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Clean Energy Technical Solutions for Power Sector Resilience

March 26, 2020

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- Policy, planning, and deployment support.
- Global technical platforms.

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The USAID-NREL Partnership’s global technical platforms provide free, state-of-the-art support on critical challenges to scaling up advanced energy systems.

REexplorer MAPPING OUR ENERGY FUTURE	Greening the Grid	I-JEDI	Resilient Energy Platform
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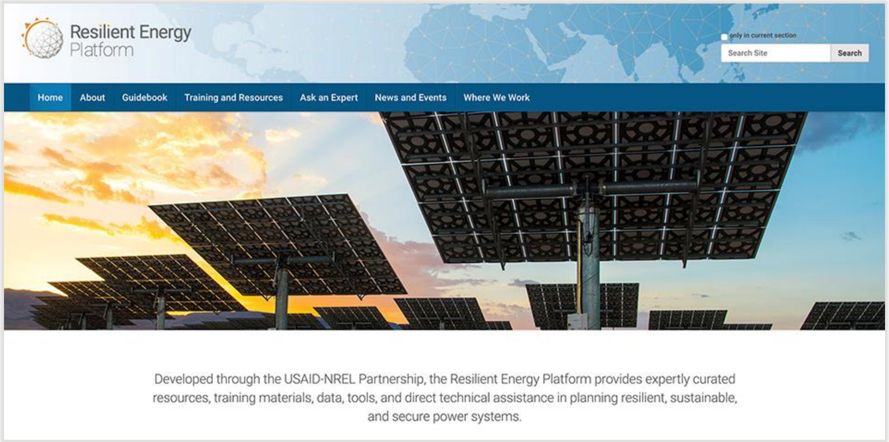
Resilient Energy Platform

- The Resilient Energy Platform provides expertly curated resources, training materials, tools, and technical assistance to enhance power sector resilience.

- Resilient Energy Platform enables decision-makers to assess power sector vulnerabilities, identify resilience solutions, and make informed decisions to enhance power sector resilience at all scales.



Developed through the USAID-NREL Partnership, the Resilient Energy Platform provides expertly curated resources, training materials, data, tools, and direct technical assistance in planning resilient, sustainable, and secure power systems.

www.resilient-energy.org

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Introductions

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Technical Solutions for Power Sector Resilience

Eliza Hotchkiss, NREL

Agenda

- Background
  - Definition of Power Sector Resilience
- Technical Solutions
  - End use energy management
  - Generation
  - Energy storage
  - Smart grids
  - Protecting vulnerable assets
- Real world examples
  - Barbados
  - Puerto Rico

What is Power Sector Resilience?

The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions to the power sector.

Resilience planning identifies the threats and hazards, vulnerabilities, and impacts to the power system, and devises strategies to mitigate them.

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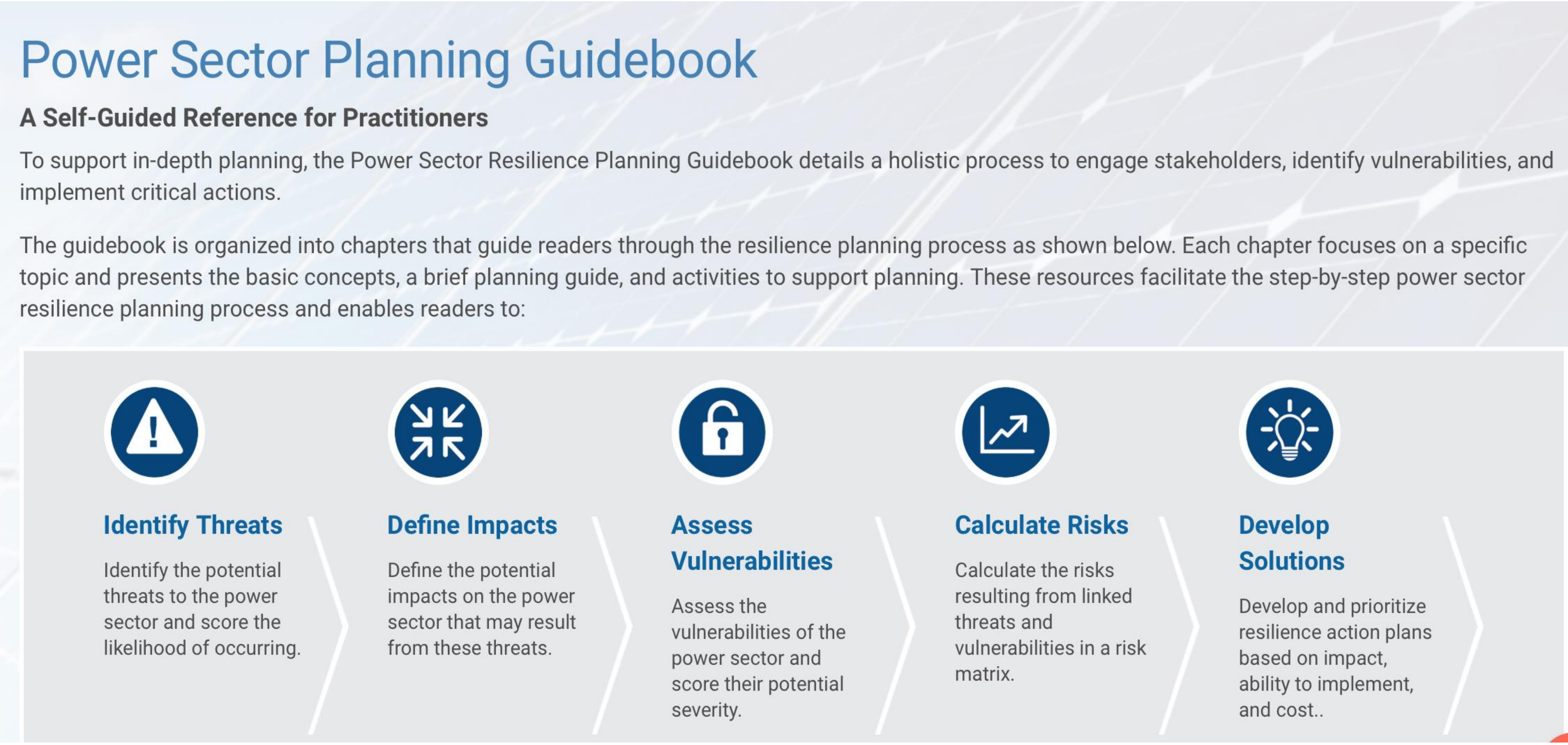


Power Sector Planning Guidebook

A Self-Guided Reference for Practitioners

To support in-depth planning, the Power Sector Resilience Planning Guidebook details a holistic process to engage stakeholders, identify vulnerabilities, and implement critical actions.

The guidebook is organized into chapters that guide readers through the resilience planning process as shown below. Each chapter focuses on a specific topic and presents the basic concepts, a brief planning guide, and activities to support planning. These resources facilitate the step-by-step power sector resilience planning process and enables readers to:

Identify Threats

Identify the potential threats to the power sector and score the likelihood of occurring.

Define Impacts

Define the potential impacts on the power sector that may result from these threats.

Assess Vulnerabilities

Assess the vulnerabilities of the power sector and score their potential severity.

Calculate Risks

Calculate the risks resulting from linked threats and vulnerabilities in a risk matrix.

Develop Solutions

Develop and prioritize resilience action plans based on impact, ability to implement, and cost..

Power Sector Vulnerabilities and Impacts

Vulnerabilities

- Weaknesses within infrastructure, systems, or operations
- Susceptible to hazards and threats

Impacts

- Power or water outages resulting from physical infrastructure damage or aging infrastructure
- Fuel supply, food, and water shortages
- Shifts in energy demand
- Ancillary financial, economic, and social implications of failures within systems.

Technical Solutions for Resilience

Resilient Power Sector

- Energy End Use Management
- Power Generation
- Energy Storage
- Asset Protection
- Smart Grids

Technical Solutions for Resilience

Energy End Use Management

Smart Grids

Power Generation

Resilient Power Sector

Asset Protection

Energy Storage

Energy End-Use Management

Conditions	**Energy Efficiency**	**Passive Survivability**
Normal operating conditions	• Reduces demand spikes, which can lead to grid disruptions • Lowers energy bills • Greater occupant comfort	• Reduces demand spikes, which can lead to grid disruptions • Lowers energy bills even further than EE alone • Greater occupant comfort
Grid outage	• Greater occupant comfort during shorter outages, as compared to inefficient buildings	• Greater occupant comfort during longer outages • Shelter in place

Passive Survivability

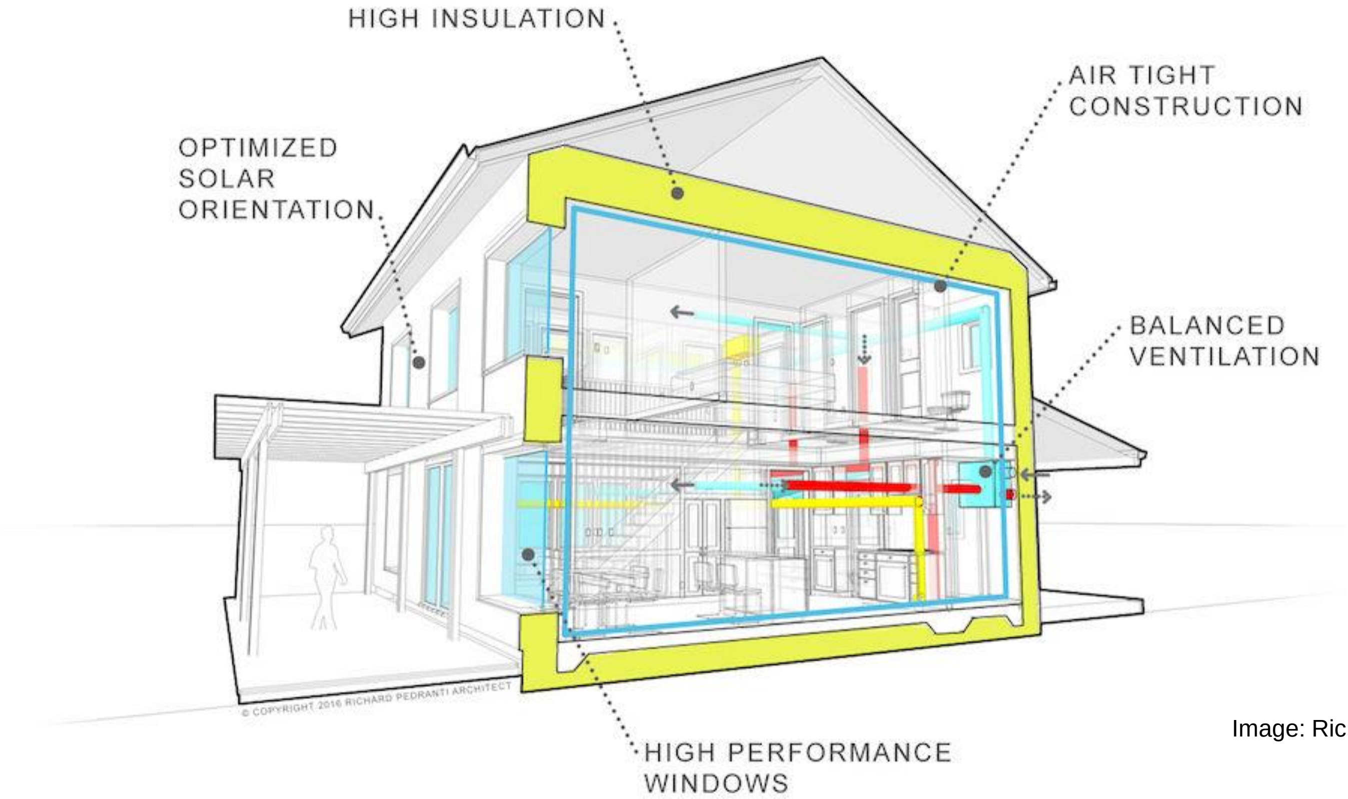


Image: Richard Pedranti Architect

Passive Survivability

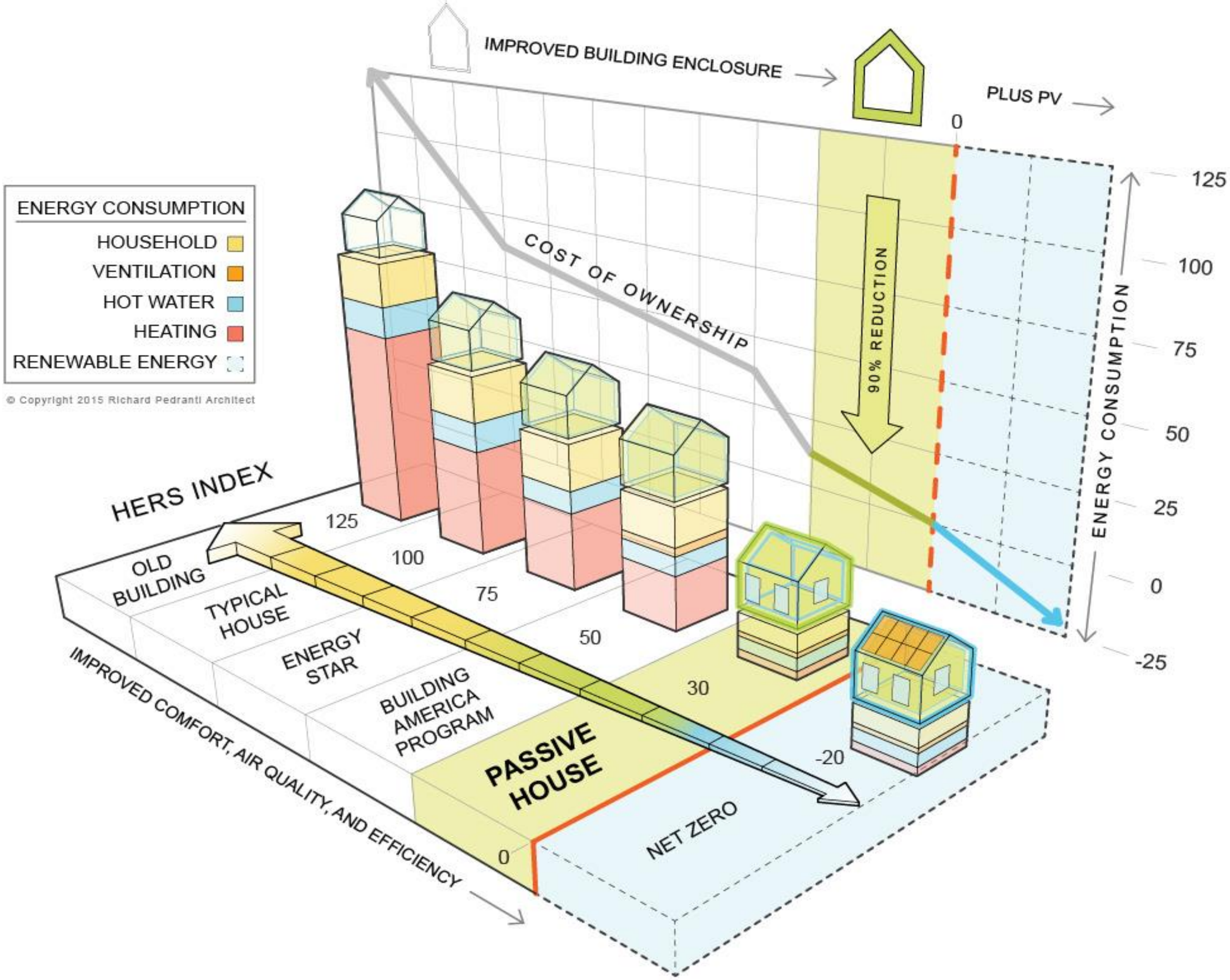
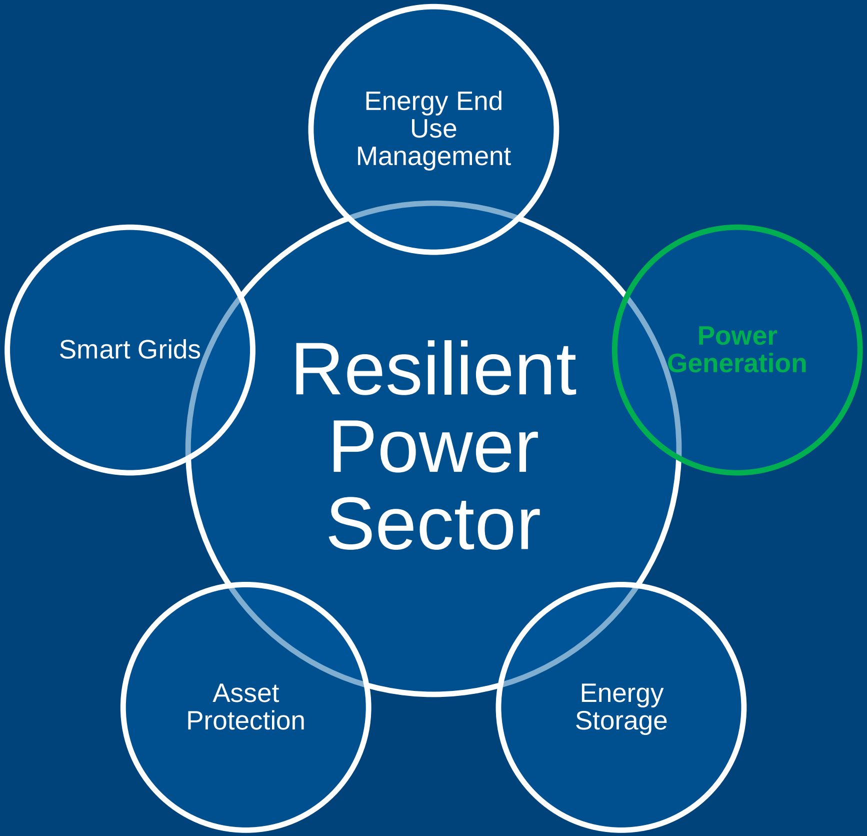


Image: Richard Pedranti Architect

Technical Solutions for Resilience



Resilient Power Sector

Energy End Use Management

Power Generation

Energy Storage

Asset Protection

Smart Grids

Power Generation

Conditions	Energy Efficiency	Passive Survivability	Onsite Generation with Storage
Normal operating conditions	• Reduces demand spikes, which can lead to grid disruptions • Lowers energy bills • Greater occupant comfort	• Reduces demand spikes, which can lead to grid disruptions • Lowers energy bills even further than EE alone • Greater occupant comfort	• More cost savings – reduced demand charges, sale of excess power to grid • Support local renewable energy goals • Reduced likelihood of service disruptions due to demand spikes
Grid outage	• Greater occupant comfort during shorter outages, as compared to inefficient buildings	• Greater occupant comfort during longer outages • Shelter in place	• Continuity of operations • Potential for long-term operation and reduced impact to users • Pressure valve for grid operators

Power Generation Solutions

Diversification

- Diversifying generation sources helps alleviate potential risks and reduces impact

Distribution

- Decentralizing energy sources, or distributing them spatially, is a technique used to enhance power system resilience.

Diversifying Energy Sources

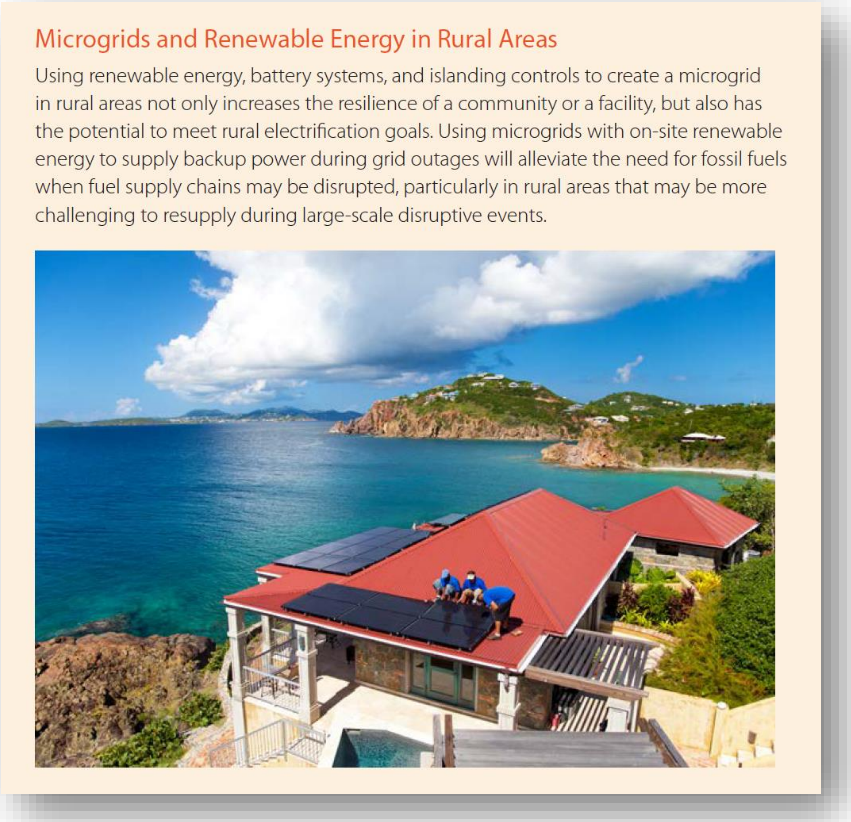
Hybrid Systems: conventional fuels paired with renewable energy technologies

Renewable Systems:

- Hydropower
- Solar PV
- Solar Thermal
- Wind
- Bioenergy
- Geothermal

Distributed Generation

- Spatial diversification
- Islandable systems
- Microgrids



Microgrids and Renewable Energy in Rural Areas

Using renewable energy, battery systems, and islanding controls to create a microgrid in rural areas not only increases the resilience of a community or a facility, but also has the potential to meet rural electrification goals. Using microgrids with on-site renewable energy to supply backup power during grid outages will alleviate the need for fossil fuels when fuel supply chains may be disrupted, particularly in rural areas that may be more challenging to resupply during large-scale disruptive events.

Technical Solutions for Resilience

Energy End Use Management

Smart Grids

Resilient Power Sector

Power Generation

Asset Protection

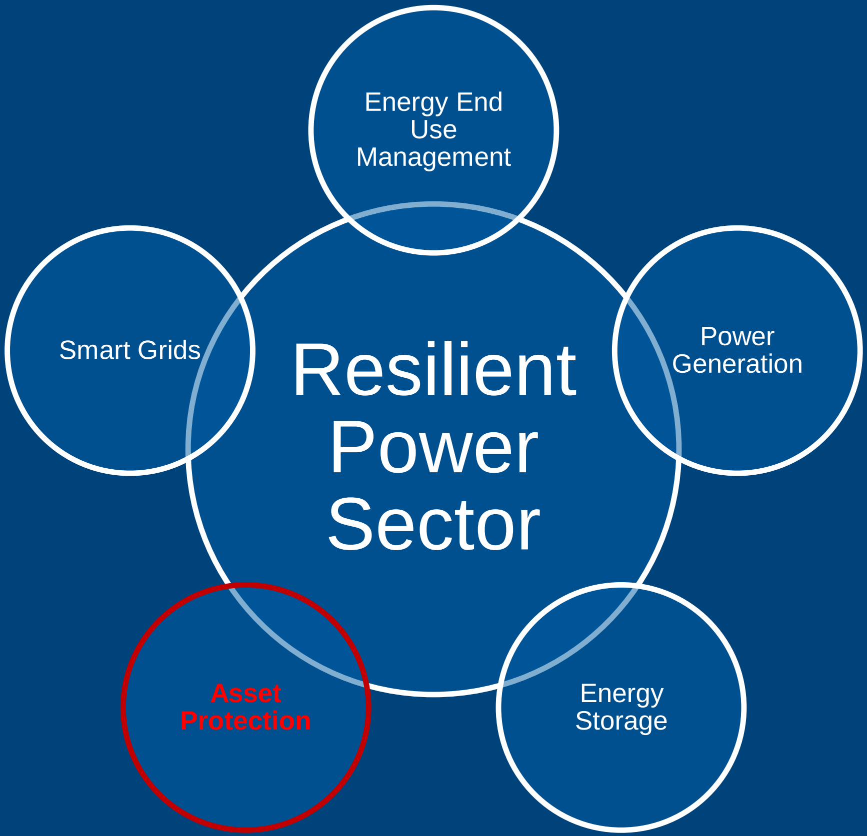
Energy Storage

Energy Storage

Types of Energy Storage:

- Battery
- Thermal
- Pumped hydro
- Compressed air
- Flywheels

Technical Solutions for Resilience



Resilient Power Sector

Energy End Use Management

Power Generation

Energy Storage

Asset Protection

Smart Grids

Asset Protection

Image Source: T&D World

Technical Solutions for Resilience

Resilient Power Sector

Energy End Use Management

Power Generation

Energy Storage

Asset Protection

Smart Grids

Smart Grids

Components of smart grids:

- Real time data
- Smart meters
- Two-way communication
- Flexible control
- Supports flexibility, efficiency, and resilience

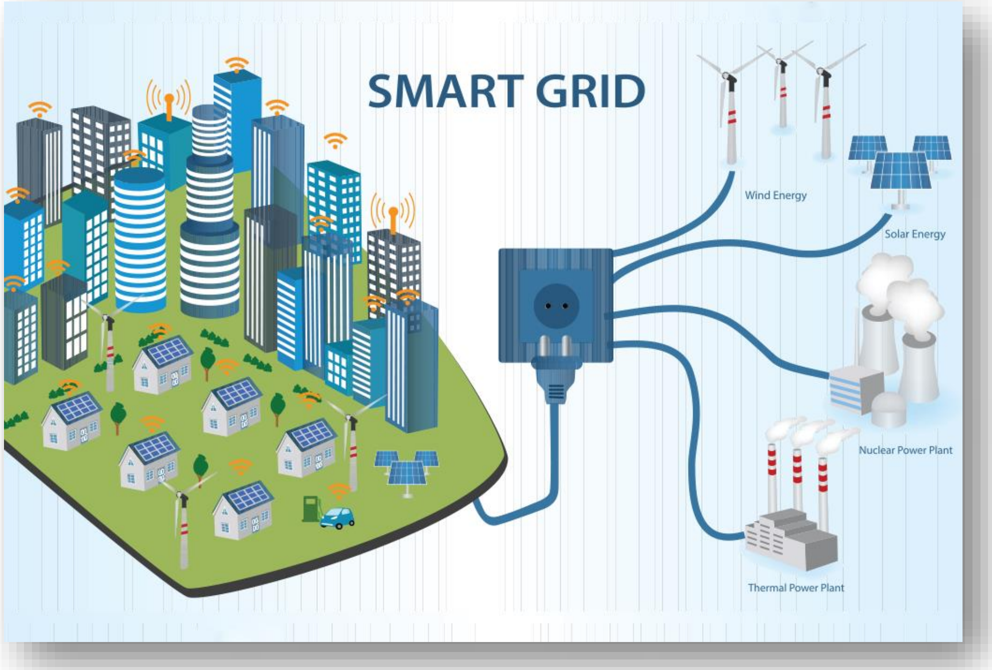


Image Source: IEEE Innovation at Work

Developing Solutions

Resilience solutions should be:

- Site specific
- Meet the energy loads
- Consider critical loads
- Installed well to survive numerous threats and hazards
- There is no “one-size fits all” approach to solutions for resilience

Photo by Dennis Schroeder, NREL 26962

Building Resilient Communities – Disaster Risk Energy Access Management (DREAM) Project in Barbados

Stuart Bannister

Agenda

- Introduction
- Overview of the DREAM Project
- DREAM Project Implementation Partners & Funding Agency
- DREAM Project Solar Photovoltaic (PV) Installations
- Photographs of the Solar PV Installations at the Community Centre’s, Pavilions and Polyclinics
- Building Capacity at the Community Level
- Photographs of Solar PV Training Course

Introduction

- Barbados has a population of approximately 285,000
- Barbados is a SIDS and has a land area of 116 square miles
- The electricity grid has an installed capacity of 239 MW which is heavily dependent of imported fossil fuels
- The current renewable energy capacity on the grid is 40 MW (30 distributed solar PV + 10 MW Utility Scale solar PV)
- Annual Electricity production is approximately 944 GWh
- Barbados is prone to tropical storms and hurricanes.

Location of Barbados

Overview of DREAM Project

- The project was divided into three (3) components:
  - Component 1:*Renewable energy policy framework* – Improving the licensing framework for the deploying of large-scale renewable energy projects
  - Component 2: *Clean energy capacity development* – Development of community focus training in solar photovoltaic installation and strategic engagement of the public
  - Component 3: *Solar photovoltaic installations* - Community and Resource Center's, Sports Pavilions and Polyclinics
- The project commenced in June 2015 and was completed in November 2019
- The project budget was 1.7 million USD

DREAM Project Implementation Partners & Funding Agency

Implementation Partners

MINISTRY OF Energy & Water Resources
UTILISING OUR NATURAL RESOURCES

UNDP
Empowered lives.
Resilient nations.

Funding Agency

gef

DREAM Project Solar PV Installations

- Twenty-two (22) PV systems with battery back-up at Community, Resource Centre's and Pavilions (Total Solar PV Capacity: 70.0 kWp)

- The battery bank (20kWh to 40kWh) of the PV systems at the Community Centre’s are designed to power the ‘critical’ loads (such as electrical sockets for telecommunication devices and lighting in offices and hall areas.)

- Nine (9) PV systems interconnected to diesel generators at Polyclinics (Total Solar PV Capacity:172 kWp)

- All nine (9) Polyclinics have 100% diesel generators back-up. The PV systems reduce the electricity consumption from the grid and are interconnected with the generators to offer fuel savings when the grid goes offline.

Photographs of the Solar PV Installations: Community Centre’s and Pavilions

7.5kWp PV System

5.0kWp PV System

Battery Bank

Hybrid Inverter, Charge Controller and Data Logger

Photographs of the Solar PV Installations: Polyclinics

15kWp PV System

51kWp PV System

13kWp PV System

66kW Inverter

Building Capacity at the Community Level

- As part of the DREAM project a National Vocational Qualification (NVQ) was developed with our Technical and Vocational Education and Training (TVET) Council in Solar Photovoltaic Installation Level 1
- Target group – Youth and under-employed
- Aim – Increase the knowledge of solar PV installation and have persons who are properly training in basic solar PV maintenance
- Pilot of Training – Thirteen (13) persons completed the training
- Engagement with Private Sector – Five (5) Solar PV Installation companies donated PV equipment, tools and safety equipment
- Internship Opportunities

Photographs of the Solar PV Training

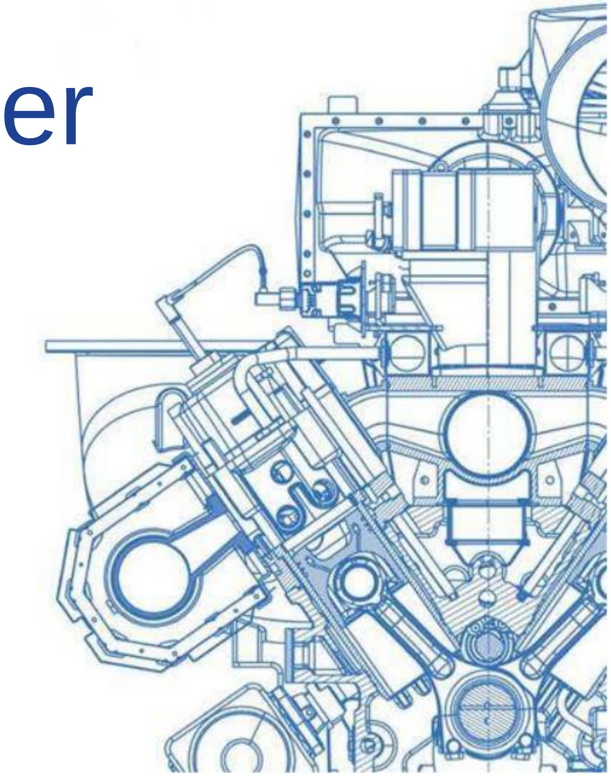
Control Your Energy Budget

and improve your Environmental Footprint

Combined Heat & Power

for a Resilience & Reliability

Roberto Acosta, MSEE



CHP
EPA COMBINED HEAT AND POWER PARTNERSHIP

Agenda

- About Puerto Rico
- Historical Resilience Challenges
- Electrical Infrastructure State & Cost Projections
- CHP Proposition – Critical Infrastructure
- Hospital de la Concepcion Case Study
- Residential Works post Hurricane Maria
- Challenges

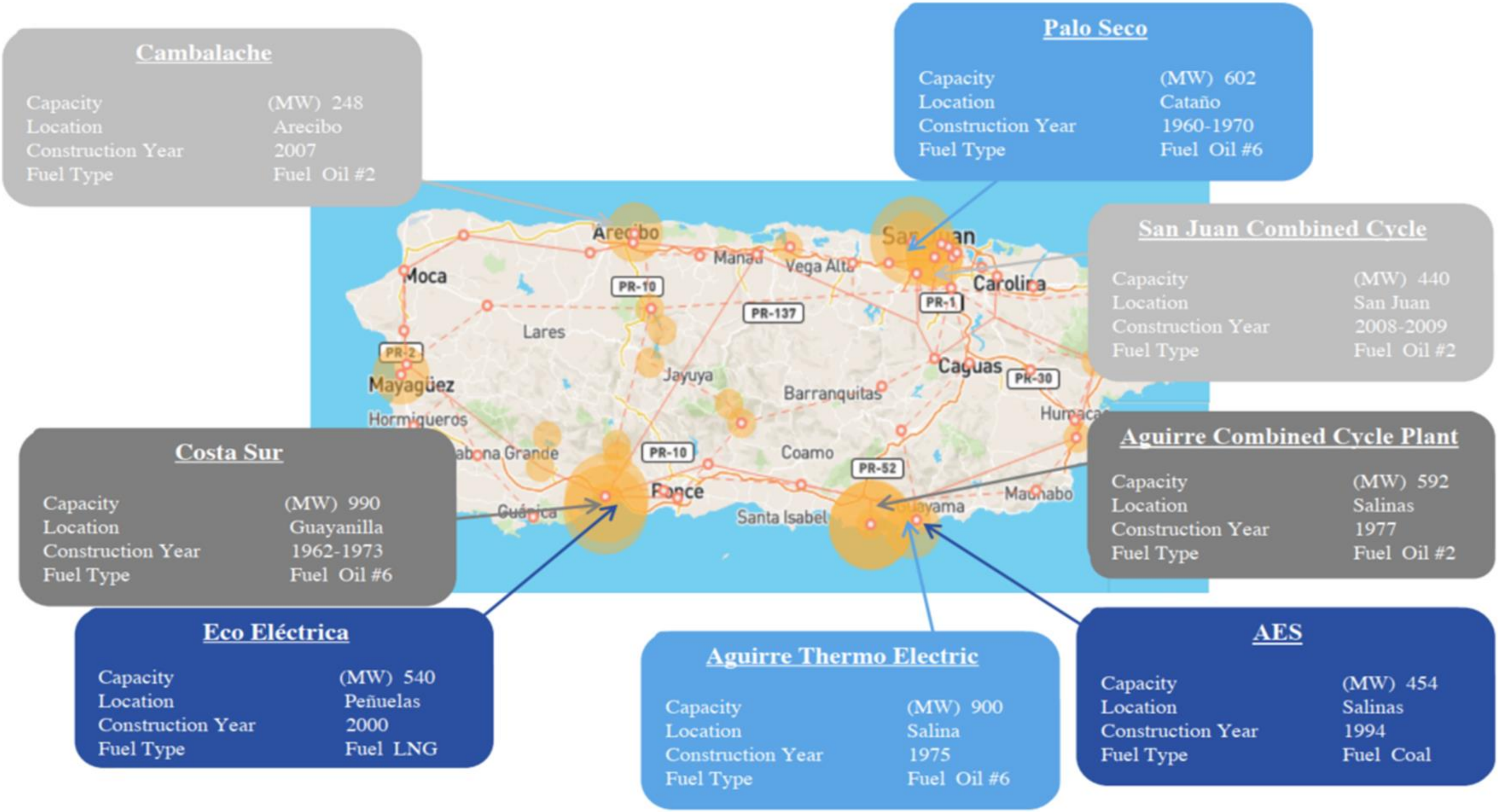
About Puerto Rico

- Puerto Rico (PR) – A U.S. territory in the Caribbean
  - Population: 3,294,626, 988 p/mi^2 (382 p/km^2)
  - Area: 100 x 35mi, 3,508 mi^2 (9,104 km^2)
  - Currency: USD; GDP: $103 billion; GNI: $86 billions
  - Sunrise/Sunset Average: 6:54am to 6:21pm
  - Climate: 80.6°F-hr Avg (27°C), 92.9°F Max 76.3% RH
- Electric Grid; PREPA $3.4B revenues, $9.4B assets, $11.4B liabilities
  - 5,839MW Capacity, 101MW Wind & 212MW PV + 30MW PV Inf. (est.)
  - 16,995,838 MWh/yr; 38% Res, 47% Com., 13% Ind.
  - 45% of power plants from oil, 34.97% cumulative efficiency
  - 2,416 miles transmission lines; 30,675 miles distribution lines
  - 238 substations 38KV, 51 substations 115KV
  - Water: 1,697.25 MG/yr fresh / 620,500 MG/yr saline (USGS-1441)
  - 14 units on MATS; EPA Mercury and Air Toxics Standards

Historical Resiliency Challenges

- 1/7/2020 - 6.4 earthquake; blackout & weeks of power outages
- 2018 - Several blackouts & power outages, Hurricane Maria Recovery
- 9/20/2017 - Hurricane Maria, longest and largest blackout in U.S. history and the second-largest blackout in the world on record.
- 9/7/2017 - Hurricane Irma, weeks of power outage
- 9/20/2016 - blackout, substation fire
- 8/1/2016 - ENDI reports 1,007 (2013), 5,707 (2015) power interruptions
- Over 120+ cumulative hours of power interruptions per year
- PR long history of hurricanes:
- 2014 (Cristobal, Bertha), 2012 (Rafel), 2011 (Irene, Emily), 2010 (Otto), 2008 (Kyle), 2007 (Olga, Noel), 2004 (Jeanne, Ivan), 2001 (Dean), 1999 (Jose), 1998 (Georges), 1996 (Hortensia), 1995 (Marilyn, Luis), 1993 (Cindy), 1989 (hugo), 1984 (Klaus), 1979 (Frederick, David, Claudette)

Major Generation Sites



Cambalache

Capacity	(MW) 248
Location	Arecibo
Construction Year	2007
Fuel Type	Fuel Oil #2

Palo Seco

Capacity	(MW) 602
Location	Cataño
Construction Year	1960-1970
Fuel Type	Fuel Oil #6

San Juan Combined Cycle

Capacity	(MW) 440
Location	San Juan
Construction Year	2008-2009
Fuel Type	Fuel Oil #2

Costa Sur

Capacity	(MW) 990
Location	Guayanilla
Construction Year	1962-1973
Fuel Type	Fuel Oil #6

Aguirre Combined Cycle Plant

Capacity	(MW) 592
Location	Salinas
Construction Year	1977
Fuel Type	Fuel Oil #2

Eco Eléctrica

Capacity	(MW) 540
Location	Peñuelas
Construction Year	2000
Fuel Type	Fuel LNG

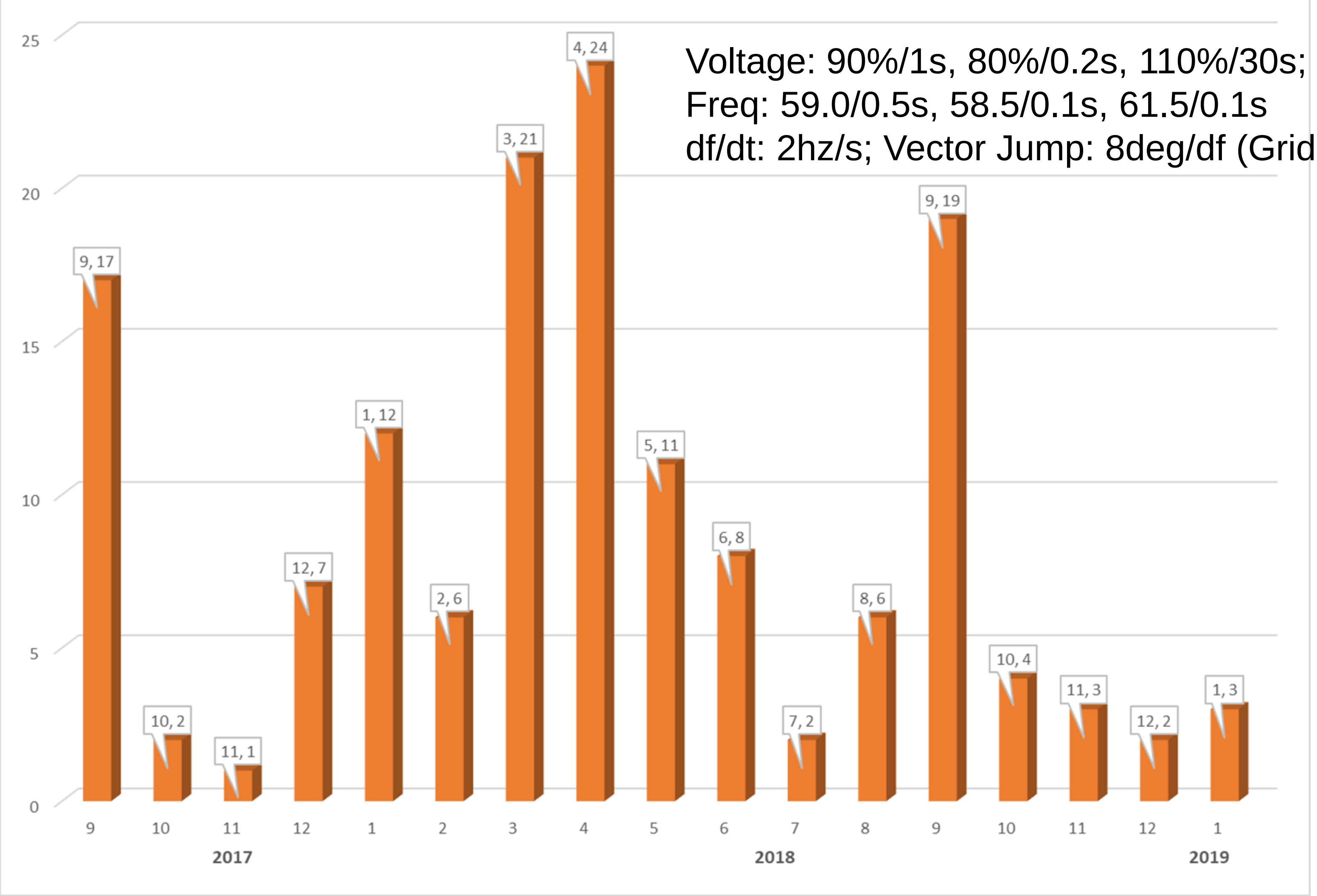
Aguirre Thermo Electric

Capacity	(MW) 900
Location	Salina
Construction Year	1975
Fuel Type	Fuel Oil #6

AES

Capacity	(MW) 454
Location	Salinas
Construction Year	1994
Fuel Type	Fuel Coal

Power Quality Incidents



Voltage: 90%/1s, 80%/0.2s, 110%/30s; 115%/0.2s
Freq: 59.0/0.5s, 58.5/0.1s, 61.5/0.1s
df/dt: 2hz/s; Vector Jump: 8deg/df (Grid Tied)

Cost Projections – Uncertain!

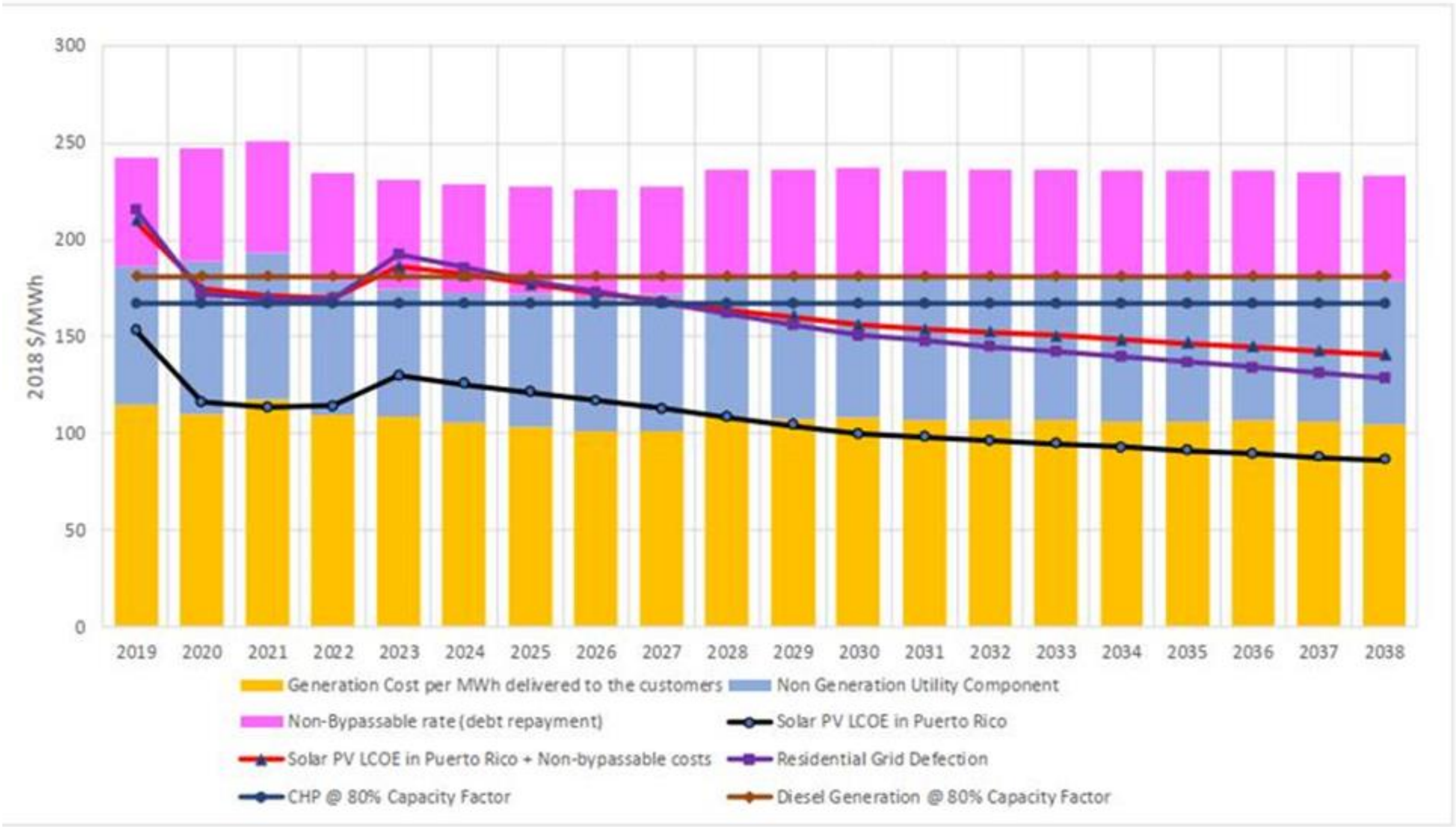


Exhibit 8-30:Final S4S2 Generation Portfolio Rates Compared to Unit Costs of Customer Alternatives

Hospital de la Concepcion


Hospital Beds: 167


Rehabilitation Beds: 19


Surgery Suites: 9

Emergency room


ER Observation: 19

ER Fast Track: 15


Imaging Center


Endoscopy Unit: 2


Laboratory and Pathology Services


Birthing Suites: 4


Intensive Neonatal

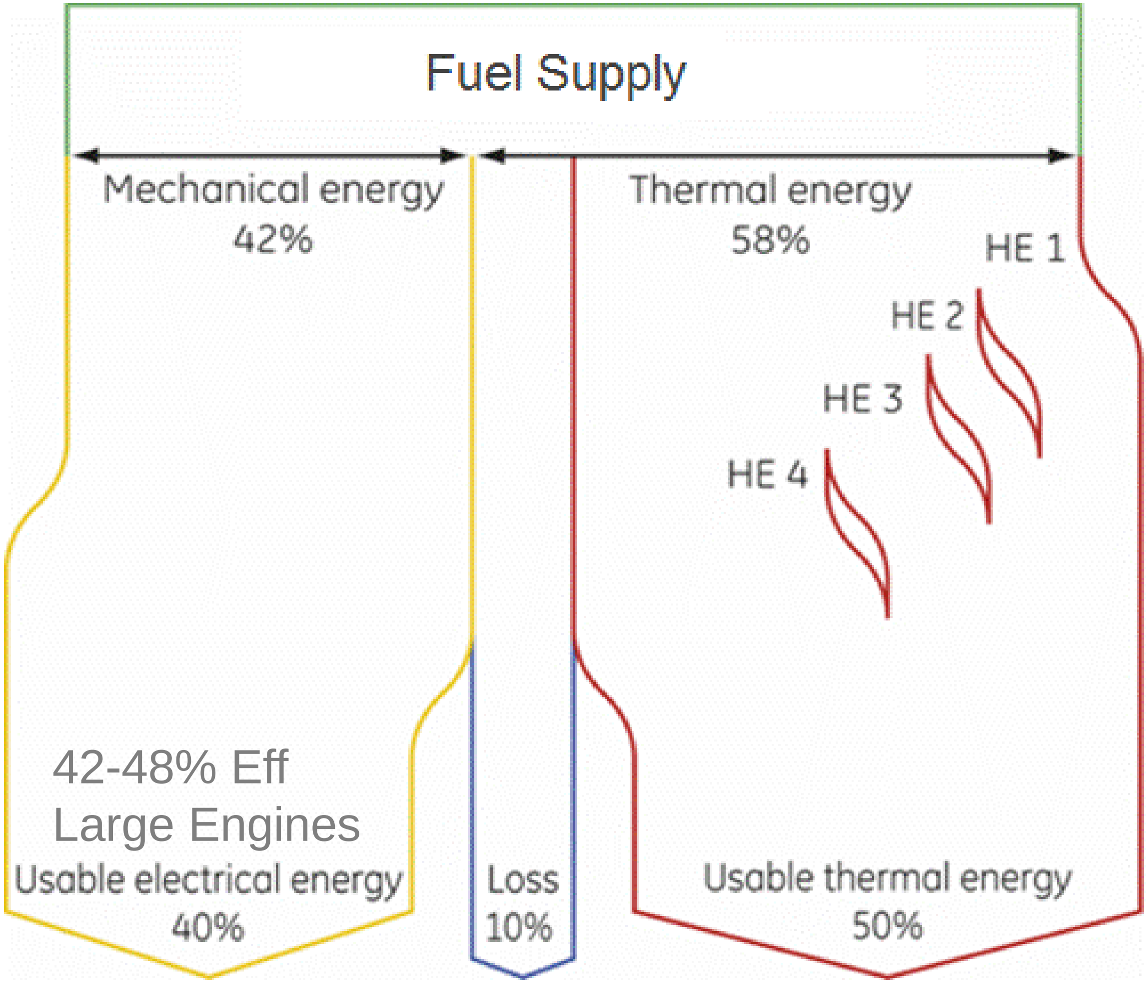

Neuro-Surgical Intensive Care

Metrics (before CHP):
- Total Square Feet: 220,000
- Energy consumption: 10.83 MWh / Year
- Max Demand: 2,133 KVA / 1,743 KW
- Avg Demand: 1,753 KVA / 1,480 MW
- Contracted Load: 1,750 KVA

Metrics Thermal:
- Cooling: 745 Tons Max
  561 Tons Avg
- System KW/Ton: 1.19
- Reheat Max: 326 KW
- Reheat Avg: 188 KW

CHP Fundamentals

CHP systems utilize the waste heat incurred during engine operation to generate high overall plant efficiencies.



HE 1

Mixture intercooler

HE 2

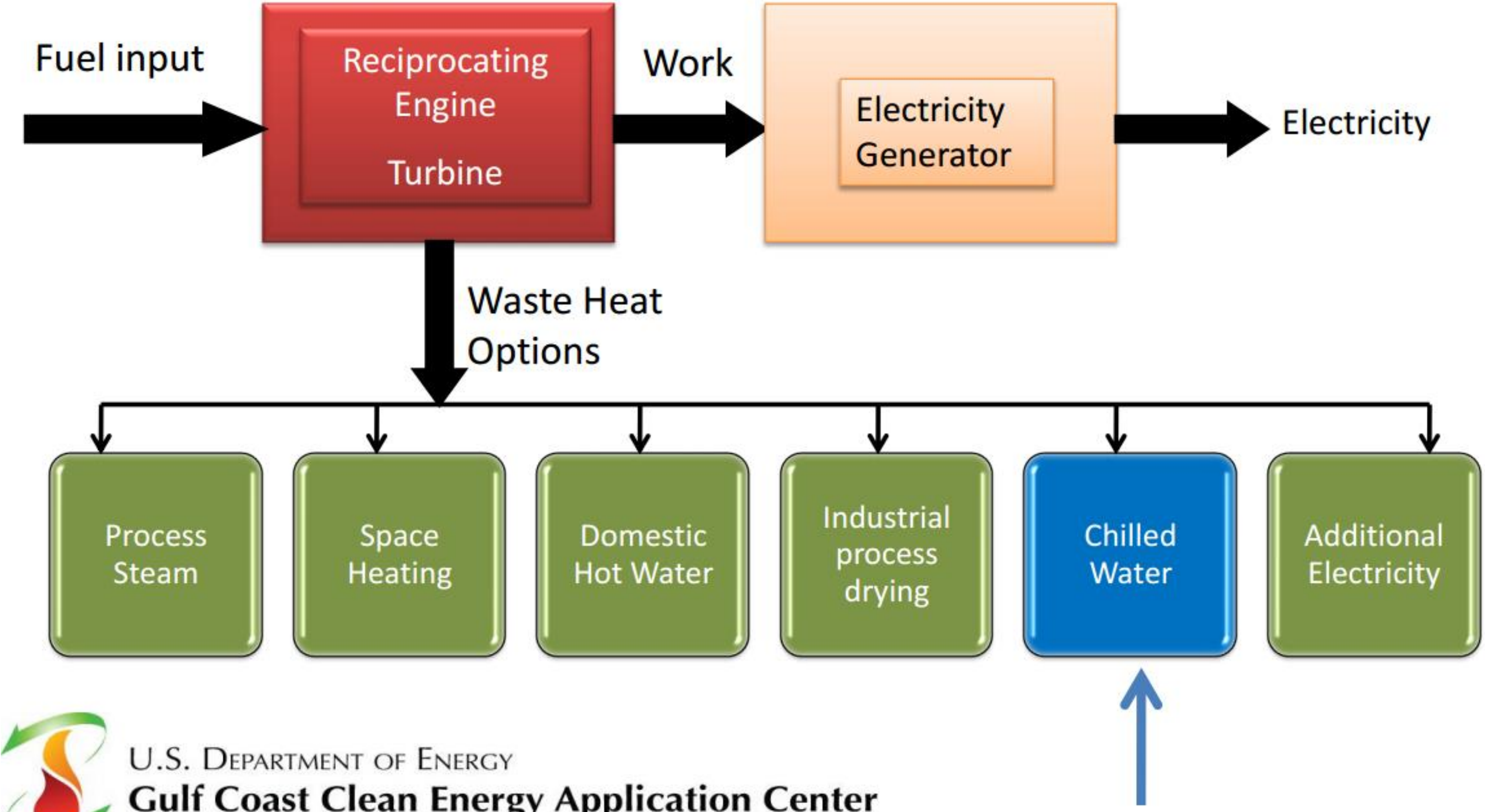
Oil exchange heater

HE 3

Engine jacket water heat exchanger

HE 4

Exhaust gas heat exchanger



Fuel input

Reciprocating Engine

Turbine

Work

Electricity Generator

Electricity

Waste Heat Options

Process Steam

Space Heating

Domestic Hot Water

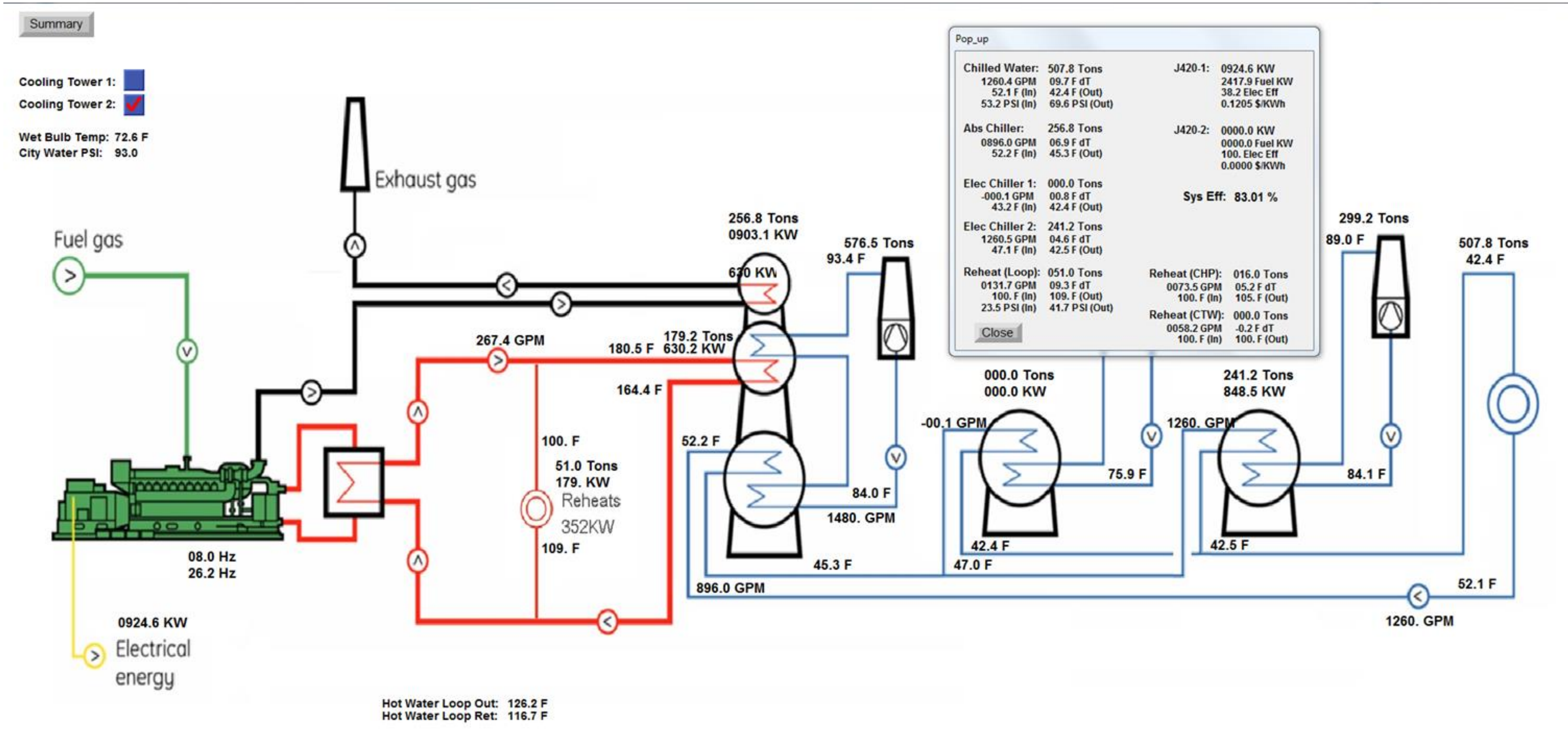
Industrial process drying

Chilled Water

Additional Electricity

U.S. Department of Energy
Gulf Coast Clean Energy Application Center

CHP System



Summary

Cooling Tower 1: 🟦
Cooling Tower 2: ☑

Wet Bulb Temp: 72.6 F
City Water PSI: 93.0

Pop_up

Chilled Water: 507.8 Tons
1260.4 GPM 09.7 F dT
52.1 F (In) 42.4 F (Out)
53.2 PSI (In) 69.6 PSI (Out)

Abs Chiller: 256.8 Tons
0896.0 GPM 06.9 F dT
52.2 F (In) 45.3 F (Out)

Elec Chiller 1: 000.0 Tons
-000.1 GPM 00.8 F dT
43.2 F (In) 42.4 F (Out)

Elec Chiller 2: 241.2 Tons
1260.5 GPM 04.6 F dT
47.1 F (In) 42.5 F (Out)

Reheat (Loop): 051.0 Tons
0131.7 GPM 09.3 F dT
100. F (In) 109. F (Out)
23.5 PSI (In) 41.7 PSI (Out)

J420-1: 0924.6 KW
2417.9 Fuel KW
38.2 Elec Eff
0.1205 $/KWh

J420-2: 0000.0 KW
0000.0 Fuel KW
100. Elec Eff
0.0000 $/KWh

Sys Eff: 83.01 %

Reheat (CHP): 016.0 Tons
0073.5 GPM 05.2 F dT
100. F (In) 105. F (Out)

Reheat (CTW): 000.0 Tons
0058.2 GPM -0.2 F dT
100. F (In) 100. F (Out)

Close

Hot Water Loop Out: 126.2 F
Hot Water Loop Ret: 116.7 F

Resilience Results

- **Hospital de la Concepcion (2 weeks after Maria)**

  Only CHP & Hospital in PR that operated without interruption, full services offered.

  Hosted the disaster relief team assistance from Human Health Services

  During the hurricane, and for the next days following the Hurricane:

    - 126 Ambulatory surgeries,
    - 1,387 CT scans,
    - 3,274 Conventional radiology services,
    - 109 MRI Services,
    - 3,523 Emergency room patients,
    - 1,330 Bed patients served,
    - 27 Hurricane related traumas,
    - 256 Inpatient surgeries
    - 57 Catheterizations
    - 474 Special radiology studies
    - 284 Dialysis
    - 67,876 Laboratory test performed
    - 60 New borns
    - 8 Hurricane neuro surgeries

  Still operates in island mode due to grid disturbances

  CHP support flicker free transfer from grid tied to island mode operation

Heat Recovery Building (Cat IV)

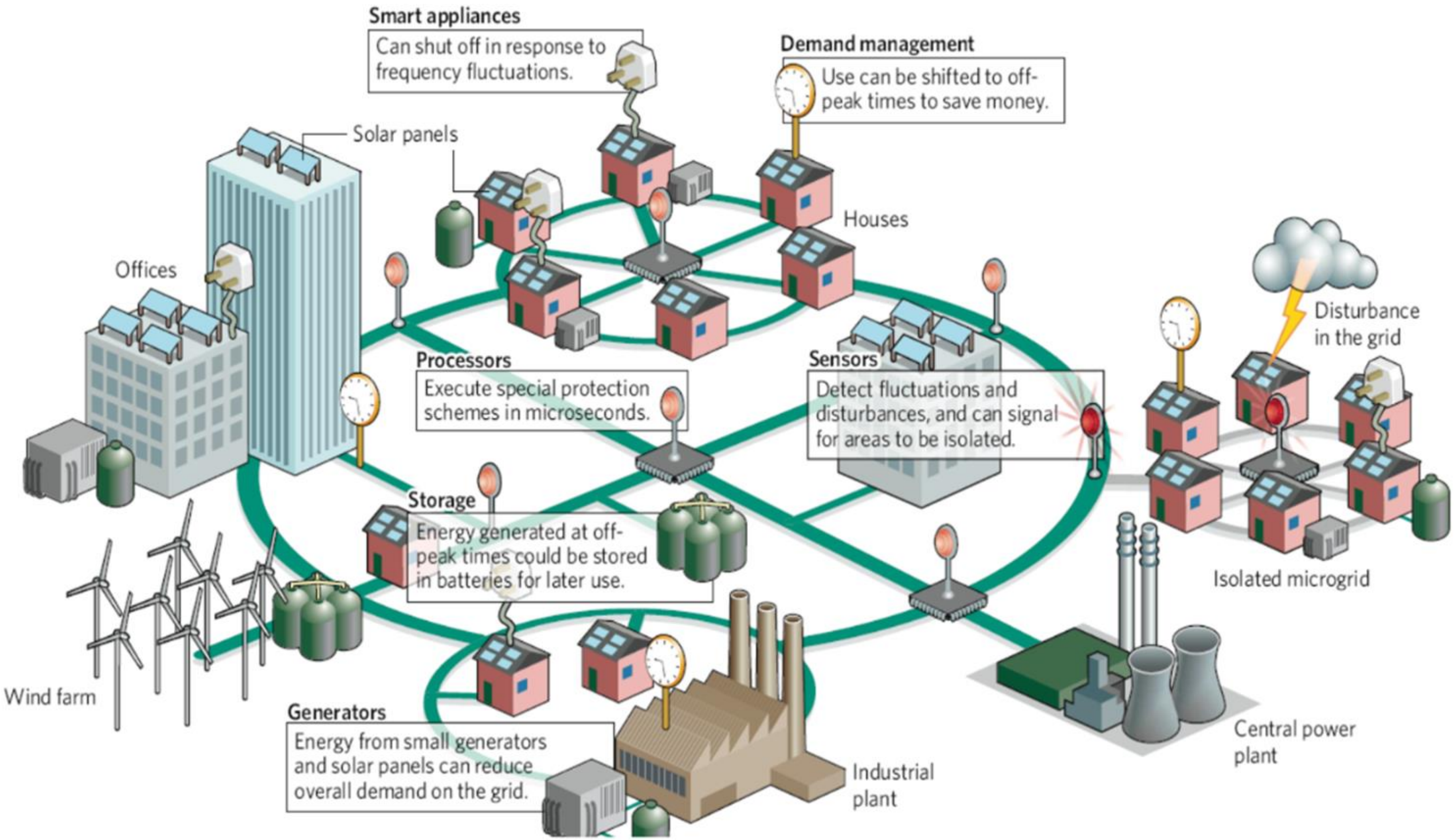
Achievements

- 280KW (18.9%) of demand reduction due to energy efficiency improvements
- Average demand: from 1.48MW to 0.898 MW (39.35% reduction) with heat recovery
- Energy cost: $0.215 Vs $0.1048(51.3%), about $900,000/yr
- Environmental:
  - 774 cars, 542 homes,
  - 95% SOx, 40% GHG Reductions,
  - Project saved 1.08 million gallons/yr of fresh water and 295.3 million gallons /yr of salt water
  - Exceeds NSPS 2015 limits
- Business continuity: excellent, two interruptions in two years
- During Maria, only fully operational hospital in the region
- Shared experiences with FEMA, PREB, CIAPR, Hospitals, etc.
- 100% design and managed by PR Engineers

Heat Recovery Building (Cat IV)

Heat Recovery Building (Cat IV)

Resilience as New Urban Model



Question and Answer

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