ENERGY STORAGE: AN OVERVIEW OF APPLICATIONS

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Energy Storage Mediates between Variable Sources and Variable Loads

Stationary Energy Storage Applications
involve Large Amounts of Energy or Power
and Offer
Substantial Potential Markets

Applications categorized by

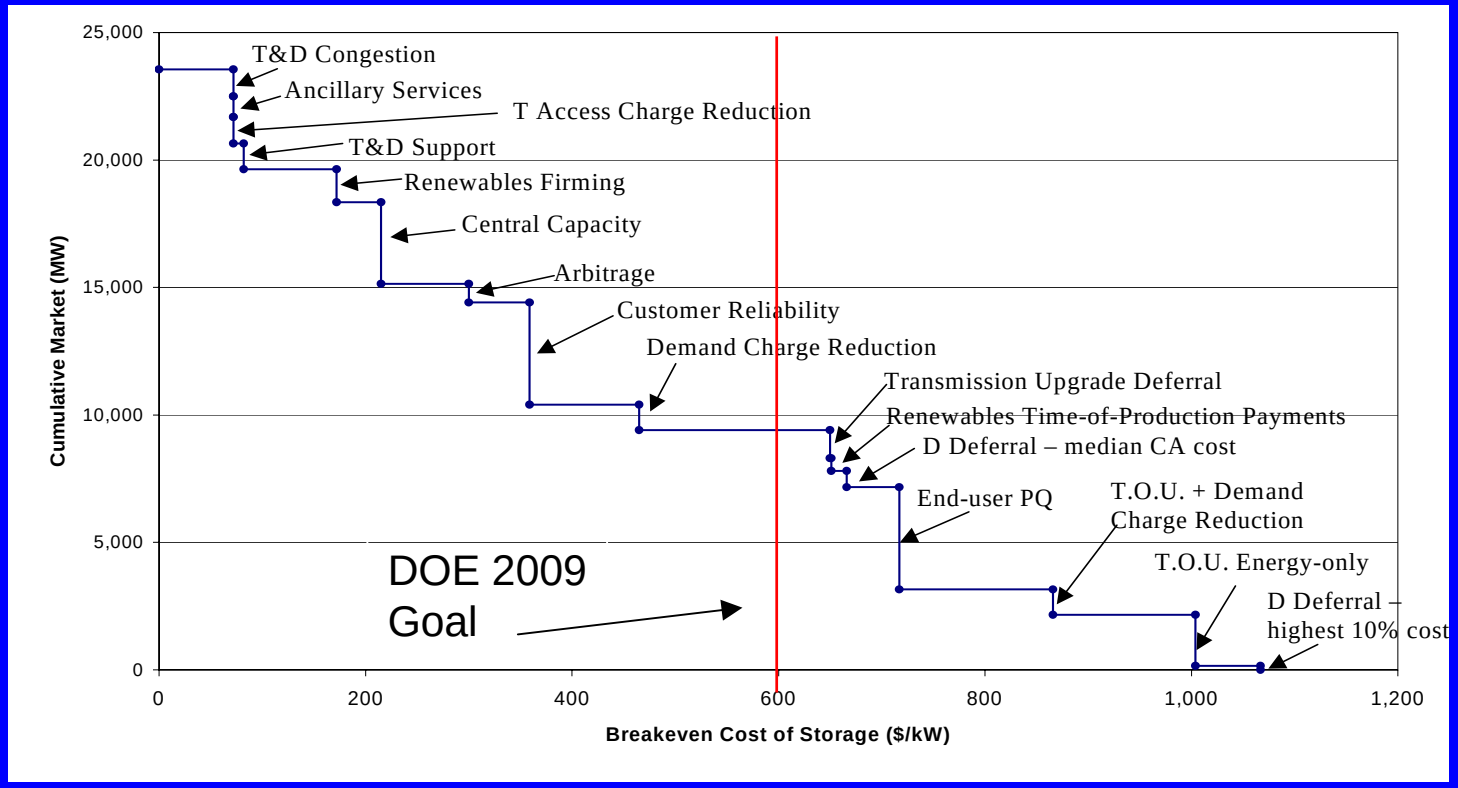
Time Scale:
very short – medium - long

and
Grid / Utility – Load / Consumer

	POWER Seconds	minutes – hours	*ENERGY* diurnal
LOAD	PQ, Digital Reliability	DER Support for Load Following	Peak Shaving to Avoid Demand Charges
GRID	Voltage Support, Transients	Dispatchability for Renewables, Village Power	Mitigation of Transmission Congestion, Arbitrage

APPLICATIONS FOR ENERGY STORAGE

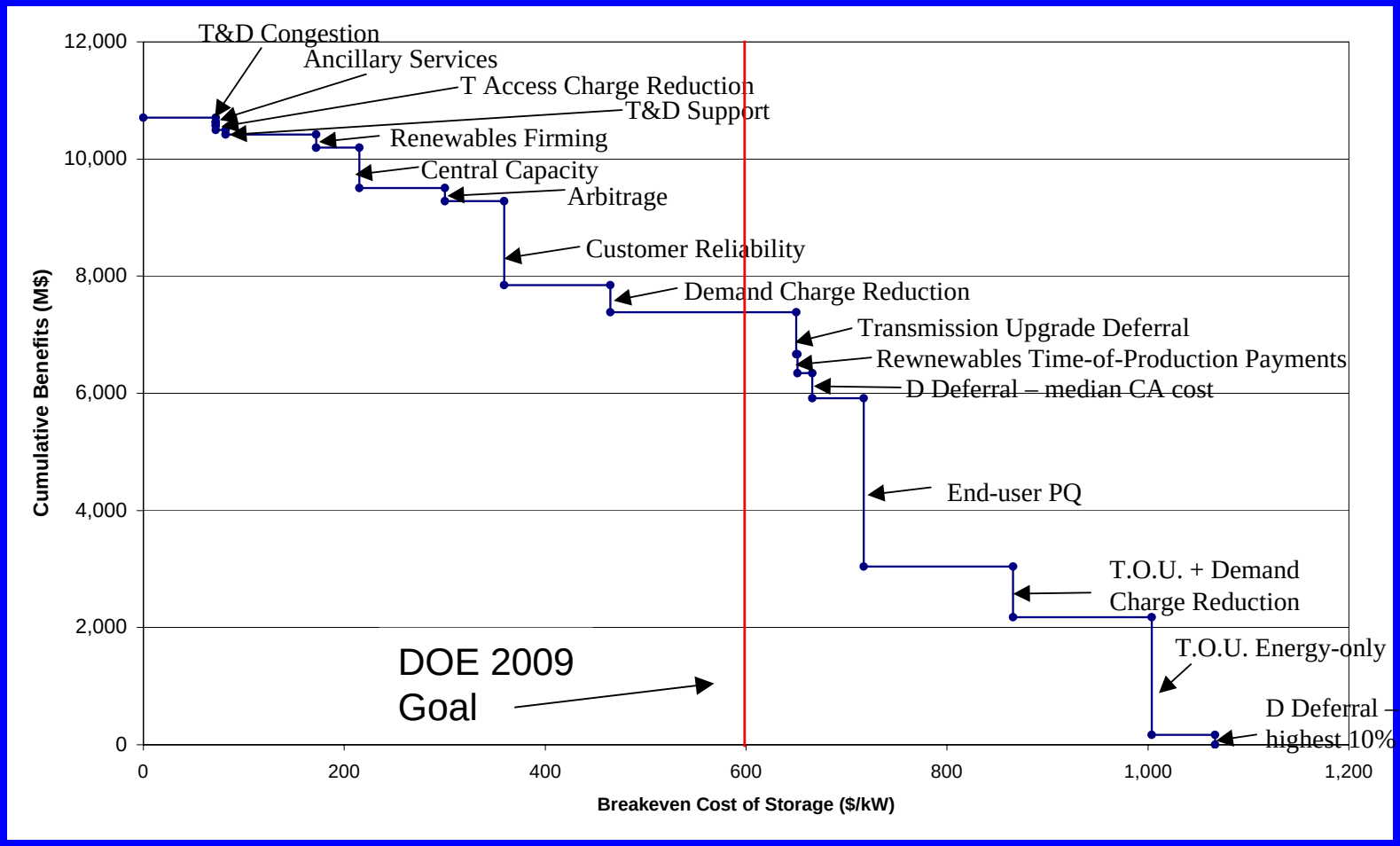
Storage Potential, California



U.S. = 8 x CA

single benefit!

Storage Benefits, California



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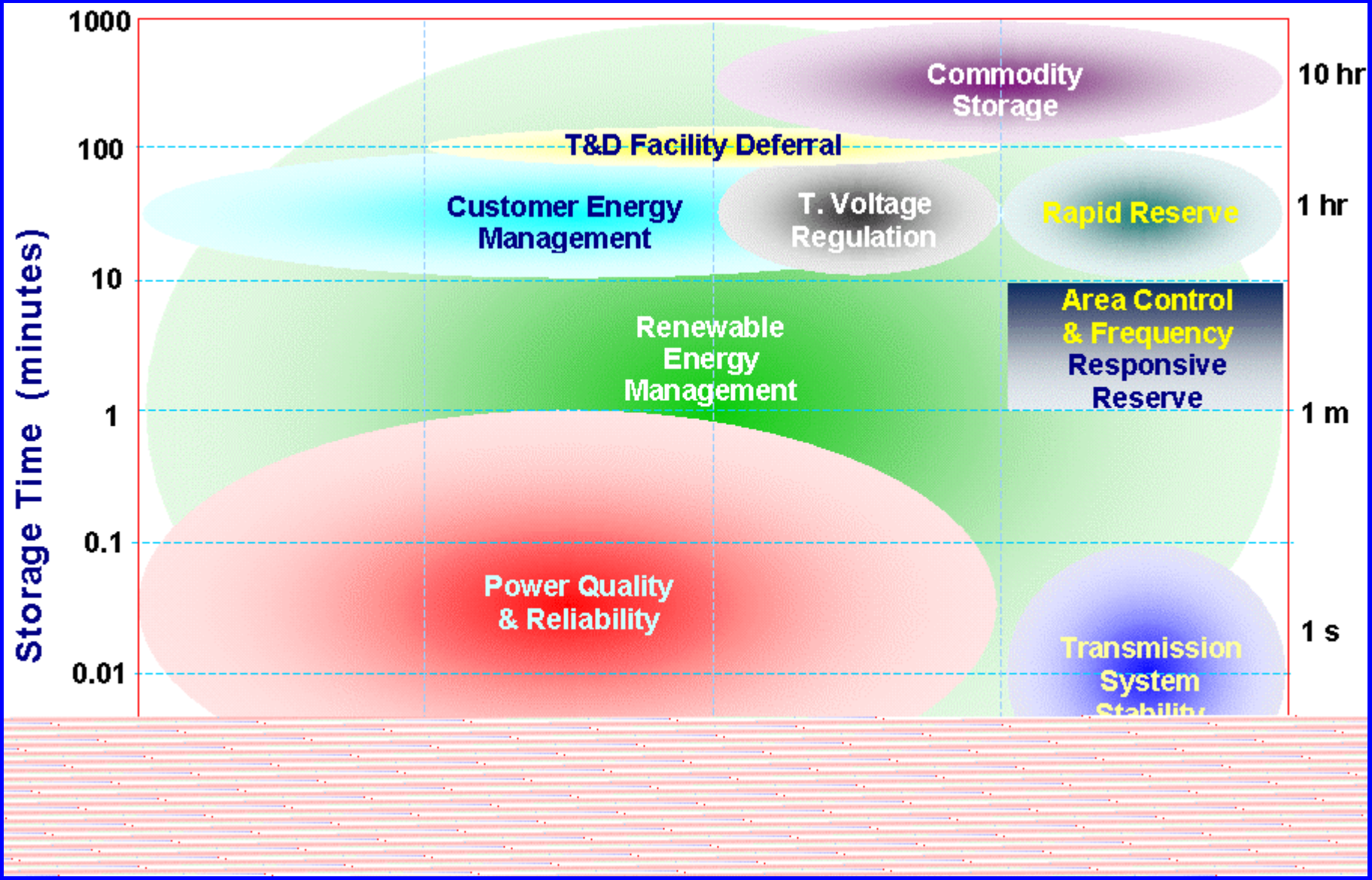

Storage Time (minutes)
1000
100
10
1
0.1
0.01
10 hr
1 hr
1 m
1 s
Commodity Storage
T&D Facility Deferral
Customer Energy Management
T. Voltage Regulation
Rapid Reserve
Renewable Energy Management
Area Control & Frequency Responsive Reserve
Power Quality & Reliability
Transmission System

A. Nourai

98% of Fatal
Power Quality Events
last less than Seconds

but Outages
lasting a Few Cycles
can cause
Hours of Downtime

ONLY ENERGY STORAGE

CAN PROVIDE

SEAMLESS CONTINUITY

OF POWER SUPPLY

10 MW - 15 sec System at Microchip Plant

Outage Costs for U.S. Industry

estimated at

$35 - $150 Billion Annually

X		

VOLTAGE SUPPORT,

TRANSIENTS,

GRID STABILITY

EXAMPLES:

D-SMES in Wisconsin

40 MW NiCd in Alaska

20 MW LA in Puerto Rico

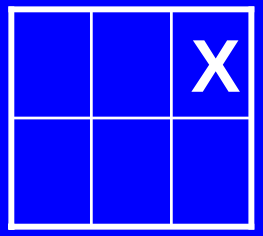
20 MW / 14 MWhr Puerto Rico

Combine a fast Power Switch (such as ETO)

with a Multi Level Inverter

and Ultracapacitors or Flywheels

for Current Injection to Maintain Grid Stability



PEAK SHAVING FOR

PROFIT AND RELIABILITY

With Energy Storage Customers can Ride out Price Peaks and Avoid Demand Charges

With Development of Aggregation Mechanisms and Appropriate Contractual Tools Customers could even Bid Unused Load at Spot Market Prices !

Systems Should Carry Load for 650 Hours/Year
5 Hours Max Period

Potential Market: 460 Gw
Potential Benefits: 875 $/kW

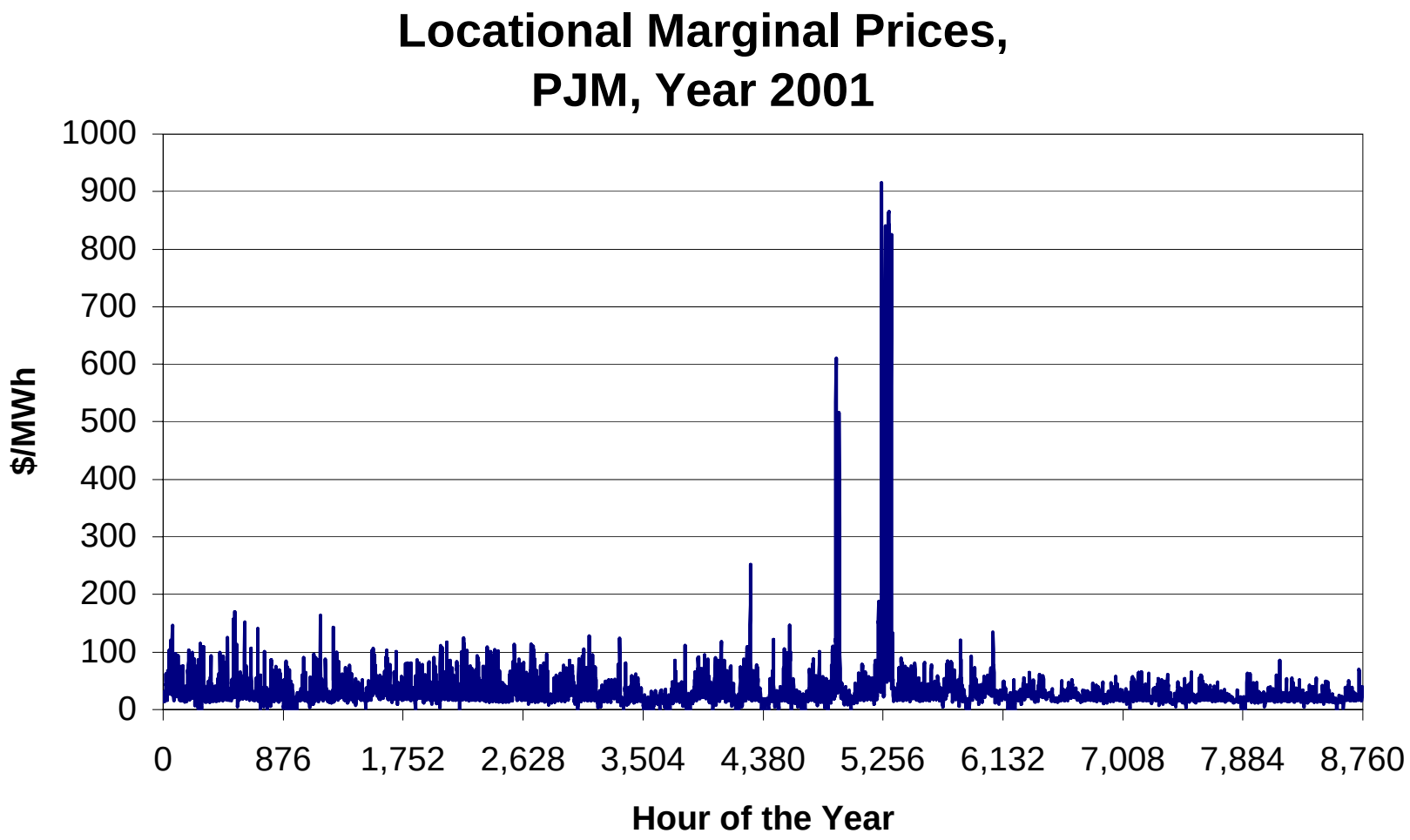
ARBITRAGE AND

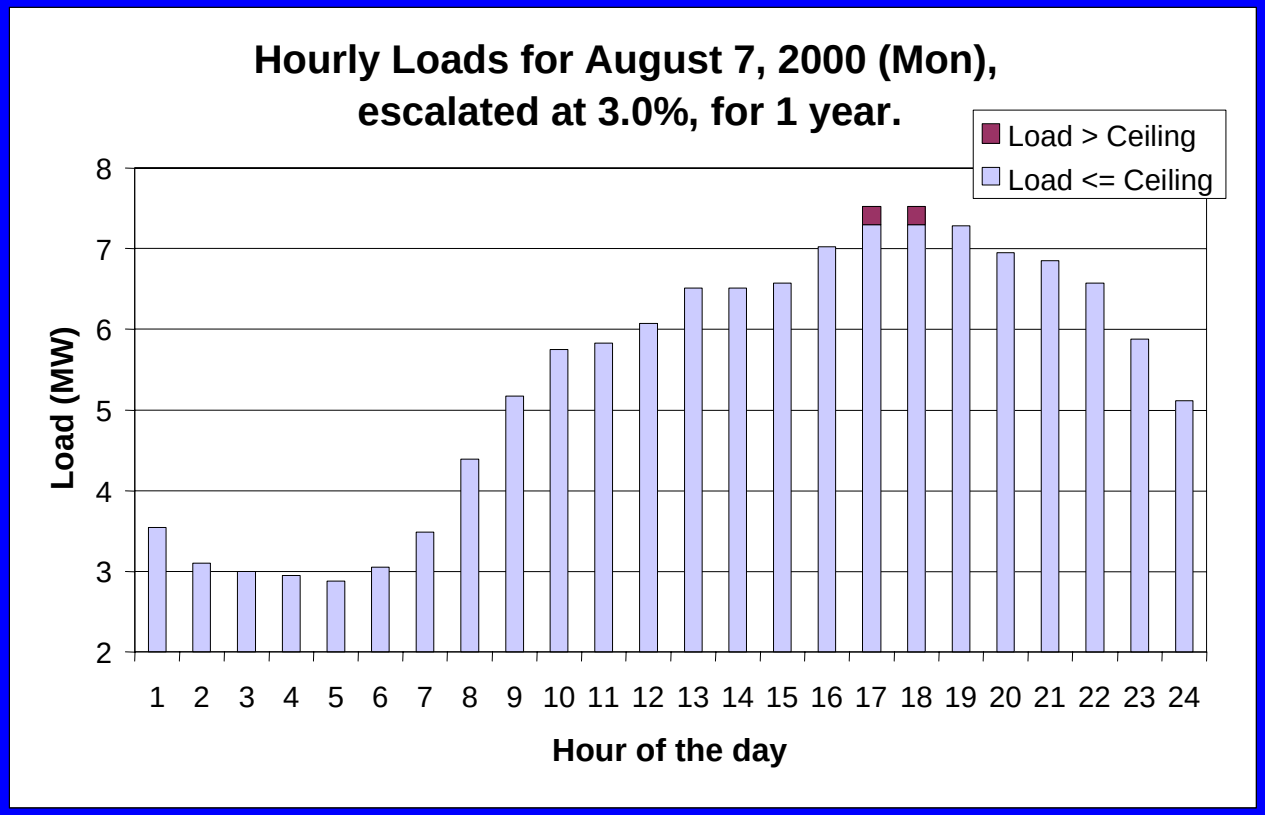
RELIEF OF

TRANSMISSION CONGESTION

Price Spikes Caused by Deregulation and Immature Energy Markets

Congestion due to Disincentives for New Transmission Construction and Load Increase


Locational Marginal Prices,
PJM, Year 2001
$/MWh
1000
900
800
700
600
500
400
300
200
100
0
0
876
1,752
2,628
3,504
4,380
5,256
6,132
7,008
7,884
8,760
Hour of the Year

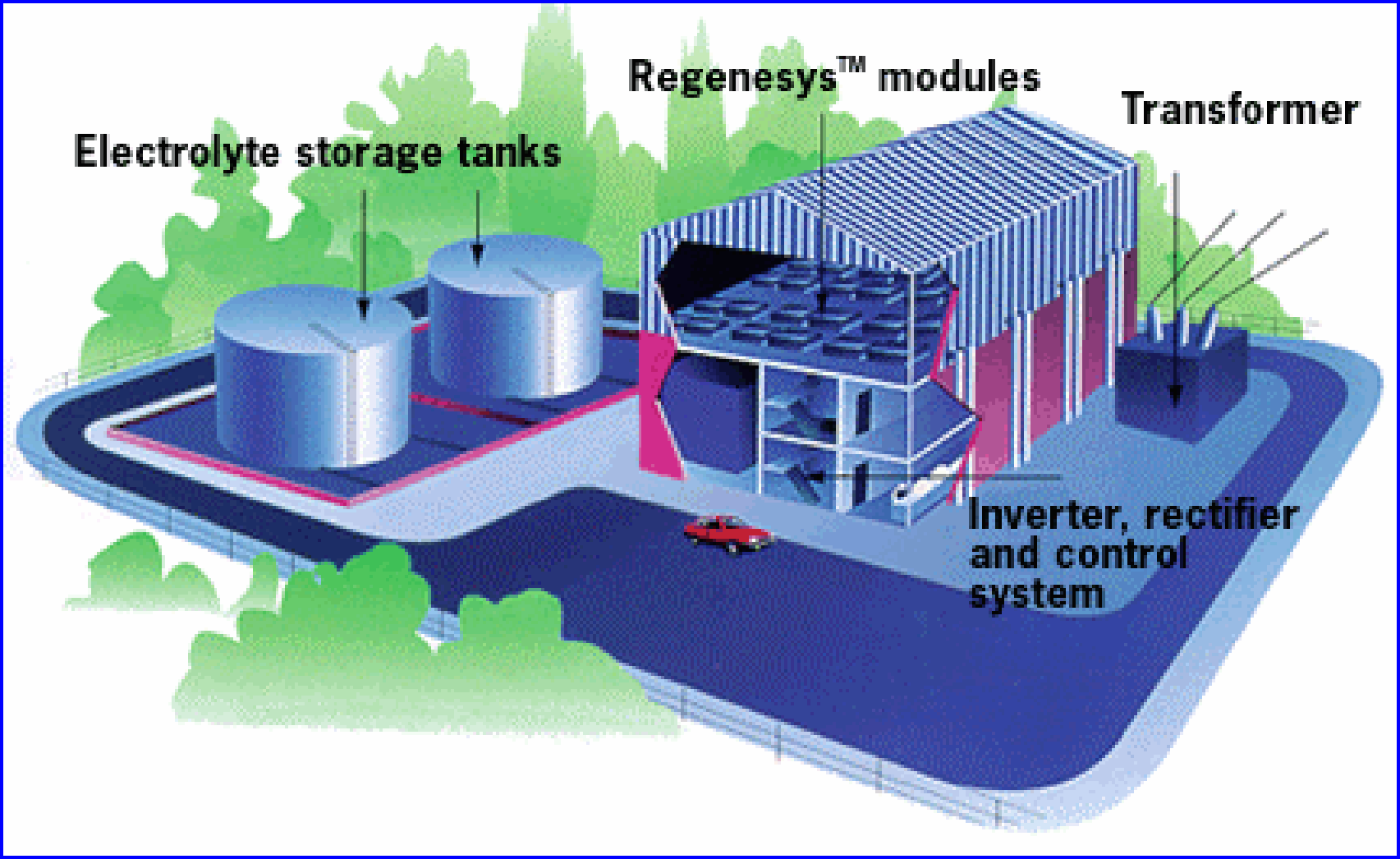


In general, Load will exceed Transmission Capacity for only a few Hours a year requiring Load Shedding or Upgrading of the Transmission Line

Models of Bulk Storage using Actual Electricity Prices and Real Transmission Loads

show Considerable Benefits from Arbitrage + Transmission Deferral

6 MW / 8hrs Sodium-Sulfur at Ohito



View of 12 MW / 8 hour Flow Battery Facility

	X	

DISTRIBUTED GENERATION LOAD FOLLOWING

	X	

MAKING RENEWABLES DISPATCHABLE

VILLAGE POWER

Storage can make Wind and PV Farms Dispatchable to bid on the Spot Market and replace Expensive Peaking Power

$466/kW Capacity Firming Benefit

Wind Market:

6 GW (US), 20 GW (Europe)

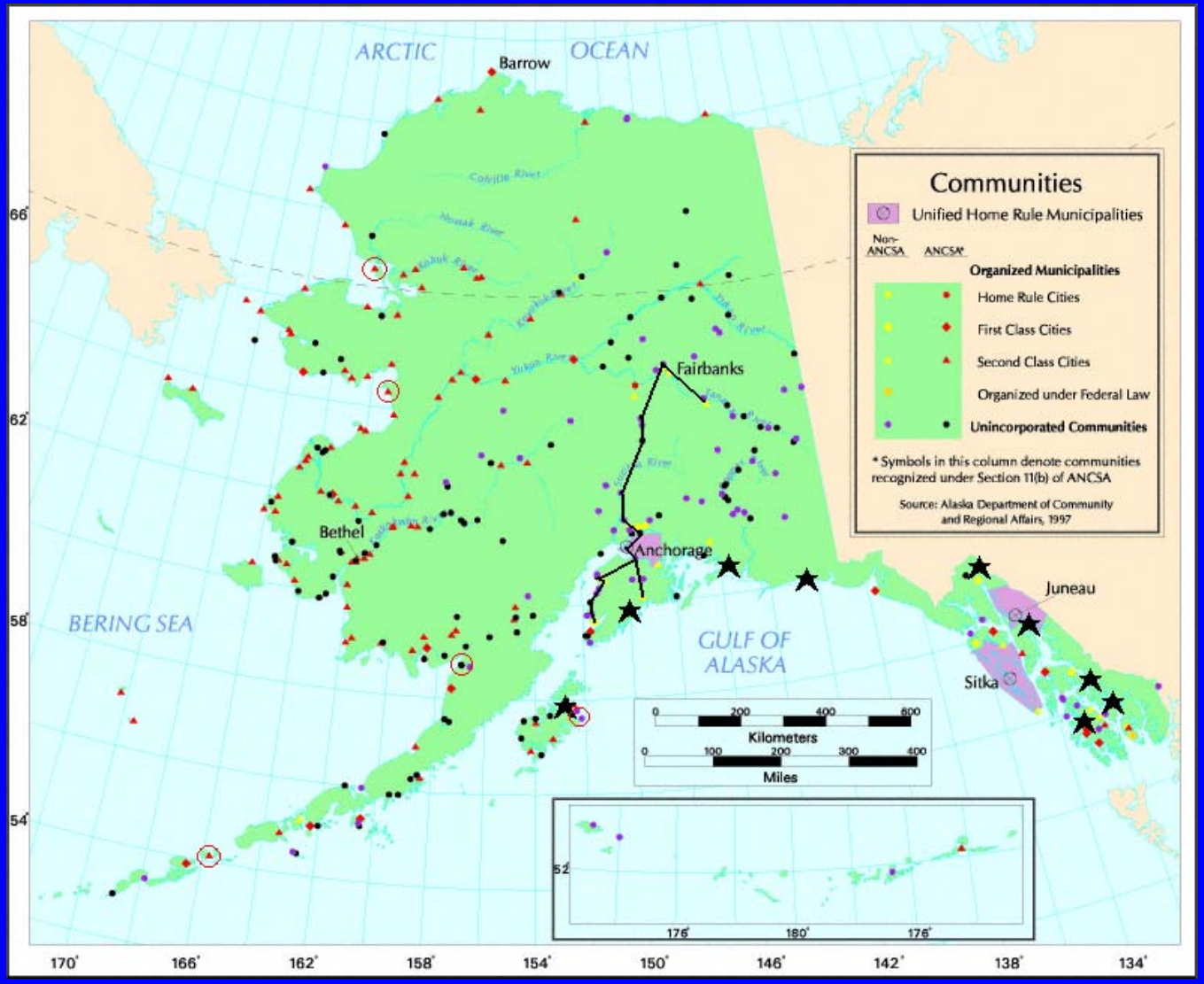
One Third of the World Population is Not Grid Connected

Storage Improves Efficiency & Reliability of a Village Grid

Market Estimate: >25 GW

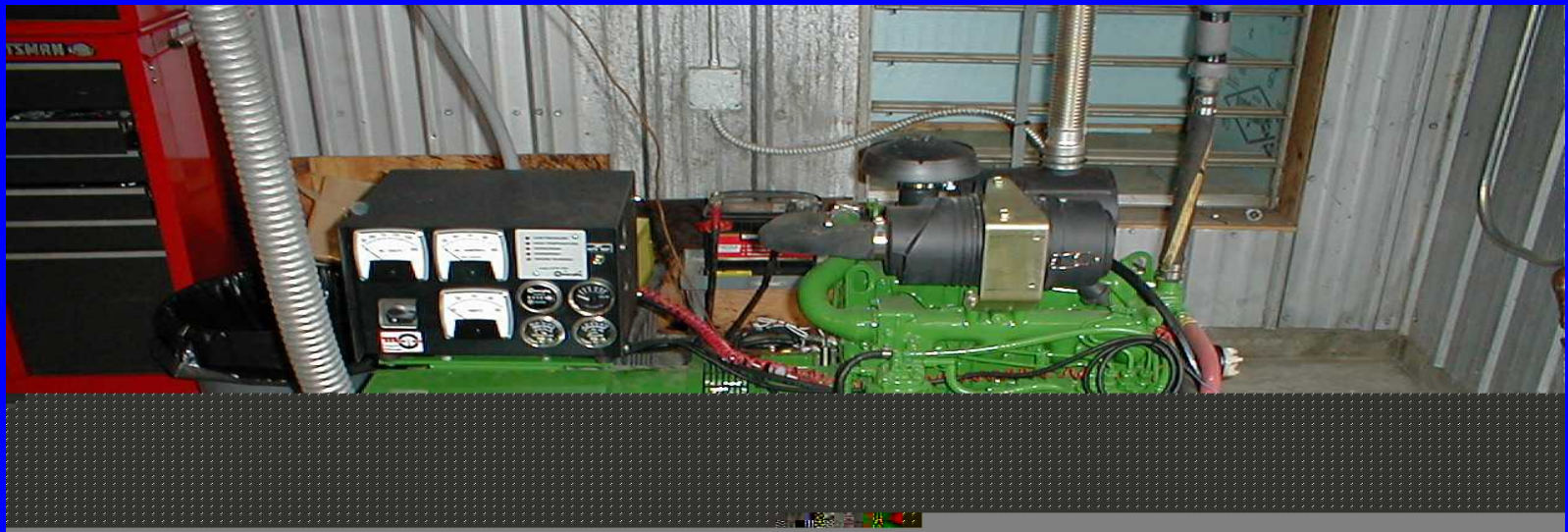
LIME VILLAGE
Diesel + PV + Storage

- Alaska Energy Authority (AEC)
- Lime Village Traditional Council
- McGrath Light and Power
- Sentech Inc.
- DOE / Sandia

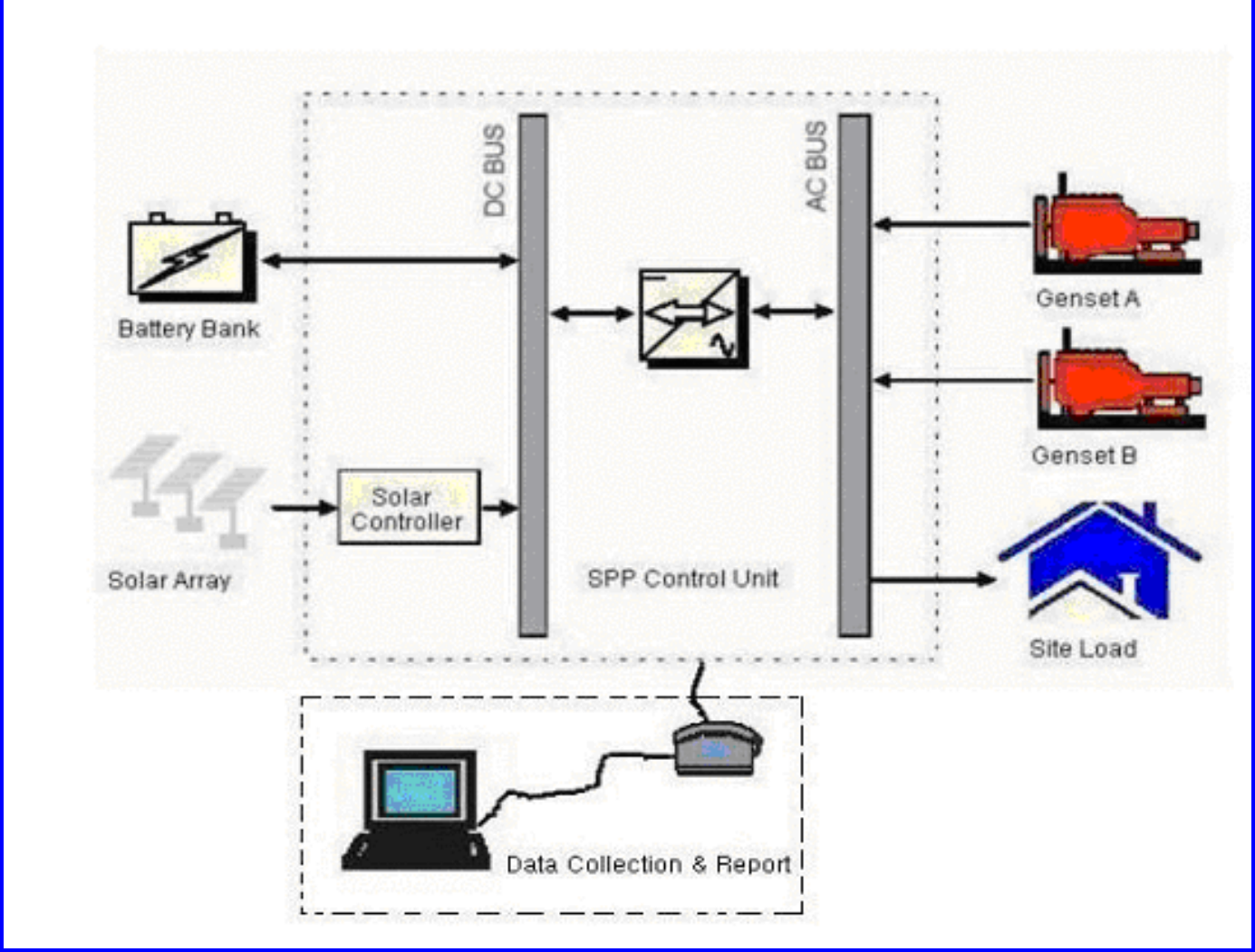


The Alaskan Grid !!

Lime Village



21kW + 35kW Diesel Generators



Diesel / PV / Battery Hybrid System

Diesel + PV + Battery:

- Integrated System
- Remote Monitoring and Diagnostics
- Modeling shows 10 – 20% Fuel Saving
- Interest by AEC to apply across State

Padre Cocha, Peru
Diesel + PV + Storage
Remote Area Power System
(RAPS)

- Ministry of Energy and Mines, Peru
- Internat. Lead-Zinc Research Org.
- World Bank
- DOE / Sandia

Peru

70,000 Remote Communities

Loreto

3,000 Remote Communities

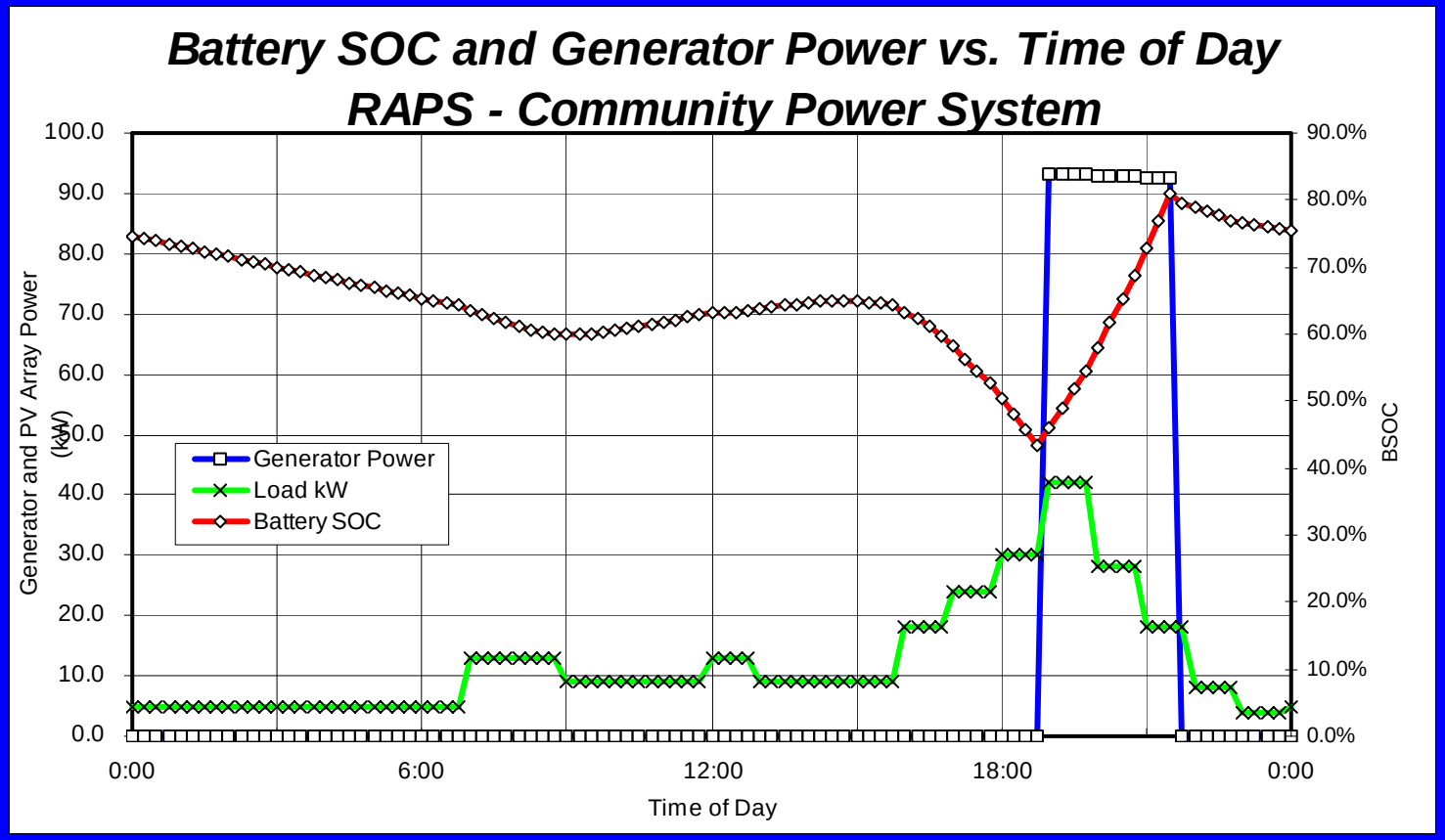
~150 Communities with small Diesel Gensets

Padre Cocha, Peru - 300kWh/day Load

30kW Solar Array = 35% of Energy

Padre Cocha System

- Load: 300 kWh/day Peak: 42 kW
- Generator: 100 kW
- PV: 30 kW peak
- DOE / Sandia
- L/A Gel Battery System: 384 kWh
- (7 – 10 year Lifetime)



Padre Cocha, Typical System Operation

Padre Cocha
Economic Analysis

- Current Energy Cost (Candles, Batteries, Kerosene, etc) $10 / month / family
- Basic RAPS service: 15kWh / month / family equivalent to $0.67 / kWh (@ $10 / month)
- RAPS operating coat: $0.16 / kWh
- Diesel only generating costs: $0.89 / kWh

The City of San Francisco, CA

San Francisco, CA
Grid + PV + Storage

- Illinois Institute of Technology
- Illinois Department of Commerce
- San Francisco PUC
- DOE / Sandia

Mandates:

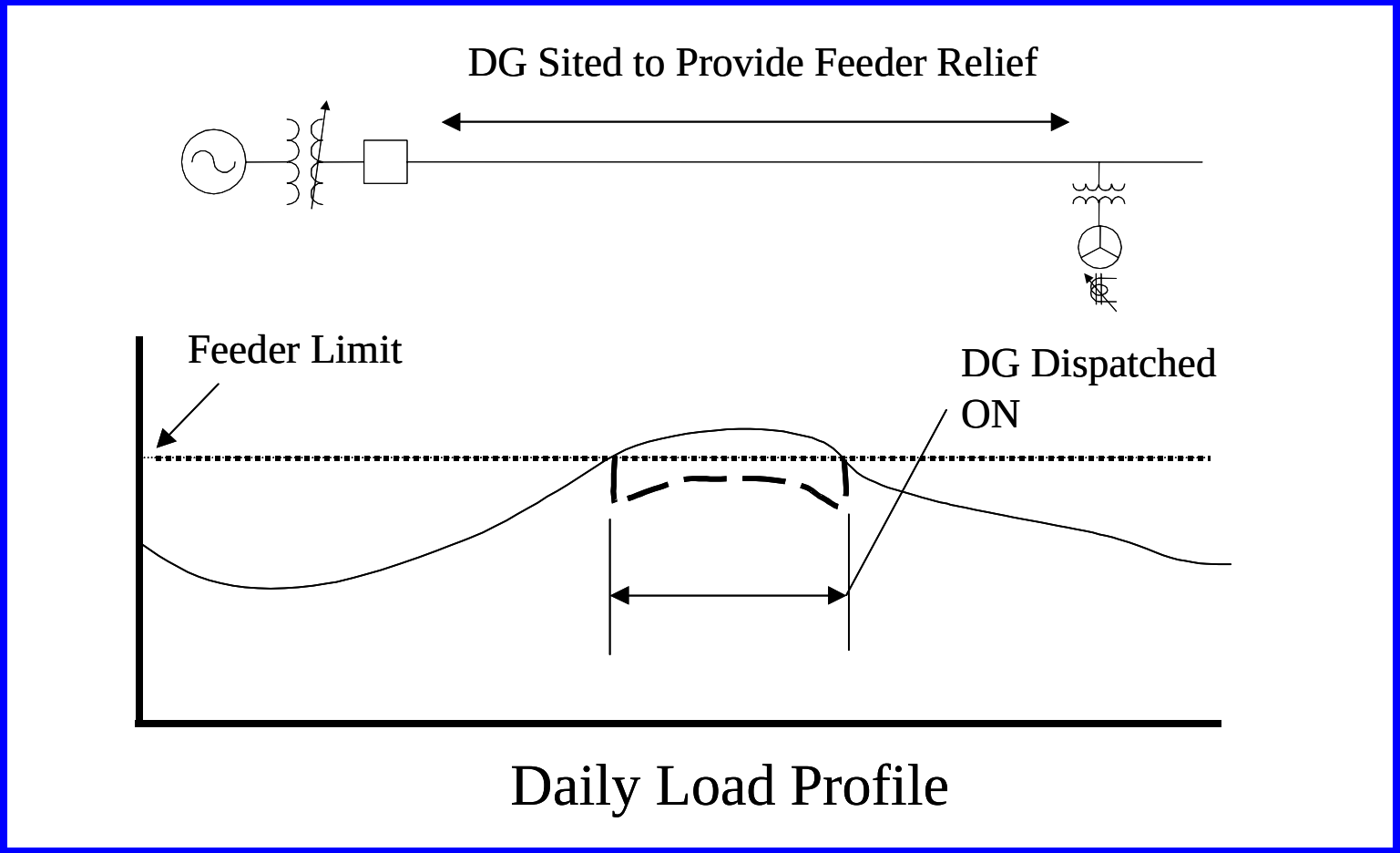
- **California Mandate:**

  20-30% Renewables

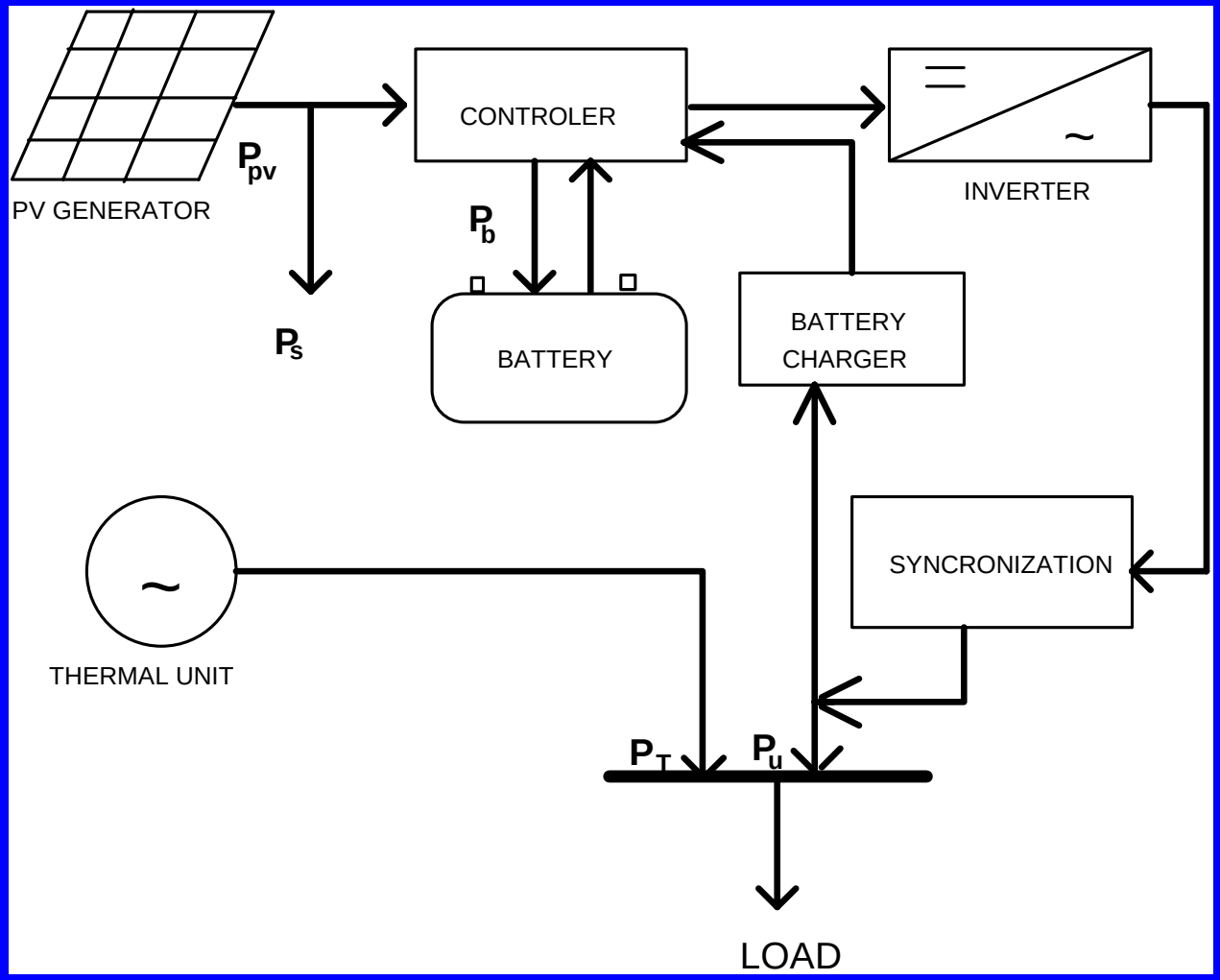
- **San Francisco Mandate:**

  10 – 25 MW PV

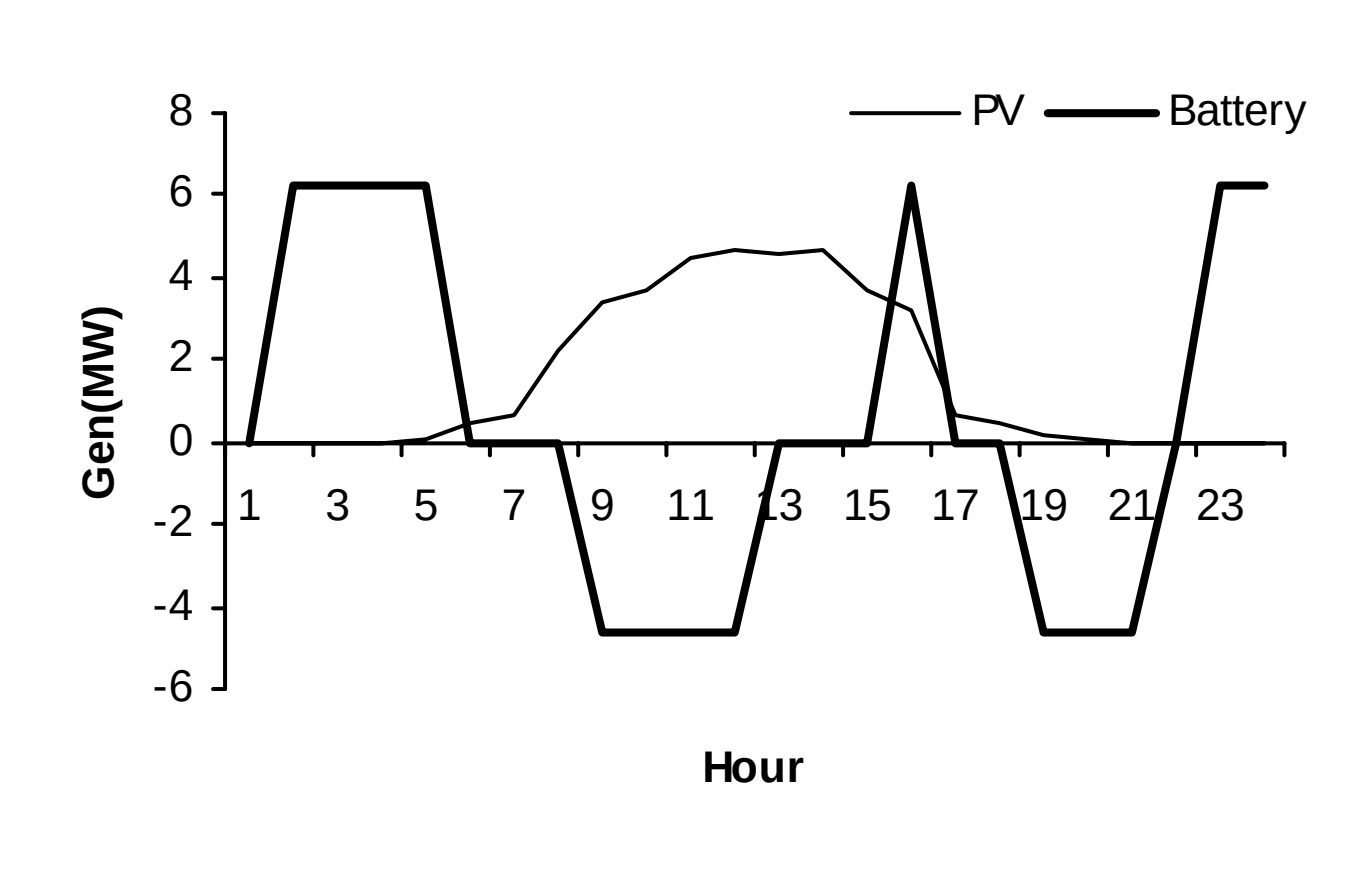
Transmission Constraints ??



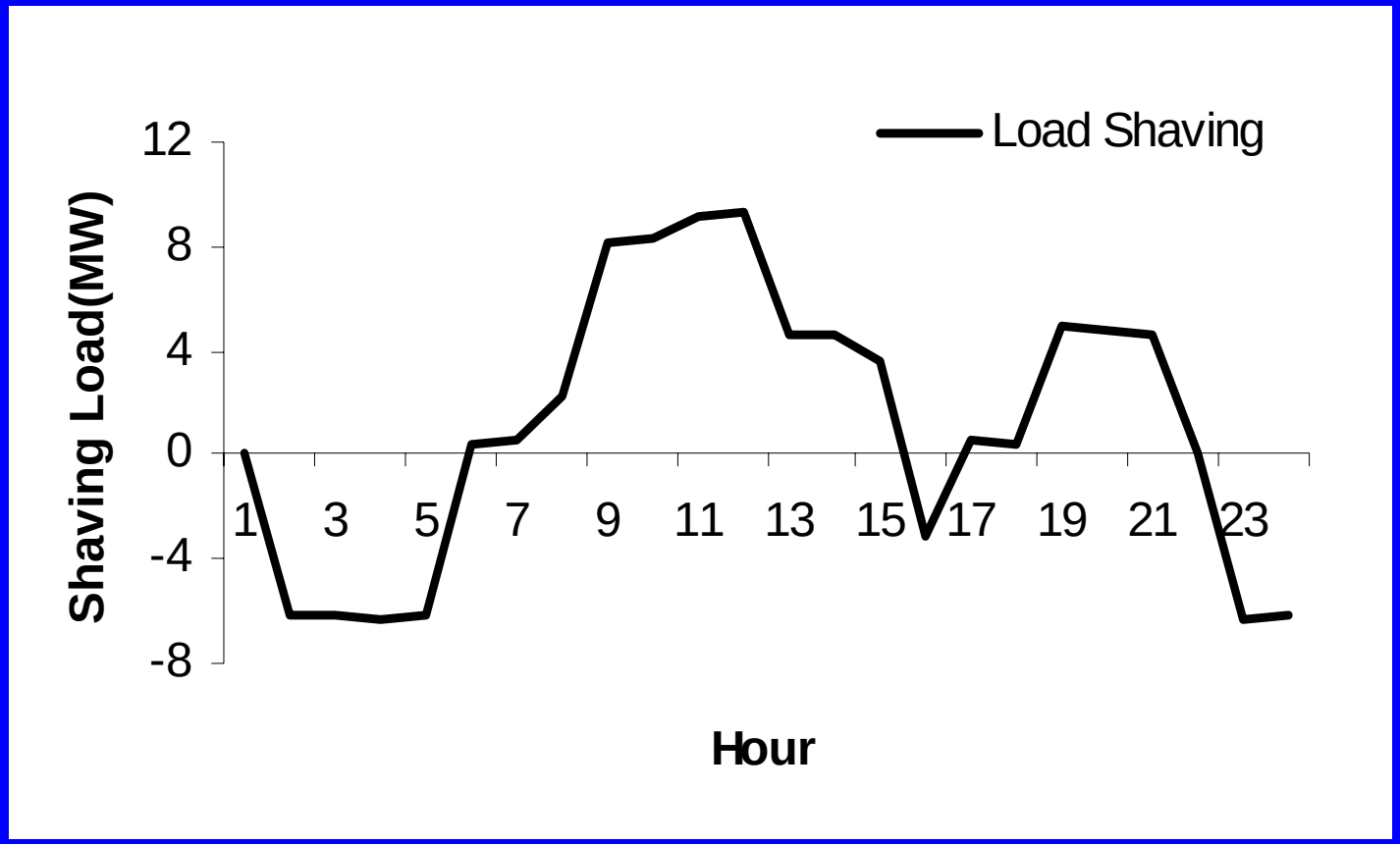
DG added during Peak Load



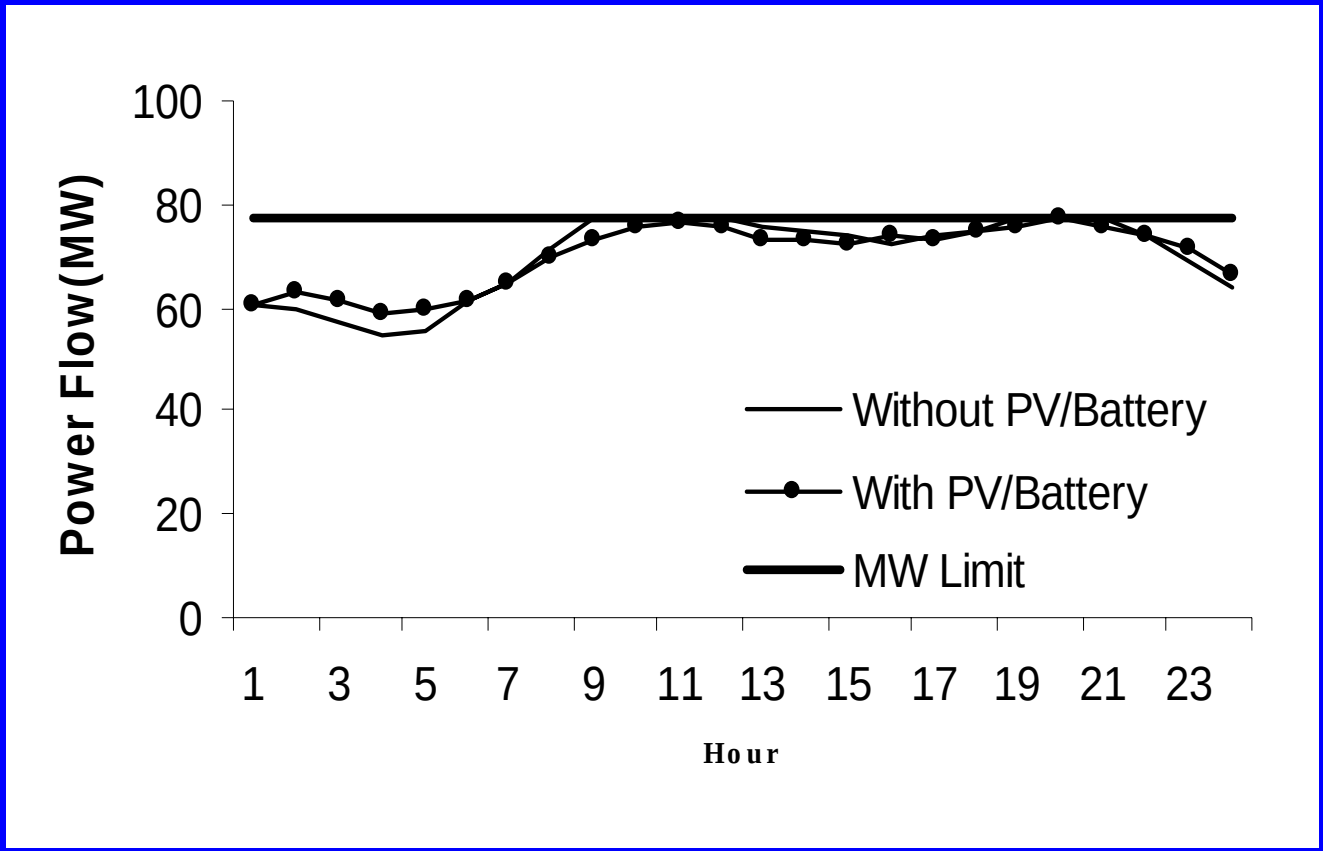
PV + Battery on Stressed Grid



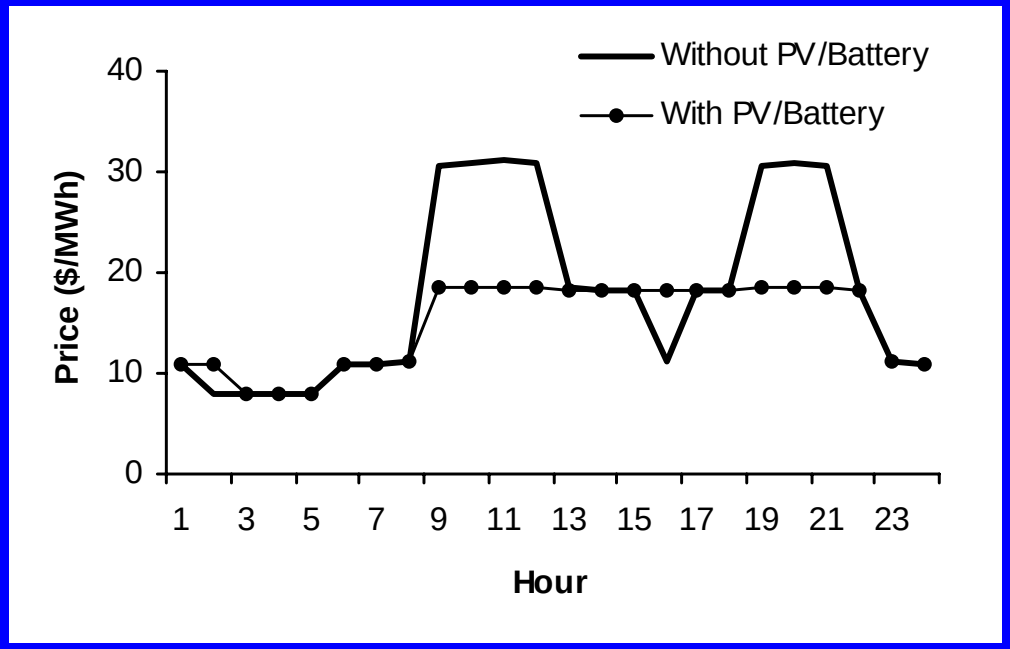
PV Generation and Storage Charging



PV + Storage Shaving Load



Load Management
Eliminates Branch Congestion



LMP at Bus 8

Hour	Thermal Generation Costs ($)	
	Without PV/Battery	With PV/Battery
1	885.06	885.13
2	852.38	915.27
3	796.85	847.15
4	741.5	791.64
5	769.15	818.89
6	959.52	954.86
7	1221.19	1214.33
8	1714.65	1689.53
9	2262.88	2108.48
10	2585.65	2358.51
11	2666.8	2407.56
12	2585.65	2339.7
13	2130.66	2046.44
14	2067.35	1981.56
15	1941.32	1874.43
16	1831.03	1871.82
17	1941.32	1929.82
18	2067.35	2059.46
19	2343.29	2231.07
20	2504.68	2362.21
21	2343.29	2234.77
22	1941.32	1941.32
23	1522.87	1592.06
24	1146.26	1214.15
SUM	41822.02	40670.16

Cost Saving

Possible PV Installations in SF

San Francisco International Airport
MUNI
Hetch Hetchy lands and reservoirs
Sewer and Water Treatment Facilities
Hunters' Point Naval Shipyard
Mission Bay
Port Property
Schools, Libraries
Civic Buildings
Police Stations, Fire Stations
City-owned Hospitals
City-Owned Convention Facilities
Recreation and Parks Facilities
Commercial facilities, Residential

To Optimize System using

Locational Marginal Pricing

and taking into account

Distribution Constraints

and PV Mandate

DOE PROGRAM GOAL:

Develop a Broad Portfolio of

Demonstrated Storage Technologies

for a Wide Spectrum of Applications