

Exceptional service in the national interest



Energy Resilience for Puerto Rico

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Renewable Energy and Distributed Systems Integration

The work described here is sponsored by the US Department of Energy's (DOE's)
Office of Electricity Delivery and Energy Reliability



Hurricanes Irma and Maria devastated Puerto Rico in September 2017

“Hurricanes Irma and Maria devastated Puerto Rico, bringing sustained winds well in excess of 150 miles per hour, heavy rains, and catastrophic flooding the likes of which the island had never seen before”

“The storms caused nearly complete devastation, including the **catastrophic failure of the Island’s power grid, water and wastewater infrastructure**, and communications networks”

“The **economy of the island ground to a halt** in the face of physical damages, loss of supporting infrastructure, and the absence of power and water.”

“Roads and bridges failed or were blocked by debris across the island, leaving communities stranded and unable to obtain life-saving aid, food, water and medicine for a period of weeks. **More than 472,000 housing units were destroyed** or experienced major damages.”

“Build Back Better- Puerto Rico”, Request for Federal Disaster Assistance
November, 2017



NASA Earth Observatory images by Joshua Stevens

Early on September 20, Hurricane Maria a powerful Category 4 hurricane directly hit Puerto Rico crossing the entire island and dumping feet of rain.

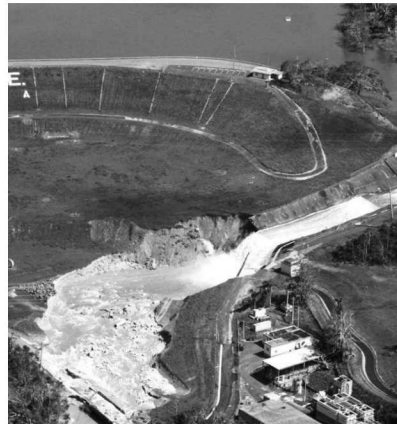
Highlighted Impacts: Power System, Water, Impact on Economy



“Build Back Better- Puerto Rico”, Request for Federal Disaster Assistance
November, 2017

“Thousands of businesses are closed or have limited operations including the pharma manufacturing industry, which caused **serious shortages of drugs supplies in the US**. Pharmaceutical products made in Puerto Rico account for nearly 10 percent of all drugs consumed by Americans.”

- “Months after the storm hit (November 2017) approximately 60% of the island was still without power”
- “Since Maria made landfall seven months ago, more than 100,000 Americans are still without power on the island” (May 2018)
- “Caused the longest sustained power outage in U.S. history”



“70 % of the potable water is either unavailable or has yet to be certified as safe to drink “
(November 2017)



Puerto Rico R&D Projects

1. Industrial Microgrids in Puerto Rico.
2. Initial recommendations for microgrid deployment in the greater San Juan area of Puerto Rico.
3. Analysis of energy storage options to improve resiliency in Puerto Rico

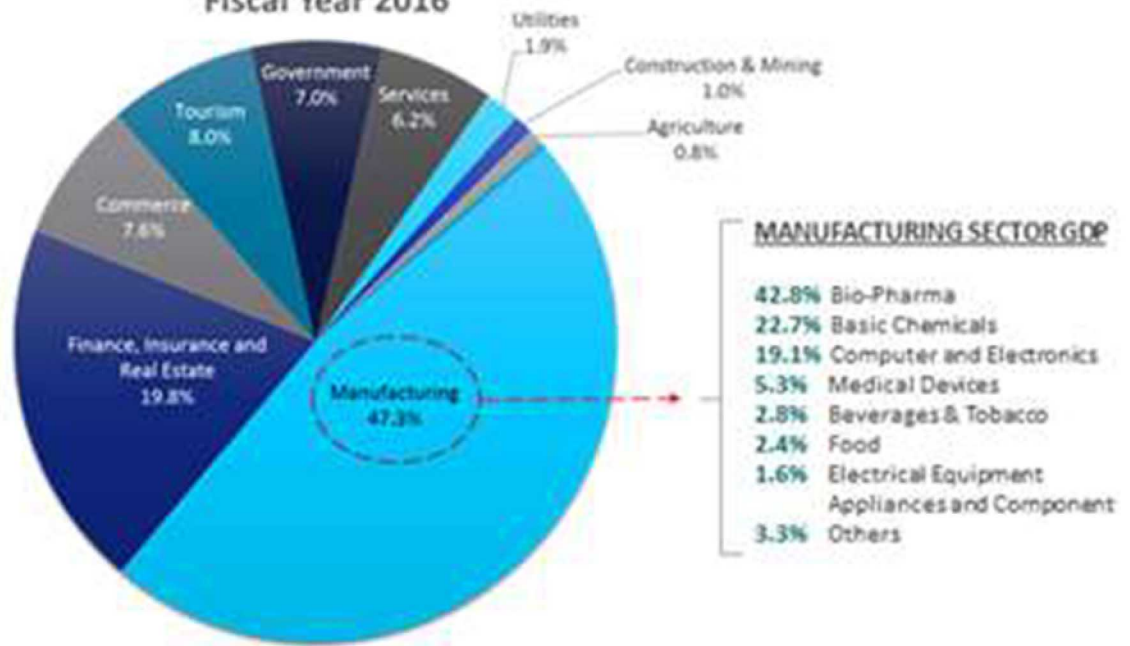
Where to focus our efforts?

Project 1: DOE office of electricity asked SNL and ORNL to team up to support the rapid installation of Industrial Microgrids in Puerto Rico.

A Modern and Diversified Economy

- GNP**
\$70.1 billion
- GDP**
\$105.0 billion
- GDP PER CAPITA**
\$30,516
- EXPORTS VALUE**
\$71.9 billion
- IMPORTS VALUE**
\$43.3 billion

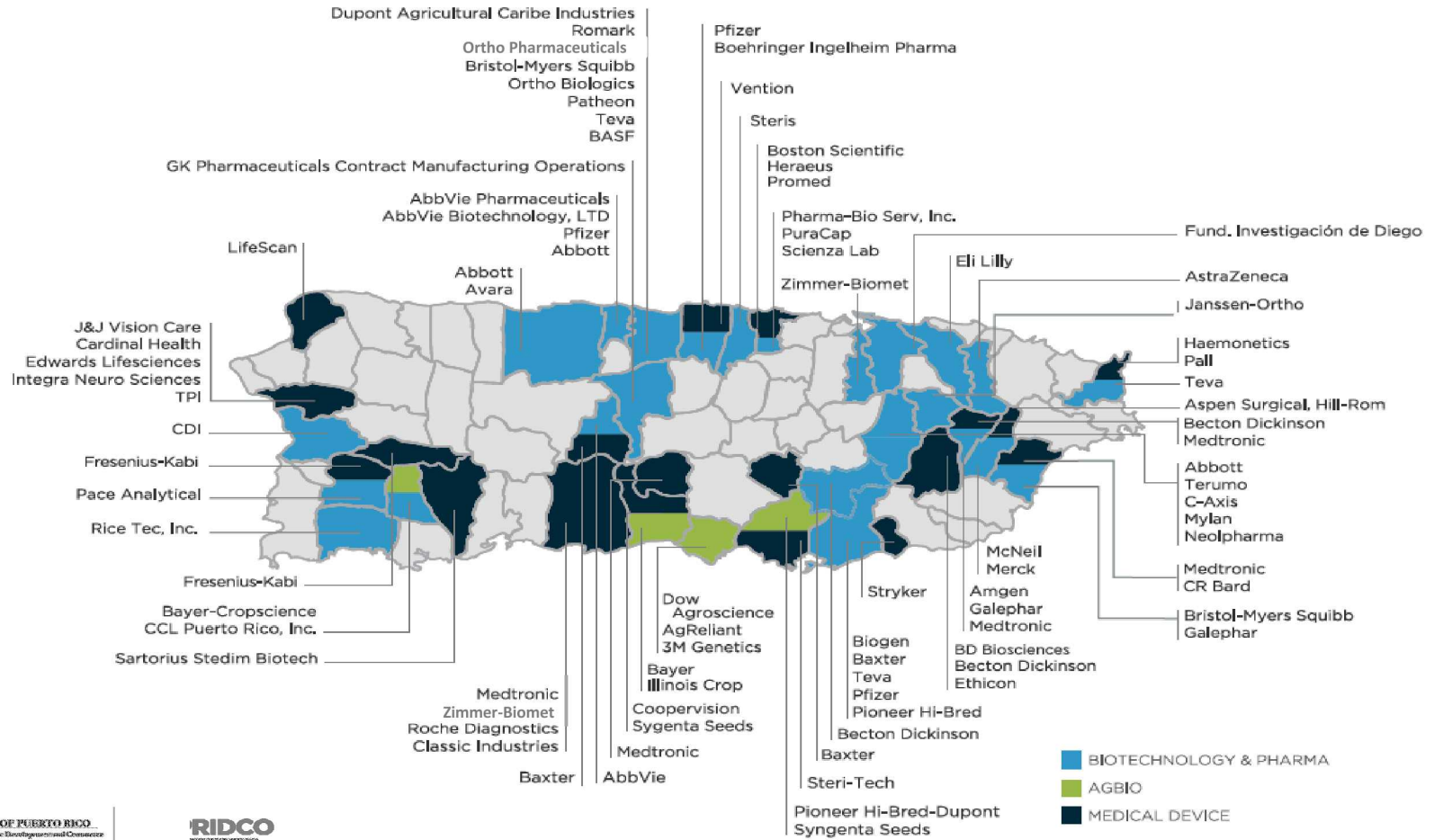
Gross Domestic Product Share by Main Economic Sector
Fiscal Year 2016



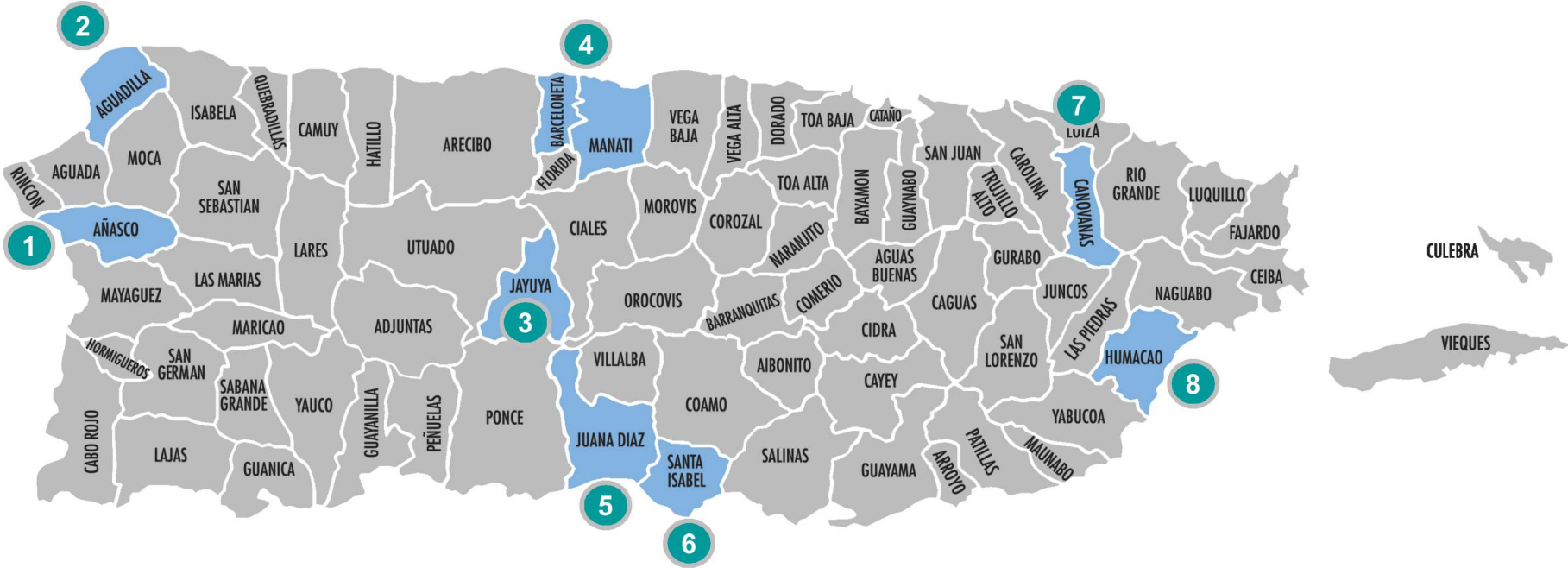
Source: PR Planning Board
The 2016 Economic Outlook for Puerto Rico is based on an economic model by The 2016 Fiscal Year Budget Council and does not necessarily match the

PRIDCO – Puerto Rico Industrial Development Company

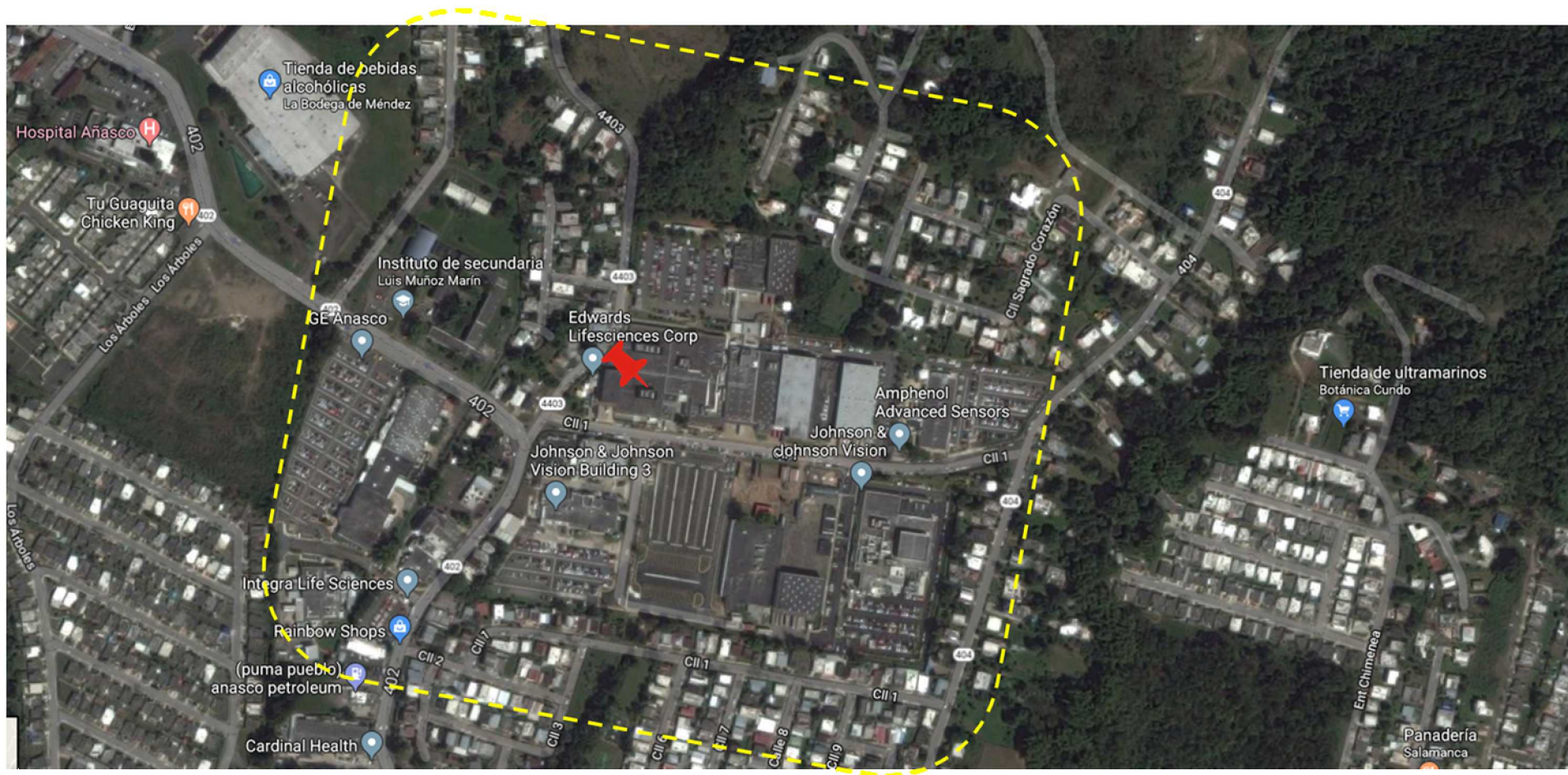
PR Cluster Map: Life Sciences



Puerto Rico – Municipalities and Proposed Microgrid Locations



1 Añasco Site – Aerial View



1 Añasco

EMPLOYEES



EDWARD LIFESCIENCES

Sole supplier to the whole world of the **Swann-Ganz hemodynamic monitoring catheter**. Catheter used to monitor oxygenation, blood pressure and temperature for people in critical care of the hospitals.

900

i.e. after an open-heart surgery.

J & J VISION CARE (AMO MANUFACTURING)

Manufactures intraocular contact lenses cataracts and myopia correction. This division of J&J is **the largest supplier in USA and in the world of “Lasik” surgery** and the intra-ocular contact lenses is the consumable.

700

INTEGRA

Critical supplier of J&J in collagen products, including a wound healing wrap used after surgeries and accidental wounds. Also, they provide different devices for the treatment of hydrocephaly.

600

GENERAL ELECTRIC (GE)

In the Añasco facility, they manufacture, power line monitoring systems.

300

AMPHENOL

Critical supplier to Edwards, they provide **temperature sensors that are installed in the Swann-Ganz catheter that Edwards manufactures**. Also, they supply the automotive and heavy equipment (Caterpillar) with the pressure sensors and differential pressure sensors that are used in the engines of the equipment.

200

CARDINAL HEALTH

In the Añasco facility, **Cardinal manufactures all of the nylon tubing and IV sets for Cardinal Health** which is one of the major healthcare providers of the US.

200

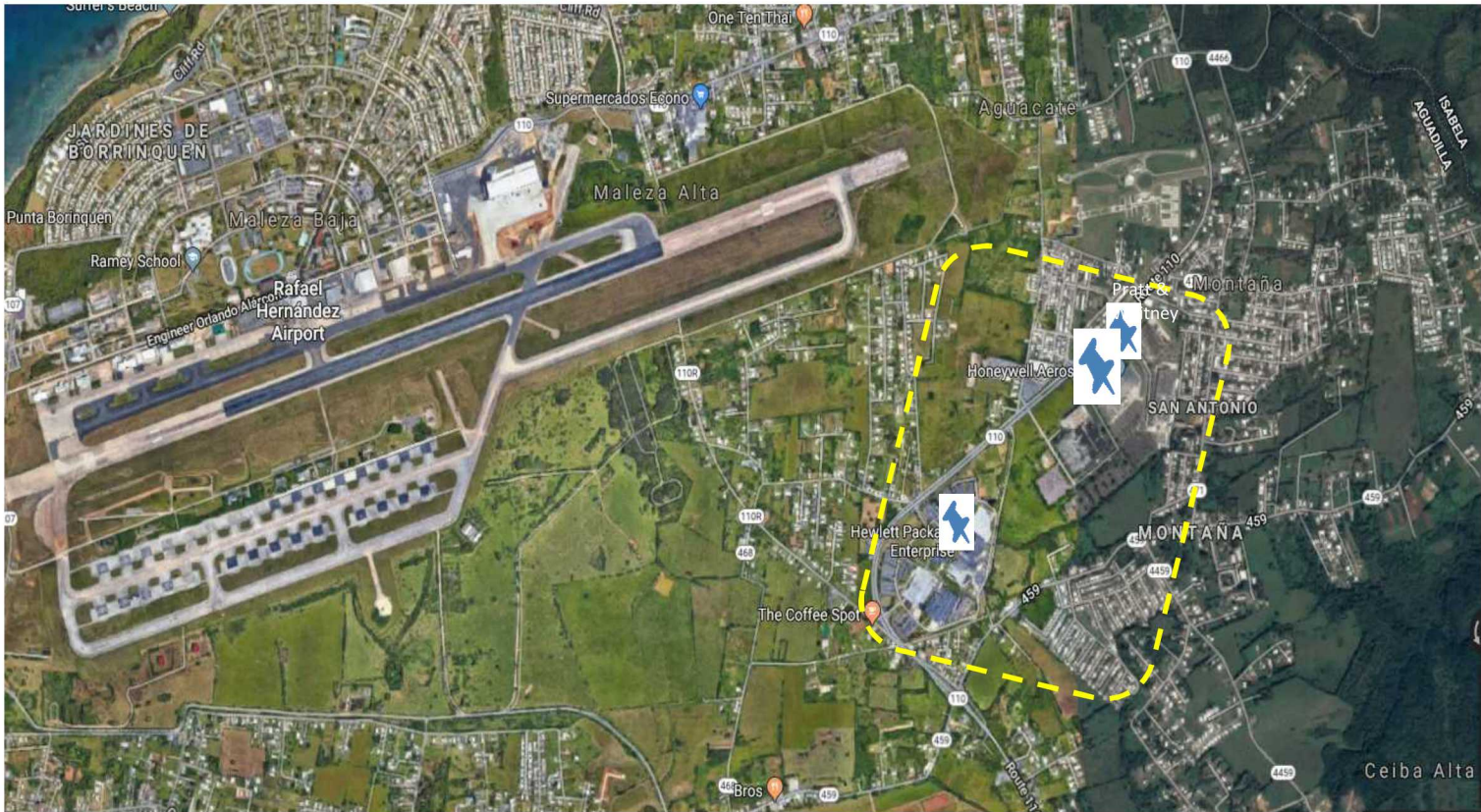
TECHNO PLASTICS (Small Business)

Critical supplier of the injection molded and subassemblies for the medical device industry, including the ones located in the Añasco Industrial Park.

100



2 Aguadilla Site – Aerial View



2 Aguadilla

EMPLOYEES



HONEYWELL

Services supplier to the commercial and defense aerospace.

1,000

PRATT & WHITNEY

Services provider to defense aerospace sector.

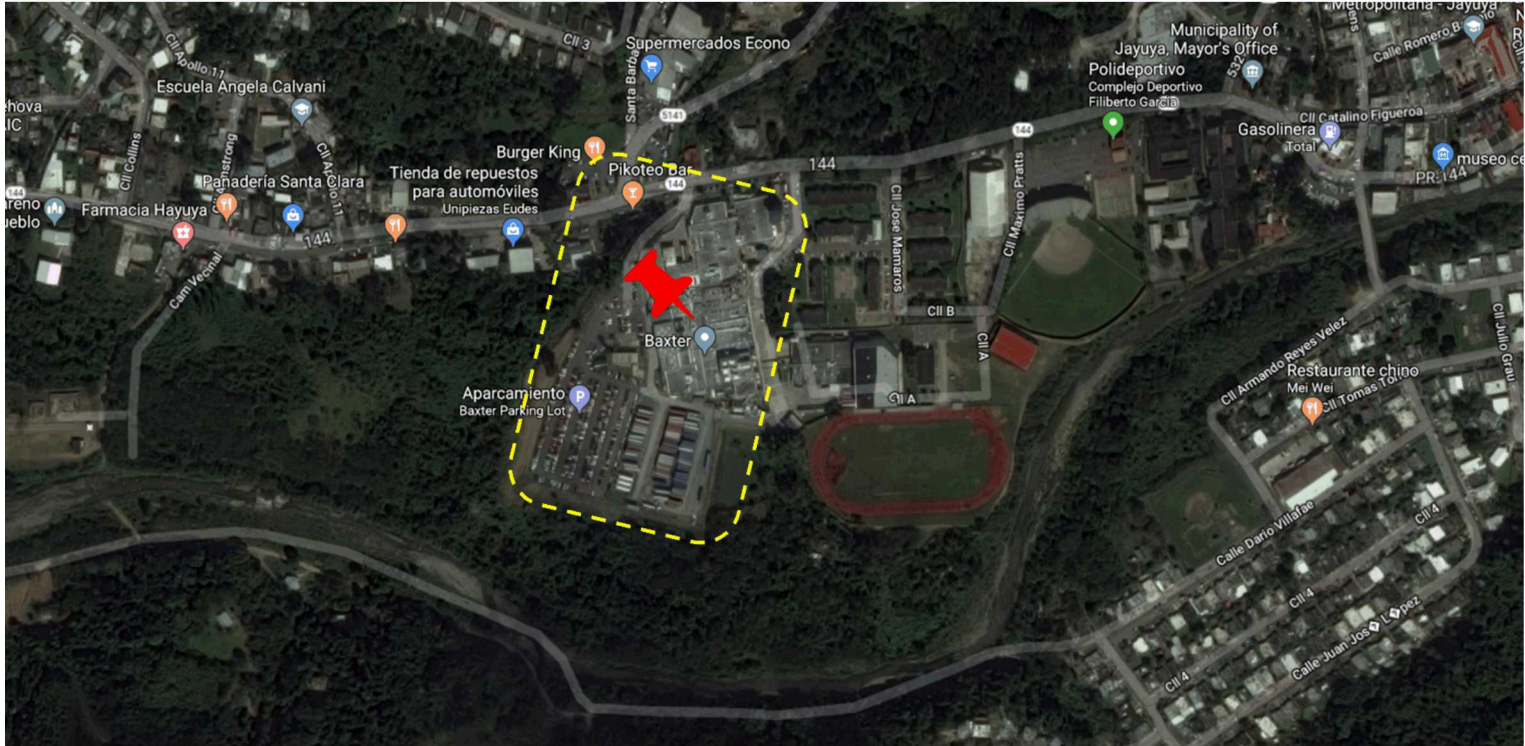
800

HEWLETT PACKARD ENTERPRISE

One of the cloud servers' data center for Hewlett Packard. Provides cloud services to the whole world.

100

3 Jayuya Site – Aerial View



3 Jayuya

EMPLOYEES



**BAXTER
HEALTHCARE**

Major supplier of Saline solution to the hospitals in mainland US.

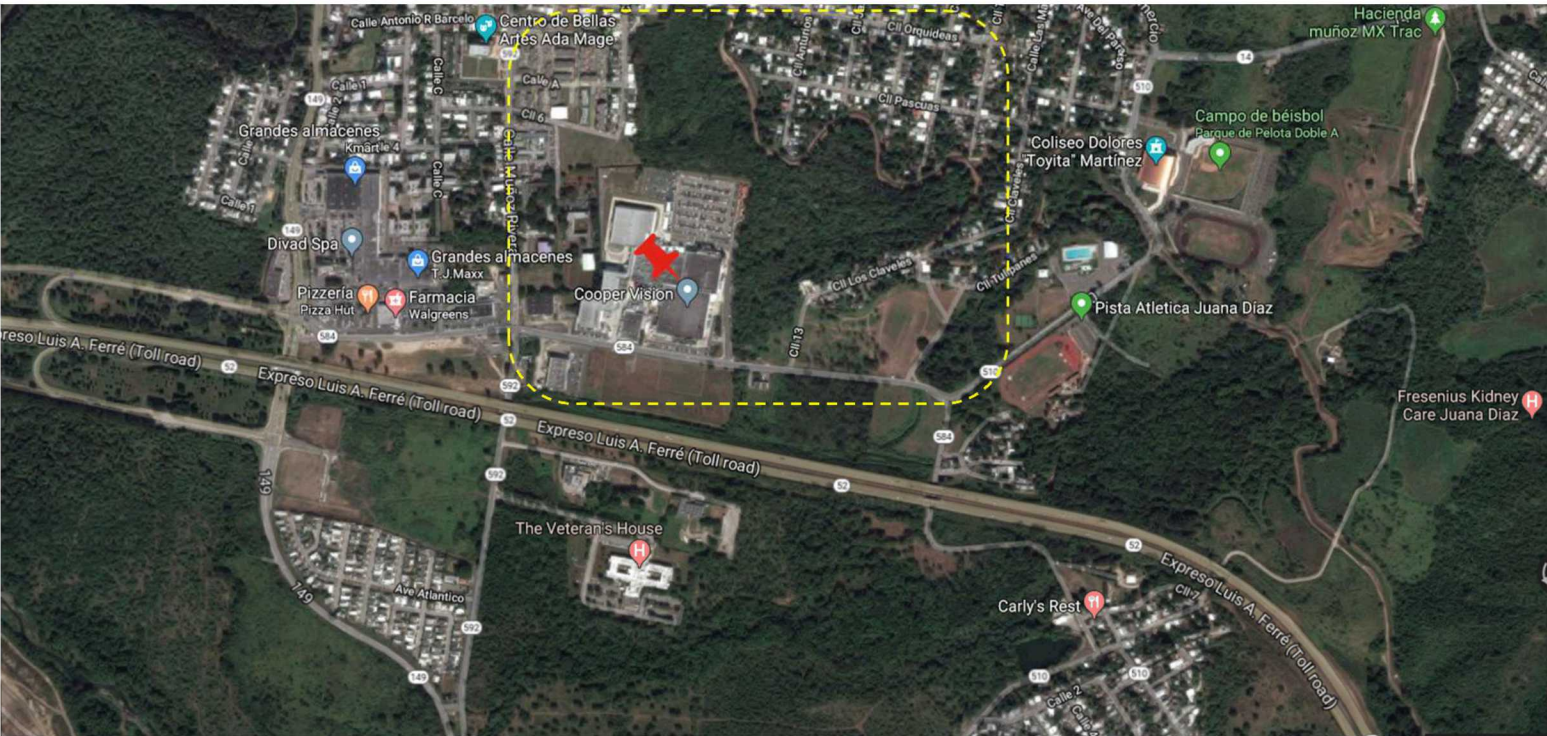
400

ABBVIE

Manufactures Levothyroxine under the Synthroid brand which is the preferred by the Physicians, and the Americas supply is manufactured in this facility.

200

5 Juana Diaz Site – Aerial View



5 Juana Diaz

EMPLOYEES

COOPERVISION

80% of the manufacturing capacity of the company in the world and is the #2 global supplier of the daily use contact lenses.

2,200

MONSANTO (BAYER)

Is one of the supplier of cotton seeds and corn seeds to the USA farmers. Plus has an Agriculture Biotechnology laboratory in corn, soybean, sorghum, cottonseed and sunflower.

550*

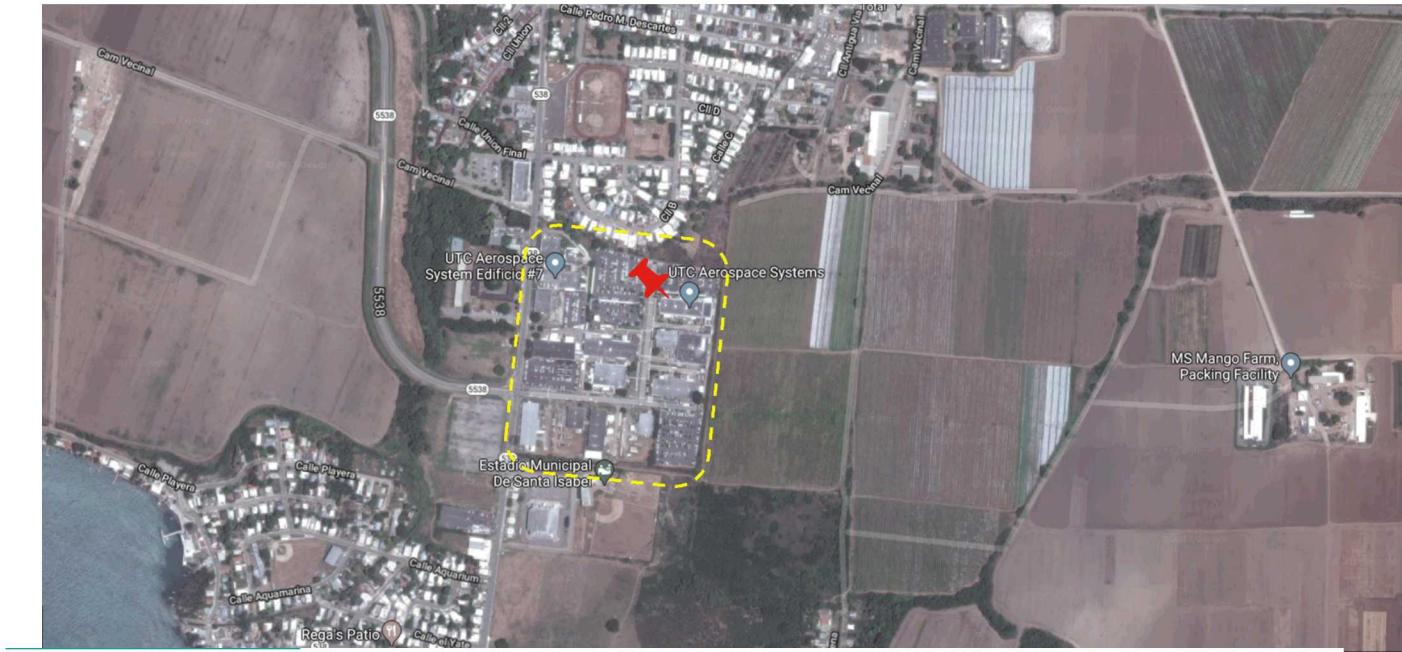
SYNGENTA

Agricultural Biotechnology lab in corn, soybean, sorghum, cottonseed and sunflower.

300*



6 Santa Isabel Site – Aerial View



UNITED TECHNOLOGIES

Aerospace parts manufacturer for defense and commercial aircraft.

1,700

AG RELIANT

Agricultural Biotechnology lab in corn, soybean, sorghum, cottonseed and sunflower.

460*

ACCENTURE

Administrative services for UTC

200

DHL

Logistics services for UTC

40

Implementation Summary

Site	Microgrid Development Potential		Industries Supported				Econ. Impact
	Immediate Action	Longer Term Action	Pharma./ Medical	Defense/ Technology	Agriculture	Other	Direct Jobs
<i>Añasco</i>	●		●	●			3,000
<i>Aguadilla</i>	●			●			1,900
<i>Jayuya</i>	●		●				600
<i>Barceloneta/ Manati</i>		●	●	●	●	●	4,660
<i>Juana Diaz</i>	●		●		●		3,050
<i>Santa Isabel</i>	●			●	●	●	2,400
<i>Canovanas</i>		●	●				175
<i>Humacao</i>		●	●				1,155

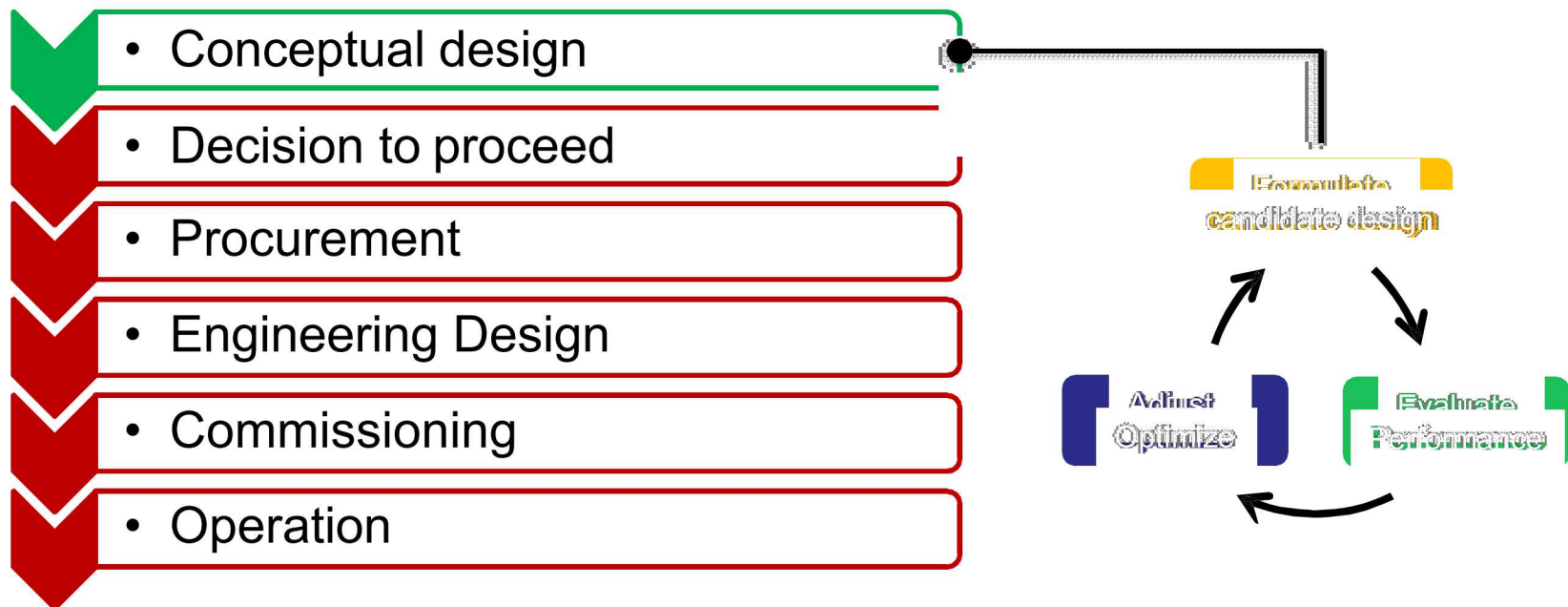
Goals for Conceptual Resilient Microgrid Design

Focus on resilient microgrids that maximize the amount of renewable energy while using conventional gensets and storage to meet LCOE targets of less than \$0.20 per kWh.

- ❑ Minimize the use of diesel fuel to reduce supply line risk.
- ❑ Standalone microgrid mode to supply 100% of power needs in industrial park without the need to connect to local utility. Avoid interconnection delays.
- ❑ Renewable Energy to reduce environmental impact and increase resiliency.
- ❑ Meet a cost target below current utility rates to make microgrid projects attractive to tenant businesses.
- ❑ Challenge to address multi tenant microgrids.

Investment Options: Conceptual Design

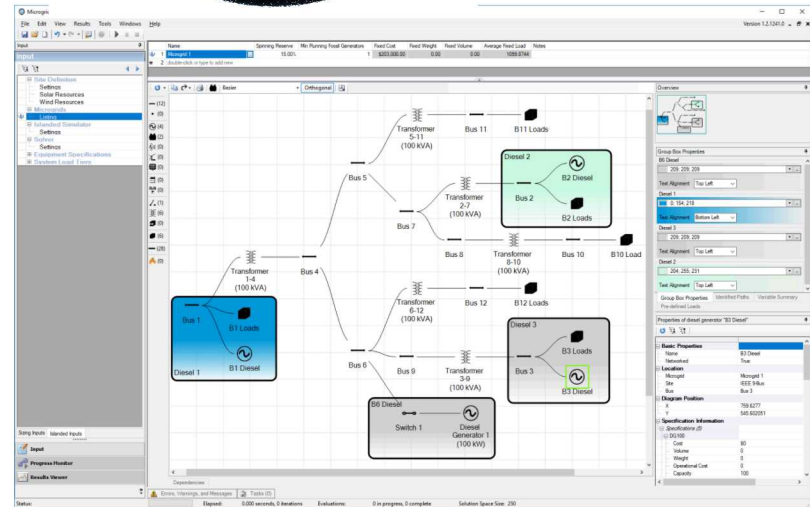
- A resilience framework compares conceptual designs options
 - Technical description of candidate resilience improvements and their respective cost estimates
 - Could involve optimization and analysis of trade-offs among options
- Useful engage stakeholders and drive decision-making



Microgrid Design Toolkit

MDT is a decision support software tool for microgrid designers in the early stages of the design process.

The software employs powerful search algorithms to identify and characterize the trade space of alternative design decisions in terms of user defined objectives. Common examples of such objectives are cost, performance, and reliability.



Version 1.2 is available for download from <https://www.energy.gov/oe/services/technology-development/smart-grid/role-microgrids-helping-advance-nation-s-energy-syst-0>

Microgrid Design Toolkit (MDT)

Mission Requirements and Baseline Models

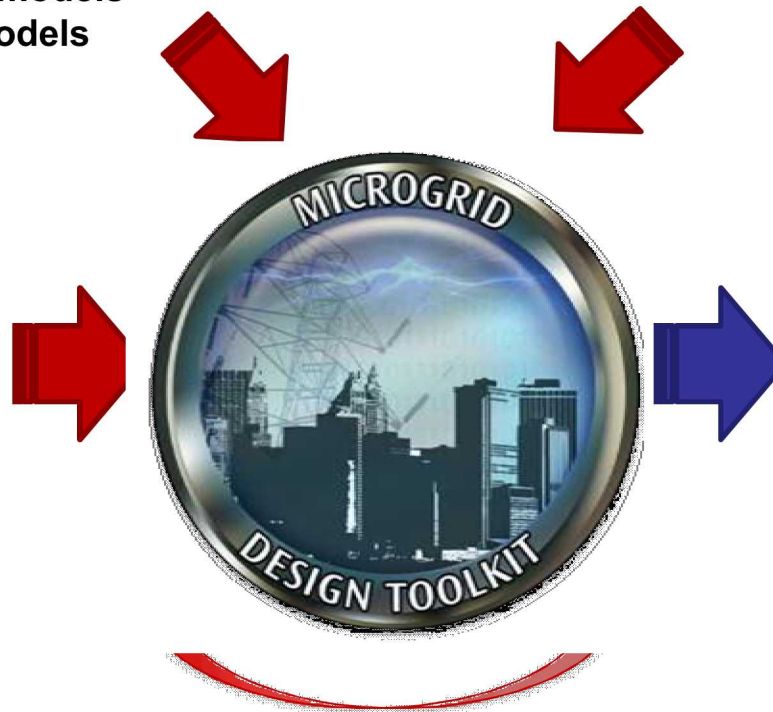
- Equipment deployed creates demand
- Or demand (load) models
- Or custom load models

Equipment Data Base

- Energy demand/production
- Usage specification
- Reliability information

Technology Options and User Inputs

- Identify energy producers and technology options
- Select location & season (solar and/or wind profile)
- Reliability and maintenance cost data
- Select user mode
 - Performance analysis
 - Parametric study
 - Optimization



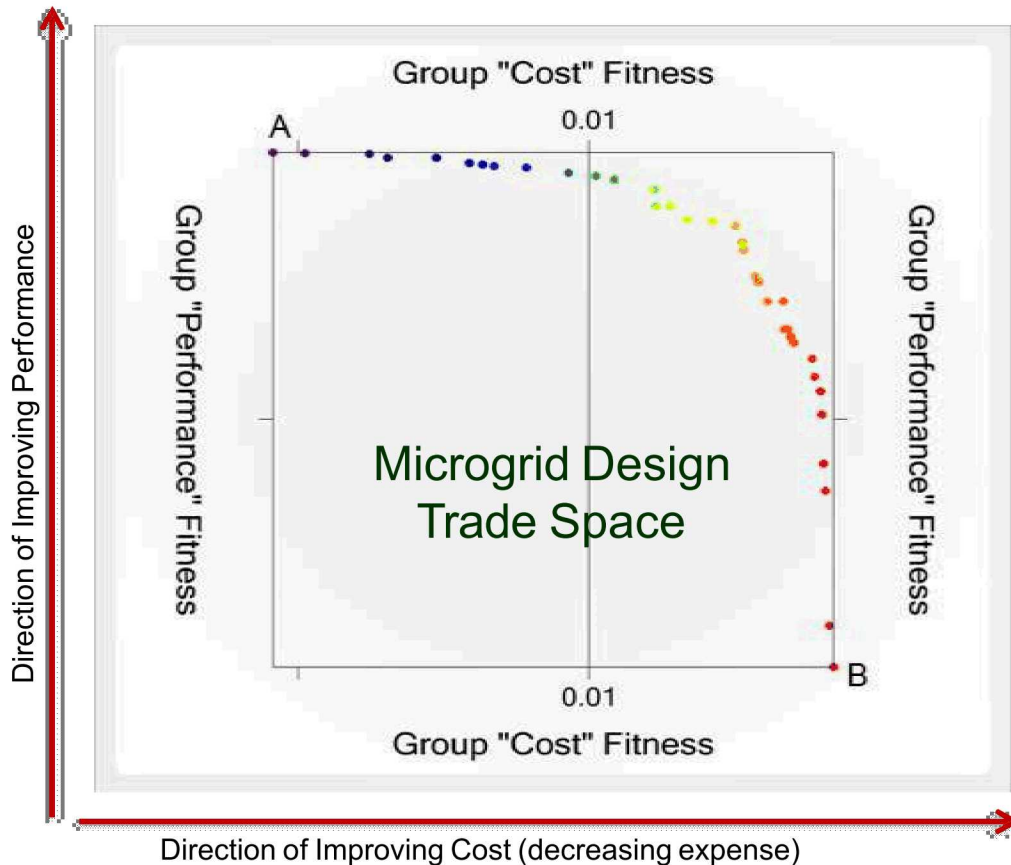
MDT Results

- Energy performance
 - Energy availability, cost, fuel used, volume, silent watch, gen utilization
- Parametric sweep results
- Optimal & feasible solutions
 - Generator types/counts
 - PV type/amount
 - Battery type/quantity

ITERATIONS to Refine Results

Microgrid Design Toolkit (MDT)

- MDT calculates a Pareto Frontier, a set of solutions that represent efficient trade-offs among the design objectives.



Each point represents a complete, unique microgrid design.

Point "A" is the highest cost, highest performing solution. Point "B" is the lowest cost, lowest performing solution. There are many options in between representing different trade offs.

Given any point on the chart, no improvement in cost can be made without corresponding decrease in performance and visa versa.

This chart shows 2 objective dimensions, cost and performance. The MDT supports up to 5 dimensions

1 Añasco Site – Location Map

AREA AVAILABLE

Roofing (<i>sf</i>)	256,114
Empty Lots (<i>quantity</i>)	1
Empty Lots (<i>acres</i>)	2.63
Parking Lots (<i>quantity</i>)	5
Parking Lots (<i>acres</i>)	6.88

Undeveloped Land

Tenants:

- A** Edwards Lifesciences
- B** J&J Vision Care (AMO)
- C** Amphenol

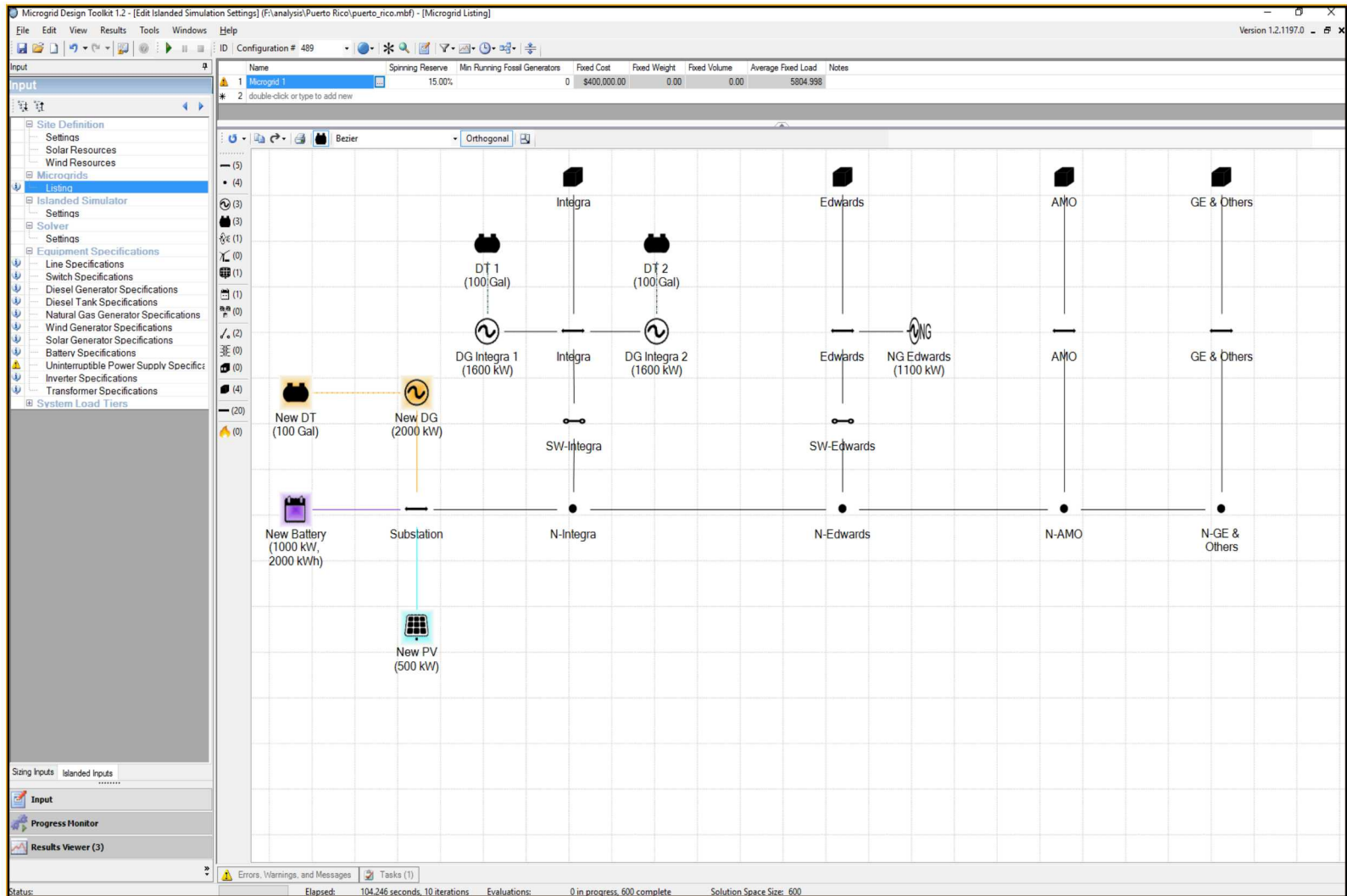
Additional Tenants that do not appear in the map:

- Cardinal Health PR
- Techno-Plastics Industries
- Integra Neurosciences PR
- GE Industrial of PR

Parking Lot



Añasco Sandia Microgrid Model



1 Añasco Sandia Microgrid Model

PV potential initial assessment



Rooftop PV: 1.0MW,

Empty Parking Lot PV (repurpose for PV only): 0.5MW,

Active Parking Lot PV (canopy style): 0.5MW

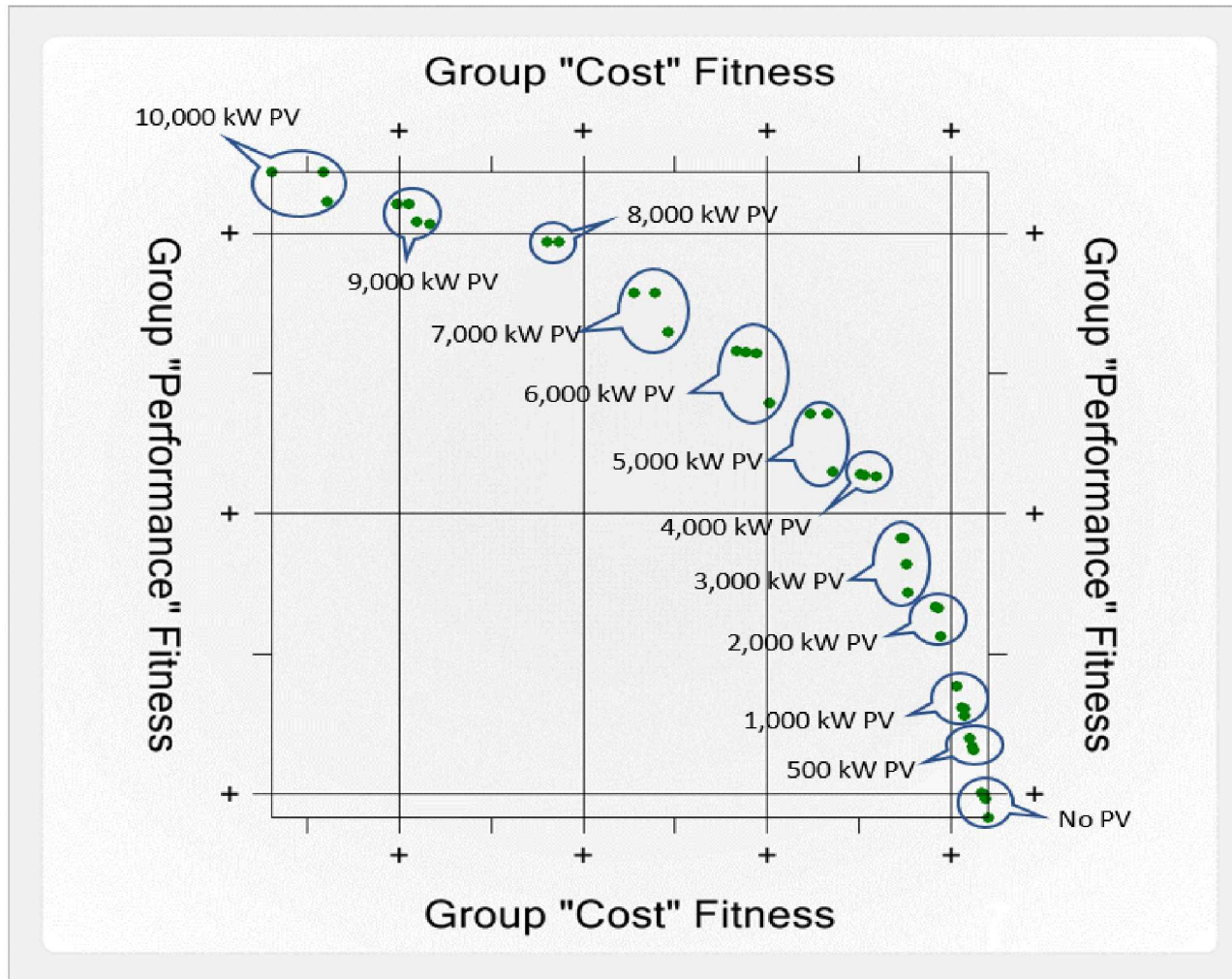
Total ~2MW



GOVERNMENT OF PUERTO RICO
Department of Economic Development and Commerce



Añasco Industrial Park



3 solutions with different cost/performance trade offs

1: Most Expensive, Highest Performing

New PV	10,000 kW
New Diesel	2,500 kW
New Storage	1,000 kW/2,000 kWh
Purchase Cost	\$33,249,000
Energy Availability	100%
Diesel Fuel Used (Gal. per 30 Days)	160,236
Total Diesel Generation	
Total Diesel Generation	5700 kW
Total Natural Gas Generation	
Total Natural Gas Generation	1100 kW
Total Solar Generation	
Total Solar Generation	10000 KW
Overall Diesel Efficiency	
Overall Diesel Efficiency	28.57%
Overall Diesel Utilization	
Overall Diesel Utilization	53.67%
Overall Natural Gas Efficiency	
Overall Natural Gas Efficiency	18.47%
Overall Natural Gas Utilization	
Overall Natural Gas Utilization	53.67%

3: Lowest Expense, Lowest Performance

New PV	None
New Diesel	3,000 kW
New Storage	None
Purchase Cost	\$2,419,000
Energy Availability	100.00%
Diesel Fuel Used (Gal. per 30 Days)	247,723.2
Total Diesel Generation	
Total Diesel Generation	6,200 kW
Total Natural Gas Generation	
Total Natural Gas Generation	1,100 kW
Overall Diesel Efficiency	
Overall Diesel Efficiency	37.48%
Overall Diesel Utilization	
Overall Diesel Utilization	80.24%
Overall Natural Gas Efficiency	
Overall Natural Gas Efficiency	24.75%
Overall Natural Gas Utilization	
Overall Natural Gas Utilization	80.24%

2: Middle Expense, Middle Performance

New PV	6,000 kW
New Diesel	2,000 kW
New Storage	250 kW/500 kWh
Purchase Cost	\$19,949,000
Energy Availability	100.00%
Diesel Fuel Used (Gal. per 30 Days)	192,679.2
Total Diesel Generation	
Total Diesel Generation	5,200 kW
Total Natural Gas Generation	
Total Natural Gas Generation	1,100 kW
Total Solar Generation	
Total Solar Generation	6,000 kW
Overall Diesel Efficiency	
Overall Diesel Efficiency	33.92%
Overall Diesel Utilization	
Overall Diesel Utilization	69.26%
Overall Natural Gas Efficiency	
Overall Natural Gas Efficiency	22.94%
Overall Natural Gas Utilization	
Overall Natural Gas Utilization	69.26%

LCOE and Budget Estimates

	Añasco		Aguadilla		Jayuya	
	Gen+PV+Battery costs	LCOE	Gen+PV+Battery costs	LCOE	Gen+PV+Battery costs	LCOE
1: Most Expensive, Highest Performing	\$32,314,000	\$0.230	\$61,457,500	\$0.222	\$20,800,000	TBD
2: Middle Expense, Middle Performance	\$18,529,000	\$0.184	\$35,157,500	\$0.179	\$12,200,000	TBD
3: Lowest Expense, Lowest Performance	\$1,614,000	\$0.133	\$11,257,500	\$0.145	\$200,000	TBD

Microgrid performance was measured by energy availability and fuel consumption.

Assumptions and caveats for LCOE analysis:

- ✓ Simulation period is for 1 year of continuous standalone microgrid operation based on an estimated load profile- 8760 hours.
- ✓ Capital cost to be financed at 6.5%. 100% financed assumed.
- ✓ Asset life time 25 years
- ✓ No PV degradation.
- ✓ Existing generation can be run continuously for no additional cost assumed for Añasco case. All new generation assumed for Aguadilla Case.
- ✓ The “Puerto Rico adder” over mainland estimated cost per KW of generation asset not yet estimated.
- ✓ T&D costs to build the connectivity of the microgrid not yet estimated and BOS not yet estimated.
- ✓ Battery utilization is small with current dispatch scheme in MDT that prioritizes energy availability. We are working on alternative formulations.

PRIDCO Sites Table Summary

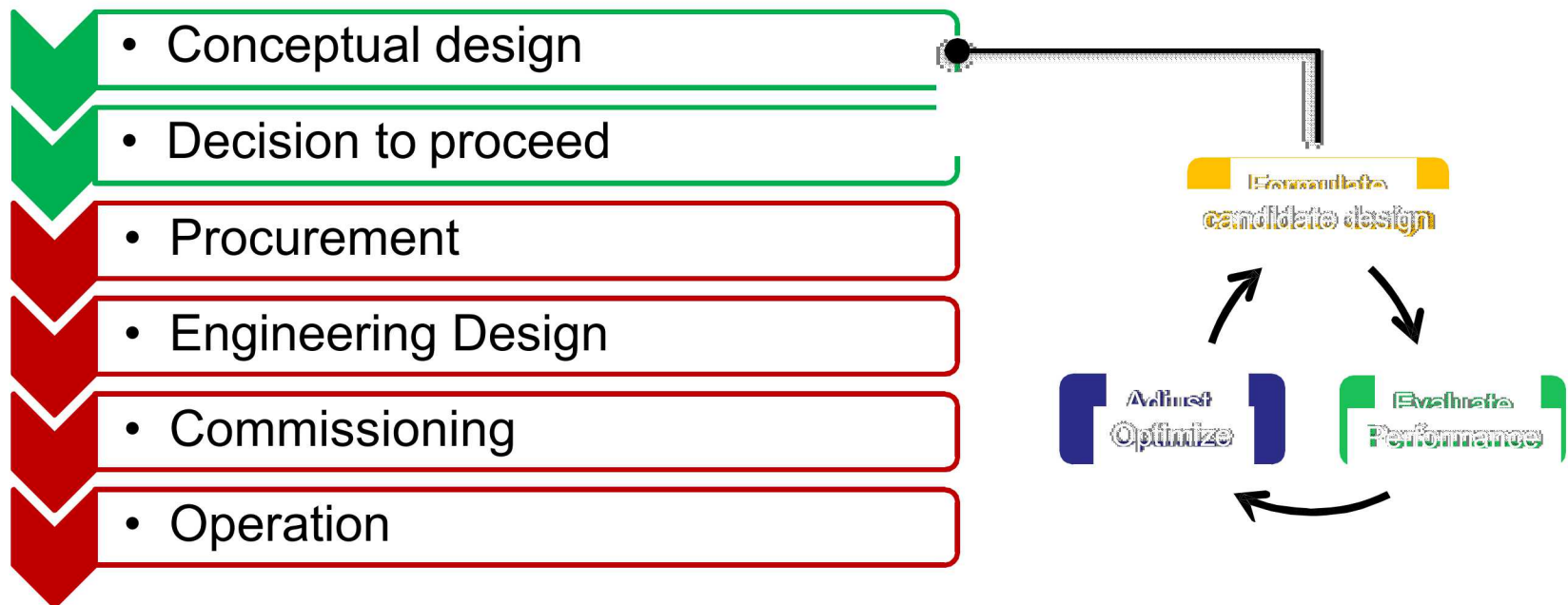
	Aguadilla	Añasco	Jayuya	Santa Isabel	Juana Diaz
Solar Potential	High	Medium	Low	High	High
Load (MVA/MW Peak)	18.75/15*	9.4/7.5*	6.25/5*	4.7/4.2	9.7/8.7
Industries Served	Aerospace, Defense, Cloud Computing, Bio-technology	Bio-pharma, technology	Bio-pharma	Aerospace, agricultural research, logistics	Manufacture of medical devices.
PQ/Outage Issues	Several per month	Several per month	Several per month	Several per month	Several per month
Critical Supplier?	No	Yes	Yes	Yes	No (in top 3)
Off-Grid Motivation	High	High	Medium	Medium	High
Cost Estimate (Middle Case for Performance)**	\$35,000,000 w/ 9 MW of PV	\$18,500,000 w/ 5 MW of PV	\$12,000,000 w/ 4 MW of PV	TBD	TBD
Employees	1900	3000	600	1500+	1500

* Estimated value

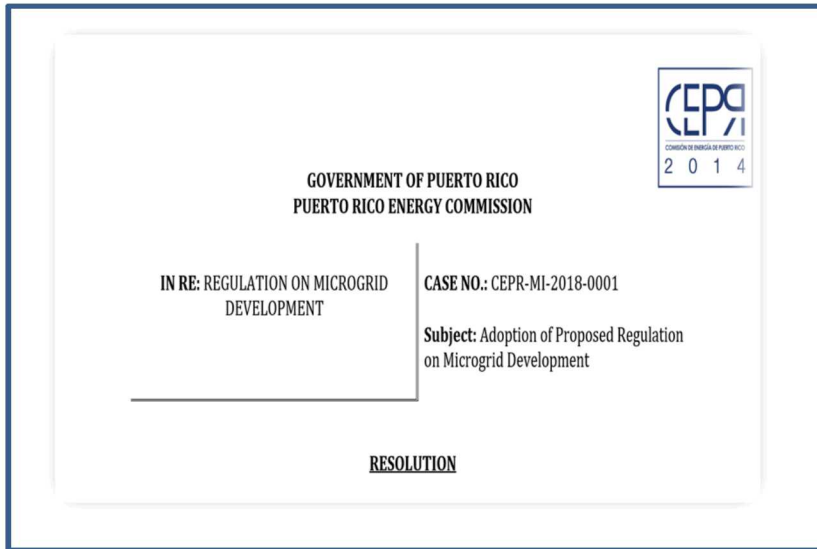
** See LCOE slide for list of assumptions. Cost estimate is for generation assets only.

Status of Project

- PRIDCO and SNL and ORNL provided detailed technical and regulatory feedback and suggested changes to the new Puerto Rico microgrid rule proposed by the Puerto Rico regulatory commission.
- A Request for Information on potential industrial microgrid solutions was issued in April 2018 and the response was excellent with industry estimated solutions right in the target LCOE range.
- Supporting PRIDCO with the development of an RFP for the 5 sites



Puerto Rico Energy Commission Microgrid Regulation



Final Microgrid Regulation
(CEPR-MI-2018-0001)
May 18th, 2018

- ✓ It establishes three classes of microgrids: Personal and Cooperative and Third Party
- ✓ Rules for Generation and Components of microgrids to qualify for this rule:
Renewable microgrid must generate 75 percent of its energy and CHP microgrids must be at least 50% CHP.
- ✓ Rules for Municipalities: A muni can enter into a contract with a third-party provider to develop a microgrid or develop one itself.
- ✓ PREPA: The regulation does not preclude PREPA from developing microgrids, but PREPA must come up with interconnection regulations within 120 days.

University of Puerto Rico at Mayagüez (UPRM) and Sandia partnership



The Consortium for Integrating Energy Systems in Engineering and Science Education (CIEESE) is a DoE sponsored project with the goal of increasing the pipe line of graduates ready to pursue a career in energy relevant fields (source: www.prec.pr).



Among the activities of the consortium is the participation of faculty and students, from Engineering and Sciences, in Energy Systems Research in collaboration with National Laboratories.

Working in SNL's Renewable Energy and Distributed Systems Integration Department



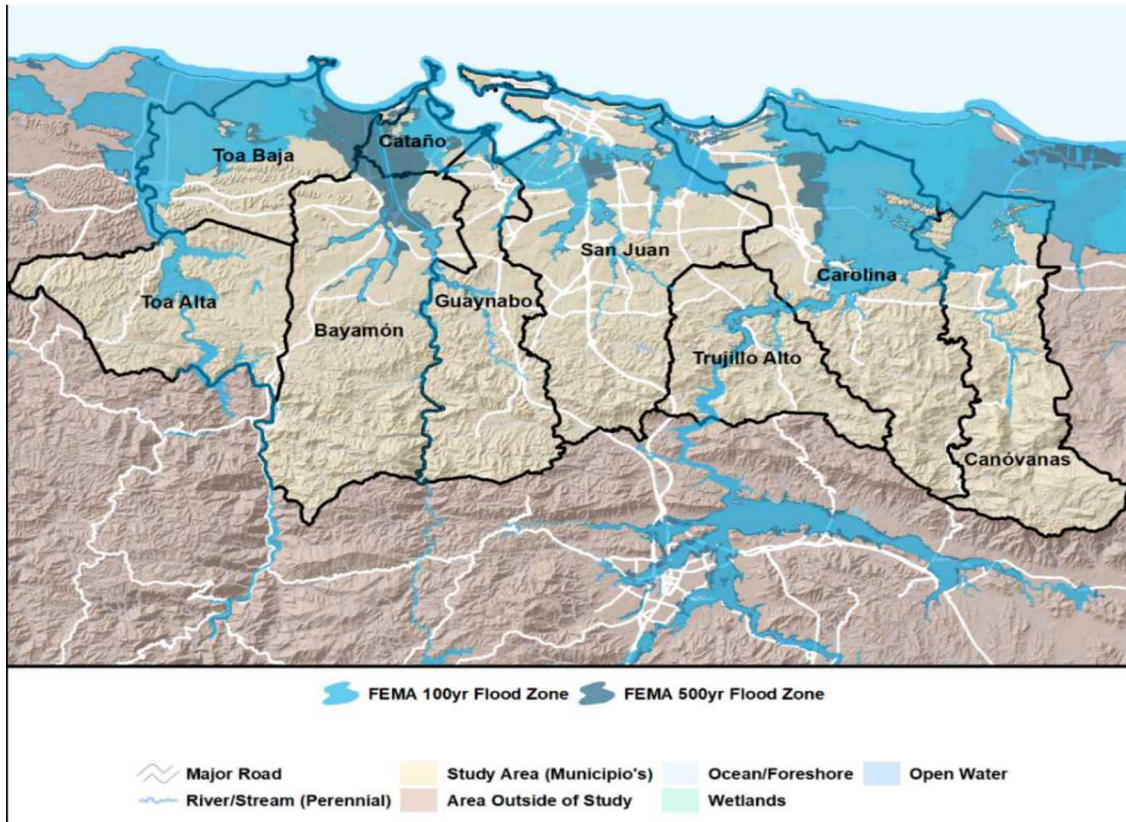
2017: 1 professor and 1 student



2018: 2 professors and 3 students

Where to focus our efforts?

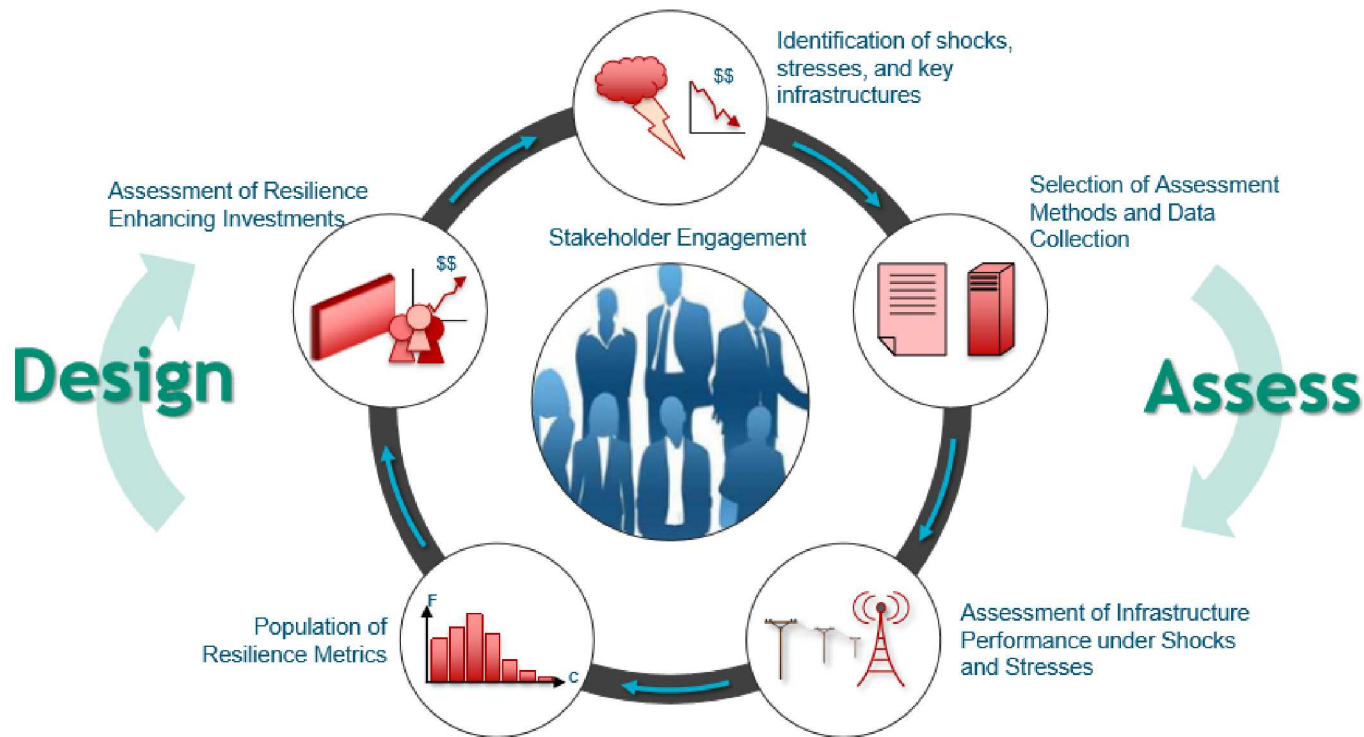
Project 2: Resiliency Analysis to recommend microgrid deployments in the greater San Juan area of Puerto Rico. PI: Robert Jeffers



Part of the larger DOE national laboratories effort to perform modeling, analysis, and high-level design of resilience-enhancement options.

Microgrids and Infrastructure Resilience

Urban Resilience Planning Framework

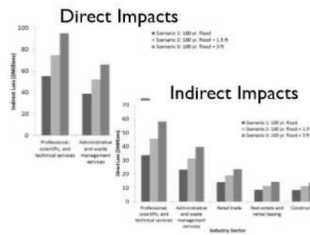
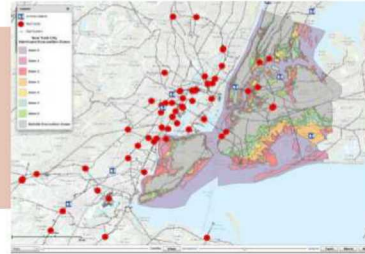


A multidisciplinary, science-based approach to quantify and improve urban resilience, with urban stakeholders at the core.

Urban Energy Resilience Tools

Other tools to understand links between grid resilience and risk to communities

Fast Map: Spatial analysis tool for rapid situational awareness and effective multi-stakeholder understanding of infrastructure dependencies

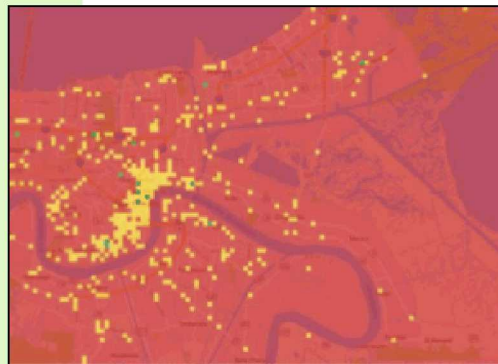


REAct: Regional Economic Accounting model – uses input-output methodology to calculate rough order of magnitude economic losses

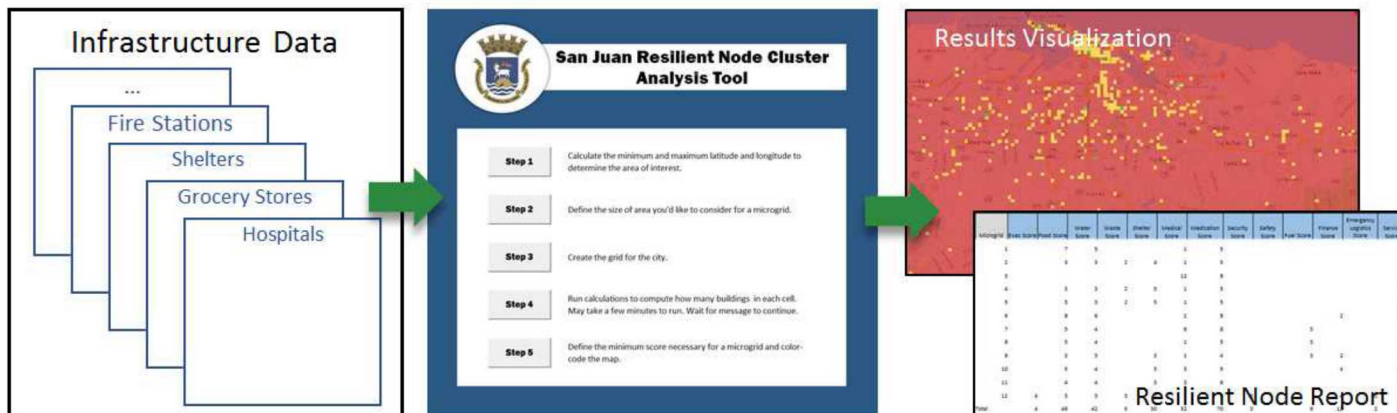


Tools to design optimal energy resilience solutions

ReNCAT: Resilient Node Clustering Analysis Tool - Optimize selection of buildings with resilient energy supply for increased community resilience based on consequence-focused resilience metrics

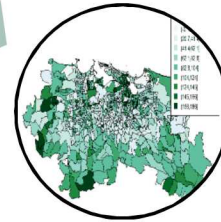
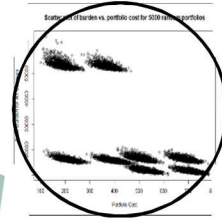
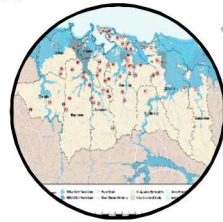


- The Resilient Node Cluster Analysis Tool (ReNCAT) was developed at Sandia to find dense concentrations of critical services in large metropolitan areas
 - Areas that contain co-located infrastructure that provide a high level of services are considered as potential sites for advanced microgrids
- The tool can accommodate any number of sectors and maps these to service categories and levels
- ReNCAT also incorporates design basis threats such as flood profiles and wind damage and excludes these areas from consideration
- The tool includes a customized user interface and two types of result visualization
- ReNCAT has been used to assess potential microgrid locations for New Orleans and San Juan, Puerto Rico



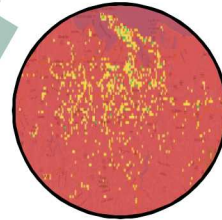
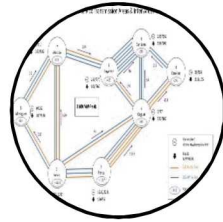
5. Calculate burden, service level, and cost metrics

4. Determine location and assets for each microgrid in the portfolio



6. Visualize metrics and resiliency options

3. Examine existing distribution, feeders, geographical layout, and storage options for candidate locations

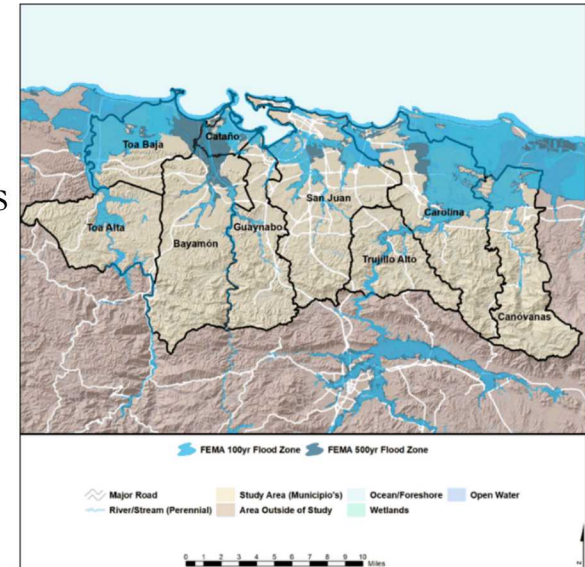


1. Obtain data for all critical infrastructure sectors

2. Run ReNCAT to determine locations providing high service levels

Assumptions for Puerto Rico Analysis

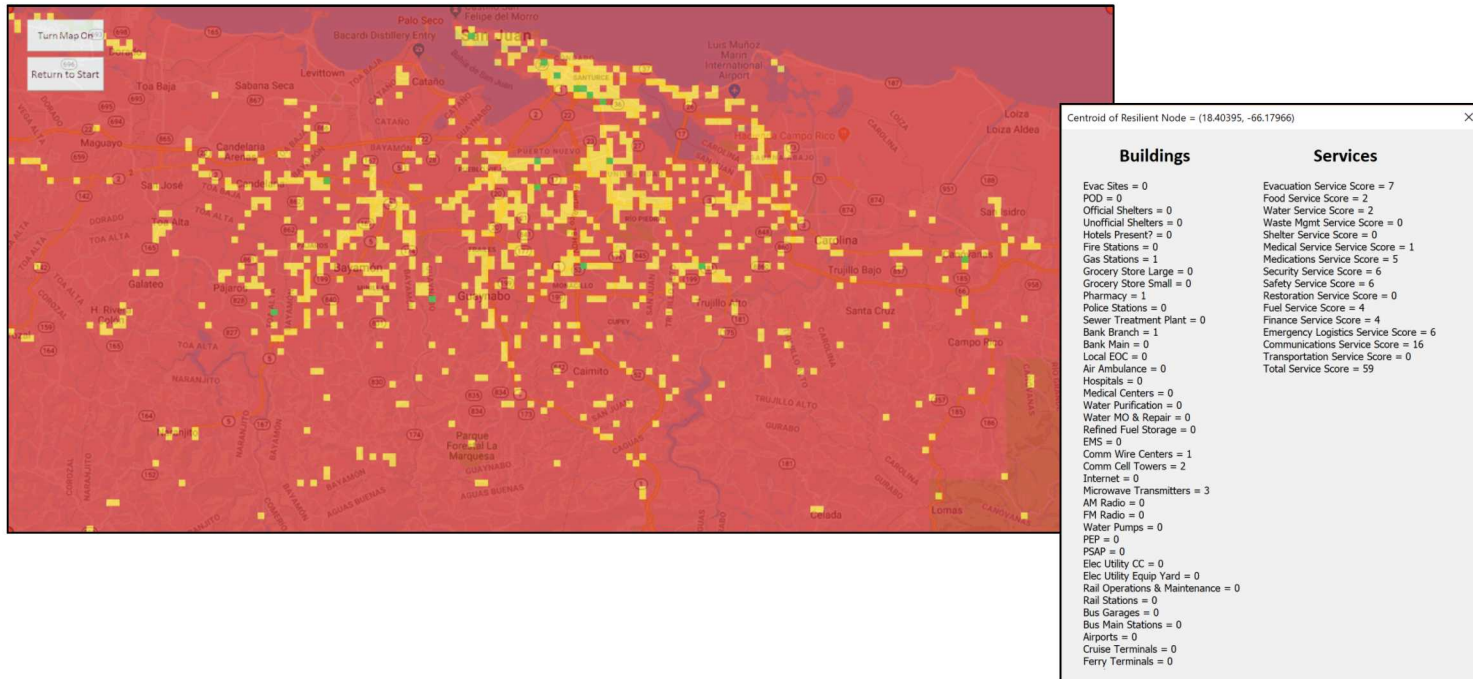
- Counties considered for analysis:
 - Toa Baja, Cataño, Toa Alta, Bayamón, Guaynabo, San Juan, Carolina, Trujillo Alto, and Canóvanas
 - Accounts for nearly half the population of Puerto Rico
 - Entire island will be used for final analysis
- Design basis threat currently includes flooding and high winds
 - Based on FEMA's 100-year and 500-year floods
- Included 40 critical infrastructure types and 15 service types
- Assuming no existing reliable backup power
- Assuming infrastructure itself is robust to high winds
 - May need to revisit for structures such as cell phone towers
- Resilience improvements include advanced microgrids, localized backup, and energy storage



Data Mapping and Sources for San Juan

Community Service	Level of Contribution by Infrastructure Sector		
	High	Medium	Low
Communications	Cell Towers; Wire Centers; Internet		Microwave Transmitters
Emergency Logistics	Local Emergency Operations Center; PEP	AM Radio Station Transmitters; FM Radio Station Transmitters	Evacuation Sites; Points of Distribution; Official Shelters; Unofficial Shelters; Wire Centers; Cell Towers
Evacuation	Evacuation Sites; PEP; Airports	Wire Centers; Rail Stations; Bus Main Stations; Cruise Terminals	Police Stations; Local Emergency Operations Center; Cell Towers; Rail Operations and Maintenance; Bus Garages; Ferry Terminals
Finance	Bank Mains	Bank Branches	Wire Centers
Food	Points of Distribution; Large Grocery Stores; Airports	Small Grocery Stores	Official Shelters; Unofficial Shelters; Hotels; Gas Stations; Pharmacies; Cruise Terminals
Fuel	Gas Stations; Fuel Storage		
Medical Services	Hospitals; EMS	Air Ambulances; Medical Centers	Fire Stations; Pharmacies
Medications	Pharmacies	Hospitals	Points of Distribution; Official Shelters; Unofficial Shelters; Gas Stations; Large Grocery Stores; Medical Centers
Restoration	Electric Utility Control Center; Electric Utility Equipment Yard	Airports	Fuel Storage
Safety	Fire Stations; PSAP	EMS	Wire Centers; Cell Towers
Security	Police Stations; PSAP		Wire Centers; Cell Towers
Shelter	Official Shelters; Hotels	Unofficial Shelters	
Transportation	Rail Stations; Bus Main Stations; Airports	Rail Operations and Maintenance; Bus Garages; Ferry Terminals	Cruise Terminals
Waste Management	Sewer Treatment Plants		Official Shelters; Unofficial Shelters
Water	POD; Water Main Office and Repair Yard	Large Grocery Stores; Water Purification; Water Pumps	Official Shelters; Unofficial Shelters; Hotels; Gas Stations; Small Grocery Stores; Pharmacies; Airports; Cruise Terminals

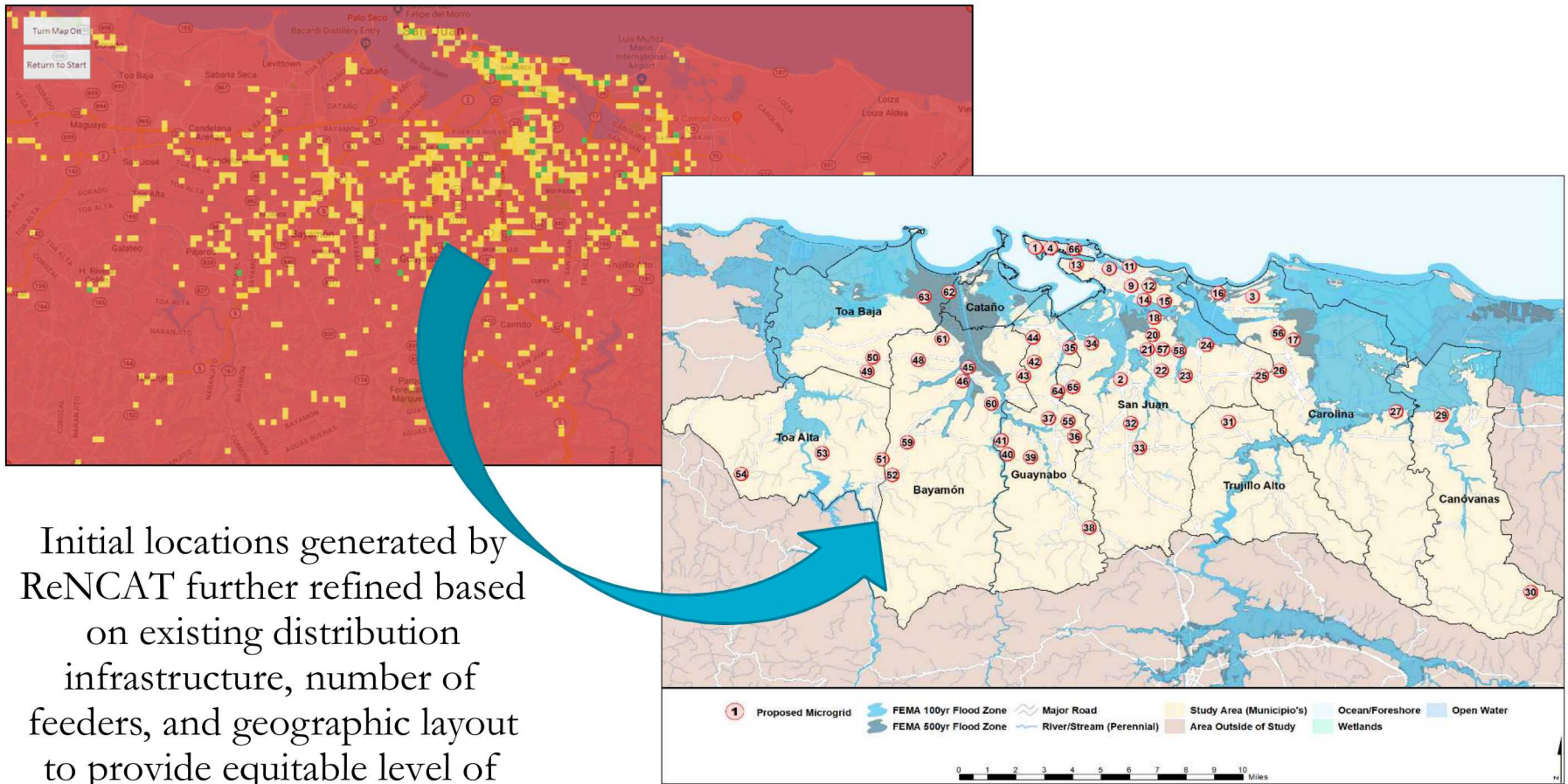
- ReNCAT utilizes a mapping matrix to translate infrastructure to services provided
- Infrastructure types are mapped to one or more service types
- San Juan analysis includes 40 sectors and 15 service types
- Different sectors can provide the same service at various contribution levels
- Main goal is to identify resilient nodes within city that provide high levels of services



- ReNCAT provides a visualization of where potential microgrids are located based on the desired area size and minimum total service score
 - Green = meets requirements
 - Yellow = has services with score below minimum
 - Red = no services or area excluded based on design basis threat
- Users can click every cell in the map grid to see a list of building types and quantities, service scores by service type, and the total service score

66 potential microgrid locations identified for the greater San Juan area

Total portfolio cost of \$895M*

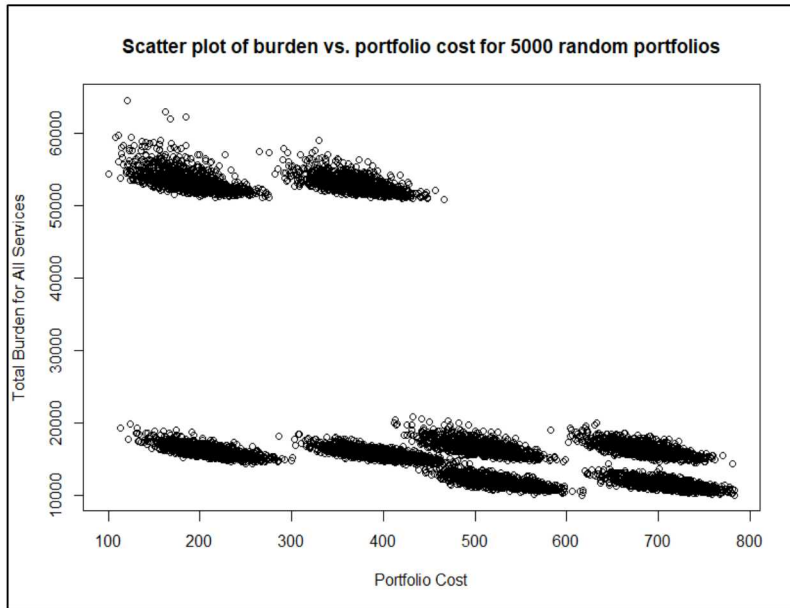


Initial locations generated by ReNCAT further refined based on existing distribution infrastructure, number of feeders, and geographic layout to provide equitable level of services across the community.

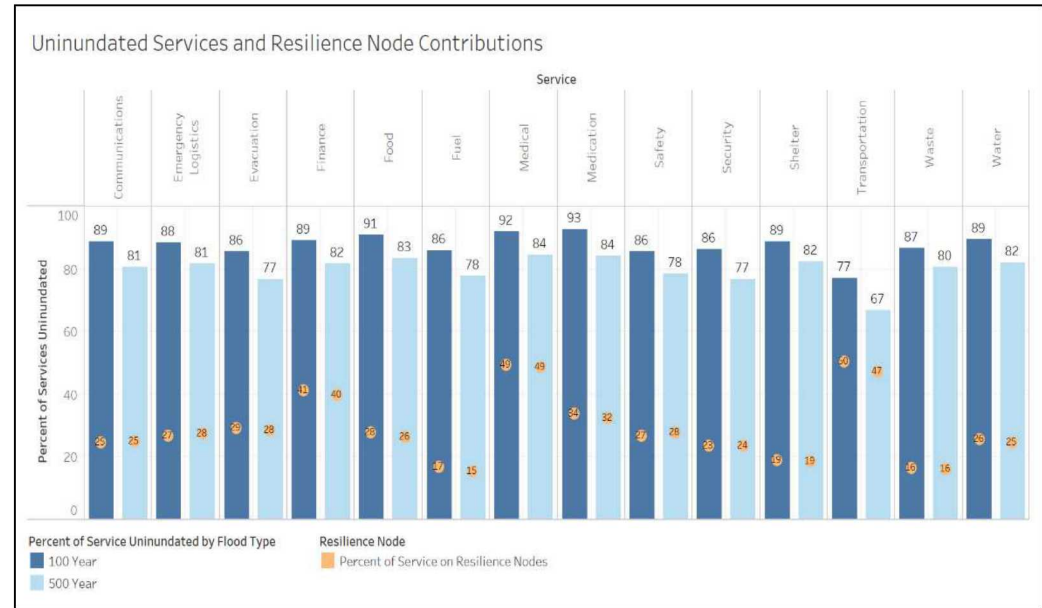
*Pending cost refinement

Resiliency Metrics

- Sandia used two primary metrics to evaluate the resiliency of the portfolio of microgrids for San Juan:
 - Burden (function of effort required to satisfy each need and an individual's ability)
 - % of Services covered (taking into account flood profiles)
- The cost for each microgrid in the portfolio was also evaluated based on building type, building load, and four microgrid options



Can obtain similar level of reduced burden for much less than cost of investing in total portfolio



Percentage of services covered by microgrids varies by sector and is affected by factors such as proximity to other critical assets

Where to focus our efforts?

Project 3: DOE office of electricity asked SNL and ORNL to team up to support the analysis of energy storage options to improve resiliency in Puerto Rico.

Scope: SNL will work with ORNL to conduct a **system wide study** of Puerto Rico transmission and distribution system to determine the optimal siting and sizing of storage systems to achieve 3 broad goals:

- (a) significantly improve grid performance during blue sky conditions,
- (b) significantly expand the system's hosting capacity for renewable energy deployment, and
- (c) significantly improve grid resilience with respect to storms and other large-scale threats.

Objectives:

- 1) Stability analysis.
- 2) Mitigation of renewable ramp rates.
- 3) Regulatory solutions for cost recovery of storage investments for both blue sky and black swan conditions.
- 4) Investigate where and how a battery system could be best utilized to demonstrate high value during blue-sky conditions, enhanced integration of renewable energy, and grid resilience.

Questions?

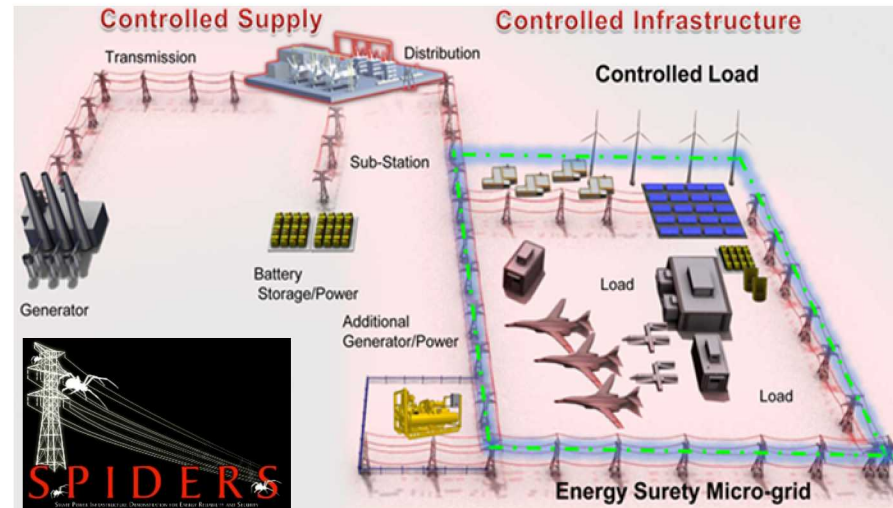
Robert Broderick,
rbroder@sandia.gov

Extra Slides

Microgrids & Energy Resilience – Defense

Smart Power Infrastructure Demonstration for Energy Reliability & Security

- Bolster the energy security and resilience of U.S. military installations, transfer knowledge to civilian critical infrastructure.
- Focused on four requirements:
 - ✓ Protect critical assets from cyber-attack
 - ✓ Sustain operations in long grid outages
 - ✓ Integrate renewable and other DER
 - ✓ Optimal design and operation to reduce fuel demand, emissions, and cost.



- Full microgrid deployment at

Microgrids & Energy Resilience –Transportation

NJ TRANSITGrid Project

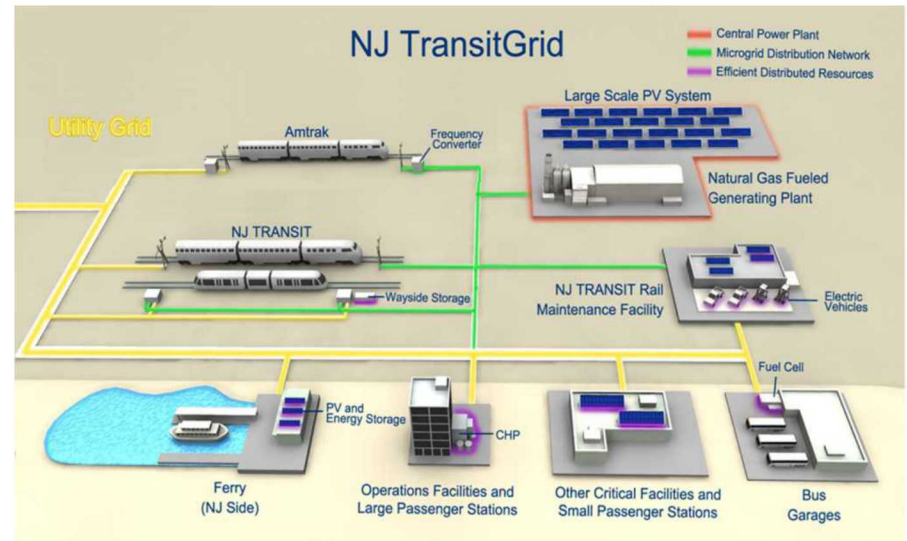
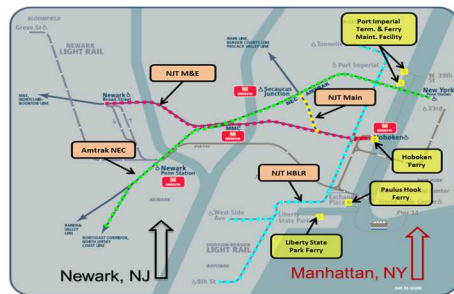
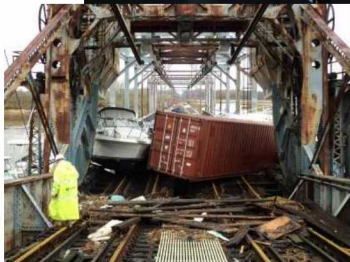
Superstorm Sandy caused major human and economic losses

The transportation in northern New Jersey and Manhattan, New York was severely disrupted for weeks, hampering evacuation and recovery efforts

NJ Transit and other rail operators suffered \$Billions in infrastructure losses

Sandia is collaborating with NJ Transit to design & deploy a resilient microgrid

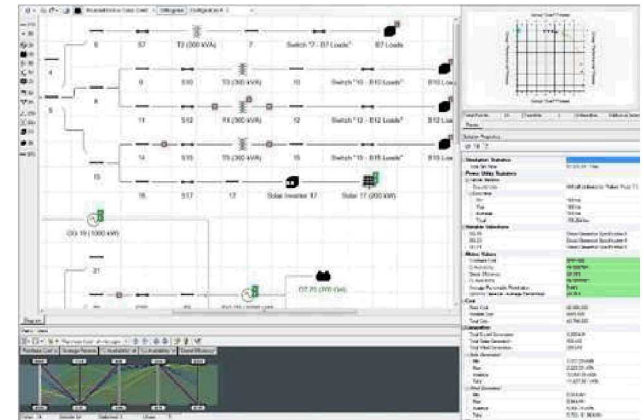
When built, it will be one of the largest microgrids in the nation



Design Optimization Tools

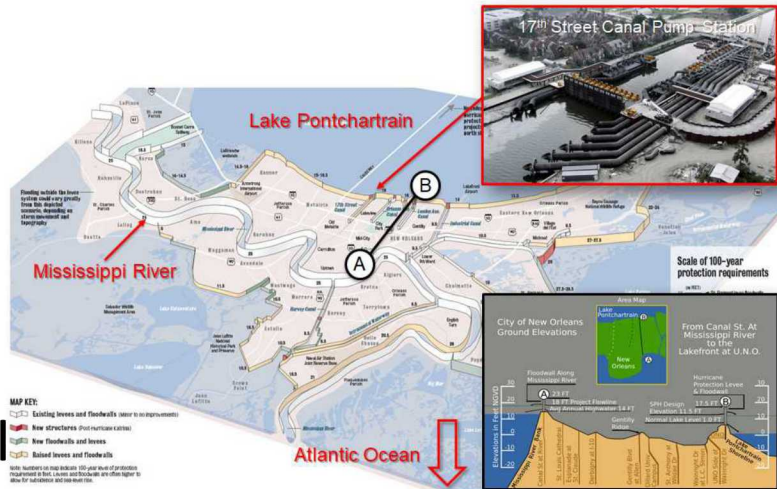
Sandia Microgrid Design Toolkit (MDT)

- A decision support tool for early-stage resilience design involving microgrids.
- Has functions to identify and compare microgrid design options in terms of user defined objectives such as cost, performance, and reliability.
- Provides many views and features to help explore that trade space and extract information.
- Publically available
 - <http://www.energy.gov/oe/services/technology-development/smart-grid/role-microgrids-helping-advance-nation-s-energy-syst-0>



Microgrids and Infrastructure Resilience

New Orleans, Louisiana (NOLA) faces high flooding risk
Levees and pumps are the main line of defense, but they can fail



RESILIENT NODES (MICROGRIDS)
Emphasized community engagement
Quantified benefits decision-making





San Juan Resilient Node Cluster Analysis Tool

Step 1

Calculate the minimum and maximum latitude and longitude to determine the area of interest.

Step 2

Define the size of area you'd like to consider for a microgrid.

Step 3

Create the grid for the city.

Step 4

Run calculations to compute how many buildings in each cell. May take a few minutes to run. Wait for message to continue.

Step 5

Define the minimum score necessary for a microgrid and color-code the map.

- The GUI guides users through the analysis process
- Users specify two key inputs:
 - Area size determines how large of an area will be considered for a potential microgrid
 - Minimum score specified the minimum total service score required for an area to qualify as a potential microgrid location
- The GUI can easily be customized for each city/customer

ReNCAT 2.0

- Sandia is actively developing ReNCAT 2.0 which will transform ReNCAT into an optimization capability
- Optimization will include all ReNCAT 1.0 functionality plus add in:
 - Burden metrics to locate microgrids in a way that minimizes burden to the population by census blocks
 - Cost metrics that account for the current layout of the distribution system to minimize the cost to build the proposed microgrids
 - Non grid-based spatial calculations to allow placement of microgrids anywhere in continuous space rather than limiting them to predetermined grid cells

ReNCAT Microgrid Report

- Each analysis also produces a report of potential microgrid locations that includes:
 - Number of buildings by sector (not shown)
 - Service score by service type
 - Total service score
- Metrics are listed for each microgrid and for the overall microgrid portfolio
- Report also gives insight into which service types are not supported by microgrids due to either low quantities of infrastructure providing that service, or the infrastructure providing those services not being co-located with other infrastructure
 - These services would be provided through more localized backup generation

Microgrid	Evacuation	Food	Water	Waste Mgmt	Shelter	Medical Service	Medications	Security	Safety	Restoration	Fuel	Finance	Emergency Logistics	Communications	Transportation	Service Score
1	8							8	8				14	16		54
2	8							8	8				8	17		49
3	2	10	8			3	14	2	2			3	2	6		52
4	6	5	4			1	6	9	4				4	14		53
5	7	2	2			1	5	6	6		4	4	6	16		59
6	6	5	5	2	6	3	5	2	2		4	1	4	5	4	54
7	4	6	6	2	10		3	4	4		4		6	10		59
8	7	1	1			1	4	9	4			1	4	14		46
9		2	2			28	22				4			1		59
10	2	5	4	1	3	6	5	2	2			6	3	19		58
11		12	12	2	10	3	16						4			59
Total	50	48	44	7	29	46	80	50	40		16	15	55	118	4	602