


*Distributed Generation & Microgrids

*Local Integrated Energy Systems and the Megagrid

*Chris Marnay

* Microgrid Design of Mendocino & China Energy Group, Berkeley Lab

* 19 May 2015, The Leuven Institute for Ireland in Europe

What is Berkeley Lab?

Lawrence Introduces Big Team Science

LBNL: The First DOE National Laboratory

*Berkeley Lab

Managed by the University of California for the United States Department of Energy

BERKELEY LAB

Lawrence Berkeley National Laboratory

* 80 ha next to U.C. Berkeley campus, ≈4500 employees, ≈half technical
* broad research areas, & typically ≈600 foreign visitors at any time
  * National Energy Research Scientific Computing Center (NERSC)
  * Joint Genome Institute (JGI), Joint BioEnergy Institute (JBEI)
  * Energy Biosciences Institute (Helios), world's biggest public partnership, etc.
* Environmental Energy Technologies Division
  broad interdisciplinary research agenda, but with a buildings focus
* China Energy Group focuses on energy and environmental policy in China

*13 Nobel Prizes

Luis W. Alvarez

Melvin Calvin

Owen Chamberlain

Steven Chu

Donald A. Glaser

Ernest Orlando Lawrence

Yuan T. Lee

Intergovernmental Panel on Climate Change (IPCC)

Edwin M. McMillan

Saul Perlmutter

Glenn T. Seaborg

Emilio G. Segrè

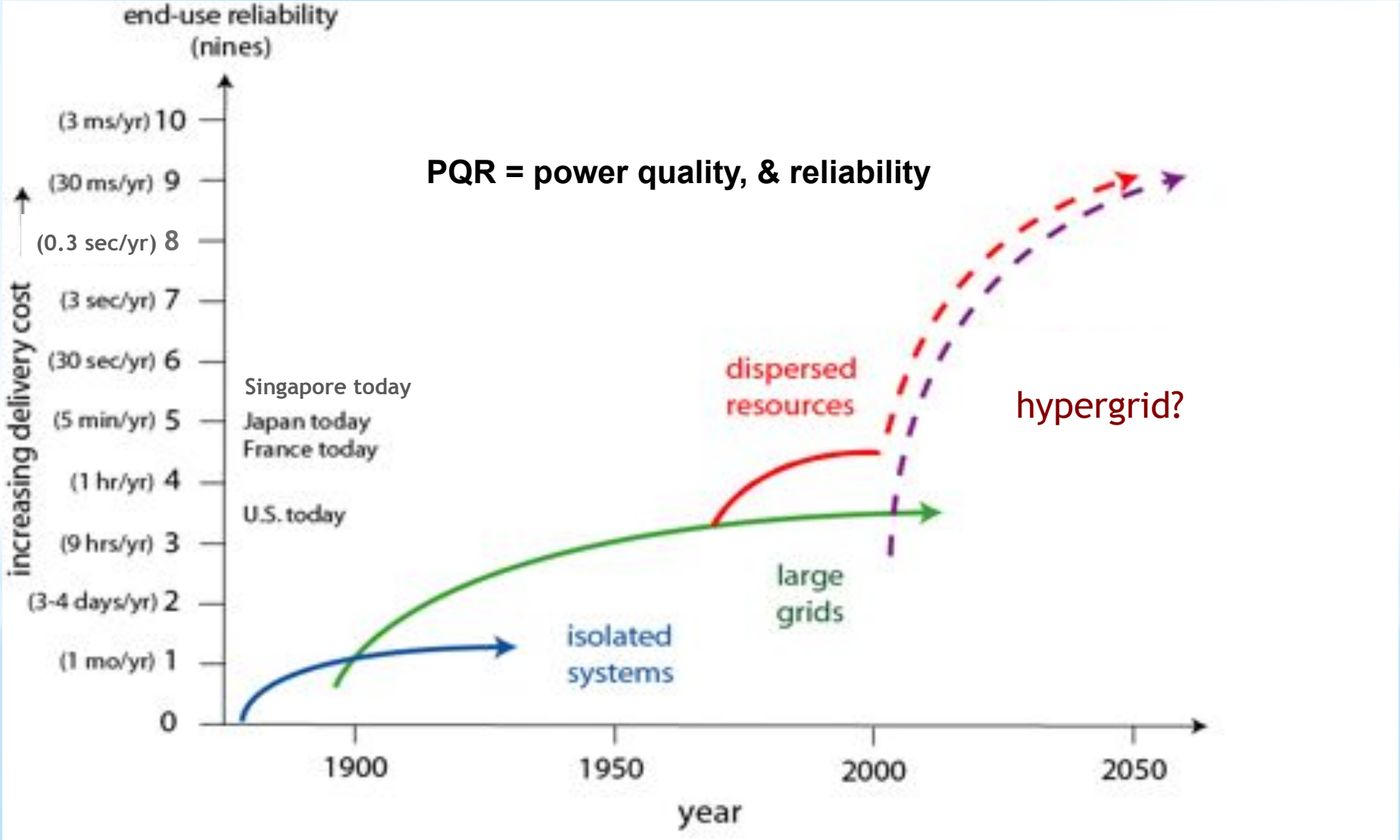
George F. Smoot

Outline

* history of the power sector
  and paradigms for the future
* introduction to microgrids
* microgrid example & economics
  (Santa Rita Jail)
* resilience
  (Japan examples & Borrego Springs)
* no conclusion only questions

Power Sector History & Paradigms

*Hypergrid Vision

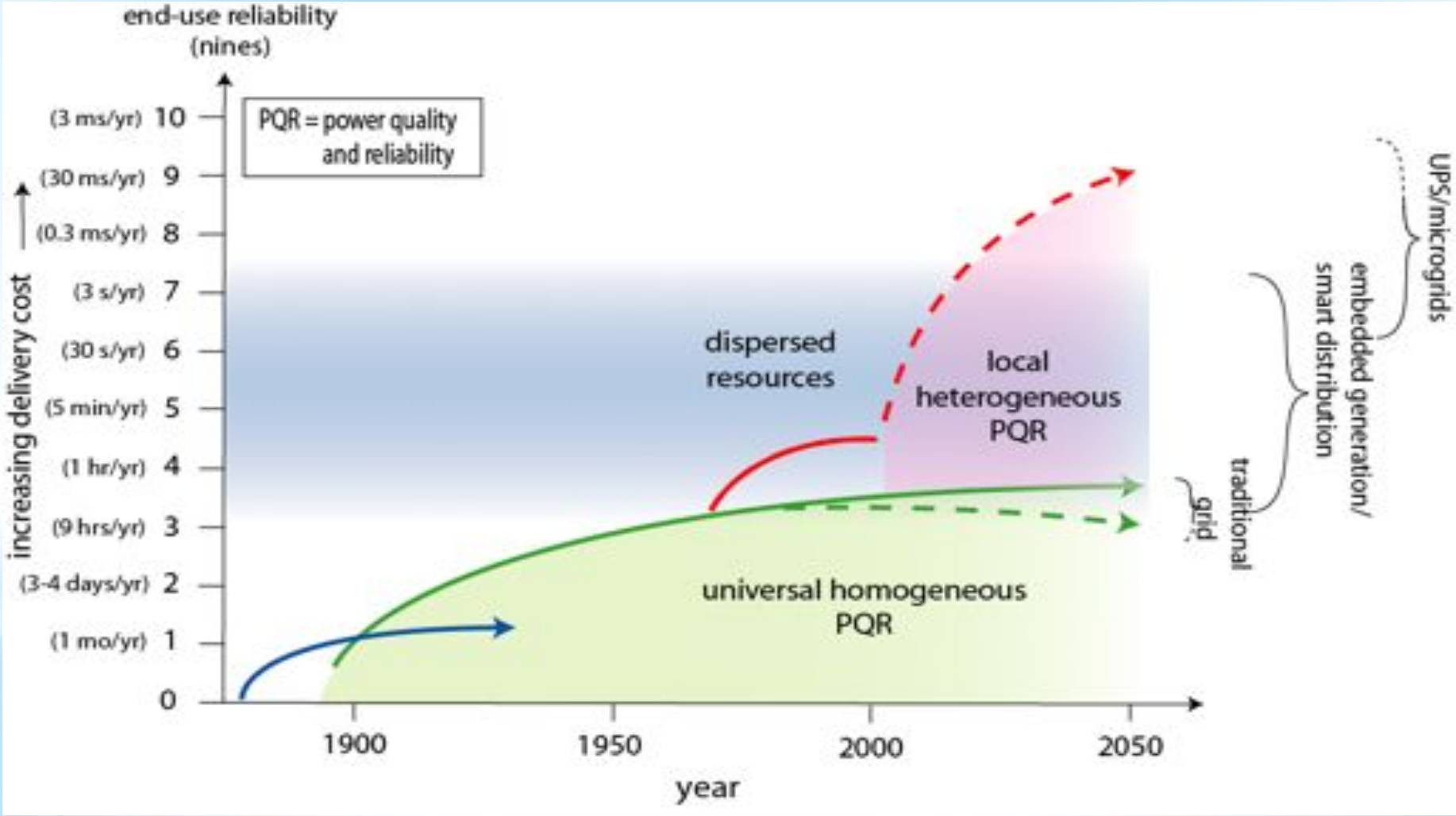


Central Paradigm Limitations

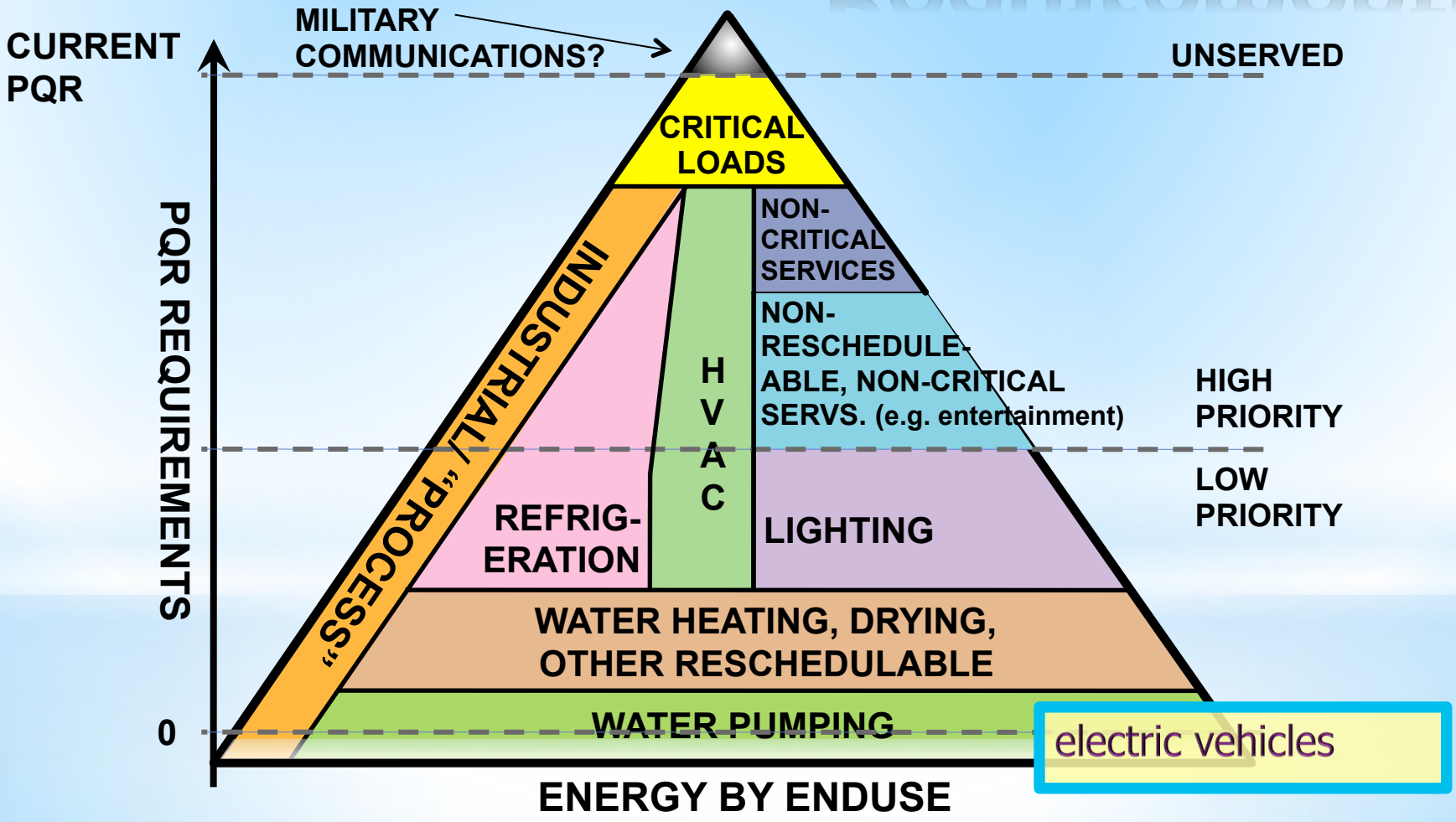
- conflicting policy objectives
  - generation competition (equipment stress, volatile markets)
  - connection of intermittent renewables
- load growth (transportation electrification, heating, …)
- environmental constraints (carbon, water, etc.)
- centralized generation heat loss
- infrastructure interdependency
- reliability is costly for a fundamentally insecure system
- restricted expansion of centralized system
- DC sources and sinks, heterogeneous power quality
- plug-in electric vehicles a potential game changer
- grid paradigm vs. internet paradigm

*Dispersed Vision

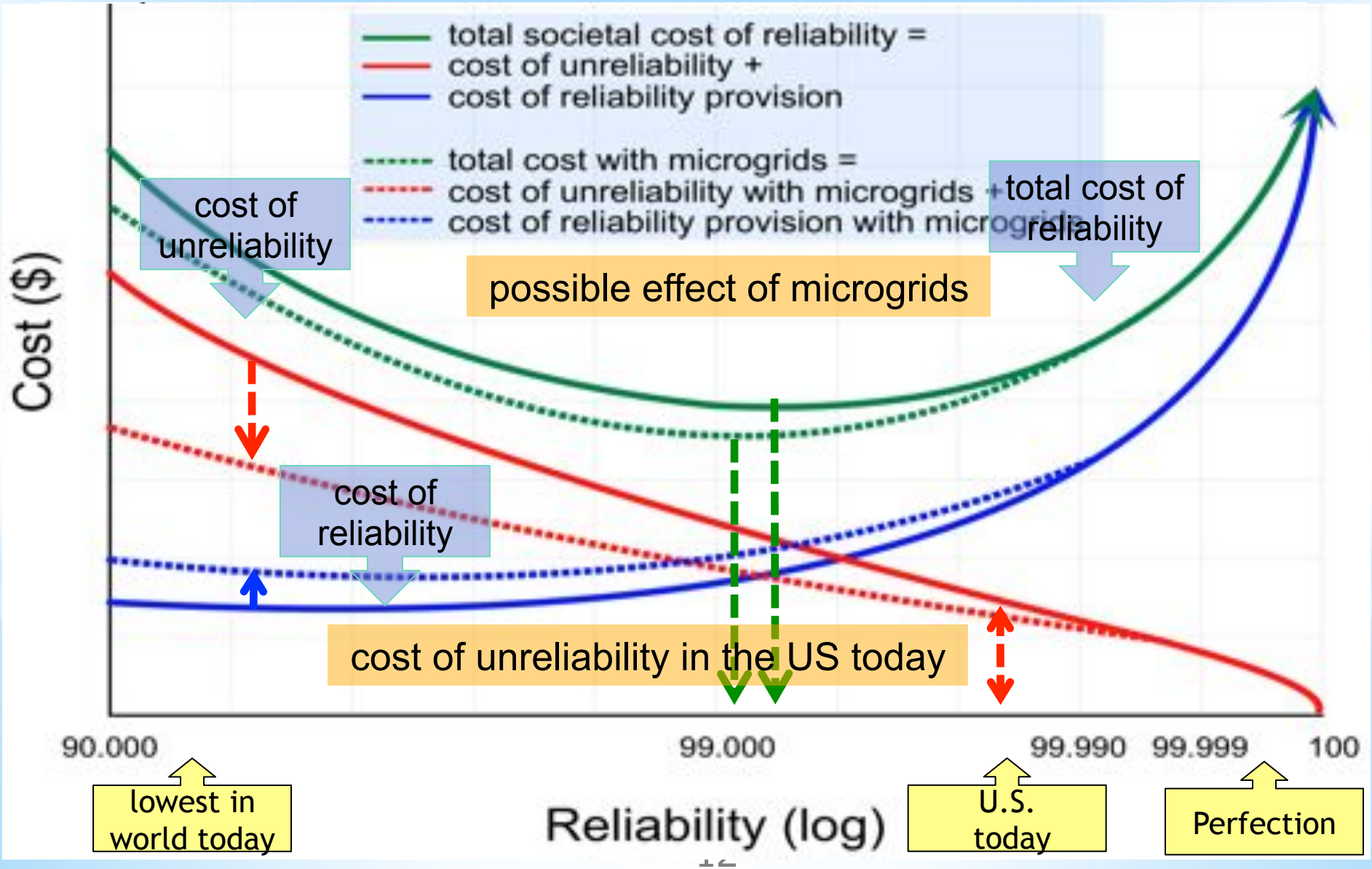
(distributed control & heterogeneous service)



*Heterogeneous PQR Requirements



*Choosing Service Quality



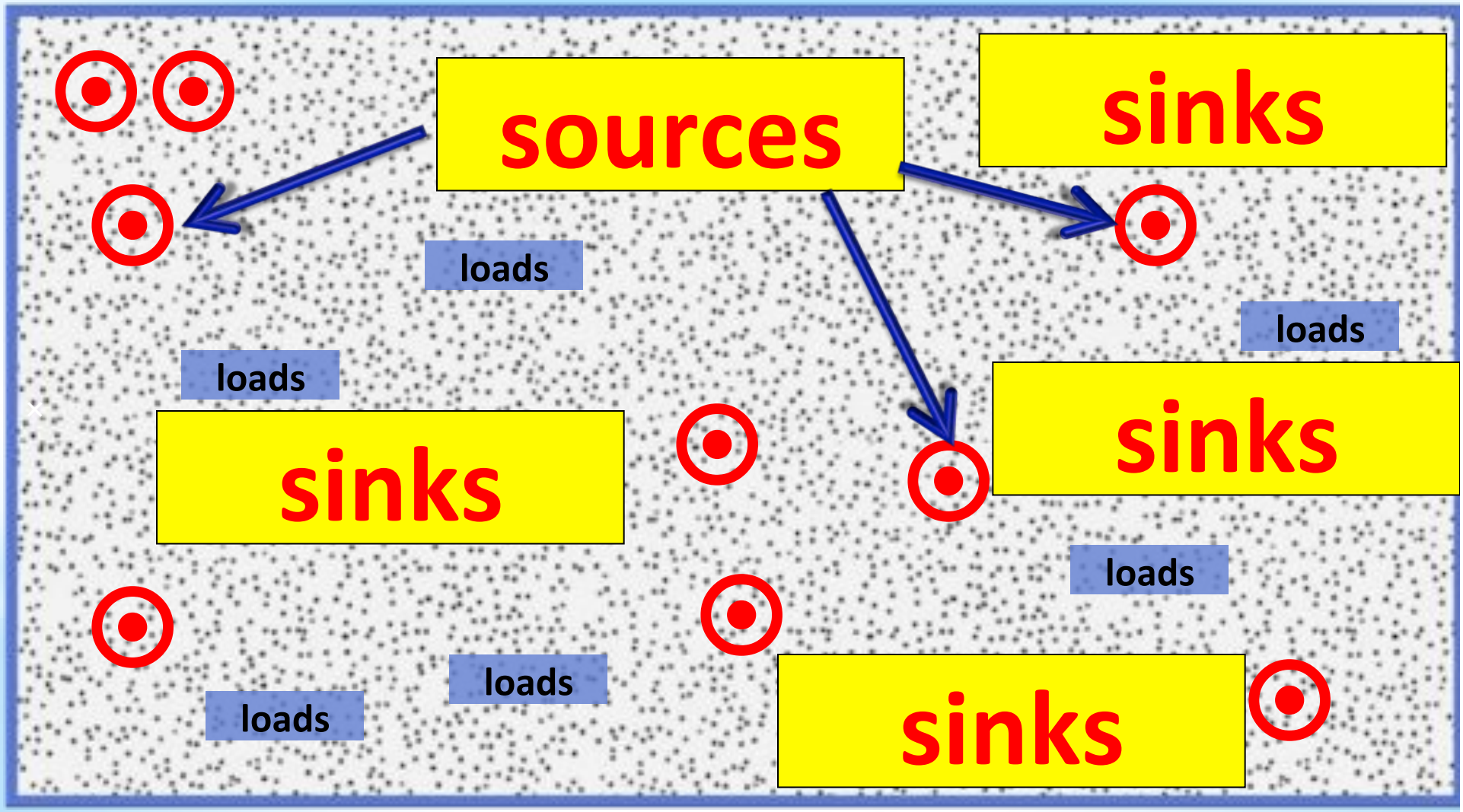
*Why Microgrids?

- *local control
- *balanced technology choice and operation
- *heterogeneous reliability and power quality
- *resilience - U.S. Presidential Policy Directive 21:

  … ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions
- *How will the emergence of microgrids change the megagrid?

Introduction to Microgrids

*Historic Landscape



*What are Distributed Energy Resources, and what's a "Microgrid?" (µ•grid or m•grid)

DER are NOT only energy conversion devices, or electricity sources:

DER are devices related to electricity supply not widely deployed in the legacy centralized, hierarchical megagrid, e.g. small gensets for non-emergency use or CHP, other generation connected at distribution voltages or below, such as PV arrays and wind turbines, local battery storage (stationary or mobile), demand response, and equipment related to other fuels incorporated with the electrical system, such as heat or cold storage, daylighting, etc.

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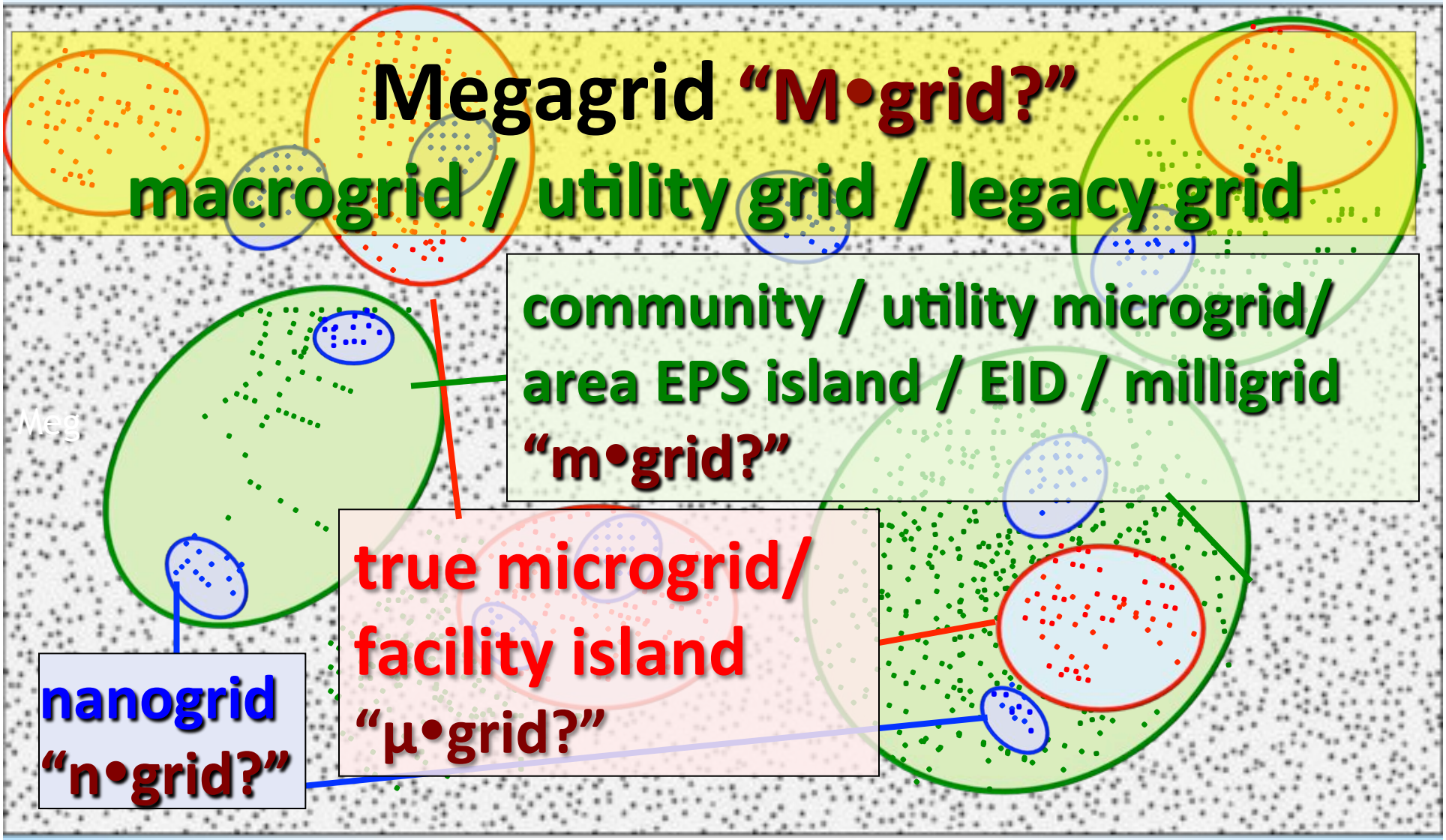
U.S. Department of Energy Microgrid Exchange Group:

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.

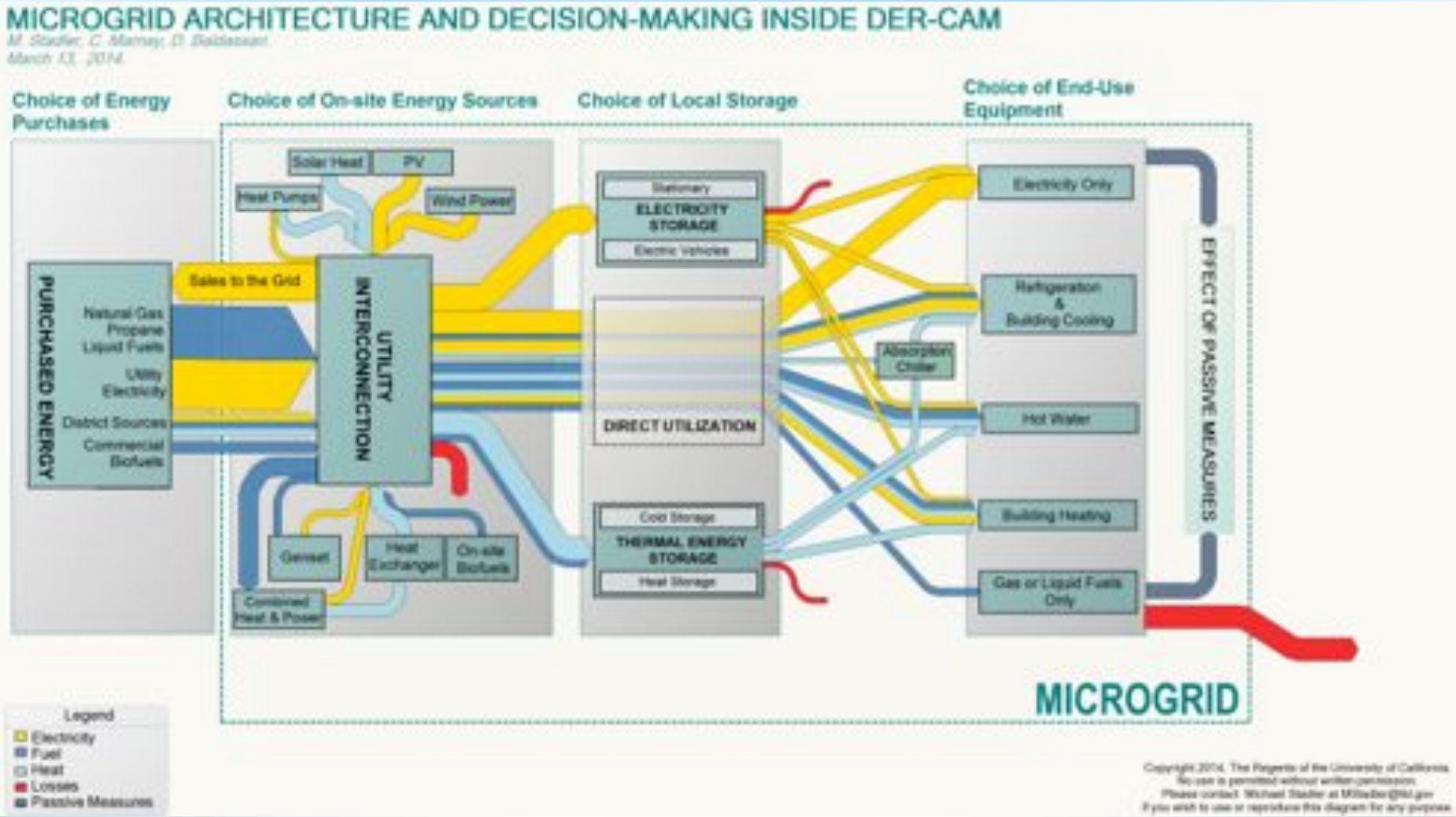
CIGRÉ C6.22 Working Group:

Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded.

*Zoom on Possible Landscape

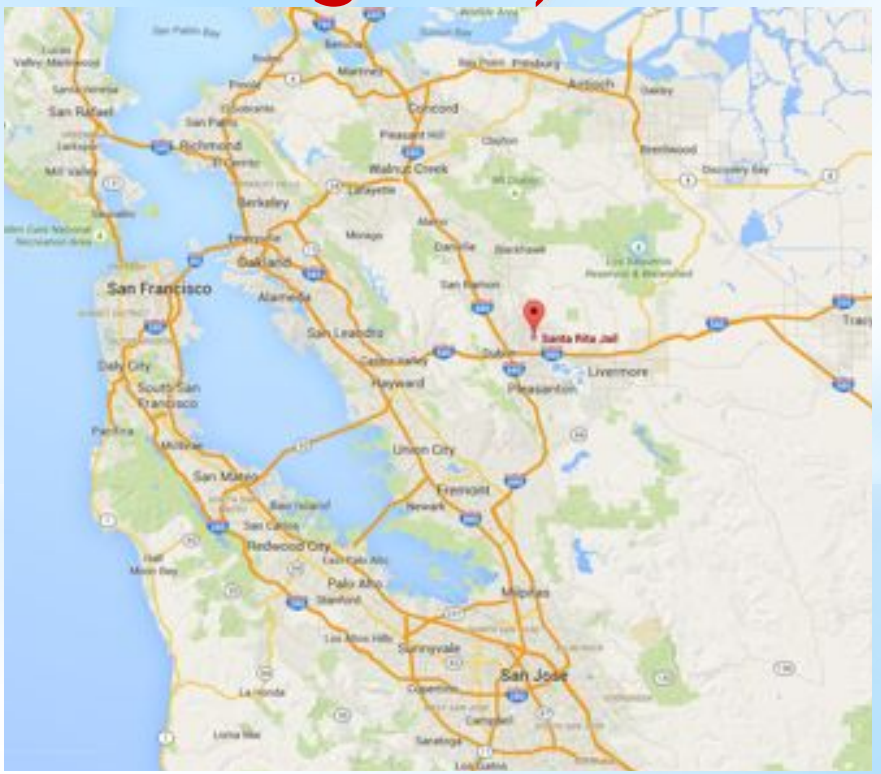


*Microgrids are Integrated Energy Systems



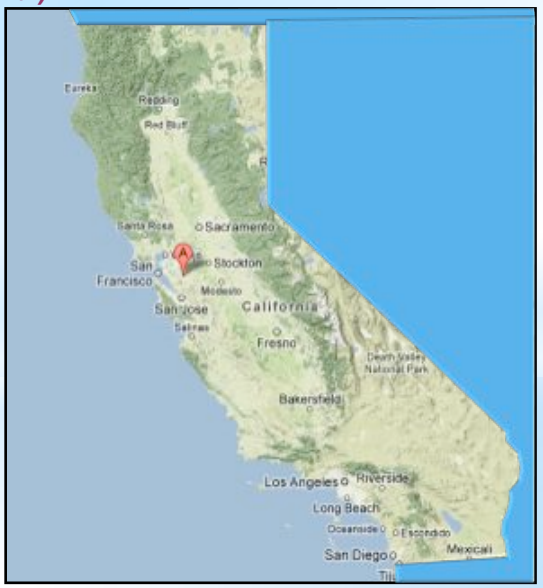
Santa Rita Jail Project

(a μ•grid "true microgrid")



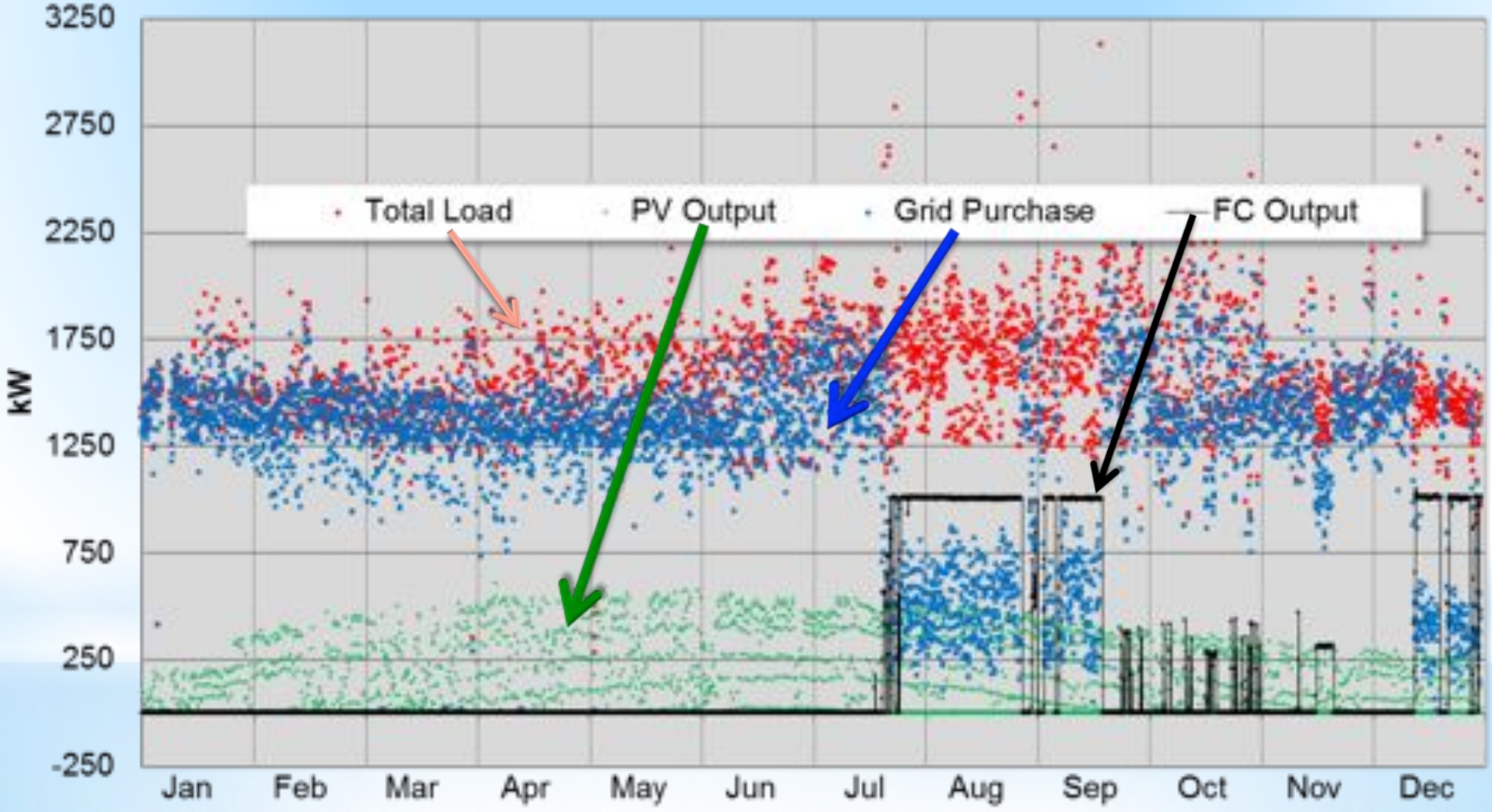
*Santa Rita Jail Summary

- one of 9 U.S. DOE RDSI projects
- Alameda Co. jail, in Dublin CA, ~50 km ESE of Bay Bridge
- 5th largest U.S. prison, 4,000-4,500 inmates
- peak load ~3 MW, and annual energy bill ~3 M$
- energy efficiency measures, e.g. chilled water plant retrofit 2001, lighting 2010
- 1.2 MW flat mount roof-top PV installed 2002 (~5% electricity bill reduction)
- 1.0 MW molten carbon fuel cell installed 2006 (6 M$)
- recent microgrid upgrade (RDSI project)
  - 2 MW – 4 MWh Li-ion battery & static switch
  - 52 single-axis solar tackers,~ 275 kW
  - concentrating solar thermal ~ 1,500 GWh/a
- microgrid cost (~12 M$)
  - CERTS Microgrid, U. of WI, Madison
  - Chevron Energy Services prime and partners
  - minor Berkeley Lab role
  - U.S.DOE: 7 M$, CEC: 2 M$,
    - PG&E incentive: 2 M$, other: 1 M$
  - additional funds for solar thermal and tracking PV

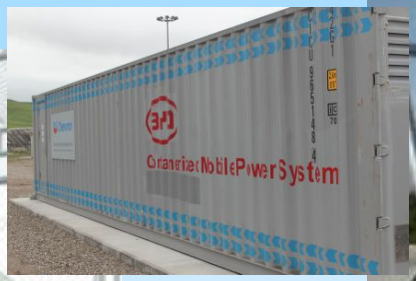


*Pre-Existing Resources

*Hourly Energy Balance 2011

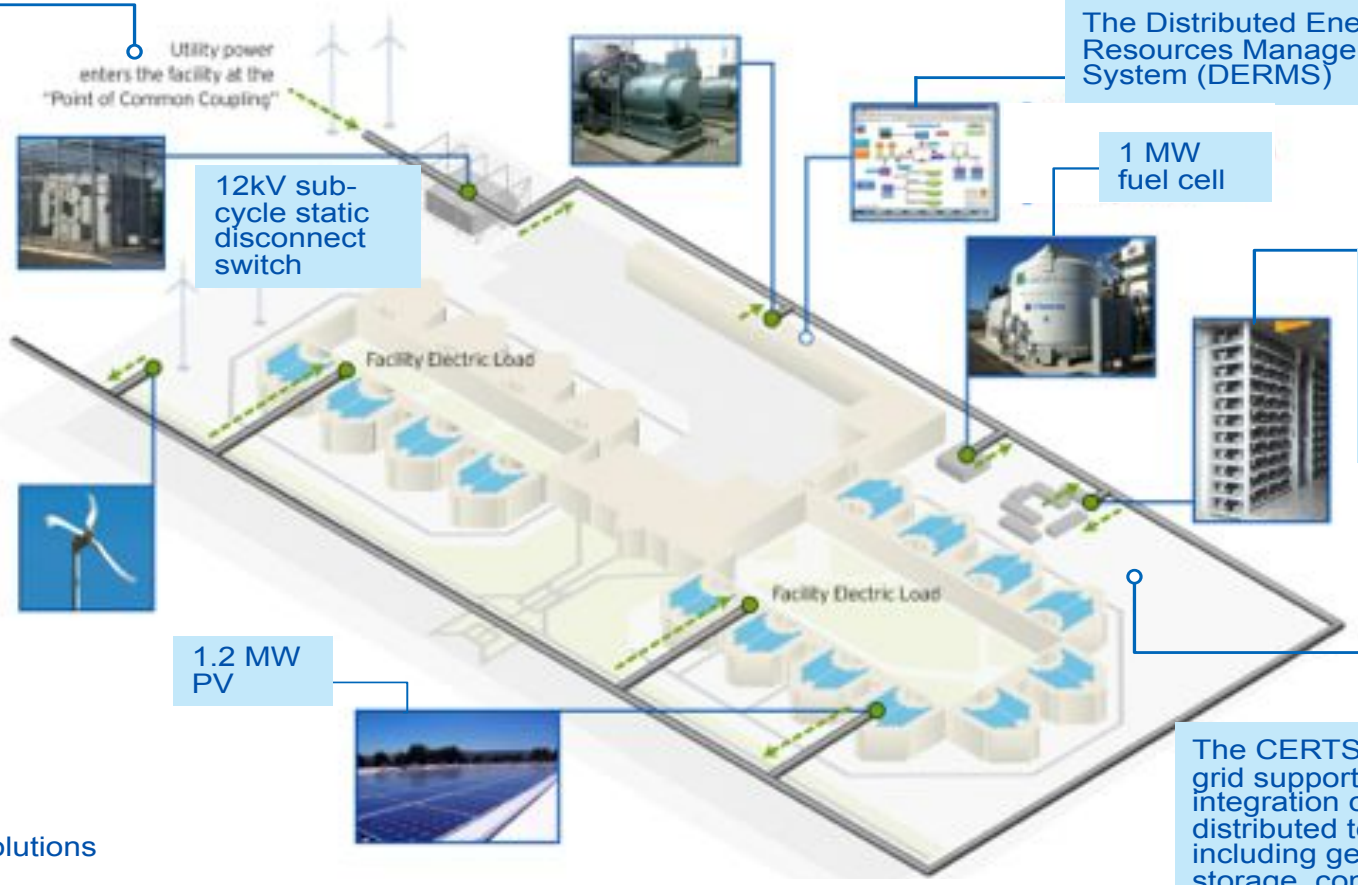


*Santa Rita Jail Upgrade



*Santa Rita Microgrid Layout

When a disturbance to the utility grid occurs, the automatic disconnect switch enables the facility to "island" itself from the main utility grid and independently generate and store its own energy.



The Distributed Energy Resources Management System (DERMS)

1 MW fuel cell

Energy Storage System:

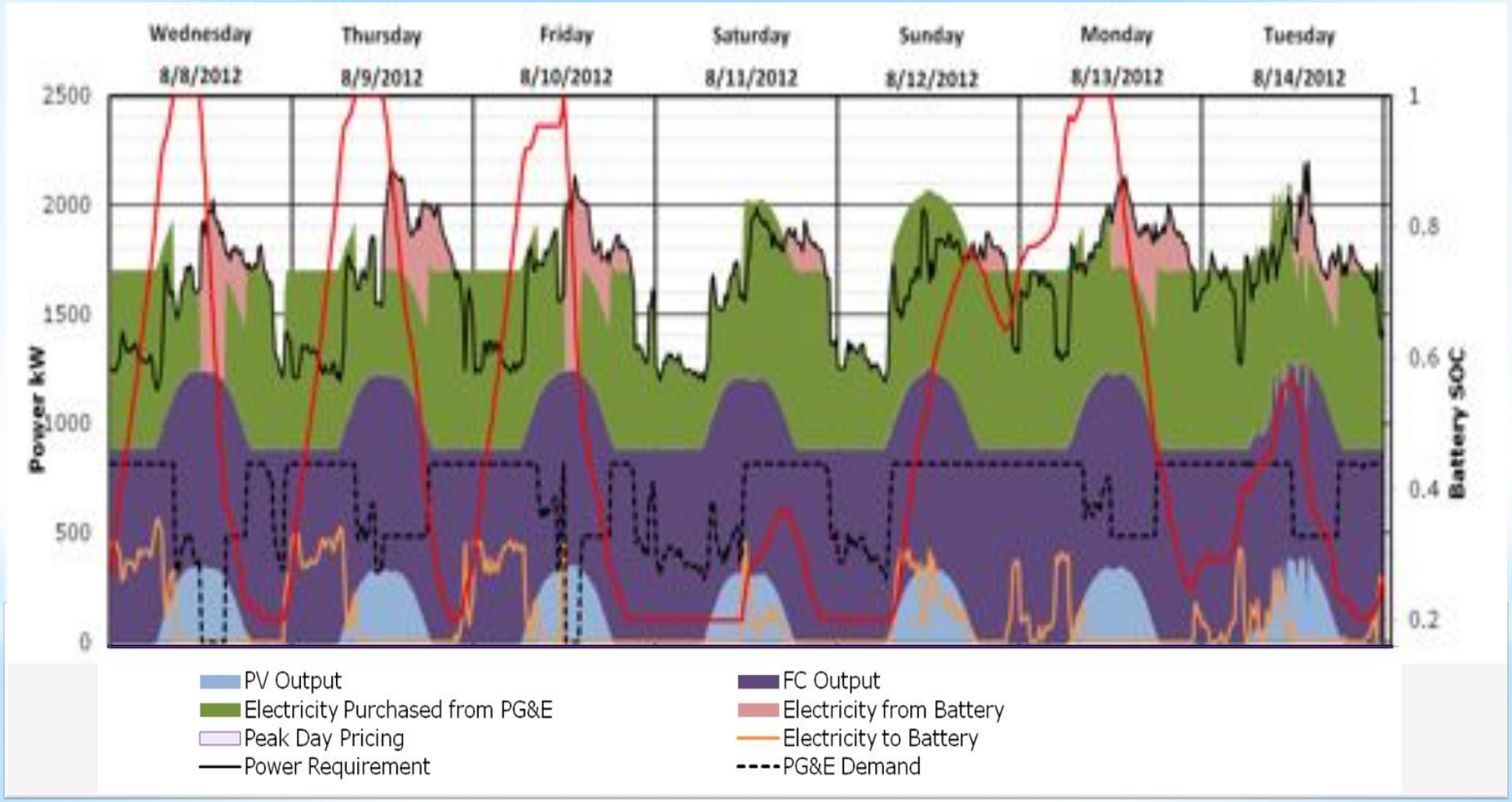
Lithium Ion
4 MW-hr
2 MW power

The CERTS-enabled smart grid supports the seamless integration of additional distributed technologies, including generation, storage, controls and communications.

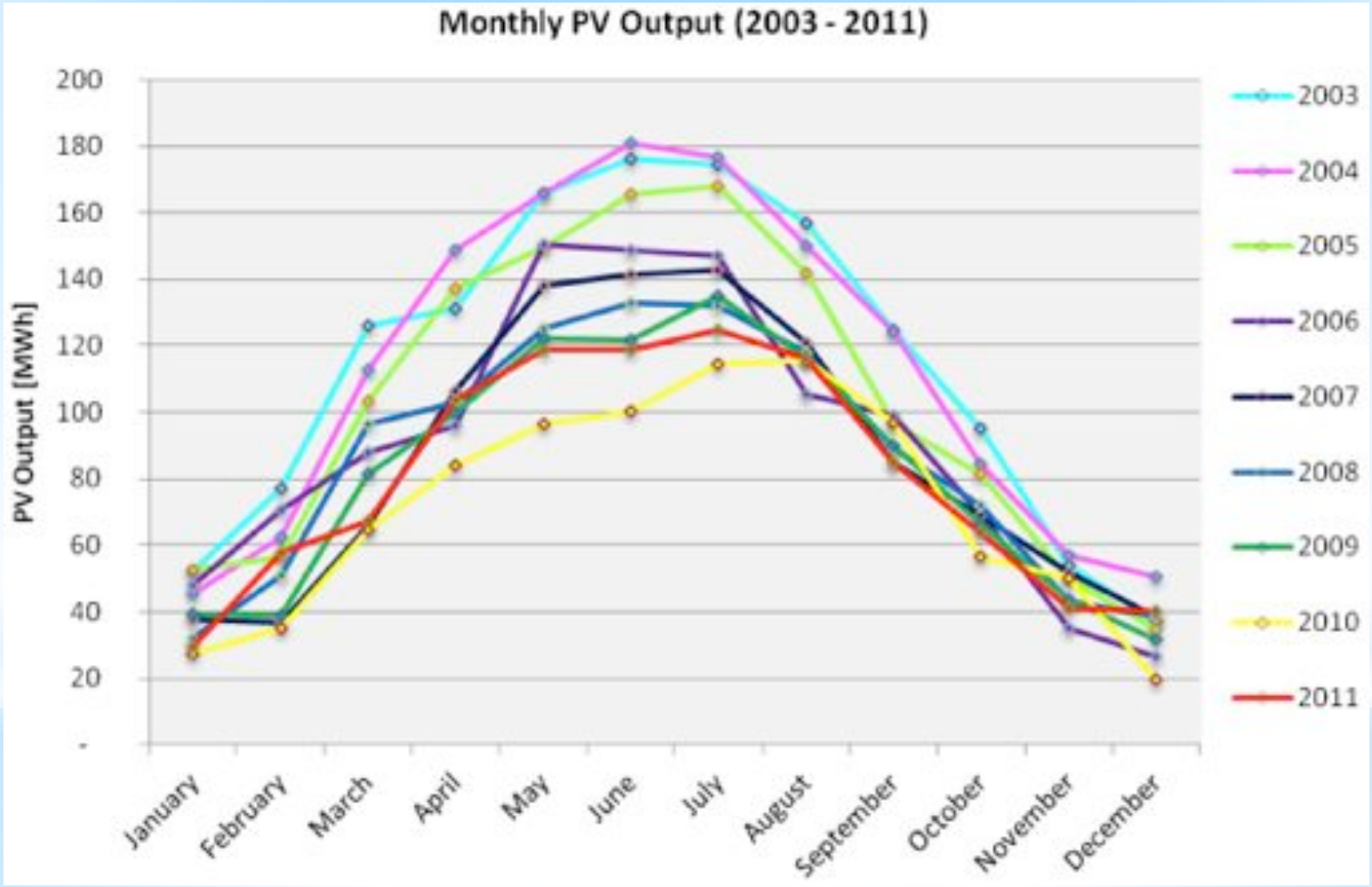
Chevron Energy Solutions

new tracking PV and concentrating solar thermal not shown

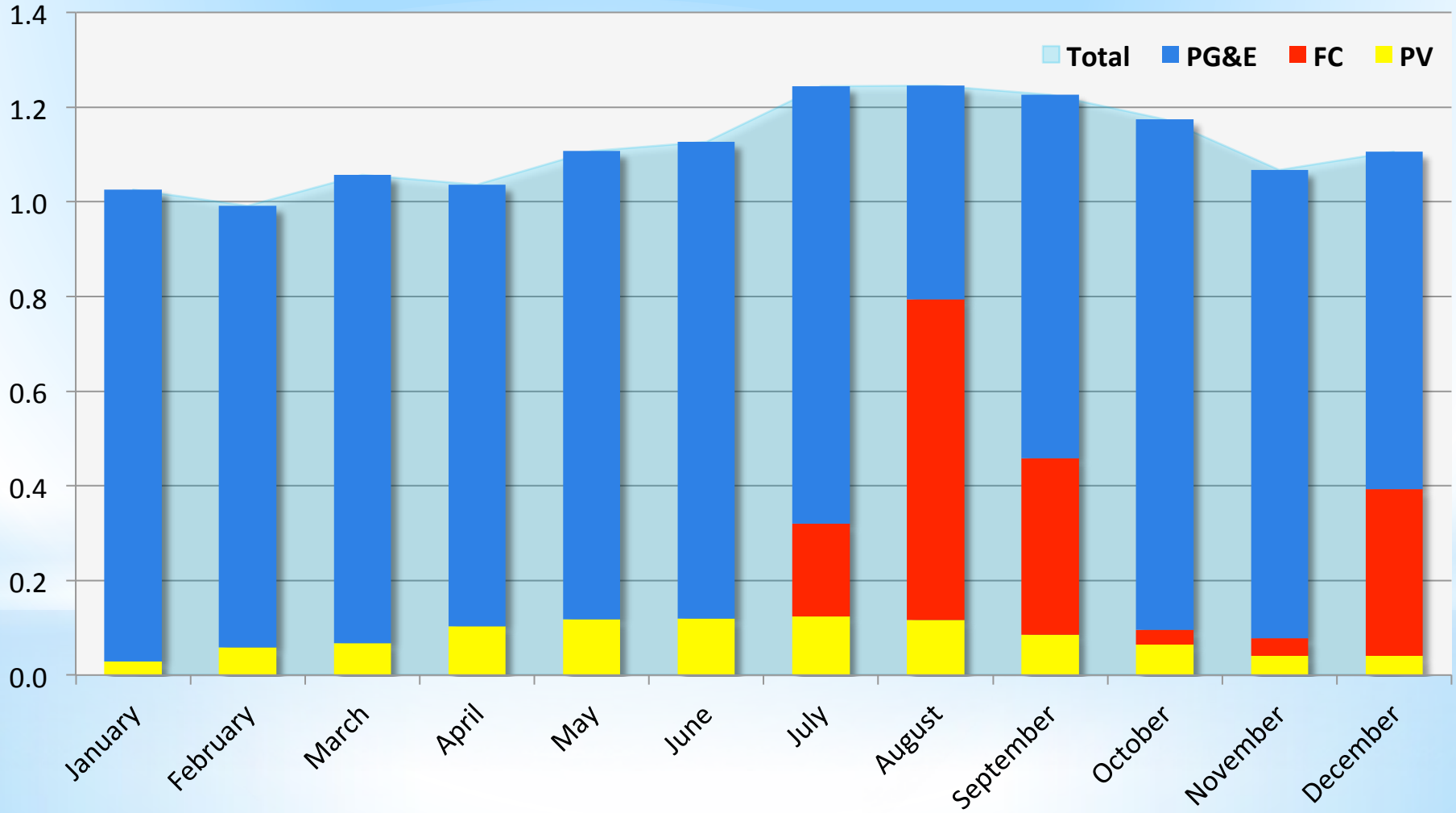
*Hot Week Schedule



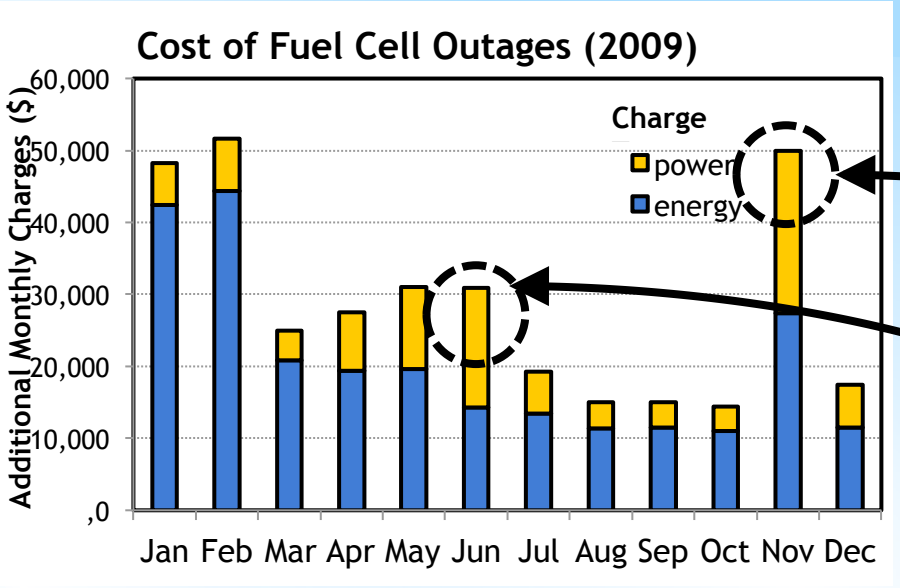
*Declining PV Output

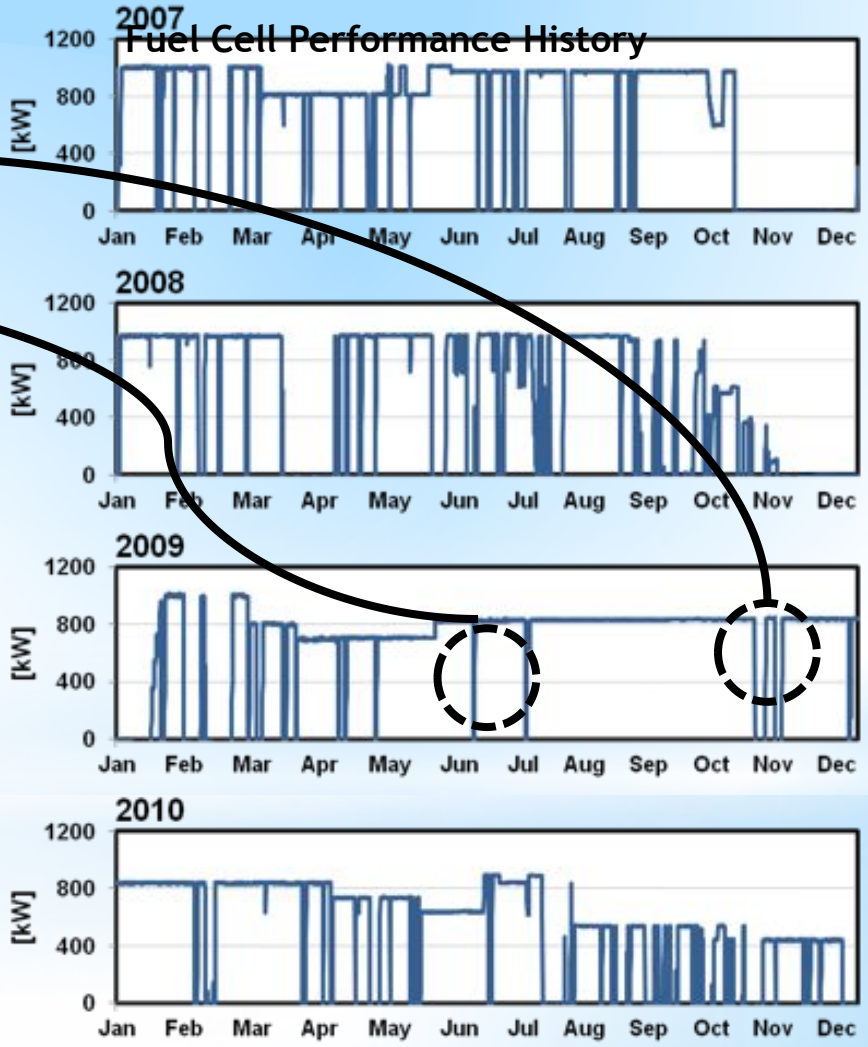


*Monthly Energy Supply - 2011



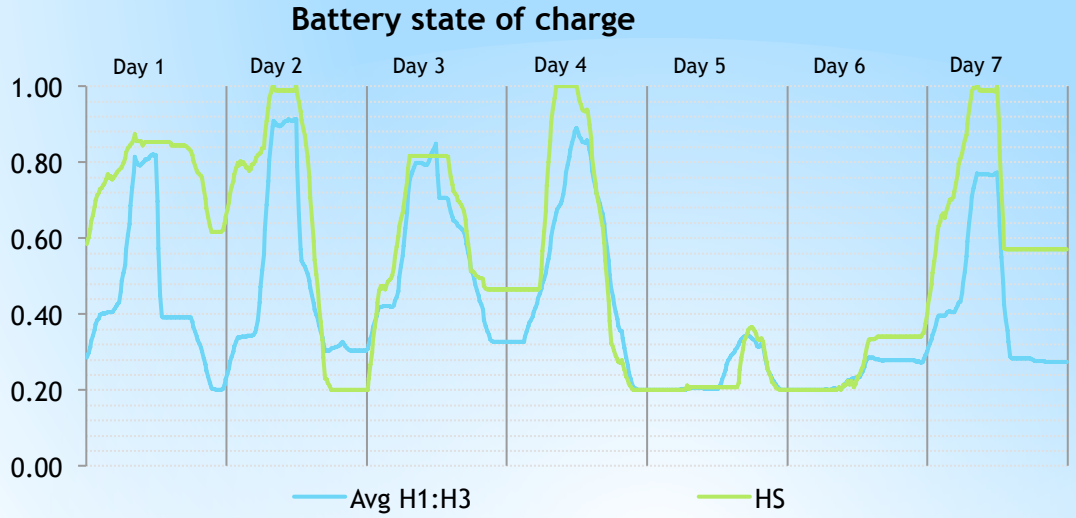
*Problems with Generation





- –fuel cell experiences frequent outages
- –even short outages can have significant economic impacts, by setting monthly power demand charges

*Stochastic Results



Avg. H1:H3 – Average of optimal battery schedules H1 to H3, obtained from fuel cell availability scenarios 1 to 3.

HS – Optimal battery schedule obtained by the stochastic model, where all scenarios are considered simultaneously.

Observed fuel cell scenario	1		2		3	
Battery schedule	Avg. H1:H3	HS	Avg. H1:H3	HS	Avg. H1:H3	HS
Total energy costs	$ 70 296	$ 69 126	$ 59 017	$ 57 560	$ 64 213	$ 60 431
TOU charges	$ 26 807	$ 26 837	$ 21 245	$ 21 351	$ 23 232	$ 21 821
Demand charges	$ 42 705	$ 41 567	$ 29 596	$ 28 160	$ 35 661	$ 30 968

- optimal battery schedules can be obtained assuming availability scenarios separately (deterministic approach) or simultaneously (stochastic approach)
- the stochastic approach results in a more conservative schedule as well as lower energy costs when unexpected events occur

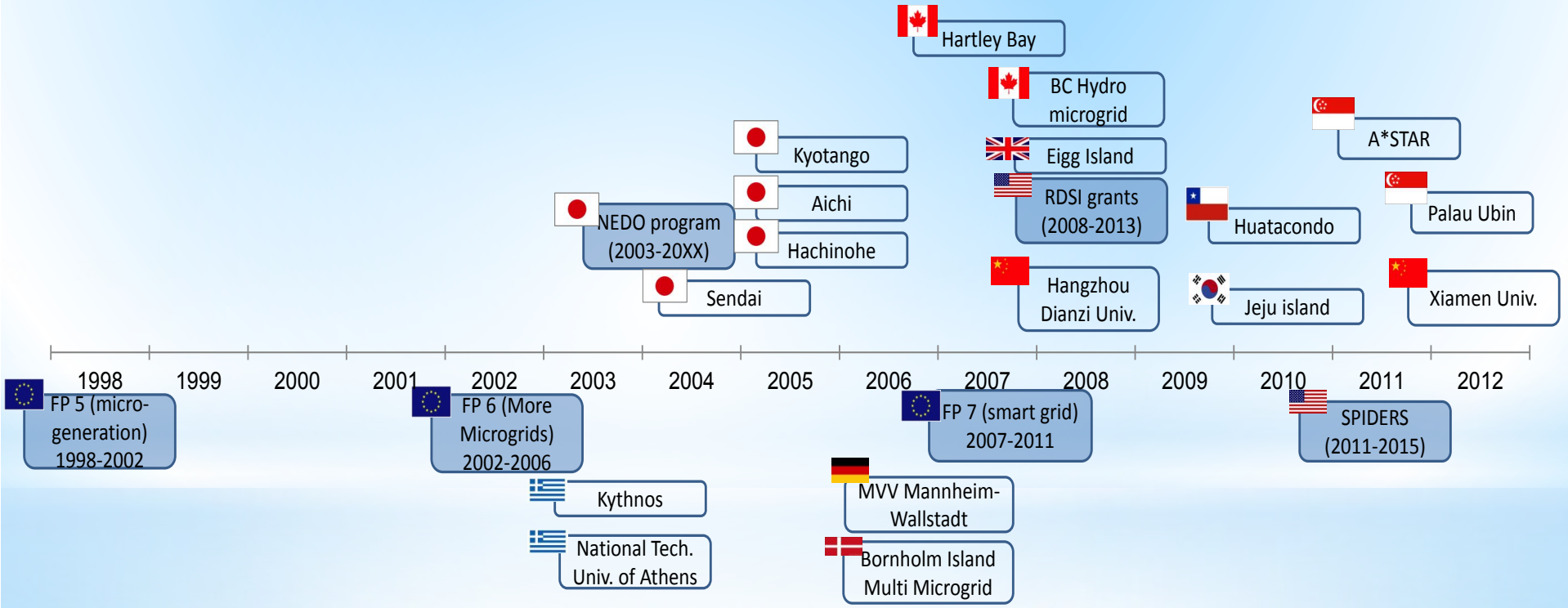
This is a different Santa Rita Jail!

Pedaling for parole: Inmates pedal stationary bikes to charge car batteries and shave days off their sentences in an innovative prison program in Santa Rita do Sapucai, Brazil. The converted car batteries are used to illuminate Santa Rita do Sapucai's town square.
Photo: Felipe Dana, Associated Press / SF

Japan Examples

*History of Microgrid R&D
(Kyoto to Fukushima)

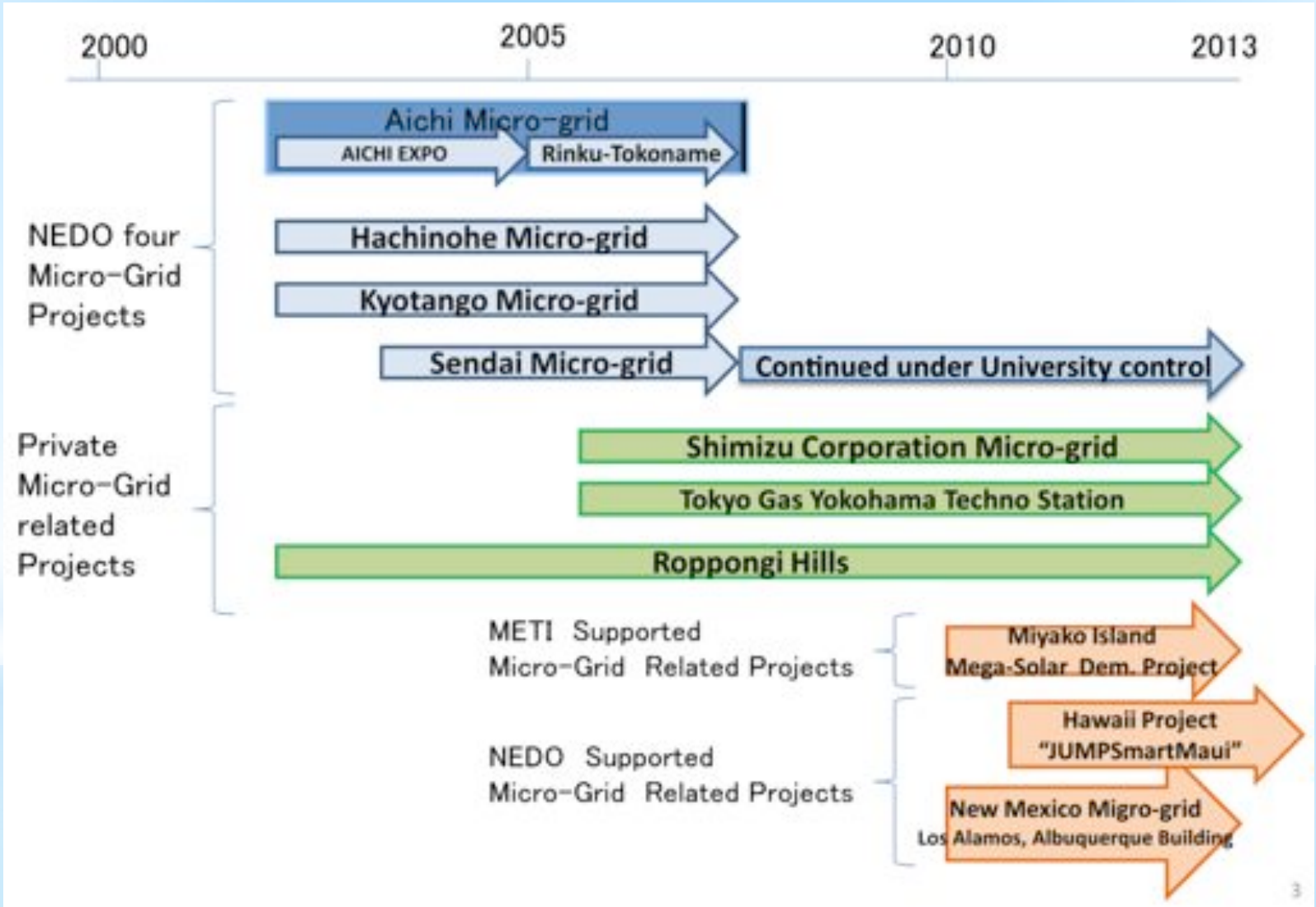
EU → Japan → US (RDSI, SPIDERS) → Asia (China, Korea, Singapore)



NEDO Microgrid Program 2002-8

- each early demonstrations focused on one aspect of microgrids
- Hachinohe: renewables, Kyotango: communications, etc.
- reliability only a major consideration in Sendai demonstration, via focus on heterogeneous power quality

*Microgrid Demos 2002-13



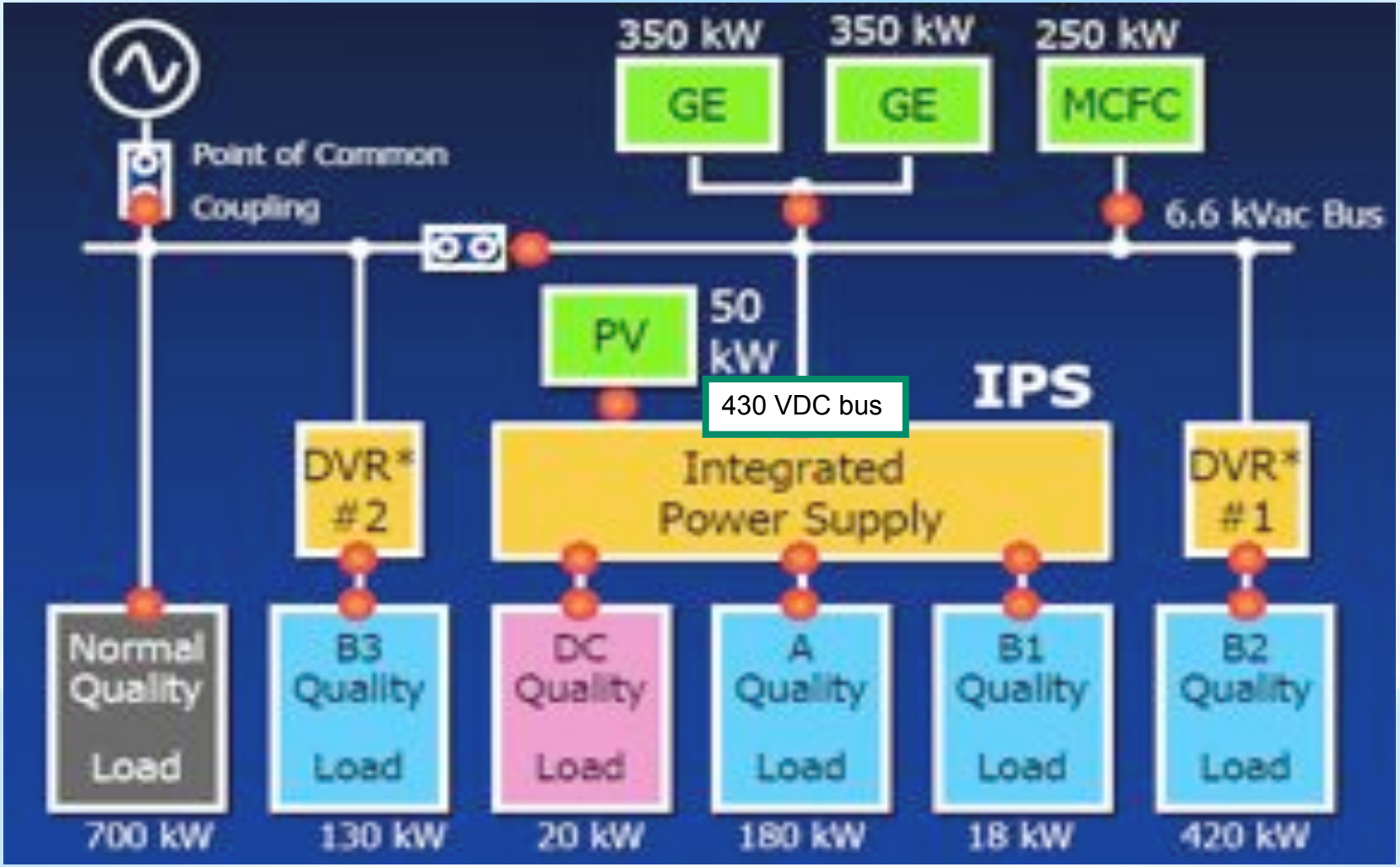
source: NEDO

*Sendai Microgrid

A: Photovoltaic Panels 50 kWp
B: Gas Engine gen-set
350 kW X2
C: Molten Carbonate Fuel Cells
250 kW
D: Dynamic Voltage Restorer #1
600 kVA
E: Dynamic Voltage Restorer #2
200 kVA
F: Building #1
Integrated Power Supply
G: Building #2
Back-to-back
Voltage Source Converters
(For Test Equipment)

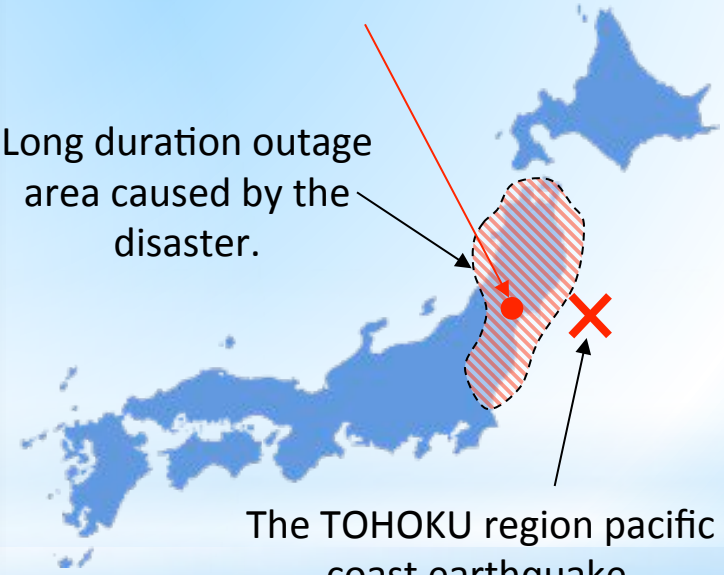
source: NTT Facilities

*Sendai Project Schematic



*Sendai Microgrid Superstar

SENDAI microgrid system by NTT Facilities



Source: http://spectrum.ieee.org/energy/the-smarter-grid/a-microgrid-that-wouldnt-quit/0

*Multiple Power Qualities

source: NTT Facilities

*Secure Natural Gas Lifeline

source: Alexis Kwasinski

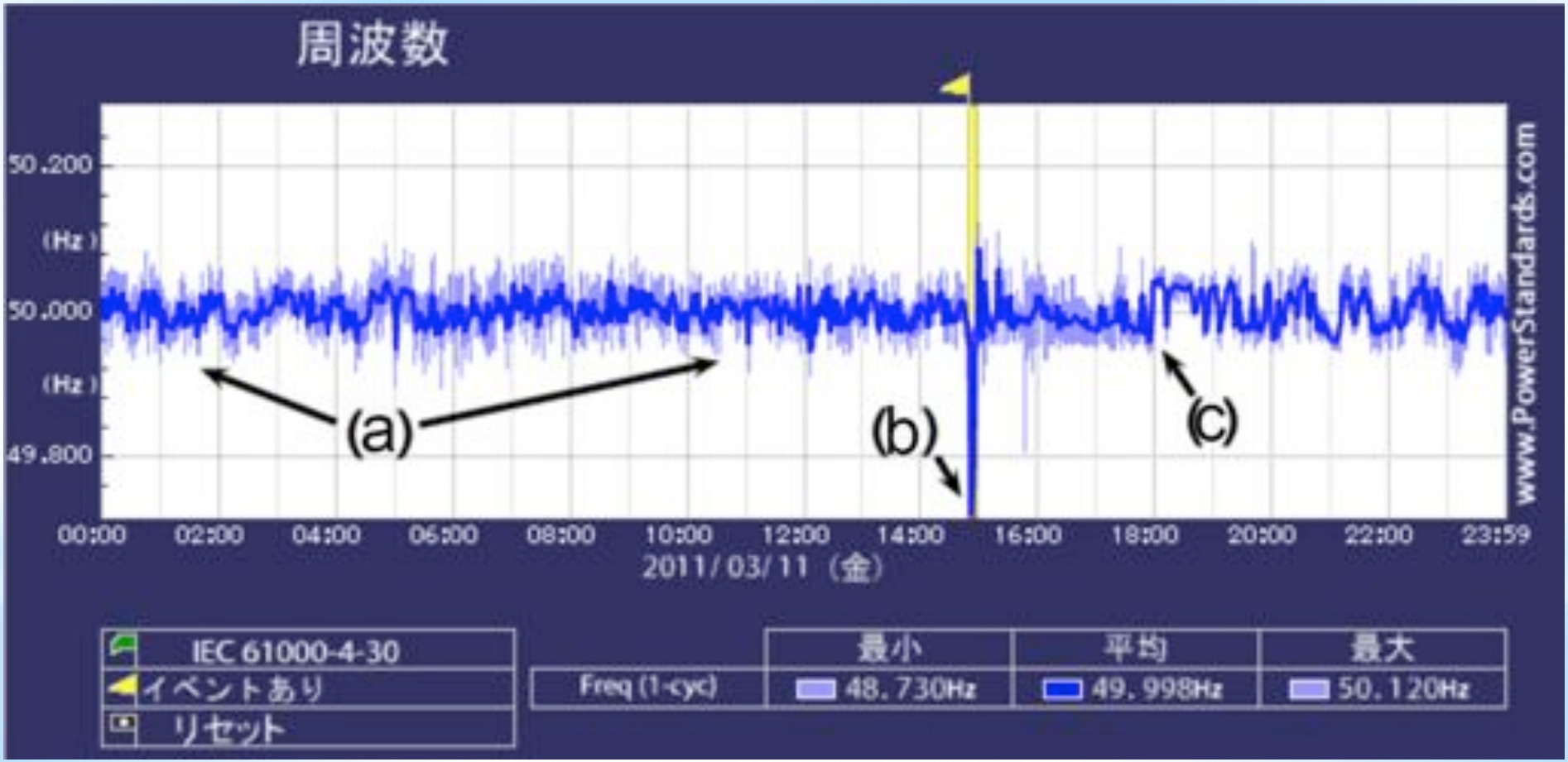
*Roppongi Hills, Tokyo

- 725 000 m^2 mixed use
- opened in 2003
- Roppongi Energy Service a "Specified Electric Utility"
- NG supply never interrupted
- kerosene back-up
- redundancy

Equipment	Capacity
Generators	38,660 kW
Gas turbine generators	6,360 kW X 6
Steam turbine generator	500 kW X 1
Steam absorption chillers	73,340 kW
Steam boilers	79.6 t/h
Exhaust heat boilers	77.76 t/h
Equipment	Capacity
Generators	38,660 kW
Gas turbine generators	6,360 kW X 6
Steam turbine generator	500 kW X 1
Steam absorption chillers	73,340 kW
Steam boilers	79.6 t/h
Exhaust heat boilers	77.76 t/h

source: Tokyo Gas

*Great East Japan Earthquake



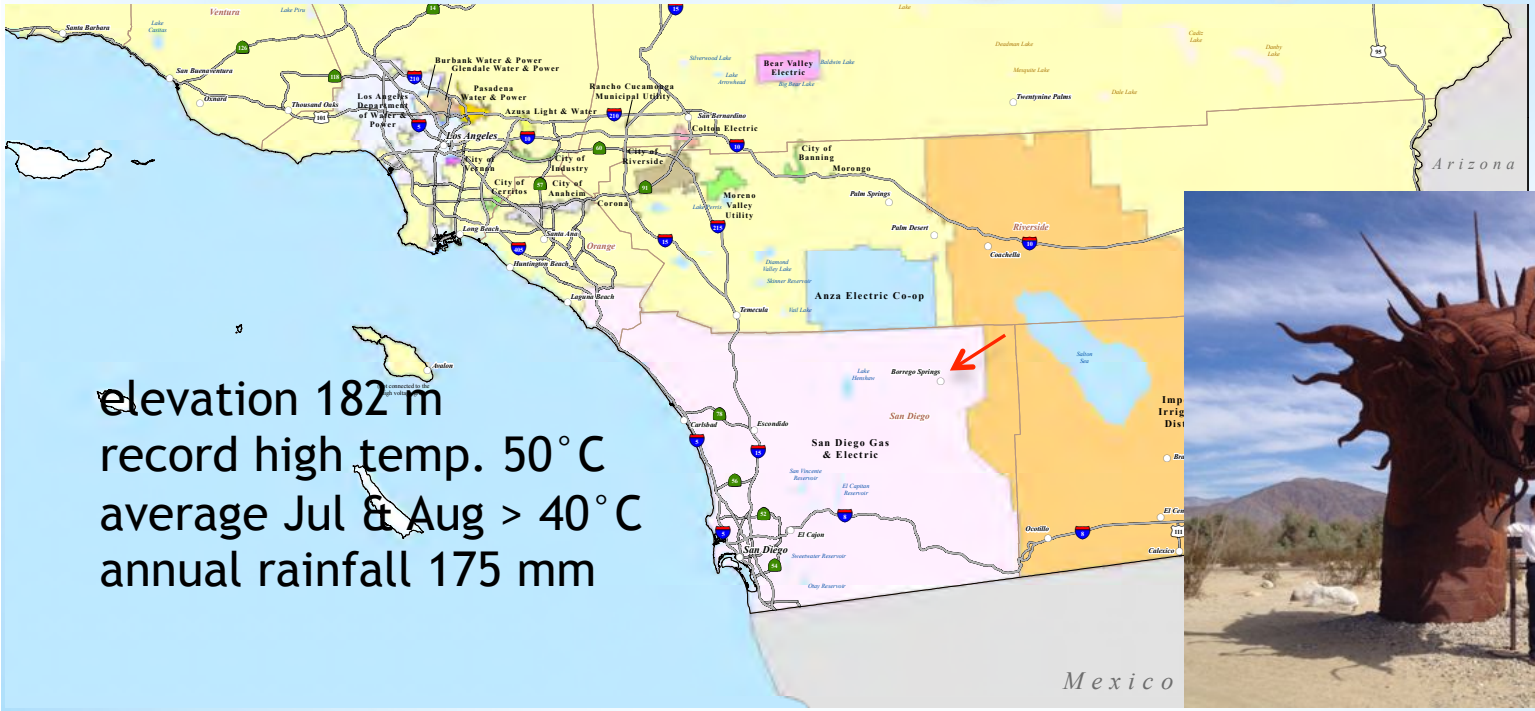
source: Power Standards Lab

*Japan's Pivot to Resilience

* long and notable history in microgrid research
* outstanding performance of Roppongi Hills and Sendai microgrids during Mar 2011 earthquake and tsunami was noticed in policy circles
* move towards greater dependency on microgrids
* interest in microgrids moved beyond NEDO, to Ministry of Environment, and others, as well as the private sector
* heterogeneous power quality represents one key to resiliency (economics & control)
* big benefit of microgrids may come from changes in the megagrid

in Anza-Borrego State Park
summer population 3,500
winter population reaches 5,000
large retired population

Borrego Springs



elevation 182 m
record high temp. 50°C
average Jul & Aug > 40°C
annual rainfall 175 mm

*CAISO Territory

*BS1: RDSI Project 2008-13

* San Diego Gas & Electric a progressive distribution company
* Renewable and Distributed Systems Integration a program of U.S. DOE
* 9 “microgrid” projects 2008-2013, incl. Santa Rita & Borrego Springs
* goal was 15% peak load reduction
* project originally intended for a coastal community but moved
* Barrego Springs depends on single vulnerable 25 km 69 kV tie
* 26 & 5 MW IPP PV arrays in the area
* 14 MW peak local load + 15 MW tie unable to absorb all PV output
* environmentally sensitive area and suspicious population
* relatively simple technology and unclear objectives
* example of a distribution utility embracing microgrids
* but regulatory response unclear

*Diesel Generators

- Two (2) 1.8 MW Caterpillar Diesel Generators
  - * Owned & operated by SDG&E
  - * Each generator rated for 1.8 MW at 480 Volts
  - * Emissions equipment retrofitted onto generators

*Substation Batteries

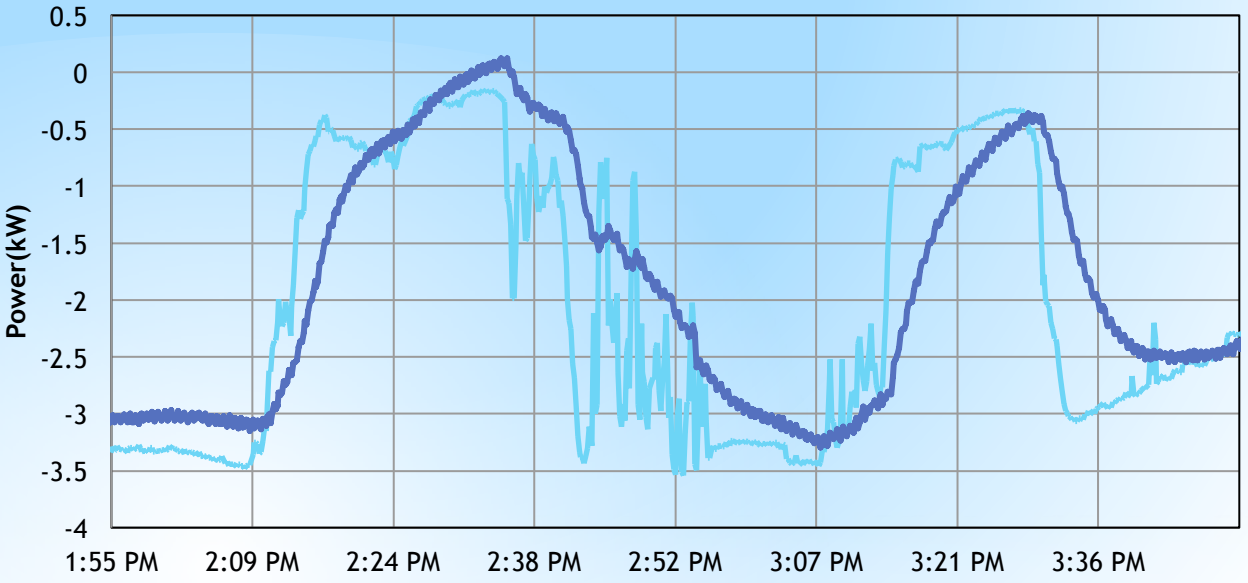
- Manufacturer: Saft / Parker Hannifin
- One 500 kW/1500 kWh battery at Borrego
- Modes of Operation
  - * Peak Shaving/Load Following
  - * Renewable Smoothing
  - * Support Islanding Operation

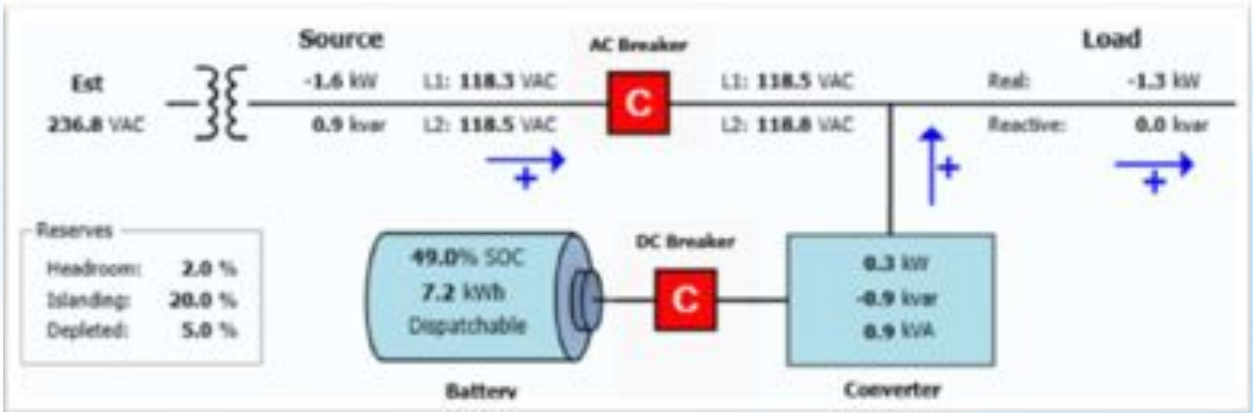
*Community Energy Storage

- Manufacturer: S&C / Kokam
- Three 25 kW/50 kWh units connected to 12 kV
  - * Operated independently and as a fleet
- Modes of Operation
  - * Peak Shaving
  - * Renewable Smoothing
  - * Voltage Support

*CES PV Smoothing Operation

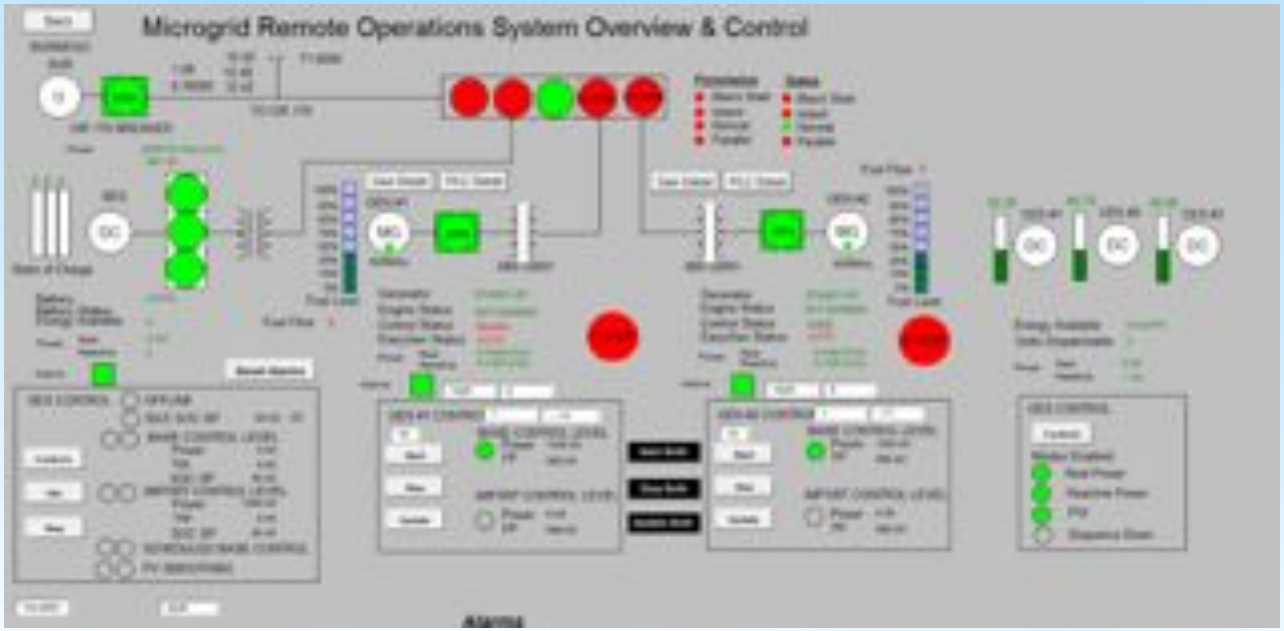
- *Units capable of smoothing intermittency caused by fluctuating power output
- *Operational variables can be user-defined i.e. Ramp rate control,





*Microgrid Controls

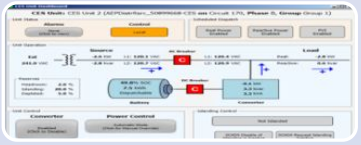
- Provides consolidated view/control of microgrid resources



Woodward controls for generator 1

Woodward controls for generator 2

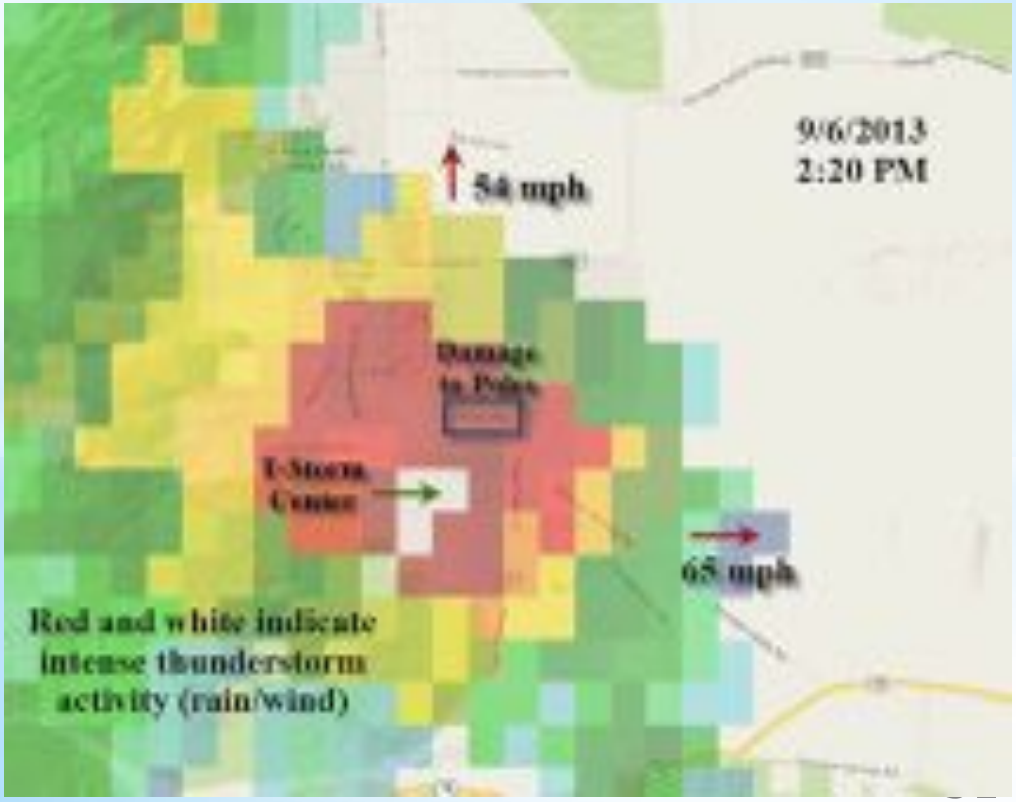
Saft SES unit



S&C CES units

*6 September 2013

* hot morning, 38°C by 10:00 and 42°C at 13:20
* thunderstorms began to form between 12:00 and 13:00
* produced rainfall totals of 33 mm at Warners by 14:00, with similar amounts along the desert slopes west of town



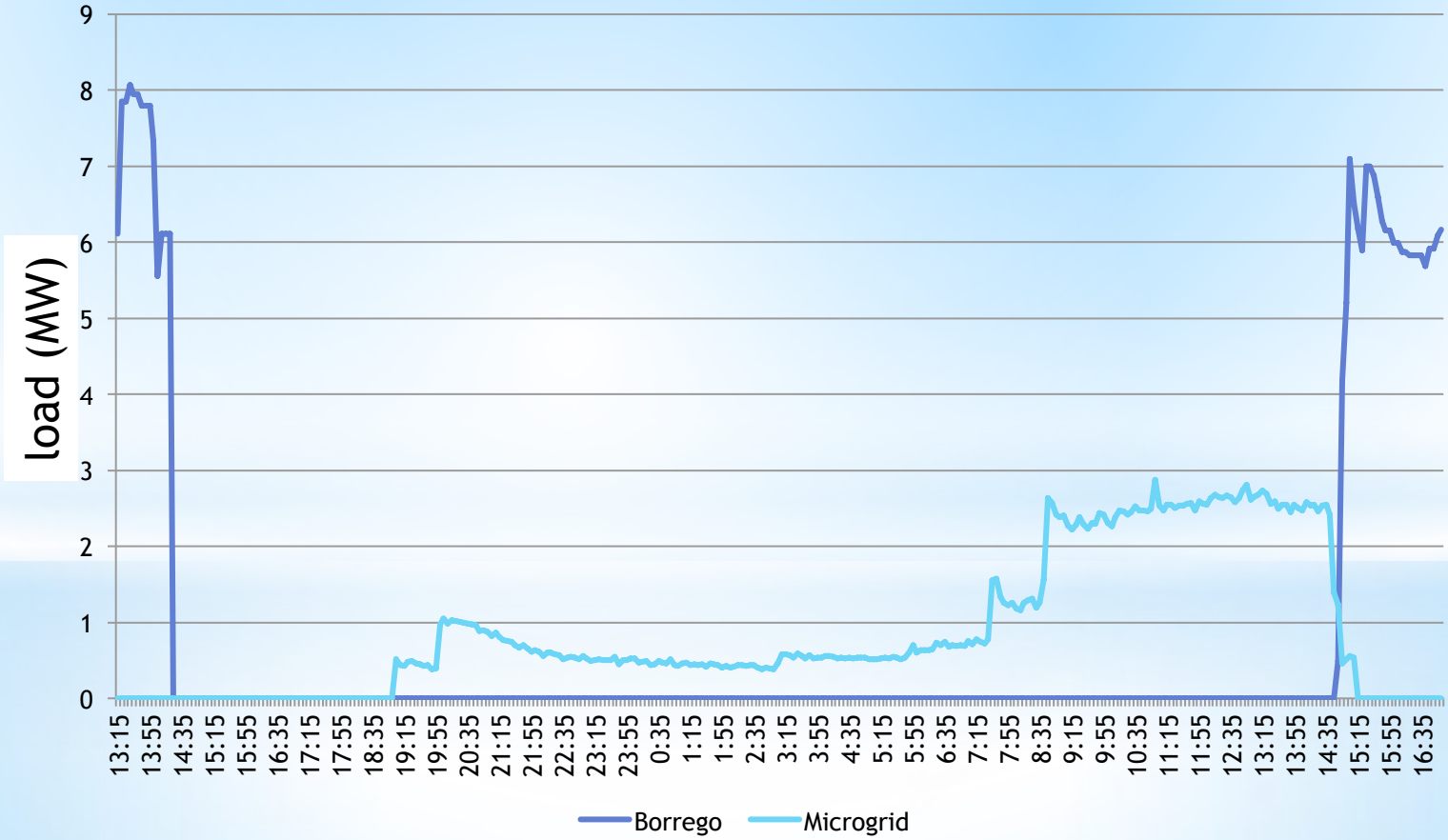
- gusty outflow winds from the thunderstorms began to reach the Borrego area at 14:00.
- peak gusts of 87-105 km/h were measured between 14:20 and 14:30, though evidence supports that a microburst likely occurred near the center of the storm, producing gusts up to 113 km/h
- ~ 167 lightning strikes occurred in the Borrego area

*6-7 September Outage

- *9 transmission and 11 distribution poles were down
- *all roads into/out of Borrego Springs were closed

*Outage Generation

* At 1420, single transmission line to Borrego trips out
* 1056 total customers restored during outage



*Restoration

* restoration took 25 h
* >200 employees involved

*Real World Non-Demonstrations

Planned Outage	• 23 June 2012 • Microgrid powered 2,128 customers for ~ 5.5 h
Planned Islanding	• Q1 2013 • Conducted 7 islanding events over 3 d
Windstorm	• 8 April 2013 • Microgrid provided power to 1,225 customers for ~ 6 h
Flashflood	• 25 August 2013 • CES units islanded six customers for ~ 5.5 h
Intense Thunderstorms	• 6 September 2013 • Microgrid provided power for up to 1,056 customers for > 20 h

*Borrego Springs Microgrid 2.0
CEC: 4.7 M$ & SDG&E: 1.75 M$

Enhance the Borrego Springs Microgrid to be more flexible and automated in responding to a variety of potential outage situations, and leverage various new technologies and Distributed Energy Resources for increased Microgrid capabilities.

Goals

- Enhance Emergency Readiness
- Increase Operational Flexibility
- Decrease Outage Response Times
- Increase Grid Resiliency
- Demonstrate New Microgrid Technologies
- Increase Microgrid Load Capacity

*BS2: CEC Project 2015-18

* additional battery capacity
* integration of PV sites into an islandable microgrid
* higher tech control of fragmentation and load prioritization

*add SAFT/ABB Substation Energy Storage System

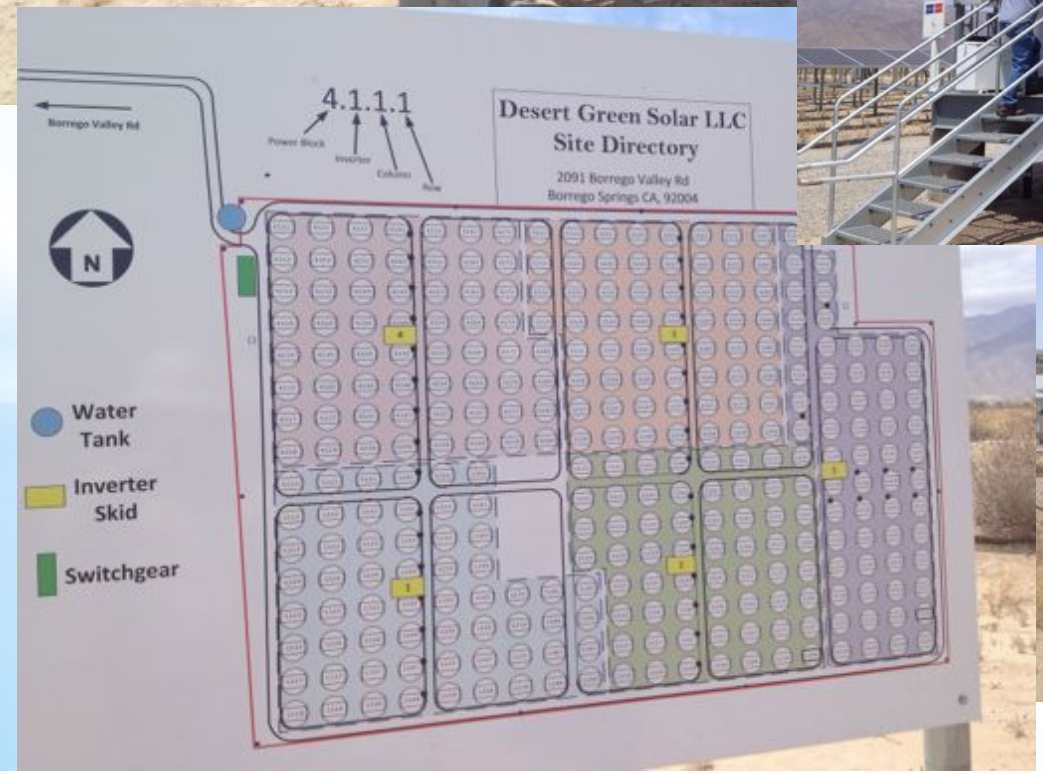
*rated for 1000 kW/3000 kWh

*islanding and blackstart capable

* solar provides generation source
* potential daytime non-emergency islanding at full load

*PV Pictures


5


Borrego Valley Rd
4.1.1.1
Power Block
Inverter
Column
Row
Desert Green Solar LLC
Site Directory
2091 Borrego Valley Rd
Borrego Springs CA, 92004
N
Water Tank
Inverter Skid
Switchgear

Interested in Microgrids?

*Aalborg, Denmark

MicroGrid RESEARCH PROGRAMME

Aalborg 2015 Symposium on MicroGrids

27 & 28 Aug. 2015 - tours: 29 & 30 Aug.

*Aalborg University

Aalborg University was created in **1974**.
Aalborg University is characterised by its educational model of **Problem Based Projects**. The student population is around 15,000.

*Aalborg Symposium Tours

Nordik Folkecenter for Renewable Energy Microgrid

*Key Question(s)

- *Given that microgrids can contribute to economic, resilient, and sustainable locally controlled integrated energy systems:
- *What is the place of microgrids?
- *What should the regulatory response be?
- *What should the role of legacy electric utilities be?
- *What will the effect of microgrids be on the megagrid?

Thank you!