Design of a More Reliable Power Grid for Puerto Rico

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Introduction

Problem Statement

- 80% of Puerto Rico's Power Grid destroyed
  - Hurricanes Irma and Maria paired with years with little to no maintenance
  - Lack of PREPA leadership focus on upkeep of system
  - Frequent blackouts which are difficult to resolve
  - $9 billion debt

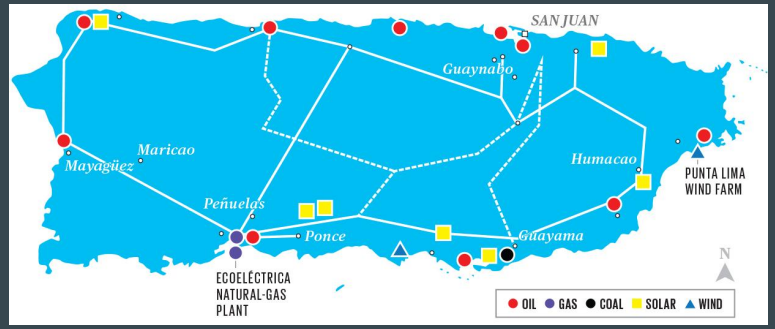
"If you have an old grid susceptible to collapse, there is no way - until you change it completely - that it can sustain the winds of a Category 4, or even really a Category 2"
- Governor Ricardo Rossello

Our Proposal

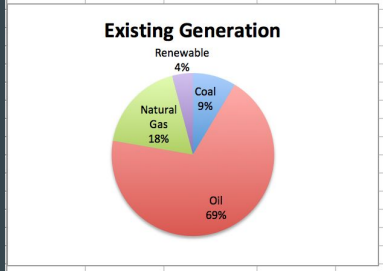
- **Generation**
  - Introduction of large-scale natural gas power through added port and pipeline
- **Transmission**
  - Updated Transmission Structures, added transmission line pathways
- **Microgrid Implementation**
  - Installing independent microgrids
- **Renewable Energy**
  - Large-Scale and Distributed 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

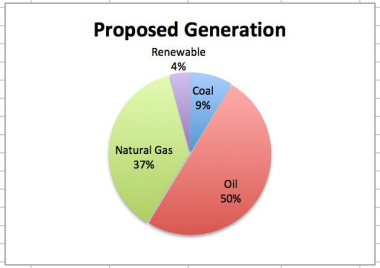
Generation

- Generating capability: 5,839MW
  - Peak demand: 3,060MW (recorded in 8/2017)
- Currently, only two facilities are equipped to be fired by Natural Gas
  - EcoElectrica - 507MW
  - Costa Sur (co-fired) - 900MW total
  - Natural Gas imported through regasification terminal at Guayanilla Bay
- Proposing converting 2 heavy oil fuel plants to natural gas
  - San Juan Generation Plant (402MW)
  - Palo Seco Generation Plant (600MW)
- Encourage Coal and Natural Gas Contracts
  - Coal is an excellent back-up for blackouts due to easy storage



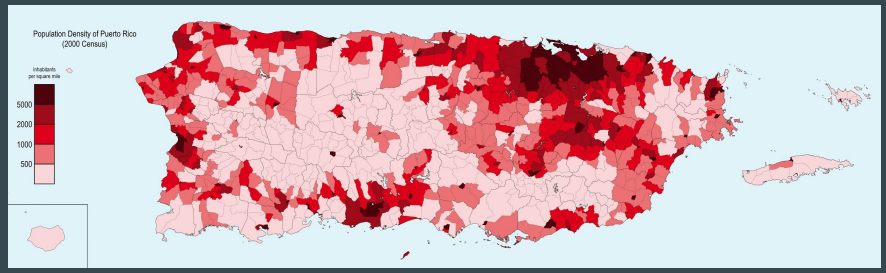
COAL	OIL	NATURAL GAS	RENEWABLE		COAL	OIL	NATURAL GAS	RENEWABLE
454	900	510	24		454	900	510	24
	247	450	45			247	450	45
	464		16			464	400	16
	592		27			592	602	27
	450		4.5			450		4.5
	602		26					26
	400		75					75

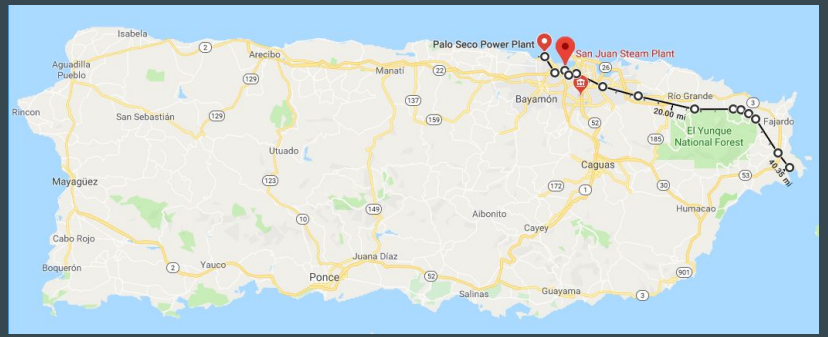




Floating Regasification and Storage Unit

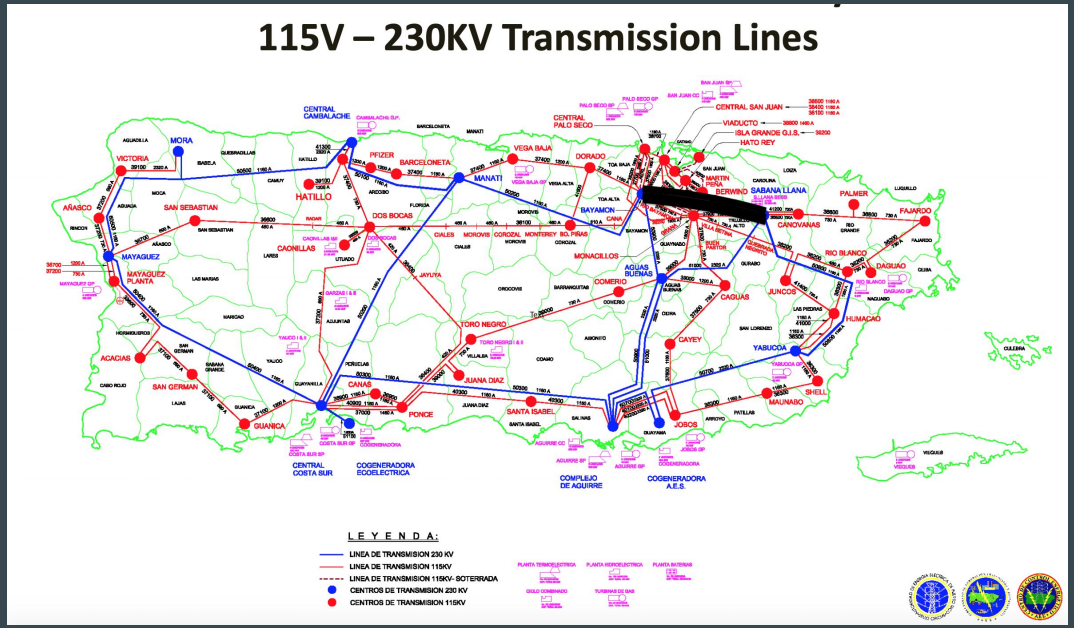
- Proposing a Floating Regasification and Storage Unit (FRSU) at Roosevelt Roads (Retired Naval Base)
  - Remodel LNG ship
- 40 mile pipeline from Roosevelt Roads to San Juan based generation facilities
- Natural Gas and Renewable Energy work together
- Similar FRSU proposals have been approved by FERC, but on South coast
  - Pipeline through mountainous centers rejected.





Transmission

- Addition of 4th Transmission Loop
- Construction of monopoles (vs. Lattice Towers)
- Expanding Right-Of-Ways and improving maintenance pla
  - Current plan: $17.4 million per year.
  - PREPA has proposed $50 million plan
  - Tree Re-Planting Policy



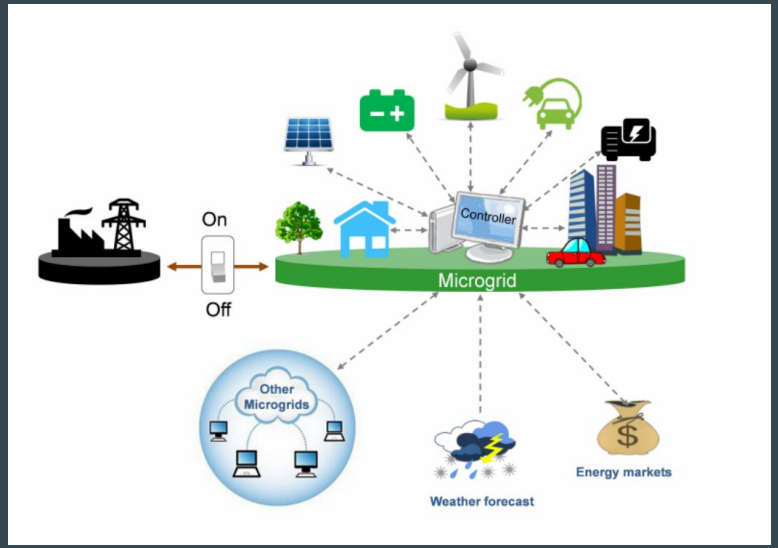
Microgrid for Interconnectivity

- To provide constant power to the whole of Puerto Rico especially during natural disasters
- To help with the storm resilience
- Function as two different ways:
  - Islanded: The microgrid can function on its own without having to depend on an external power source.
  - Grid-tied: To support the other microgrids passively which will ensure constant power supply throughout the whole island.
- Important for rural areas which would be more difficult for constant maintenance of the microgrid.

- Our proposal:
  - To implement a number of microgrids throughout the island to be able to function both ways so fight against the natural disasters that can occur.

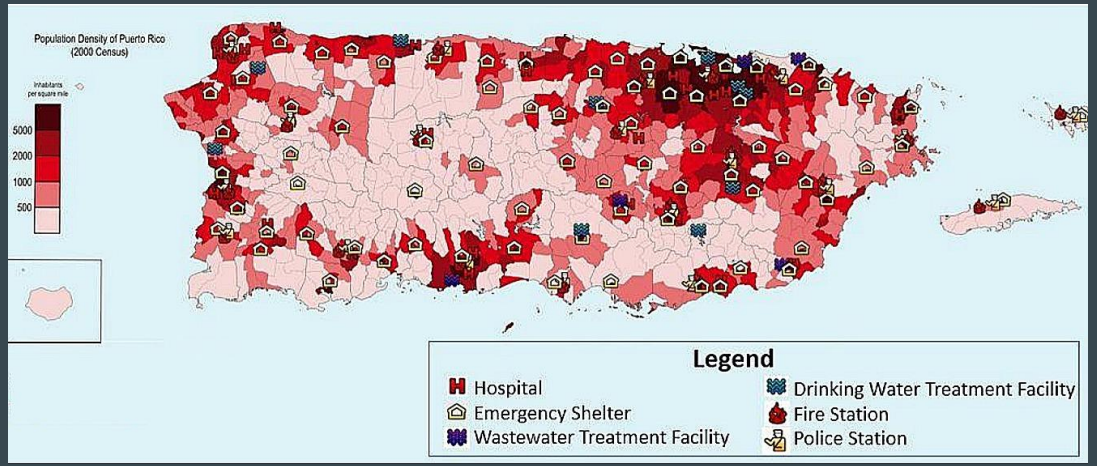
Microgrid Content

- Average microgrid should consist of:
  - Solar panels
    - Building code effects this implementation
    - Solution: Solar house
  - Energy storage
  - Gas and Coal turbines
  - Control center
- External power coming into the microgrid:
  - Solar farms located south of the island
  - Wind turbines off-shore near the north coast
  - Natural gas which will be pipelined to San Juan



Microgrid Distribution

- Population: 3.3 million
- Microgrids implemented based on the population of the area and the closest proximity of important infrastructure such as:
  - Hospitals
  - Police and fire departments
  - Emergency shelters
  - Water waste treatment facility
  - Drinking water treatment facility



- Implementing ≈ 160 independent microgrids
- Each grid can supply ≈ 15,000 consumers
  - San Juan (pop. ≈ 355,000) will have 24 microgrids; Manatí (pop. ≈ 16,000) will have 1 microgrid

Microgrid Testing

- Testing software for the microgrid design:
  - OpenDSS
  - Gridlab-d
  - Distributed Energy Resources - Customer Adoption Model (DER-CAM)
    - Implementation to determine optimal energy resources investment
  - Microgrid Design Toolkit (MDT)

Resources in Puerto Rico

Reserves

Reserves	Puerto Rico	United States	Period
Crude Oil	0 billion barrels	NA	2018
Natural Gas	0 trillion cu ft	322 trillion cu ft	2017
Recoverable Coal	0 million short tons	254,896 million short tons	2015
Capacity	**Puerto Rico**	**United States**	**Period**
Total Electricity Installed Capacity	6 million kW	1,064 million kW	2015

Australia’s project

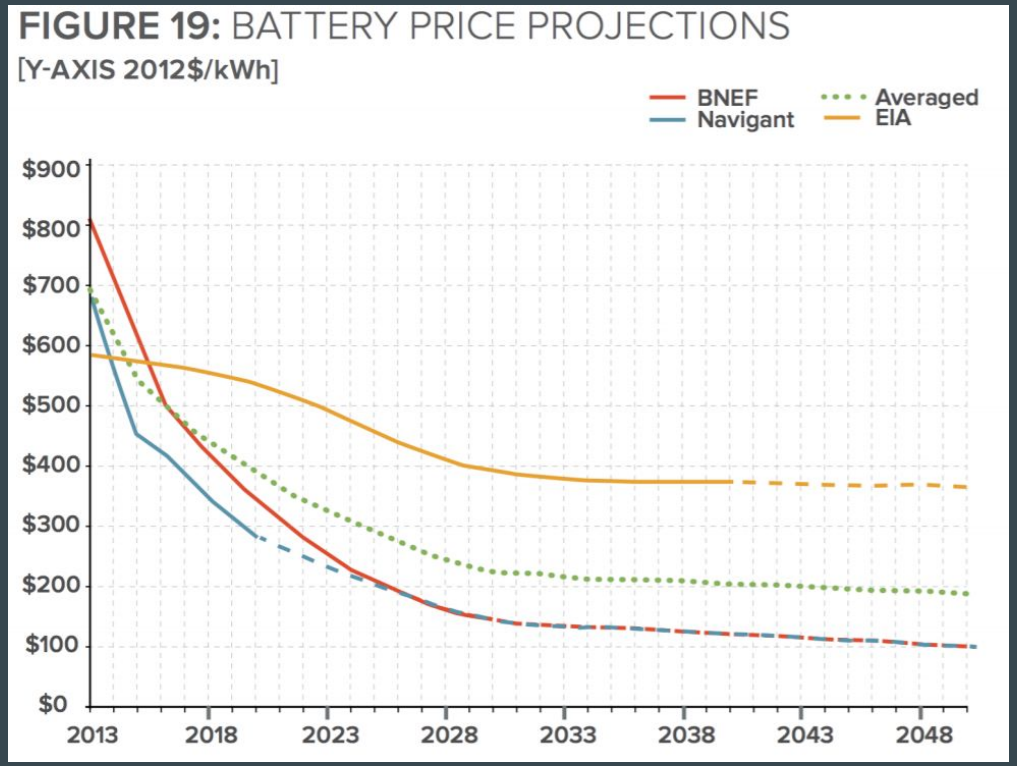
- Neoen
  - 100 MW battery storage facility (Tesla)
- Cost was 66 million (195$/kWh)
- Has made the 26 % of the initial investment in less than a year
- Cheaper, quicker and with zero emissions

Energy Storage

Tesla's rates and costs

Model	Technology	Price (US$)[a]	Capacity (kWh)	Wh per US$	US$per kWh	Power
Powerwall 1	Lithium-ion	US$3,000	6.4	2.13	469	2 kW continuous
Powerwall 2	Lithium-ion	US$5,500 later U	13.5	2.46	437	7 kW peak; 5 kW continuous
Model	**Technology**	**Capacity (kWh)**	**Wh per US$**	**US$ per kWh**	**Operating temp.**	**Weight**
Powerpack 1	Lithium-ion	100	2.13	470	-	-
Powerpack 2	Lithium-ion	200	2.51	398	−22 to 122 °F (−30 to 50 °C)	3,575 lb (1,622 kg)

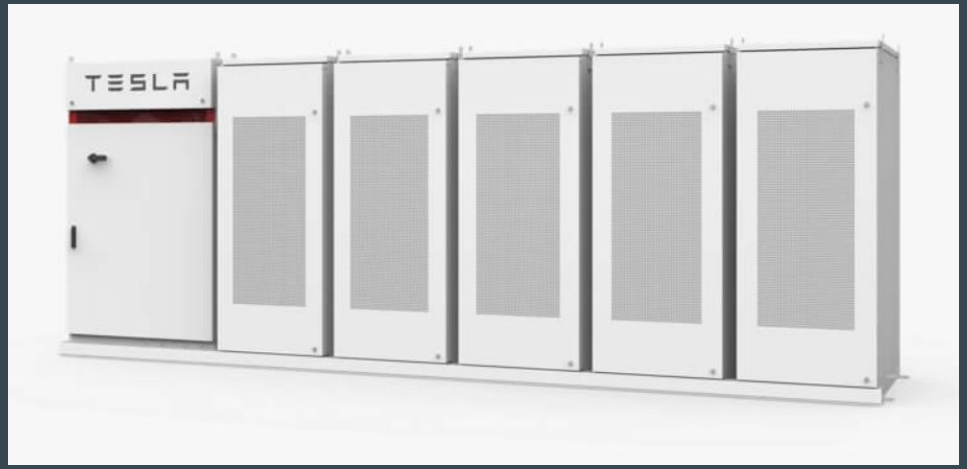
Anticipated Battery Cost Projections



The current average price for batteries in the world is 209$/kWh and there is an expected drop of the 50% by 2025.

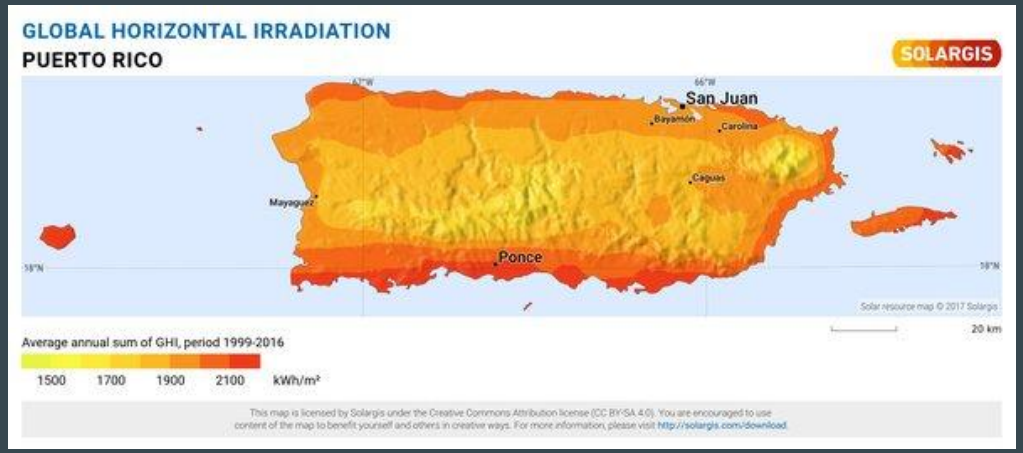
Final Plan for storage

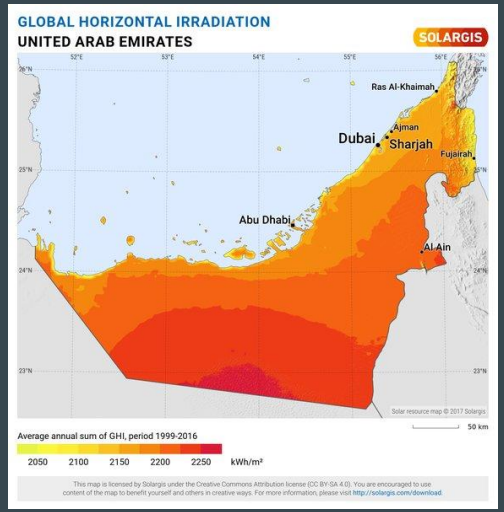
- Puerto Rico (population 3.3 million) Uses 18.8 billion kWh/year
  - 30% consumption in storage
- $141 million investment
  - At $209/kWh price. Invest in crucial areas (San Juan, rural communities), but can wait until prices drop to implement to reduce cost.



Renewable Energy - Solar Insolation

- PR has plenty of sunshine – along the south coast, 2100 kWh/m^2 per year
- Even near San Juan, 2000 kWh/m^2 per year
- Only about 5% less than Dubai and Abu Dhabi – cost of 1.2 GW plant in Abu Dhabi 2.42 c/kWh
- Costs of solar power delivered to the grid should be similar in PR, just slightly higher





Renewable Energy - Solar Radiation and Cost

- Puerto Rico's yearly solar insolation is about 1900-**2000kwh/m^2**,unit cost is ~**3.0 c/kwh**

  [based on costs for similar central station plants in Dubai, Chile and India]

- In California, in 2017 December, the average cost of solar panels (installed cost) was $ 3.23/W , including 30% federal credit. PR should be similar

- Rooftop will generate electricity at ~ 13 c/kWh (1900 kWh/kW annual output, LCOE cost over 30 years at 5% interest)

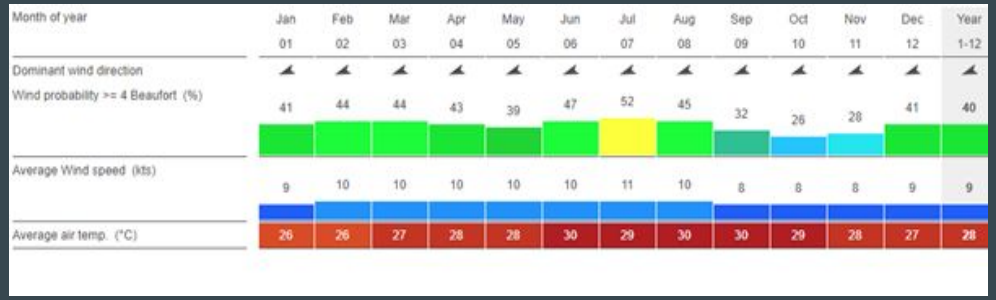
- Very economical for rooftops so long as there is a reasonable buyback provision with the utility as in California

Renewable Energy - Wind

- Appropriately designed turbine towers can withstand hurricanes
  - Many steel monopole structures withstood Irma and Maria
- Wind Farms installed at coastlines
- Wind Speeds ≈ 15-22 mph
  - Turbines operate between 8-30mph, full capacity year round.
- Proposing 30 MW of wind power(30 turbines ranked at 1MW)
- Total cost ≈ $90 million
  - $2,000/kW for turbine, $1000/kW for installation

Offshore Wind Proposal

- 10-25m average depth off San Juan Coast very suitable for offshore wind
- Proposing 50MW offshore wind turbines (2 MW turbines) near San Juan.
    - Similar turbines in Massachusetts provide power to consumers at 6.5 c/kWh (after 6.5 c/kWh subsidy)



Economics and Policies

- Introduce subsidies to critical loads to reduce spending and promote cognizant energy use
- Repeal free energy plan
  - Free = Waste
- Increase cost of electricity (currently $0.10 below Caribbean average)
  - Residential: 21.17 c/kWh to 26.17 c/kWh
  - Industrial: 19.78 c/kWh to 24.78 c/kWh
  - Commercial: 24.32 c/kWh to 29.32 c/kWh
- Encourage natural gas contracts while costs are low
- Encourage coal contracts for disaster preparedness while contracts are low
- Buyback policies for excess electricity as in California
- Update some environmental regulations to allow for grid maintenance
  - No net tree cutting (a policy implemented world-wide)
- Pass policy allowing and encouraging rooftop solar

Capital Investment

Title	Cost (millions)	Details
Generation - Misc. Upgrades	$1,700	Storm Hardening, Facility Repairs
Generation - Natural Gas Generation	$2,600	Dual-Fired F-Class 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	$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	$161	50 MW solar investment and installation
Renewable Energy - Onshore Wind	$90	30 MW of onshore wind investment and installation
Renewable Energy - Offshore Wind	$152	50 MW offshore wind investment and installation
Renewable Energy - Energy Storage	$141	Lithium Ion batteries at $209/kWh
Total	$20,166	

Conclusion

- Introduction of microgrids to increase resilience and strengthen grid against blackouts
- Transition to Natural Gas by constructing a regasification facility for LNG at Roosevelt Roads
  - Build a short gas pipeline from Roosevelt Roads to San Juan
- Encourage coal turbines and storage to allow for resiliency and fuel for blackouts
- Significantly increased use of renewable energy (both solar and wind) to maximize Puerto Rico's resources
  - Solar and wind, coupled with batteries and gas turbines, are likely to be the lowest cop options for resilient energy generation in Puerto Rico
- Encouraging smart energy usage through updated energy policies – demand side management, doing away with free electricity.
- Update some environmental regulations to allow for proper transmission maintenance
  - No net cutting of trees

Questions?