Towards Systemic Analysis of Building Energy Systems

seminar presented at the

Carnegie Mellon University
Electricity Industry Center

30 May 2006

by

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research supported by the U.S. Dept of Energy and the California Energy Commission

Outline

1. Introduction to Microgrids
2. Distributed Energy Resources
   Customer Adoption Model (DER-CAM)
3. Example Study: San Bernardino CA USPS P&DC
   (parts A & B)
4. Power Quality and Reliability (PQR)
5. Lessons Learned/Future Work

History of U.S. Electricity Sector

phases of centralization

1. isolated developments (pre 1900)
2. consolidation and monopolization (1900-1933)
3. fossilization and total centralization (1933-1980)

phases of decentralization

1. independent investment (avoided cost) (1980-1995)
2. wholesale (and some retail) competition (1995-)
3. decentralization and full competition? (2000-)

What is a Microgrid?

A ***controlled*** grouping of energy (including electricity) sources and sinks that is connected to the macrogrid but can function independently of it.

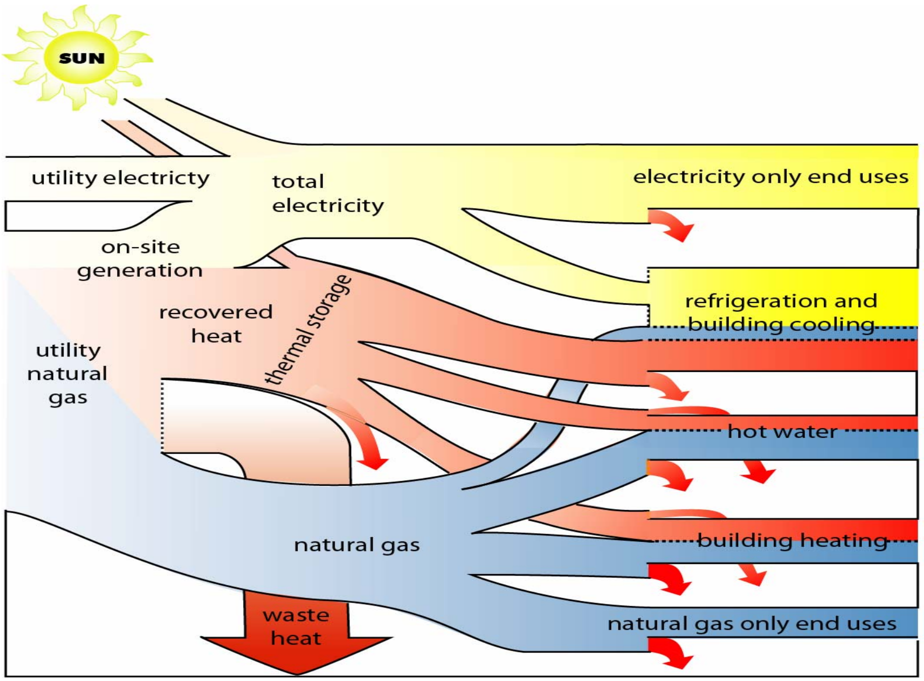
Two Main Benefits to Developers of Microgrids:

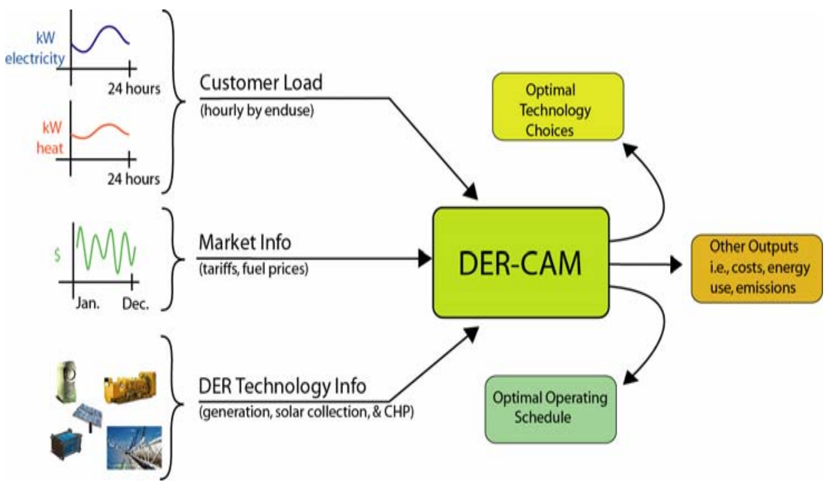
- **pushing efficiency limits by heat recovery (CHP)**
- **providing heterogeneous power quality and reliability (PQR)**

There are other societal benefits.

2. Distributed Energy Resources Customer Adoption Model (DER-CAM)

DER Customer Adoption Model (DER-CAM)





DER-CAM: Mathematical Model

- DER-CAM uses GAMS to model an MIP solved with Cplex
- minimize
  - customer (annual) energy bill

  (DER investment, DER operation, energy purchases, energy sales) annualized
- subject to:
  - energy balance
  - electricity & NG tariffs
  - DER characteristics (investment cost, heat rate, and maintenance cost)
  - heat production/available waste heat/CHP technology

    (heat storage & solar thermal assistance)
  - solar insolation

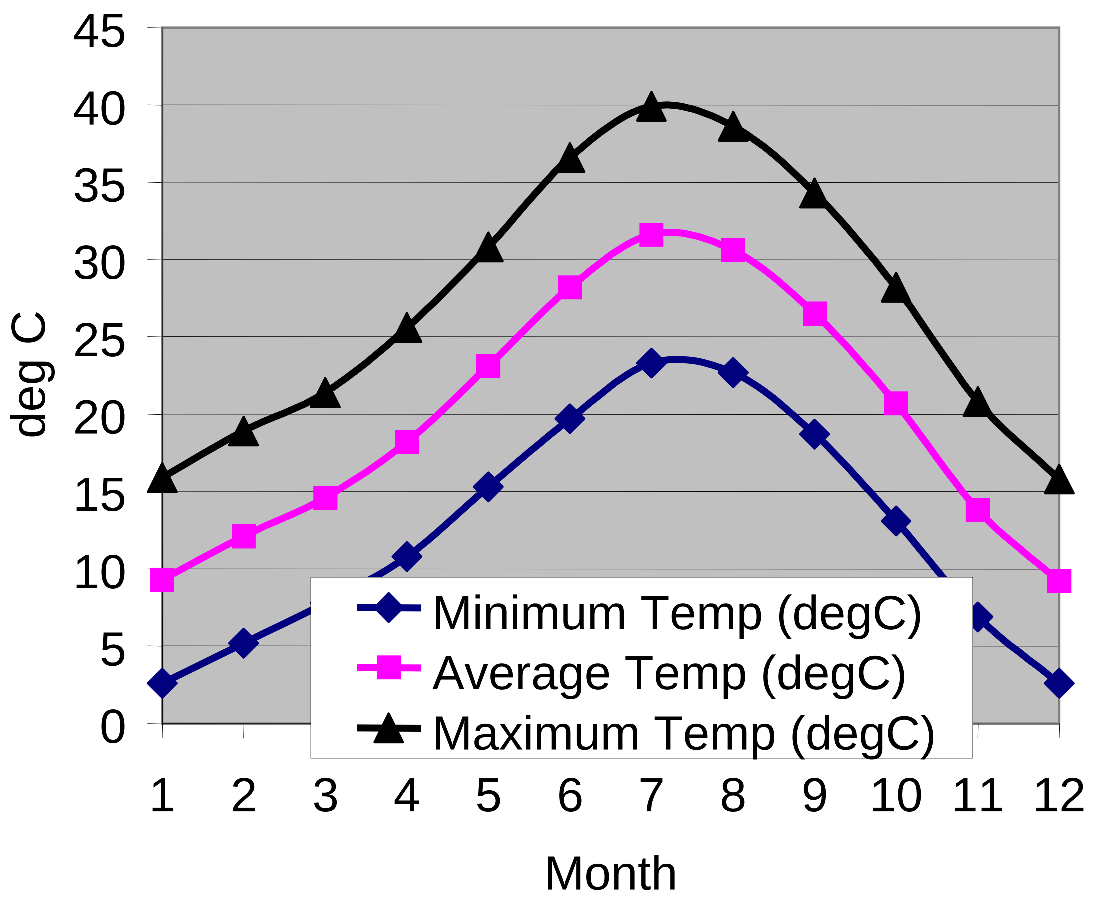
3. San Bernardino Processing and Distribution Center

Part A: 2002

San Bernardino USPS, Redlands CA

Redlands, California

San Bernardino USPS: Temperature



source: Renewable Resource Data Center, National Renewable Energy Laboratory, http://rredc.nrel.gov/

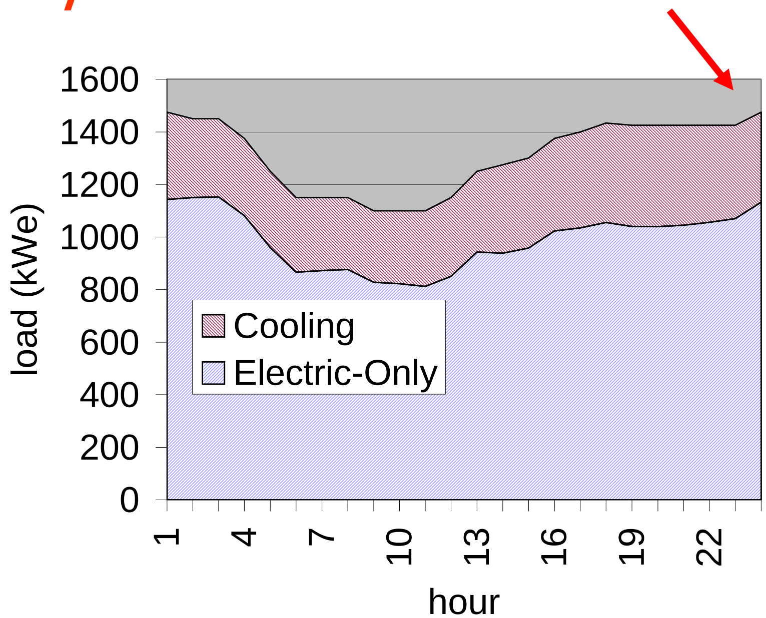
San Bernardino USPS, Redlands CA

25 000 m^2 single-story

equipment runs mostly during evening and night

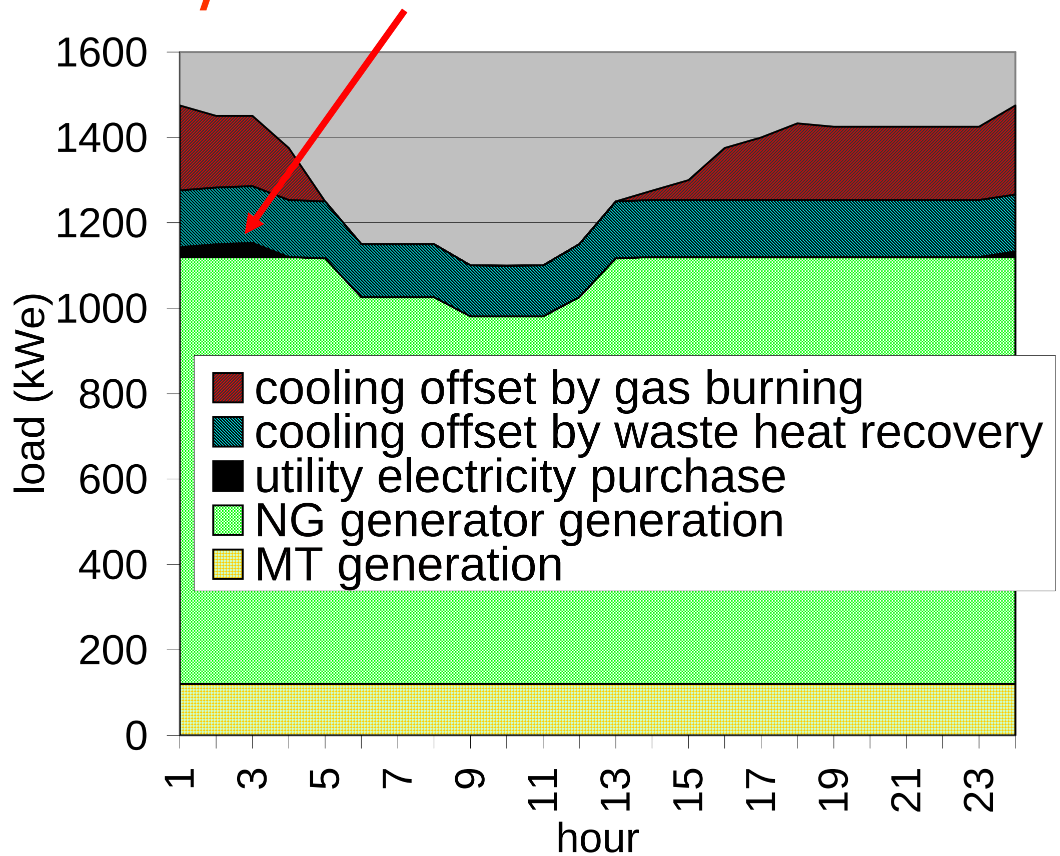
USPS July Weekday Electric Loads

peak load = 1500 kW



site electric loads

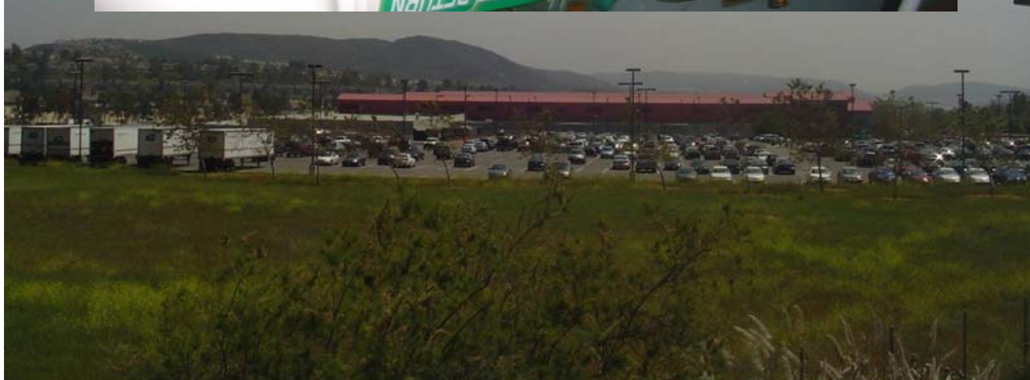
peak load = 1150 kW



How site electric loads are met.

San Diego USPS

(Margaret L. Sellers Processing and Distribution Center)

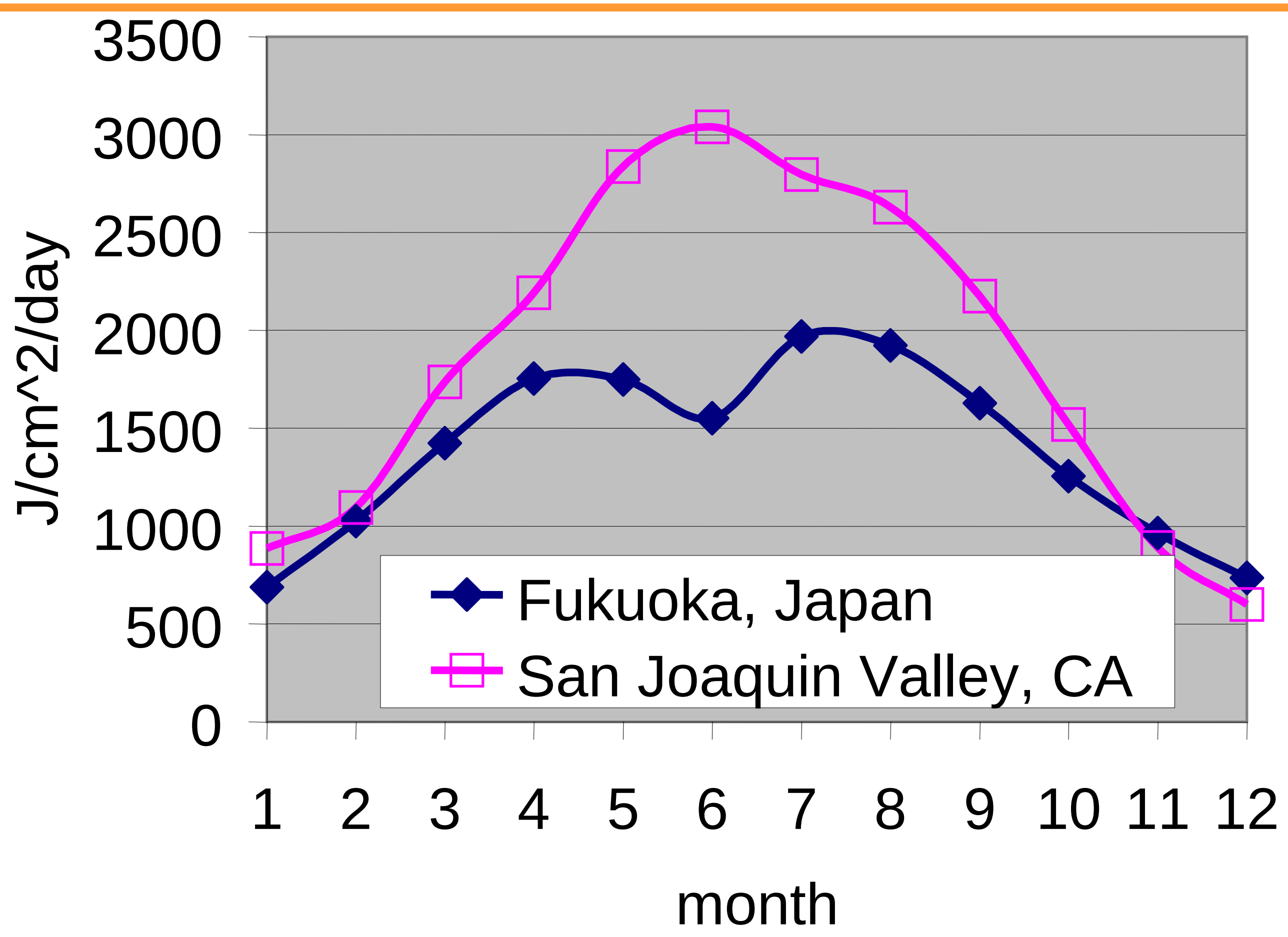


East Bay Municipal Utility District Microturbine Installation with Cooling

3. San Bernardino Processing and Distribution Center

Part B: 2005

San Bernardino USPS: Solar Radiation



source: 2001 data from World Radiation Data Centre, http://wrdc.mgo.rssi.ru/

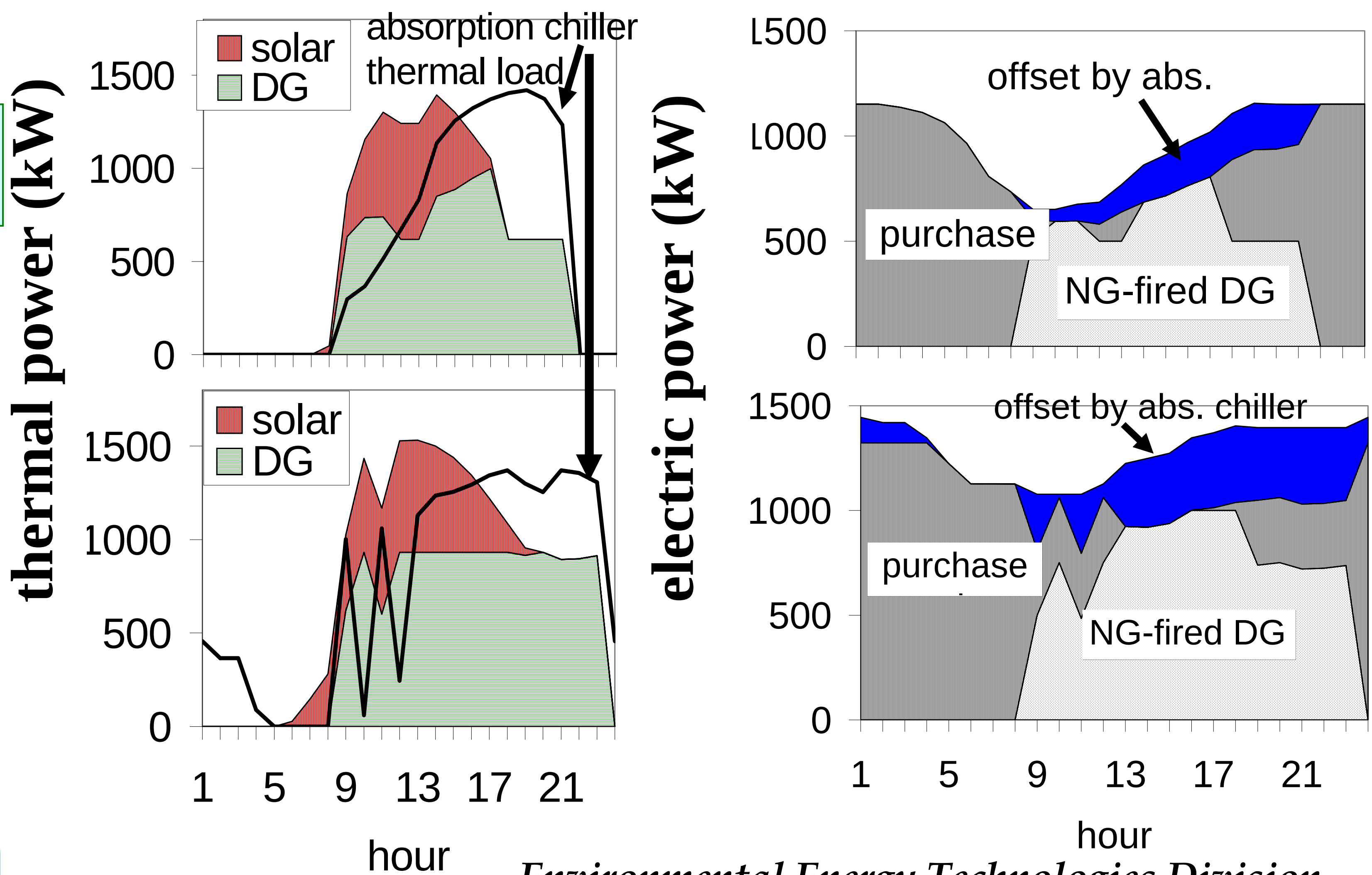
Minimum Cost Results

- low temp. collectors are economic
- chosen system:
  - 1 MW (electric capacity) of reciprocating engines
  - 1.7 MW (thermal cooling capacity) single-effect abs. chiller
  - 1.5 MW (heat delivered) low temperature collectors
- but only provide 45% of heat
- and only lower the annual bill by 1%
- high temp. collectors and PV are not chosen

Meeting Absorption Chiller and Electric Loads

US$150/kW
low temp.
Jan

$500/kW
high temp.
July



Deteriorating Economics of DG-CHP

		2002		2004		2006	
		summer	winter	summer	winter	summer	winter
electricity							
monthly fee ($)		~300	~300	~300	~300	~300	~300
demand charge	noncoincident	6.6	0.0	8.3	8.3	8.5	8.5
($/kW monthly peak)	on-peak	18.0	0.0	21.7	0.0	29.7	0.0
	mid-peak	2.7	0.0	3.3	0.0	4.8	0.0
	off-peak	0.0	0.0	0.0	0.0	0.0	0.0
volumetric charge	on-peak	0.195	n/a	0.122	n/a	0.163	
($/kWh)	mid-peak	0.109	0.121	0.072	0.091	0.094	0.118
	off-peak	0.088	0.089	0.041	0.043	0.054	0.056
natural gas							
monthly fee ($)		~600	~600	~600	~600	~600	~600
volumetric ($/kWh)		0.014	0.013	0.02	0.021	0.024	0.024
($/GJ)		*3.89*	*3.61*	*5.56*	*5.83*	*6.67*	*6.67*
		to	*to*	*to*	*to*	*to*	*to*
($/kWh)		0.02	0.023	0.026	0.028	0.032	0.041
($/GJ)		*5.56*	*6.39*	*7.22*	*7.78*	*8.89*	*11.39*
on-site generation marginal cost							
electricity only		0.042	0.039	0.061	0.064	0.073	0.073
($/kWh)		*to*	*to*	*to*	*to*	*to*	*to*
		0.061	0.070	0.079	0.085	0.097	0.124
electricity and absorption cooling		0.039	0.037	0.056	0.059	0.068	0.068
($/kWh)		*to*	*to*	*to*	*to*	*to*	*to*
		0.056	0.065	0.073	0.079	0.090	0.116

Optimal System Results (130 g/kWh)

	Installed Capacity (MW)				*Energy cost (k$/a)*					*Energy purchase (MWh/a)*		Carbon emissions (t/a)
	NG ICE*	Abs. chiller**	Heat exchanger***	Solar collector****	Total	DER	Maint-enance	Elec-tricity	Natural Gas	Electricity	Natural gas	
no investment	0.0	0.0	0.0	0.0	932	0	0	930	2	9770	13.9	1271
CHP, no solar	1.0	1.7	1.1	0.0	813	58	37	437	281	6092	9326	1277
low temp. $150/kW	1.0	1.7	1.1	1.5	802	75	35	426	266	5224	10197	1236
high temp. $500/kW	1.0	1.6	0.9	0.8	798	95	32	424	247	5886	8168	1190
high temp. $900/kW	1.0	1.6	0.6	0.1	819	69	24	515	211	6933	6825	1256

* *capacity in units of 0.5 MW engines*

** *chiller capacity stated as amount of thermal power consumed. Chillers are single effect for the low temp. case and double effect for the high temp. cases.*

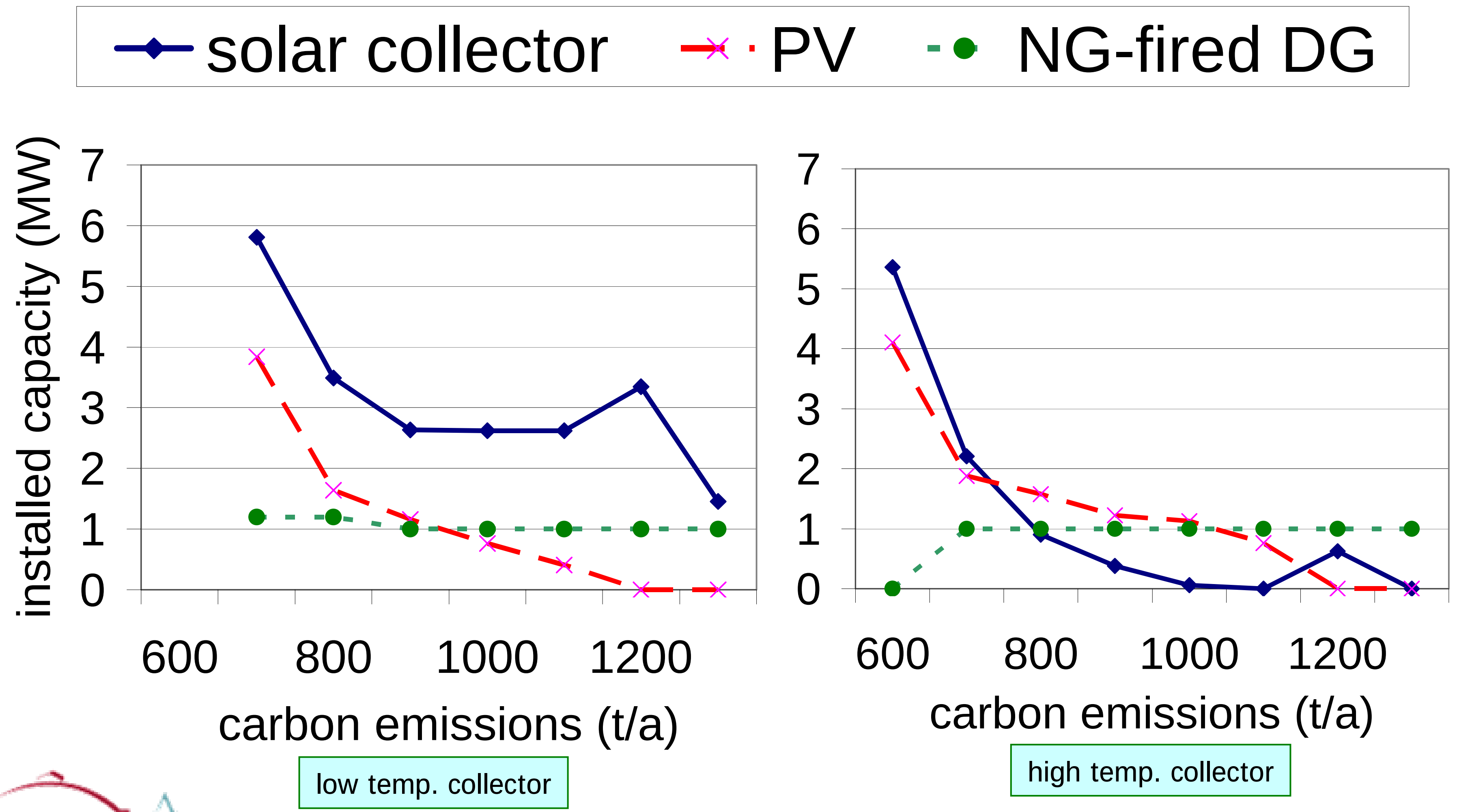
*** *capacity in units of rated thermal power transfer*

**** *capacity in units of thermal power production at 1 kW/m^2 solar radiation*

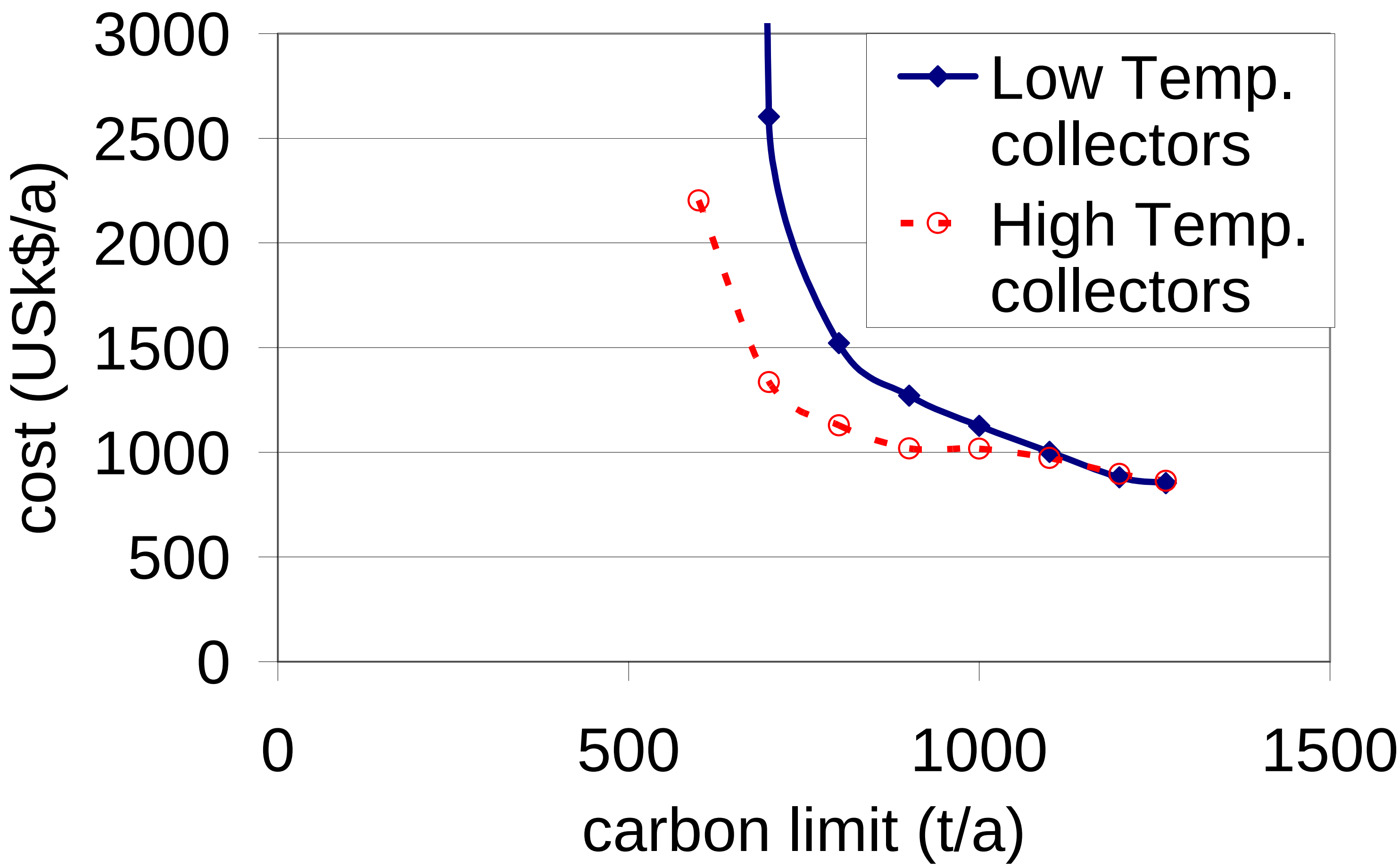
Carbon Constraint Results

- high temp. collectors provide carbon savings at lower control cost than low temp. collectors
- for low carbon reductions PV is...
  - more economic than high temp. collectors
  - competitive with low temp. collectors
- solar thermal is still valuable because of storage which offsets evening cooling loads

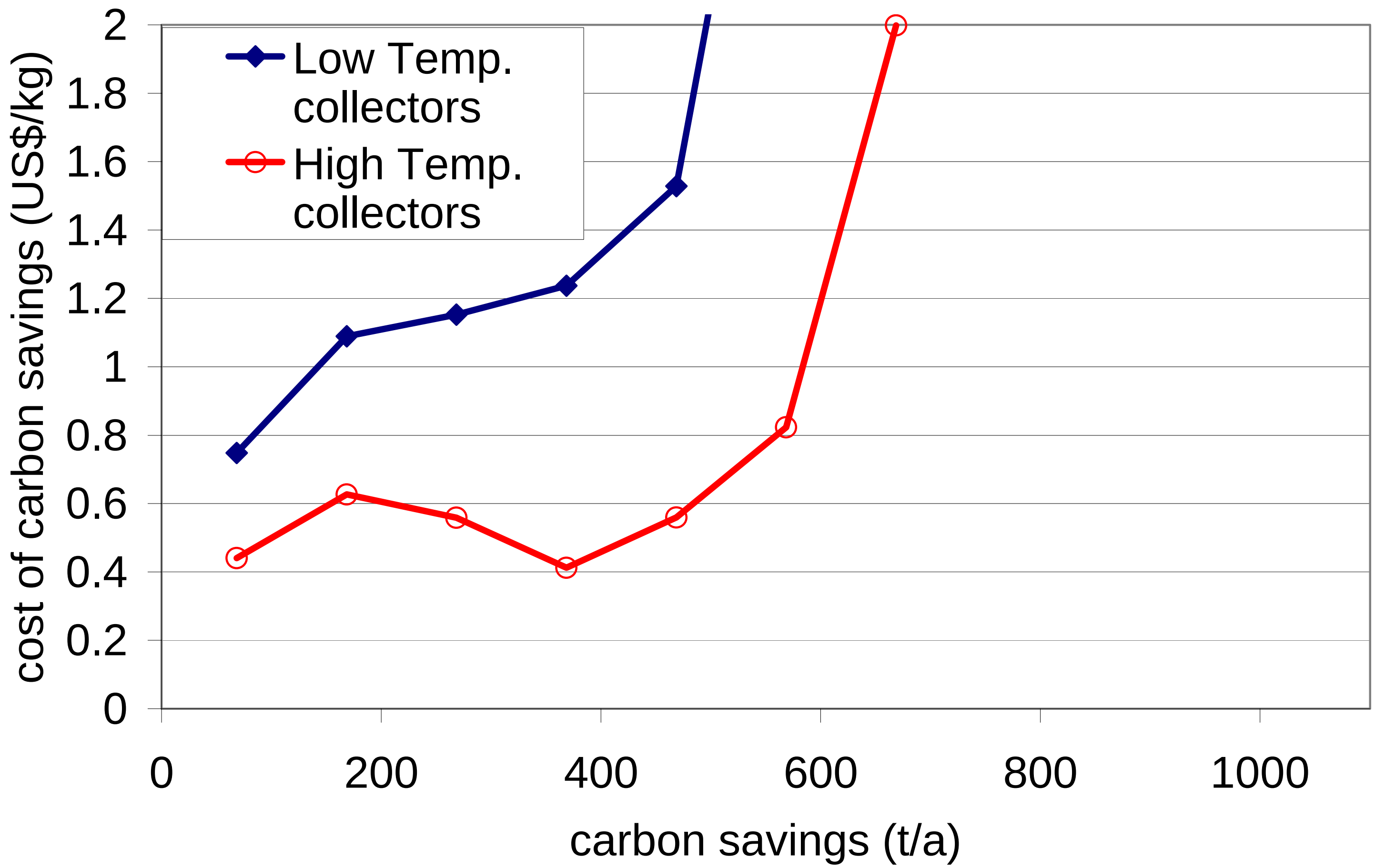
DER Equipment Installation Under Carbon Constraint (130 g/kWh)



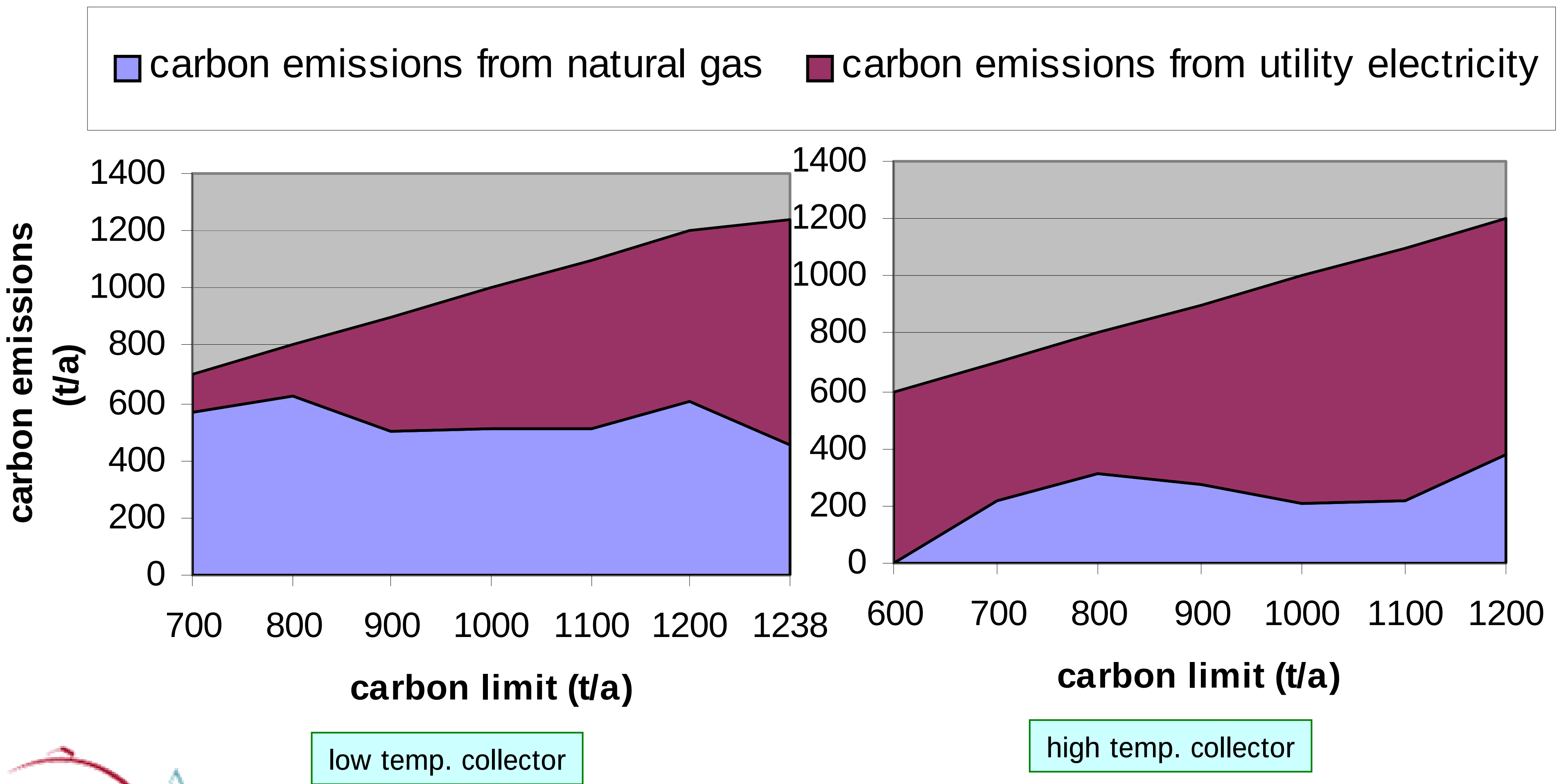
Pareto Minimization of Cost and Carbon Emissions (130 g/kWh)



Cost of Carbon Savings (130 g/kWh)

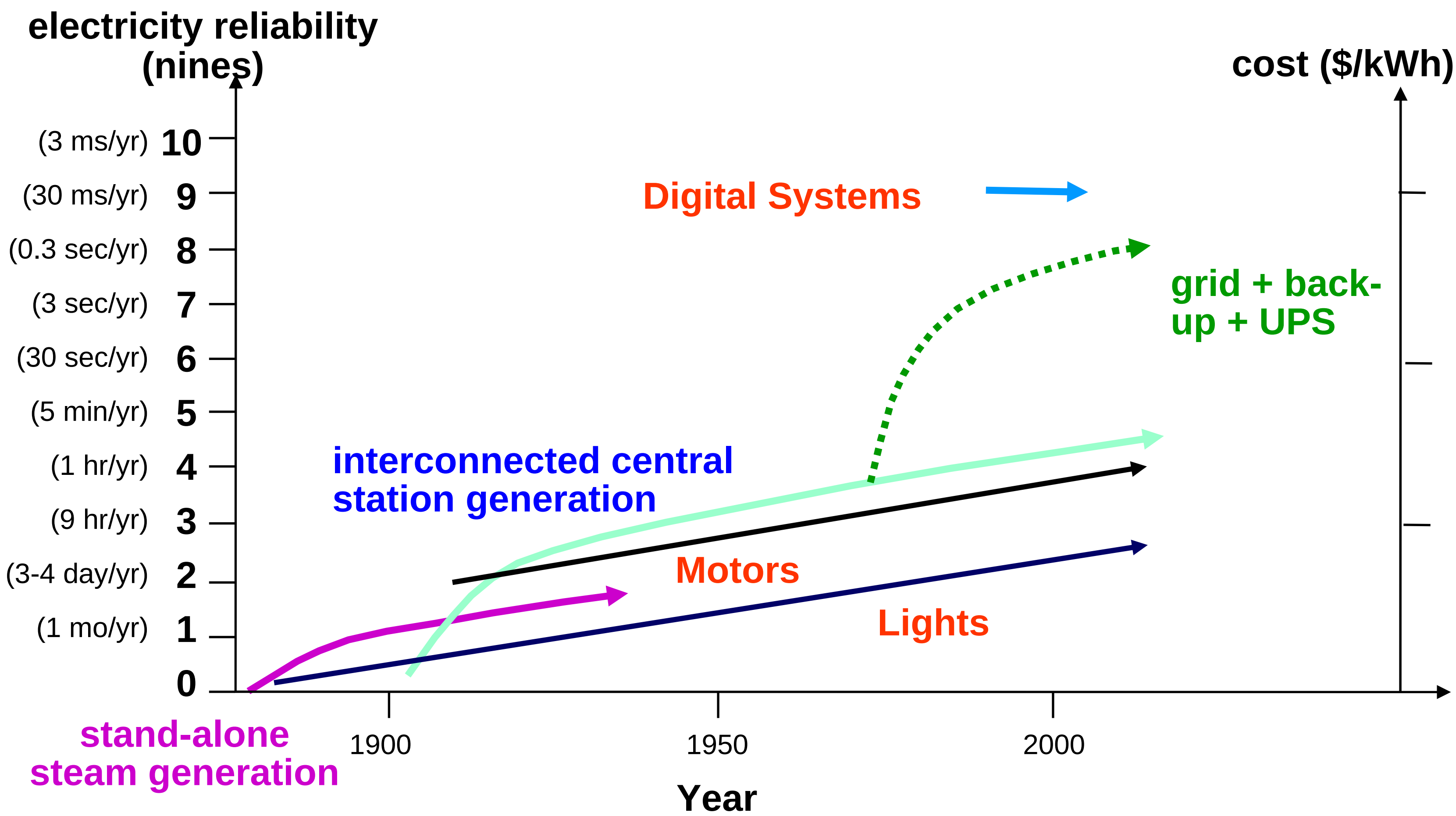


Source of Carbon Emissions (130 g/kWh)

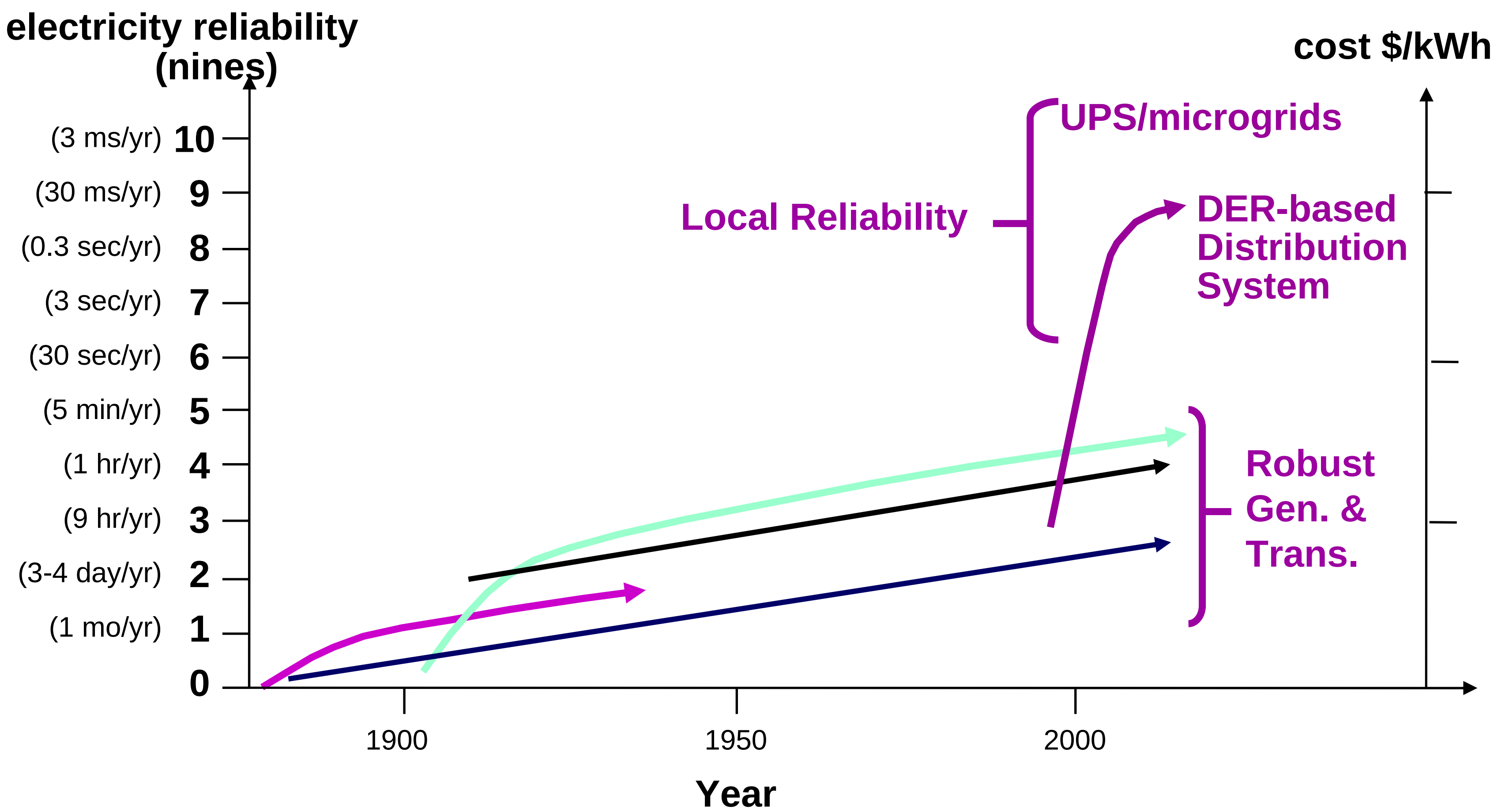


4. Power Quality and Reliability

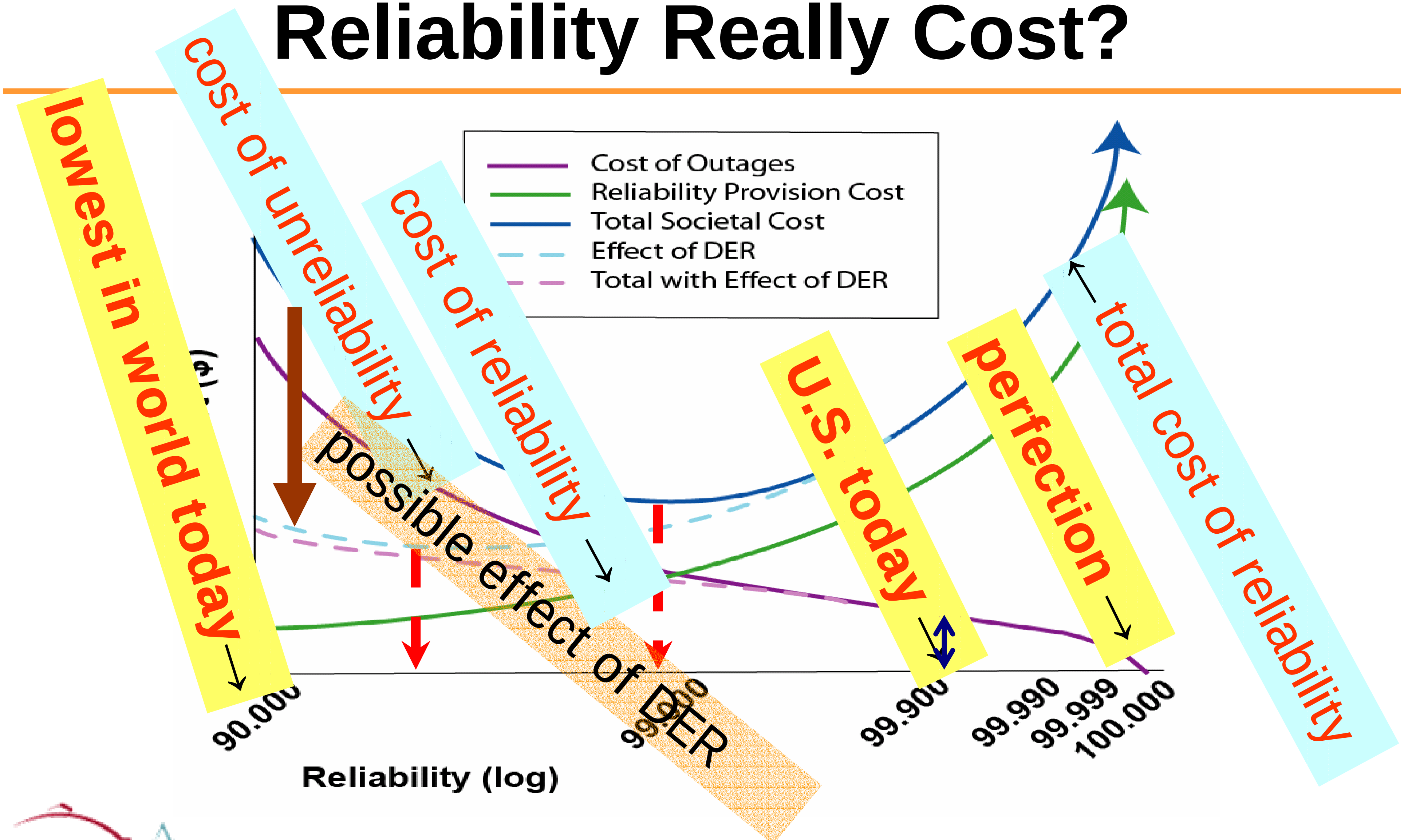
Electricity Reliability, Technology, and Cost (Traditional)



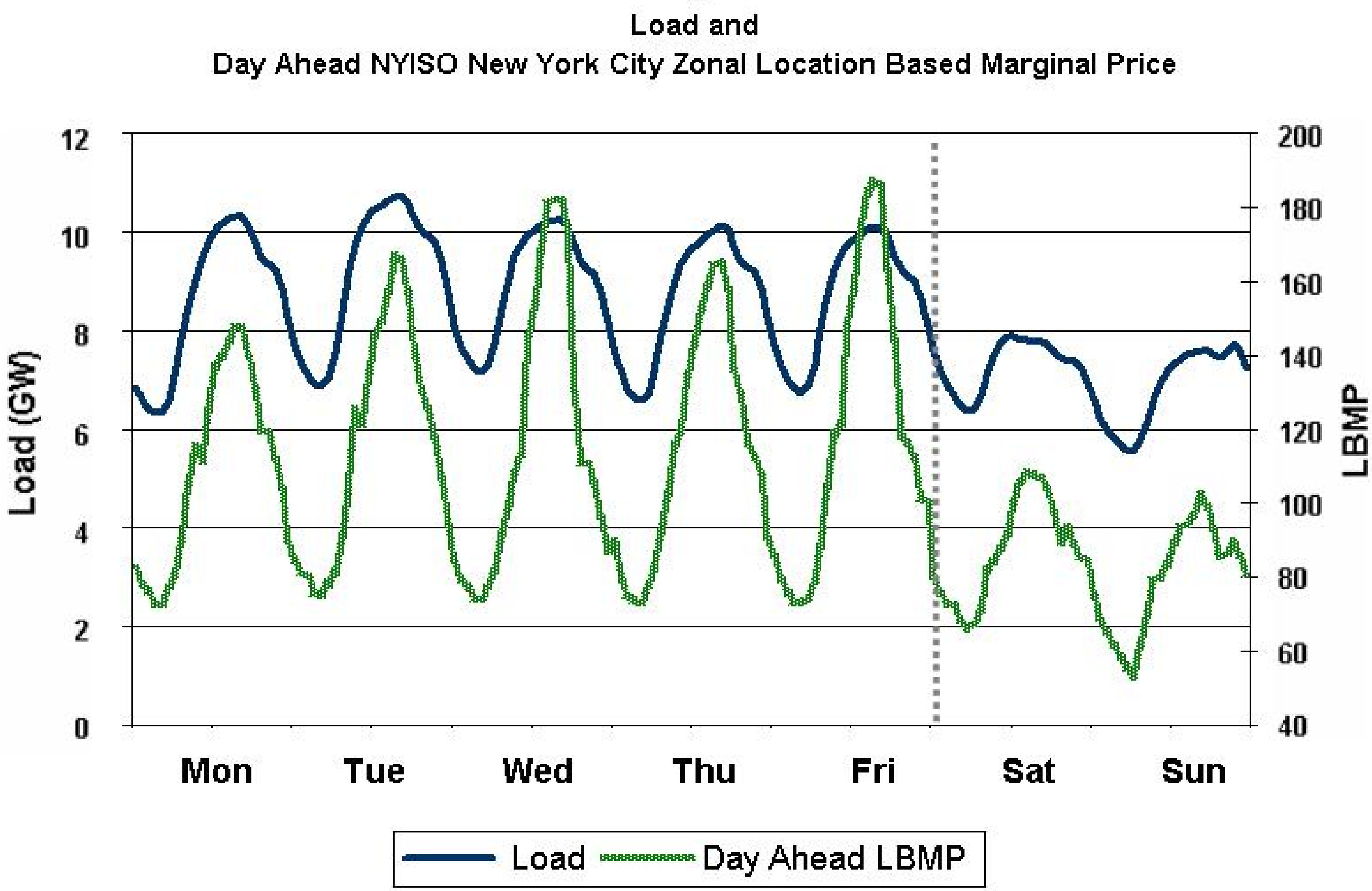
Electricity Reliability, Technology, and Cost (Distributed)



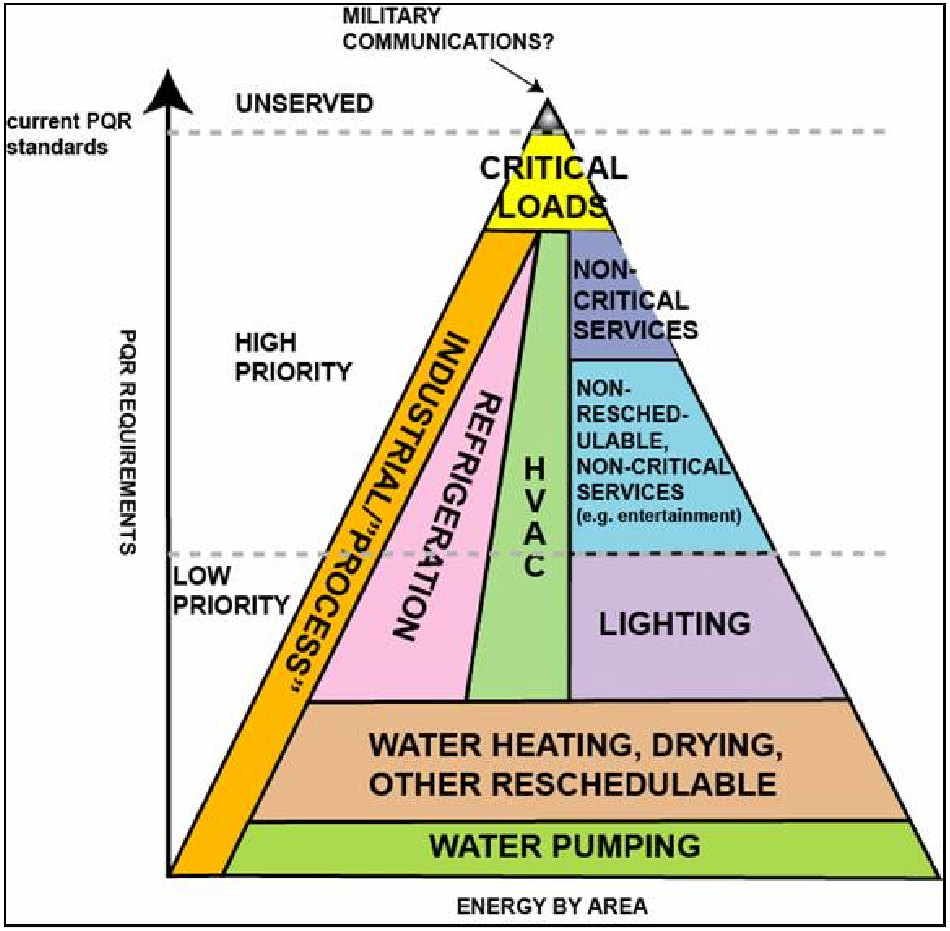
What Does Power Quality and Reliability Really Cost?



Temporal Electricity Price Variation is Familiar



An PQR Pyramid



- Loads are often broken down by time and enduse but not by PQR requirements.
- The most demanding PQR requirements are not met.
- Highly sensitive loads are small and they could be smaller.
- Local supply could tailor PQR to the needs of the enduse.

5. Lessons Learned/Future Work/ Conclusion

Lessons Learned

- reciprocating engines are the strongly incumbent technology
- mixed technology systems sometimes economically attractive
- DER economics are driven more by electricity than fuel prices
- optimal systems are larger than are typically built today
- DER-CAM sizes more to meet electricity than heat loads
- in moderate climates, cooling loads can justify CHP systems
- PV becomes economic with subsidies or carbon constraints
- demand charges encourage bigger systems
- energy efficiency gains significant when CHP involved, but modest overall
- efficiency constraints can run counter to system economics
- markets are highly regionalized and building specific

DER-CAM On-Going Work

- bottom up modeling of effects of DER/microgrid adoption (environmental/PQR?)
- evaluating economics of microgrid technology improvements
- extending storage capability to electricity
- estimation of national benefits of U.S. DER adoption and DG R&D
- development of EnergyManager capabilities
- applying algorithms in Energy+
- PQR valuation

Conclusion

- DER-CAM has been developed to identify cost minimizing technology neutral microgrid systems
- useful energy flow requirements are met systemically by equipment investments and operations, including CHP and endogenous effects
- devices/investments interaction endogenously solved
- results provide valuable starting point yardstick for building analysis or can be generalized to produce higher level estimates of DER adoption
- incorporating PQR is the big challenge

THE END