the underlying causes of fuel shortages during mass evacuations, and to identify and evaluate potential solutions to strengthen Florida's fuel distribution network to alleviate those shortages.

2. Overview of Florida's Gasoline Markets

Key Takeaways

- Florida's gasoline supply is primarily delivered by tanker and barge to the state's ports—Port Everglades, Port Tampa, Port Manatee, Port Canaveral, JaxPort, and the four ports in the western Panhandle. A pipeline-fed terminal in Georgia also supplies fuel to the Tallahassee area.
- In 2016, statewide inventories of gasoline and gasoline blendstock (not including ethanol) at the state's primary fuel terminals ranged from 11 to 16 days of normal supply.
- Working inventories of finished gasoline (including ethanol content) at the state's gas stations are estimated to average approximately three to five days of normal supply.

Florida's gasoline and other petroleum products are overwhelmingly supplied via marine tankers and barges that deliver into the state's ports—primarily the ports of Tampa, Manatee, Everglades, Jacksonville, Canaveral, and ports along the Florida Panhandle. Florida's marine terminals offload the products, store them in bulk storage tanks, and distribute them to individual service stations by truck. In addition to marine supply, the Florida Panhandle also is supplied by truck from distribution terminals in southern Georgia that receive fuels from the Colonial Pipeline, and from terminals in southern Alabama and Mississippi. Ethanol, which makes up approximately 10% of Florida's gasoline supply, is shipped into the state via both rail and the ports. The only long-distance pipeline transporting gasoline in the state is Kinder Morgan's Central Florida Pipeline, which runs from the Port of Tampa to a distribution terminal in Orlando.

Total sales of finished motor gasoline (including ethanol content) in Florida are approximately 25 million gallons per day (MMgal/d). Florida's gasoline consumption is high on a per capita basis because of the tourism industry, which attracts a sizeable population of out-of-state visitors. The state has 34 primary terminals with a total gasoline storage capacity of 614 million gallons (MMgal), not including ethanol.[1] Over the past three years, gasoline stocks in Florida (not including ethanol stocks or gasoline stocks at terminals in neighboring states) ranged between 240 and 354 MMgal, or enough to meet approximately 11 to 16 days of average gasoline sales (excluding ethanol).[2] Over this period, gasoline stocks at primary terminals averaged approximately 13 days of supply.

Exhibit 3 maps every retail gas station in Florida and identifies the source of supply for each station. The exhibit divides the state into five regions that correspond to the primary gasoline supply patterns. For regional maps of Florida's petroleum infrastructure, including primary terminals, pipelines, and retail gas stations, see *Appendix B: Florida's Fuel Supply and Distribution Infrastructure.*

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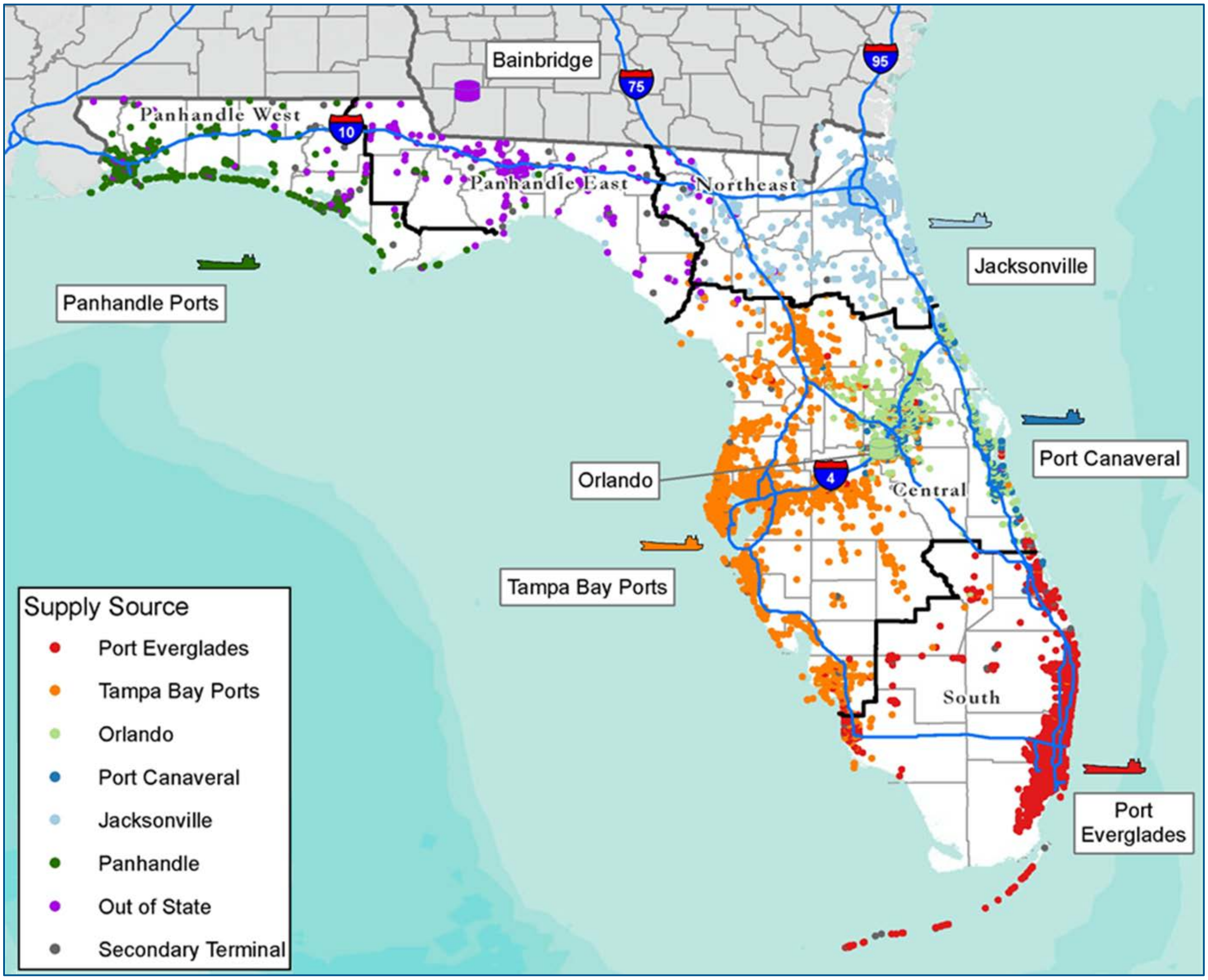
[1] Ethanol tanks are not regulated by the Florida Department of Environmental Protection or any other Florida agency.

[2] U.S. Energy Information Administration (EIA). Florida Gasoline Blending Components Stocks at Refineries, Bulk Terminals, and Natural Gas Plants and Florida Finished Motor Gasoline Stocks at Refineries, Bulk Terminals, and Natural Gas Plants.

Exhibit 3. Florida's Retail Gas Stations by Source of Supply



Source: ICF analysis of data from the Florida Department of Revenue and Florida Department of Environmental Protection .

Region	Primary Supply Source(s)
South Florida	Port Everglades
Central Florida	Port Tampa Bay, Port Manatee, Orlando, and Port Canaveral
Northeast Florida	JaxPort
Panhandle East	Bainbridge, GA (Colonial Pipeline)
Panhandle West	Ports of Pensacola, Panama City, Niceville, and Freeport

2.1. Florida's Current Fuel Market

2.1.1. Gasoline Supply

Florida's gasoline supply is primarily shipped into the state via coastal ports. Exhibit 4 presents average daily gasoline supply (not including ethanol) in ports in each of the previously defined supply regions in 2016, according to data from various sources. The exhibit shows that approximately 21.3 MMgal/d of gasoline entered Florida in 2016. Most of this volume—20.8 MMgal/d—enters by marine vessel to terminals at Florida's ports, with the remainder trucked in from surrounding states. In addition, ethanol makes up approximately 10% of Florida's gasoline supply and an additional 2.1 MMgal/d of ethanol is estimated to have been received into the state by rail, marine tanker, and barge for gasoline blending. In total, ICF estimates that Florida's gasoline supply (including ethanol) totaled 23.4 MMgal/d in 2016.

Exhibit 4. Florida Gasoline Supply by Source and Region, 2016

		Supply (gal/d)[A]	
Region	**Supply Source**	**Source**	**Region Total**
South	Port Everglades	6,436,000	**6,436,000**
Central	Port Tampa[B]	8,753,000	**10,505,000**
	Port Manatee	355,000	
	Port Canaveral	1,397,000	
Northeast	JaxPort	2,747,000	**2,747,000**
Panhandle East	Southern Georgia[C]	547,000	**547,000**
Panhandle West[3]	Port of Pensacola	323,000	**1,091,000**
	Port Niceville	295,000	
	Port Panama City	247,000	
	Port Freeport	148,000	
	Southern AL/MS[D]	78,000	
Florida Total		**21,326,000**	

A. Includes gasoline and gasoline blendstocks (excluding ethanol).
B. Includes supply received in Tampa and shipped by pipeline to Orlando on the Central Florida Pipeline.
C. Includes truck deliveries from Colonial Pipeline-fed terminals in Bainbridge and Albany, GA.
D. Includes truck deliveries from Mobile, AL, and Pascagoula, MS, terminals.
Source: ICF analysis of data from the U.S. Army Corps of Engineers, Waterborne Commerce of the United States (2016); EIA Company Level Imports (2016); and Florida Department of Revenue.

2.1.2. Primary Terminal Gasoline Storage

Florida terminals, on average, hold gasoline inventories equal to nearly two weeks of normal supply. Exhibit 5 presents the gasoline storage capacity and estimated average working inventories at primary terminals in Florida. Florida terminals have a total gasoline shell capacity of 614 MMgal. Assuming that each tank has unusable tank bottoms of 10% and is, on average, utilizing 50% of its usable storage capacity at any given time, this equates to approximately 13.3 days of supply given average 2016 gasoline receipts at primary terminals. On a regional basis,

[3] The recent impact of Hurricane Michael closed the ports in the Panhandle West region. Panama City was the hardest hit, and it returned to service on October 22, 2018, roughly 10 days after landfall.

estimated days of supply range from about nine days in the Panhandle West region to 24 days in Northeast Florida.

Exhibit 5. Florida Primary Terminal Days of Supply by Region

Region	Gasoline Storage Capacity (MMgal)[A]	Est. Avg. Working Inventory (MMgal)[B]	Truck-Loading Bays[C]	2016 Avg. Terminal Sales (MMgal/d)	Est. Days of Supply
South	165.6	74.5	48	6.4	**11.6**
Central	283.8	127.7	80	10.5	**12.2**
Northeast	143.8	64.7	31	2.7	**23.6**
Panhandle East[D]	N/A	N/A	N/A	N/A	**N/A**
Panhandle West	20.6	9.3	9	1.1	**8.5**
Florida Total	**613.8**	**276.2**	**168**	**20.8**	**13.3**

A. Gasoline tank shell storage capacity per Florida Department of Environmental Protection (does not include ethanol).

B. Based on an estimate of working storage to be 90% of the shell capacity and assuming working inventory levels are 50% full, on average.

C. Loading bay data included where available from Title V permits.

D. Bainbridge, GA, terminals supply this region. There are no Florida terminals within this region.

2.1.3. Gasoline Demand

Retail gas stations account for the vast majority of Florida's gasoline demand. Exhibit 6 shows normal wholesale gasoline sales (including ethanol content) from primary and secondary terminals to buyers in Florida based on a sample of data obtained from the Florida Department of Revenue. Total wholesale gasoline sales in the state totaled 24.9 MMgal/d over the sample period, although this volume may include some double counting of volumes first sold from primary terminals to secondary (distributor) terminals and then subsequently sold to end users.[4] The exhibit shows that wholesale sales to retail gas stations averaged 23.1 MMgal/d, or approximately 93% of total sales. The remaining sales were made to government buyers (state, county, and local), other users (primarily commercial, agricultural, and marine users), and buyers who were unregulated or unclassified according to Department of Revenue data.

Exhibit 6. Wholesale Gasoline Sales by Region and Buyer Type, 2017 Sample (MMgal/d)

Region	Retail Station	Government	Other User	Unregulated/ Unclassified	Total
South	7,370,000	112,000	215,000	342,000	**8,040,000**
Central	11,278,000	95,000	245,000	410,000	**12,028,000**
Northeast	2,698,000	24,000	46,000	84,000	**2,852,000**
Panhandle East	612,000	9,000	6,000	51,000	**678,000**
Panhandle West	1,188,000	11,000	25,000	75,000	**1,299,000**
Total	**23,145,000**	**250,000**	**538,000**	**963,000**	**24,896,000**

Source: ICF analysis of Department of Revenue data (August 27 – September 4, 2017).

[4] Total wholesale sales were 24.9 MMgal/d over the sample period, compared with average wholesale sales of 25.1 MMgal/d in fiscal year 2016–2017.

2.1.4. Retail Gas Station Gasoline Storage

Florida's 7,338 retail gas stations, on average, hold gasoline inventories equal to about three to five days of supply. Exhibit 7 presents gasoline storage capacity and estimated average working inventories at retail gas stations in Florida. Florida gas stations have a total gasoline tank shell capacity of 184 MMgal. Assuming approximately 5% of this capacity consists of unusable tank bottoms that cannot be pumped and that each station utilizes 50% of its storage capacity, on average, this equates to approximately 3.8 days of supply given normal wholesale gasoline sales (including ethanol content) to retail gas stations. Estimated days of supply at Florida gas stations range from 3.3 days of supply in South Florida to 4.9 days of supply in the Panhandle East region.

Exhibit 7. Florida Gas Station Days of Supply by Region

Region	Number of Gas Stations	Gasoline Storage Capacity (MMgal)[A]	Est. Avg. Working Inventory (MMgal)[B]	2017 Sample Gasoline Sales (MMgal/d)[C]	Est. Days of Supply
South	1,947	50.6	24.0	7.4	3.3
Central	3,664	93.5	44.4	11.3	3.9
Northeast	915	22.7	10.8	2.7	4.0
Panhandle East	314	6.3	3.0	0.6	4.9
Panhandle West	498	10.6	5.0	1.2	4.2
Florida Total	**7,338**	**183.7**	**87.3**	**23.1**	**3.8**

A. Gasoline tank shell storage capacity per Florida Department of Environmental Protection (includes ethanol).
B. Based on an estimate of working storage to be 95% of the shell capacity and assuming working inventory levels are 50% full, on average.
C. 2016 retail station gasoline sales (including ethanol content) from the Department of Revenue. Does not include gasoline consumption at non-retail sites (e.g., state or county government use, agricultural use).

2.2. Florida Fuel Market Growth

For the most part, this study considers current gasoline supply and demand patterns, developing analysis, and potential fuel distribution network enhancements. These enhancements are intended to be put in place relatively quickly (within one or two years) to address the problems that the state is likely to face over the next 10 to 20 years. However, the estimation of potential benefits in Chapter 5 recognizes that population growth is likely to lead to potentially larger evacuations and larger surges in gasoline demand, and these estimations are considered when assessing the optimal size of the system enhancements proposed.

Data from the University of Florida's Bureau of Economic and Business Research (BEBR)[5] indicates that Florida's population could grow to approximately 25.5 million by 2035, an increase of almost 4 million from 2017.[6] Assuming that the state's fuel demands increase proportionally with population growth, Florida's gasoline consumption could increase from the 24.9 MMgal/d in 2016 to about 29 MMgal/d in 2035. While increased penetration of electric vehicles and increased use of public transportation may help mitigate some demand growth, it is unlikely that

[5] https://www.bebr.ufl.edu/population
[6] According to BEBR, the range of population growth could be from 2.6 million at the low end to 5.2 million on the high end.

they will have a significant impact on growth in gasoline demand during evacuation periods. Vehicle fuel efficiency is likely to continue to increase over the next 20 years; however, this may be offset, to some degree, by the trend toward larger vehicles, such as sport utility vehicles.

Florida petroleum terminal owners, suppliers, and retail dealers are likely to make investments in the fuel distribution network needed to serve future growth in gasoline demand. These investments will add capacity to the fuel supply and distribution network; however, this capacity will be designed to serve the growing normal daily demands. The system enhancements proposed later in this study, in contrast, are designed to increase the network's gasoline deliverability to meet surges in demand above normal daily throughputs.

3. Review of Hurricane Irma Evacuation Fuel Distribution Issues

Key Takeaways

- Approximately half of all retail gas stations in Florida were out of gasoline after the Irma evacuation, according to data from GasBudddy.com.
- Although gasoline stocks at primary terminals in Florida were sufficient to meet evacuation demands, truck-loading limitations at terminals and traffic issues slowed the ability to deliver fuel from the terminals to retail stations.
- Overall, ICF estimates that the fuel shortage during the Irma evacuation totaled approximately 49.1 MMgal, or approximately 16.4 MMgal/d if apportioned over the three heaviest evacuation days.

This chapter reviews the characteristics of the Hurricane Irma evacuation and analyzes the fuel supply, distribution, and demand patterns and issues experienced during the evacuation period. The analysis in this chapter draws on available fuel system data and interviews with industry stakeholders to identify where the fuel supply chain was most constrained in the period before Irma's landfall, and quantifying—to the extent possible—where problems were the most severe. The purpose of this task is to inform the configuration, size, and location of potential enhancements to Florida's fuel distribution network. As part of this task, ICF reviewed:

- Reports prepared by the Government of Florida, including Hurricane Irma's Effect on Florida's Fuel Distribution System and Recommended Improvements, prepared by the Florida Department of Transportation;
- Presentations on fuel supply issues made by various stakeholders to the Florida Legislature's Select Committee on Hurricane Response and Preparedness;
- Interviews with stakeholders, including port officials, petroleum terminal operators, petroleum wholesale marketers, retail station operators, and industry groups representing the petroleum industry; and
- Data from various sources, including data on Florida gasoline inventories, tanker arrivals at Florida ports, wholesale gasoline sales, and retail gas station outages.

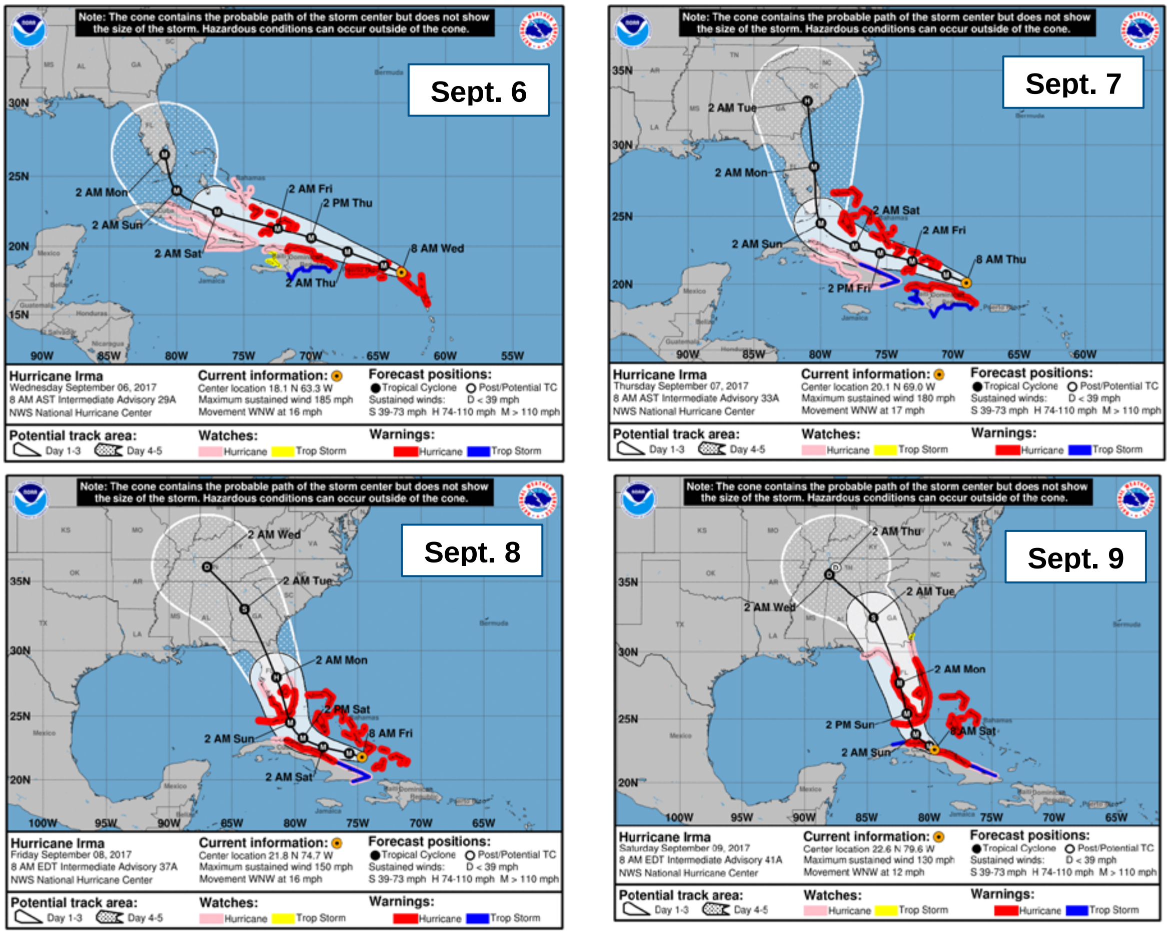
3.1. Hurricane Irma Evacuation Characteristics

Hurricane Irma first developed as a storm in the Atlantic Ocean on August 30, 2017. By September 4, it became clear that Irma would likely affect Florida as a major hurricane (wind speeds > 110 miles per hour [mph]) over the next five days. The September 4 forecast prompted the Governor, working with Florida counties and cities, to issue mandatory evacuation orders for counties in South Florida and voluntary evacuation orders for the remainder of the state.[7] By September 5, Irma had strengthened to a Category 5 storm, and by September 6 had reached peak sustained wind speeds of 185 mph. Between September 5 and 9, the forecast track of the storm shifted several times (see Exhibit 8), prompting an expansion of the evacuation orders. On September 7, the track shifted eastward, putting Irma on a path through the Miami metropolitan area and up the state's Atlantic Coast. On September 8–9, the forecast shifted back to west, eventually settling on Irma's eventual track with the storm making landfall

[7] http://www.fdot.gov/info/CO/news/newsreleases/020118_FDOT-Fuel-Report.pdf

in the Florida Keys on the morning of September 10, before moving up the state's western coast through Southwest Florida, Tampa, and the Eastern Panhandle on September 10–11. The shifting forecast of the storm meant that much of the state was put under mandatory evacuation orders at one point or another between September 4 and 9. The Florida Division of Emergency Management estimates that a record-breaking 6.8 million people were given mandatory evacuation orders in the days before Irma's landfall.

Exhibit 8. Hurricane Irma Forecast Tracks, September 6–9, 2017



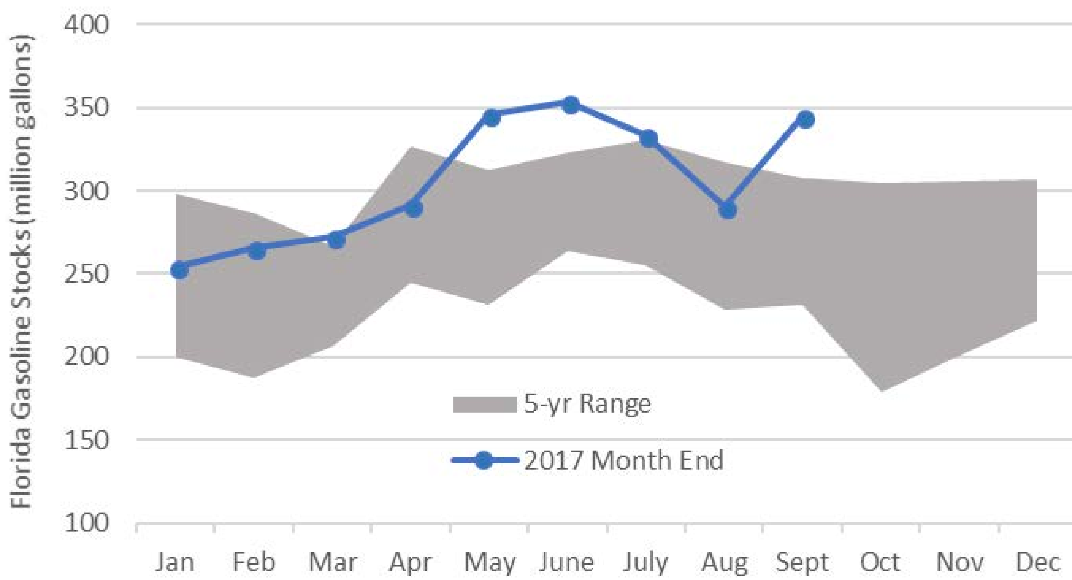
Source: National Hurricane Center, IRMA Graphics Archive.

3.2. Fuel Supply

3.2.1. Primary Terminal Gasoline Inventories

The Irma evacuation led to a drawdown of gasoline inventories at Florida's primary petroleum terminals; however, sufficient fuel remained in the terminal to meet the demands. Exhibit 9 presents month-end gasoline inventory levels at Florida terminals in 2017, compared with the previous five-year range, according to data from the U.S. Energy Information Administration (EIA). At the end of August—four days before the Governor issued evacuation orders—there were 290 MMgal of gasoline at primary terminals statewide, equal to nearly 12 days of normal daily demands and well within the five-year range for the time of year. During the Irma evacuation, state officials at the Florida Emergency Operations Center (EOC) were in daily contact with port and terminal operators to track the status of the state's bulk fuel supplies. State officials noted that gasoline stocks, at their lowest point, fell to approximately 125 MMgal, or about five days of normal demand. If EIA and EOC stock data cover the same terminal respondent group (which they may not), this would represent a net gasoline drawdown of approximately 165 MMgal, or about 57%, from the end of August. Even though evacuation gasoline demands drew down terminal inventories, substantial volumes of gasoline remained at the terminals. Operators surveyed by ICF for this study noted that only a small number of terminals had to restrict truck loadings because of low inventories during the Irma evacuation.

Exhibit 9. Florida Month-End Gasoline Inventories at Bulk Terminals, 2017



Source: EIA Refinery, Bulk Terminal, and Natural Gas Plant Stocks by state.

3.2.2. Tanker Ship Arrivals at Florida Ports

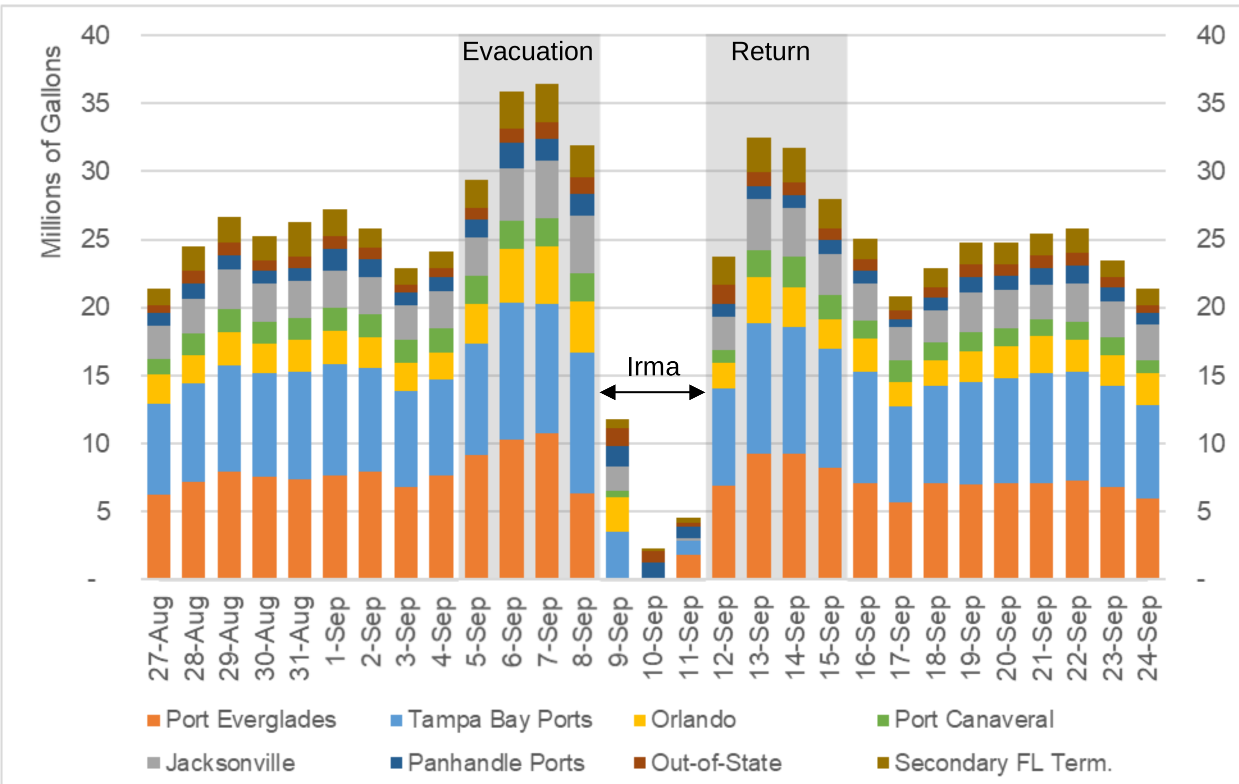
Tanker ships continued to supply gasoline and other fuels into Florida terminals up until the ports closed. ICF reviewed data on tanker ship arrivals at Florida ports. On average, the state's ports received approximately three tankers per day. These tankers are typically medium-size tankers, carrying approximately 12 to 14 MMgal of petroleum products (gasoline, diesel, or jet fuel). Some of these tankers deliver full loads, while others deliver partial loads as part of a "milk run" to multiple ports. During September 5–8, tanker shipments into Florida continued to average approximately three tanker arrivals per day. The last tanker arrivals prior to Irma occurred on September 7 in Port Everglades and September 8 in Tampa. Port Everglades and Tampa opened quickly after the storm passed, each receiving their first cargoes on September 12.

3.3. Fuel Distribution

3.3.1. Petroleum Terminal Truck Distribution

Tanker truck deliveries of gasoline from petroleum terminals to retail gas station increased by approximately one-third during the Irma evacuation. Exhibit 10 charts wholesale gasoline deliveries to Florida purchasers, in millions of gallons, broken down by supply source before, during, and after Hurricane Irma. These deliveries, which are tracked by the Florida Department of Revenue, are registered at truck-loading racks at in-state and out-of-state primary and secondary terminals. Approximately 93% of these deliveries are from terminals to retail gas stations, with the remainder made up of sales to other end users (state or local governments or large commercial accounts) or sales from primary terminals to secondary (distributor) terminals.

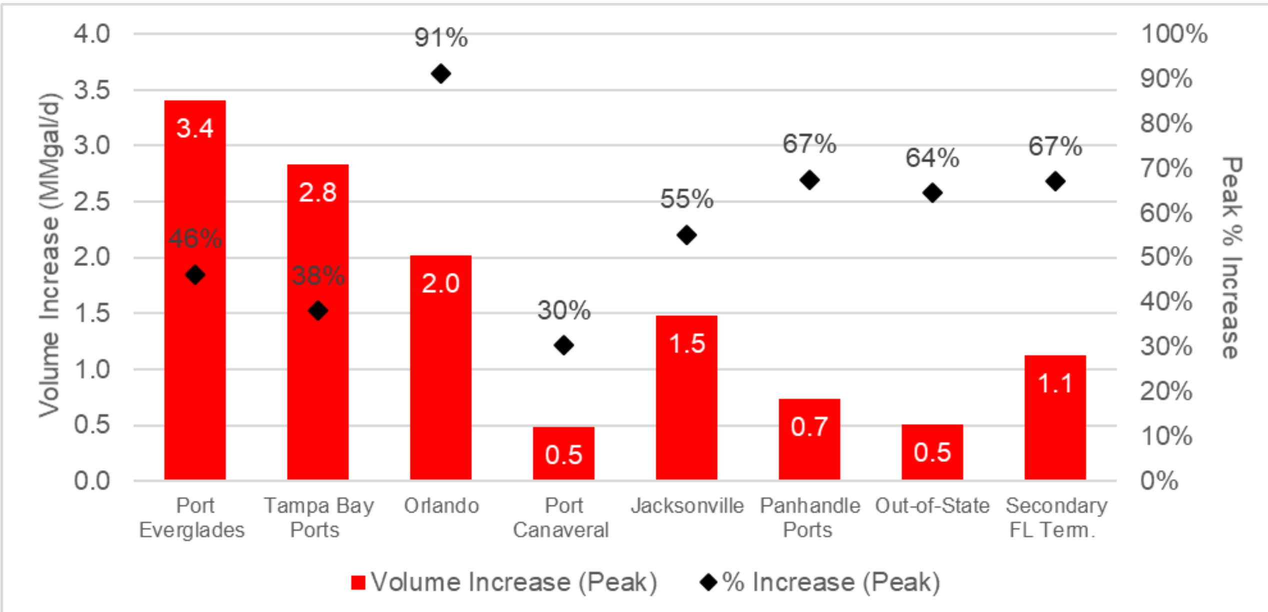
Exhibit 10. Wholesale Gasoline Deliveries From Petroleum Terminals to Florida Retail Stations, August 27 – September 24, 2017



Source: ICF analysis of Florida Department of Revenue data.

Exhibit 10 shows that during the normal demand period before the Hurricane Irma evacuation—from August 27 to September 4, 2017—wholesale gasoline deliveries averaged approximately 24.9 MMgal/d. This period includes the Labor Day holiday weekend (September 2–4), which is a popular travel weekend. During the Irma evacuation period—from September 5–8, 2017—deliveries rose rapidly, averaging 33.4 MMgal/d, an increase of more than a third. Gasoline deliveries peaked at 36.4 MMgal/d on September 7, an increase of more than 45%. This increase in volume represents the ability of in-state and out-of-state suppliers and distributors to increase gasoline supply out of wholesale facilities to serve retail evacuation demand. (Note: This does not mean that the supply increase was sufficient to meet the demand from motorists at retail stations.) The volume increase during the evacuation period was not consistent across supply sources, with distribution from each source peaking on different days (either September 6 or 7). Exhibit 11 charts the peak increase in daily gasoline deliveries by supply source over the Irma evacuation period. This increase is shown in volumetric terms (MMgal/d) and as a percentage of normal supply.

Exhibit 11. Florida Peak Wholesale Gasoline Delivery Increases During the Irma Evacuation by Supply Source



Source: ICF analysis of Florida Department of Revenue data.

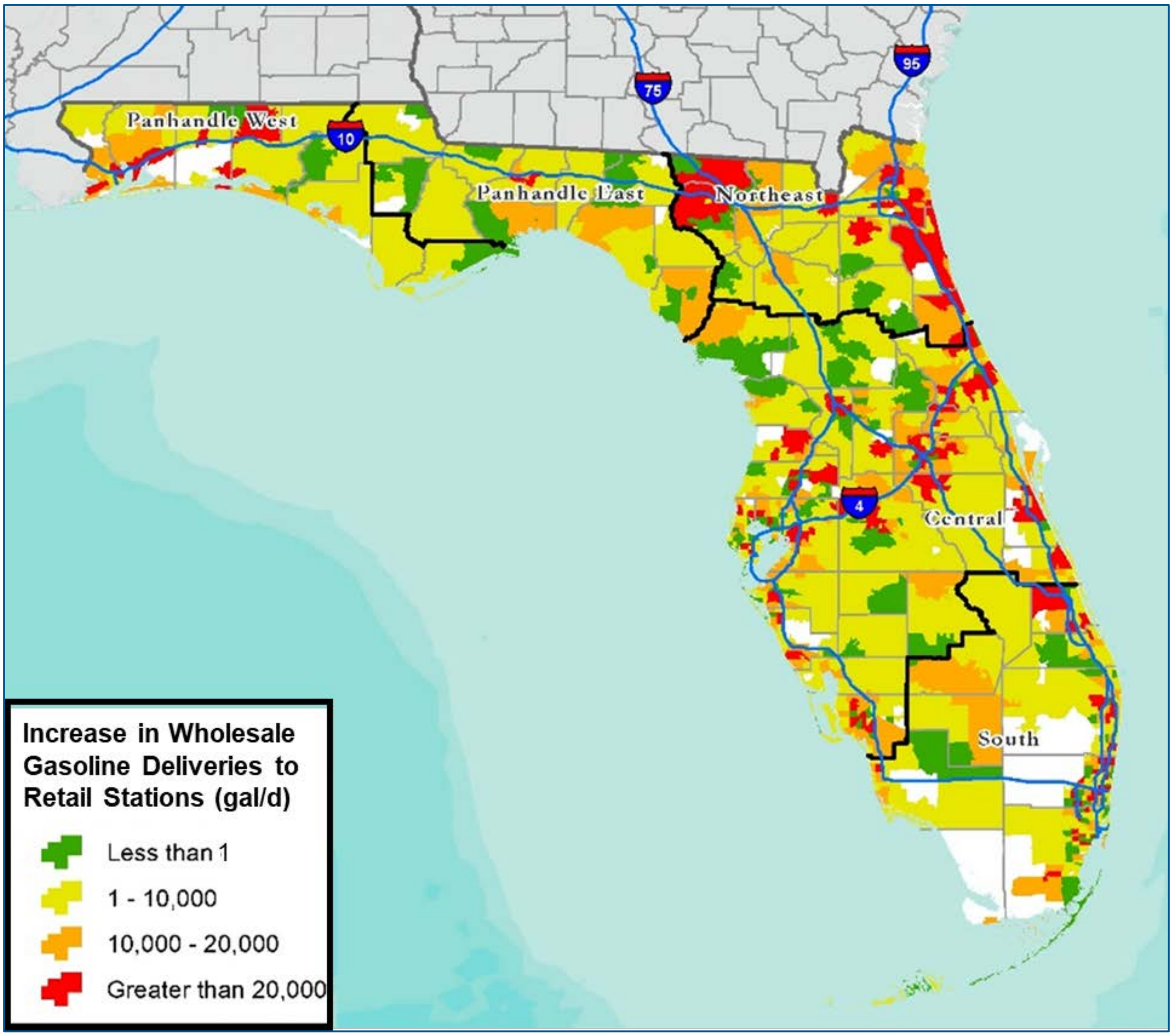
Exhibit 11 shows that peak distribution rose the most in absolute terms from Port Everglades and Tampa, which are the two largest sources of supply in Florida. On a percentage basis, however, distribution increased the most from Orlando, with deliveries increasing by 91%. This spike in deliveries from Orlando may represent the terminal's greater spare capacity to load trucks, greater availability of truck drivers to load and distribute fuel, less congestion or traffic chokepoints on routes out of the terminal, and/or greater increases in demand from stations close to the Orlando terminal.

3.4. Fuel Demand

3.4.1. Wholesale Deliveries to Retail Stations

Truck deliveries to retail gas stations increased in nearly every Florida market during the Irma evacuation, but were highest in major metropolitan areas and along major evacuation routes. Exhibit 12 maps each ZIP code in Florida, with different colors indicating the percentage increase in wholesale gasoline deliveries during the Irma evacuation compared with the normal pre-evacuation deliveries. Wholesale deliveries represent truck deliveries of gasoline from terminal suppliers to retail stations and are an indicator of retail demand. Often, retail gas stations automatically order wholesale truck deliveries to resupply their facilities when the supply inventory falls below a certain level in their storage tanks. Exhibit 12 indicates that wholesale purchases increased in virtually every ZIP code in the state. ZIP codes that saw the greatest increases in purchases—greater than 20,000 gallons—were primarily located either in major metropolitan areas near supply terminals (Miami, Tampa, Orlando, and Jacksonville) or along key evacuation routes (I-95, I-75, I-4, and Florida's Turnpike).

Exhibit 12. Increases in Florida Gas Station Daily Wholesale Gasoline Deliveries by ZIP Code During the Irma Evacuation



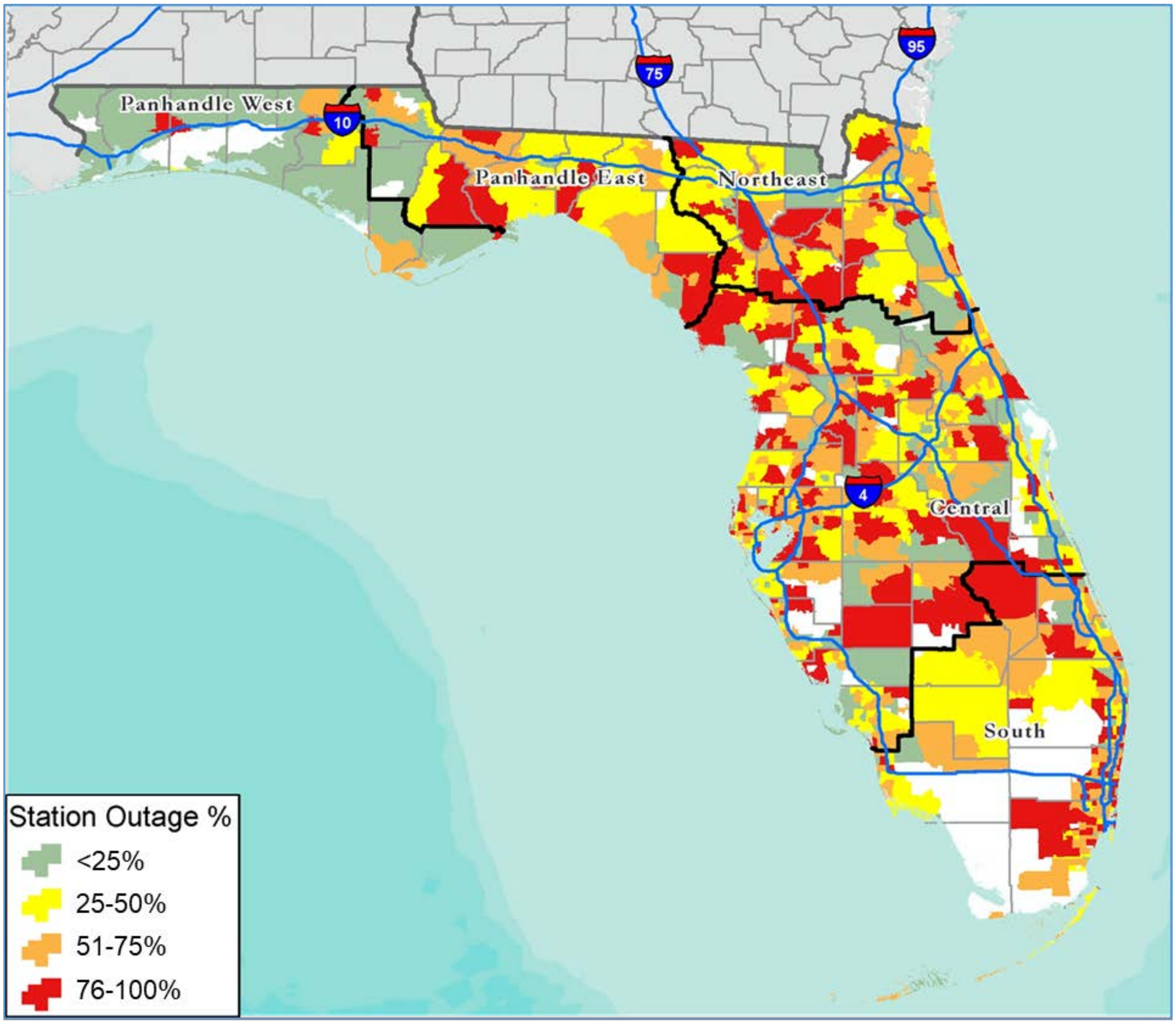
Source: ICF analysis of Florida Department of Revenue data.

3.4.2. Retail Station Outages

Fuel outages at retail gas stations in Florida were widespread during the Irma evacuation as retail gasoline demand exceeded wholesale deliveries, thus drawing down station inventories. Exhibit 13 maps the percentage of retail gas stations without fuel in Florida by ZIP code, as reported on the afternoon of September 11, 2017, the earliest date for which data were available from GasBuddy.com, a website and smartphone application that crowd sources information on gas station operations during emergencies. Retail station managers and consumers report fuel availability at gas stations to GasBuddy directly through the smartphone app. During the Irma evacuation, Governor Rick Scott encouraged Floridians to use the app to locate stations with fuel. Because of the way this data is collected, station information may not always be regularly updated, particularly during the period when the storm is affecting the state.

For example, on the afternoon of September 11, 2017 (while Irma was still affecting much of the state), the statuses for most stations were last updated on either September 9 or 10. Exhibit 13 shows a high level of outages across the state, with the exception of the Panhandle West region, which was outside the projected path of the storm and did not see as large an increase in traffic during the evacuation period.

Exhibit 13. Percentage of Retail Gas Station Fuel Outages by ZIP Code on September 11, 2017, One Day After Irma Landfall



Source: ICF Analysis of GasBuddy.com data.

Exhibit 14 provides a summary of station outages by region, including the total number of stations, the number of stations reported without gasoline, and the percentage of stations without gasoline as of September 11, 2017. Exhibit 14 shows that the percentage of station outages was highest in the South region, where 62% of all retail stations lacked fuel on September 11. Meanwhile, approximately half of all stations were without fuel in the Central, Eastern, and Panhandle East regions. Statewide, 52% of the stations had no fuel.

Exhibit 14. Total Stations and Station Outages by Region, September 11, 2017

Region	Total Stations	No Fuel (Sept. 11)	% Out
South	1,947	1,212	**62%**
Central	3,664	1,882	**51%**
Northeast	915	498	**54%**
Panhandle East	314	156	**50%**
Panhandle West	498	42	**8%**
Grand Total	**7,338**	**3,790**	**52%**

Source: ICF Analysis of GasBuddy.com data.

3.4.3. Retail Gasoline Sales

ICF estimates that retail gasoline sales doubled during the Irma evacuation. Daily retail gasoline sales are not tracked by the state; however, gasoline outages at retail fueling stations can provide an insight into retail sales. If a gas station ran out of fuel during the evacuation period, the station would have sold off any gasoline delivered to the station over that period plus all of the gasoline held in the inventory at the beginning of the evacuation. On any given day, on average, gasoline inventories at retail gas stations are at approximately 50% of their maximum capacity (some have more and some have less, depending on where they are in the normal delivery cycle). This means that for each gas station that ran out of fuel, total retail sales can be estimated as 100% of wholesale truck deliveries plus 50% of gasoline storage capacity at the station. Based on these assumptions, it is estimated that 49.1 MMgal of gasoline were sold out of storage at retail gas stations. Assuming that these inventory drawdowns/sales were concentrated during the three-day peak of the evacuation (September 6–8), this would imply retail sales out of storage of approximately 16.4 MMgal/d. Exhibit 15 estimates total retail gasoline sales at retail gas stations by combining the wholesale truck deliveries and stock drawdowns. The exhibit shows that estimated retail sales at Florida gas stations during the Irma evacuation were approximately 52.8 MMgal/d, or more than double the normal daily sales volumes.

Exhibit 15. Estimated Peak Retail Sales During the Irma Evacuation (MMgal/d)

Region	Peak Day Truck Deliveries	Stock Drawdown	Est. Retail Sales
South	11,954,726	5,397,749	17,352,475
Central	17,075,531	8,189,131	25,264,662
Northeast	4,529,475	2,102,979	6,632,454
Panhandle East	1,019,033	547,983	1,567,016
Panhandle West	1,863,300	139,205	2,002,505
Total	**36,442,065**	**16,377,047**	**52,819,112**

3.5. Fuel Supply Chain Constraints

The review of data at all levels of the petroleum supply indicate that gasoline supply was not a problem during the Hurricane Irma evacuation, but that distribution was. Gasoline inventories at the state's petroleum terminals were drawn below normal levels; however, even at their lowest point, they would have been sufficient to cover at least five days of normal demands. In addition, tanker ships continued supplying gasoline and other petroleum products into the state's terminal right up until the ports closed. Interviews with stakeholders indicate that the fuel shortages experienced during the Irma evacuation were primarily due to distribution issues. Although wholesale gasoline deliveries from petroleum terminals to retail stations increased by as much as 45% statewide, this increase was not enough to keep up with the unprecedented demands from evacuating motorists. ICF interviewed industry stakeholders, including terminal operators, trucking companies, and retail station operators to identify the factors that limited the fuel distribution network and to better understand how the system could be enhanced to meet fuel demands during the next major storm. These constraints are briefly discussed in the subsections below.

3.5.1. Terminal Truck Rack Loading Constraints

Truck racks are the parts of petroleum terminals where gasoline and ethanol from the terminal's storage tanks are loaded into trucks for delivery to retail gas stations. As with most infrastructure, terminal truck racks are typically designed to serve normal demands, although terminals often have some spare capacity to provide operational flexibility and to provide room for future growth. Furthermore, while many terminals are open 24/7, they typically do less loadings at night and on weekends. During the Hurricane Irma evacuation, stakeholders reported severe delays—waits of two hours or more—for truck loading at Florida petroleum terminals, compared to normal load times of approximately 30 minutes.

3.5.2. Truck Driver Constraints

During evacuation periods, truck drivers are more likely to supply markets that vary from their typical routes. This can cause problems at petroleum terminals for two reasons. First, fuel carriers who are filling at facilities outside of their typical market are unlikely to have completed the terminal-specific training. Although many terminals have similar loading procedures, many terminals have specific loading processes or traffic patterns that may be unfamiliar to new drivers. This can cause loading delays for these drivers, as well as for fuel carriers behind them in line at the terminal. A second issue has to do with Transportation Worker Identification Credential (TWIC) cards. A TWIC card is required by the Maritime Transportation Security Act for secure areas at maritime facilities. These cards are required at most terminals located at port facilities, including at many of the terminals in Florida. As a result, fuel carriers that do not normally load from port facilities may not have TWIC cards, and as a result, are not allowed to load at port terminals.

3.5.3. Traffic Constraints

With nearly 7 million people attempting to evacuate in advance of Irma, there were numerous traffic jams along major interstates and key evacuation routes. Traffic delays significantly slow the ability of fuel carriers to deliver fuel from petroleum terminals to retail stations. Traffic issues are particularly compounded for deliveries to stations located long distances from petroleum terminals. For example, one trucking company noted that fuel deliveries from Tampa origins to service stations in the Gainesville area took nine hours round trip during the Irma evacuation, compared to five hours normally.

4. Potential Fuel Distribution Network Enhancements

Key Takeaways

- ICF evaluated two strategies for enhancing the deliverability of Florida's fuel distribution network—debottlenecking truck loading and delivery operations out of existing terminals and establishing PDCs in areas of the state that are remote from existing terminals.
- Potential terminal debottlenecking locations were identified in Port Everglades, Tampa, Orlando/Port Canaveral, Jacksonville, Bainbridge, GA, and at the Panhandle ports. Potential PDC locations were identified in the I-75 Corridor, the Fort Pierce area, and Southwest Florida.
- Terminal debottlenecking can be cost-effectively achieved through the addition of truck-loading bays or by increasing pumping rates at existing bays.
- PDC sites can be feasibly configured either as small new-build terminals with aboveground storage tanks and truck-loading capabilities, or as rail-to-truck transloading facilities; however, the latter option may be more expensive and may have significant scaling issues for larger-sized storage volumes.

This chapter discusses fuel supply and distribution network enhancements that have the potential to alleviate retail fuel shortages during high-demand evacuation periods. Enhancements primarily focus on the development of new infrastructure, such as building PDCs or expanding gasoline-loading capabilities at existing petroleum terminals, but also include non-infrastructure enhancements, such as increased use of police escorts to expedite tanker truck movements from terminals to retail stations or encouraging the expansion of the tanker truck fleet during emergencies.

4.1. Overview of Potential Fuel Network Enhancements

The fuel shortages experienced during the Irma evacuation were primarily due to deliverability constraints (i.e., constraints in the capability of the fuel distribution network to move fuel from petroleum terminals to retail gas stations to meet the demands of evacuating motorists). Although Florida's fuel distribution network has significant deliverability—gasoline deliveries increased by as much as 45% above normal during the Irma evacuation—the system did not have sufficient capacity to meet the unprecedented surge in demand. This chapter focuses on potential enhancements to strengthen gasoline deliverability in the state.

4.1.1. Strategies for Potential Fuel Network Enhancements

ICF evaluated two complementary strategies to strengthen Florida's gasoline distribution network. These enhancements, which consider the state's unique geography, are as follows:

1. **Debottlenecking Existing Fuel Distribution Terminals:** In areas of the state that are close to (within approximately 100 miles) the petroleum supply terminals (e.g., Miami, Tampa, Orlando), the fuel distribution network can more easily be enhanced by debottlenecking truck loading and transportation from the petroleum terminal to the retail gas station. Actions to debottleneck fuel distribution from petroleum terminals include increasing the capability of petroleum terminals to load trucks, expediting the delivery of

fuel from the terminals to retail stations, and increasing the fleet of fuel transport trucks and drivers in the state.

2. **Establishing Petroleum Distribution Centers:** In areas of the state that are remote from petroleum supply terminals (such as the I-75 corridor from Wildwood to the Georgia border), there may be value in establishing PDCs—gasoline storage facilities that can quickly be drawn down, if needed, to cover fuel shortages along the state's evacuation routes. These facilities can be configured in a number of different ways, but would generally involve onsite storage of gasoline (utilizing either bulk tank storage or rail tank cars), paired with an ability to load trucks.

Each of the enhancements described above are designed for use only during evacuation periods. The enhancements add value by adding deliverability to the gasoline distribution system (beyond the system's current capacity) to enable more fuel to reach consumers during high-demand evacuation periods. Potential technical configurations and the practical considerations of these solutions are discussed later in this chapter.

4.1.2. Location of Potential Fuel Network Enhancements

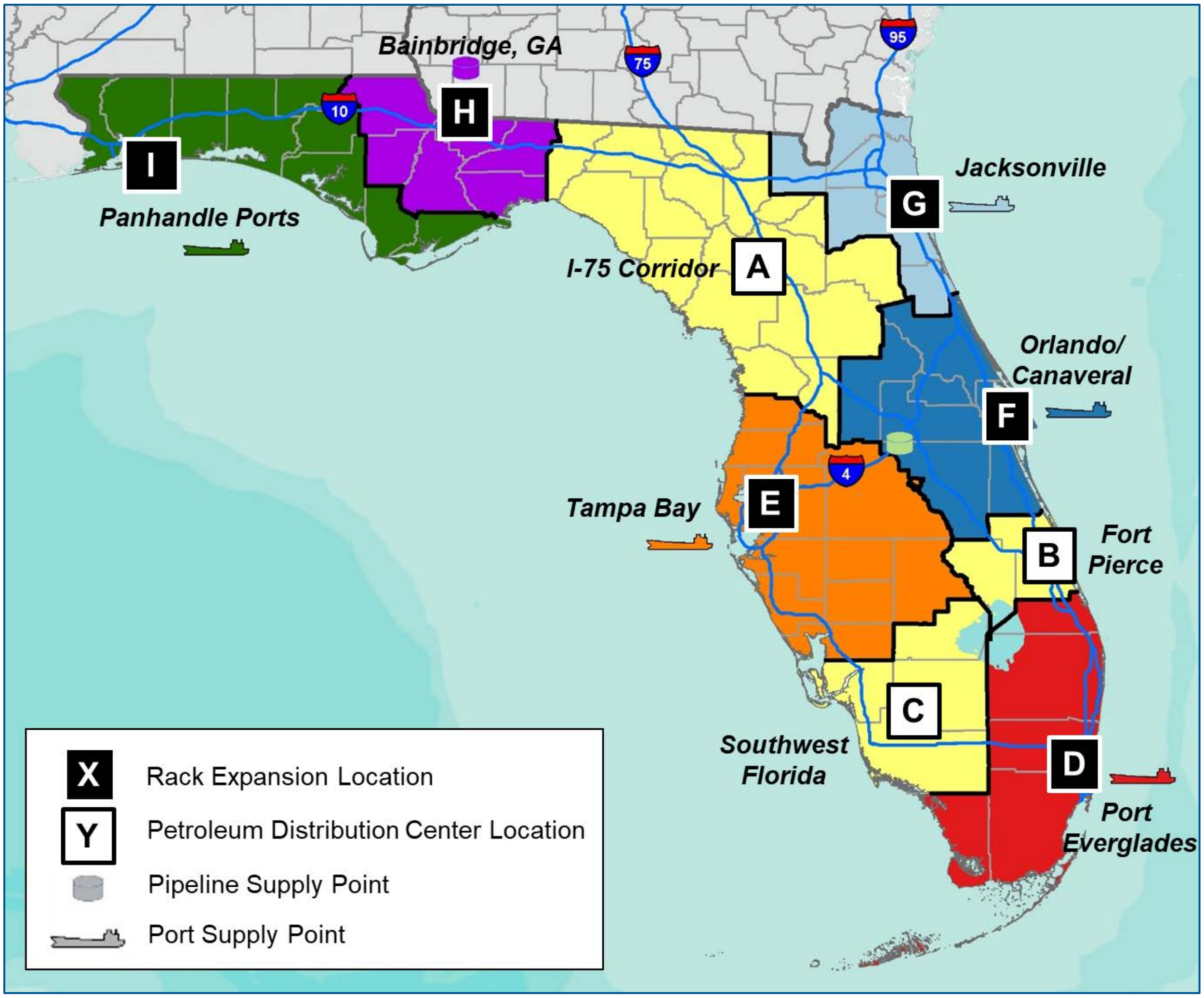
ICF analyzed the pattern of fuel shortages during the Irma evacuation to estimate the approximate size and target locations of the fuel distribution network enhancements needed. ICF identified three areas in Florida that are approximately 100 miles or more from the nearest bulk petroleum terminal and may benefit from the establishment of local PDCs:

A. The I-75 Corridor from Wildwood north to the Georgia border;
B. The Fort Pierce area near where I-95 meets the Florida Turnpike; and
C. Southwest Florida, including the cities of Naples, Cape Coral, and Fort Myers.

The remainder of Florida, including the state's largest metropolitan areas, are best served by debottlenecking fuel distribution from regional terminals. ICF identified the need for distribution enhancements in six existing supply locations: Port Everglades (D), Tampa Bay (E), Orlando/Canaveral (F), Jacksonville (G), Bainbridge, GA (H),[8] and Panhandle Ports (I). Exhibit 16 identifies the proposed PDC and rack expansion locations.

[8] The Bainbridge supply source is located at a terminus of the Colonial Pipeline in southern Georgia. Florida may need to consider the policy implications of funding or incentivizing investments in another state. Investments in this location may require a partnership with the State of Georgia.

Exhibit 16. Proposed Locations of Florida Petroleum Distribution Network Improvements



4.1.3. Size of Potential Fuel Network Enhancements

ICF estimated the sizes of the potential distribution network enhancements by estimating the additional volume of fuel needed to avoid supply outages at retail gas stations in each of the nine proposed locations. During the Irma evacuation, petroleum terminals showed a capability to deliver more than 36 MMgal/d, representing an approximately 40% increase over normal daily volumes. ICF estimates that to fully avoid supply outages, approximately 16.4 MMgal/d of gasoline of additional delivery capacity would be needed, which is a 45% increase over the observed peak capability.

Exhibit 17 presents five size options, ranging in deliverability from 3.9 to 16.3 MMgal/d. The largest size option was determined by taking the estimated statewide deliverability shortage during the Irma evacuation (16.4 MMgal/d) and estimating the closest number of loading bay additions needed to cover the shortage given that each loading bay has an approximate maximum loading capacity of 430,000 gallons per day (gal/d).[9] In this case, 38 loading bay

[9] ICF estimates that a single loading bay can load approximately forty-eight 9,000-gallon (gal) trucks per day (or approximately 432,000 gal/d) if operated 24 hours per day.

additions would add a total of 16.3 MMgal/d, which is reasonably close to the estimated Irma shortage. Each subsequent option was sized as a fraction (one-half or one-quarter) of the largest option. For each option, deliverability (in 430,000-gal/d increments) was then apportioned to each location based on the estimated shortage in those counties during Irma. For PDC locations, Exhibit 17 also presents the working storage volumes required to maintain the maximum deliverability rates over a three-day evacuation period.

Exhibit 17. Potential Distribution Network Solutions and Size Options

Location	OPTION 1: *16.3 MMgal/d*		OPTION 2: *12.0 MMgal/d*	
	Storage Volume* (gal)	Deliver-ability (gal/d)	Storage Volume* (gal)	Deliver-ability (gal/d)
PDCs				
A) I-75 Corridor	5,200,000	1,720,000	3,900,000	1,290,000
B) Fort Pierce	2,600,000	860,000	1,300,000	430,000
C) Southwest	1,300,000	430,000	1,300,000	430,000
Rack Expansions				
D) Port Everglades	–	4,730,000	–	3,440,000
E) Tampa Bay	–	3,870,000	–	3,010,000
F) Orlando/Canaveral	–	3,010,000	–	2,150,000
G) Jacksonville	–	1,290,000	–	860,000
H) Bainbridge	–	430,000	–	430,000
I) Panhandle Ports	–	–	–	–
Total	**9,100,000**	**16,340,000**	**6,500,000**	**12,040,000**

* Working storage (heel not included)

Location	OPTION 3: *8.2 MMgal/d*		OPTION 4: *3.9 MMgal/d*		OPTION 5: *8.2 MMgal/d, No Storage*
	Storage Volume* (gal)	Deliver-ability (gal/d)	Storage Volume* (gal)	Deliver-ability (gal/d)	Deliver-ability (gal/d)
PDCs					
A) I-75 Corridor	2,600,000	860,000	1,300,000	430,000	–
B) Fort Pierce	1,300,000	430,000	–	–	–
C) Southwest	–	–	–	–	–
Rack Expansions					
D) Port Everglades	–	2,580,000	–	1,290,000	3,010,000
E) Tampa Bay	–	2,150,000	–	860,000	2,580,000
F) Orlando/Canaveral	–	1,290,000	–	860,000	1,290,000
G) Jacksonville	–	860,000	–	430,000	1,290,000
H) Bainbridge	–	–	–	–	–
I) Panhandle Ports	–	–	–	–	–
Total	**3,900,000**	**8,170,000**	**1,300,000**	**3,870,000**	**8,170,000**

* Working storage (heel not included)

Option 1 in Exhibit 17 utilizes both PDCs and rack expansions, and is sized with sufficient deliverability (16.3 MMgal/d) to eliminate nearly all retail gas station outages during the Irma evacuation. However, it is likely not necessary to eliminate all station outages to provide benefits to evacuating motorists. In other words, it may be acceptable for some number of retail stations to completely draw down their stocks, as long as adequate fuel is available at other stations to meet evacuation demands.

Options 2, 3, and 4 maintain the same PDC and rack configuration with incrementally smaller deliverability volumes (12.0 MMgal/d, 8.1 MMgal/d, and 3.9 MMgal/d, respectively). These options would increase fuel availability less than in Option 1, but have the advantage of reducing the level of upfront investment needed while still providing a significant increase in fuel deliverability.

Option 5 provides the same overall deliverability as Option 3, but does so entirely by utilizing rack expansions at existing terminals. Because it does not require the construction of storage tanks, Option 5 would have less upfront investment costs than Option 3, despite having the same deliverability. Option 5 also avoids some operational issues associated with PDCs, such as the need to turnover product at the end of the hurricane season (these issues will be discussed in greater detail later in this chapter). However, Option 5 may increase trucking requirements because trucks would need to deliver fuel over longer distances to reach the remote areas served by PDCs in Options 1 through 4. Under the Option 5 configuration, traffic issues also would be a significant risk factor for deliveries into those areas.

Each of these size and configuration options presented here will be evaluated in the *Cost-Benefit Analysis of Potential Network* chapter in this report (Chapter 5).

4.1.4. Feasibility and Costs of Fuel Network Enhancement Configurations

The two fuel distribution network strategies outlined in 4.1.1 (rack expansions and PDCs) can be executed using several different infrastructure configurations. As an overview, these configurations, their feasibility, and their approximate costs are briefly summarized in Exhibit 18. Sections 4.2 and 4.3 further discuss and define the design, cost, and implementation issues associated with these infrastructure configurations. Non-infrastructure enhancements associated with terminal debottlenecking, such as providing terminal guides or police escorts, are also discussed in those sections.

Exhibit 18. Feasibility Comments and Costs of Fuel Network Enhancement Configurations

Configuration	Feasibility Comments	Approximate Unit Costs ($ per gal/day)
Rack Expansions		
Add New Loading Bays	Feasible. Adds new positions at terminals for trucks to load. This option utilizes existing terminal logistics infrastructure at existing terminals, but may be limited by available space and could have additional permitting and regulatory concerns.	$2
Increase Loading Rates	Feasible. Increases loading rates at existing loading positions. Less capital intensive than adding new loading bays and has fewer space issues. Still has permitting and regulatory concerns.	$1
PDCs		
Build Grassroots Terminal	Feasible. Adds new terminal with fuel storage and truck-loading capacity. Expensive option, but provides flexibility for siting enhancements in remote markets, reducing the burden on the truck fleet. Logistics are not optimal because the inventory fill each year would likely require trucking from port terminals. Time to build and construct may be longer than other options.	$10–$15
Utilize Secondary Terminal	Not feasible. This option would utilize existing capabilities at secondary (distributor) terminals to establish the PDC. However, there are no potential sites with sufficient storage capacity in the target PDC areas.	N/A
Build Rail-to-Truck Transloading Facility	Feasible. Uses mobile pump carts to load trucks directly from rail tank cars. Can be sited almost anywhere with rail access, including target PDC areas. Rail supply logistics allow the site to be filled and re-filled more quickly than a truck-supplied grassroots terminal. The facility could potentially be repositioned within the state if needed. Upfront costs may be lower because of the ability to lease rail tank cars; however, there is a current shortage of the newest, safest tank cars, and lease rates are expensive.	$17+
Expand Retail Station Tankage	Not feasible. Adds underground storage tanks (USTs) directly at retail stations. Number of tank additions needed would be prohibitive for considered size options. Could be a potential solution in small, remote markets (e.g., Florida Keys); however installing USTs has significant permitting issues.	N/A

4.1.5. Implementation of Fuel Network Enhancements

The state does not have the resources to implement the proposed network solutions on its own and would need to contract with private companies to design, build, and operate the proposed PDCs and rack expansions. Under these contracts, the state would make an upfront payment to offset the initial capital costs of designing and constructing the infrastructure solution, followed by an annual operations, maintenance, and management fee. The duration of these contracts can be set to any time horizon, but may be most effective over a long-term horizon (e.g., 20 years) to allow the state to extract the full value from the upfront investments made. At the end of the contract term, the terminal would have the option to renew the contract with the state or buy back the infrastructure for its own use. Contracting should be done through a competitive process to ensure that awards are made transparently and cost-effectively. Through this process, the state would identify the lowest-cost mix of solutions capable of providing the required deliverability targets in each of the defined market areas.

4.2. Debottleneck Fuel Distribution from Terminals

Gasoline deliverability during hurricane evacuations can be increased by debottlenecking distribution logistics between the state's existing petroleum terminals and retail gas stations. This solution would be employed in areas of the state that are in relative proximity (within approximately 100 miles) of existing petroleum supply terminals. Actions for debottlenecking fuel distribution from petroleum terminals include:

- Increasing the capability of petroleum terminals to load trucks by expanding truck rack loading capacity;
- Increasing the fleet of fuel transport trucks and drivers; and
- Expediting the delivery of fuel from the terminals to retail stations.

These actions will be discussed in the following subsections.

4.2.1. Expanding Truck-Loading Capacity at Petroleum Terminals

Truck racks are the parts of petroleum terminals where gasoline and ethanol from the terminal's storage tanks are loaded into trucks for delivery to retail gas stations. During the Hurricane Irma evacuation, stakeholders reported severe delays—waits of two hours or more—for truck loading at Florida petroleum terminals. These delays were due to loading capacity at the terminal truck racks being unable to keep up with the surge in demand for fuel loading. Expanding truck rack loading capacity would reduce truck queues and waiting times at terminals during high-demand evacuation periods, allowing trucks to more quickly load and distribute fuel to retail stations. Truck rack loading capacity is a function of the number loading bays (positions) and the pumping rates at each of those bays. Truck rack loading capacity can be expanded either by adding new loading bays (and new pumps for those bays) or by increasing pumping rates at existing loading bays.

4.2.1.1. Design, Feasibility, and Costs

Increasing truck-loading capability—either through the addition of new loading bays or by increasing loading rates at existing bays—requires that the terminal have a sufficient inventory of gasoline to load out trucks at the higher loading rates during evacuation periods without running out of fuel. The extent to which a terminal can feasibly expand loading capacity before stressing the inventory will vary by terminal, however, overall, the state's terminal network holds a sufficient inventory to support added deliverability, especially over an evacuation period. The state's terminals, on average, hold anywhere from one to two weeks of gasoline supply at any given time. An approximate doubling of gasoline demand during hurricane evacuations means that six days of normal gasoline supply may be loaded out over a three-day period. So even terminals at the low end of the inventory range should have a sufficient gasoline inventory on hand to double loadings without running out of inventory. Added deliverability at terminals also may incentivize suppliers at the terminal to hold higher levels of stocks during the hurricane season.

4.2.1.1.1. Adding Truck-Loading Bays

Truck-loading bays vary in configuration, but generally consist of loading arms, a steel support structure, stairs, railings, piping, valves, pumps, meters, electrical wiring, controls, and safety systems. The feasibility of adding loading bays is subject to several site-specific design considerations. Chief among these considerations is space. In some cases, existing terminals may simply not have sufficient space to add a loading bay; other terminals may have room to add several bays. Additional space may also be required to accommodate additional trucks and to provide an adequate turning radius for trucks exiting the facility after loading. Other technical considerations include the need to add or expand storage tank pumps, piping from the storage tanks to the rack, vapor recovery unit (VRU) capacity, and road access and egress. Finally, terminals may need to consider a number of safety, environmental, and commercial regulations, such as those pertaining to metering, vapor recovery, spill contingencies, and the degree of terminal automation. All of these considerations need to be evaluated at individual terminals to assess the feasibility of adding loading bays.

Truck-loading bays often have multiple loading arms to supply various products (e.g., regular gasoline, premium gasoline, diesel, ethanol). Loading bays constructed to support evacuations would only require loading arms for regular conventional gasoline blendstock (conventional blendstock for oxygenate blending [CBOB]) and ethanol. CBOB and ethanol would be blended at the rack to create finished conventional gasoline. A single truck-loading arm has the capacity to fill trucks at a rate of approximately 500–600 gallons per minute (gpm).[10] Given this capacity, a truck-loading bay with a single gasoline-loading arm can load a truck in approximately 15–18 minutes. Allowing for time between truck loadings for truck positioning, connecting the loading arm to the truck for each storage compartment, disconnecting the loading arms between compartments, and truck egress, it is estimated that a single bay can fill a truck approximately every 30 minutes, or about two 9,000-gal trucks per hour. If a terminal is running 24-hour operations during an evacuation, a single loading bay may have the capacity to load approximately 432,000 gal/d, or approximately 1.3 MMgal over a three-day evacuation period. Some terminal operators interviewed by ICF reported the capability to load and turn over trucks at a faster rate.

Costs

Costs for adding a loading bay will vary at each terminal, depending on facility-specific factors that influence the design, location, and need for additional modifications to accommodate increased truck traffic. The estimated cost to add a “bare bones” truck-loading bay at an existing terminal is about $850,000, or approximately $2/gal of daily deliverability. This estimate includes costs for extending the rack, canopy, and piping, and adding pumps, vapor control, loading control, motors, valves, and loading arms. The estimate also includes ancillary costs for paving additional lanes and extending drainage, fencing, lighting, and security systems, as necessary, to accommodate the new bay. The estimate assumes that the bay is close to existing bays so that there would be no need for land acquisition, significant new piping from the storage tanks to the bays, or for major road modifications for tanker truck ingress and egress. The estimate also

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[10] Based on survey responders, noting that ethanol may be in-line blended with the CBOB gasoline blendstock.

assumes that the feed piping from the tanks has a sufficient flow capacity and that the vapor system and the fire system can be extended without major upgrades.

4.2.1.1.2. Increasing Loading Rates at Existing Bays

Another method for enhancing truck-loading rates at existing terminals is to add additional pumping equipment or additional loading arms to increase loading rates and reduce truck-loading time at existing bays. In addition to new pumps and loading arms, increasing loading rates at existing bays also requires investments in additional meters, piping, valves, electrical wiring, controls, and safety systems. Increasing loading rates at an existing bay has less space availability concerns compared to adding a new loading bay, but has many of the same technical capacity considerations (e.g., vapor recovery capacity, storage tank pump capacity, piping needs) and regulatory considerations (e.g., safety, environmental).

Increasing loading rates at an existing loading rack incrementally increases truck-loading capacity at existing terminals. For example, if a truck-loading rack were to increase pumping rates from 500 to 600 gpm, it would reduce the pumping time from 18 to 15 minutes, saving approximately 3 minutes in loading time per truck. Because the time for truck positioning, connections, and egress at the bay would stay the same, total truck-loading time would be reduced from approximately 30 minutes to approximately 27 minutes, a reduction of 10%. Over the course of 24 hours, this would allow an additional five trucks to load at the bay—an increase in deliverability of about 48,000 gal/d. On the other hand, if a truck-loading bay with an existing 500-gpm gasoline-loading arm added a second 500-gpm gasoline-loading arm, then the pumping time per truck could be reduced from 18 minutes to 9 minutes. The terminal would be able to load 20 more trucks per day, or more than 180,000 gal/d of additional deliverability. This is approximately 40% of the daily deliverability of adding a new bay (432,000 gal/d).

Costs

Each terminal's ability to increase its truck-loading rate is dependent upon its existing operation, equipment, and technical and regulatory constraints. Without detailed knowledge of the existing equipment at each terminal, the cost of improving the loading rate is difficult to quantify and may vary widely from terminal to terminal. As a rough estimate, the cost of adding 500 gpm of pumping capacity at four loading bays (for a total deliverability increase of approximately 720,000 gal/d) would be about the same as the cost of adding a new loading rack—approximately $750,000. This cost estimate includes additions and modifications to control valves, loading arms, pumps, and associated equipment. The per unit cost of increasing pumping capacity is a little over $1/gal of added daily deliverability, which is about half the unit cost of adding deliverability by adding new loading bays.

4.2.1.1.3. Expediting Truck Loading

In addition to increasing the technical ability to load trucks through the above-mentioned methods, terminals can further streamline truck-loading operations at existing terminals by using in-house personnel to escort out-of-market truck drivers who are unfamiliar with the terminal's loading procedures and protocols. During evacuations, out-of-market truck drivers often enter the Florida market to help meet the demand for fuel deliveries. If these drivers are not familiar with procedures at the terminal, this can lead to delays in loading. Terminals operators should utilize in-house personnel to escort these out-of-market drivers to expedite truck-loading operations, including accessing the loading bay, filling, and egressing. Having in-house personnel act as escorts for out-of-market truck drivers (or temporarily take control of the vehicles during loading operations) may be a requirement at some port terminals where TWICs are required to enter the terminal facility.

Costs

The feasibility and cost of utilizing terminal personnel to expedite truck loading is dependent upon the availability of onsite staff to act in this capacity during evacuation events, which are typically very busy times for terminals. The availability of personnel will vary from terminal to terminal, and may be strained as the hurricane nears landfall and terminal workers may need time off to make personal preparations for the storm, including securing property and evacuating with their families. The terminal companies should carefully consider staffing needs and consider bringing in out-of-state resources, as needed, to handle increased loading demands during an evacuation.

4.2.1.2. Management

The State of Florida should utilize a competitive process to solicit bids from terminal owners and operators to design, build, and operate the truck rack expansions. Through this process, the state would contract with terminal owners to expand truck rack loading capacity and hold that capacity in reserve for use during emergencies. Under the terms of the agreed-upon contract, the state could provide an upfront payment to offset the cost of construction and an annual fee for operations, maintenance, and management of the rack infrastructure. The contract would need to be designed to meet the deliverability rates identified in Exhibit 17. In some areas where significant new deliverability is required (Port Everglades, Tampa, and Jacksonville), the state may consider funding expansions at multiple terminals that, in aggregate, satisfy the deliverability requirement in the target area. The competitive process for each region should clearly define the contract requirements, including, but not limited to, the following:

- **Location Requirement:** Region or list of counties where the rack expansions are to be located.
- **Deliverability Requirement:** Total additional truck-loading capacity sought within the defined region.
- **Minimum Inventory Requirement:** The operator must show that minimum gasoline inventories at the terminal during the hurricane season (June through November) are at least equal to three times the terminal's maximum gasoline truck-loading capacity after expansion.[11] This requirement ensures that a sufficient supply would be available to support maximum loadings over a three-day evacuation period.
- **Staffing Requirement:** The operator must show that it is adequately staffed to handle additional truck loadings at the terminal during the hurricane season and that staff are available to escort out-of-market drivers to expedite truck loadings.
- **Resiliency Requirement:** Availability of backup power resources (onsite or offsite) capable to maintain maximum gasoline loading rates at the terminal.
- **Term Requirement:** Defined length of the agreement between the state and the terminal operator (suggested minimum of 10 years).

[11] It should be recognized that, in many cases, the terminal owner does not own the fuel in the terminal, and that the fuel owners (suppliers) may need to agree with some stipulations of the investments.

- **Non-Emergency Use Clause:** Identify the conditions under which the terminal operator would be allowed to utilize the state-funded capacity for non-emergency uses and how the state would be compensated for non-emergency usage.
- **Buy-Back Clause:** Identify the terms under which the terminal has the ability to buy back the state's capacity at the end of the contract term.

A competitive process should generate responses that address each of the items above and outline the project's proposed:

- **Costs/Fees**, including construction, operations and maintenance (O&M), and management costs;
- **Implementation timetable** for planning, procurement, permitting, and construction;
- **Design** for achieving deliverability increase (i.e., added bay(s) or increased pumping rates); and
- **Equipment** to be added as part of the expansion (e.g., added bays, new lanes, added pumps, VRU expansion).

As part of the competitive response, the terminal operator would be required to include detailed information on existing terminal capabilities, including the current (pre-expansion) maximum loading capacity. When evaluating responses, the state should evaluate the proposed deliverability volumes, costs, and location, and whether the key criteria outlined during the competitive process are sufficiently met. As part of the competitive process, the state should work with terminal operators to better understand existing terminal capabilities and costs, as well as the contract terms that would be amenable to potential operators of the rack expansions. Information gathered during the process would help inform the structure of the contract for rack expansions.

4.2.2. Police Escorts for Fuel Trucks

During the Hurricane Irma evacuation, traffic issues delayed fuel truck deliveries, particularly along evacuation routes. Trucking companies interviewed for this study noted severe delays on some routes, with delivery times taking as much as twice as long as normal (with some of this delay due to traffic delays and some due to loading delays at the rack). During the Irma evacuation, the Florida Highway Patrol (FHP) and the Florida Sheriffs Association alleviated some of these delays by providing escorts for gasoline tanker trucks delivering fuel from terminals to retail stations along key evacuation routes. During the Irma evacuation, FHP supported 18 of these missions with funding facilitated from Emergency Support Function 16 for Law Enforcement. Industry stakeholders interviewed for this study indicated that the police escorts had a very positive effect in speeding up delivery times, and noted that more escorts would have further improved fuel delivery. During the Irma evacuation, police escorts also were used at port terminals when the U.S. Department of Homeland Security waived TWIC card requirements for truck drivers if a police escort accompanied them. This allowed truck drivers who did not have a TWIC card to fill at port terminals where TWIC card access is required.

The state should continue to leverage law enforcement resources to expedite fuel deliveries during evacuations. This process could potentially be improved by making more escorts available, creating staging points near key supply points, and further coordinating with suppliers and distributors to run caravans along certain routes to maximize the number of trucks helped with limited state resources. Well before an evacuation takes place, the state may wish to develop relationships with fuel suppliers and distributors, create standard procedures for requesting fuel escorts, and establish criteria for prioritizing fuel missions along key evacuation routes. Some potential criteria for prioritization could include the distance from terminal to gas station(s), the proximity of gas stations being refueled to evacuation routes, and the volume of fuel being transported. The state also could inform its prioritization decisions using the forecast hurricane track, real-time and projected traffic data, and information on station outages from GasBuddy.com.

Costs

Police escorts are an effective strategy for expediting fuel deliveries, but may divert the state's limited resources away from performing other critical functions in advance of a major storm, such as ensuring that people are heeding evacuation orders, facilitating traffic flow, and addressing public safety concerns. The dedication of police resources to fuel missions should be carefully balanced against other demands. The state may consider avenues to utilize local police resources or bring in law enforcement resources from outside the state to further assist with fuel missions.

4.2.3. Enhance Tanker Truck Fleet

During high-demand evacuation periods, Florida's tanker truck fleet and drivers may be insufficient to meet the surge in demand for delivery services. Trucking companies report that, during high-demand periods, they have drivers working in 12-hour shifts with trucks running 24 hours per day. In addition, larger trucking firms were able to bring in drivers from out-of-state to help handle increased demands for delivery services. Out-of-state truckers must be paid above the typical rates, provided with paid lodging, and provided with additional allowances for food. The trucking companies interviewed for this study indicated that hiring out-of-state truckers is problematic because gas station operators are reluctant to pass these higher costs on to consumers at the gas pump out of fear of triggering violations of price-gouging laws, which are designed to protect consumers from unreasonable or exploitative price increases for fuel (and other essentials) during hurricanes or other natural disasters. With that purpose still in mind, the state may want to explore alternative means that allow the trucking companies to recover their higher costs while continuing to protect consumers from much higher prices. Trucking companies may, for example, be able to negotiate emergency rates in their contracts with petroleum companies to allow small increases in trucking fees across all gallons hauled during emergencies to cover the trucking companies' added costs during these periods. As an alternative to this market-based solution, the state could consider subsidizing trucking companies for bringing in additional trucks by either direct payments or tax credits that would cover the additional costs incurred.

4.3. Establish Petroleum Distribution Centers

PDCs may have value in areas of the state that are remote (more than approximately 100 miles) from existing petroleum supply terminals. In these areas, long distances and heavy traffic during evacuations can slow truck deliveries of fuel to retail stations. Constructing PDCs in these areas would provide an emergency supply of fuel that can be drawn down to quickly cover fuel shortages at retail stations along the state's evacuation routes. PDCs can be configured in a number of different ways, but would generally involve onsite storage of gasoline paired with an ability to load trucks.

4.3.1. Design, Feasibility, and Costs

ICF evaluated four potential configurations for PDCs in Florida. These include the following:

- Constructing grassroots (new-build) terminals.
- Utilizing capabilities at existing secondary terminals.
- Constructing TRANSFLO (CSX) rail-to-truck transloading facilities.
- Expanding retail station underground storage.

Each of the four PDC configurations are discussed further in the subsections below. Under the first three options, the state would pay for and own the fuel inventory at the PDC. The PDC operator would be responsible for staffing the facility for operations, maintenance, and transaction processing. The operator also would be responsible for procuring fuel prior to the hurricane season, hedging the fuel to protect against price drops, liquidating the fuel at the end of the season, and unwinding the hedges as the volume is sold—either at the end of the season or as the fuel is loaded onto trucks during an evacuation. The state would pay the operator a fee for these services. Under each of the first three options, the state may also own some or all of the facility's infrastructure, although this infrastructure may be leased back to the terminal developer/operator.

The state's partnership with private companies to build and/or operate the PDCs are intended to enhance the distribution of fuel to retail stations during an evacuation. However, the PDC operator may realize efficiencies by operating a normal commercial business alongside the PDC after the requirements of the PDC have been met. This activity would be allowed under the terms of the state contract (as long as the required PDC capabilities are held solely for emergency use). The PDC operator would be responsible for the costs of any facilities constructed at the PDC site beyond the PDC requirements outlined in the state contract.

4.3.1.1. Grassroots (New-Build) Terminals

This option entails building new fuel storage terminals in the proposed PDC locations. The major components of a PDC terminal would be storage tanks; a truck-loading and unloading rack; a VRU; and associated pumps, piping, and control systems to move fuel from the storage tanks to the truck rack. Required ancillary elements include an office, maintenance facilities, an electrical motor control center building, laboratory equipment, lighting, and a security/surveillance system. The PDC terminals would be optimally located close to the highway, and any roads between the terminal and the highway may need to be zoned for hazardous materials truck traffic.

To implement this option, the state would contract with one or more terminal companies (via a competitive process) to construct and operate the PDC terminals based on the state's specifications. The developer, with the state's help, would need to identify and acquire available land, and obtain all relevant federal, state, and local permits to develop the site and operate it as a terminal. The PDC terminals would be designed to meet the target storage and deliverability volumes for each of the three PDC locations outlined in Exhibit 17. Storage tank shell capacity design would be based on the target reserve volumes plus approximately 5%–10% additional capacity to hold the tank heel—the inaccessible fuel that is stranded between the tank bottom and the floating roof when the roof is at its lowest operating position. The loading rack should be designed to release the total volume of fuel reserves over a three-day evacuation period. The terminal's VRU and the air permit should cover expected truck loadings for the full storage volume plus some margin.

Exhibit 19. Typical Terminal (including truck rack, tankage, and piping)

Source: www.hlswatch.com

Costs

Rough order of magnitude (ROM) cost estimates (±50%) were developed for each terminal location and size outlined in Exhibit 17. These estimates, which are detailed in Chapter 5 of this report, were developed by reviewing several recent new-build terminal projects in the Southeast and include costs for site development; site drainage; one or more aboveground storage tanks (ASTs) for gasoline blendstock; an AST for ethanol; an AST for firefighting water; tank patio berms; one or more loading bays with associated pumps, valves, controls, and key card hardware; piping between the tanks and the loading rack; paved entry, loading, and exit areas; a small building; secondary containment; and fencing, lighting, and security systems. The total cost estimates also include a construction cost contingency; an allowance for construction management, engineering, insurance, bonds, and permits; and land costs.

The ROM estimates show that a one-truck-bay terminal PDC with approximately 1.3 MMgal of storage and a maximum deliverability of about 430,000 gal/d may cost about $6.3 million to construct, or approximately $15/gal of daily deliverability. Due to economies of scale, the unit costs of terminals decrease as capacity increases. ROM unit costs for a four-bay terminal (5.2 MMgal of storage and 1.72 MMgal/d of deliverability) fall to approximately $10/gal of daily deliverability.

Leveraging the PDC

As noted in Section 4.3.1, there could be benefits if the PDC developer were to utilize the PDC site to store and supply gasoline, and possibly diesel fuel, to regional customers, in addition to managing the state's investment in the storage and loading racks. The developer could elect to build additional storage and loading capacity at the site for commercial customers at their own cost. The benefits could include the following:

1. Suppliers will be able to provide fuel to local service stations with a much shorter transit time than from a major port center.
2. The gasoline in the PDC terminal will be routinely turned over during the year, so the quality is always better for the service stations, including during emergencies.
3. There will be no need to procure fuel more than once (unless an evacuation occurs and the stocks need to be replenished), and there is no need to hedge the fuel.
4. The terminal would be in constant use, so operators and truck drivers would be very familiar with the operation and the equipment.

There could be additional benefits as well. While routine use of the portions of the PDC not held for state use in evacuations would be dependent upon the commercial terms that the PDC developer and operator would offer to potential suppliers, this leverage would position supply closer to consumers in the more remote regions of the state.

4.3.1.2. Utilizing Existing Secondary Terminals

Secondary terminals are smaller distribution terminals that typically both receive and distribute fuel by tanker trucks (primary terminals, in contrast, typically receive product via pipeline or marine deliveries). Rather than constructing new grassroots terminals, the state could potentially operate PDCs out of existing secondary terminals. This option may be more cost-effective than developing grassroots terminals because the facilities already would have much of the necessary equipment (i.e., tanks, piping, truck rack). To evaluate the feasibility of utilizing secondary terminals, ICF reviewed data on storage capacity at secondary terminals in Florida provided by the Florida Department of Environmental Protection. Across the state, there is only 3.5 MMgal of gasoline storage capacity at secondary terminals, with only 513,000 gal of storage in the I-75 Corridor, 378,000 gal in Southwest Florida, and 385,000 gal in Fort Pierce.[12] These volumes are well below the PDC target capacities, which range from 1.3 MMgal to 5.2 MMgal. Furthermore, much of this existing storage capacity is being actively used by existing distributors and is likely not available to hold PDC reserves.

Florida Power & Light (FPL) was contacted for this study, and the utility does not have sufficient available tankage that could be utilized for the PDCs. FPL has the capacity to store 4 MMgal of biodiesel in Riviera Beach (with plans to add 150,000 gal of capacity) and 900,000 gal of diesel in Fort Lauderdale. While there is some unused diesel storage capacity at Riviera Beach and Fort Lauderdale, there is no unused gasoline storage capacity. In addition, although many of FPL’s thermal plants have shifted from burning fuel oil to natural gas as the primary fuel, all of FPL’s oil storage tank capacity is still used to store backup ultra-low-sulfur diesel in the event of natural gas supply disruptions.

Although it may not be possible to utilize existing storage at secondary terminals to store PDC volumes, there may be an opportunity to expand existing secondary terminals (which are already zoned as terminals) to meet PDC storage and delivery requirements. As such, secondary terminal operators in the target PDC areas should be invited to participate in any competitive process. If sufficient space is available, expanding an existing secondary terminal may be feasible and less expensive than constructing a grassroots terminal. In addition, there are potential synergies in co-locating the state’s PDCs with existing commercial operations. For

[12] Storage terminal data are from the Florida Department of Environmental Protection.

example, the existing commercial business may be able to turn over the PDC gasoline volumes through the course of its normal business, thereby avoiding the need for the state to purchase fuel at the beginning of the hurricane season and sell off fuel at the end of the season.

4.3.1.3. Rail-to-Truck Fuel Transloading Facilities

Rail-to-truck fuel transloading facilities are currently used in the Southeast for ethanol distribution. In Mexico, they also are being used for gasoline, diesel, and propane distribution. In a rail-to-truck fuel transloading facility, ethanol railcars are positioned at a siding (with appropriate controls and diking) and mobile pump carts pump the fuel out of the railcars and load it directly into tanker trucks (see Exhibit 20). This infrastructure can potentially be purposed for use as a PDC to store and distribute gasoline to meet Florida's evacuation demands. Instead of fixed, ASTs, a rail-to-truck fuel transloading PDC would utilize railcars to hold the emergency reserves of finished gasoline (either conventional gasoline [E0] or conventional gasoline blended with ethanol [E-10]). The gasoline supply could be sourced at locations along the Gulf Coast that are able to load gasoline into railcars.[13] The rail-to-truck transloading facilities could be positioned anywhere in Florida with rail access (including in the three PDC areas). At least one company—TRANSFLO (a subsidiary of CSX)—currently offers rail-to-truck transloading of ethanol in Florida.

Exhibit 20. TRANSFLO Rail-to-Truck Transloading Facility

Source: CSX.com.

Rail-to-truck transloading facilities have several potential advantages over grassroots terminals when used as a PDC. First, the upfront investment in constructing a rail-to-truck transloading PDC may be less expensive per unit of storage volume than a terminal PDC because no new-build tankage is necessary (the state or the designated PDC operator would lease existing railcars to hold the reserves). Second, the supply to the PDC would be delivered via bulk rail shipments, rather than via smaller, less-efficient truck deliveries. This would allow the reserve to be filled (and re-filled after a drawdown) at a faster rate than a terminal PDC receiving supply by truck. Finally, because most of the key facility equipment is mobile (railcars and mobile pump carts), the facility can be potentially repositioned at other locations in the state, if needed.

[13] Gasoline supply sources may include refineries or storage facilities from Houston, Texas, east to Pascagoula, Mississippi.

Despite these advantages, rail-to-truck transloading facilities have several drawbacks. First, rail-to-truck transloading facilities load trucks at a slower rate than terminal truck racks and require more time to connect and disconnect loading equipment. Rail-to-truck transloading facilities require approximately 45–60 minutes to load a truck (compared to approximately 30 minutes at terminal truck racks), and pump carts must be disconnected from railcars when the railcars are empty and repositioned and reconnected to a full railcar. One railcar holds enough fuel to fill approximately three tanker trucks, so the pump cart would need to be repositioned once every third truck, further limiting the maximum daily loading rates from a single pump cart. Overall, more loading positions and more personnel are likely to be necessary to provide the same deliverability as a standard terminal truck rack.

Another potential drawback may be the availability and cost of leasing railcars. Rail companies interviewed for this study indicated that there is currently a shortage of the newest, safest (DOT-117) railcars for transporting gasoline. According to industry reports from June 2018, the DOT-117 tank car fleet was fully utilized. For perspective, a 1.3-MMgal reserve would require about 43 railcars, or about half a mile of track. Scaling up for larger-sized PDCs would create a considerable challenge. A 5.2-MMgal reserve would require 173 railcars and two miles of track.

Costs

As of June 2018, lease rates for DOT-117 railcars were approximately $700 per month. Assuming that this rate remains the same in nominal terms, lease costs for a 43-car PDC (with 1.3 MMgal of storage and 430,000 gal/d of deliverability) would be about $360,000 per year or about $7.2 million over a 20-year period. This equates to approximately $17 per gal/d of deliverability. On top of this would be the cost of buying or leasing the mobile pump carts, developing the project site (including siding, diking, lighting, security, and so forth), and potentially the need for storing the railcars during the portion of the year when the railcars are not in use. Operational costs may also be more expensive than a standard terminal due to the need to have more trained personnel onsite to facilitate the pump cart hookup and filling procedures.

Establishing a rail-to-truck transloading facility as a PDC could be a feasible alternative to a full-terminal PDC. It would require a fuel logistics provider to work with a railroad and rail-to-truck transloading operator to develop a proposal. There are several drawbacks, including a higher cost and challenges in scaling up to larger-sized operations. It may be more suited for areas where the required reserve volumes are smaller.

4.3.1.4. Expansion of Retail Station Underground Storage

An alternative to establishing centralized bulk storage facilities is to add storage capacity directly at retail fueling stations. This could be achieved by adding underground storage tanks (USTs) at existing stations if space is available, or by adding storage at new gas stations as they are being built. The priority locations would be stations close to evacuation routes with sufficient dispensing capabilities to handle increased volumes.

Given the scale of the PDC storage requirements in Exhibit 17, it is unlikely that UST expansions at retail gas stations are a feasible solution. Typical underground storage can hold 10,000–20,000 gal of fuel. To achieve the 4.6 MMgal of storage required in the I-75 Corridor PDC area under Option 1, 240–480 USTs would need to be built, while the Option 2 solution would require 120–240 USTs. To put this number in context, the I-75 Corridor PDC area has

558 retail stations with a total gasoline UST capacity of 12.6 MMgal. This means that the required UST expansions equal 40% and 20% of the region's gasoline UST capacity under Option 1 and Option 2, respectively. Furthermore, while some stations may have space to add additional USTs, many existing retail stations are constrained by the size of their property, and permitting issues may limit the ability of stations to add USTs even if space is available. Stakeholders interviewed for this study noted that it is very difficult to build new USTs in the state, even in areas that need of new service stations, due to difficulties in obtaining local permits.

While UST additions may not be a feasible solution for the large PDC areas identified in this study, they may merit consideration in niche markets where a relatively small volume of additional gasoline storage is required. For example, many retail stations in the Florida Keys are located a long distance from the closest supply source (Port Everglades), and the population to be evacuated is too small to support the construction of a centralized PDC. The Florida Keys (Monroe County) have 58 service stations, with an average gasoline storage capacity of 20,000 gal. Approximately half of these stations ran out of fuel during the Irma evacuation, according to data from GasBuddy. Adding USTs at large retail stations in the Keys may be an effective small-scale method of enhancing fuel availability. Adding a total of 50,000 gal of additional storage at three to five large service stations (with a sufficient dispensing capacity) would provide a reserve equal to about half a day of Monroe County's normal demand, providing an immediate deliverability increase to the Keys. To implement this solution, state funding would need to be made available to station owners to incentivize UST expansions.

4.3.2. Management

Management of PDC operations should be contracted out to a private company with experience in petroleum product distribution. Selection of a PDC operator should be done through a competitive process to ensure transparency and cost-effectiveness. Potential management issues are discussed in the subsections below.

4.3.2.1. Contracting

The state should solicit bids from terminal owners and operators, wholesale fuel marketers, and other entities to design, build, and operate the PDC solutions. The solicitation should outline the services required by the state to establish the PDC and maintain fuel inventories and deliverability for emergency situations.[14] These services may include:

- PDC engineering, design, and construction;
- PDC O&M; and
- Fuel procurement, management, and sales.

A separate competitive process should be required for each of the three identified PDC areas. In addition, the state may decide to issue separate competitive processes for each of the services identified above for each PDC, although it may be more efficient to issue a single solicitation for combined services and have companies respond as project teams. The

[14] The New York State Energy Research and Development Authority (NYSERDA) created a request for proposal (RFP) for their Strategic Fuel Reserve Program. This RFP can potentially be used as a starting point for developing a competitive process for Florida's PDC/Terminal Rack Expansion Program.

solicitation should clearly define the requirements of the PDC, including, but not limited to the following:

- **Location Requirement:** Region or list of counties where the facility is to be located and general requirements related to highway access.
- **Storage Capacity Requirement:** Total working volume of product to be held.
- **Deliverability Requirement:** Total maximum ability to load trucks.
- **Equipment Requirement:** A general list of the primary and ancillary equipment required (e.g., storage, truck-loading facilities, instrumentation, custody transfer, security, lighting, vapor recovery system, generic additive system).
- **Resiliency Requirement:** Availability of backup power resources (onsite or offsite) capable of maintaining maximum gasoline loadings at the terminal.
- **Staffing Requirement:** Ability to adequately staff the facility and begin fuel disbursement within several hours of the issuance of evacuation orders.
- **Fuel Procurement and Sales Requirement:** Capability of arranging and processing product procurement and sales, including in-tank transfers and truck rack sales, and price risk management (hedging).
- **Term Requirement:** Defined length of the agreement between the state and the terminal operator (suggested 20-year minimum).
- **Non-Emergency Use Clause:** Identify the conditions under which the terminal operator would be allowed to utilize the PDC capacity for non-emergency uses and how the state would be compensated for non-emergency use. This is particularly important if the operator is operating a commercial business out of the same facility.
- **Buy-Back Clause:** Identify the terms under which the terminal has the ability to buy back the state's capacity at the end of the contract term.

Responses to the competitive process should address each of the items above and outline the project's proposed:

- **Costs/Fees**, including land acquisition, permitting, construction, O&M, fuel procurement, and management costs;
- **Implementation timetable** for planning, procurement, permitting, and construction;
- **Design** of the facility (e.g., terminal, truck-to-rail transloading facility); and
- **Equipment** to be added as part of the expansion (e.g., storage tanks, truck rack).

When evaluating responses, the state should evaluate the proposed facility design, ability to meet storage and deliverability requirements, costs, location, and whether the key criteria in the solicitation are sufficiently met.

4.3.2.2. Fuel Inventory Requirements

The PDCs should be designed to store gasoline and be ready to load it into trucks to support evacuations during the hurricane season. For terminal PDCs, 90% of the storage should be dedicated to conventional gasoline blendstock (CBOB) and 10% should be dedicated to ethanol. The PDC would blend CBOB and ethanol at the terminal rack at a ratio of 9-to-1 through in-line blending to create finished gasoline at the truck rack. CBOB and ethanol are widely available products in Florida and can be delivered to the PDC by tanker truck from primary terminals. If the PDC is supplied by rail or barge, product can be sourced directly from the Gulf Coast. In the case of rail-to-truck transloading facilities, the product stored in the railcars can be already-blended E10.

Fuel inventory requirements also would include the capability to store additives and blend them with gasoline at the truck rack. The U.S. Environmental Protection Agency (EPA) mandates that all gasoline sold to consumers contain EPA-certified detergent additives—chemical compounds that control deposit formation in gasoline. All unbranded gasoline contains a generic additive package that complies with EPA regulations. Most of the major oil marketers have proprietary blends of additives that set their brands apart. These additive blends may contain other active components, such as corrosion inhibitors, antioxidants, metal deactivators, and handling solvents. At a minimum, the PDCs will need to be equipped to store and blend generic additives. Some branded gasoline marketers that make use of the PDC may wish to store proprietary additives at the PDC site (some brands require that the branded gas station only sell gasoline that contains branded additives). The PDC should honor these requests, if feasible, although the cost of installing the additive system and the additives themselves would be paid for entirely by the requesting company.

4.3.2.3. Fuel Inventory Management

Gasoline at the PDC needs to be available during the Atlantic hurricane season, which runs from June 1 to November 30. The operator would begin filling the PDC starting in late April, when summer-grade (low Reid vapor pressure [RVP]) becomes available, and the reserve would be filled to target volumes by June 1. Following an evacuation that partially or fully depletes the PDC reserve, the state would need to determine whether to refill the reserve or allow it to remain depleted until the end of the hurricane season. At the end of the hurricane season (after November 30), any remaining fuel in the reserve would be auctioned off in a manner that does not materially disrupt the fuel market (gasoline cannot be held in the reserve indefinitely because the fuel will degrade over time).

The PDC operation involves buying gasoline at one time (primarily in May) and selling it either during an evacuation period (from June through November) or at the end of the hurricane season in December. In many years, the PDC would be purchasing summer-grade (low RVP) gasoline and selling the fuel during periods when winter-grade (high RVP) gasoline is used (after September 15). Although winter-grade gasoline cannot be used in the summer, summer-grade gasoline can be used all year long in Florida, so this would not create a regulatory concern. Should the state want to add the ability to convert summer-grade gasoline to winter-grade gasoline, butane blending storage and blending facilities could be installed at an added cost, although this is not necessary.

Due to the significant timing differences in the purchase and sale of the fuel, the PDC operation is exposed to significant price risk and the state or PDC operator would need to establish a hedging program to protect against downward movements in the price of fuel. Hedging strategies for the PDC operation may be complicated due to the uncertain timing of the gasoline sales (the product could be sold at any time over a six-month period), and the state would need to consult a financial expert to develop an appropriate risk management strategy.

Many of the timing issues described above can be mitigated to some extent if the PDC operator operates a commercial terminal business alongside the PDC reserve. This would allow the PDC and commercial business to comingle product inventory, allowing the product to be rotated through the course of the commercial in- and out-bound loadings. As a result, the state would not need to buy and sell the fuel every year, and transportation and transaction costs could be avoided. In this scenario, the state would still need to pay fees to the PDC operator for terminal storage volume and reserve truck rack capacity for emergency use during the hurricane season.

4.3.2.4. Fuel Supply Logistics

For rail-to-truck PDC configurations, fuel supply would (by definition) be supplied via rail. For terminal PDC configurations, supply can be delivered by truck, rail, or barge; however, it is likely most cost-effective for the reserve to be filled by truck. There are no petroleum product supply pipelines in the proposed PDC areas, and it is not considered feasible to build new long-distance pipeline infrastructure because of permitting issues. All three of the proposed PDC areas can potentially be supplied by rail, and the Southwest and Fort Pierce PDC areas, which are located near the coast, also have the potential for supply by barge. However, overall, it is unlikely that investments in marine or rail unloading infrastructure at terminal PDCs would be cost-effective given that the infrastructure would only be used to fill the reserve once per year (or twice per year in the event of an early season hurricane and a decision to restock the reserve). Although truck supply is generally not an efficient bulk supply method, it may still be economical on a once-per-year basis. Even the largest PDC size option—4.8 MMgal—could be filled over a 45-day period with only 12 truck deliveries per day. The smaller 1.2-MMgal PDCs could be filled with three truck deliveries per day over the same period. Rail or barge supply may become economically feasible if the PDC operator develops a commercial business alongside the PDC site because this would increase the utilization of rail or marine infrastructure investments.

4.3.2.5. Fuel Sales and Distribution

Fuel sales out of the PDC would occur either during an emergency evacuation event or at the end of the hurricane season. During an emergency, the state may have multiple requests for fuel, and a process would need to be in place to quickly and efficiently sell the fuel to parties in need. In order to ensure that potential buyers are serving the demands for evacuation, distributors buying fuel from the PDC would be required to prequalify with the state. Eligibility could be based on the characteristics of the buyer (e.g., number of stations on evacuation routes, number of fuel dispensers, the retail stations' backup power capabilities). In addition, eligibility could be extended to distributors who supply state and local first responders (police, fire, and emergency medical) or critical infrastructure operators (e.g., electric utilities, water treatment plants), which would potentially extend the benefits of the PDC even after the evacuation period. Prequalified buyers would need to set up payment and credit accounts with the state and have their trucking firms' drivers trained on loading and safety protocols at the PDC. A one-time training for drivers could be held prior to the first hurricane season, and once-per-year retraining could be conducted as part of the sales period at the end of hurricane season.

During an evacuation event, the state would issue a notice to prequalified buyers indicating that fuel is available for release each day. This notice should detail the volume available at each PDC, the sale price, and the timeline for receiving fuel requests and fuel pickup. Emergency pricing should be set at a premium to the current rack pricing at the closest primary terminal cluster (e.g., Port Everglades, Tampa, Jacksonville). The PDC premium would reflect the truck transport cost to the PDC plus a fee for storage and loading. The resulting PDC rack price would be set (by formula) higher than the cost of buying fuel at the primary terminal and transporting it to the PDC area. This pricing method would ensure that buyers will only seek fuel from the PDC as a last resort when fuel is unavailable or too difficult (due to traffic or long lines at terminal racks) to purchase and transport from their normal supply terminals.

Prequalified distributors who are interested in purchasing fuel from the PDC would reply to the state's notice with the volume of fuel they are seeking, indicating the individual stations or commercial accounts where the fuel would be delivered. If more volume requests are made than the total volume offered, the state may need to prioritize or allocate requests. Price would not be a factor in supply allocation because all parties would receive the same price. State allocation decisions could take a number of factors into consideration, including the projected path of the storm, real-time and forecast traffic on evacuation routes, and data from GasBuddy.com on retail station outages. To simplify allocation decisions, the state should develop a clear formula or methodology for allocating supply. The state would reserve the authority to prioritize any truckloading deemed critical, and to determine the total volume released on any given day.

Finally, the PDC operator would need to ensure that each loaded truck is billed the prevailing price for the gallons loaded, and that the state is kept apprised of the remaining fuel in the PDC. The operator also would need to ensure that as trucks are loaded, hedging contracts are unwound, so the state will not be exposed to gasoline commodity price changes from when the fuel was originally procured.

For product sales at the end of the hurricane season, sales may be extended to parties that have not prequalified with the state. Pricing would need to be set equivalent to prices at the closest terminal cluster. Liquidation could take place in small allotments over several weeks to avoid an excessive impact on the regional fuel market.

Competitive Auction

One alternative to the sales method outlined in the previous section is to sell the gasoline competitively through an online auction to pre-registered bidders. This is the sales method utilized by the U.S. Department of Energy's Northeast Gasoline Supply Reserve.[15] Under an online bidding system, potential buyers that have been pre-screened by the state would compete on price to obtain fuel from the PDC reserve. This method of price discovery avoids the potential problem of the state underpricing fuel relative to market demand and ensures that fuel from the reserve is distributed to the party most in need (willing to pay for it).

[15] https://refinedproduct.fossil.energy.gov/

5. Cost-Benefit Analysis of Potential Network Enhancements

Key Takeaways

- ICF compared the costs of potential enhancements to the Florida gasoline distribution network against the expected benefits. Benefits were defined by the reduction in the number of hurricane-related deaths and injuries that result from greater fuel availability for evacuations. Costs for each potential network enhancement include the initial capital cost of constructing the facility, annual operating and maintenance costs, and annual fuel inventory and handling costs.
- The cost-benefit analysis uses a Monte Carlo simulation wherein the frequency, location and severity of future hurricanes affecting Florida are represented by probability distributions based on the statistical histories of actual hurricanes.
- ICF evaluated five infrastructure options ranging from 3.9 to 16.3 MMgal/d of added deliverability from a combination of existing terminals and new PDCs. All five infrastructure options evaluated had benefits that exceeded costs.
- ICF identified the 8.2 MMgal/d configuration (Option 3) as the option that delivered the highest level of total benefits while also providing a benefit-cost ratio strong enough to withstand potential unfavorable changes in key model inputs.

The cost-benefit analysis is a way of comparing the costs of potential improvements to the Florida gasoline distribution network against the expected benefits of those improvements measured in dollars. The dollar benefits are computed as the reduction in the number of hurricane-related deaths and injuries that is expected to result from the network improvements times the economic cost to society for each type of personal-injury incident.

This chapter begins with a brief overview of the methodology used to perform the cost-benefit analysis and then presents in summary form the data and methodology for projecting:

- Frequency, location, and severity of future hurricanes that could affect Florida;
- Number of deaths and injuries as a function of hurricane characteristics and evacuation effectiveness;
- Number of planned evacuations;
- Increase in gasoline demand; and
- Impact of increased demand on the ability of gas stations to provide gasoline to consumers.

These topics are presented in more details in *Appendix C: Additional Information on Methodology and Data for Cost-Benefit Analysis.*

The last part of this chapter presents the cost-benefit calculations for five size, configuration, and location options for improving the Florida gasoline distribution network. The conclusion of the cost-benefit analysis presented in this chapter is that all of the examined options have estimated economic benefits that exceed their estimated costs.

5.1. Overview of the Cost-Benefit Methodology

The cost-benefit analysis presented in this report compares the costs of potential fuel distribution network enhancements against the benefits of those enhancements given certain expectations regarding the frequency, location, and severity of future hurricanes affecting Florida. A Monte Carlo simulation[16] is used to generate the characteristics of possible future hurricanes. The probability distributions for these characteristics are based on the statistical histories of actual hurricanes.

The costs of each potential network improvement include the initial capital cost of constructing the facilities, annual O&M costs, and annual fuel inventory and handling (FI&H) costs. These costs are presented here in real 2018 dollars and are converted to annualized costs[17] assuming a 20-year life and a discount rate of 7% per year. This discount rate is the one recommended by the Federal Emergency Management Administration (FEMA), and several other federal agencies, for performing cost-benefit analyses.

The benefits of the potential network improvements are calculated for each simulated hurricane in terms of the expected number of lives saved and injuries prevented through making more fuel available to facilitate faster and more complete evacuations. The mean, or expected value, of lives saved *per hurricane* is computed as the average result for all simulated hurricanes, and then those results are adjusted to *per year* benefits by multiplying by the number of hurricanes expected each year. The expected number of lives saved and injuries prevented each year are converted to dollars of benefit using the FEMA recommended standard societal costs of one death or one injury of a particular severity. A final adjustment is made to the estimated annual benefits to account for future growth in Florida population over the 20-year forecast period.

The ratio of annual dollar benefits divided by annualized costs is called the benefit-to-cost ratio (BCR). A BCR that exceeds 1.0 indicates that the improvements to the fuel distribution network are economical in that estimated dollar benefits exceed dollar costs. Comparisons among alternative network enhancement options can be made by comparing their BCRs. The higher the BCR for an option, the more relative benefit or “bang for the buck” that the option provides.

5.2. Cost Estimates

5.2.1. Capital Costs

ICF estimated the ROM construction cost estimates for each PDC and rack expansion based on the storage size (in gal) and deliverability (in gal/d) requirements outlined in the previous chapter (see Exhibit 21 through Exhibit 25). These costs are based on research and analysis of

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[16] A Monte Carlo simulation is a mathematical technique that generates random variables for systems where there are risks in the frequency and characteristics of important outcomes and their effects. The random variables are represented as probability distributions. The Monte Carlo process uses sequences of random numbers to generate the random variables and then combines them into a large number of simulations, whose characteristics have statistics (mean, standard deviations, and probability density functions) that are intended to represent what would occur in the real world over a very long period.
[17] Annualized costs are computed by spreading the initial capital costs (including the time value of money or the interest rate on the capital cost) over the life of the facilities and then adding the average expected annual O&M and FI&H costs.

similar projects in the Southeast, but are not based on detailed engineering of a project site. As such, these costs have a potential error of about ±50%.[18] Although the PDC can take a number of potential configurations (grassroots terminals, utilization of secondary terminals, or rail-to-truck transloading facilities) for the purposes of the cost-benefit analysis, ICF assumed that the PDCs would be constructed as grassroots (new-build) terminals. Cost data were compiled from numerous sources, including the RSMeans cost database, the U.S. Department of Defense Unified Facilities Criteria cost database, industry publications, company press releases, corporate presentations, government documents, news articles, and real estate listings. The estimates presented include costs for site development; site drainage; one or more ASTs for gasoline blendstock; an AST for ethanol; an AST for firefighting water; tank patio berms; one or more loading bays with associated pumps, valves, controls, and key card hardware; piping between the tanks and the loading rack; paved entry, loading, and exit areas; a small building; secondary containment; and fencing, lighting, and security systems. The total cost estimate also includes a construction cost contingency; an allowance for construction management, engineering, insurance, bonds, and permits; and land costs.

Rack expansion cost estimates are based on ROM costs for adding a “bare bones” truck-loading bay at an existing terminal. The cost for a single loading bay with approximately 430,000 gal/d of loading capacity is about $850,000. This estimate includes the costs for extending the rack, canopy, and piping, and adding pumps, vapor control, loading control, motors, valves, and loading arms. The estimate also includes the ancillary costs for paving additional lanes and extending drainage, fencing, lighting, and security systems, as necessary, to accommodate the new bay. The estimate assumes that the bay is close to existing bays so that there would be no need for land acquisition, significant new piping from the storage tanks to the bays, or for major road modifications for tanker truck ingress and egress. The estimate also assumes that the feed piping from the tanks has a sufficient flow capacity, and that the vapor system and the fire system can be extended without major upgrades.

Exhibit 21 through Exhibit 25 provide ROM capital cost estimates for each of the five options evaluated. Total capital costs range from a low of $12.4 million for Option 4 (3.9 MMgal/d of deliverability) to $60.4 million for Option 1 (16.3 MMgal/d of deliverability). Generally, the tables show that as deliverability sizes increase, so do the total costs. The unit costs of each option—the total cost per gallon of daily deliverability—vary from option to option based on the specific configuration of PDCs and rack expansions required. Unit costs are lowest for options that rely more heavily on rack expansions for deliverability. For rack expansions, the unit costs stay constant at $1.97 per gal/d of deliverability regardless of the total deliverability. This is because deliverability is increased through the modular addition of loading bays. Unit costs for PDCs are much higher because of the need to build storage and other project and site development costs. However, PDC unit costs decrease for larger-sized options due to economies of scale in storage tank construction. The unit cost for the smallest size of PDC (1.3 MMgal of storage) is $14.56 per gal/d of deliverability compared to $10.39 per gal/d for the largest size of PDC (5.2 MMgal of storage).

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[18] ROM costs are ballpark cost estimates provided in the early stages of a project when the project’s scope and requirements have not been fully defined. The Project Management Body of Knowledge (PMBOK), 4th Edition defines a ROM estimate as having an error of ±50%.

Exhibit 21. Option 1 (16.3 MMgal/d) ROM Capital Costs

Location	Storage (gal)	Deliverability (gal/d)	Cost	Unit Cost ($ per gal/d)
PDCs				
A. I-75 Corridor PDC	5,200,000	1,720,000	$ 17,865,214	**$10.39**
B. Fort Pierce PDC	2,600,000	860,000	$ 9,983,454	**$11.61**
C. Southwest PDC	1,300,000	430,000	$ 6,260,643	**$14.56**
Rack Expansions				
D. Port Everglades	–	4,730,000	$ 9,326,761	**$1.97**
E. Tampa Bay	–	3,870,000	$ 7,630,986	**$1.97**
F. Orlando/Canaveral	–	3,010,000	$ 5,935,211	**$1.97**
G. Jacksonville	–	1,290,000	$ 2,543,662	**$1.97**
H. Bainbridge	–	430,000	$ 847,887	**$1.97**
I. Panhandle Ports	–	–	–	**–**
Totals	**9,100,000**	**16,340,000**	**$ 60,393,819**	**$3.70**

Exhibit 22. Option 2 (12.0 MMgal/d) ROM Capital Costs

Location	Storage (gal)	Deliverability (gal/d)	Cost	Unit Cost ($ per gal/d)
PDCs				
A. I-75 Corridor PDC	3,900,000	1,290,000	$ 13,899,287	**$10.77**
B. Fort Pierce PDC	1,300,000	430,000	$ 5,735,643	**$13.34**
C. Southwest PDC	1,300,000	430,000	$ 6,260,643	**$14.56**
Rack Expansions				
D. Port Everglades	–	3,440,000	$ 6,783,099	**$1.97**
E. Tampa Bay	–	3,010,000	$ 5,935,211	**$1.97**
F. Orlando/Canaveral	–	2,150,000	$ 4,239,437	**$1.97**
G. Jacksonville	–	860,000	$ 1,695,775	**$1.97**
H. Bainbridge	–	430,000	$ 847,887	**$1.97**
I. Panhandle Ports	–	–	–	**–**
Totals	**6,500,000**	**12,040,000**	**$ 45,396,982**	**$3.77**

Exhibit 23. Option 3 (8.2 MMgal/d) ROM Capital Costs

Location	Storage (gal)	Deliverability (gal/d)	Cost	Unit Cost ($ per gal/d)
PDCs				
A. I-75 Corridor PDC	2,600,000	860,000	$ 9,893,454	**$11.50**
B. Fort Pierce PDC	1,300,000	430,000	$ 5,735,643	**$13.34**
C. Southwest PDC	–	–	–	**–**
Rack Expansions				
D. Port Everglades	–	2,580,000	$ 5,087,324	**$1.97**
E. Tampa Bay	–	2,150,000	$ 4,239,437	**$1.97**
F. Orlando/Canaveral	–	1,290,000	$ 2,543,662	**$1.97**
G. Jacksonville	–	860,000	$ 1,695,775	**$1.97**
H. Bainbridge	–	–	–	**–**
I. Panhandle Ports	–	–	–	**–**
Totals	**3,900,000**	**8,170,000**	**$ 29,195,295**	**$3.57**

Exhibit 24. Option 4 (3.9 MMgal/d) ROM Capital Costs

Location	Storage (gal)	Deliverability (gal/d)	Cost	Unit Cost ($ per gal/d)
PDCs				
A. I-75 Corridor PDC	1,300,000	430,000	$ 5,660,643	**$13.16**
B. Fort Pierce PDC	–	–	–	**–**
C. Southwest PDC	–	–	–	**–**
Rack Expansions				
D. Port Everglades	N/A	1,290,000	$ 2,543,662	**$1.97**
E. Tampa Bay	N/A	860,000	$ 1,695,775	**$1.97**
F. Orlando/Canaveral	N/A	860,000	$ 1,695,775	**$1.97**
G. Jacksonville	N/A	430,000	$ 847,887	**$1.97**
H. Bainbridge	N/A	–	–	**–**
I. Panhandle Ports	N/A	–	–	**–**
Totals	**1,300,000**	**3,870,000**	**$ 12,443,742**	**$3.22**

Exhibit 25. Option 5 (8.2 MMgal/d, No Storage) ROM Capital Costs

Location	Storage (gal)	Deliverability (gal/d)	Cost	Unit Cost ($ per gal/d)
PDCs				
A. I-75 Corridor PDC	–	–	–	**–**
B. Fort Pierce PDC	–	–	–	**–**
C. Southwest PDC	–	–	–	**–**
Rack Expansions				
D. Port Everglades	–	3,010,000	$ 5,935,211	**$1.97**
E. Tampa Bay	–	2,580,000	$ 5,087,324	**$1.97**
F. Orlando/Canaveral	–	1,290,000	$ 2,543,662	**$1.97**
G. Jacksonville	–	1,290,000	$ 2,543,662	**$1.97**
H. Bainbridge	–	–	–	**–**
I. Panhandle Ports	–	–	–	**–**
Totals	**–**	**8,170,000**	**$ 16,109,859**	**$1.97**

5.2.2. Operating Costs

ICF estimated the annual operating costs, including operation and maintenance (O&M) costs and the fuel inventory and handling costs (FI&H) costs for newly-constructed PDCs and for rack expansions at existing terminals. These costs are presented in Exhibit 26.

For the PDCs, annual operation costs include estimates for insurance, property tax, personnel, security, and electricity. Insurance costs were estimated at 1% of the capital cost based on published cost data for similar facilities. Property taxes in Florida were estimated at 1% of the capital cost based on typical property tax rates in Florida. Personnel cost estimates assume two operators working one shift during the annual PDC filling period and two operators working one shift during the annual PDC emptying period. During emergencies, the estimates assume four operators per shift and three shifts per day for four days. The estimates do not include costs for full-time, manned security but do include a provision for remote monitoring of cameras and other sensors. Electricity costs include estimates for site lighting, alarms, and general use year round, plus additional costs for operating the pumps and other equipment during periods of PDC activity. PDC annual maintenance costs are calculated as $0.0774 per gallon of storage capacity based on published cost databases for bulk liquid fuel storage facilities. Inventory costs include the interest cost to finance the purchase of the stored gasoline for 6 months and equal $0.077 per gallon, assuming a cost of $2.20 per gallon and a 7% interest rate.[19] ICF has also estimated a $0.028 per gallon handling charge for delivery of the gasoline from the PDC to the retail station during the annual PDC emptying period.

For the rack expansions, the estimated annual costs include the 1% insurance estimate, the 1% property tax estimate, plus an additional 1% of the rack expansion capital cost as an O&M fee to the terminal operator to cover any marginal security, electricity, and maintenance costs. The estimate assumes that any additional labor cost at a terminal is covered by the terminal rack fee for the additional volume sold.

Exhibit 26. Annual Operating Costs

	Option 1 (+16.3 MMgal/d)	Option 2 (+12.0 MMgal/d)	Option 3 (+8.2 MMgal/d)	Option 4 (+3.9 MMgal/d)	Option 5 (+8.2 MMgal/d, No Storage)
PDCs					
PDC Storage (gal)	9,100,000	6,500,000	3,900,000	1,300,000	-
PDC Capital Cost	$ 34,109,312	$ 25,895,574	$ 15,629,098	$ 5,660,643	$ -
PDC O&M Cost	$ 1,779,648	$ 1,363,635	$ 851,205	$ 309,547	$ -
PDC Inventory Cost	$ 700,700	$ 500,500	$ 300,300	$ 100,100	$ -
PDC Handling Cost	$ 254,800	$ 182,000	$ 109,200	$ 36,400	$ -
Rack Expansions					
Rack Capital Cost	$ 26,284,507	$ 19,501,409	$ 13,566,197	$ 6,783,099	$ 16,109,859
Rack O&M Cost	$ 788,535	$ 585,042	$ 406,986	$ 203,493	$ 483,296
Rack Inventory Cost	$ -	$ -	$ -	$ -	$ -
Rack Handling Cost	$ -	$ -	$ -	$ -	$ -
Total	**$3,523,683**	**$2,631,177**	**$1,667,691**	**$649,540**	**$483,296**

5.3. Hurricane Threats

A critical part of the cost-benefit analysis of any kind of infrastructure investment is the estimation of how often that infrastructure will be used and the economic value of its use. The cost-benefit analysis of potential improvements to the Florida gasoline distribution network to supply gasoline for hurricane evacuations depends critically on the frequency, location, and severity of the projected future hurricanes and the estimated costs those hurricanes might impose on Florida in terms of lost lives and injuries. The characteristics of future hurricanes used in this analysis are derived from the Florida Public Hurricane Loss Model (FPHLM), version 6.2.[20] Parameters from that model were used in the Monte Carlo analysis to generate

[19] The price of $2.20/gallon is the average New York Harbor Reformulated RBOB Regular Gasoline Future Contract price over the last ten years.
[20] For more information on the Florida Public Hurricane Loss Model, see http://fphlm.cs.fiu.edu/

simulated hurricanes that were then analyzed to determine the potential loss of life and injuries, and how different infrastructure options for a more effective gasoline distribution might reduce those deaths and injuries.

The annual occurrence rates by landfall location and by hurricane category (defined by maximum wind speed at landfall on the Saffir-Simpson scale[21]) used in the ICF cost-benefit analysis are shown in Exhibit 27. The modeled frequencies are consistent with the FPHLM, which, in turn, is consistent with the 116-year historical record upon which it is based. Note that a single hurricane can make landfall more than once. Therefore, the expected number of hurricanes making at least one landfall in Florida is 0.548 per year, while the expected number of landfalls is slightly higher at 0.616.

More information on how these estimates were derived can be found in *Appendix C.1. Hurricane Threats.*

Exhibit 27. Expected Number of Hurricanes, by Landfall Region and Category

	Hurricane Category							
Region of Landfall	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5	Any Cat. Any Landfall	Any Cat. First Landfall	Any Cat. Second Landfall
NW	0.129	0.051	0.037	0.015	0.002	0.233	0.206	0.028
NE	0.009	0.005	0.005	0.001	0.000	0.020	0.017	0.004
SW	0.073	0.044	0.041	0.018	0.004	0.179	0.161	0.019
SE	0.059	0.034	0.046	0.034	0.010	0.183	0.164	0.019
Any Landfall	0.270	0.134	0.129	0.068	0.016	0.616		
First Landfall	0.231	0.118	0.119	0.065	0.015	0.548	0.548	
Second Landfall	0.039	0.016	0.010	0.003	0.001	0.069		0.069

Source: Florida Public Hurricane Loss Model, version 6.2, April 17, 2017. In addition to hurricanes represented in this table, 0.12 hurricanes per year will closely bypass Florida, but not make landfall in the state.

5.4. Hurricane Vulnerabilities

The cost-benefit analysis computes the benefits in terms of the reduction in deaths and injuries that could come about through a more efficient gasoline distribution system. This section briefly explains how hurricane deaths and injury are estimated, and what economic value is placed on their avoidance.

The Monte Carlo process estimates the number of deaths expected for the 10,000 simulated future hurricanes as a function of the maximum sustained wind speeds and storm surge heights expected in each county for each event. For this purpose, the "actual" wind speeds and storm surge heights, rather than the "planned" values, are used.[22] The algorithms used to predict the

[21] The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 rating based on a hurricane's sustained wind speed. This scale estimates potential property damage. Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage. Category 1 and 2 storms are still dangerous, however, and require preventative measures. See https://www.nhc.noaa.gov/aboutsshws.php

[22] The cost-benefit analysis methodology estimates evacuations assuming that the actual path of a hurricane is not known, and thus several alternative "planning" paths are used to determine who should

number of deaths for each hurricane are calibrated to achieve an average (across all 10,000 simulated hurricanes) of 29 deaths per hurricane. The value of 29 deaths was chosen as a target to match the historical number of deaths in the United States from 1963 to 2017. In addition, for each death caused by a hurricane, this analysis expects there to be 5.7 injuries requiring hospitalization, 20.3 injuries treated at an emergency room (ER) or clinic (without hospitalization), and 41.2 injuries that are treated at home.

For the purposes of computing the dollar cost of injuries (and the dollar benefits of avoiding such injuries), the count of each type of injury is multiplied by the social costs of the one injury event, as recommended by FEMA for cost-benefit analysis.[23] Exhibit 28 shows these standard values as last published in June 2009 and what those cost are in 2018 dollars adjusted for general inflation. The standard values of social costs include not just the cost of treating the injuries, but also the cost of lost wages, lost productivity, the lost values of good health, and the value of lost companionship and care for family members.

More information on how these estimates were derived can be found in *Appendix C.2. Hurricane Vulnerabilities.*

Exhibit 28. Assigned Cost of Hurricane Deaths and Injuries per FEMA Standards

FEMA Standard Values for Cost-Benefit Analysis			Weighted Average of All Causes	
Injury Severity Level	As of June 2009	2018 dollars	Count Relative to 1 Death	Cost Relative to 1 Death
Death	$5,800,000	$6,932,000	1.0	$ 6,932,000
Hospitalized	$1,088,000	$1,300,000	5.7	$ 7,464,165
Treat & Release	$90,000	$108,000	20.3	$ 2,187,900
Self-Treatment	$12,000	$14,000	41.2	$ 576,807
All Severity Levels			68.2	$17,160,872

Source for standard values: BCA Reference Guide, FEMA, June 2009.

5.5. Hurricane Evacuations

For each simulated hurricane, the number of people to be evacuated by county is modeled as a function of hurricane characteristics (specifically location, size, wind speed, and storm surge) and a factor to account for the landfall location error. The landfall location error is intended to account for the fact that the track of the hurricane cannot be known with certainty at the start and during the evacuation period and, therefore, the area evacuated is typically larger than the area that would have been evacuated if the hurricane track could have been known with certainty. The number of people who would be expected to evacuate due to simulated future

evacuate. The "planned" wind speed/storm surge are the highest values from any hurricane planning path and are always equal to, or higher than, the actual wind speed/storm surge for a county. The "planned" paths are simulated by ICF assuming that there is a random "hurricane forecasting error" representing the number of miles away from the actual landfall location a hurricane would be forecast to possibly make landfall as anticipated at the start of the evacuation period. This is commonly referred to as the hurricane "cone" given its shape.

[23] BCA Reference Guide, FEMA, June 2009.

hurricane events is computed in the cost-benefit analysis using the SRES[24] Situational Awareness Tool BETA, maintained by the Florida Division of Emergency Management (FDEM).

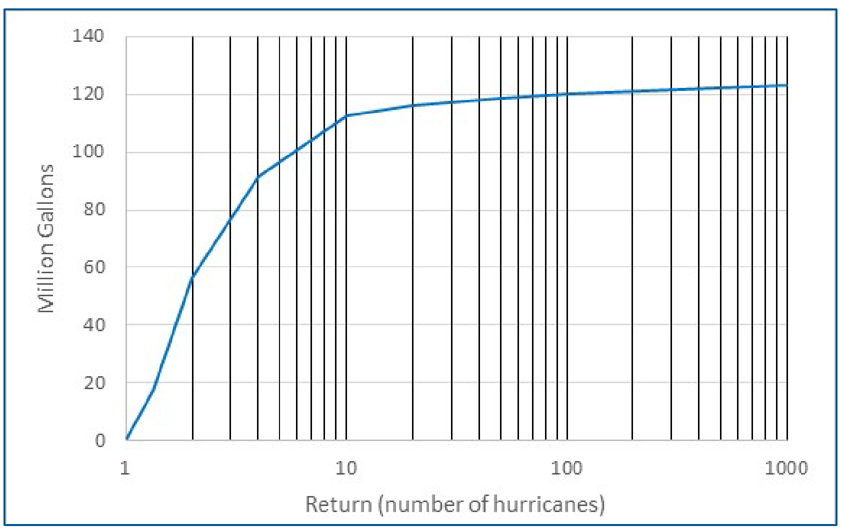
Because the probability of deaths and injuries are functions of wind speed and storm surge levels, more severe storms impose greater social costs related to deaths and injuries. The least severe hurricanes have social values under $20 per marginal evacuee, while the most severe hurricanes have calculated social values of more than $1,600 per marginal evacuee. Across all simulated hurricanes, the social values average $208 per marginal evacuee. More information on how these estimates were derived can be found in *Appendix C.3. Hurricane Evacuations.*

5.5.1. Gasoline Demand Surge Monte Carlo Modeling Results

The cost-benefit analysis compares the costs of potential enhancements to the Florida gasoline distribution network against the expected benefits of those enhancements in terms of the dollar value of the reduction in the number of hurricane-related deaths and injuries. The reduction in deaths and injuries would come about because drivers would more easily find the gasoline supplies they need for their planned evacuations, thereby speeding the evacuation process and making it more likely that they will be out of harm's way. A key component in the cost-benefit analysis is the estimation of how much more gasoline demand will occur due to the evacuations and other factors that increase gasoline demand during hurricane evacuation periods.

The methodology used here is to compute increased demand for gasoline in two parts. The first part is the gasoline needed for the evacuation itself. The second part of the gasoline demand increase is modeled as coming from vehicle owners who do not evacuate, but who top off their gas tanks in anticipation of gasoline supply disruptions. The distribution in the result for the total gasoline demand surge (evacuation demand plus topping off demand) is shown in Exhibit 29. The gasoline demand surge ranges from a few gallons to more than 120 MMgal over the entire evacuation period. The average demand surge across all 10,000 simulated hurricanes is 75.9 MMgal.

Exhibit 29. Gasoline Demand Surge over the Entire Evacuation Period (Monte Carlo Results)



[24] This acronym refers to Florida's Statewide Regional Evacuation Study Program.

The gasoline surge is assumed to be spread over the three days before hurricane landfall. Therefore, the average of the 75.9 MMgal of surge demand translates into a daily gasoline demand of 25.3 MMgal/d. When added to the typical daily demand of 24.7 MMgal/d, this produces a total demand of 50.0 MMgal/d for the average hurricane.

5.5.2. Estimates of Gas Station Outages, Lost Sales, and Unmet Demand

The estimated values for station outages, lost sales, and unmet demand are computed in the cost-benefit analysis on a daily basis over the evacuation period. A gas station outage occurs when a station runs out of unleaded regular gasoline at some point in a day. The term *lost sale* refers to the quantity of gasoline that customers visiting that station wanted to buy, but were unable to buy it because of that outage. Because customers can sometimes purchase gasoline at another station, the quantity of lost sales does not necessarily equate to unmet demand. The term *unmet demand* means that customers could not readily find gasoline (after typically visiting several stations) and gave up looking for that day.

> **Key Definitions**
>
> **Station outage** or **station stockout**: An event defined as a gas station running out of gasoline during a day. Measured as a count of events.
>
> **Lost sales**: The volume of gas that would have been purchased by customers attempting to purchase gasoline at a single station experiencing a station outage for given day. Measured in gallons per day or gallons over an evacuation period.
>
> **Unmet demand**: The volume of gasoline that would have been purchased by customers attempting to purchase gasoline on a given day but who gave up trying to find fuel after encountering several stations experiencing station outages. Measured in gallons per day or gallons over an evacuation period. Unmet demand would be expected usually to be a smaller volume than lost sales. Unmet demand is the key statistic for measuring how the availability of gasoline might constrain evacuations.

When there is a surge in demand for gasoline before a hurricane arrives, the quantity of demand exceeds the capacity of terminals and the tanker truck fleet to restock the gas stations. The result is that the inventory of gasoline at stations declines. If the decline in the inventory is great and prolonged, then a portion of the stations in a county may run out of gasoline. These station outages, or “stockouts,” then lead to lost sales from customers who would like to use those stations to purchase gasoline but cannot do so.

The cost-benefit analysis represents the probability of gas station outages on any given day as being primarily a function of (1) the beginning-of-day inventory at the stations, and (2) that day’s deliveries to the stations. The relationship between the probability of station outages as a function of inventory and deliveries was estimated through a computer simulation of gas stations inventories. That simulation also produced estimates of lost sales as a function of beginning-of-day inventories and daily deliveries. As for unmet demand, the cost-benefit analysis shown later in this chapter uses both a low and high estimate for unmet demand and calculates a third (middle) value that is the average of the low and high estimates. We use this average estimate of unmet demand to summarize the benefits of each infrastructure option.

5.5.3. Simulation of the Transportation of Gasoline from Terminals to Stations

The cost-benefit analysis simulates how gas stations would be restocked during the evacuation period from existing terminals and from any new PDCs that might be built in the future. The maximum amount of gasoline that can be loaded at each existing terminal is assumed in the base case to be the maximum loadings that were actually achieved during the Hurricane Irma evacuation. For policy cases that assume that new loading racks will be added at some existing terminals, the historical maximum loadings are increased per the specifications of that policy case. New PDCs with specific loading capacities and storage capacities may also be specified for any policy case.

The evacuations for each hurricane are simulated once under base case infrastructure conditions and again for the policy case that is being considered. Because the policy case usually increases available loading capacity at the terminals, the policy case reduces the chances of stockouts and lost sales. The benefit from the policy case is computed by assuming that the reduction in lost sales (and the related reductions in unmet demand) increases the chance that more people will successfully evacuate and, thus, will be less likely to be injured in the hurricane. However, it is important to remember that much of the demand increase for gasoline that occurs during evacuation periods is from non-evacuees topping off their tanks. We assume that the extra supplies provided under the policy cases will enter the general gasoline market. Therefore, much of the extra supply is siphoned off for non-evacuee use and for rebuilding of gas station inventories.

5.6. Cost-Benefit Calculations

5.6.1. Implied Economic Value of Increased Fuel Availability

The model used for the cost-benefit analysis solves for the movement of gasoline between each supply source (existing terminal or PDC) and the gas stations in each county. For the purposes of this analysis, all terminals within a specific port/terminal cluster are combined into a single source and all gas stations in a specific county are combined into a single “sink.” The model balances between these sources and sinks by refilling the stations each day at the level of daily demand in each county over a three-day evacuation period for each hurricane. There are two constraints that limit fuel distribution outcomes:

(1) Truck-loading capacity (in gal/d) at each supply source, and
(2) Number of trucks needed to transport the gasoline.

When the demand for refill volumes exceeds that of the terminal loading capacity or the truck transportation capacity, then each county is supplied with a proportionate share of its surge-adjusted demand.

The cost-benefit model evaluates the five fuel network enhancement options, which provide varying degrees of increased deliverability through rack expansions at existing terminals and the establishment of PDCs in remote areas. Although certain options provide greater deliverability, the associated capital costs are also larger (see Section 5.2). The model determines the benefits by first generating base case results assuming only currently existing infrastructure and capabilities. A set of policy case results is then generated where increased deliverability is added, as represented by each of the five fuel network enhancement options. The difference between the policy case and the base case results across all modeled hurricanes determines the potential benefits from the increase in available infrastructure and fuel deliverability. Exhibit 30 presents the cost-benefit results for each of the five options.

Exhibit 30. Summary of Cost-Benefit Analysis by Fuel Network Enhancement Option

		Option 1 (+16.3 MMgal/d)	Option 2 (+12.0 MMgal/d)	Option 3 (+8.2 MMgal/d)	Option 4 (+3.9 MMgal/d)	Option 5 (+8.2 MMgal/d, no new PDCs)
A	Deliverability Added at New PDCs (gal/d)	3,010,000	2,150,000	1,290,000	430,000	–
B	Deliverability Added at Existing Terminals (gal/d)	13,330,000	9,890,000	6,880,000	3,440,000	8,170,000
C	Total Deliverability Added (gal/d) [A + B]	16,340,000	12,040,000	8,170,000	3,870,000	8,170,000
D	Total Capital Costs	$60,393,819	$45,396,982	$29,195,295	$12,443,742	$16,109,859
E	Annualized Total Capital Costs	$5,700,749	$4,285,154	$2,755,829	$1,174,601	$1,520,657
F	Annual Operating Costs	$3,523,683	$2,631,177	$1,667,691	$649,540	$483,296
G	Total Annual Costs [E + F]	$9,224,432	$6,916,331	$4,423,520	$1,824,141	$2,003,953
H	Benefits per Year Measured in Lives Saved Adj. for Pop. Growth	0.72	0.58	0.43	0.23	0.43
I	Benefits per Year Measured in Reduced Injuries Adj. for Pop. Growth	48.23	39.11	29.07	15.74	29.07
J	Benefits per Year in Dollars Adjusted for Pop. Growth	$12,316,804	$9,986,876	$7,423,309	$4,020,406	$7,423,309
K	Benefit-to-Cost Ratio [J / G]	1.34	1.44	1.68	2.20	3.70

The annualized capital costs shown in Exhibit 30 are the capital costs to construct the associated facilities (see sub-section 5.2.1) amortized over a 20-year project life at a discount rate of 7% per year. Annual operating costs, including O&M and FI&H, were derived in sub-section 5.2.2.

The benefit of the potential network improvements are calculated in terms of the expected number of lives saved and injuries prevented by making more fuel available to facilitate faster and more complete evacuations. The mean, or expected value, of lives saved per hurricane is computed as the average result for all simulated hurricanes, and then those results are adjusted to per year benefits by multiplying by the number of hurricanes expected each year. The expected number of lives saved and injuries prevented each year are converted to dollars of benefit using the FEMA-recommended standard societal costs of one death or one injury of a particular severity. A final adjustment is made to the estimated annual benefits to account for future growth in the Florida population over the 20-year forecast period. For example, for Option 3, we would expect 0.43 lives to be saved per year and 29.07 injuries to be prevented. These have an economic value of $7.4 million per year compared to the annual cost of $4.4 million, resulting in a BCR of 1.68. Any BCR greater than 1.0 indicates that the improvements to the fuel distribution network have benefits that exceed costs. The higher the BCR for an option, the more relative benefit that option provides.

As mentioned previously, the cost-benefit model considers two estimates for unmet demand. The high value of unmet demand is all lost sales, or the volume that customers wanted to buy but were unable to do so because of station outages. That value represents an overestimation, as someone is unlikely to stop looking for available fuel after encountering a single gas station without fuel. The low value of unmet demand is the lost sales counted only when all gas stations in a county are out of gas. This is likely an underestimation, as someone is unlikely to search every gas station in a county for fuel before giving up. The results shown in Exhibit 30 are computed from the average of the two estimates. This value of unmet demand likely provides the closest estimate to real-world outcomes.

5.6.2. Discussion of the Results

In general, as the deliverability of fuel distribution network enhancements increases, both costs and benefits increase. However, benefits tend to increase at a slower rate than costs, thus decreasing the BCR for larger sizes. Adding deliverability follows the law of diminishing returns because each incremental addition to deliverability requires a larger (and less likely) surge in gasoline to trigger its use. Thus, the largest deliverability options are needed only for the most severe hurricanes, which are less likely to occur than hurricanes with fewer evacuations and lower associated surge demands. This effect is shown more clearly in Exhibit 31 where the incremental BCR is shown for each option compared to the next smaller option. In going from zero to 3.9 MMgal/d, the incremental BCR is 2.20. That ratio decreases to 1.31, going from 3.9 to 8.2 MMgal/d. The ratio then drops to 1.03, going from 8.2 to 12.0 MMgal/d, and 1.01, going from 12.0 to 16.3 MMgal/d. Because the incremental BCR is still above 1.0 for the 16.3-MMgal/d option, that option is economically justified, as are all smaller options.

Exhibit 31. Incremental Costs and Benefits Compared to the Next Smaller Option

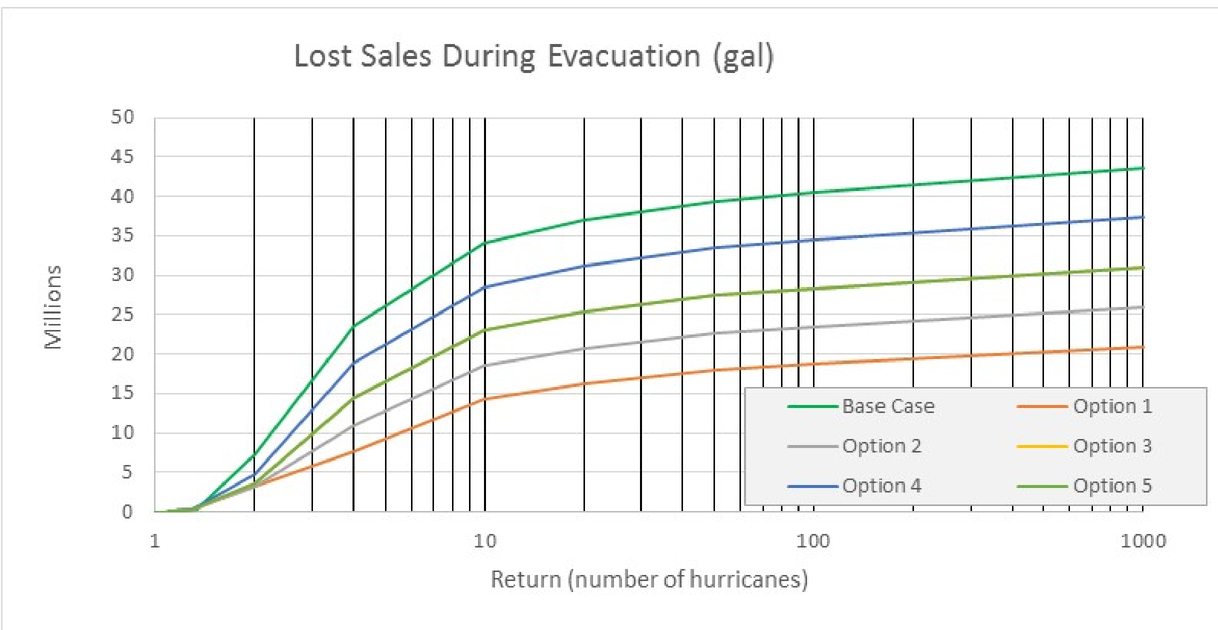
	Option 1 (+16.3 MMgal/d)	Option 2 (+12.0 MMgal/d)	Option 3 (+8.2 MMgal/d)	Option 4 (+3.9 MMgal/d)
Annual Costs	$9,224,432	$6,916,331	$4,423,520	$1,824,141
Annual Benefits	$12,316,804	$9,986,876	$7,423,309	$4,020,406
Incremental Costs	$2,308,101	$2,492,811	$2,599,379	$1,824,141
Incremental Benefits	$2,329,928	$2,563,567	$3,402,903	$4,020,406
Incremental BCR	**1.01**	**1.03**	**1.31**	**2.20**

Exhibit 32 through Exhibit 34 show various performance measures determined by the cost-benefit model. As with previous charts shown in this chapter, the x-axis of the Monte Carlo modeling results is shown in terms of returns or the expected interval between occurrences having a value equal to or greater than the y-axis. For these charts, the intervals are measured as the number of hurricanes that will come about before the y-axis value (or higher) reoccurs or returns. For instance, from Exhibit 32, it can be understood that under Option 1, at least 3.27 MMgal/d of lost sales can be expected for every two hurricanes experienced, or approximately 50% of the time.

Exhibit 32 shows lost sales during evacuations (See section 5.5.2 for definition of lost sales). The exhibit shows that average lost sales decrease as deliverability rates increase; however, the difference between larger and smaller sizes is more pronounced during larger, less frequent hurricanes.

Exhibit 32. Lost Sales During Evacuation (gal/d)

Return (no. of hurricanes)	Percentiles	Option 1 (+16.3 MMgal/d)	Option 2 (+12.0 MMgal/d)	Option 3 (+8.2 MMgal/d)	Option 4 (+3.9 MMgal/d)	Option 5 (+8.2 MMgal/d, no new PDCs)
1.01	1.00%	0	0	0	0	0
1.05	5.00%	0	0	0	0	0
1.11	10.00%	65,997	65,997	65,997	65,997	65,997
1.33	25.00%	330,644	330,644	330,644	330,644	330,644
2	50.00%	3,270,616	3,270,616	3,542,029	4,880,290	3,542,029
4	75.00%	7,721,921	11,050,227	14,554,376	18,993,626	14,554,376
10	90.00%	14,327,175	18,634,252	22,996,716	28,489,752	22,996,716
20	95.00%	16,268,365	20,776,698	25,365,122	31,119,255	25,365,122
50	98.00%	17,985,071	22,704,883	27,490,100	33,468,960	27,490,100
100	99.00%	18,688,185	23,479,065	28,340,595	34,409,257	28,340,595
1,000	99.90%	20,988,995	25,987,114	31,055,429	37,336,421	31,055,429
Average		5,000,114	6,218,514	7,705,904	9,840,273	7,705,904



In Exhibit 33, the maximum loading capacity for each option is reached as each line flattens. This indicates that, eventually, a hurricane will occur, which requires the full terminal loading capacity based on demand. As shown, Option 1 is less likely to experience the maximum loading requirement because there is more deliverability available.

Exhibit 33. Loadings From All Terminals (gal/d)

Return (no. of hurricanes)	Percentiles	Option 1 (+16.3 MMgal/d)	Option 2 (+12.0 MMgal/d)	Option 3 (+8.2 MMgal/d)	Option 4 (+3.9 MMgal/d)	Option 5 (+8.2 MMgal/d, no new PDCs)
1.01	1.00%	24,966,936	24,966,936	24,966,936	24,966,936	24,966,936
1.05	5.00%	25,992,477	25,992,477	25,992,477	25,992,477	25,992,477
1.11	10.00%	26,863,025	26,863,025	26,863,025	26,863,025	26,863,025
1.33	25.00%	30,457,920	30,457,920	30,457,920	30,457,920	30,457,920
2	50.00%	43,551,368	43,551,368	43,551,368	40,781,168	43,551,368
4	75.00%	53,251,168	48,951,168	45,081,168	40,781,168	45,081,168
10	90.00%	53,251,168	48,951,168	45,081,168	40,781,168	45,081,168
20	95.00%	53,251,168	48,951,168	45,081,168	40,781,168	45,081,168
50	98.00%	53,251,169	48,951,169	45,081,169	40,781,169	45,081,169
100	99.00%	53,251,169	48,951,169	45,081,169	40,781,169	45,081,169
1,000	99.90%	53,251,169	48,951,169	45,081,169	40,781,169	45,081,169
Average		41,761,323	40,424,481	38,814,760	36,596,835	38,814,760

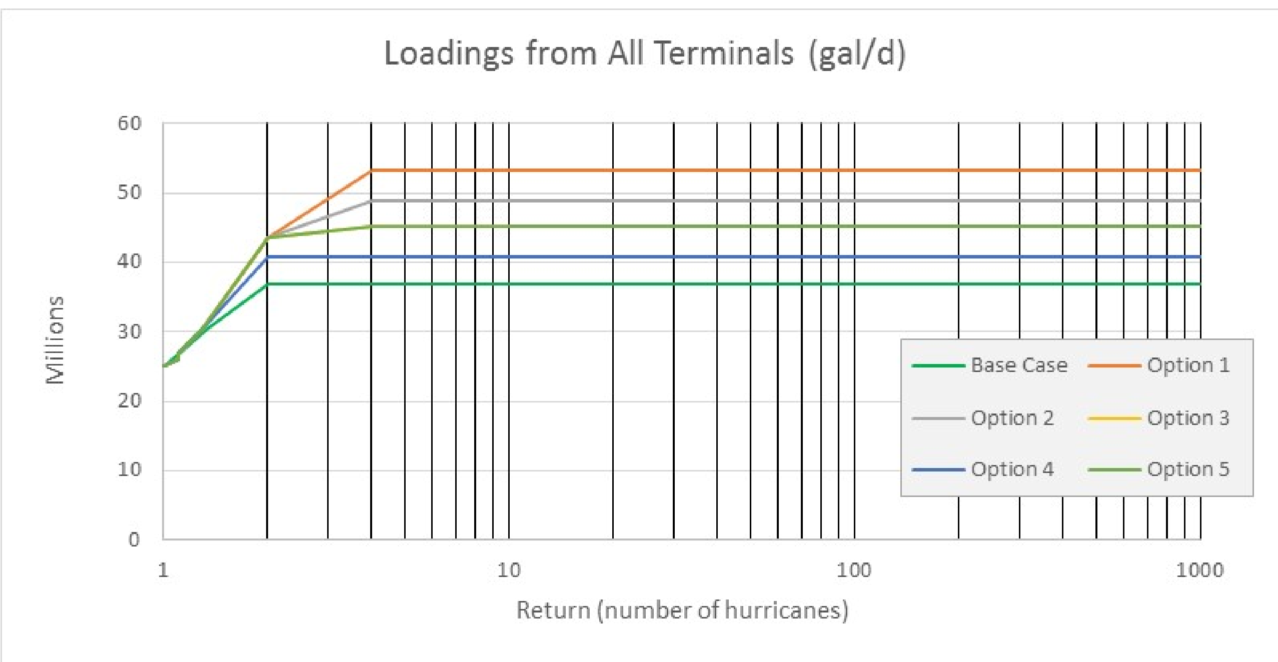
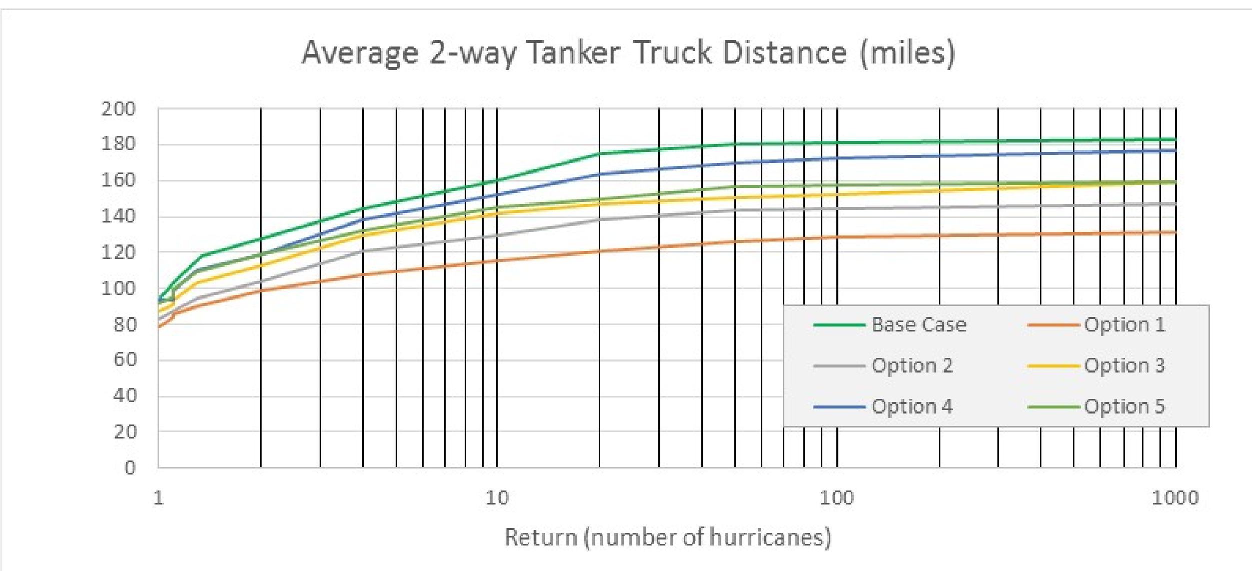


Exhibit 34 shows that increased fuel availability decreases the two-way average truck distance. In Option 1, where fuel deliverability is highest, the distance that trucks must travel, on average, is much lower. It should be noted that despite the higher capital costs associated with establishing PDCs, there is additional benefit in that trucks must travel shorter distances, and thus there is a decreased impact on evacuation traffic and less chance for the trucks to be caught in traffic jams.

Exhibit 34. Average Two-Way Tanker-Truck Distance (miles)

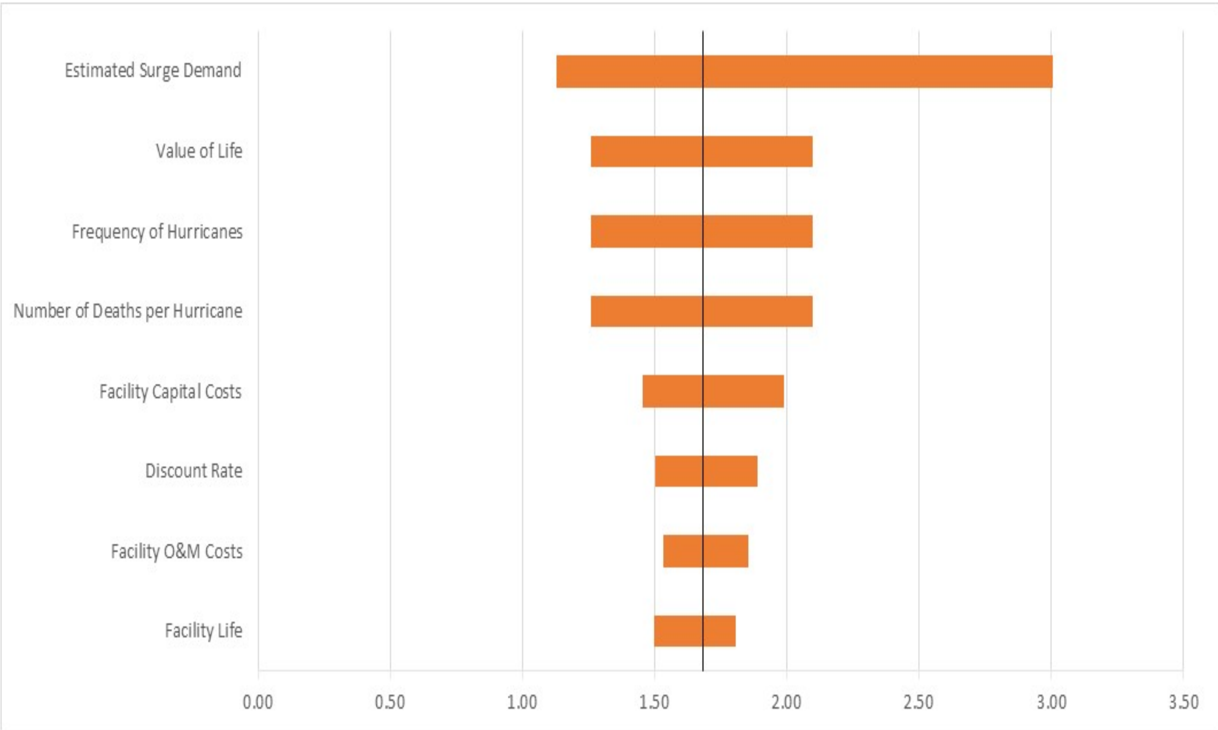
Return (no. of hurricanes)	Percentiles	Option 1 (+16.3 MMgal/d)	Option 2 (+12.0 MMgal/d)	Option 3 (+8.2 MMgal/d)	Option 4 (+3.9 MMgal/d)	Option 5 (+8.2 MMgal/d, no new PDCs)
1.01	1.00%	79	83	87	94	92
1.05	5.00%	84	87	91	94	95
1.11	10.00%	86	88	94	99	100
1.33	25.00%	90	94	103	110	109
2	50.00%	99	104	112	119	119
4	75.00%	108	121	130	138	132
10	90.00%	115	130	142	153	145
20	95.00%	120	139	147	164	149
50	98.00%	126	144	150	170	157
100	99.00%	129	144	153	172	158
1,000	99.90%	132	147	159	177	160
Average		100	108	116	124	121



5.6.3. Sensitivity Analysis

To illustrate how assumptions can affect the cost-benefit results, certain key inputs were varied by ±25%. Option 3 was used for this effort. Option 3 has both PDC storage and rack expansion capacity that totals 8.2 MMgal/d. Its BCR (as shown in Exhibit 30) is 1.68 using our standard assumptions. Exhibit 35 below shows how the ratio was influenced by each parameter chosen. As illustrated, the three most influential parameters on the BCR are the estimated surge demand, the frequency of hurricanes, and the number of deaths per hurricane. Because larger sized deliverability options (Options 1 and 2) utilize their full capabilities less frequently than Option 3, their benefits are likely to be more sensitive to unfavorable changes in those key variables and are thus more likely to yield a negative BCR under sensitivity cases. Option 4, by contrast, utilizes its full capabilities more often than Option 3 and would therefore likely be less sensitive to changes in those key factors.

Exhibit 35. Impact on BCR of Changing Selected Parameters ±25%
(based on Option 3 with 8.3-MMgal/d added deliverability)



5.6.4. Selection of the Optimal Deliverability Option

Strengthening Florida's fuel distribution system to better serve motorists during future evacuations is similar to buying an insurance policy. How much insurance to buy is a strategic decision that may not be determined by purely economic factors. The cost-benefit calculations presented in this report are based on historical probabilities of hurricane events and are intended to help guide the State toward a reasonable investment decision. For the purpose of this analysis, ICF defines the optimal deliverability option as the option that provides the greatest benefits in terms of lives saved and injuries avoided given the probability of future hurricane impacts, while at the same time having benefits exceed the estimated costs of establishing and operating the option's required infrastructure (as exhibited by a positive BCR).

As shown in Exhibit 30, all of the mixed options (the four options that involve building both PDC and rack expansions) yielded positive BCRs. However, Exhibit 31 showed that these results exhibited diminishing returns—as the deliverability rates increased, the benefits continued to increase but at a slower rate than the costs. The exhibit showed that the incremental BCR—the incremental change in benefits and costs between the different deliverability options—converges towards 1 for the larger options.

This cost-benefit analysis suggests that Option 1 (the 16.3-MMgal/d deliverability option) may be optimal as this option delivers the greatest total benefits and also has a positive BCR of 1.34 under base case assumptions. However, as with any complex analysis, there are significant uncertainties surrounding these results, and changes in key parameters can significantly affect the benefit-cost results. The sensitivity analysis in subsection 5.6.3 showed the BCR results are highly sensitive to changes in assumptions about gasoline surge demand, numbers of deaths per hurricane, and frequency of hurricanes (among other variables). As a conservative measure, it may be wise to select an option with a strong enough BCR and incremental BCR to withstand the potential downside sensitivities. Based on this conservative approach, ICF identified Option 3 (the 8.2-MMgal/d deliverability option) as the optimal deliverability size. As shown previously, this option has a BCR of 1.68 and an incremental BCR of 1.31. The sensitivity analysis in sub-section 5.6.3 showed that the BCR for this option remains positive even when assuming unfavorable changes to the key sensitivity parameters. Because larger sized deliverability options utilize their full capabilities less frequently, their benefits are likely to be more sensitive to unfavorable changes in key variables and are thus more likely to yield a negative BCRs under sensitivity cases.

Option 5—the 8.2-MMgal/d deliverability rack expansion-only option—exhibited a significantly higher BCR (3.70) than the similarly sized mixed Option 3. Although the benefits of the two options were the same, the rack expansion-only option has significantly lower construction, operating, and management costs. Despite the higher BCR, the rack expansion-only option relies on the assumption that traffic flows at normal (generally free-flowing) rates, thus allowing trucks to efficiently deliver fuel to remote locations that are covered by the PDCs under the mixed-configuration options. Because traffic during evacuation periods is anticipated to be a real-world constraint—one that is likely to worsen as Florida's population grows—this option is not recommended. However, the results of this analysis indicate the potential benefits possible if traffic issues during evacuations could be efficiently managed.

It is important to note that the benefits calculated in this analysis are based on the availability of fuel for evacuating motorists. Fuel availability is correlated with gas station availability but gas station outages do not need to be reduced to zero in order for there to be sufficient fuel to meet evacuation demands. In other words, some level of stock drawdowns and retail station outages are acceptable across the system so long as fuel is sufficiently available for motorists at other stations to meet demand. In Chapter 3, it was estimated that Florida experienced a deliverability shortfall of approximately 16.4 MMgal/d over the three peak days of the Irma evacuation. This is the daily volume of additional fuel deliveries that would have been needed to both meet retail demand and maintain retail gas station stocks at normal levels (approximately 50% across the state). Because some stock drawdowns at gas stations are tolerable during an evacuation, the additional deliverability needed to meet the evacuation demand would have been less than this volume. The relationship between gas station outages, lost sales, and unmet demand is discussed in detail in sub-section 5.5.2.

5.6.5. Caveats of the Analysis

The cost-benefit analysis presented in this chapter is limited in its scope and relies on data, relationships, and assumptions that cannot be known with certainty. This analysis comes with several important caveats:

- **Future hurricane activity may differ from history:** Historic hurricane data were used as the basis for modeling the frequency, location, size and severity of future hurricanes, and the BCRs are computed based on expected long-term averages. The actual hurricanes that will occur over the next 20 years will be random. Also, they might be influenced by climate patterns that differ from the historical record.
- **Future population growth may affect future traffic:** Population growth was taken into account when estimating the number of people who might need to be evacuated due to future hurricanes; however, it was not taken into account how higher populations might exacerbate traffic congestion and complicate evacuations and the restocking of gas stations during evacuations.
- **Evacuation return benefits were not assessed:** The benefits computed here are limited to the prevention of injuries and deaths through more effective evacuations. We have not calculated the benefits during the post-evacuation period when added gasoline supply and deliverability could speed up the return of evacuees and the recovery of the Florida economy.
- **Post-storm response benefits were not assessed:** We also did not evaluate how hurricanes might damage existing petroleum terminals and how the added PDC storage capacity and deliverability could help in post-hurricane response and recovery.
- **Other terminal capability growth was not modeled:** We have implicitly assumed that, in the future, terminal capacity will grow with gasoline demand and that Florida's petroleum distribution infrastructure's ability to respond to future emergencies will be similar to what it is today.
- **Value of human life may be lower than other estimates:** We have used FEMA's value of a human life rather than other estimates, which are often higher.
- **Electric vehicle growth may curb future gasoline demands:** We have not tried to factor into our calculation the potential for electric vehicles to gain a large market share in the future. This would reduce the need for gasoline during hurricane evacuations, but would pose new problems for refueling along evacuation routes.
- **Better shelters may reduce the size of future evacuations:** We have not explored and compared the BCRs of other options, such as expanding shelter-in-place; reinforcing buildings to prevent hurricane damage and injuries; and using buses, carpools, and so forth to reduce evacuation traffic and fuel requirements.

6. Conclusions and Next Steps

This study analyzed the challenges that Florida's gasoline supply and distribution network faced during the evacuation that preceded Hurricane Irma and develops strategies for enhancing the system to perform better during future evacuations. The study provided an overview of Florida's fuel supply and distribution network, a review of fuel distribution issues experienced during the Irma evacuation, a feasibility assessment of potential fuel distribution network enhancements, and an economic evaluation of the costs and benefits of those enhancements.

6.1. Fuel Network Constraints During the Irma Evacuation

Retail gasoline sales in Florida doubled over the four-day Irma evacuation, leading to widespread outages at retail gas stations. Although there was a sufficient gasoline supply available at primary storage terminals in Florida to meet the needs of evacuees, this fuel could not be loaded into trucks and delivered to gas stations fast enough to keep pace with the unprecedented increase in demand. The primary constraint in the system was that petroleum terminals did not have sufficient excess truck-loading capacity to handle a doubling of normal demands. Heavy traffic on Florida's major roadways was another key factor limiting deliveries, particularly in parts of the state far from the primary terminals where traffic issues were compounded exponentially. Overall, ICF estimated that to eliminate all gas station outages during Irma, the state would need approximately 16.4 MMgal/d of additional gasoline deliverability—the capacity of primary terminals to outload fuel and deliver it to retail stations.

6.2. Feasibility Assessment of Potential Fuel Network Enhancements

To alleviate retail fuel shortages during future evacuations, ICF assessed two strategies aimed at increasing the state's gasoline deliverability:

1. **Debottlenecking Fuel Distribution at Existing Terminals (Rack Expansions):** In areas of the state close to (fewer than 100 miles from) major supply sources, truck-loading (rack) capacity could be expanded at existing terminals that have sufficient storage inventories to support increased demand. This can be done either by building new truck-loading bays and associated pumps, or by increasing filing rates at existing loading bays. In addition, other actions can be taken to streamline deliveries from existing terminals, such as providing guides at terminals to expedite truck loading, providing additional police escorts to help move trucks through traffic to areas experiencing shortages, and providing methods to bring additional trucks and drivers into the state to provide additional fuel transportation capabilities during emergencies. Debottlenecking would be the optimal strategy for Florida fuel markets close to Port Everglades, Tampa, Orlando, Port Canaveral, Jacksonville, the Panhandle ports, and the Bainbridge, GA, terminal that supplies the Eastern Panhandle.
2. **Establish Petroleum Distribution Centers:** In areas of the state that are remote from primary terminals, it may be beneficial to establish PDCs—state-owned facilities that consist of both gasoline storage and truck-loading capability. PDCs can either be configured as small terminals—consisting of ASTs, truck-loading rack facilities, and associated infrastructure—or as rail-to-truck transloading facilities that utilize rail tank cars to hold inventory and mobile pump carts to load fuel directly from the railcars into tanker trucks. Potential PDC sites include the I-75 Corridor from Wildwood to the Georgia border, the Fort Pierce area near where I-95 and the Florida Turnpike intersect, and Southwest Florida, including the cities of Naples, Cape Coral, and Fort Myers.

These two strategies are designed to complement each other, with rack expansions enhancing the fuel distribution network in areas near existing terminals and PDCs providing additional coverage in remote areas of the state. The specific size and location options evaluated in this study considered employing a mix of both of these strategies. The proposed fuel distribution network enhancements add value by adding excess deliverability to the gasoline distribution system (beyond the system's current capacity) to enable more fuel to reach consumers during high-demand evacuation periods. For both the rack expansion and PDC enhancements, the state would contract with private companies to build, operate, and manage the proposed infrastructure. Although the infrastructure operators would be permitted to operate a commercial business alongside the state-funded infrastructure, the infrastructure's deliverability would be reserved for use at the state's direction.

ICF assessed the feasibility and costs of several potential configurations for the PDC enhancements: constructing grassroots (new-build) terminals, utilizing existing secondary terminals, deploying rail-to-truck gasoline-loading infrastructure, and expanding UST capacity at existing retail stations. Of these configurations, the grassroots terminal and rail-to-truck options were deemed to be feasible. Retail storage tank expansions would not be feasible due to the number of expansions needed, site-specific space issues, and difficulty in obtaining the necessary local permits. Utilizing secondary terminals would not be feasible because existing secondary terminals in Florida are not large enough to support potential reserve volumes, and the capacity that is there is likely being used for existing commercial operations.

Of the two feasible options, rail-to-truck terminals have several advantages over grassroots terminals, including lower upfront costs, faster and more efficient filling and re-filling of the PDC reserve, and the ability to reposition the facility, if needed. Despite these advantages, rail operators have noted a shortage of the newest, safest rail tank cars, and given current lease rates for those cars, infrastructure costs may be more expensive than a terminal PDC per unit of deliverability. Furthermore, rail-to-truck technologies typically require more personnel to facilitate truck loadings, likely leading to higher overall operating costs. Finally, larger PDC size options may require a significant number of railcars (and track), which can potentially raise space concerns.

6.3. Cost-Benefit Analysis of Potential Fuel Network Enhancements

ICF compared the economic costs and benefits of five fuel distribution network enhancement options that varied in deliverability size and configuration. The first four options were configured to utilize both rack expansions and PDCs, and varied in deliverability with distinct sizes of 16.3, 12.0, 8.2, and 3.9 MMgal/d. The purpose of this analysis was to evaluate which deliverability options provide the greatest benefits, while still providing acceptable BCRs. The fifth option evaluated was a mid-size deliverability (8.2-MMgal/d) option configured to rely entirely on deliverability enhancements through rack expansions. This option was evaluated to determine the relative value of adding PDCs versus utilizing less expensive rack expansions.

To estimate costs and benefits, ICF utilized a Monte Carlo simulation that modeled future hurricane landfalls, sizes, intensities, and the resulting evacuation fuel demands across a 20-year period. The benefits were determined by estimating the lives saved and injuries avoided due to the greater availability of fuel at retail stations during the evacuation period. Costs for each deliverability option were based on the estimated costs of building, operating, and managing the new infrastructure. For the purposes of the analysis, it was assumed that the PDCs would be configured as grassroots (new-build) terminals and that rack expansions would be achieved through the addition of loading bays at existing truck racks.

All five of the options evaluated yielded positive BCRs—in other words, the estimated benefits in terms of lives saved and injuries avoided exceed the estimated costs of establishing and operating the infrastructure. However, the fifth option—the 8.2-MMgal/d deliverability rack expansion-only option—exhibited a significantly higher BCR than any of the four mixed PDC and rack expansion options. Although the benefits of the fifth option were the same as the similarly sized mixed option (the 8.2-MMgal/d Option 3), the rack expansion-only option has significantly lower construction, operating, and management costs. Despite the higher BCR, the rack expansion-only option relies on the assumption that traffic flows at normal (generally free-flowing) rates, thus allowing trucks to efficiently deliver fuel to remote locations that are covered by the PDCs under the mixed-configuration options. Because traffic during evacuation periods is anticipated to be a real-world constraint—one that is likely to worsen as Florida's population grows—this option is not recommended.

The BCRs for the four mixed PDC and rack expansion configurations exhibited diminishing returns—as the deliverability rates increased, the benefits continued to increase but at a slower rate than the costs. As a result, the incremental BCR—the incremental change in benefits and costs between the different deliverability options—converges toward 1 for the larger options. As with any complex analysis, there are significant uncertainties surrounding this analysis and changes in key parameters can significantly affect the benefit-cost results. As a conservative measure, it is may be wise to select an option with a strong enough BCR and incremental BCR to withstand potential downside sensitivities. Based on this approach, ICF identified the 8.2-MMgal/d deliverability option as the optimal deliverability size. This option provides 6.9 MMgal/d of deliverability through the addition of 16 truck-loading bays at existing terminals in four coastal Florida locations and 1.3 MMgal/d through the development of two PDC sites in the I-75 Corridor and the Fort Pierce regions. This option has a BCR of 1.68 and an incremental BCR of 1.31.

6.4. Next Steps

This study was designed to identify feasible strategies to enhance the fuel distribution network to alleviate retail fuel shortages during future evacuations. The study identified the types of enhancements capable of addressing the network constraints observed during the Hurricane Irma evacuation, identified potential locations for those enhancements, and calculated the optimal size and configuration of those enhancements. The next step is for the state to begin implementing the strategies outlined in this study. This may involve:

1. **Establishing a Lead Agency:** The state should select a lead agency to coordinate and implement the fuel network enhancement program and provide that agency with the necessary resources to carry out its mission. It may be logical to select a lead agency whose current mission includes assisting in evacuations (e.g., FDEM, the Florida Department of Transportation, or the Governor's Office).
2. **Develop an Implementation Plan:** The lead agency should develop an implementation plan to execute the strategies developed in this feasibility study. As part of the

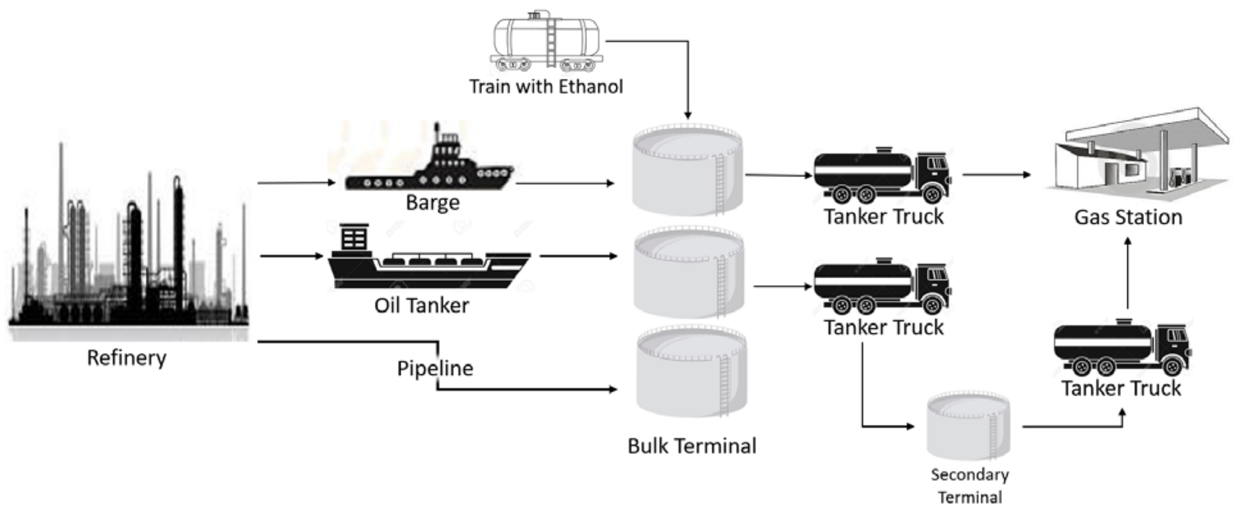
implementation plan, the lead agency will assign project tasks to various State agencies as needed. The lead agency will coordinate and facilitate the tasks among the various agencies.

3. **Obtaining Funding:** ICF estimates the cost of implementing the optimal solution at approximately $29.2 million, with annual operating and management costs of $1.7 million per year. This funding can potentially come from any number of sources, including from the state's general tax revenue, an increase in the state's gasoline tax, and/or through FEMA's Hazard Mitigation Grant Program.
4. **Developing a Solicitation:** Once a lead agency has been assigned and funding identified, the lead agency should competitively solicit interest from industry stakeholders to develop the required fuel network enhancements. Prior to solicitation, the lead agency may wish to reach out to stakeholders through a Request for Information process to identify additional considerations for the contract between the state and the project developer.
5. **Selecting Projects to Fund:** The lead agency should review proposals from potential developers and select the optimal mix of projects to fund in order to cost-effectively meet the target deliverability requirements and other key criteria. For the PDC sites, this also requires selecting a company to manage PDC operations.
6. **Establishing a Distribution Policy:** For the PDC sites, the lead agency would need to work with suppliers and distributors to develop a reasonable process for distributing state-owned fuel from the reserves and for apportioning distributions if the demand exceeds the supply. Considerations for how to structure such a policy were discussed in *Section 4.3.2.5. Fuel Sales and Distribution*.
7. **Filling the PDC Reserves:** Once the PDCs have been constructed and staffed, the state (or the PDC operator acting on the state's behalf) needs to procure fuel to fill the reserve. Considerations for fuel procurement were discussed in *Section 4.3.2.4. Fuel Supply Logistics*.

Appendix A: Florida's Fuel Supply Chain

Gasoline supply is shipped to Florida's petroleum product storage and blending terminals (i.e., bulk terminals by tanker ship and barge from petroleum refineries primarily in Texas, Louisiana, and Mississippi). Ethanol, which makes up approximately 10% of Florida's gasoline supply, is produced at ethanol refineries in the Midwest and transported to Florida by rail or imported at the state's ports. Both gasoline blendstock and ethanol also are imported from foreign sources to Florida's ports. Gasoline blendstock and ethanol are blended at Florida's terminals to make a finished gasoline product. Gasoline is distributed from Florida's terminals to retail gas stations by tanker truck. Fuel from terminals is also transported to wholesale distributors that store the product at secondary distribution terminals for later delivery to consumer sites. A simplified supply chain is shown in Exhibit 36.

Exhibit 36. Simplified Fuel Supply Chain



A.1. Port Infrastructure

Florida lacks in-state refineries and is not served directly by long-distance pipelines. As a result, the state relies on waterborne shipments of refined products for more than 95% of its gasoline, diesel and jet fuel supply (excluding ethanol, which arrives by marine and rail). Waterborne cargos of finished petroleum products are supplied from domestic and foreign sources by oil companies, marketers, and trading companies to storage terminals located at Florida's coastal ports. Infrastructure that supports the waterborne movement of fuels includes tankers and barges specifically designed to transport hazardous liquids; privately owned docks, jetties, and fuel loading/unloading facilities; and the ports and waterways themselves, which are often publicly owned.

A.2. Terminal Infrastructure

Refined product distribution terminals (also referred to as bulk storage facilities, tank farms, or depots) receive bulk fuel supply by pipeline, waterborne vessels, or, in some remote areas, by rail or truck, and store the product until it is delivered by truck to retail outlets, large commercial consumers, or distribution companies. All terminals have storage tanks, as well as infrastructure, to facilitate the movement of material into and out of the terminal. This infrastructure may include pipeline interconnections, marine jetties and other marine infrastructure for loading or unloading ships or barges, rail track and railcar loading and unloading infrastructure, and/or truck racks for loading or unloading tanker trucks. Refined product terminals also typically have infrastructure to support blending biofuels (such as ethanol and biodiesel) and additives into finished fuels.

Some refined product distribution terminals are owned and operated by oil companies, such as ExxonMobil or Marathon Petroleum. This means that the companies own the terminal infrastructure (e.g., tanks), as well as the fuel inventory being held in the terminal. Other terminals are owned and operated by third-party logistics companies, such as Kinder Morgan, TransMontaigne, or Buckeye Partners. In these cases, marketers, distributors, and trading companies may lease storage capacity at the third-party terminals, or they may pay a throughput fee based on the volumes they move in and out of the terminal, and the third party manages that activity. Oil companies that own and operate their own terminals can also either lease storage to other companies or allow other companies to utilize the terminal for a throughput fee.

A.3. Pipeline Infrastructure

Pipelines provide a safe, reliable, energy-efficient, and cost-effective mode of transportation for bulk liquid volumes, particularly over long distances. Petroleum pipeline infrastructure includes mostly underground interstate and intrastate pipelines that carry petroleum products, pumping stations that are used to manage pipeline flow and pressure, interconnection stations that allow for product to flow from one system into another, and breakout tankage that provides temporary storage along the pipeline system. The Colonial Pipeline, which is the largest refined products pipeline in the United States, has a terminus in Bainbridge, GA, just north of Tallahassee. The Central Florida Pipeline system, which transports fuel from Tampa to Orlando, is the only pipeline system that transports fuel within Florida.

A.4. Trucking

Truck transportation infrastructure includes privately owned tanker trucks of various sizes and a network of public roadways, bridges, and tunnels on which they travel. Because of the small size and wide geographic distribution of refined product end users, trucks are often the only transportation mode that can deliver fuels on the final mile of the supply chain. Product is transferred from bulk terminal storage to delivery tanker trucks over the terminal truck rack. Tanker trucks deliver gasoline and diesel fuels to retail outlets where consumers fill up their vehicles. Some distributors own their own fleet of tanker trucks, or they may have a contract with a common carrier fleet to distribute their fuel to service stations. There are numerous fuel trucking companies that operate in Florida. These companies are chartered by suppliers or buyers to transport fuel from terminals to retail stations. The largest two fuel trucking companies by volume are Kenan Advantage Group and Eagle Transport Corporation. Some suppliers own their own fleets of tanker trucks.

A.5. Retail Stations

Fuel products are sold to end users at branded or unbranded retail stations. A branded retail stations is one where the station operates under the brand name of an integrated oil company. Branded stations are either owned by an integrated oil company or are owned and operated by independent retailers who are licensed to represent the brand. Branded independent retailers typically have strict contracts to exclusively buy product from the associated oil company. These stations sell a gasoline with an additive mixture that is exclusive to their brand (e.g., Chevron's Techron additive package, Exxon's Synergy package). Branded gas stations can be given preferential treatment for fuel deliveries when supply is scarce because of the nature of their contracts.

Unbranded stations do not have the contractual obligation to sell a specific brand of fuel with a specific refiner/supplier's special additives. Unbranded stations can still have term contracts to buy their fuel through one or more oil companies or distributors, but they have the flexibility to select from among several of their contractual suppliers, often selecting the lowest price supplier. They sell gasoline with a generic additive package and cannot advertise their gasoline as being from a branded supplier. Unbranded dealers, under normal circumstances, have more purchasing flexibility than branded dealers. When supply is tight, however, unbranded dealers may be allocated less fuel than branded customers because branded dealer contractual obligations are the priority for branded fuel suppliers.

Appendix B: Florida's Fuel Supply and Distribution Infrastructure

B.1. South Florida

Exhibit 37. South Florida Petroleum Infrastructure

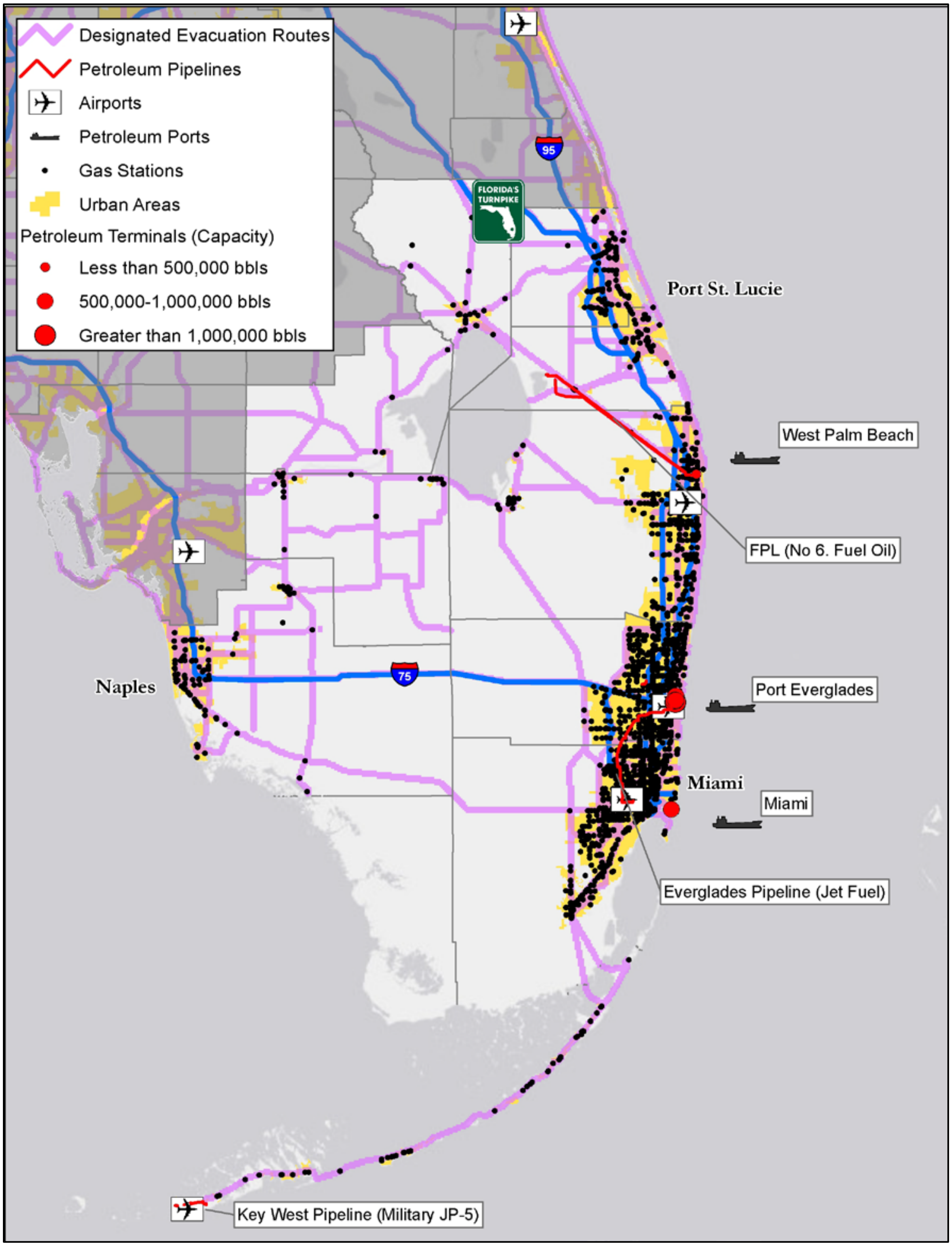


Exhibit 38. South Florida Gasoline Terminals

Terminal	Gasoline Storage Capacity (MMgal)[A]	Truck-Loading Bays[B]
Port Everglades		
TransMontaigne North Terminal	22.7	8
Vecenergy	19.0	4
Motiva South Terminal	15.6	4
Chevron	10.7	5
ExxonMobil	21.7	4
Citgo	5.6	3
TransMontaigne South Terminal	11.9	8
Marathon Eisenhower Terminal	8.5	3
Motiva West Terminal	14.9	0
Buckeye	14.6	3
Marathon Spangler Terminal	12.3	2
Motiva Spangler Terminal	8.0	4
South Florida Total	**165.5**	**48**

A. Gasoline tank shell storage capacity per Florida Department of Environmental Protection (does not include ethanol).

B. Loading bay data included, where available, from Title V permits.

Sources: Florida Department of Environmental Protection, Facility Title V Permits, ICF Stakeholder Surveys, and Google Maps.

B.2. Central Florida

Exhibit 39. Central Florida Petroleum Infrastructure

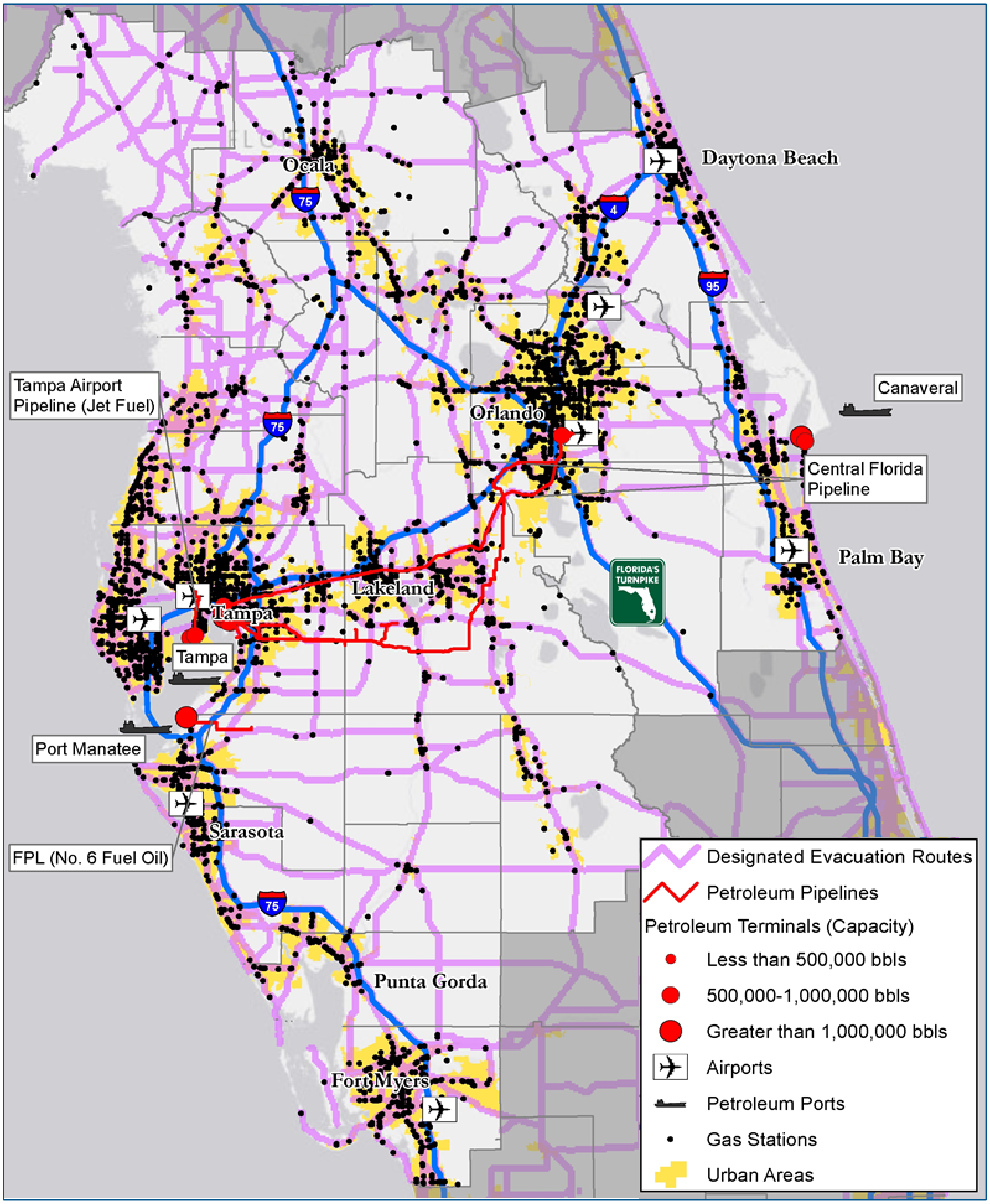


Exhibit 40. Central Florida Gasoline Terminals

Terminal	Gasoline Storage Capacity (MMgal)[A]	Truck-Loading Bays[B]
Tampa Bay		
Kinder Morgan	34.2	5
Marathon	24.8	10
Citgo	27.8	6
TransMontaigne Port Manatee	23.4	7
TransMontaigne Tampa	23.9	8
Chevron	8.4	4
Murphy	16.4	3
Buckeye South Terminal	14.5	3
Motiva	14.3	4
Buckeye North Terminal	14.3	4
Tampa Bay Subtotal	**202.1**	**54**
Cape Canaveral		
Seaport Canaveral	50.4	10
TransMontaigne	10.4	3
Cape Canaveral Subtotal	**60.8**	**13**
Orlando		
Kinder Morgan	20.9	13
Orlando Subtotal	**20.9**	**13**
Central Florida Total	**283.8**	**80**

A. Gasoline tank shell storage capacity per Florida Department of Environmental Protection (does not include ethanol).
B. Loading-bay data included, where available, from Title V permits.
Source: Florida Department of Environmental Protection, Facility Title V Permits, ICF Stakeholder Surveys, and Google Maps.

B.3. Northeast Florida

Exhibit 41. Northeast Florida Petroleum Infrastructure

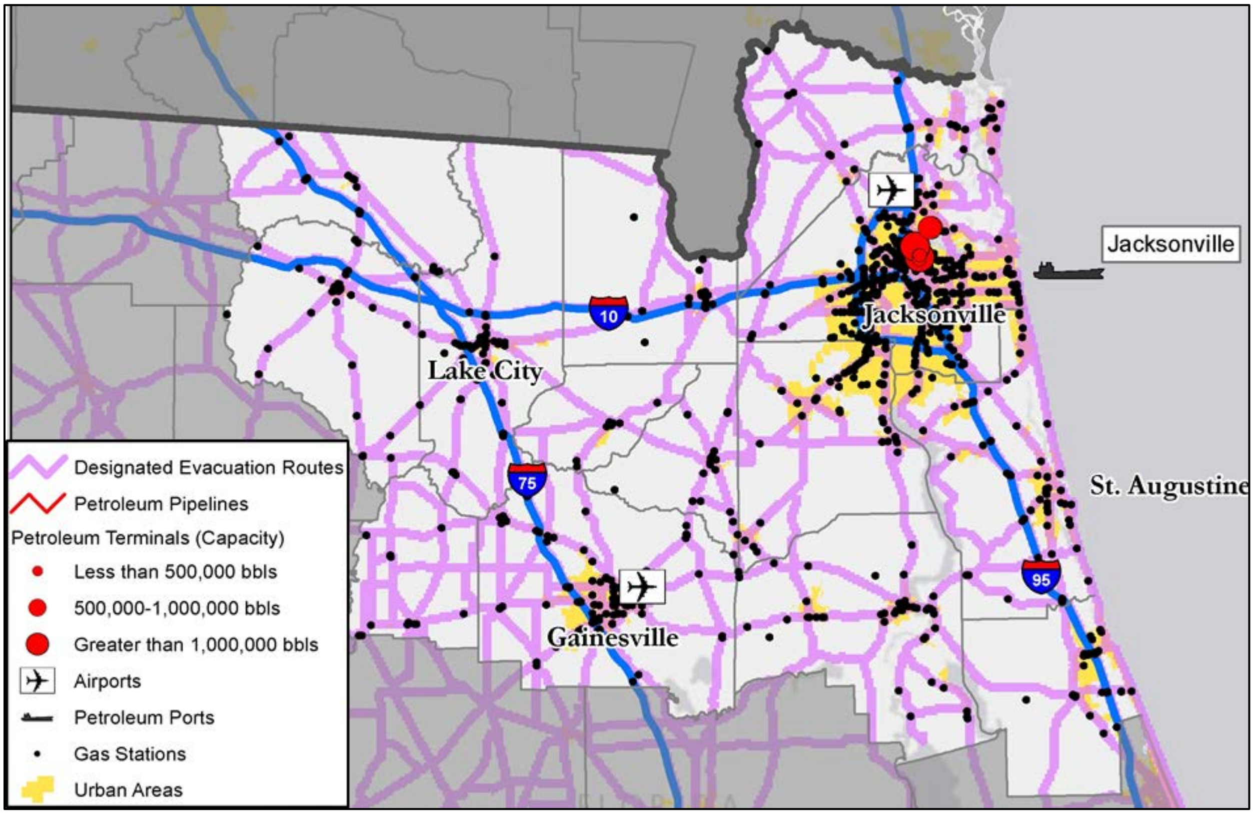


Exhibit 42. Northeast Florida Gasoline Terminals

Terminal	Gasoline Storage Capacity (MMgal)[A]	Truck-Loading Bays[B]
Jacksonville		
NuStar	50.0	14
Marathon	31.1	4
Center Point	39.1	6
Buckeye	21.0	6
Petroleum Fuel & Terminal Company	2.6	1
Northeast Florida Total	**143.8**	**31**

A. Gasoline tank shell storage capacity per Florida Department of Environmental Protection (does not include ethanol).
B. Loading-bay data included, where available, from Title V permits.
Source: Florida Department of Environmental Protection, Facility Title V Permits, ICF Stakeholder Surveys, and Google Maps.

B.4. Florida Panhandle East

Exhibit 43. Florida Panhandle East Petroleum Infrastructure

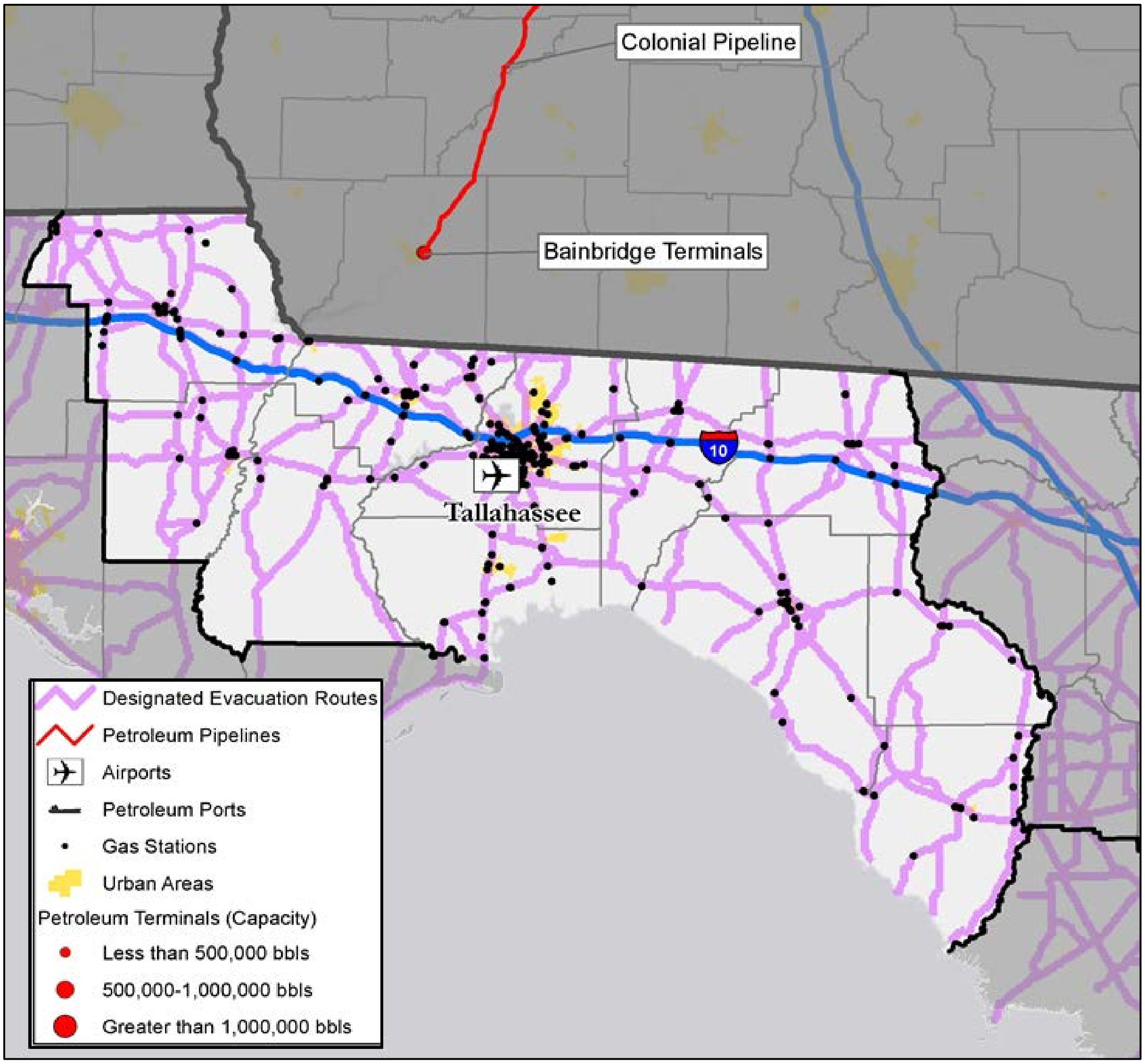


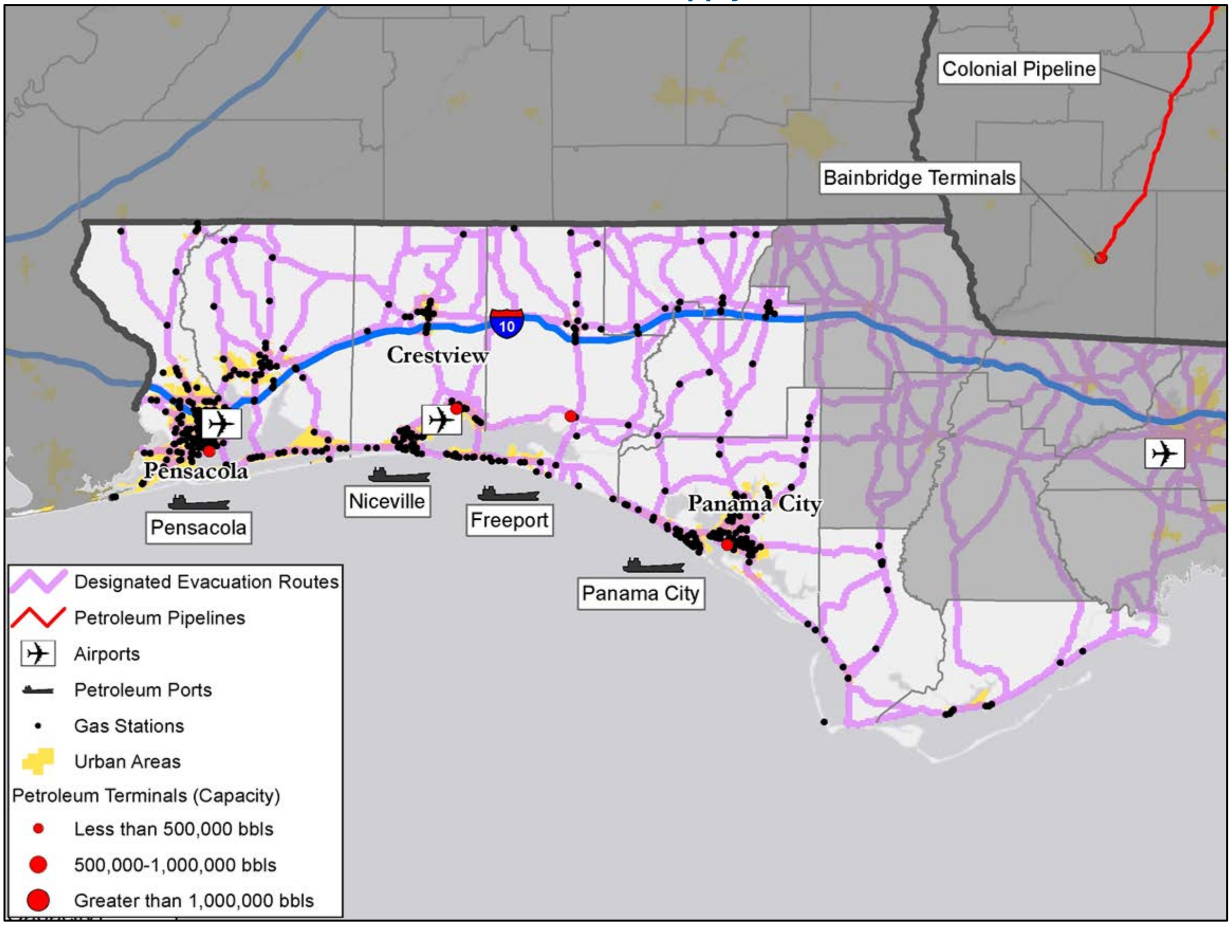
Exhibit 44. Florida Panhandle East Gasoline Terminals

Terminal	Total Storage Capacity (MMgal)	Gasoline Storage Capacity (MMgal)[A]
Bainbridge, GA		
TransMontaigne	15.6	4.7
Motiva	10.2	N/A
Panhandle East Total	**25.9**	

A. Gasoline tank shell storage capacity included, where available (does not include ethanol).
Source: 2018 Oil Price Information Service (OPIS) Terminal Data.

B.5. Florida Panhandle West

Exhibit 45. Florida Panhandle West Petroleum Supply Infrastructure



Note: The recent impact of Hurricane Michael closed the ports in the Panhandle West region. Panama City was the hardest hit, and it returned to service on October 22, 2018, roughly 10 days after landfall.

Exhibit 46. Florida Panhandle West Gasoline Terminals

Terminal	Gasoline Storage Capacity (MMgal)[A]	Truck-Loading Bays[B]
TransMontaigne – Pensacola	6.8	2
Chevron – Panama City	5.6	3
Citgo – Niceville	4.8	2
Murphy – Freeport	3.4	2
Florida Panhandle Total	**20.6**	**9**

A. Gasoline tank shell storage capacity per Florida Department of Environmental Protection (does not include ethanol).
B. Loading-bay data included, where available, from Title V permits.
Source: Florida Department of Environmental Protection, Facility Title V Permits, ICF Stakeholder Surveys, and Google Maps.

Appendix C: Additional Information on Methodology and Data for Cost-Benefit Analysis

This appendix provides additional details on the methodology and data used in the cost-benefit analysis. As was explained in Chapter 5, the cost-benefit analysis is a way of comparing the costs of potential improvements to the Florida gasoline distribution network against the expected dollar-denominated benefits of those improvements. The benefits are defined as the reduction in the number of hurricane-related deaths and injuries that is expected to result from the network improvements. These are converted to dollars of benefit by multiplying the reductions in deaths and injuries by the economic cost to society for each type of personal-injury incident.

This appendix begins with a presentation of the data and methodology for projecting the frequency, location, and severity of future hurricanes that could affect Florida. The next part of the appendix explains how the expected number of deaths and injuries are estimated as a function of hurricane characteristics and evacuation effectiveness. The appendix then explains how the number of planned evacuations is estimated and how the increase in gasoline demand is computed.

C.1. Hurricane Threats

A critical part of the cost-benefit analysis of any kind of infrastructure investment is the estimation of how often that infrastructure will be used and the economic value of its use. The cost-benefit analysis of potential improvements to the Florida gasoline distribution network to supply gasoline for hurricane evacuations depends critically on the frequency, location, and severity of projected future hurricanes and the estimated costs those hurricanes might impose on Florida in terms of lost lives and injuries. The characteristics of future hurricanes used in this analysis are derived from the Florida Public Hurricane Loss Model (FPHLM), version 6.2.[25] Parameters from that model were used in the Monte Carlo analysis[26] to generate simulated hurricanes that were then analyzed to determine potential loss of life and injuries, and how different infrastructure options for a more effective gasoline distribution might reduce those deaths and injuries.

C.1.1. Background on the Florida Public Hurricane Loss Model and Its Use

The FPHLM is a hurricane catastrophe model developed by a multidisciplinary team of experts in the fields of meteorology, wind and structural engineering, computer science, Geographic Information System (GIS), statistics, finance, and actuarial science. The FPHLM is used to

[25] For more information on the Florida Public Hurricane Loss Model, version 6 V6.2, see https://www.sbafla.com/method/Portals/Methodology/Meetings/2017/20170510_FPM_15Standards.pdf and https://www4.cis.fiu.edu/hurricaneloss/html/model001.html#1.

[26] A Monte Carlo analysis or simulation is a mathematical technique that generates pseudo random variables for systems where there are risks in the frequency and characteristics of important outcomes and their effects. The random variables are represented as probability distributions (a representation of how often different outcomes are likely to occur). A Monte Carlo analysis uses sequences of pseudo random numbers to generate the random variables and then combines them into a large number of simulations, or trials, whose characteristics have statistics (mean, standard deviations, and probability distributions) that are intended to represent what would occur in the real world over a very long period.

estimate residential property losses related to buildings, appurtenant structure, contents, and additional living expenses. The FPHLM is used to investigate insurance losses, justifiable residential insurance rates, and the potential benefits of different kinds of residential building construction and retrofit standards.

The Florida Office of Insurance Regulation contracted with and funded Florida International University to develop the FPHLM. The model is based at the Laboratory for Insurance, Financial and Economic Research, which is part of the International Hurricane Research Center at Florida International University. The model was developed, tested, and evaluated by a multidisciplinary team of professors and outside experts from Florida International University, Florida Institute of Technology, Florida State University, University of Florida, the Hurricane Research Division of the U.S. National Oceanic and Atmospheric Administration (NOAA), and the University of Miami.

The model consists of three major components: wind hazard (meteorology), vulnerability (engineering), and insured loss cost (actuarial). The results from the wind hazard model were used in the ICF cost-benefit analysis. The main components of the wind hazard model are:

- **Storm Track and Intensity Model:** Generates the storm tracks and intensity for simulated hurricanes based on historical initial conditions.
- **Inland Storm Decay Model:** Estimates the drop-off in wind speed (the so-called “decay”) after landfall.
- **Wind Field Model:** Generates open terrain wind speeds (i.e., wind speeds that would occur in the absence of trees, buildings, hills, and so forth) for each of the hurricane-affected ZIP code.
- **Gust Factor Model:** Generates peak gust wind speeds for each ZIP code.
- **Terrain Roughness Model:** Corrects open terrain wind speed for terrain roughness.
- **Wind Probabilities Model:** Generates wind speed probabilities for each Zip code.
- **ArcIMS Environment:** Visualize Florida GIS information and the associated data results over the Internet.

The wind model generates storm tracks and intensities based on historical storm conditions and motions. The initial meteorological conditions (the so-called “seeds”) for the storms are derived from the Hurricane Databases (commonly referred to as the HURDAT database[27]) through 2015, and are modified by the addition of small uniform random error terms to generate thousands of years of stochastic[28] tracks. Subsequent storm motion change and intensity are obtained by Monte Carlo sampling from empirically derived probability distributions. A sample of tracks generated by the stochastic track and intensity model is shown in Exhibit 47. The exhibit indicates that hurricanes can reach landfall in Florida from many directions, including from the

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[27] HURDAT is a set of large databases of historical hurricane information. The Base Hurricane Storm Set of FPHLM, version 6.2, is based on the 1900–2015 period of historical record as provided in the February 17, 2016, version of HURDAT released by the National Hurricane Center. The most recent dataset, as of May 2018, includes 2017 data and can be found at https://www.nhc.noaa.gov/data/hurdat/hurdat2-1851-2017-050118.txt.

[28] The route or track traveled by a hurricane is one of several stochastic variables that are used to characterize hypothetical future hurricanes. A stochastic variable is randomly determined. It has a random probability distribution or pattern that may be analyzed statistically, but may not be predicted precisely.

Atlantic (moving generally toward the west and north) and from the Gulf of Mexico (moving to the east and north). The model has been validated by examining key hurricane statistics relative to HURDAT at 30-mile intervals along the Gulf and Atlantic coasts. The parameters examined include average central pressure deficit,[29] average heading angle and speed, and total occurrence by Saffir-Simpson category.[30] The statistics for future hurricanes can be summarized be the FPHLM Hurricane Landfall Regions, the boundaries for which are shown in Exhibit 48.

Exhibit 47. Sample Hurricane Tracks Generated by the Florida Public Hurricane Loss Model (FPHLM)

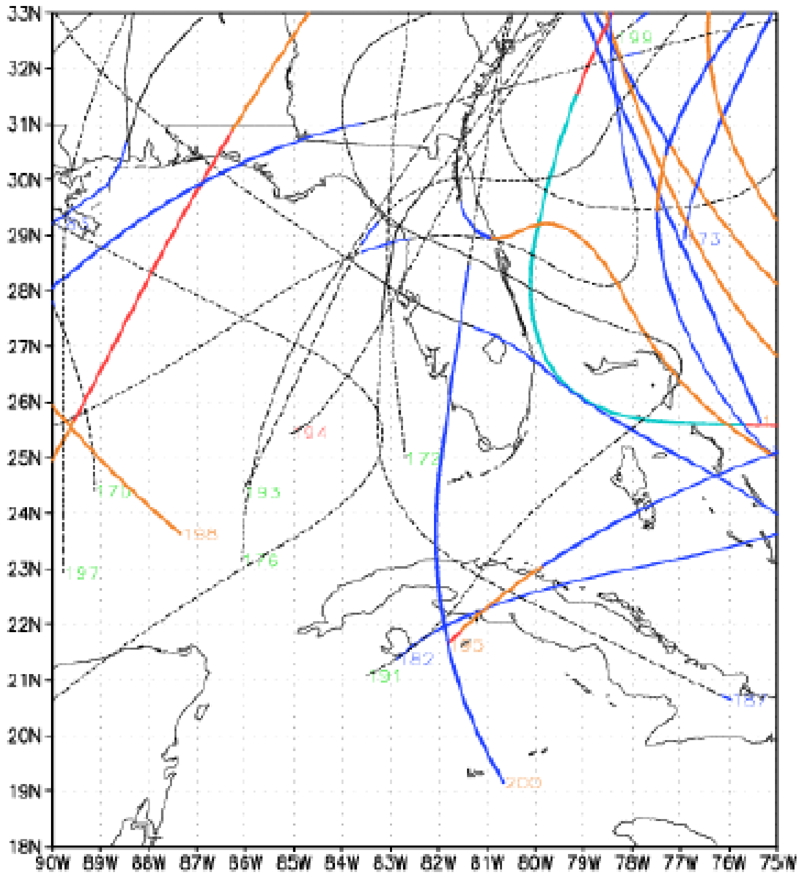

Figure 3. Examples of simulated hurricane tracks. Numbers refer to the stochastic track number, and colors represent storm intensity based on central pressure. Dashed lines represent tropical storm strength winds, and Cat 1-5 winds are represented by black, blue, orange, red, and turquoise, respectively.

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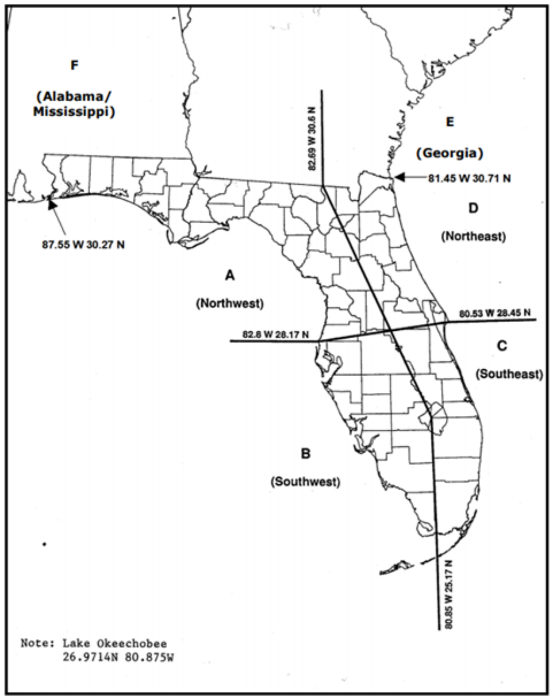
[29] The central pressure deficit refers to the difference in pressure between the center of the storm and outside it.

[30] The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 rating based on a hurricane's sustained wind speed. This scale estimates potential property damage. Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage. Category 1 and 2 storms are still dangerous, however, and require preventative measures. See https://www.nhc.noaa.gov/aboutsshws.php

Exhibit 48. Hurricane Landfall Regions Defined in the FPHLM



C.1.2. Expected Frequency, Landfall Region, and Category of Hurricanes

The annual occurrence rates by landfall regions (see Exhibit 48) and by hurricane category (defined by maximum wind speed at landfall on the Saffir-Simpson scale) used in the ICF cost-benefit analysis are shown in Exhibit 49. The modeled frequencies are consistent with the FPHLM, which, in turn, is consistent with the 116-year historical record upon which it is based. Note that a single hurricane can make landfall more than once. Therefore, the expected number of hurricanes making at least one landfall in Florida is 0.548 per year, while the expected number of landfalls is slightly higher at 0.616.

Exhibit 49. Expected Number of Hurricanes, by Landfall Region and Category

	Hurricane Category							
Region of Landfall	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5	Any Cat. Any Landfall	Any Cat. First Landfall	Any Cat. Second Landfall
NW	0.129	0.051	0.037	0.015	0.002	0.233	0.206	0.028
NE	0.009	0.005	0.005	0.001	0.000	0.020	0.017	0.004
SW	0.073	0.044	0.041	0.018	0.004	0.179	0.161	0.019
SE	0.059	0.034	0.046	0.034	0.010	0.183	0.164	0.019
Any Landfall	0.270	0.134	0.129	0.068	0.016	0.616		
First Landfall	0.231	0.118	0.119	0.065	0.015	0.548	0.548	
Second Landfall	0.039	0.016	0.010	0.003	0.001	0.069		0.069

Source: Florida Public Hurricane Loss Model, version 6.2, April 17, 2017. In addition to hurricanes represented in this table, 0.12 hurricanes per year will closely bypass Florida, but not make landfall in the state.

C.1.3. Expected Number of Hurricanes in One Year

More than one hurricane can occur in a single year. The probability distribution for how many hurricanes make landfall at least once in Florida is shown in Exhibit 50. The FPHLM shows that there is a 63.44% probability of no hurricanes in any given year, a 23.27% probability of exactly one hurricane, and a 9.26% probability of exactly two hurricanes. The probability of three or more hurricanes in one year is about 4%.

Exhibit 50. Number of Hurricanes Making Landfall in Florida Each Year

Number per Year	Historical Probabilities	Modeled Probabilities
0	62.07%	63.44%
1	22.41%	23.27%
2	12.93%	9.26%
3	2.59%	3.20%
4	0.00%	0.78%
5	0.00%	0.05%
All	100.00%	100.00%
Weighted Average Hurricanes per Year	0.560	0.548

Source: Florida Public Hurricane Loss Model, version 6.2, April 17, 2017. Includes only hurricanes making landfall in Florida.

C.1.4. Occurrences by Month and Week in Hurricane Season

The expected occurrences of hurricanes by month is shown in Exhibit 51. These are values estimated by ICF from historical hurricane data and are not part of the FPHLM results. The exhibit shows that the strongest hurricanes (categories 4 and 5) tend to occur from August to October when Atlantic Ocean water temperatures are relatively high.

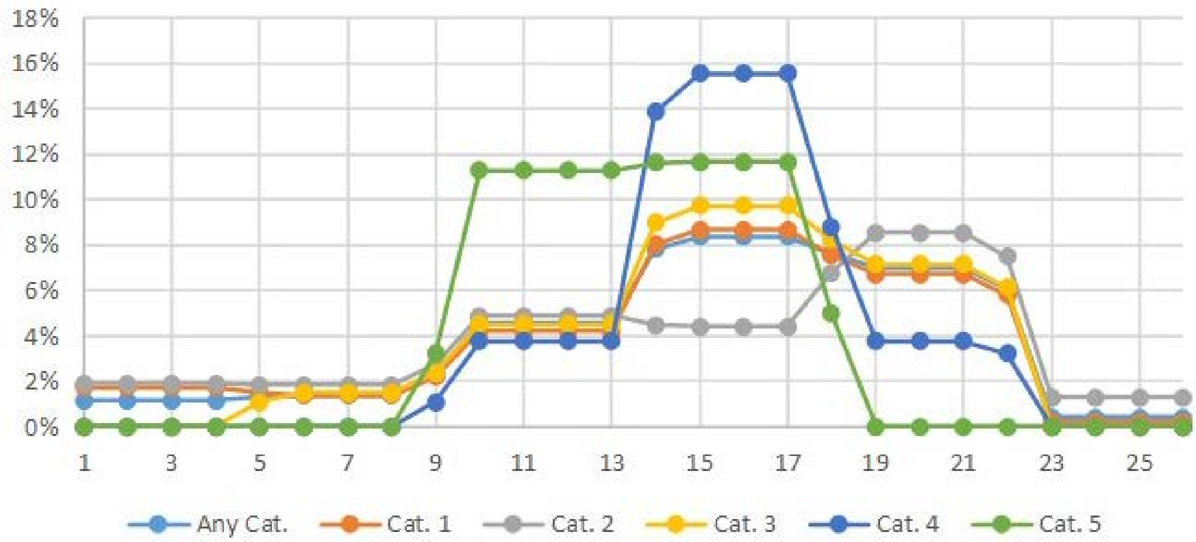
Exhibit 51. Number of Hurricanes Making Landfall in Florida by Month

	Any	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
June	4.96%	7.44%	8.11%	0.00%	0.00%	0.00%
July	6.20%	6.20%	8.11%	6.67%	0.00%	0.00%
August	20.25%	18.60%	21.62%	20.00%	16.67%	50.00%
September	35.95%	37.19%	18.92%	41.67%	66.67%	50.00%
October	30.99%	29.75%	37.84%	31.67%	16.67%	0.00%
November	1.65%	0.83%	5.41%	0.00%	0.00%	0.00%
Sum by Month	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Source: ICF estimate from NOAA data. See http://www.aoml.noaa.gov/hrd/hurdat/All_U.S._Hurricanes.html

The timing of hurricanes over the hurricane season is shown graphically in Exhibit 52. Specifically, for each category of hurricane, the chart shows the likelihood of its occurrence in any given week of the season (assuming that a hurricane of that category exists at all). All types of hurricanes are relatively unlikely to occur during the first nine weeks (beginning in June) of the 26-week hurricane season. All hurricanes are more likely to occur in weeks 10 through 18. After week 18, the strongest categories have much lower probabilities.

Exhibit 52. Hurricane Probability by Week of Hurricane Season

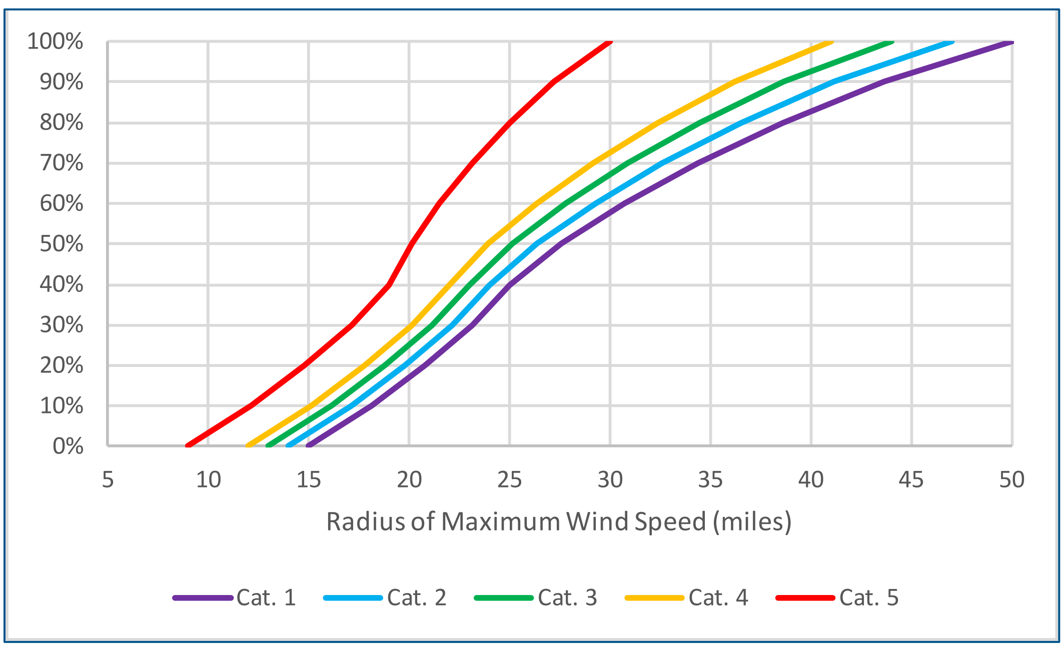


Source: ICF estimate from NOAA data. See
http://www.aoml.noaa.gov/hrd/hurdat/All_U.S._Hurricanes.html

C.1.5. Hurricane Size (Rmax)

Hurricane size is often measured in terms of the radius of maximum wind speed (Rmax). It represents the furthest distance from the center at which the maximum wind speeds can be expected to occur. Exhibit 53 shows the probability distribution used for this parameter in ICF's Monte Carlo analysis. Note that stronger hurricanes tend to have smaller radii of maximum wind speed. The importance of Rmax is that it determines the size of the area over which the most severe property damage, loss of life, and injuries can be expected to occur.

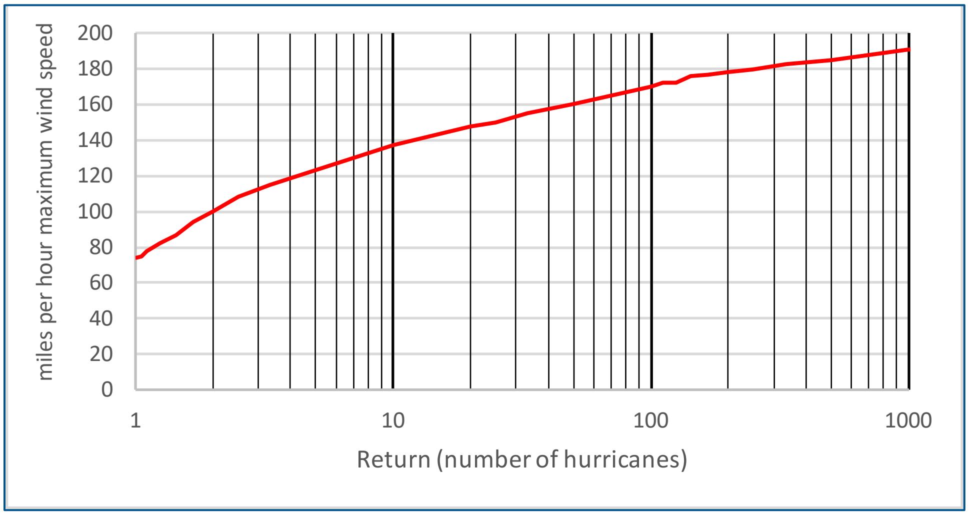
Exhibit 53. Cumulative Probability Distributions for the Rmax of a Hurricane



C.1.6. Monte Carlo Modeling Results for Hurricane Characteristics

The Monte Carlo process used by ICF creates 10,000 simulated hurricanes that have the statistical properties of the parameters discussed above, including the category (based on the Saffir-Simpson scale), landfall region, Rmax, and week of the hurricane season. The precise maximum sustained wind speed for each simulated hurricane is determined using a statistical distribution of wind speeds within each category. Exhibit 54 shows the probability results for maximum sustained wind speeds in miles per hour (MPH) across all 10,000 simulated hurricanes. The distribution of wind speeds begins at 74 MPH—the threshold speed that defines a hurricane. As the maximum wind speed on the y-axis increases, there are fewer and fewer hurricanes that will have maximum wind speeds at or above each value. Consistent with the FPHLM, the maximum wind speed modeled is 195 MPH. As a point of comparison, the highest historical wind speed recorded in Florida was during the Labor Day Hurricane of 1935, which struck the Florida Keys as a Category 5 hurricane with sustained winds of 185 MPH.

Exhibit 54. Maximum Sustained Wind Speed (Monte Carlo modeling results in MPH)



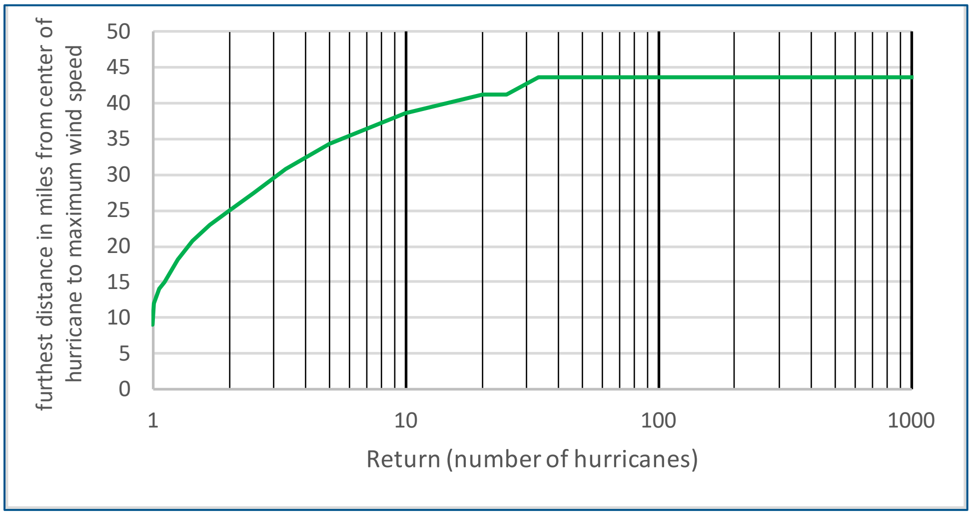
Note: This chart represents the distribution of 10,000 Monte Carlo trials of hurricane characteristics. A return (x-axis) value of every two hurricanes represents the 50th percentile, 10 represents the 90th percentile, 100 represents the 99th percentile, and 1,000 represents the 99.9th percentile.

Note that the x-axis of Monte Carlo modeling results is shown in terms of returns, or the expected interval between occurrences having a value equal to, or greater than, the y-axis. For these charts, the intervals are measured as the number of hurricanes that will come about before the y-axis value (or higher) reoccurs or returns. For example, every second hurricane will have a wind speed of 100 MPH or greater, every 10th hurricane will have a wind speed of 139 MPH or greater, and every 100th hurricane will have a wind speed of 170 MPH or greater. Note that every second hurricane represents the 50th percentile, every 10th hurricane represents the 90th percentile, and every 100th hurricane represents the 99th percentile.

Returns can also be measured in units of time. Because 0.548 hurricanes are expected per year, the returns (measured in years) can be computed by dividing the x-axis value by 0.548. For example, a wind speed of 139 MPH or greater can be statistically expected to occur every 10 hurricanes, or once every 18 years. A wind speed of 170 MPH or greater will be expected to reoccur every 100 hurricanes, or every 182 years.

The distribution of Rmax measured in miles for the 10,000 simulated hurricanes is shown in Exhibit 55. The hurricanes with the shortest Rmax have distances of just under 10 miles from the center of the hurricane out to where the highest wind speeds can be measured.

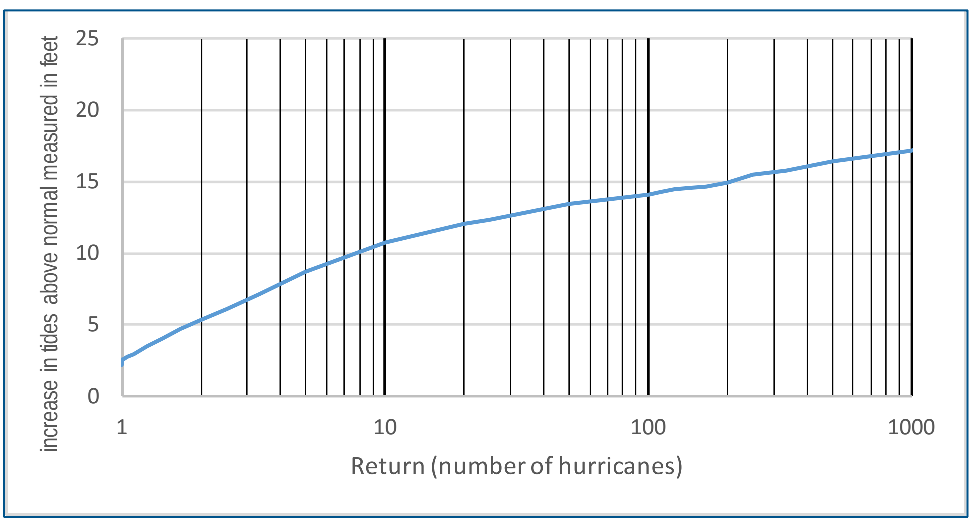
Exhibit 55. Rmax (Monte Carlo modeling results in miles)



Note: This chart represents the distribution of 10,000 Monte Carlo trials of hurricane characteristics. A return (x-axis) value of every two hurricanes represents the 50th percentile, 10 represents the 90th percentile, 100 represents the 99th percentile, and 1,000 represents the 99.9th percentile.

Exhibit 56 shows the probability results of the Monte Carlo simulation for storm surge in feet above normal tide levels in the landfall county. By way of comparison, the highest historical storm surge recorded for a Florida hurricane was 15 feet at Coconut Grove during the Great Miami Hurricane of 1926.[31]

Exhibit 56. Storm Surge (Monte Carlo modeling results in feet)



Note: This chart represents the distribution of 10,000 Monte Carlo trials of hurricane characteristics. A return (x-axis) value of every two hurricanes represents the 50th percentile, 10 represents the 90th percentile, 100 represents the 99th percentile, and 1,000 represents the 99.9th percentile.

[31] NOAA statistics are reported at https://www.wunderground.com/hurricane/surge_us_records.asp.

C.2. Hurricane Vulnerabilities

The cost-benefit analysis computes benefits in terms of the reduction in deaths and injuries that could come about through a more efficient gasoline distribution system. This section explains how hurricane deaths and injuries are estimated and what economic value is placed on their avoidance.

C.2.1. Historical Hurricane Deaths and Injuries

The National Hurricane Center at NOAA collects various types of data on hurricanes, including statistics on property damage and deaths. In 2014, Edward N. Rappaport published a report, entitled *Fatalities in the United States From Atlantic Tropical Cyclones*, which investigated the causes of hurricane-related deaths. The 2,544 deaths reported by Rappaport for the 87 Atlantic hurricanes occurring during the period 1963–2012 comes to an average of 29.2 deaths per event. Adding in data for the six additional hurricanes that occurred between 2013 and 2017 brings the average to 29.3 deaths per event.

Exhibit 57 presents a breakdown of the cause of hurricane-related deaths as reported in the Rappaport study. The exhibit shows that storm surge and ocean-related hazards (listed as storm surge, surf, and offshore) were responsible for about 61% of the total deaths. These would be expected to occur in coastal areas. The remaining causes (chiefly rain, wind, and tornados) were responsible for the remaining 39% of deaths. These deaths would be expected to occur in both coastal and inland areas.

Exhibit 57. Causes of Hurricane-Related Deaths (1963–2012)

Causes of Hurricane-Related Deaths	
Storm Surge	49%
Rain	27%
Surf	6%
Offshore	6%
Wind	8%
Tornado	3%
Other	1%
All Causes	**100%**
Modeled as Surge/Surf/Offshore-Related	61%
Modeled as Rain/Wind/Tornado/Other-Related	39%

Source: Fatalities in the United States from Atlantic Tropical Cyclones, Edward N. Rappaport, 2014, National Hurricane Center – NOAA.

There is no comprehensive and consistent compilation of statistics on nonfatal injuries caused by hurricanes. However, there are studies done for individual hurricanes to determine what impact the hurricanes had on the demands for medical services and the long-term effects on survivors' physical and mental health. One study commissioned by the Centers for Disease Control and Prevention (CDC) looked at the injuries and illnesses related to Hurricane Andrew in Louisiana in 1992.[32] The study reported on the results of an active emergency surveillance system set up in 19 parishes to monitor events related to the approaching hurricane. A

[32] Injuries and Illnesses Related to Hurricane Andrew – Louisiana, 1992. See https://www.cdc.gov/mmwr/preview/mmwrhtml/00020139.htm.

hurricane-related fatal or nonfatal injury/illness was defined as one that occurred from 12 noon on August 24 through 12 midnight on September 21, which resulted from the preparation for, impact of, or clean up after the hurricane and required treatment in a hospital ER or caused death. A questionnaire was used to collect data on demographic variables (i.e., age, sex, marital status, and parish); the nature of the injury/illness (e.g., cut, fall, electrocution, rash); body part affected; location, etiology, and time of the injury/illness; and the reporting institution. A total of 462 hurricane-related events were reported. Of the 462 hurricane-related events, 445 (96%) had nonfatal outcomes. Of the 445 nonfatal events, 86% were injuries and 14% were illnesses. The most common nonfatal injury was a cut/laceration/puncture wound (41%), followed by a strain/sprain (11%).

The CDC study for Hurricane Andrew suggested that there were 26 injuries treated at ERs or clinics for each death. However, the CDC study did not compile data on injuries that did not require treatment at hospitals or clinics. To estimate such injuries, ICF looked at a comprehensive study of injuries related to tornados and found that there were 1.58 self-treated injuries for each injury that required hospitalization or treatment at an ER or clinic.[33] The tornado study used the Abbreviated Injury Score (AIS) to classify injuries. ICF mapped the AIS classification into the injury categories used by FEMA to perform a cost-benefit analysis. The results are shown in Exhibit 58. The exhibit indicates that there are a far larger number of injuries, as compared to deaths, and that the number of injuries increases as the severity of the injury lessens. Each death caused by a tornado, on average, is accompanied by 11.3 injuries requiring hospitalization, 39.3 injuries requiring treatment at an ER or clinic, and 81.1 injuries that are treated at home.

Exhibit 58. Pattern of Deaths and Injuries Related to Tornados

Relative Injury Counts for Tornados		
Injury Severity Level (per FEMA categories)	Count Relative to 1 Death	Percentage of Injuries
Death	1.0	0.75%
Hospitalized	11.3	8.48%
Treated & Released	39.9	29.92%
Self-Treatment	81.1	60.85%
All Severity Levels	133.3	100.00%
Ratio: (Hospitalized + T&R) vs. Deaths	*51.2*	
Ratio: Self-Treatments vs. (Hospitalized + T&R)	*1.58*	

Source: https://bmjopen.bmj.com/content/8/6/e021552. Injuries in the original source were reported by AIS score and were converted by ICF to FEMA injury categories.

The assumed pattern of hurricane-related deaths and injuries used in the cost-benefit analysis is shown in Exhibit 59. The categories of severity of injury shown include those used by FEMA (see Exhibit 58). For all causes of death (the two right-most columns), we assume that there are

[33] Pattern and Spectrum of Tornado Injury and Its Geographical Information System Distribution in Yancheng, China, Qiangyu Deng, Yipeng Lv, Chen Xue, Peng Kang, Junqiang Dong, and Lulu Zhang. See https://bmjopen.bmj.com/content/8/6/e021552.

26 injuries requiring hospitalization or treat and release for each death. This assumption comes from the CDC study of Hurricane Andrew. The pattern of injuries by specific severity category and the estimate of self-treatment injuries comes from the cited study of injuries related to tornados. Taken together, this means that, for each death caused by a hurricane, we would expect there to be 5.7 injuries requiring hospitalization, 20.3 injuries treated at an ER or clinic (without hospitalization), and 41.2 injuries that are treated at home.

Exhibit 59. Assumed Pattern of Hurricane-Related Deaths and Injuries

	Rain, Wind, Tornado, & Other Related (39%)		Storm Surge, Surf, & Offshore Related (61%)		Weighted Average of All Causes (100%)	
Injury Severity Level	Percentage of Injuries	Count Relative to 1 Death	Percentage of Injuries	Count Relative to 1 Death	Percentage of Injuries	Count Relative to 1 Death
Death	1.3%	1.0	1.6%	1.0	1.5%	1.0
Hospitalized	8.4%	6.4	8.4%	5.3	8.4%	5.7
Treat & Release	29.7%	22.5	29.7%	18.8	29.7%	20.3
Self-Treatment	60.5%	45.8	60.3%	38.3	60.4%	41.2
All Severity Levels	100.0%	75.7	100.0%	63.4	100.0%	68.2
Ratio: (Hospitalized + T&R) vs. Deaths		*28.9*		*24.1*		*26.0*
Ratio: Self-Treatments vs. (Hospitalized + T&R)		*1.58*		*1.58*		*1.58*

Note: Relative occurrences are estimated by ICF from various sources, with a target of 26 hospitalizations and treat & release events per death, and a ratio of self-treatment to hospitalized plus treat & release of 1.58 to 1. Based on past patterns, 39% of deaths are expected to be rain, wind, tornado, and other non-surge related. The remaining 61% of deaths are expected to be related to surge and other ocean hazards.

C.2.2. Assignment of Costs to Deaths and Injuries (per FEMA standards)

For the purposes of computing the dollar cost of injuries (and the dollar benefits of avoiding such injuries), the count of each type of injury is multiplied by the social costs of the one injury event, as recommended by FEMA for cost-benefit analysis.[34] Exhibit 60 shows these standard values as last published in June 2009 and what those cost are in 2018, adjusted for general inflation. The standard values of social costs include not just the cost of treating the injuries, but also the costs of lost wages, lost productivity, the lost value of good health, and the value of lost companionship and care for family members.

The exhibit indicates that the standard value used by FEMA for one death is $6.9 million in 2018 dollars. Adding in the standard values of nonfatal injuries that are statistically associated with one death yields a total social cost of $17.2 million per death. Given that the average hurricane can be expected to kill 29.3 people, this means that the social costs of deaths and injuries are about $503 million per average hurricane.

[34] BCA Reference Guide, FEMA, June 2009.

Exhibit 60. Assigned Cost of Hurricane Deaths and Injuries per FEMA Standards

FEMA Standard Values for Cost-Benefit Analysis			Weighted Average of All Causes	
Injury Severity Level	As of June 2009	2018 dollars	Count Relative to 1 Death	Cost Relative to 1 Death
Death	$5,800,000	$6,932,000	1.0	$6,932,000
Hospitalized	$1,088,000	$1,300,000	5.7	$7,464,165
Treat & Release	$90,000	$108,000	20.3	$2,187,900
Self-Treatment	$12,000	$14,000	41.2	$576,807
All Severity Levels			68.2	$17,160,872

Source of standard value: BCA Reference Guide, FEMA, June 2009.

C.2.3. Modeling of Deaths and Injuries in the Cost-Benefit Analysis

For the cost-benefit analysis, we estimate the number of deaths expected for the 10,000 simulated future hurricanes as a function of the maximum sustained wind speeds and storm surge heights expected in each county for each event. For this purpose, the actual wind speeds and storm surge heights, rather than the "planned" values, are used.[35] The algorithms used to predict the number of deaths for each hurricane are calibrated to achieve an average (across all 10,000 simulated hurricanes) of 29 deaths per hurricane. The value of 29 deaths was chosen as a target to match the historical number of deaths per hurricane in the United States from 1963 to 2017.

The cost-benefit analysis estimates deaths separately for surge/surf/offshore causes (applying primarily to coastal counties) versus deaths from rain/wind/tornado/other causes. The first equation for surge/surf/offshore causes is shown below:

$$SRDEATHS_c = (POP_c - EVAC_c) * (COEFF1_s * SURGE_c + COEFF2_s * SURGE_c^2)$$

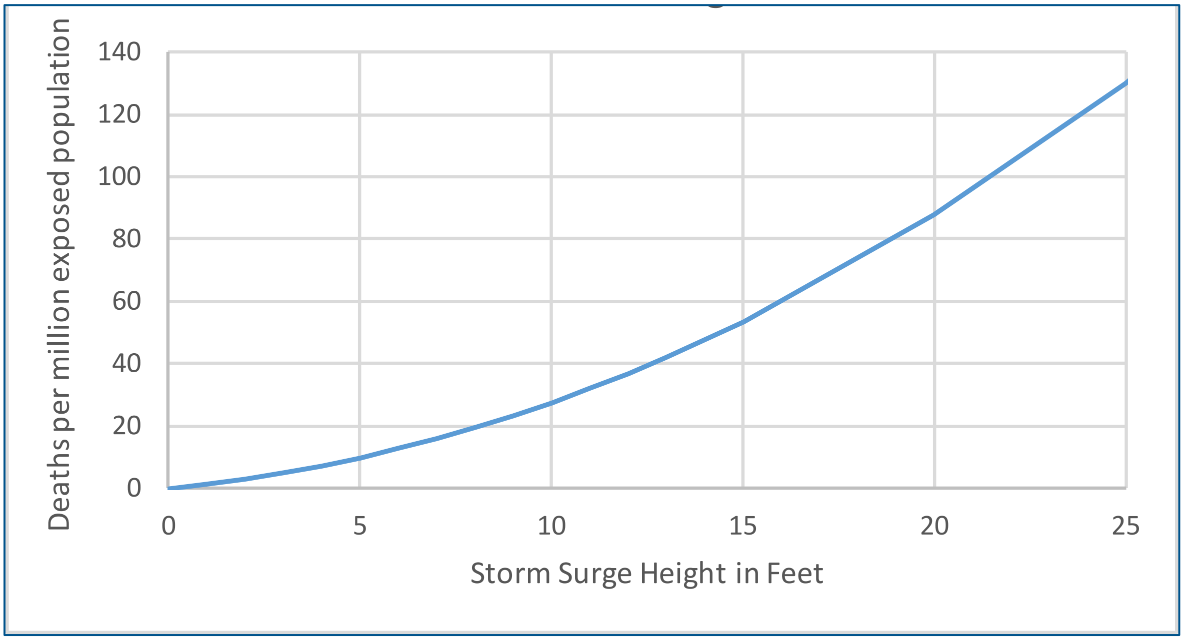
where:

$SRDEATHS_c$ = Surge/surf/offshore-related deaths in each county (c)
POP_c = 2017 population in each county (c)
$EVAC_c$ = Number of people who are planned to evacuate from each county (c)
$SURGE_c$ = Height of the storm surge measured in feet
$COEFF1_s$ = Coefficient for linear term with a value of 1.120 chosen to produce an average of 29 deaths per hurricane of which 61% are surge/surf/offshore-related
$COEFF2_s$ = Coefficient for squared term with a value of 0.163 chosen to produce an average of 29 deaths per hurricane of which 61% are surge/surf/offshore-related

This modeled relationship between storm surge height and expected deaths per one million exposed population (i.e., the total population less the number of planned evacuees) is shown in Exhibit 61. This exhibit indicates that deaths related to surge and surf are approximately 10 per one million exposed population at five feet of storm surge and increase to about 54 deaths per one million exposed population at 15 feet of storm surge.

[35] The cost-benefit analysis methodology estimates evacuations assuming that the "actual" path of a hurricane is not known, and thus several alternative "planning" paths are used to determine who should evacuate. The "planned" wind speed/storm surge for a county are the highest values from any hurricane planning path and are always equal to, or higher than, the "actual" wind speed/storm surge for that county.

Exhibit 61. Expected Surge- and Surf-Related Deaths (per one million exposed people) Versus Storm Surge Height



The second equation for deaths related to other factors (such as rain, wind, and tornados) is shown below:

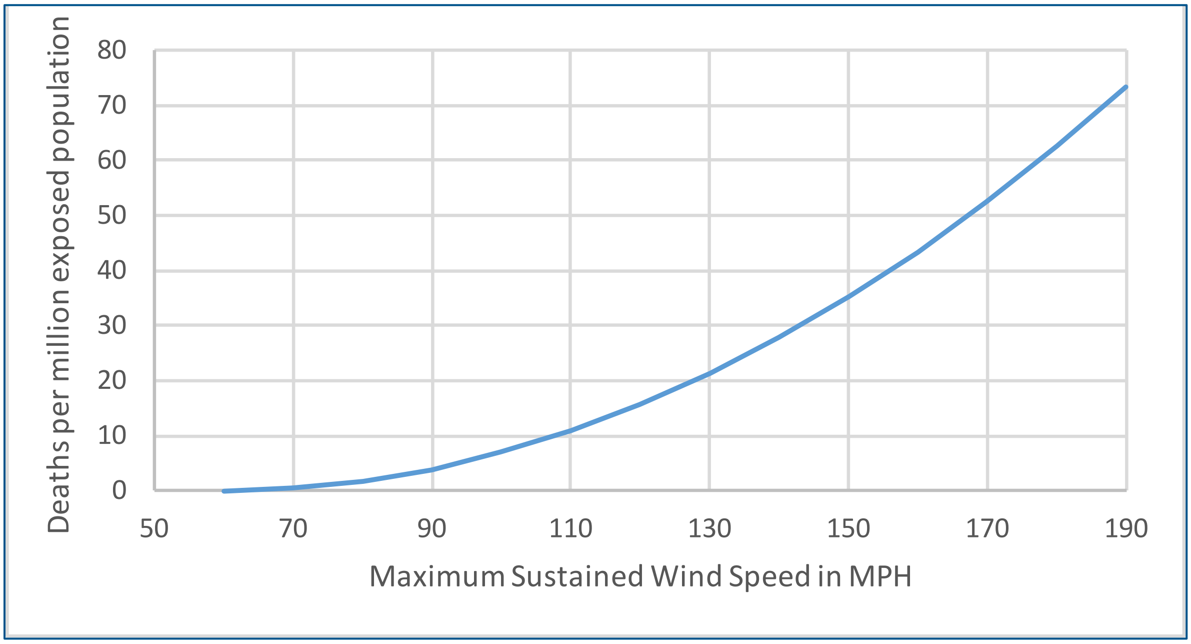
$$WRDEATHS_c = (POP_c - EVAC_c)/1e6 * COEFF_w * (WS_c\text{-}60)^2$$

where:

$WRDEATHS_c$ = Rain/wind/tornado/other related deaths in each county (c)
POP_c = 2017 population in each county (c)
$EVAC_c$ = Number of people who are planned to evacuate from each county (c)
WS_c = Maximum sustained wind speed in each county (c) measured in miles per hour
$COEFF_w$ = Coefficient with a value of 0.004345 chosen to produce an average of 29 deaths of which 39% are rain/wind/tornado/other-related

This modeled relationship between wind speeds and expected deaths per one million exposed population (i.e., the total population less the number of planned evacuees) is shown in Exhibit 62. This exhibit indicates that deaths related to rain, wind, tornados, and other factors (excluding storm surge and surf) are approximately four per one million exposed population at 90-MPH sustained winds and increase to about 21 deaths per one million exposed population at 130-MPH sustained winds.

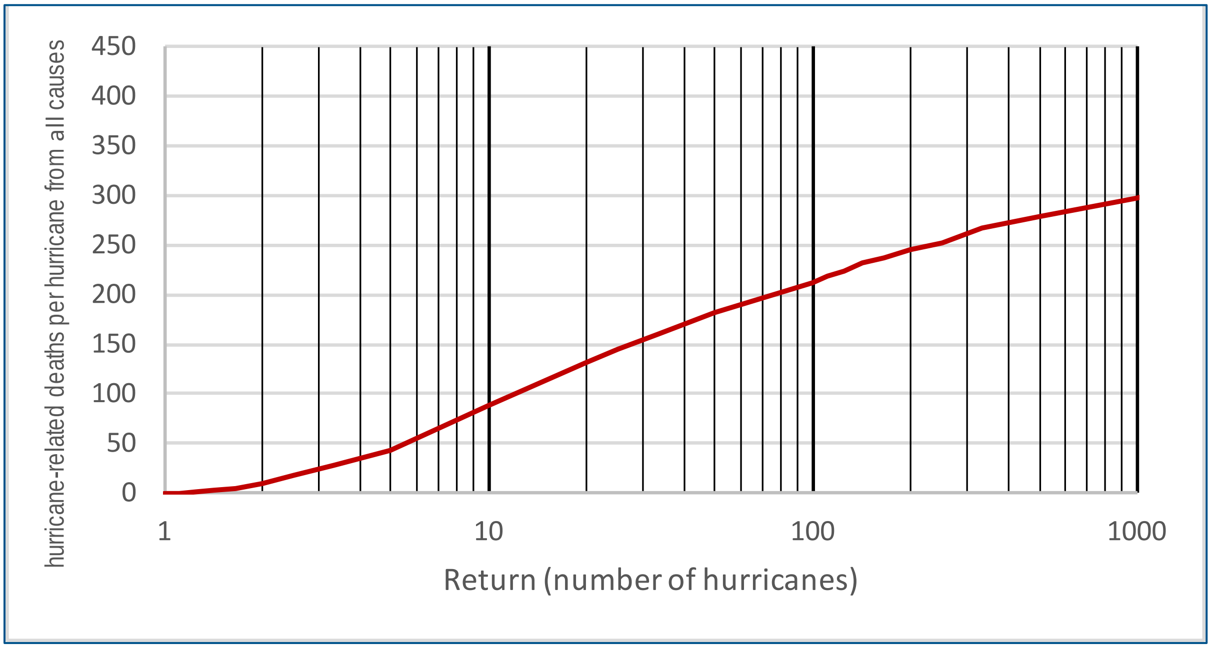
Exhibit 62. Expected Rain/Wind/Tornado/Other Deaths (per one million exposed people) Versus Maximum Sustained Wind Speeds



C.2.4. Monte Carlo Modeling Results for Hurricane Deaths, Injuries, and Associated Costs

Total deaths for hurricanes simulated in the cost-benefit analysis are the sum of deaths from surge/surf/offshore causes (applying primarily to coastal counties) plus the deaths from rain/wind/tornado/other causes. Exhibit 63 shows the Monte Carlo result for the number of deaths expected for the 10,000 simulated hurricanes that could occur in the future and includes the deaths calculated by the algorithms represented in Exhibit 61 (as a function of storm surge) and those in Exhibit 62 (as a function of wind speed). As was explained above, these two algorithms used to predict the number of deaths for each hurricane were calibrated to achieve an average of 29 deaths per hurricane across all 10,000 simulated hurricanes.

Exhibit 63. Expected Number of Deaths (Monte Carlo modeling results per one million exposed people)[36]



Note: This chart represents 10,000 Monte Carlo trials of hurricane characteristics and the distribution of their consequences in terms of deaths from all causes. A return (x-axis) value of every two hurricanes represents the 50th percentile, 10 represents the 90th percentile, 100 represents the 99th percentile, and 1,000 represents the 99.9th percentile.

Given the expected distribution of the number of hurricane-related deaths represented in Exhibit 63, we can use the factors for injuries discussed above to calculate the injuries. For each estimated death, there is expected to be, on average, 5.7 injuries requiring hospitalization, 20.3 injuries treated at an ER or clinic (without hospitalization), and 41.2 injuries that are treated at home. The social costs of predicted deaths and injuries are calculated by applying the standard values used by FEMA for cost-benefit analyses. For a single death, the FEMA standard value is $6.9 million in 2018 dollars. Adding in the standard values of nonfatal injuries that are statistically associated with each death produces a total social cost of $17.2 million per death.

C.3. Hurricane Evacuations

The characterization of each hypothetical future hurricane (in terms of location, size, wind speed, etc.) is also used to estimate how many people would have to evacuate to preserve public safety. These evacuation numbers, in turn, are used to estimate how much additional

[36] While the chart is calibrated to an expected number of deaths per hurricane, the average of 29 represents the number of deaths experienced across all states affected by the hurricane rather than Florida specifically. In terms of the cost-benefit analysis, only 70% of expected deaths were considered to occur in Florida for hurricanes that made direct landfall in the state. Of hurricanes that traveled close to Florida but did not make direct landfall, 20% of the expected deaths were considered to occur in Florida.

gasoline will be required and how infrastructure improvements could ensure adequate supplies for those evacuations.

For the cost-benefit analysis, the number of people to be evacuated by county is modeled as a function of each hurricane's characteristics (specifically location, size, wind speed, and storm surge) and a factor to account for the landfall location error. The landfall location error is intended to account for the fact that the track of the hurricane cannot be known with certainty at the start and during the evacuation period. Therefore, the area evacuated is typically larger than the area that would have been evacuated if the hurricane track could have been known with certainty.

C.3.1. Modeled Evacuations by County

The number of people who would be expected to evacuate due to simulated future hurricane events is computed in the cost-benefit analysis using the SRES[37] Situational Awareness Tool BETA, maintained by FDEM. ICF received an Excel spreadsheet tool from FDEM. The tool provides population estimates for the metrics shown in Exhibit 64 of a hurricane event given the expected level of storm (represented by the letters A through E). The hurricane level is determined either by wind speed or, where relevant, storm surge.

Exhibit 64. Estimates provided by the SRES Situation Awareness Tool

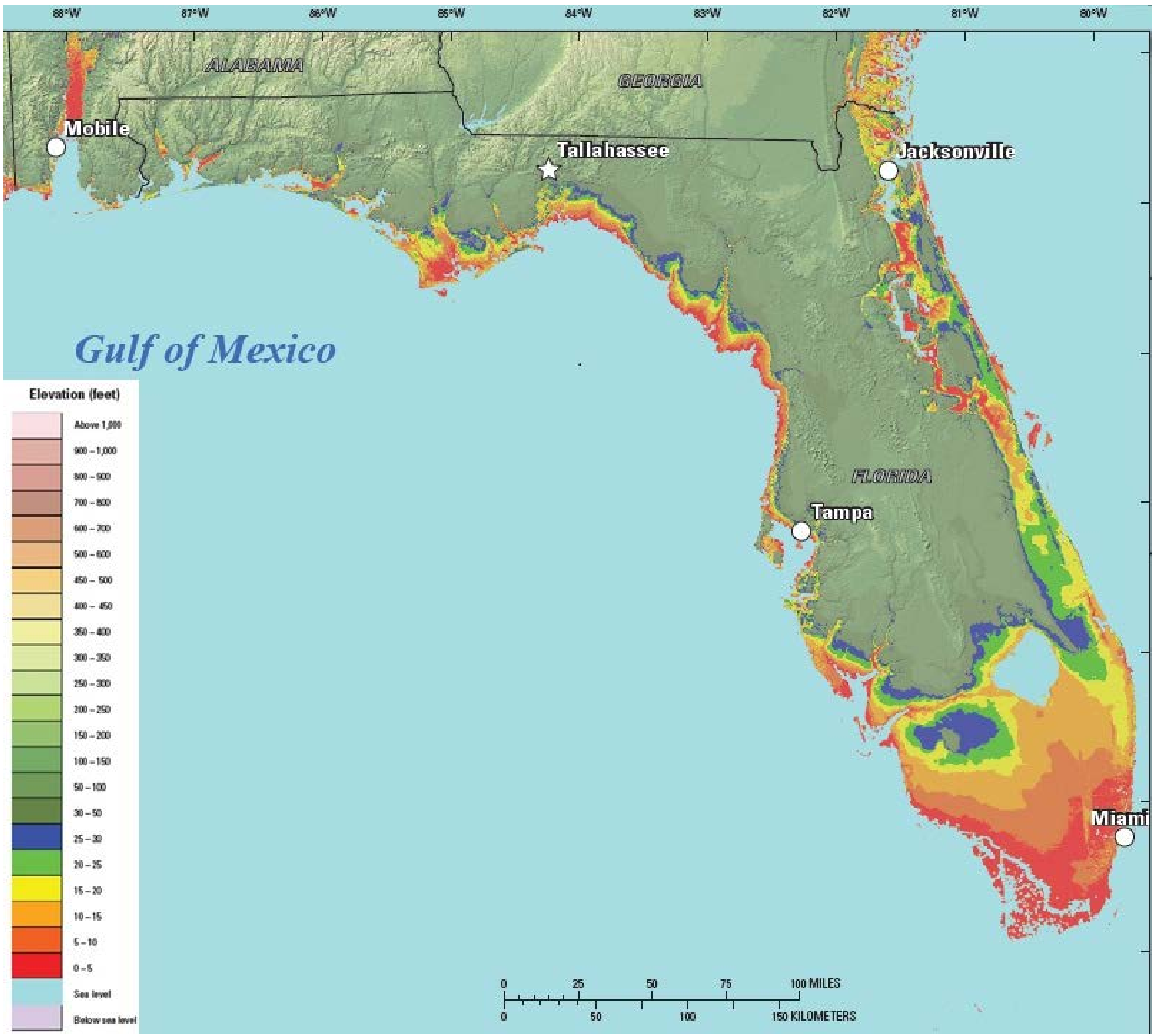
Estimated Metric (by county)	Description
Evacuation Estimates	Based on the level of the hurricane, an estimate of the number of evacuees by county. The vintage year of population data is 2015. (This was adjusted by ICF to reflect the 2017 population.)
Shelter Demand Estimates	Based on the level of the hurricane, an estimate of the number of people needing shelter by county. The vintage year of population data is 2015.
Transportation Assistance Estimates	Percentage of households needing outside help from government agencies.
Destination Estimates: Friend/Relative	Percentage of households needing outside help from a friend/relative.
Destination Estimates: Hotel/Motel	Percentage of evacuees staying at hotels/motels.
Destination Estimates: Other: Second home, workplace, church	Percentage of evacuees staying at other location (second home, workplace, church).

The 67 counties in Florida are divided into seven hurricane evacuation regions for hurricane planning. If a county is inland, then the population to be evacuated is planned for based on wind speed thresholds represented in levels A through E.[38] If a county is coastal, then the storm

[37] This acronym refers to Florida's Statewide Regional Evacuation Study Program.
[38] The A through E levels of hurricanes for evacuation planning generally correspond to the Saffir-Simpson Hurricane Wind Scale and, indeed, are directly comparable for inland counties (i.e., Level A = Category 1, Level B = Category 2, and so forth). For coastal counties, the level is determined by the expected storm surge height, which while largely a function of wind speed, is also affected by hurricane-

surge height expected for that county is used to estimate the intensity level (A–E) of the hurricane. The evacuation estimate developed for coastal counties are based on a mapping of the populations within areas of high threat based on the area's distance to the shore and elevation (see Exhibit 65). The typical wind speed needed to generate a given level of storm surge varies among Florida counties due to differences in the shape of the coast and the slope of the sea floor. The level of storm surge for any given wind speed will also be affected by hurricane-specific factors such as the storm track, storm speed, the central pressure of the storm, and the level of regular tides.

Exhibit 65. Map of Florida Elevation



Source: U.S. Geological Survey, https://pubs.usgs.gov/sim/3047/.

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specific factors such storm track, storm speed, the central pressure of the storm, and the level of the regular tides.

Exhibit 66 shows the number of evacuations that would be expected from each of Florida's 67 counties for different levels of hurricanes. The count of people to be evacuated is taken from the SRES tool, but adjusted upward for the differences between each county's 2017 population versus its 2015 population (the base year for the SRES tool).

Exhibit 66. Planned Hurricane Evacuations by County (count of people)

Hurricane Level	Level A	Level B	Level C	Level D	Level E	2017 Population
MPH Wind Speed Threshold (applies directly to inland counties, but is adjusted for coastal counties based on expected storm surge height)	74	96	111	131	156	
County						
Alachua	31,604	42,886	65,446	76,727	88,009	260,003
Baker	12,653	13,471	14,289	15,108	15,926	27,191
Bay	62,123	80,091	90,065	108,624	126,161	178,820
Bradford	8,746	9,544	10,340	11,934	12,732	27,642
Brevard	211,812	233,224	260,783	320,676	446,528	575,211
Broward	224,491	231,681	320,971	462,102	653,530	1,873,970
Calhoun	5,053	5,492	6,370	6,808	7,247	15,001
Charlotte	81,784	148,055	172,720	172,720	172,720	172,720
Citrus	62,269	67,938	73,608	86,382	95,144	143,801
Clay	52,986	67,773	113,072	125,172	131,222	208,549
Collier	168,065	299,068	357,470	357,470	357,470	357,470
Columbia	27,408	29,430	33,472	35,493	37,514	68,943
Desoto	12,012	13,209	14,905	16,935	17,867	35,621
Dixie	11,123	11,342	11,874	13,463	14,462	16,726
Duval	289,891	354,996	484,909	557,334	629,907	936,811
Escambia	46,393	63,070	81,606	113,328	141,367	313,381
Flagler	26,622	40,118	46,426	59,194	67,992	105,157
Franklin	7,976	10,982	11,003	11,011	11,017	12,161
Gadsden	17,109	18,676	20,243	21,811	23,378	48,263
Gilchrist	9,965	10,323	10,680	11,038	11,395	17,224
Glades	7,617	8,081	8,974	9,643	9,992	13,087
Gulf	7,187	9,556	11,148	11,448	11,530	16,297
Hamilton	6,419	6,728	7,037	7,346	7,654	14,663
Hardee	8,468	8,468	9,423	10,378	11,334	27,426
Hendry	19,683	20,853	23,128	24,207	25,239	39,057
Hernando	48,440	49,977	61,864	95,981	117,286	181,882
Highlands	25,231	25,231	29,221	37,206	41,216	102,138
Hillsborough	298,983	378,531	481,628	562,251	683,314	1,379,302
Holmes	6,159	6,818	7,478	8,138	8,798	20,210
Indian River	34,818	52,671	54,742	67,377	72,798	148,962
Jackson	12,672	14,212	17,289	18,829	20,368	50,418
Jefferson	6,123	6,551	7,034	7,640	8,005	14,611
Lafayette	3,129	3,129	3,323	3,710	3,904	8,479

Feasibility Analysis for Petroleum Distribution Centers

Hurricane Level	Level A	Level B	Level C	Level D	Level E	2017 Population
MPH Wind Speed Threshold (applies directly to inland counties, but is adjusted for coastal counties based on expected storm surge height)	74	96	111	131	156	
County						
Lake	80,352	94,438	108,524	136,697	164,869	331,724
Lee	353,570	545,734	685,783	698,468	698,468	698,468
Leon	36,605	49,151	76,803	90,815	103,116	287,899
Levy	24,074	24,916	26,366	28,666	31,961	41,015
Liberty	3,583	3,788	4,173	4,374	4,587	8,719
Madison	7,793	8,333	8,873	9,414	9,954	19,377
Manatee	117,420	141,985	178,910	240,413	294,810	368,782
Marion	114,067	127,911	141,754	155,598	155,598	349,267
Martin	32,906	39,192	50,099	61,471	84,535	153,022
Miami-Dade	388,433	522,361	547,380	779,938	992,349	2,743,095
Monroe	71,632	71,632	71,632	71,632	71,632	76,889
Nassau	60,404	61,824	67,863	70,328	72,832	80,456
Okaloosa	25,466	37,178	61,889	96,825	123,207	195,488
Okeechobee	23,475	28,810	39,610	39,610	39,610	41,140
Orange	162,752	162,752	221,225	279,700	338,174	1,313,880
Osceola	42,814	60,231	77,647	95,063	112,479	337,614
Palm Beach	136,076	187,868	311,136	396,362	490,586	1,414,144
Pasco	145,664	180,084	255,449	286,406	312,045	505,709
Pinellas	296,171	394,879	516,887	596,037	660,114	962,003
Polk	156,886	182,902	208,917	234,933	260,948	661,645
Putnam	39,363	40,625	44,885	47,318	50,869	73,176
Santa Rosa	39,626	45,381	66,089	85,793	101,876	170,835
Sarasota	109,677	158,347	262,488	321,822	350,619	407,260
Seminole	52,742	52,742	74,296	95,848	117,402	454,757
St. Johns	111,471	159,723	166,821	176,210	184,484	229,715
St. Lucie	52,812	67,655	69,379	104,248	117,942	297,634
Sumter	30,908	35,245	39,581	43,916	48,252	120,700
Suwannee	23,710	24,770	25,193	26,887	27,947	44,690
Taylor	9,177	9,233	10,554	12,219	13,582	22,295
Union	4,721	5,050	5,379	6,037	6,366	15,947
Volusia	162,917	188,758	243,937	289,199	388,019	523,405
Wakulla	20,146	22,124	26,339	26,509	26,680	31,909
Walton	32,644	56,281	64,499	65,301	65,301	65,301
Washington	8,030	8,803	10,347	11,119	11,892	24,985
Sum of All	4,833,098	6,142,882	7,693,250	9,132,656	10,616,129	20,484,142

Source: The FDEM hurricane planning model adjusted to 2017 population values. Population data for 2015 and 2017 are from https://www.bebr.ufl.edu/population/data

C.3.2. Wind Speeds and Location Landfall Forecasting Error

For each simulated hurricane, ICF estimated (1) the maximum sustained wind speed in all Florida counties and (2) storm surge for Florida coastal counties and a few low-lying inland counties connected to the ocean through river systems. The predicted wind speed in each was based on the distance between each county and the county of landfall, the maximum wind speed at landfall, and the size of the storm measured as the Rmax. The equation used for this calculation is shown below: [39]

$$MSWS_c = MSWS_{lf} / (D_{c,lf}/Rmax)^{0.5}$$

where:

$MSWS_c$ = Maximum sustained wind speed in each county (c)
$MSWS_{lf}$ = Maximum sustained wind speed in the landfall county (lf)
$D_{c,lf}$ = Distance in miles between each county (c) and the landfall county (lf)
Rmax = Radius of maximum sustained wind measured in miles

In cases where landfall occurs in two Florida counties, the corresponding wind speeds are computed for surrounding counties relative to each of the two landfall locations, and the higher wind speed is used for each county. The storm surge for coastal and certain inland counties is based on a statistical relationship between wind speeds and surge levels specific to each county as represented in the SRES tool.

To account for the variance in projected landfall locations (due to changes over time in the forecasted storm track), ICF uses a random variable in the Monte Carlo simulation to represent the forecasting error in landfall location. There are five possible values of this variable, ranging from 50 miles to 150 miles (Exhibit 67). The error values are stated in statute miles (used for distances on land) as opposed to nautical miles (used for distances on seas). The error values are based on historical forecasting errors compiled by NOAA for prior hurricanes (Exhibit 68). The modeled forecasting errors and the probability of any hypothetical hurricane having one of those five values are shown in Exhibit 67.

The error term is applied to modeled landfall locations to compute alternative landfall locations along the Florida coastline. For each alternative landfall location, the distance-based equation is applied to predict “planned” sustained wind speeds and storm surges for all Florida counties. The highest estimated sustained wind speed (chosen from among the wind speeds computed from the actual landfall location or any of the alternative landfall locations falling within the forecasting error) is then used to estimate the number of evacuations. On average, the introduction of the forecasting error more than doubles the predicted number of evacuees compared to using only the actual landfall location(s).

It is important to note, that while the forecasting error is used to estimate evacuations, only the actual landfall location (or the two actual locations for hurricanes that make two landfalls) is used to estimate deaths and injuries.

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[39] This formulation is adapted from the United States Landfalling Hurricane Probability Webpage, Philip J. Klotzbach, Colorado State University. See https://tropical.colostate.edu/.

Exhibit 67. Modeled Forecasting Error in Landfall Location

Probability	Error (miles)
20.0%	50
20.0%	75
20.0%	100
20.0%	125
20.0%	150
Average	100

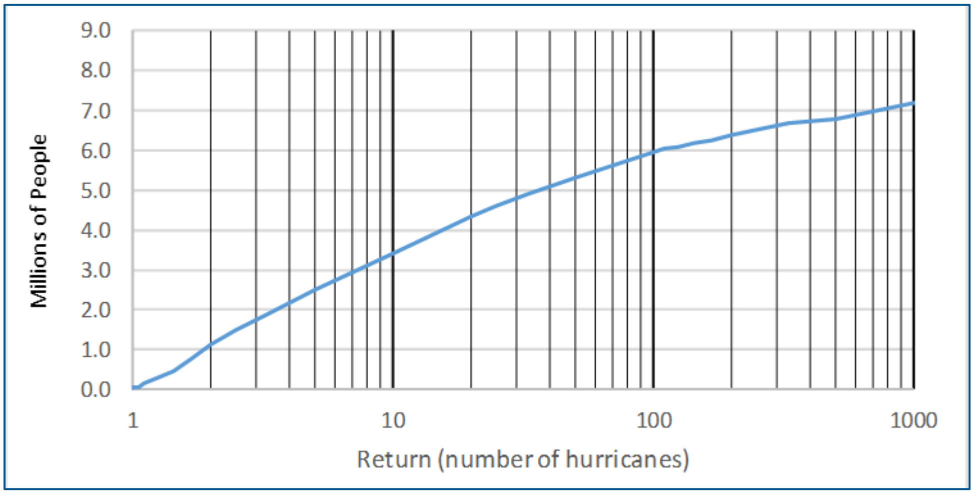
Exhibit 68. Historical Forecasting Error in Landfall Location

Hours Before Landfall	Average Error in Miles (2012–2016)
12	29
24	46
36	62
48	82
72	122
96	179
120	240
Source: National Hurricane Center Tropical Cyclone Report: Hurricane Irma, June 2018.	

C.3.3. Evacuation Monte Carlo Modeling Results

The number of people who are planned to evacuate in the 10,000 simulated future hurricanes is shown in Exhibit 69 and the number of counties with at least some evacuations for each hurricane is shown in Exhibit 70. Exhibit 69 indicates that the smallest and least severe hurricanes located in less populated areas are predicted to have very few planned evacuations. The largest number of predicted evacuations is eight million people (based on 2017 population). The x-axis of Exhibit 69 indicates how many hurricanes there would be between successive occurrences or returns with planned evacuations equal to or greater than the corresponding y-axis values. For example, the x-axis value of two hurricanes corresponds to 1.1 million planned evacuations. This means that every second hurricane would have 1.1 million or more evacuations. Another way of saying this is that the return value of two hurricanes corresponds to the 50th percentile. Therefore, one-half of the simulated hurricanes have fewer than 1.1 million evacuees and the other half have more. Likewise, the value of 10 hurricanes on the x-axis corresponds to the 90th percentile. Therefore, we can say that 90% of the simulated hurricanes have fewer than 3.4 million evacuees and 10% have that number or more. The value of 100 hurricanes on the x-axis corresponds to the 99th percentile and has a y-axis value of 6.0 million evacuees. This means that just 1% of simulated hurricanes are expected to have planned evacuations of 6.0 million or more people. By way of comparison, the Hurricane Irma evacuations were approximately 6.8 million people.

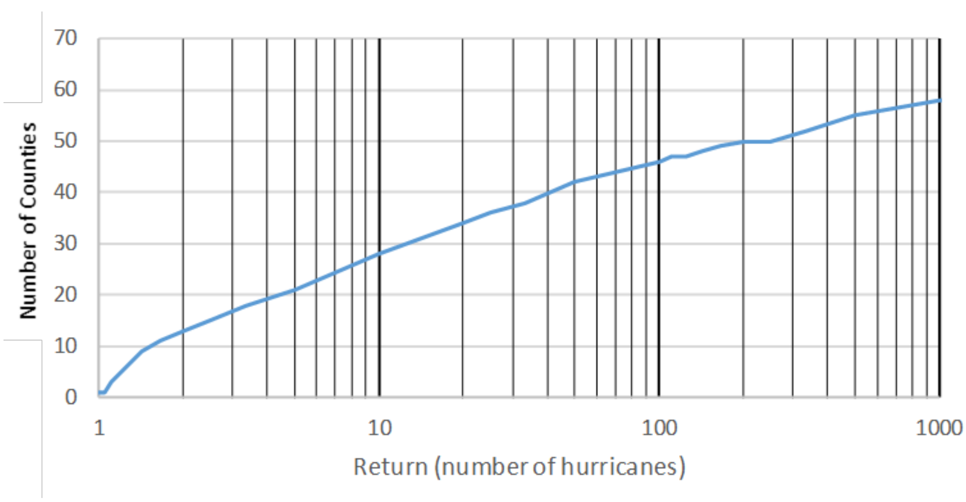
Exhibit 69. Florida Population Planned to Evacuate (Monte Carlo modeling results)



Note: This chart represents 10,000 Monte Carlo trials of hurricane characteristics and the distribution of their consequences in terms of planned evacuations. A return (x-axis) value of every two hurricanes represents the 50th percentile, 10 represents the 90th percentile, 100 represents the 99th percentile, and 1,000 represents the 99.9th percentile.

Note that the theoretical maximum number of evacuations of 10.6 million people calculated by summing the SRES maximums for each county (Exhibit 66) does not occur in the simulations. This is because there is no simulated hurricane that simultaneously generates the most severe wind speed and surge thresholds in all counties. However, there are large simulated hurricanes where the planned evacuations encompass almost 60 out of the 67 Florida counties (Exhibit 70).

Exhibit 70. Number of Florida Counties From Which Evacuations Occur (Monte Carlo modeling results)



Note: The chart represents 10,000 Monte Carlo trials of hurricane characteristics and the distribution of their consequences in terms of count of counties with evacuations. A return (x-axis) value of every two hurricanes represents the 50th percentile, 10 represents the 90th percentile, 100 represents the 99th percentile, and 1,000 represents the 99.9th percentile.

C.3.4. Implied Economic Value per Evacuee

Because the probability of deaths and injuries are functions of wind speed and storm surge levels, more severe storms impose greater social costs related to deaths and injuries. Exhibit 71 shows the results of the Monte Carlo simulation showing how many deaths (at the margin[40]) are avoided per one million evacuees and the social costs that are avoided by those evacuations. The least severe hurricanes have social values under $20 per marginal evacuee, while the most severe hurricane have calculated social values of more than $1,600 per marginal evacuee. Across all simulated hurricanes, the social values average $208 per marginal evacuee.

These costs are referred to as being *at the margin* in that people living in the most dangerous areas have largely been evacuated and deaths are being estimated for the remaining population that, presumably on average, is living in less dangerous areas. The cost-benefit model's algorithms for predicting deaths are calibrated to the historical record of 29 deaths per hurricane since 1963, when modern hurricane tracking and warning systems were in place. If modern hurricane tracking and warning system were *not* in place, then we would expect a typical hurricane to cause *hundreds* of deaths as hurricanes did in the first part of the 20th century, even when coastal populations were much less dense than they are now. In such a world, the value of the next evacuation of a household (and the value of supplying gasoline for that evacuation) would be much higher than we are calculating here.

Exhibit 71. Avoided Deaths per One Million Evacuees at the Margin (Monte Carlo modeling results)

Return (no. of hurricanes)	Percentiles	Avoided Deaths per 1 Million Evacuees	Avoided Injuries per 1 Million Evacuees	Dollar Value of 1 Million Evacuees	Dollar Value per Planned Evacuee
1.0	1.0%	0.2	16	$4,063,430	$4
1.1	5.0%	0.6	42	$10,755,543	$11
1.1	10.0%	1.1	72	$18,270,050	$18
1.3	25.0%	2.4	159	$40,722,694	$41
2.0	50.0%	6.6	444	$113,296,621	$113
4.0	75.0%	16.8	1,131	$288,744,669	$289
10.0	90.0%	28.9	1,941	$495,592,826	$496
20.0	95.0%	44.3	2,974	$759,384,976	$759
50.0	98.0%	60.2	4,048	$1,033,759,490	$1,034
100.0	99.0%	75.1	5,045	$1,288,371,892	$1,288
1000.0	99.9%	95.5	6,417	$1,638,768,413	$1,639
Average		12.1	813	$207,570,202	$208

Note: This table shows the avoided deaths at the margin after people living in the most dangerous areas have been evacuated and deaths are being estimated for the remaining (exposed) population.

[40] The phrase *at the margin* is used by economists to describe the value or cost of the next unit or measured increment of a good or service. In the context of this study, we are measuring the value of the marginal (next) person to evacuate or the gasoline needed to allow that next evacuation.

C.3.5. Gasoline Demand Surge Monte Carlo Modeling Results

The cost-benefit analysis compares the costs of potential improvements to the Florida gasoline distribution network against the expected benefits of those improvements in terms of the dollar value of the reduction in the number of hurricane-related deaths and injuries that is expected to result from the network improvements. The reduction in deaths and injuries would come about because drivers would more easily find the gasoline supplies they need for their planned evacuations, thereby speeding the evacuation process and making it more likely that they will be out of harm's way. A key component in the cost-benefit analysis is the estimation of how much more gasoline demand will occur due to the evacuations and other factors that increase gasoline demand during hurricane evacuation periods.

The methodology used here is to compute increased demand for gasoline in two parts. The first part is the gasoline needed for the evacuation itself. It is estimated in each county using these relationships:

$EVACVEHICLES_c = EVACPEOPLE_c / PPV$
$EVACDEM_c = EVACVEHICLES_c * EVACMILES_c / MPG$

where:

$EVACVEHICLES_c$ = Number of evacuation vehicles in each county (c)
$EVACPEOPLE_c$ = Number of evacuees (count of people) in each county (c)
$EVACDEM_c$ = Gasoline demand for evacuation measured in gallons in each origination county (c)
$EVACMILES_c$ = Average number of one-way miles each evacuating vehicle will travel from each originating county (c). This assumes that a fraction of the vehicles leave the state and that the remaining vehicles stop at various point in the state. The value of this variable ranges from 20 to 398 miles among the counties. The average weighted by registered vehicle in each county is 204 miles.
PPV = Number of evacuees per vehicle. This is assumed to be 2.5 in all counties.
MPG = Average efficiency of the evacuating vehicle in miles per gallon. This is assumed to be 22.0 miles per gallon for all counties.

The second part of the gasoline demand increase is modeled as coming from vehicle owners who do not evacuate, but who top off their gas tanks in anticipation of gasoline supply disruptions.

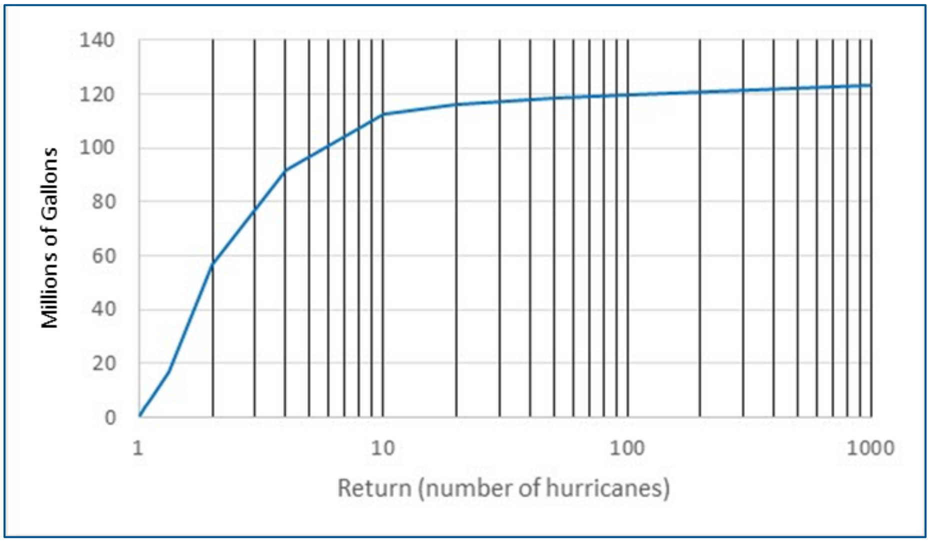
$TOPOFFDEM_c = (TOTALVEHICLES_c - EVACVEHICLES_c) * TOGPV$

where:

$TOPOFFDEM_c$ = Gasoline demand for topping off measured in gallons related to evacuation in each county (c)
$TOTALVEHICLES_c$ = Number of total vehicles in each county (c)
$EVACVEHICLES_c$ = Number of evacuation vehicles in each county (c)
TOGPV = Top-off gallons per vehicle. This is assumed to be 7.8 gallons.

The distribution of the results for the total gasoline demand surge (evacuation demand plus the topping-off demand) is shown in Exhibit 72. The gasoline demand surge ranges from a few gallons to more than 120 MMgal. The average demand surge across all 10,000 simulated hurricanes is 75.9 MMgal.

Exhibit 72. Gasoline Demand Surge Over the Entire Evacuation Period (Monte Carlo modeling results)



The gasoline surge is assumed to be spread over the three days before hurricane landfall. Therefore, the average of 75.9 MMgal of surge demand translates into a daily gasoline demand of 25.3 MMgal/d. When added to the typical daily demand of 24.7 MMgal/d, this produces a total demand of 50.0 MMgal/d for the average hurricane. Note that this is the amount that consumers would wish to purchase, but is not necessarily the amount they will actually be able to purchase. In other words, retail sales can fall below retail demand when there are gas station outages.

C.3.6. Reallocating Gasoline From the Origin County to the Sales County

The equations shown above estimate for each Florida county the gasoline that will be demanded for evacuating vehicles and for non-evacuating vehicles that are topped off. For the cost-benefit analysis, it is assumed that all of the demand for the topping off of vehicles plus a little over half of the demand for evacuating vehicles (about 59%, on average) will be met with purchases from gas stations located inside the origin counties where the vehicles are registered. The remaining portion of the demand for evacuating vehicles (about 41%, on average) will be met by purchases in other counties along the evacuation routes. This is calculated starting from the assumption that one-half of the evacuating drivers will fill up before setting off. The portion of gasoline demand that is purchased *en route* in each county is based on the total miles that evacuees will travel and a *pro rata* allocation among counties based on how many of those highway miles are in each county along the route. The evacuation routes leading out of the state are primarily along the I-75 corridor and, to a lesser degree, along the I-95 corridor.

C.3.7. Adjustment for Future Population Growth

All of the calculations shown above related to the number of evacuees, hurricane-related deaths and injuries, and the volume of additional gasoline demand are based on the 2017 population in each county. The cost-benefit analysis presented in this report makes adjustments to account for future population growth that would increase the number of people who might be subject to evacuations and personal injuries caused by hurricanes. These adjustments have the effect of increasing the economic benefit of improving the Florida gasoline distribution network as compared to making no adjustment for future population growth.

These adjustments are made using populations projections from the University of Florida's Bureau of Economic and Business Research (BEBR).[41] BEBR's Population Program produces Florida's official city, county, and state population estimates each year. BEBR reports that these estimates are used for state revenue-sharing and many other planning, budgeting, and analytical purposes. BEBR's most recent low, medium, and high population growth estimates are presented in Exhibit 73. We calculate the adjustment for future growth by multiplying the benefits by a factor of 1.10 based on BEBR's Medium population projection of 1.12% increase per year.[42]

Exhibit 73. BEBR Florida Population Projections

	Low	Medium	High
2017 Population		20,484,142	
2040 Population	24,063,200	26,492,000	28,870,500
Annual Growth Rate	0.70%	1.12%	1.50%

Source: https://www.bebr.ufl.edu/population/data

C.3.8. Estimates of Gasoline Station Outages, Lost Sales, and Unmet Demand

The estimated values for station outages, lost sales, and unmet demand are computed in the cost-benefit analysis on a daily basis over the evacuation period. A gas station outage occurs when a station runs out of unleaded regular gasoline at some point in a day. The term *lost sale* refers to the quantity of gasoline that customers visiting that station wanted to buy, but were unable to buy it because of that outage. Because customers can sometimes purchase gasoline at another station, the quantity of lost sales does not necessarily equate to unmet demand. The term *unmet demand* means that customers could not readily find gasoline and gave up looking for that day. In addition to computing the daily statistics, the results of the cost-benefit analysis also make use of the statistics for the maximum number of station outages for any day over the evacuation period of the simulated hurricanes. In addition, the cumulative amount of lost sales and unmet demand summed over all days of the evacuation might also be reported in the results.

The calculation of these statistics for simulated hurricanes rely on the basic accounting framework that estimates for each county the level of gasoline station inventory summed across all gas stations in that county. That accounting framework computes the end-of-day (EOD)

[41] See https://www.bebr.ufl.edu/content/population-studies.

[42] The cost-benefit analysis is based on a 20-year evaluation period and a 7% annual discount rate. Capital costs are annualized over 20 years at a 7% discount rate and are added to the annual operating cost to arrive at the total annual costs. The total annual costs are then compared to the expected annual benefits. The factor of 1.10 by which the benefits are adjusted to account for population growth is computed as the ratio of the net present value (7% discount rate) of 20 years of population projected at the anticipated growth rate versus the net present value (7% discount rate) of 20 years of static population. This is the correct way to make the adjustment because simply taking a ratio of the average of the projected population over the next 20 years compared to the present population (yielding an adjustment factor of 1.13) overstates the benefits by not applying a discount factor for the time value of money.

inventory as being the beginning-of-day (BOD) inventory *minus* customer sales *plus* restocking deliveries from terminals. That EOD inventory then becomes the BOD inventory for the next day, and so on. The equations used for this accounting framework are:

$INVEOD_{c,d} = INVBOD_{c,d} - SALES_{c,d} + DELIV_{c,d}$
$INVBOD_{c,d} = INVEOD_{c,d-1}$

where:

$INVEOD_{c,d}$ = Gas station inventory in gallons at end of day (d) in county (c)
$INVBOD_{c,d}$ = Gas station inventory in gallons at beginning of day (d) in county (c)
$SALES_{c,d}$ = Sales in gallons of gasoline at gas stations during day (d) in county (c)
$DELIV_{c,d}$ = Deliveries in gallons of gasoline to gas stations from terminals during day (d) in county (c)

When there is a surge of demand for gasoline before a hurricane arrives, the quantity of demand exceeds the capacity of terminals and the tanker truck fleet to restock the gas stations. The result is that the inventory of gasoline at stations declines. If the decline in inventory is great and prolonged, then a portion of the stations in a county may run out of gasoline. These station outages, or stockouts, then lead to lost sales from customers who would like to use those stations to purchase gasoline but cannot do so. The cost-benefit analysis estimates the probability of gas station outages as being primarily a function of an index calculated as the BOD inventory at stations on any given day divided by the desired sales for that day. A second index calculated as the deliveries to stations on any given day divided by the desired sales for that day is also used to estimate the probability of outages.

The relationship between the probability of station outages as a function of BOD inventory and deliveries (both represented as an index computed by dividing their values by the volume of daily demand) was estimated through a computer simulation of gas station inventories, assuming that the gas stations in a county could be divided into cohorts based on their normal refill schedules. If the stations were refilled once every seven days, then there would be seven cohorts with an equal number of stations in each cohort. Such a scenario is shown in Exhibit 74, where the height of the blue bars represents the BOD inventories for each cohort. Each chart in the exhibit represents one of three successive normal days with demand unaffected by hurricanes. On such normal days, inventories will sum for all cohorts to 100.5 MMgal. The cohort that would be refilled on Day 1 (cohort #1 in the exhibit) would have the lowest BOD inventory at the start of Day 1. The next cohort (#2, representing stations to be refilled on Day 2) would have the second lowest inventory at the start of Day 1 (equal to the first cohort's inventory level plus one day of cohort sales). The third cohort would have an inventory equal to the second cohort plus one day of cohort sales, and, so on. The seventh cohort would have the highest inventory because it represents stations that were refilled the day before Day 1.

Under normal conditions, when daily deliveries to the stations (alternating among one of the seven cohorts each day) equal the daily sales for all cohorts, the total inventory at the start of each day summed across all stations stays the same. In addition, the profile of the inventories for the seven cohorts also does not change, except that the cohorts swap rank orders (i.e., ranked starting from the cohort with the smallest inventory to the cohort with the largest inventory). For example, the stations filled on Day 1 move from having the lowest ranking inventory at the start of Day 1 to the largest at the start of Day 2. All of the other cohorts moved down in rank each day as their inventories go down by a volume representing one day of sales.

Exhibit 74. Gas Station Inventories Under Normal Conditions (total inventories stay at 100.5 MMgal and the probability of outages are zero)

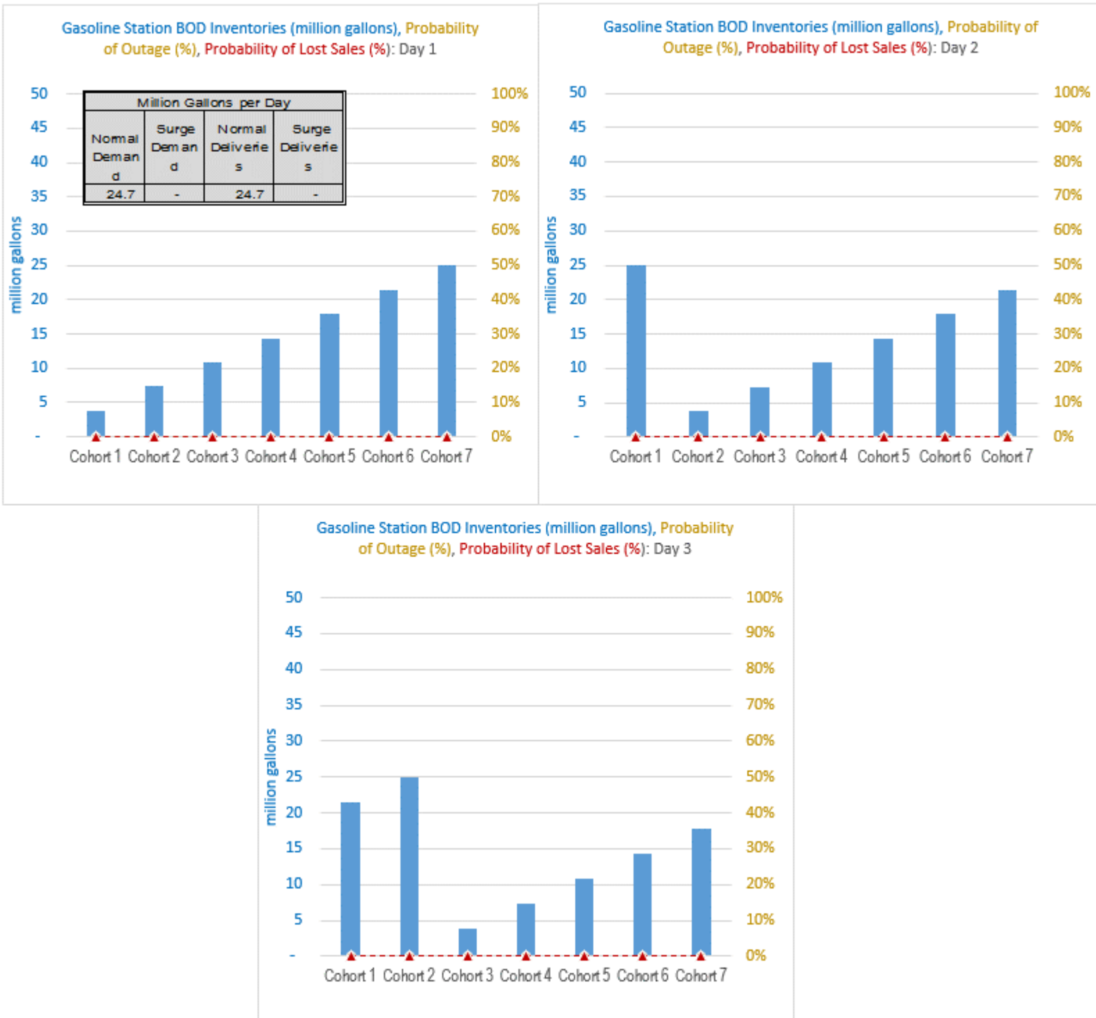
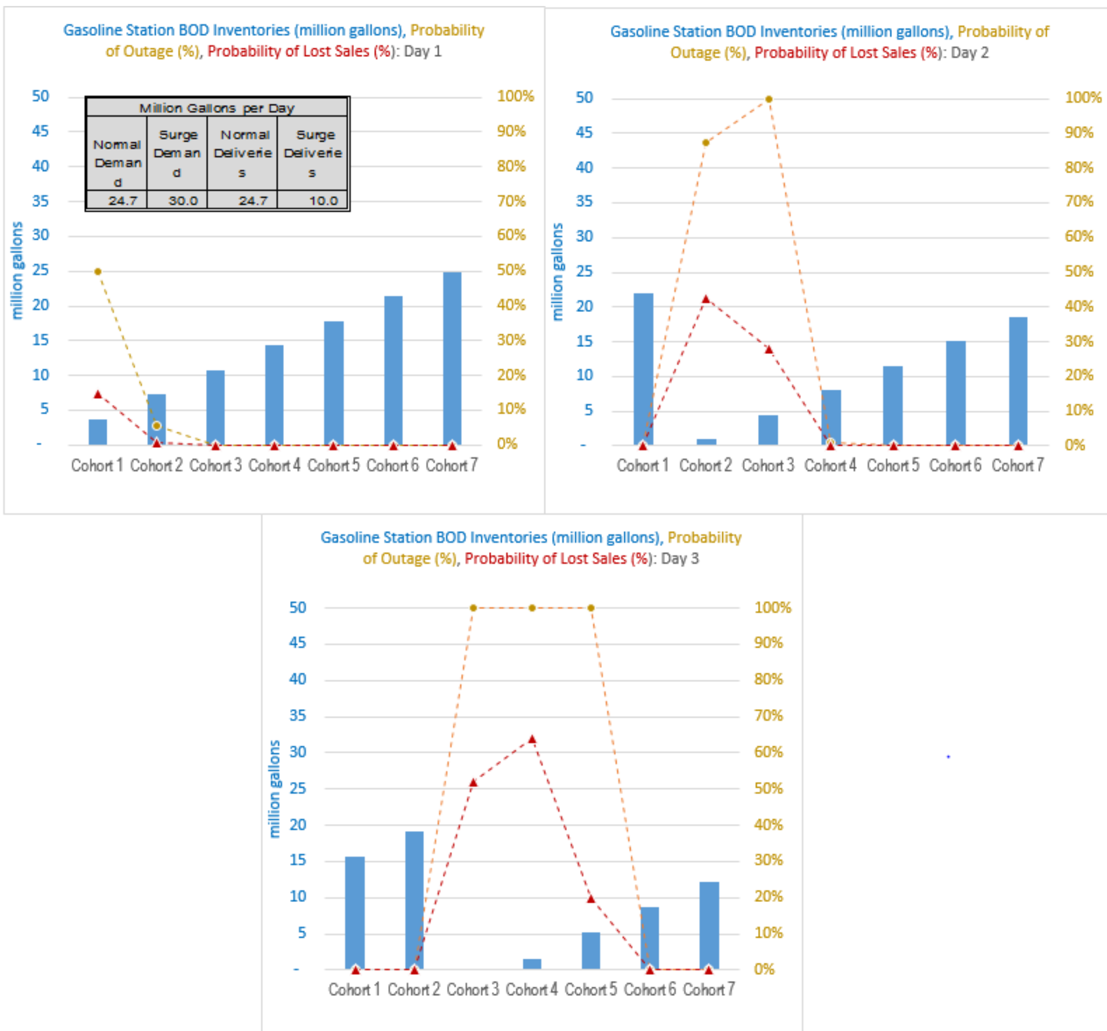


Exhibit 75 shows the gas station inventory pattern that might be expected among cohorts when demand surges due to an approaching hurricane. Here the three days represent days of evacuation. Restocking deliveries to the stations go up when demand surges, but are usually not sufficient to cover the demand increase because the loading capacities at the terminals (and possibly tanker truck capacity) can be binding constraints. If gas station sales exceed restocking deliveries, then the average inventories must go down. In the example shown in Exhibit 75, demand increases by 30 MMgal/d, while restocking deliveries go up by 10 MMgal/d. This means that overall inventories could decline by 20 MMgal/d or by 60 MMgal over three days.[43] The gas station cohorts with the lowest inventories are the ones that most likely will run out of stocks first. As the surge demand continues through the evacuation period, more stations may experience stockouts. The probability of outages during each day of evacuation for each cohort

[43] In reality, the desired level of sales might not be feasible for a large-scale evacuation if the gas stations run out of gasoline. If that occurs, then the stock drawdown would be less than 60 MMgal.

is shown in the exhibit as orange circles measured on the right-hand axis. The lost sales as a percentage of demand are shown as red triangles.

Exhibit 75. Gas Station Inventories and Probability of Outages Under Demand Surge Conditions



The maximum number of station stockouts occurs on Day 3 when 42.9% of the stations have a stockout during the day. For comparison, 52% of Florida gas stations were reported as not having gas in the days before Hurricane Irma struck in 2017. However, Irma did experience a higher storm demand than the example shown here. The calculated lost sales for the example shown in Exhibit 75 above are 19.5% of the surge-adjusted demand, or 10.6 MMgal on the third day.[44] Over the three days, lost sales total 17.3 MMgal, or an average of 10.6% of the surge-adjusted demand for those days.

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[44] Lost sales as a percentage of demand is usually lower than the stockout percentage because some portion of the demand can be met by BOD inventories and any deliveries made that day. If a group of stations begins the day with zero inventory and gets no deliveries, then the stockout percentage and the lost sales percentage will both be 100%.

The maximum estimate of unmet demand for the example shown in Exhibit 75 would be the volume of lost sales. However, this high value likely would be an overestimate of unmet demand given that customers might be able to buy gasoline at other stations, particularly in the early days of the evacuation, when stockouts are less pervasive. For the purposes of the cost-benefit analysis, we calculate a second estimate of unmet demand (the low estimate of unmet demand) as being the lost sales that would be estimated by pooling *all of the gas stations in a county together* and treating all sales in the county as coming from that one station. The low estimate of unmet demand occurs when the beginning inventory of gasoline on the first day of the evacuation *plus* deliveries to the stations from terminals through day (d) is less than the cumulative demand through day (d). In other words, the low estimate for unmet demand comes about only when all gas stations in a county are out of gas. This low-end value for unmet demand is almost certainly an underestimate given that customer will be discouraged from looking for gasoline long before they search at all of the stations in the county.

The cost-benefit analysis shown later in this chapter uses both the low and high estimates for unmet demand and calculates a third (middle) value that is the average of the two. We use this average estimate of unmet demand to summarize the benefits of each infrastructure option.

C.3.9. Simulation of Transportation of Gasoline From Terminals to Stations

The cost-benefit analysis uses a linear program[45] to simulate how gas stations would be restocked during the evacuation period from existing terminals and from any new PDCs that might be built in the future. The maximum amount of gasoline that can be loaded at each existing terminal is assumed, in the base case, to be the maximum loadings that were actually achieved during the Hurricane Irma evacuation. For policy cases that assume that new loading racks will be added at some existing terminals, the historical maximum loadings are increased per the specifications of that policy case. New PDCs with specific loading capacities and storage capacities were also specified for four out of the five policy cases. The solution process of the linear program determines how many truckloads of gasoline move from each existing or new terminal to gas stations in each county. The objective function of the linear program is to minimize the miles traveled by those trucks.

The objective function can be represented in mathematical terms as:

$$minimize \sum_{T=1}^{N} \sum_{C=1}^{67} \left(Miles_{T,C} \cdot Truckloads_{T,C} \right)$$

[45] A linear program is a mathematical procedure to find the values of the decision variables that achieve the maximum or minimum value of the objective function subject to various constraints. In a linear program, all of the relationships between the decision variables and the objective function, and between the decision variables and the constraints, are represented by linear functions. In this cost-benefit analysis, the decision variables are the volumes of gasoline to be moved from each terminal to the gasoline stations in each county. The objective function is to minimize the total number of miles that tanker trucks must travel between terminals and the gasoline stations they are re-stocking. One constraint is that the volume delivered from each terminal cannot exceed the daily loading capacity of that terminal. A second important constraint is that the total number of tanker trucks cannot exceed the available number of tanker trucks.

where:

T = An index representing each of N different terminals or PDCs
C = An index representing gasoline stations in each of Florida's 67 counties
$Miles_{T,C}$ = Average distance between terminal T and gasoline stations in county C
$Truckloads_{T,C}$ = Decision variables for the number of truckloads moving each day between terminal T and county C

There are two main constraints on the linear program solution. The first is that the loadings at each terminal must be equal to or less than the terminal's daily loading capacity. This is assumed to be the historic maximum loadings during the Hurricane Irma evacuation plus (for policy cases) any proposed infrastructure enhancements. This is represented mathematically as:

$$DailyCapacity_T \geq \sum_{T=1}^{N} \sum_{C=1}^{67} (9000 \cdot Truckloads_{T,C})$$

where:

T = An index representing each of N different terminals or PDCs
C = An index representing gasoline stations in each of Florida's 67 counties
$Truckloads_{T,C}$ = Decision variables for the number of truckloads moving each day between terminal T and county C. Each truck moves an average of 9,000 gal per trip.
$DailyCapacity_T$ = Maximum gallons per day that can be loaded at terminal T

The second key constraint is that the total number of trucks employed must be less than or equal to a specified maximum number of available trucks. The required truck counts are computed using the average travel distance from each terminal to gas stations in each county, an assumed average driving speed, the time needed for loading the tanker trucks at the terminals, the time needed to unload the tanker trucks at the gas stations, and the number of hours each day each truck can operate. This can be represented as:

$$MaxTrucks \geq \sum_{T=1}^{N} \sum_{C=1}^{67} ((Load + Unload) \cdot Truckloads_{T,C} + (Miles_{T,C} \cdot Truckloads_{T,C} \ / MPH \ )) \ /MaxHoursPerDay$$

where:

T = An index representing each of N different terminals or PDCs
C = An index representing gasoline stations in each of Florida's 67 counties
$Miles_{T,C}$ = Average distance between terminal T and gasoline stations in county C
$Truckloads_{T,C}$ = Decision variables for the number of truckloads moving each day between terminal T and county C. Each truck moves an average of 9,000 gal per trip.
Load = Number of hours needed to load a tanker truck
Unload = Number of hours needed to unload a tanker truck
MaxHoursPerDay = Maximum hours each truck can operate

When one or both of the first two constraints are binding, deliveries to all counties must be the same ratio of their surge-adjusted demand. This means that under large evacuation scenarios, counties located far from the hurricane and experiencing no evacuation-related surge in demand receive *less* gasoline than they would under normal conditions. The far-away counties experience drops in gas station inventories, but usually are able to get by because their demand has not gone up. On the other hand, counties undergoing evacuations get *more* gasoline deliveries than normal (they get all of the extra deliveries from the terminals plus supplies diverted from non-evacuating counties), but because their demand levels have increased substantially, they experience a rapid decline in gas station inventories and are subject to gas station stockouts and lost sales.

The evacuations for each hurricane are simulated once under base case infrastructure conditions and again for the policy case that is being considered. Because the policy case usually increases available loading capacity at the terminals, the policy case reduces the chances of stockouts and lost sales. The benefit from the policy case is computed by assuming that the reduction in lost sales (and the related reductions in unmet demand) increases the chance that more people will successfully evacuate and, thus, will be less likely to be injured in the hurricane. However, it is important to remember that much of the demand increase for gasoline that occurs during evacuation periods is from non-evacuees topping off their tanks. We assume that the extra supplies provided under the policy cases will enter the general gasoline market. Therefore, much of the extra supply is siphoned off for non-evacuee use and for the rebuilding of gas station inventories.

C.3.10. Assumptions for Truck Calculations

There are a number of operational trucking assumptions that affect the linear program solution. These are represented in the model as considerations for each truck receiving and delivering fuel, including loading and unloading rates at the terminals and stations, as well as the average travel speed and distance. The cost-benefit model assumes that it takes 45 minutes (0.75 hours) to fill the truck at the terminal. This includes the filling process itself, as well as any paperwork and waiting time. The time it takes for each truck to unload fuel at the gas station is assumed to be 60 minutes (1.0 hours).

Truck availability to deliver fuel within the model is also considered. Based on the number of trucks and the average gallons delivered for two trucking companies that deliver 33% of the state's gasoline volumes, each truck delivers, on average, 19,000 gal of fuel per day, or just about two deliveries per day per truck, on average, during normal demand periods. Based on normal delivered volumes, this would imply that there are approximately 1,300 trucks serving the State of Florida (including trucks from the Bainbridge, GA, terminal). To account for trucks transporting diesel fuel, the proportion of gasoline and diesel daily demand was considered. Gasoline made up 84% of total demand, so the model was constrained to allow for the use of up to 1,100 trucks for gasoline deliveries. Although the responses mentioned that additional trucks were brought in to support evacuation efforts from outside of the state, those counts were minor, at approximately 5% of the standing available truck fleet. Because the out-of-state trucks are small in number, and some number of in-state trucks may be rendered unusable because their drivers are evacuating their own families, the available truck count is assumed to number 1,100 in all cost-benefit analysis cases.

Truck operational time is another parameter considered within the model. Trucking companies interviewed for this study noted that during evacuation conditions, trucks can operate up to 24 hours per day with drivers working 12-hour shifts. Taking into account unavoidable downtime over the course of a shift, the model assumes that each truck can be actively working (i.e., loading, unloading, and moving on the road) up to 22 hours per day under emergency conditions.

To consider trip distance, the mileage between each terminal to supplied gas stations was first determined using GIS mapping. The distance calculated by GIS represents the "as the crow flies" distance, or a direct path between two points. To account for actual on-road route distance, Google Maps was used to determine on-road distances between each terminal and a sampling of gas stations. Using these sample routes, on-road mileage was recorded and compared with the "as the crow flies" distances according to GIS mapping. On-road conditions were found to be 38.9% greater, on average, across the routes considered, and thus all "as the crow flies" distances were multiplied by 1.389 to estimate on-road distances.

The model also considers an average travel speed for each truck's trip. To determine this, expected travel times according to Google Maps were also recorded from the routes used in the on-road mileage adjustment. Both congested and off-peak travel times were generated to consider variances in expected traffic. Using the ratio of distance and travel time, each route was given a congested and off-peak average speed. Exhibit 76 and Exhibit 77 show the average travel speed in miles per hour given the required trip distance and the regression lines estimated from those data. The exhibits indicate that travel speeds increase as the distance traveled goes up, and there is a larger percentage of the routes made up of freeways rather than local streets. The exhibits also show that travel speeds are higher during off-peak (late nighttime) periods as opposed to congested (morning and afternoon rush hour) periods. Given that evacuation conditions result in heavily congested traffic, the model assumes an average speed as determined during the congested condition. ICF used the equation for travel speed versus travel distance fitted during congested periods to compute the speed at which trucks could be expected to move between each gas station in Florida to the closest terminal. The average speed for these thousands of routes came to 45.8 miles per hour.

Exhibit 76. Average Travel Speed (y-axis) Versus Distance Traveled (x-axis) During Periods With Congested Traffic (this is more representative of evacuation periods)

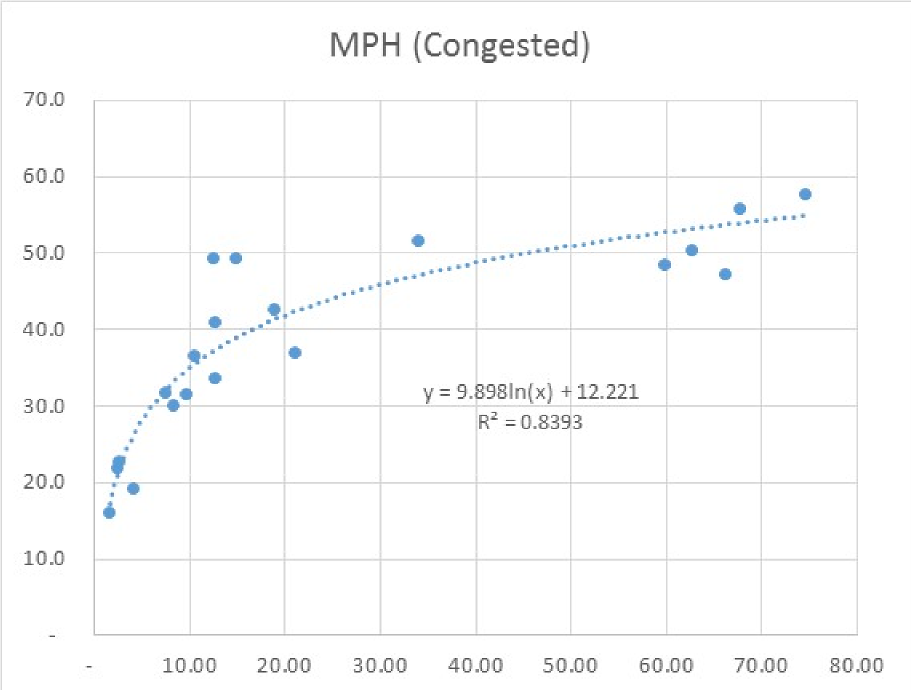

Exhibit 77. Average Travel Speed (y-axis) Versus Distance Traveled (x-axis) During Off-Peak Periods (this is more representative of normal periods)