

## ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

---

### **Smart buildings with electric vehicle interconnection as buffer for local renewables?**

*Michael Stadler, Gonçalo Cardoso, Nicholas DeForest, Jon Donadee, Tomás Gómez, Judy Lai, Chris Marnay, Olivier Mégel, Gonçalo Mendes, and Afzal Siddiqui*

**Environmental Energy  
Technologies Division**

**presented at Researching the Intelligent City:  
Key Challenges of Integrating Urban Energy and Mobility  
Systems Research Symposium, Berlin, May 30, 2011**

*<http://eetd.lbl.gov/EA/EMP/emp-pubs.html>*

The work described in this presentation was funded by the Office of Electricity Delivery and Energy Reliability, Distributed Energy Program of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231 and partly by NEC Laboratories America Inc.



## **Disclaimer**

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Ernest Orlando Lawrence Berkeley National Laboratory is an equal opportunity employer.





**BERKELEY LAB**  
LAWRENCE BERKELEY NATIONAL LABORATORY



# Smart buildings with electric vehicle interconnection as buffer for local renewables? \*)

*Michael Stadler*

*Gonçalo Cardoso, Nicholas DeForest, Jon Donadee, Tomáz Gómez, Judy Lai,  
Chris Marnay, Olivier Mégel, Gonçalo Mendes, Afzal Siddiqui*

**Researching the Intelligent City:  
Key Challenges of Integrating Urban Energy and Mobility Systems  
Research Symposium, Berlin, May 30, 2011**

[MStadler@lbl.gov](mailto:MStadler@lbl.gov)

<http://der.lbl.gov/>

\*) The work described in this presentation was funded by the Office of Electricity Delivery and Energy Reliability, Distributed Energy Program of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231 and partly by NEC Laboratories America Inc.



ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY is a U.S. Department of Energy National Laboratory operated by the University of California

# Outline



- Lawrence Berkeley National Laboratory
- are we considering both sides of the coin?
- Lawrence Berkeley National Laboratory's Distributed Energy Resources Customer Adoption Model (DER-CAM)
- Web-Optimization, software as service for a University building
- Example result for a University building and electric vehicle (EV) modeling  
*How does the number of EVs connected to the building change with different optimization goals (cost versus CO<sub>2</sub>) ?*
- conclusions
- additional Information



# Lawrence Berkeley National Lab



- Located in the San Francisco Bay Area
- Berkeley Lab was founded in 1931 by Ernest Orlando Lawrence, a physicist who won the 1939 Nobel Prize in physics for his invention of the cyclotron
- Berkeley Lab is a member of the U.S. laboratory system supported by the U.S. Department of Energy and attached to the University of California (UC) Berkeley and is charged with conducting unclassified research across a wide range of scientific disciplines in 23 divisions as Accelerator & Fusion Research, Physics, Environmental Energy Technology, etc.
- 4 200 scientists, engineers, support staff and students
- budget of \$811 million in 2010
- eleven Nobel Prizes



*Environmental Energy Technologies Division*

# Are we considering both sides of the coin?



mobile and local storage can absorb renewable energy in principle



mobile storage can be linked in principle to commercial and residential buildings and integrated in smart buildings



Is it that simple or does the research community simplify?



How will a building optimize its energy usage without knowing its hourly consumption? Smart meters?



Do we have the proper communication and data infrastructure to optimize buildings?



What are the incentives for building owners to integrate renewables and electric vehicles?



# Complex research problems



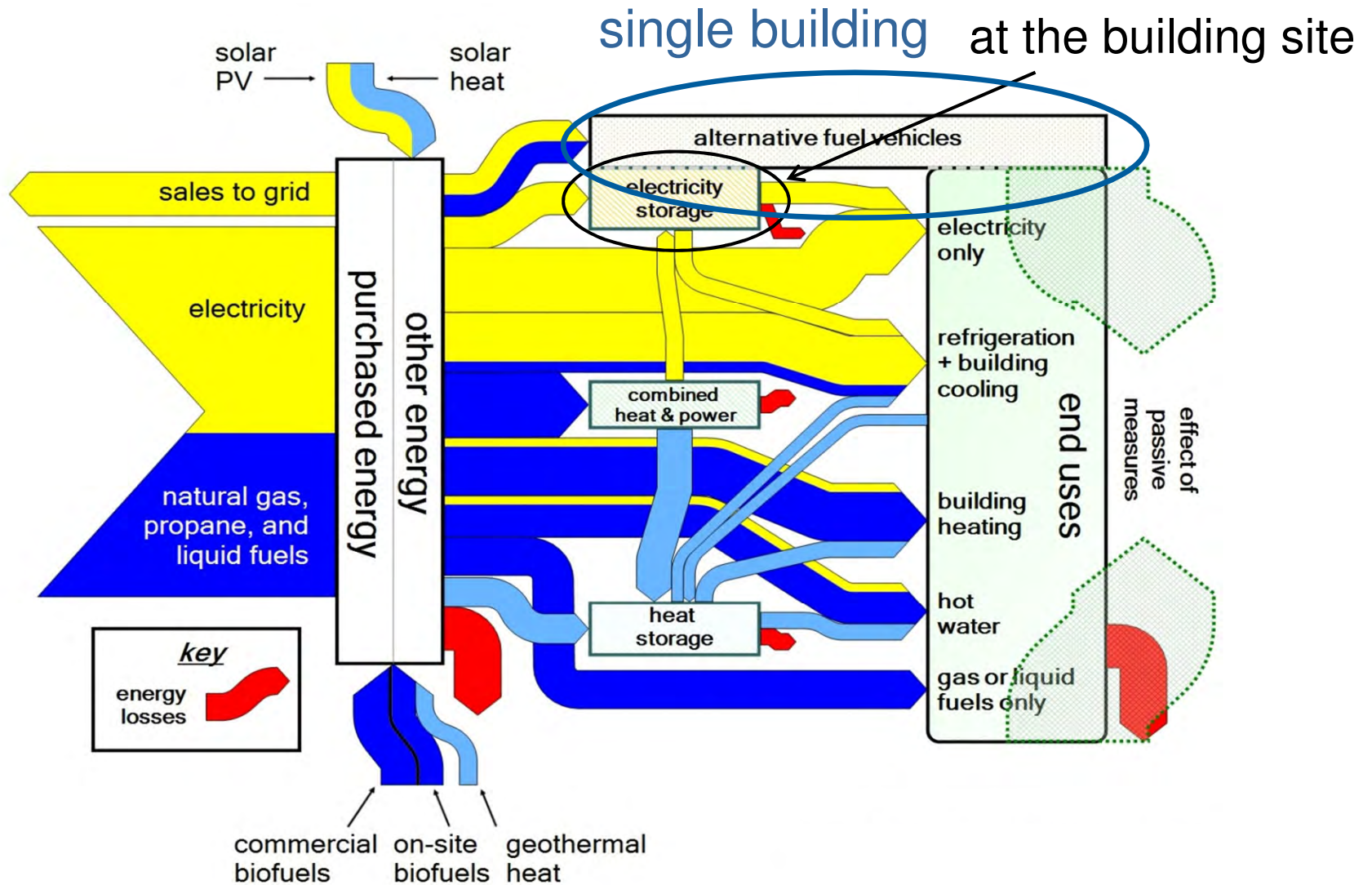
Is it that simple or does the research community simplify?

Yes, too simple. Complex interactions between competing decentralized technologies are neglected mostly.

## The Distributed Energy Resources Customer Adoption Model (DER-CAM)



# Building optimization concept



# DER-CAM



- is a deterministic Mixed Integer Linear Program (MILP), written in the General Algebraic Modeling System (GAMS®)
- minimizes annual energy costs, CO<sub>2</sub> emissions, or multiple objectives of providing services to a building micro-/smartgrid
- produces technology neutral pure optimal results, delivers investment decision and operational schedule
- has been designed for more than 9 years by Berkeley Lab and collaborations in the US, Germany, Spain, Portugal, Belgium, Japan, and Australia
- first commercialization and real-time optimization steps, e.g. Storage & PV Viability Optimization Web-Service (SVOW), <http://der.lbl.gov/microgrids-lbnl/current-project-storage-viability-website>



# Hourly demand

---



How will a building optimize its energy usage without knowing its hourly consumption?

It can hardly optimize its energy usage and models for estimating the hourly consumption are needed.



Do we have the proper communication and data infrastructure to optimize buildings?

Projects performed in the U.S. and ongoing research in Europe indicate that we do not have the proper infrastructure and data collection in place.

# Optimization over the web

---



**Web-Optimization to provide a simple optimization platform, which also forecasts loads for the building**

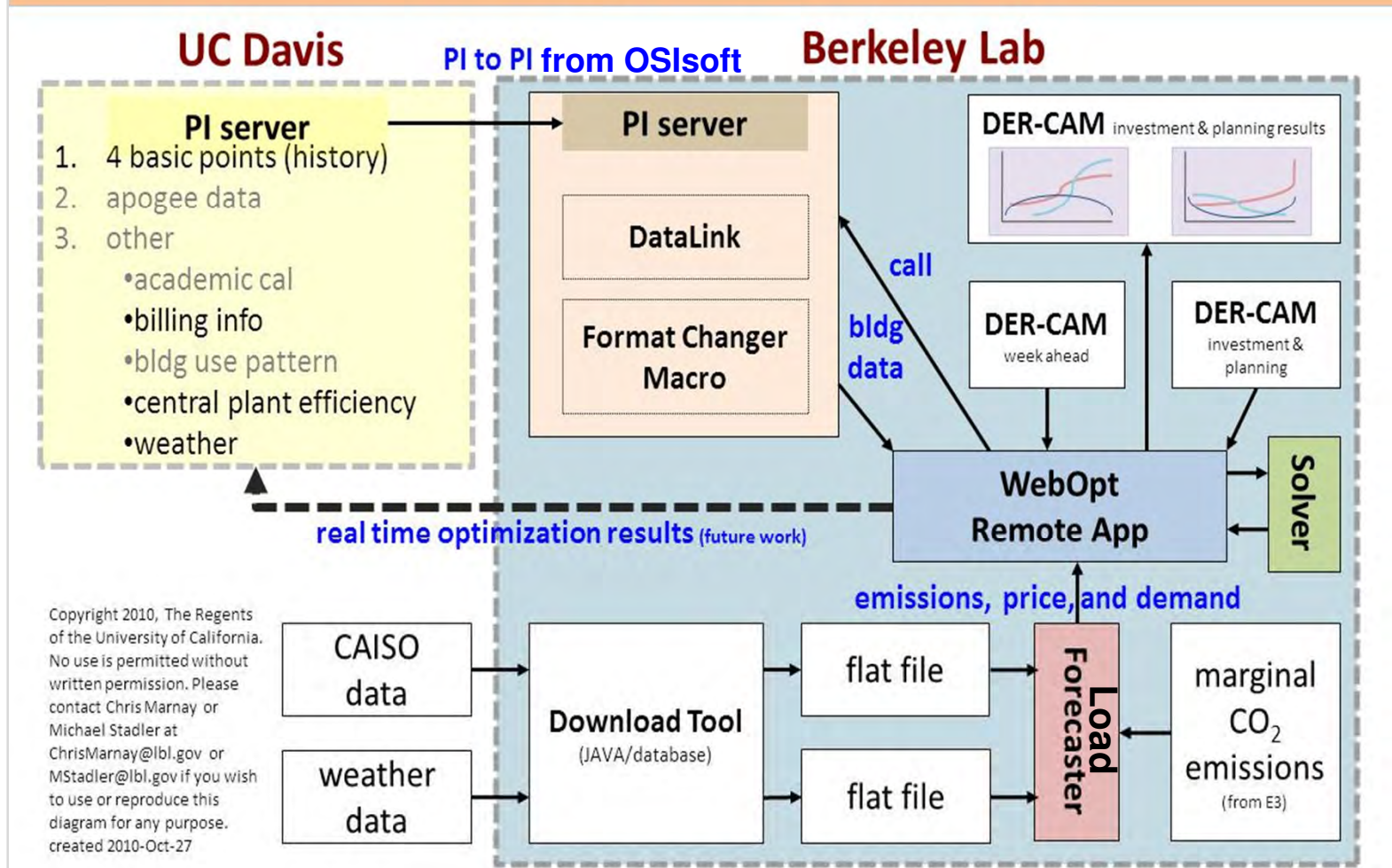




# Web-Optimization with DER-CAM for the University of Davis

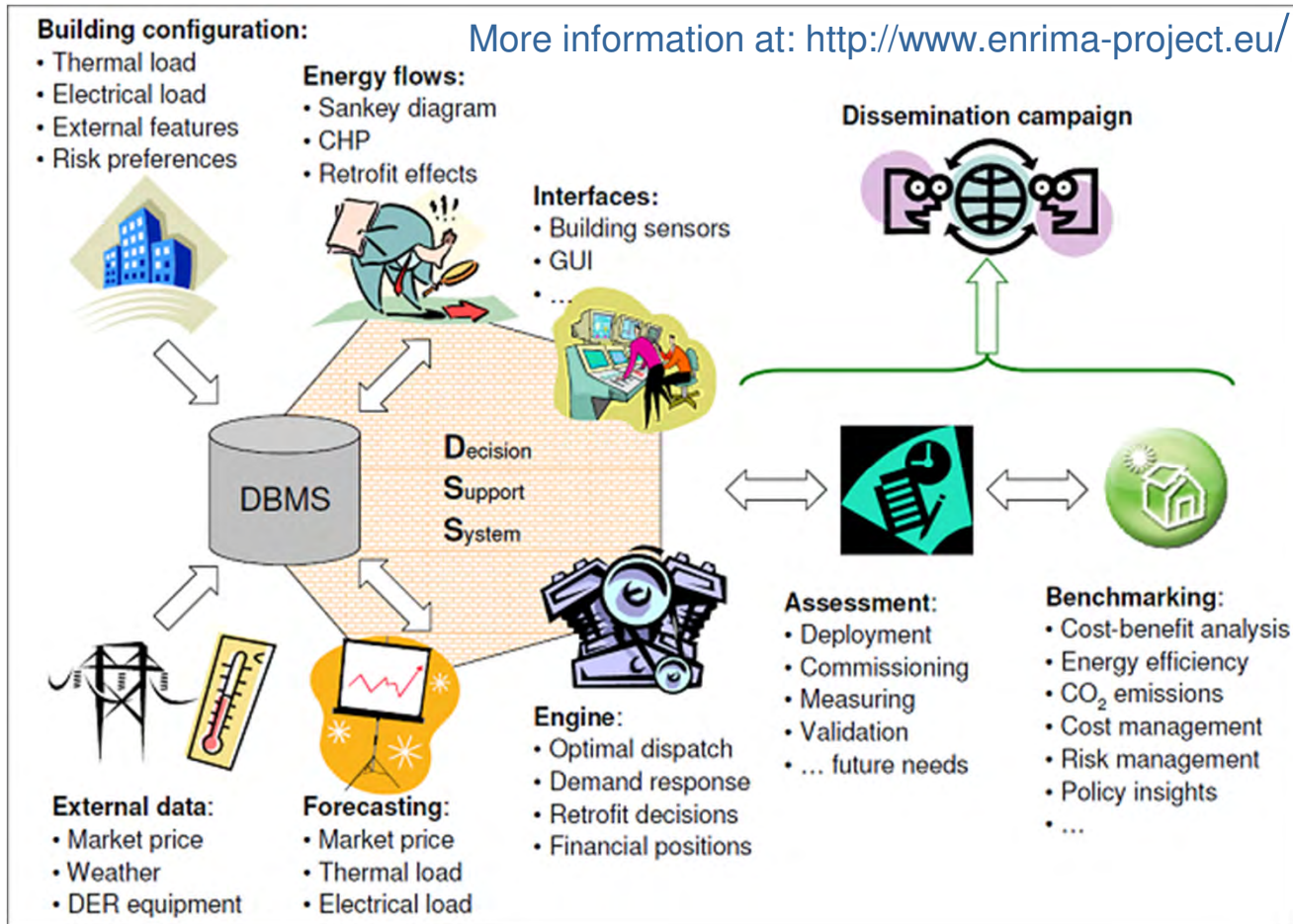


## Flow diagram of WebOpt



More information at: [der.lbl.gov](http://der.lbl.gov)  
**Environmental Energy Technologies Division**

# European project EnRiMa<sup>\*)</sup>



<sup>\*)</sup> Energy Efficiency and Risk Management in Public Buildings

For example: test sites in Austria do not collect hourly loads and energy management system (EMS) data. Reason: no priority on energy saving or no idea how to use the data → web-optimization service



# Costs versus CO<sub>2</sub>

---



What are the incentives for building owners to integrate renewables and electric vehicles?

**Example results for a University at Davis  
Building and Electric Vehicle Modeling  
for a Healthcare Facility in San Diego,  
California**



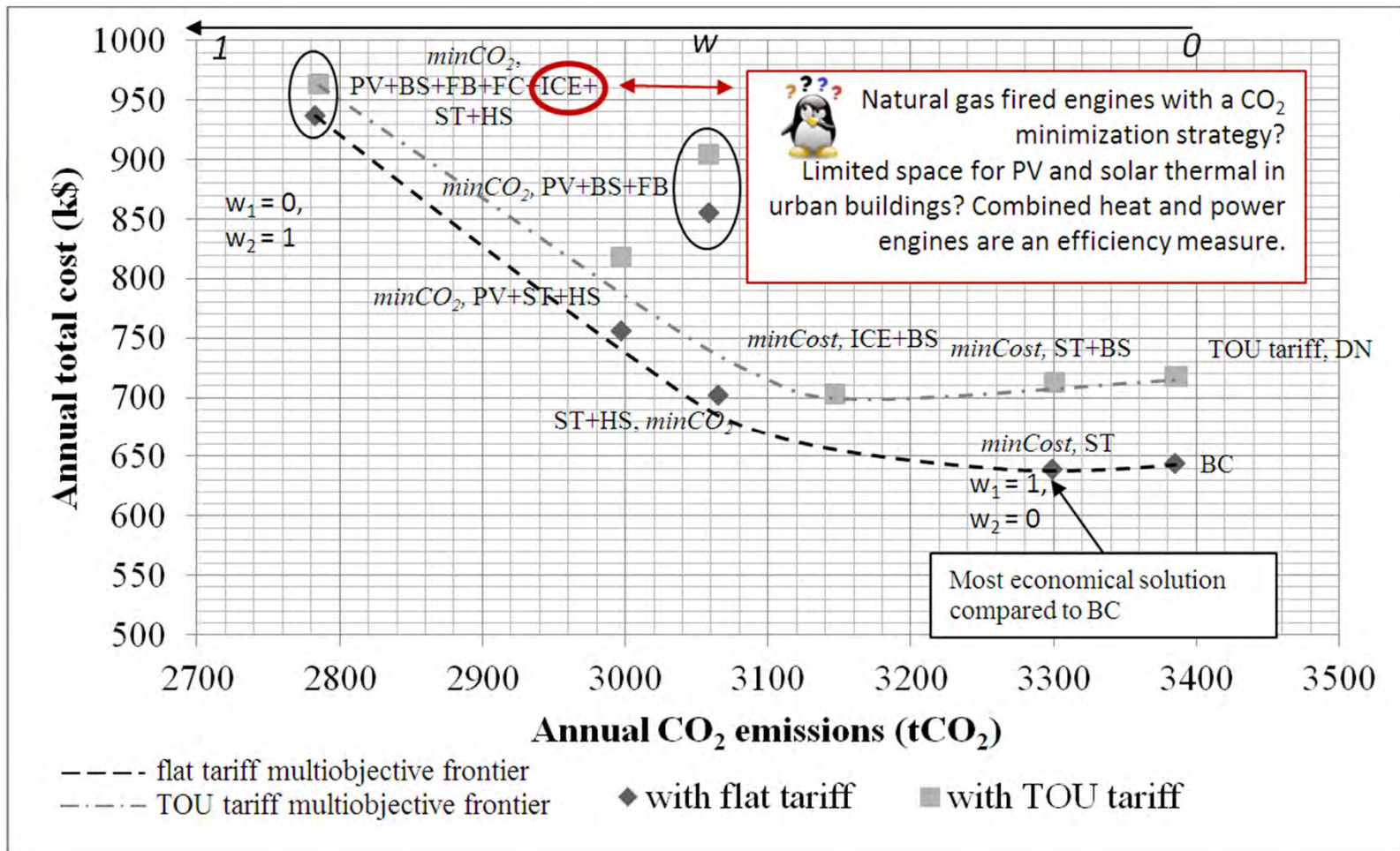
# Different optimization goals



**Multi-objective frontier (minimize the combination of costs and CO<sub>2</sub> emissions for building)**

$$\min \left( (1 - \omega) \cdot \frac{\text{Cost}}{\text{ReferenceCost}} + \omega \cdot \frac{\text{CO}_2 \text{emissions}}{\text{ReferenceCO}_2 \text{emissions}} \right)$$

# Web-Optimization with DER-CAM for the University of Davis



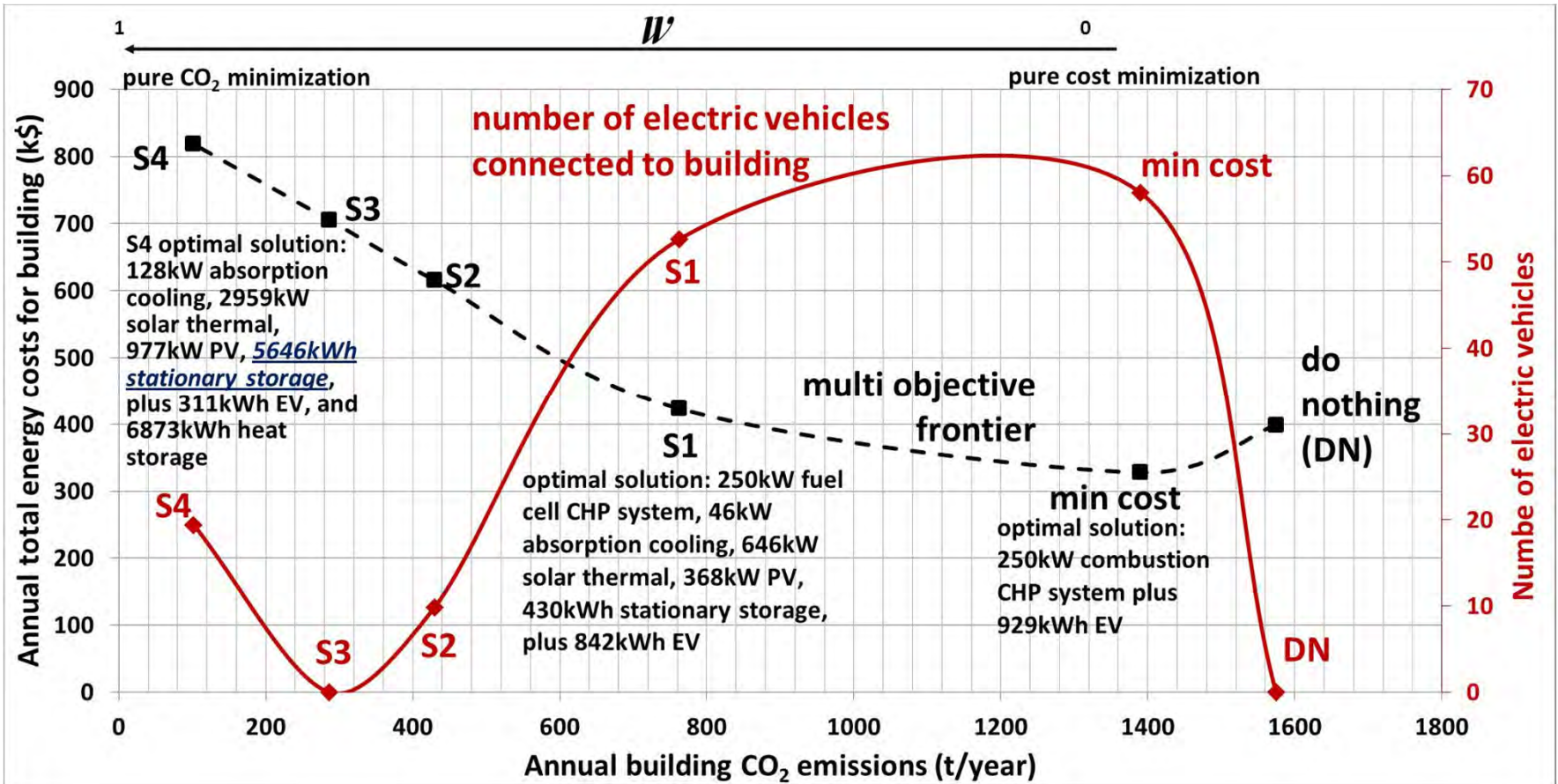
PV: photovoltaic, BS: conventional lead acid battery, FB: Zinc Bromine flow battery, FC: fuel cell with waste heat utilization, ICE: internal combustion engine with waste heat utilization, ST: solar thermal conventional collectors, HS: Heat storage, BC: Base case, and DN: "Do nothing" case



More information at: [der.lbl.gov](http://der.lbl.gov)

**Environmental Energy Technologies Division**

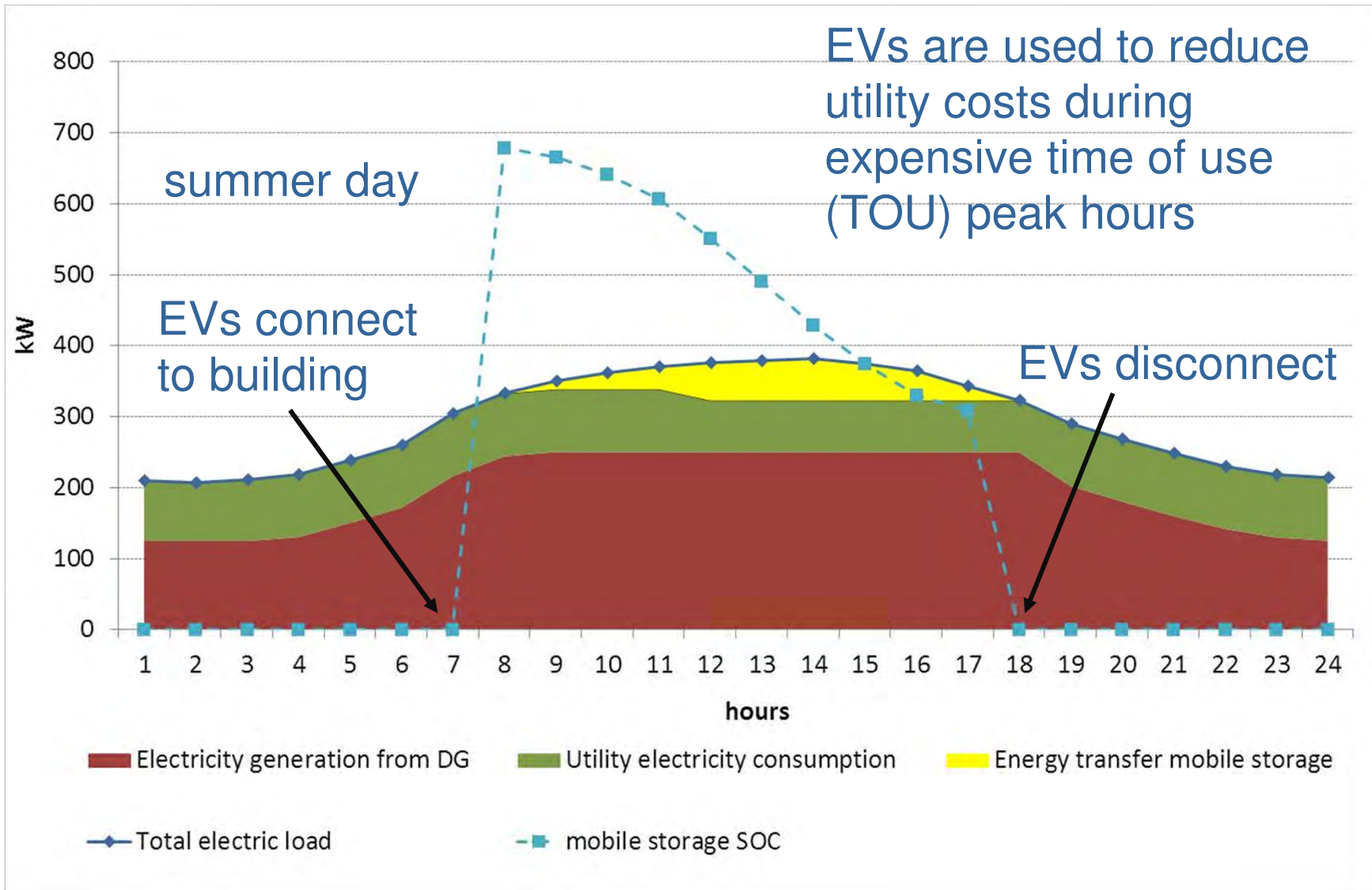
# Multi-objective frontier / EVs connected @ healthcare facility



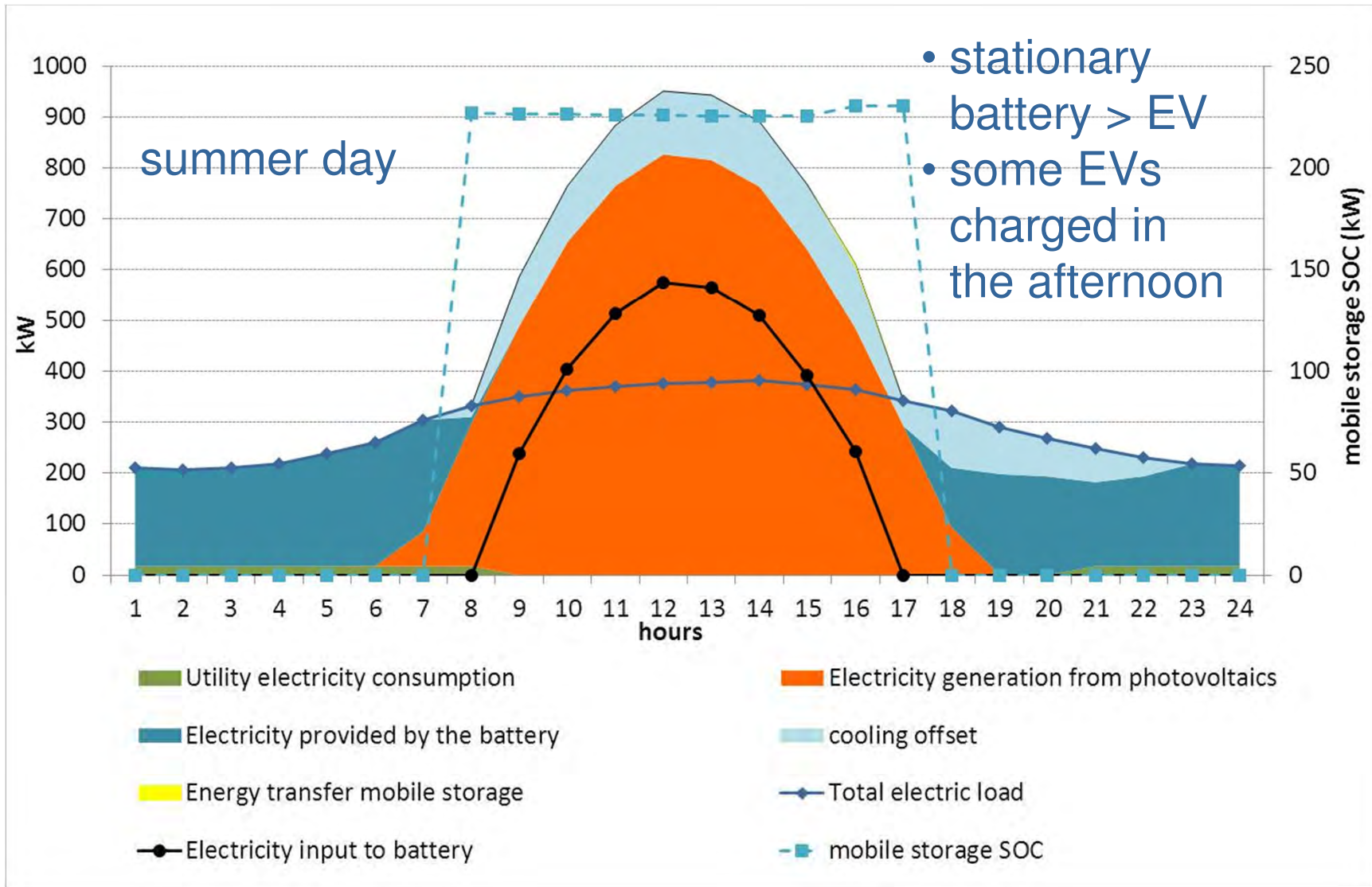
- ✓ connected EVs reach maximum around “min cost” solution ( $w=0$ )
- ✓ with increasing  $w$ : stationary batteries become more attractive to building than EVs → second life of EV batteries?



# Diurnal electric pattern for min cost @ healthcare facility



# Diurnal electric pattern for point S4 @ healthcare facility



# Conclusions

---



## Conclusions for a Healthcare Facility in San Diego



*Environmental Energy Technologies Division*

# Conclusions



- EV Charging / discharging pattern mainly depends on the objective of the building (cost versus CO<sub>2</sub>)
- performed optimization runs show that stationary batteries are more attractive than mobile storage when putting more focus on CO<sub>2</sub> emissions. Why? Stationary storage is available 24 hours a day for energy management → more effective
- stationary storage will be charged by PV, mobile only marginally
- results will depend on the considered region and tariff
  - final research work will show the results for 138 different buildings in nine different climate zones and three major utility service territories





# Literature

---

Stadler Michael, Ilan Momber, Olivier Mégel, Tomás Gómez, Chris Marnay, Sebastian Beer, Judy Lai, and Vincent Battaglia: “*The added economic and environmental value of plug-in electric vehicles connected to commercial building microgrids*,” 2nd European Conference on SmartGrids and E-Mobility, 20-21 October 2010, Bedford Hotel & Congress Centre, Brussels, Belgium, LBNL-3885E.

Momber Ilan, Tomás Gómez, Giri Venkataramanan, Michael Stadler, Sebastian Beer, Judy Lai, Chris Marnay, and Vincent Battaglia: “*Plug-in Electric Vehicle Interactions with a Small Office Building: An Economic Analysis using DER-CAM*,” IEEE PES 2010 General Meeting, Power System Analysis and Computing and Economics, July 25th - 29th, 2010, Minnesota, USA, LBNL-3555E.

Siddiqui Afzal, Michael Stadler, Chris Marnay, and Judy Lai: “*Optimal Control of Distributed Energy Resources and Demand Response under Uncertainty*,” IAEE’s Rio 2010 International Conference, 6-9 June 2010, InterContinental Rio Hotel – Rio de Janeiro, Brazil.

Stadler Michael, Chris Marnay, Judy Lai, Gonçalo Cardoso, Olivier Mégel, and Afzal Siddiqui: “*The Influence of a CO<sub>2</sub> Pricing Scheme on Distributed Energy Resources in California’s Commercial Buildings*,” 23rd Annual Western Conference, Advanced Workshop in Regulation and Competition, 23-25 June 2010, Hyatt Regency, Monterey, California, USA, LBNL-3560E.

“The CO<sub>2</sub> Abatement Potential of California’s Mid-Sized Commercial Buildings.” Michael Stadler, Chris Marnay, Gonçalo Cardoso, Tim Lipman, Olivier Mégel, Srirupa Ganguly, Afzal Siddiqui, and Judy Lai, California Energy Commission, Public Interest Energy Research Program, CEC-500-07-043, 500-99-013, LBNL-3024E, December 2009.

Stadler Michael, Afzal Siddiqui, Chris Marnay, Hirohisa Aki, Judy LAI: “*Control of Greenhouse Gas Emissions by Optimal DER Technology Investment and Energy Management in Zero-Net-Energy Buildings*,” European Transactions on Electrical Power 2009, Special Issue on Microgrids and Energy Management, LBNL-2692E.

Stadler Michael, Chris Marnay, Afzal Siddiqui, Judy Lai, and Hirohisa Aki: “*Integrated building energy systems design considering storage technologies*,” ECEEE 2009 Summer Study, 1–6 June 2009, La Colle sur Loup, Côte d'Azur, France, ISBN 978-91-633-4454-1 and LBNL-1752E.

# End

---



## Thank you!

Questions and comments are very welcome.



*Environmental Energy Technologies Division*

# Ongoing EV modeling for California

---

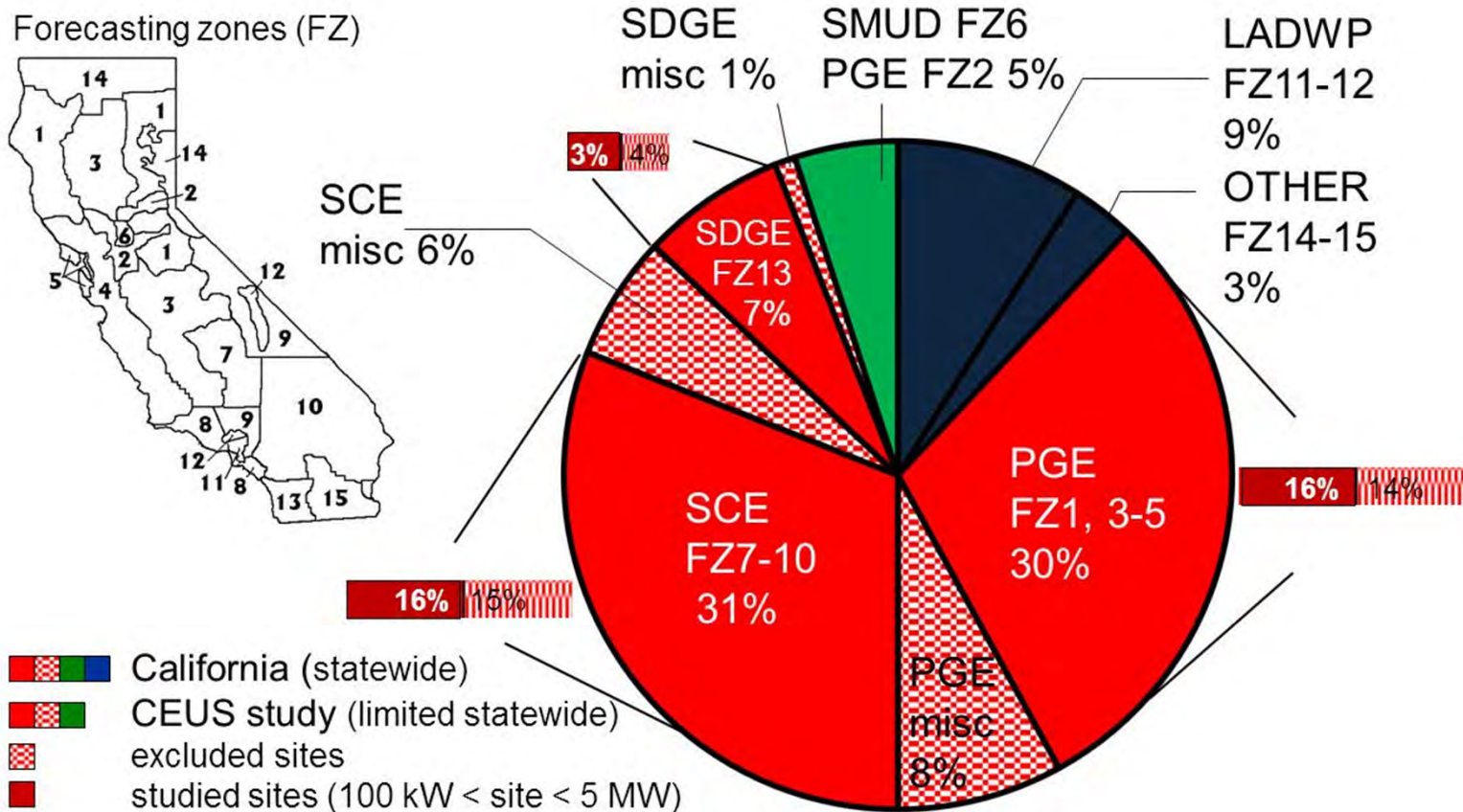


## The California Commercial End-Use Survey (CEUS) Database



*Environmental Energy Technologies Division*

# CEUS



objective / final EV project goal : EV modeling at 138 buildings<sup>x)</sup> in nine climate zones

<sup>x)</sup> hospitals, colleges, schools, restaurants, warehouses, retail stores, groceries, offices, and hotels



# Details for healthcare facility

---



## 2020 Equipment Options, Tariffs, and Building Analyzed



# Equipment



- EVs belong to employees/commuters
- EVs can transfer energy to the building and vice versa
- the building energy management system (EMS) can manage (charge/discharge) the EV batteries during connection hours
- EV owner receives exact compensation for battery degradation and energy delivered to the building

<b>EV-building connection period</b>	<b>8am – 5pm</b>
<b>EV-home connection period</b>	<b>7pm – 7am</b>
<b>EV battery state-of-charge (SOC) when arriving at the healthcare facility</b>	<b>73%</b>
<b>EV battery SOC when leaving the healthcare facility</b>	<b>≥32%</b>
<b>EV battery charging efficiency</b>	<b>95.4%</b>
<b>EV battery discharging efficiency</b>	<b>95.4%</b>
<b>EV battery capacity</b>	<b>16 kWh</b>
<b>Maximum EV battery charging rate</b>	<b>0.45 [1/h]</b>



# Equipment



- also combined heat and power (CHP), PV, solar thermal, stationary battery, etc. is considered in the analysis
- technology costs in 2020 are based on “Assumptions to the Annual U.S. Energy Outlook”, e.g.
  - fuel cell with heat exchanger: \$2220 - \$2770/kW, lifetime: 10 years
  - internal combustion engine with heat exchanger: \$2180 - \$3580/kW, lifetime: 20 years
  - PV: \$3237/kW, lifetime: 20 years
  - stationary battery: \$193/kWh
  - etc.

Details can be found at “The CO<sub>2</sub> Abatement Potential of California’s Mid-Sized Commercial Buildings.” Michael Stadler, Chris Marnay, Gonçalo Cardoso, Tim Lipman, Olivier Mégel, Srirupa Ganguly, Afzal Siddiqui, and Judy Lai, California Energy Commission, Public Interest Energy Research Program, CEC-500-07-043, 500-99-013, LBNL-3024E, December 2009.



# Building / tariffs



- electricity and gas loads for a San Diego healthcare facility are based on CEUS
  - peak electric demand: 399 kW
  - annual electricity demand: 2.33 GWh
  - annual natural gas consumption: 2.13 GWh (72700 therm)
- TOU rates and demand charges:
  - on-peak electricity up to 0.13 \$/kWh
  - off-peak rates around 0.09 \$/kWh
  - demand charges up to 12.8 \$/kW-month
- electric rate at residences (homes) for EV charging: \$0.138/kWh



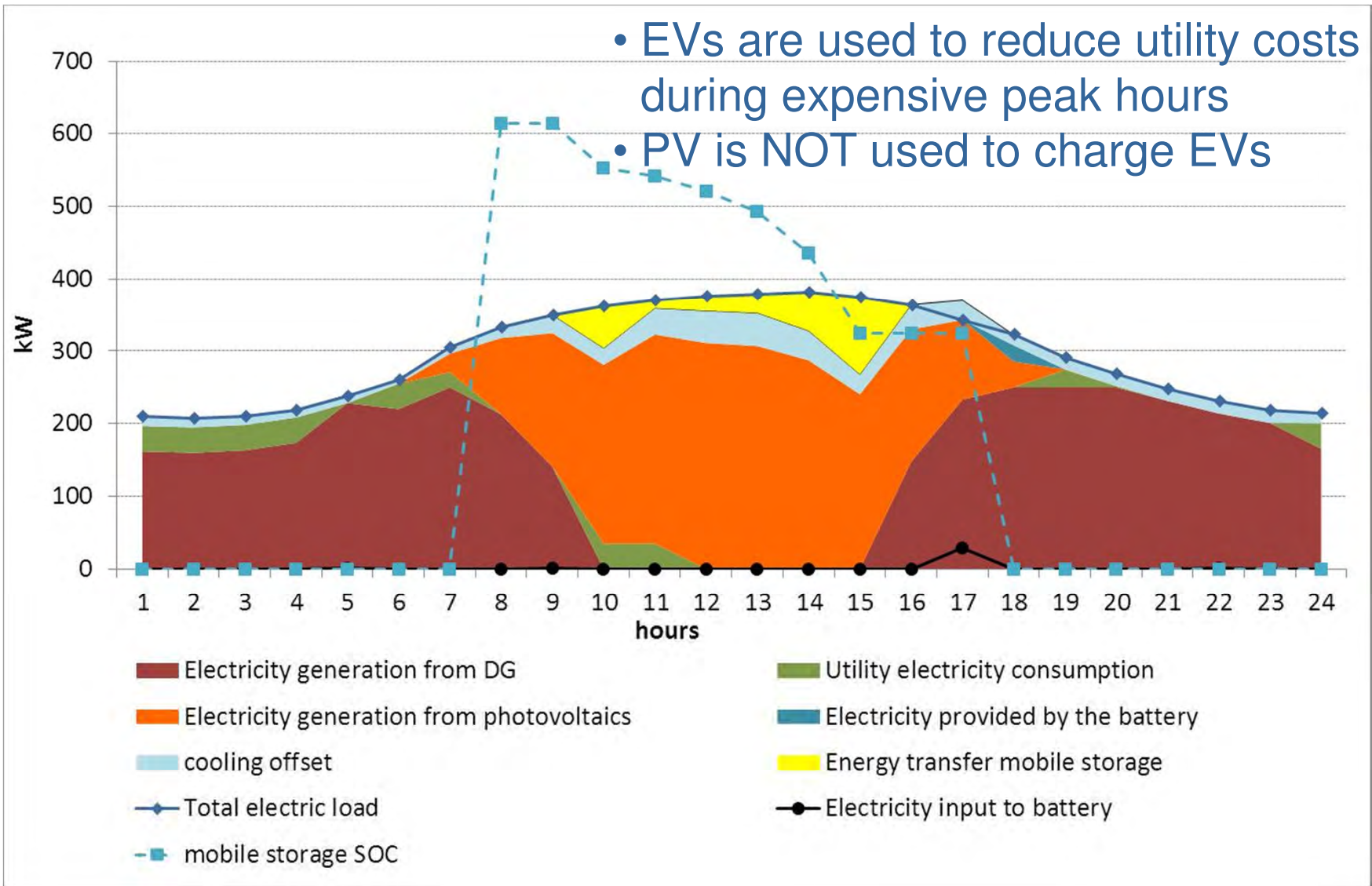




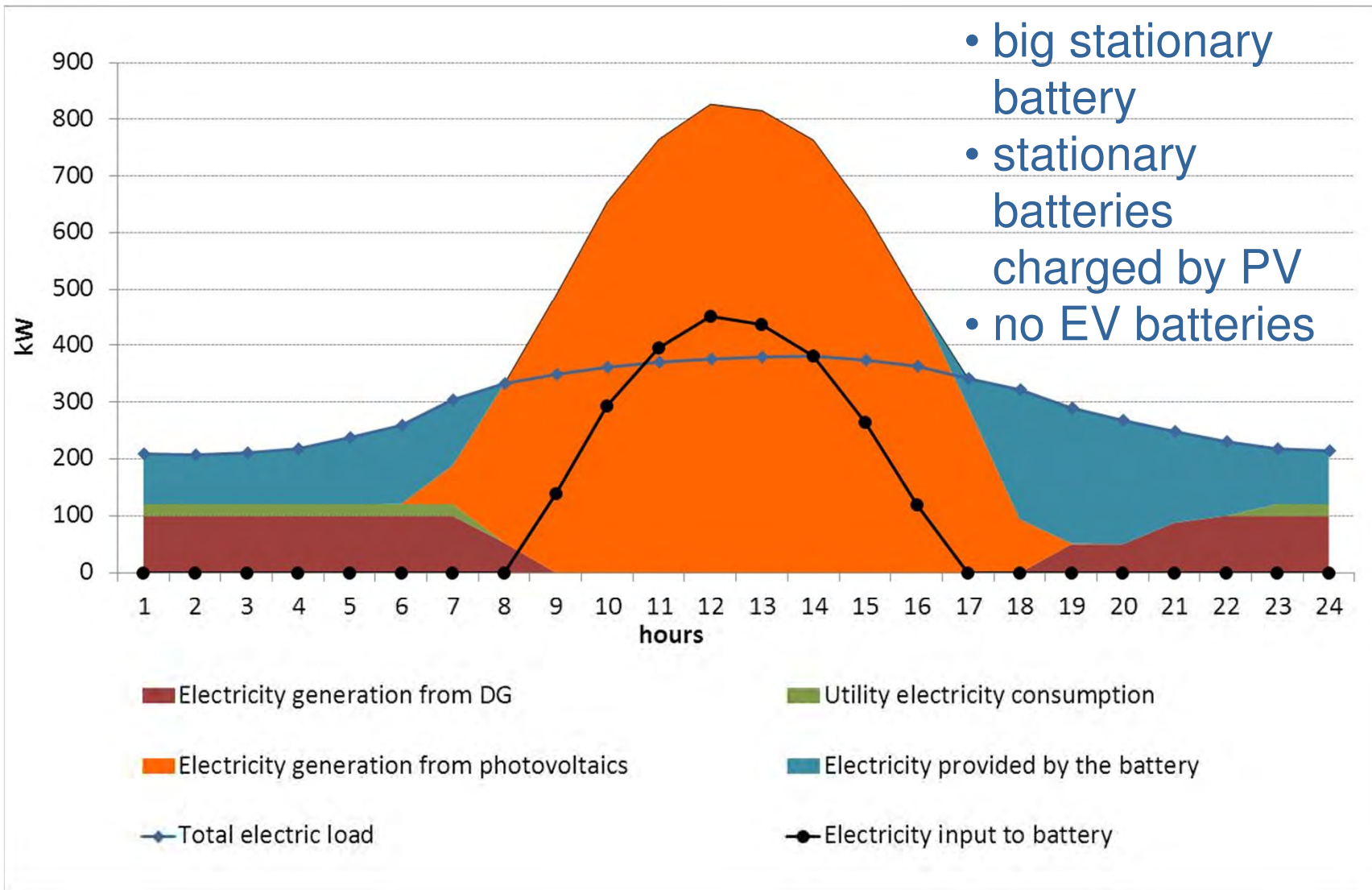
## Optimization Results for Summer Days

**Optimal Investments in DER Technologies and Operation, Optimal EV Discharging / Charging subject to different building strategies**

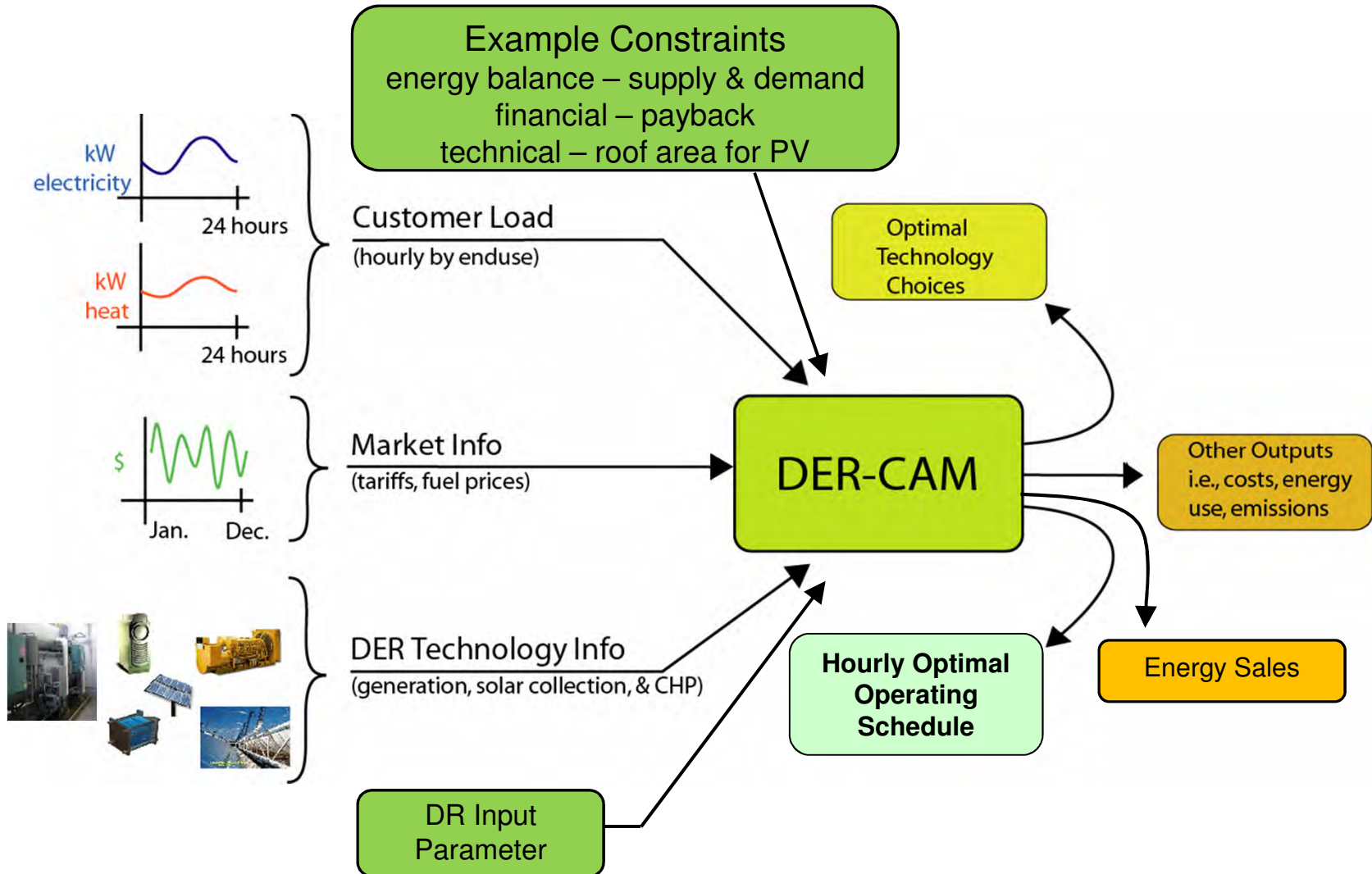
# Diurnal electric pattern for point S1 @ healthcare facility



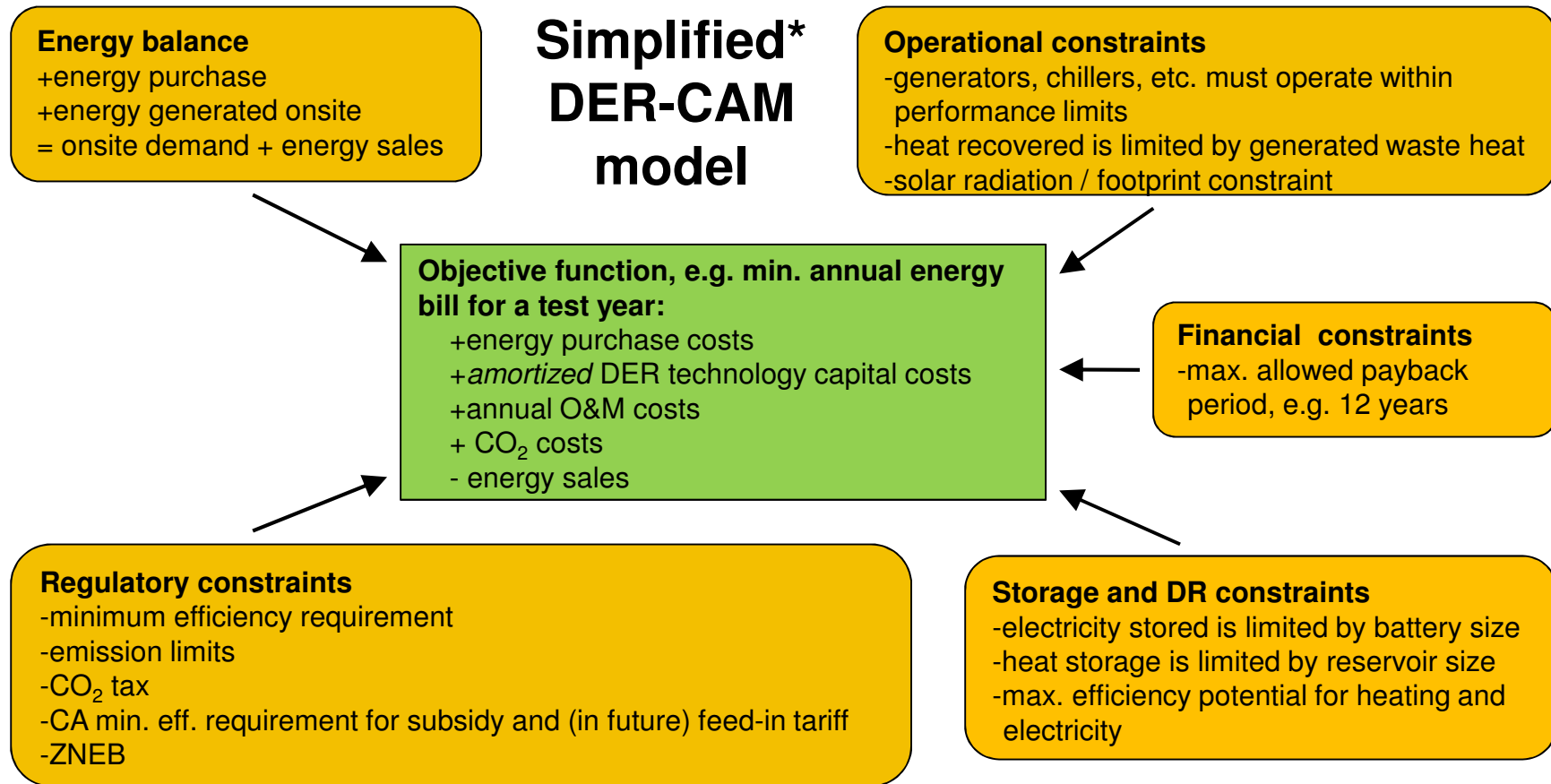
# Diurnal electric pattern for point S3 @ healthcare facility



# High-level schematic of DER-CAM



# Representative MILP



**\*does not show all constraints**





# Disclaimer



This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Ernest Orlando Lawrence Berkeley National Laboratory is an equal opportunity employer.