

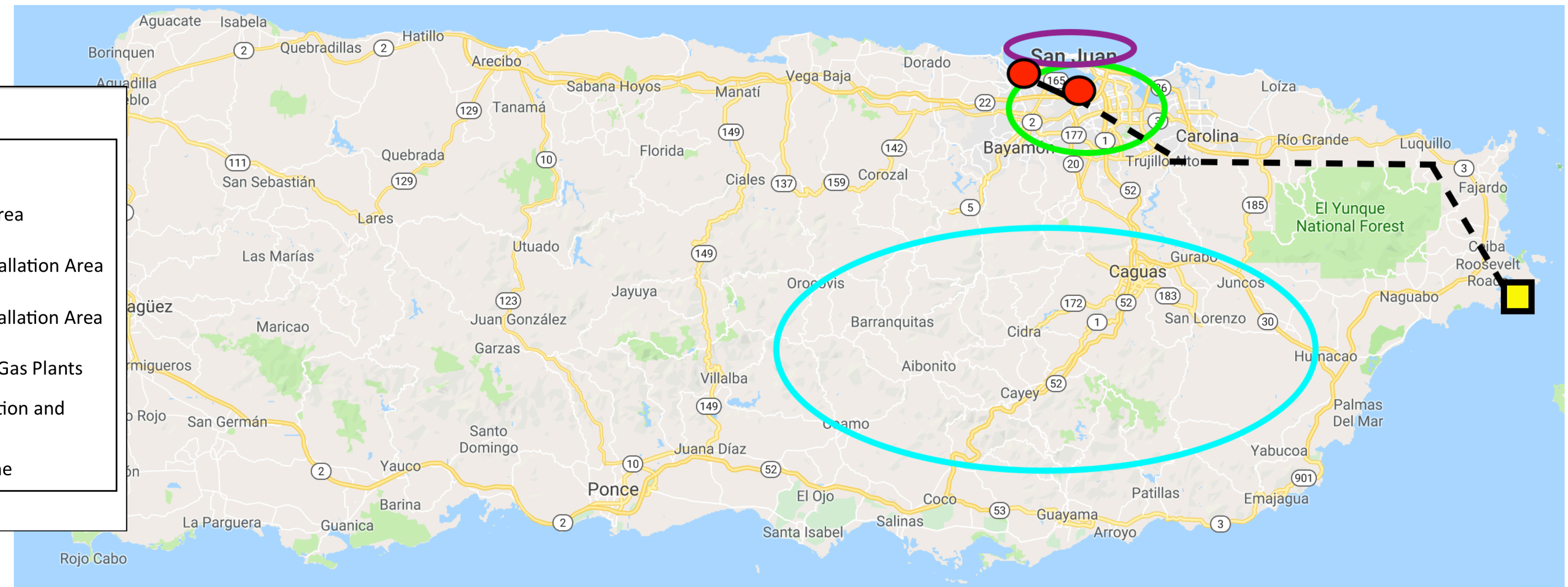
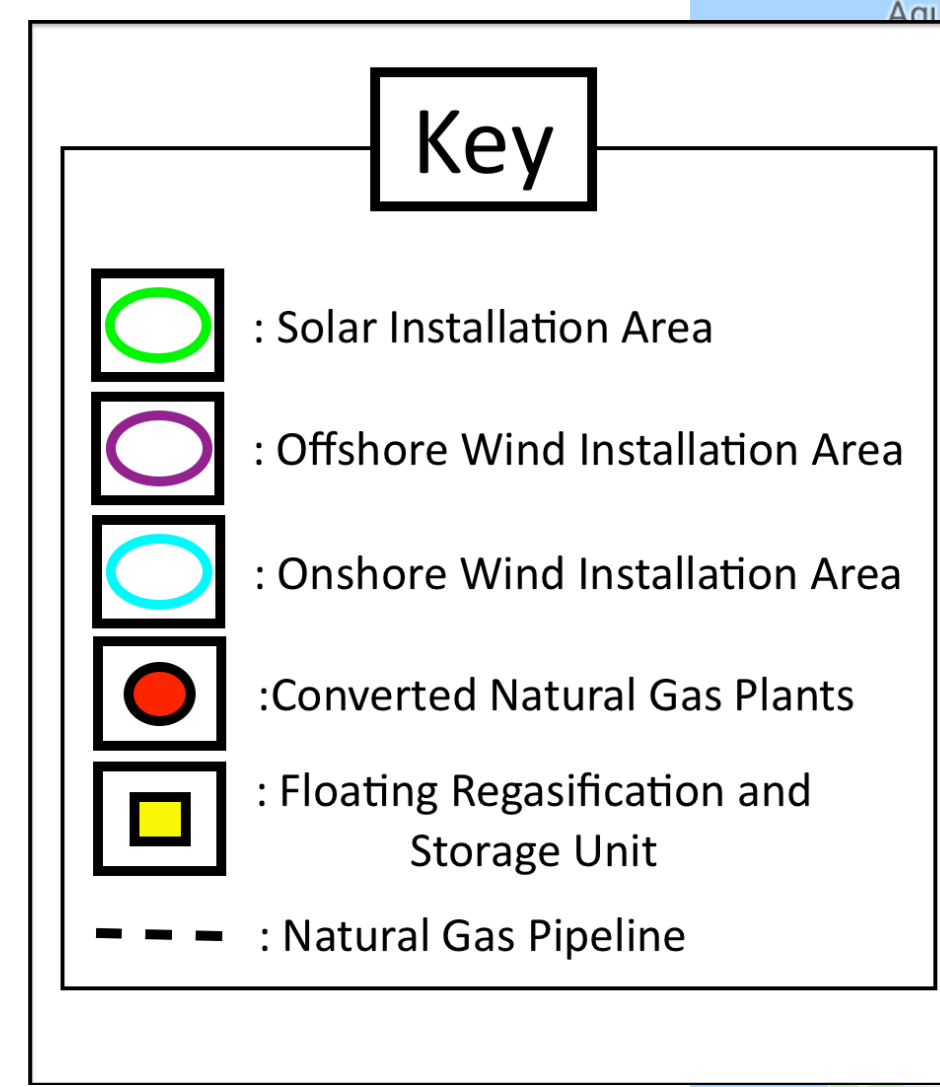
DESIGN OF A MORE RELIABLE POWER GRID FOR PUERTO RICO

sddec18-03

Introduction

- 80% of Puerto Rico's power grid was recently destroyed in hurricanes Irma and Maria
- Wide-Spread island blackouts due to lack of maintenance long before hurricanes struck
- Lack of redundancy
- Puerto Rico Electric Power Authority (PREPA) providing free electricity

Intended Use: Author a written proposal encompassing the technologies, policies, and economics surrounding Puerto Rico's Power Market targeted at PREPA to adopt and implement.



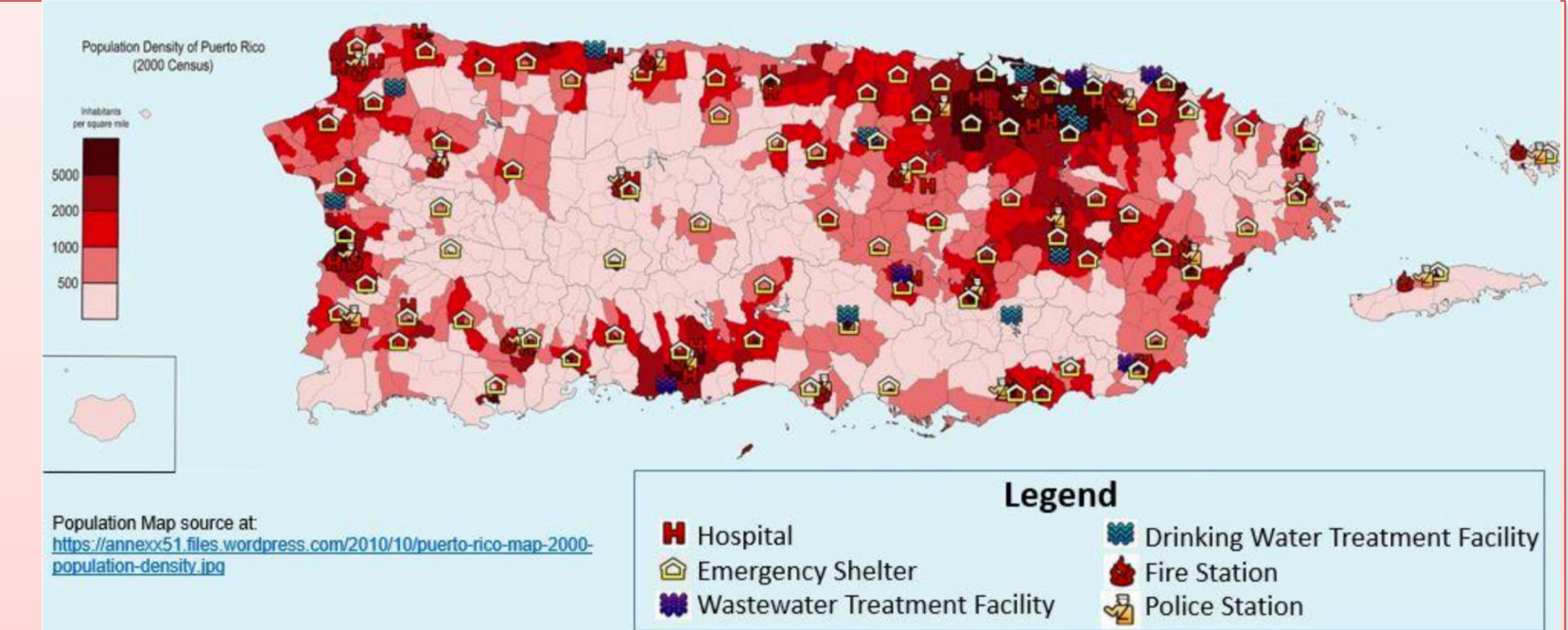
Our Design

- Generation**
 - Introduction of large-scale natural gas power through added port and pipeline
- Transmission**
 - Updated Transmission Structures, added transmission line pathways
- Microgrid Implementation**
 - Installing independent microgrids
- Renewable Energy**
 - Large-Scale and Distributed Solar and Wind energy paired with energy storage measures and back-up natural gas turbines
- Economics and Policies**
 - Recommending updated environmental policies and energy costs

Other Requirements: Feasible, Reasonable Budget. Built to Category 4 Storm Standards. Operating in Puerto Rican Climate with natural disaster history.

Microgrid Implementation

- Microgrid Implementation**
 - Proposing 159 independent microgrids across the island with 15,000-20,000 consumers per grid
 - San Juan (population ≈ 355,000): Approximately 25 grids
 - Smaller Cities/Rural Cities (ex: Manatí, population ≈ 16,000): 1 grid
 - Microgrids centered around crucial loads (hospitals, police departments, etc.) and high population centers.
 - Two roles: connected to main grid (supporting), supplying power for connected community (independent)



Energy Storage

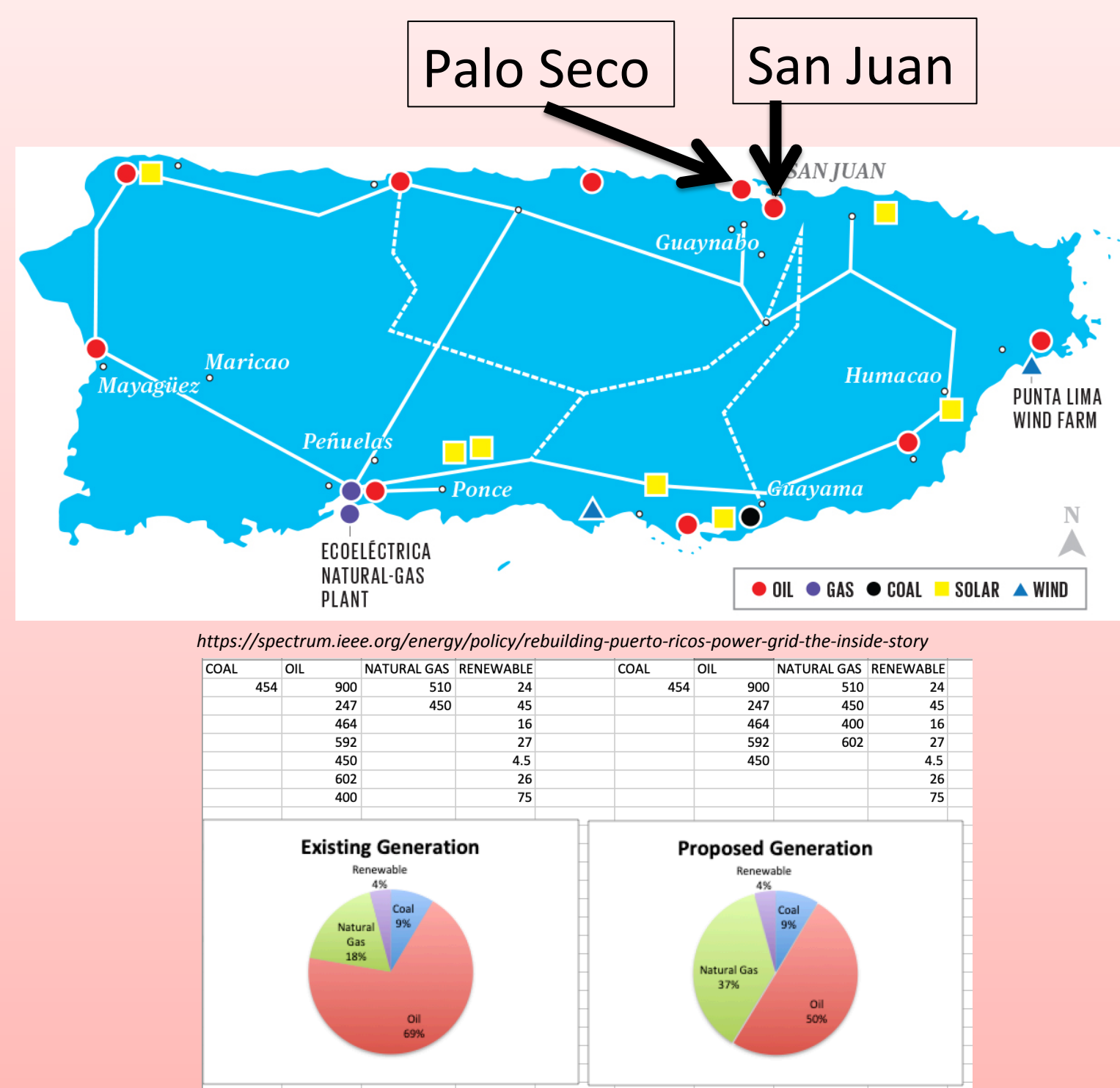
- Prioritizing Rural areas (≈150,000 consumers)
- PREPA aims for 30% consumption in storage
 - Rural consumption ≈ 2309988 kWh/day
- Using 100kWh batteries @ industry average \$209/kWh, investment of \$468 million
 - Lithium ion battery pricing expected to drop by 50+%, wait for urban areas.

Generation

Only 2 power plants are equipped to be fueled by natural gas.

Proposing

- Construct a LNG floating storage and regasification terminal at Roosevelt Roads
 - Rebuild LNG ship ≈ \$8B
- Construct LNG pipeline from Roosevelt Roads to Palo Seco Generation Plant (602 MW) and San Juan Generation Plant (400 MW)
 - Convert from heavy oil generation to natural gas generation.
 - Reduces heavy oil fuel consumption to 50%



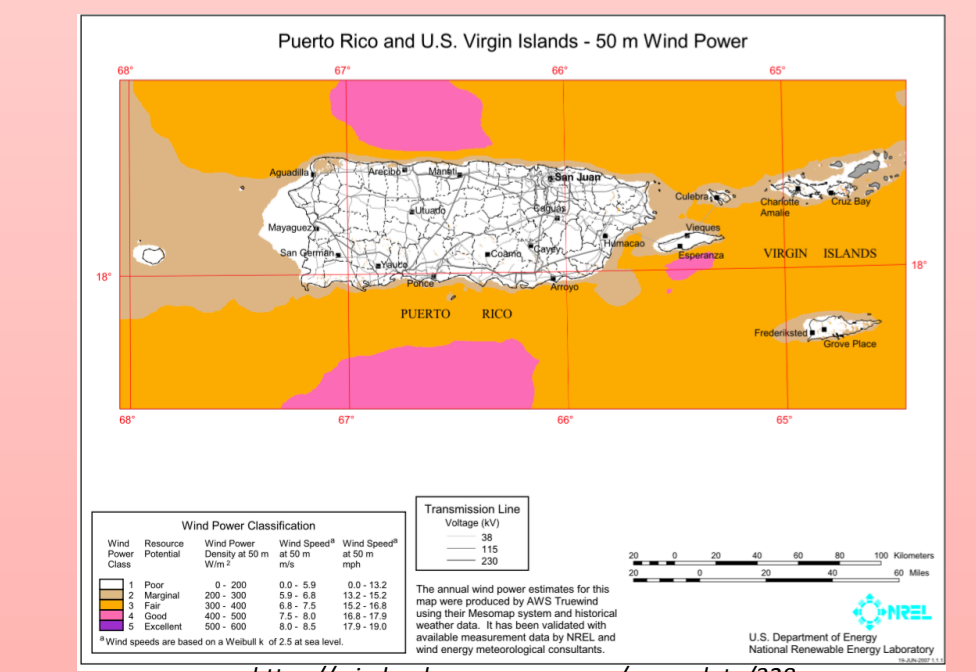
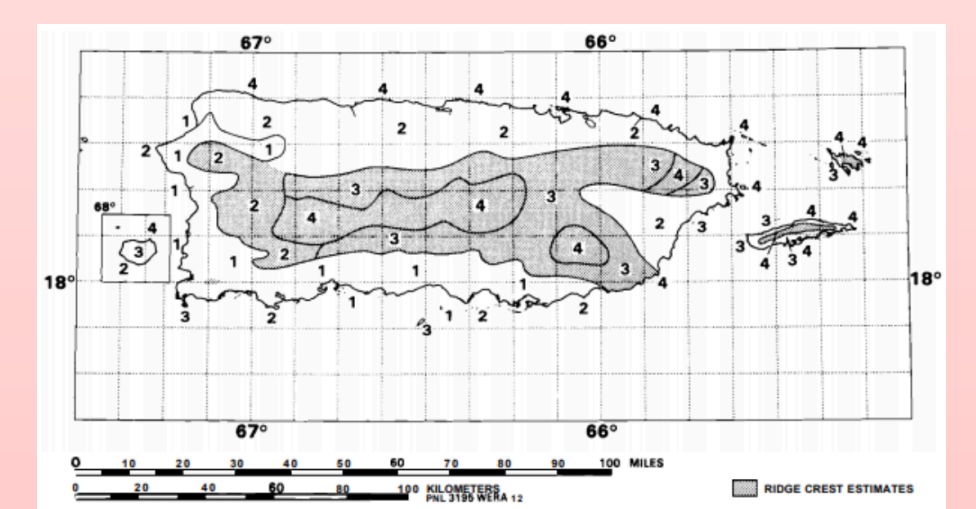
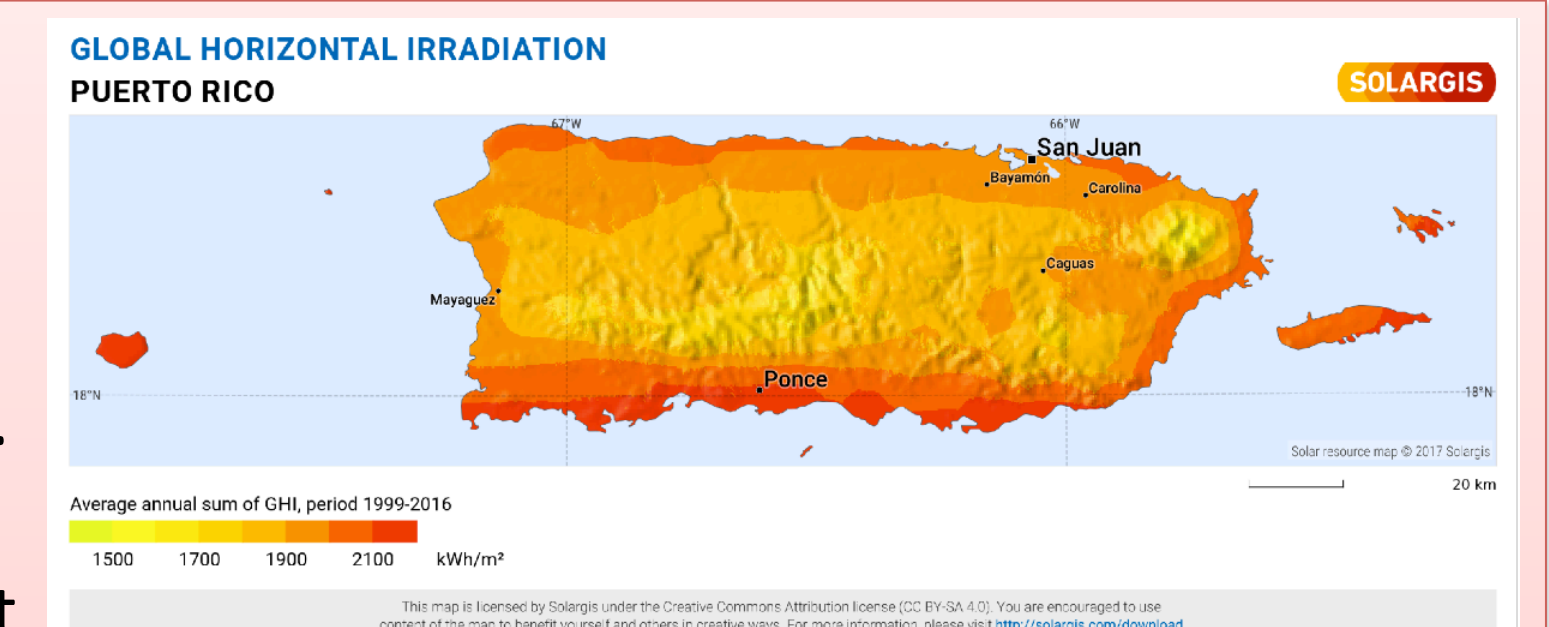
Renewable Energy

Distributed Solar Energy

- Prioritizing Rural areas
- Ground Mounted Systems \$5-8 thousand for 5kW. Allows for low maintenance and easy installation.
 - Less energy density than roof mount, but a fraction of the cost.

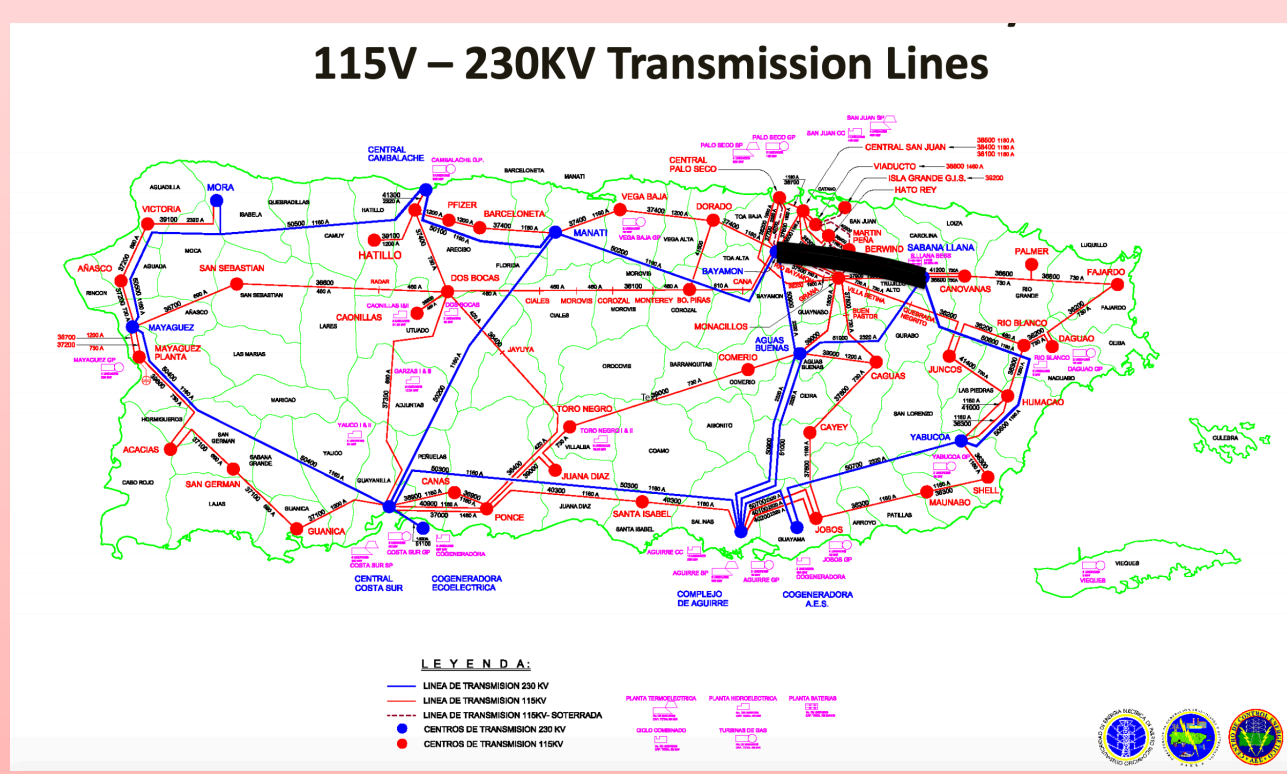
Large-Scale Solar Energy

- Existing: 5 privately owned solar farms totaling approximately 120MW
- Proposing 50MW fixed-tilt rooftop solar in San Juan
- Wind Energy**
 - Maximum capacity expected 7 months per year, with function year-round
 - 30 MW On-Shore Turbines @ \$3000/kW
 - 10MW Off-Shore Turbines @ \$10,000/kW
 - Shallow continental shelf off San Juan very suitable for turbines installed at a depth of 15-25m



Transmission

- Adding resiliency by constructing 4th Transmission Loop (shown in black)
- Extensive repair of downed poles and lines
 - Installing monopoles vs. Lattice Structures



Monopole designs generally performed better than lattice tower designs. Source: NYPAC/Con Edison Damage Assessments

Economics and Policies

- Increase cost of electricity to closer match Caribbean average

	Current	Proposed
Residential	21.17 c/kWh	26.17 c/kWh
Industrial	19.78 c/kWh	24.78 c/kWh
Commercial	24.32 c/kWh	29.32 c/kWh

- Encourage natural gas contracts now while prices are low
- Subsidies to Critical Loads to reduce losses and promote cognizant energy use
- Right-Of-Way Maintenance: Increase maintenance budget from \$17.1 million to \$50 million. 140 foot ROW clearance for 230kV lines.
 - Environmental: Plant 1 tree per each tree removed for ROW clearing
- Repeal Policy requiring solar-powered water heating

Cost of Proposal

Title	Cost (millions)	Details
Generation – Misc. Upgrades	\$1,700	Storm Hardening, Facility Repairs
Generation – Natural Gas	\$2,600	Dual-fired F-class machines at Palo Seco and San Juan
Generation – Natural Gas Pipeline	\$272	40 mile pipeline at U.S. average pricing including installation, labor, right of way, and miscellaneous expenditures
Generation – Natural Gas Regasification Port	\$8,000	Repurposed LNG Floating Regasification and Storage Unit
Transmission – Misc. Upgrades	\$7,050	Transmission Infrastructure Upgrades, Substation Upgrades, Storm Hardening, Transmission Additions
Renewable Energy - Solar	\$297	50MW fixed-tilt solar investment and installation
Renewable Energy - Wind	\$190	40MW combined on and offshore wind turbine investment and installation
Renewable Energy – Energy Storage	\$468	Lithium Ion batteries for Rural Populations at \$209/kWh
Total	\$20,577	

Test Plan

- Each component of plan tested for feasibility, budget, and reliability
- Microgrid design and testing
 - Migrogrid Design Tool (MDT), DER-CAM, OpenDSS, Gridlab-D
- Comparing Puerto Rico's solution options to solutions around the world
 - Energy storage in Australia, Solar in Dubai, Natural Gas in the United States, etc.

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