The Distributed Energy Resources Costumer Adoption Model (DER-CAM) for Building Energy Use Optimization

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Outline

- Introduction
- Systemic analysis of building energy systems – global concept
- The Distributed Energy Resources - Customer Adoption Model (DER-CAM) – the DER-CAM Concept
- Most recent study for commercial buildings considering storage, PV, and solar thermal technologies
- Ongoing work for passive technologies, zero net energy, carbon minimization, and multi-objective functions
- Conclusions and future work

Introduction

- Commercial sites such as hotels, data centers, hospitals, etc. are already using Distributed Energy Resources (DER) with and without Combined Heat and Power (CHP) as well as absorption chillers.

- Very limited understanding of economic and environmental interactions between DER with CHP, absorption chillers, Photovoltaic (PV), solar thermal, storage, and demand response exists.

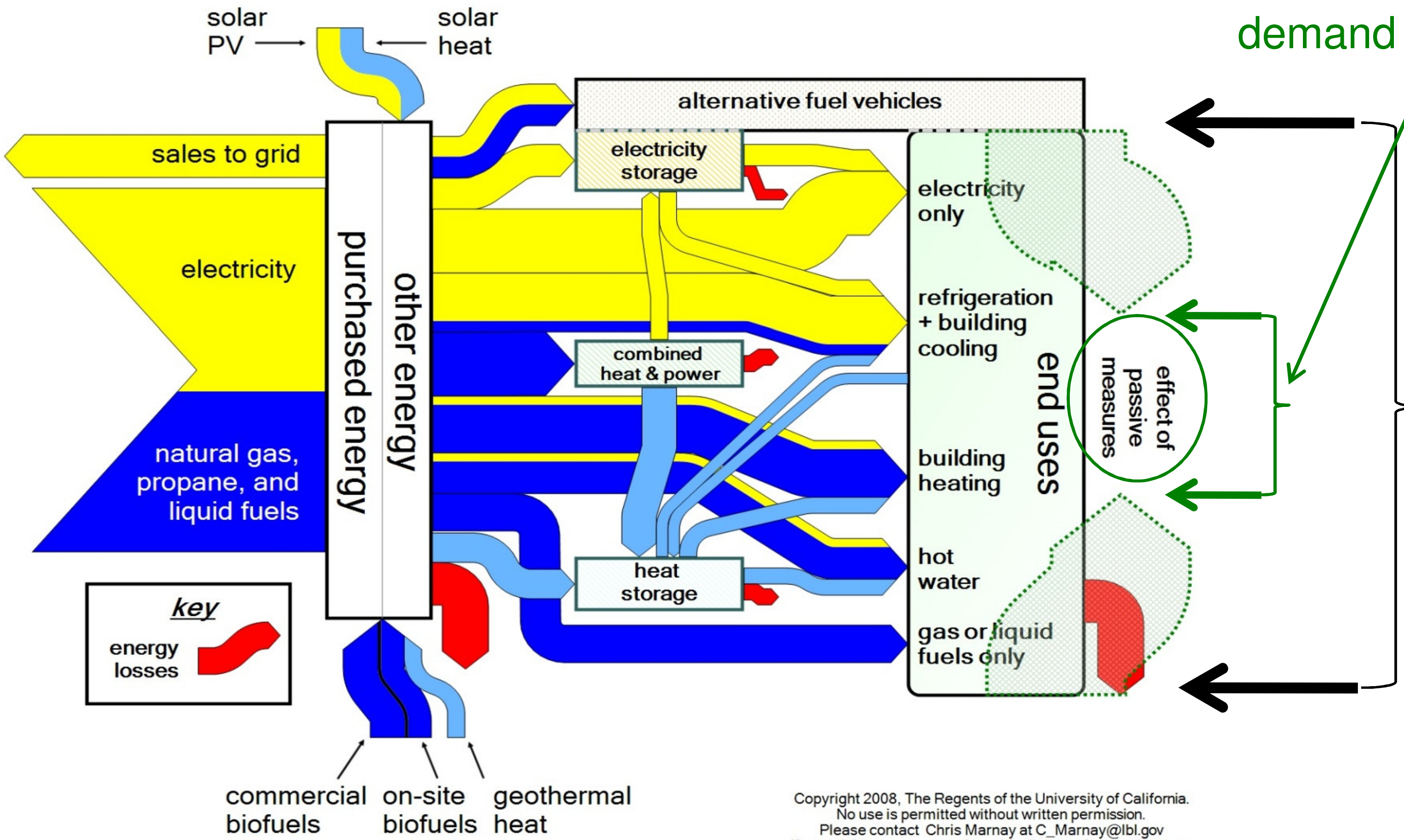
- How does the presence of storage technologies alter the sites' energy costs and carbon emissions?

- Do electric storage systems support PV penetration?

Introduction

- What technologies are economically attractive?
- How can zero net energy buildings (ZNEB) or zero carbon buildings (ZCB) be accomplished?
- Can zero net energy buildings be accomplished by Photovoltaic and solar thermal only or is CHP necessary?
- What demand-side measure (DSM) contribution is required to reach ZNEB?
- What are the costs for ZNEB or ZCB?

Global Concept



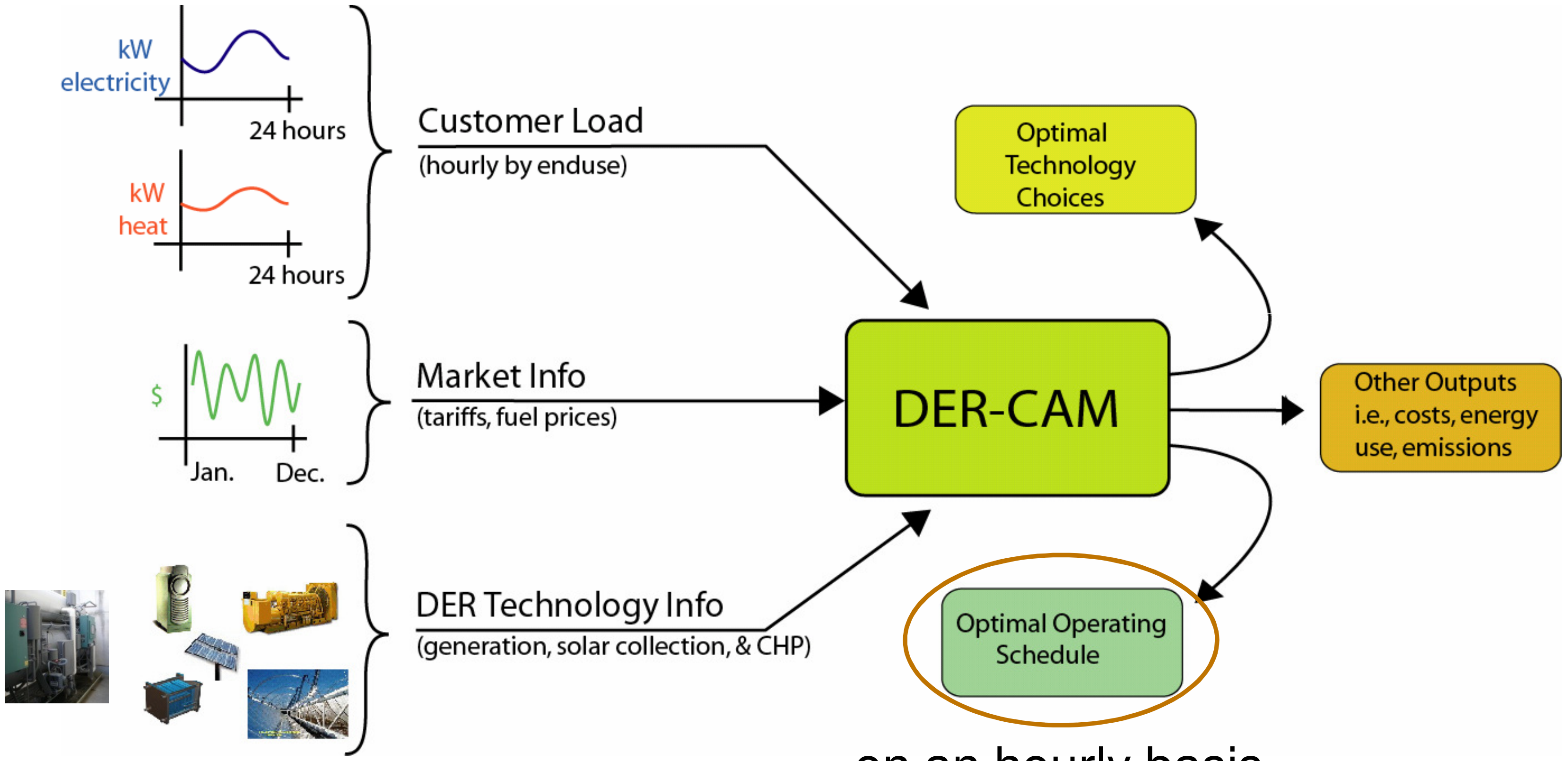
reduced service demand

original service demand

DER-CAM Concept

- Mixed Integer Linear Program (MILP), written in the General Algebraic Modeling System (GAMS®)
- Minimizes annual energy costs (or carbon emissions or multiple objectives) of providing services on a microgrid level (typically buildings with 250-2000 kW peak)
- Produces technology neutral pure optimal results with highly variable run times
- Has been designed for more than 7 years by Berkeley Lab and under license by researchers in the US, Germany, Spain, Belgium, Japan, and Australia.

DER-CAM Concept



Customer Load
(hourly by enduse)

Market Info
(tariffs, fuel prices)

DER Technology Info
(generation, solar collection, & CHP)

DER-CAM

Optimal Technology Choices

Other Outputs i.e., costs, energy use, emissions

Optimal Operating Schedule

on an hourly basis

Most Recent Study

- Results from a recent two-year research project performed for the U.S. Department of Energy
- DER-CAM model was extended by storage technologies, PV and solar thermal systems
- Two completely different markets were investigated
  - CA and NY
  - in CA TOU-tariffs and in NY flat electric tariffs are used
  - nursing home, school with and without heated pool, and data center
- In this talk, the results for the nursing home in CA and NY are shown.

DER Equipment Parameters

discrete

	reciprocating engine	fuel cell
capacity (kW)	100	200
sprint capacity	125	╳
installed costs ($/kW)	2400	5005
installed costs with heat recovery ($/kW)	3000	5200
variable maintenance ($/kWh)	0.02	0.029
efficiency (%), (HHV)	26	35
lifetime (a)	20	10

only integer numbers available

continuous

fixed unavoidable costs →

	electrical storage (lead acid)	thermal storage	flow battery	absorption chiller	solar thermal	photovoltaics
intercept costs ($)	295	10000	0	20000	1000	1000
variable costs ($/kW or $/kWh)	193	100	220 / 2125	127	500	6675
lifetime (a)	5	17	10	15	15	20

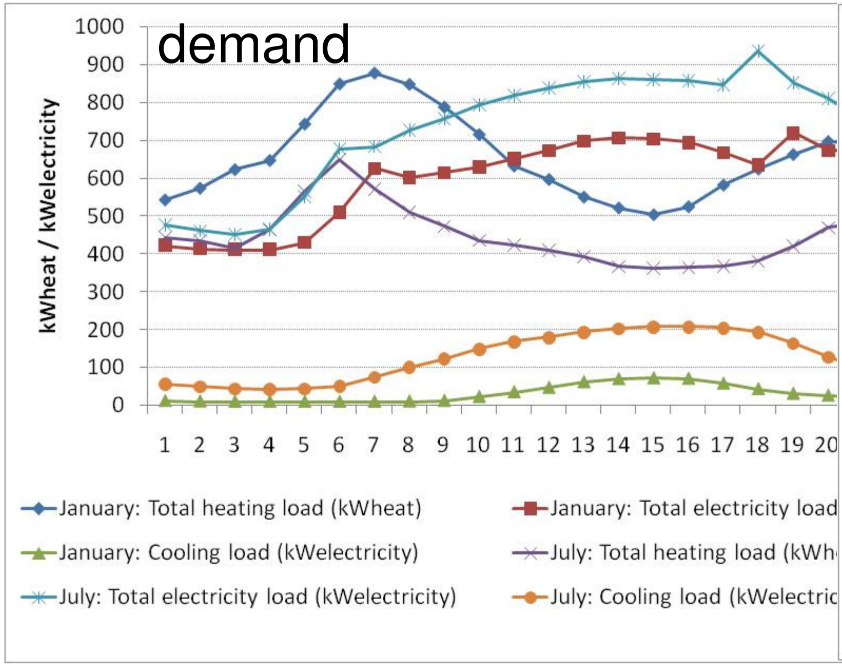
DER Equipment Parameters

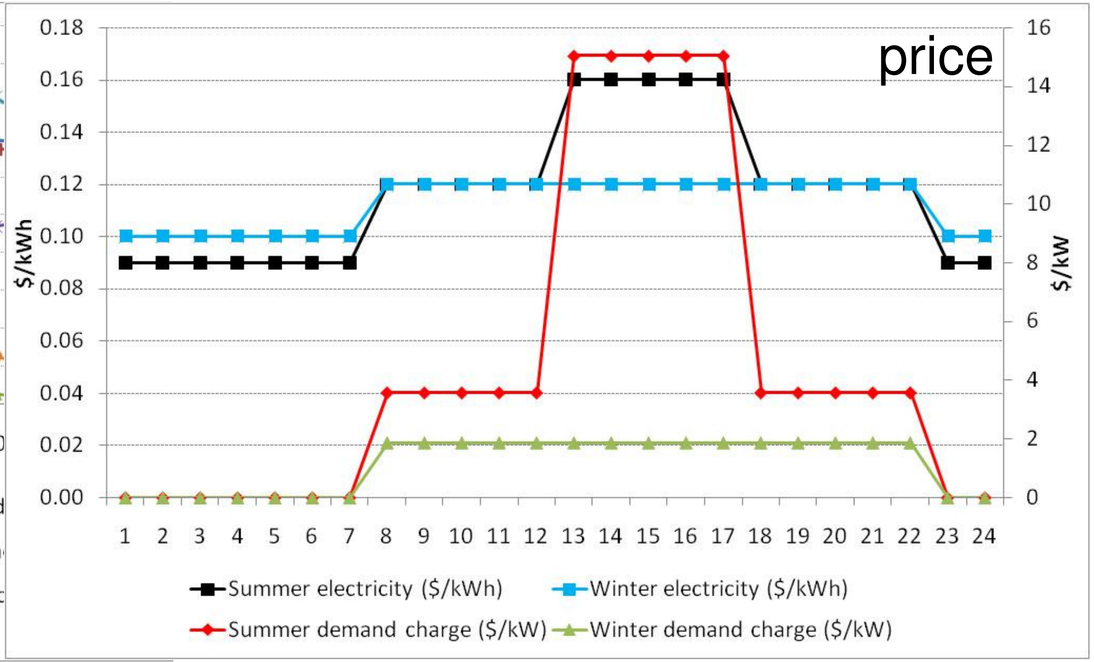
- Inverter-based variable speed internal combustion engine (ICE) genset from Tecogen, surge (125 kW), and CHP
- Designated sensitive load supplied during grid disturbance

→ E.g. important for data centers or hospitals

→ But makes engine more expensive

CA Nursing Home





during expensive mid- and on-peak hours, significant electricity and heat demand, as well as cooling loads → can be met thermally by waste heat → **prime candidate for on-site generation**

CA Nursing Home

- Most important runs that are shown in this presentation are
  - case A: no investments in DER, all energy is purchased
  - case B: all DER technologies are allowed, current technology costs are used
  - case C: storage costs are reduced by ca. 60% and PV incentive of $2.5/W
  - case D: results from case C are forced as DER-CAM solution except storage itself. This allows assessing the benefit of storage.
  - case E: storage costs and PV costs are reduced by ca. 60%

CA Nursing Home

at current technology costs

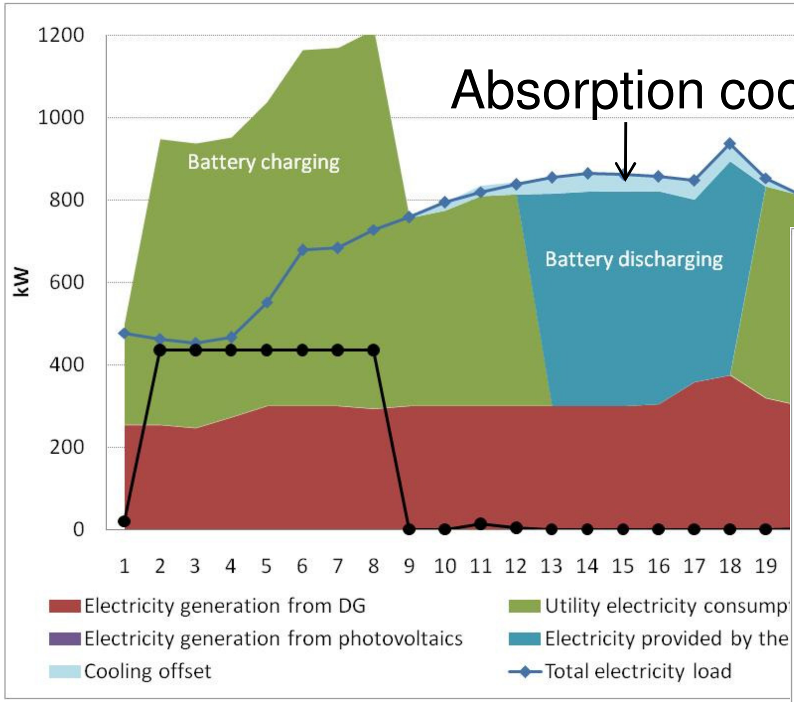
	A	B	C	D	E
	do- nothing	invest in all technologies	low storage costs and PV incentive of 2.5$/W	force low storage / PV and solar thermal results	low storage and PV costs (PV incentive 60%)
equipment					
Tecogen 100 kW ICE with HX (kW)	n/a	300	300	300	300
abs. Chiller (kW in terms of electricity)		48	46	46	40
solar thermal collector (kW)		134	109	109	43
PV (kW)		0	0	0	517
electric storage (kWh)		0	4359	n/a	2082
thermal storage (kWh)		0	123	n/a	47
annual costs (k$)					
total	964	926	916	926	910
% savings compared to do-nothing	n/a	3.94	4.98	3.94	5.60
annual energy consumption (GWh)					
electricity	5.76	3.23	3.33	3.22	2.40
NG	5.70	9.99	10.00	10.03	10.10
annual carbon emissions (t/a)					
emissions	1088	945	960	946	834
% savings compared to do-nothing	n/a	13.14	11.76	13.05	23.35

marginal carbon emission rate PG&E: 140g/kWh

← ICEs are a very stable solution

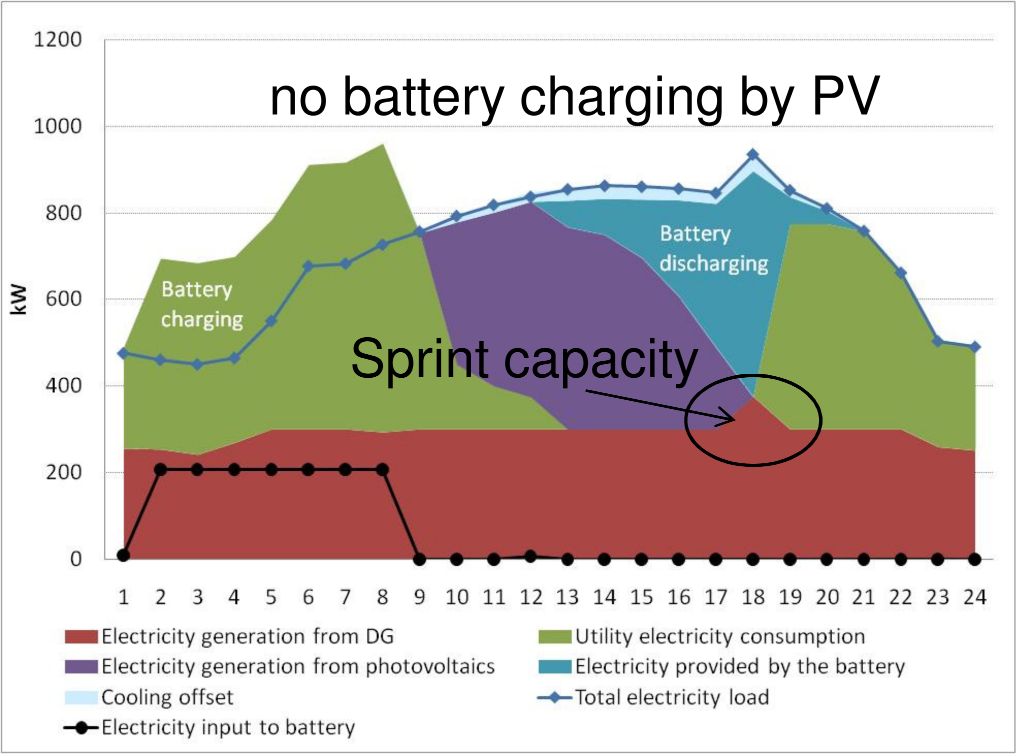
less carbon reduction potential with storage

CA Nursing Home


Absorption cooling

Case C: Diurnal Electricity Pattern for the CA Nursing Home on a July Weekday

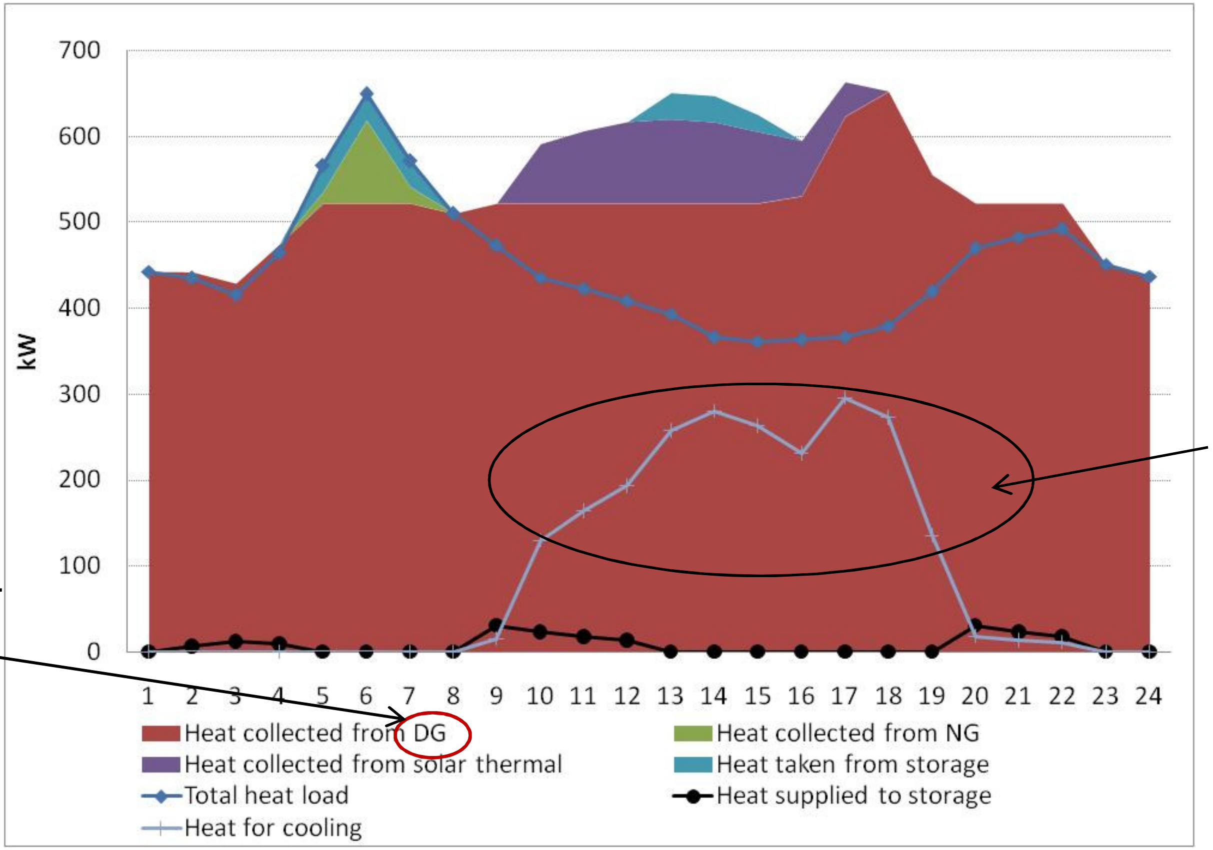
Case E: Diurnal Electricity Pattern for the CA Nursing Home on a July Weekday


no battery charging by PV

Sprint capacity

CA Nursing Home

Case C: Diurnal Heat Pattern for the CA Nursing Home on a July Weekday



Absorption cooling

without PV and solar thermal

CA Nursing Home

- Storage technologies are not attractive at current price levels
- Electric storage systems are charged by cheap off-peak electricity and not by PV
- Storage inefficiencies and the same marginal carbon emissions during on- and off-peak periods result in higher carbon emissions
- PV is not an *economic* option to charge electric storage, even at price levels 60% lower than today’s prices.

NY Nursing Home

at current technology costs

	A	B	C	D	E
	do-nothing	invest in all technologies	low storage costs and PV incentive of 2.5$/W	force low storage / PV and solar thermal results	low storage and PV costs (PV incentive 60%)
equipment					
Tecogen 100 kW ICE with HX (kW)	n/a	0	0	0	0
abs. chiller (kW in terms of electricity)		100	112	112	112
solar thermal collector (kW)		1438	2350	2350	2350
PV (kW)		0	0	0	0
electric storage (kWh)		0	294	n/a	294
thermal storage (kWh)		0	4862	n/a	4862
annual costs (k$)					
Total	1195.5	1161.27	1148.6	1178.56	1148.6
% savings compared to do-nothing	n/a	2.86	3.92	1.42	3.92
annual energy consumption (GWh)					
electricity	6.02	5.9	5.95	5.82	5.95
NG	7.14	5.24	3.5	4.82	3.5
annual carbon emissions (t/a)					
emissions	1555.23	1439.26	1361.49	1402.2	1361.49
% savings compared to do-nothing	n/a	7.46	12.46	9.84	12.46

marginal carbon emission rate ConEd: 200g/kWh

ICE and PV is not an option

11 times bigger than in CA!

storage adoption is inverse to the CA case

higher carbon reduction potential with heat storage

Comparison

- NY examples with flat electricity tariffs and higher natural gas prices show
  - ☐ less or no electric storage and ICE adoption
  - ☐ but more solar thermal adoption despite less solar radiation

  → tariff is most influential factor (TOU and demand charges in CA versus almost flat tariffs in NY)

- Storage inefficiencies and constant marginal emissions cause higher carbon emissions

- Problem worse if coal is marginal off-peak

Ongoing Work

- All research was based on cost minimization strategy of the microgrid

→ Consideration of carbon minimization or multi-objective function

multi-objective function:

$$\min\{w \cdot \frac{Cost\,[\$/a]}{MaxCost\,[\$/a]} + (1-w) \cdot \frac{Carbon[t/a]}{MaxCarbon[t/a]}\} \qquad 0 \leq w \leq 1$$

MaxCost and MaxCarbon are parameters during optimizations

- Addition of demand-side measures (passive technologies) to consider the impact of service reductions
- Extension by the ZNEB or ZCB concept

DSM

demand measures are characterized by the:

- costs of reducing 1 kW of load ($/kW)
- max. potential of **load** reduction (%), and
- annual time limit (h of behavioral change or technical limit)

Electricity	VariableCost ($/kW)	MaxContribution (%)	MaxHours (hours)
low	0.00	30	4380
mid	0.06	10	8760
high	1.00	5	760

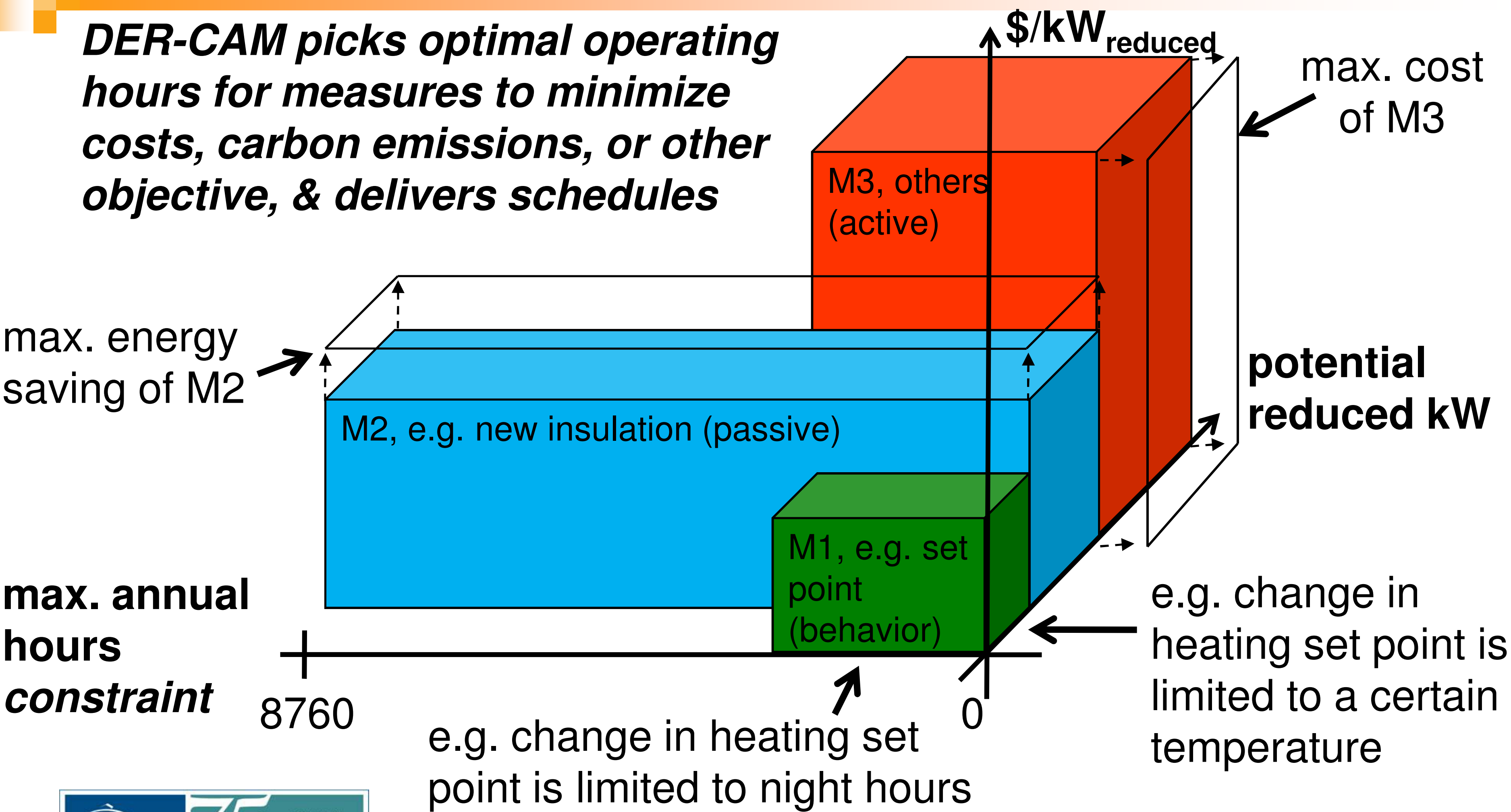
assumed data used here
→ refinement possible

heating measure costs for “mid” are assumed to be slightly less than, and for “high” slightly higher than, PG&E NG costs

Heating	VariableCost ($/kW)	MaxContribution (%)	MaxHours (h)
low	0.00	30	1095
mid	0.03	20	8760
high	0.05	10	8760

DSM

DER-CAM picks optimal operating hours for measures to minimize costs, carbon emissions, or other objective, & delivers schedules



$/kW$_{reduced}$

max. cost of M3

M3, others (active)

max. energy saving of M2

M2, e.g. new insulation (passive)

potential reduced kW

M1, e.g. set point (behavior)

max. annual hours *constraint*

8760

0

e.g. change in heating set point is limited to a certain temperature

e.g. change in heating set point is limited to night hours

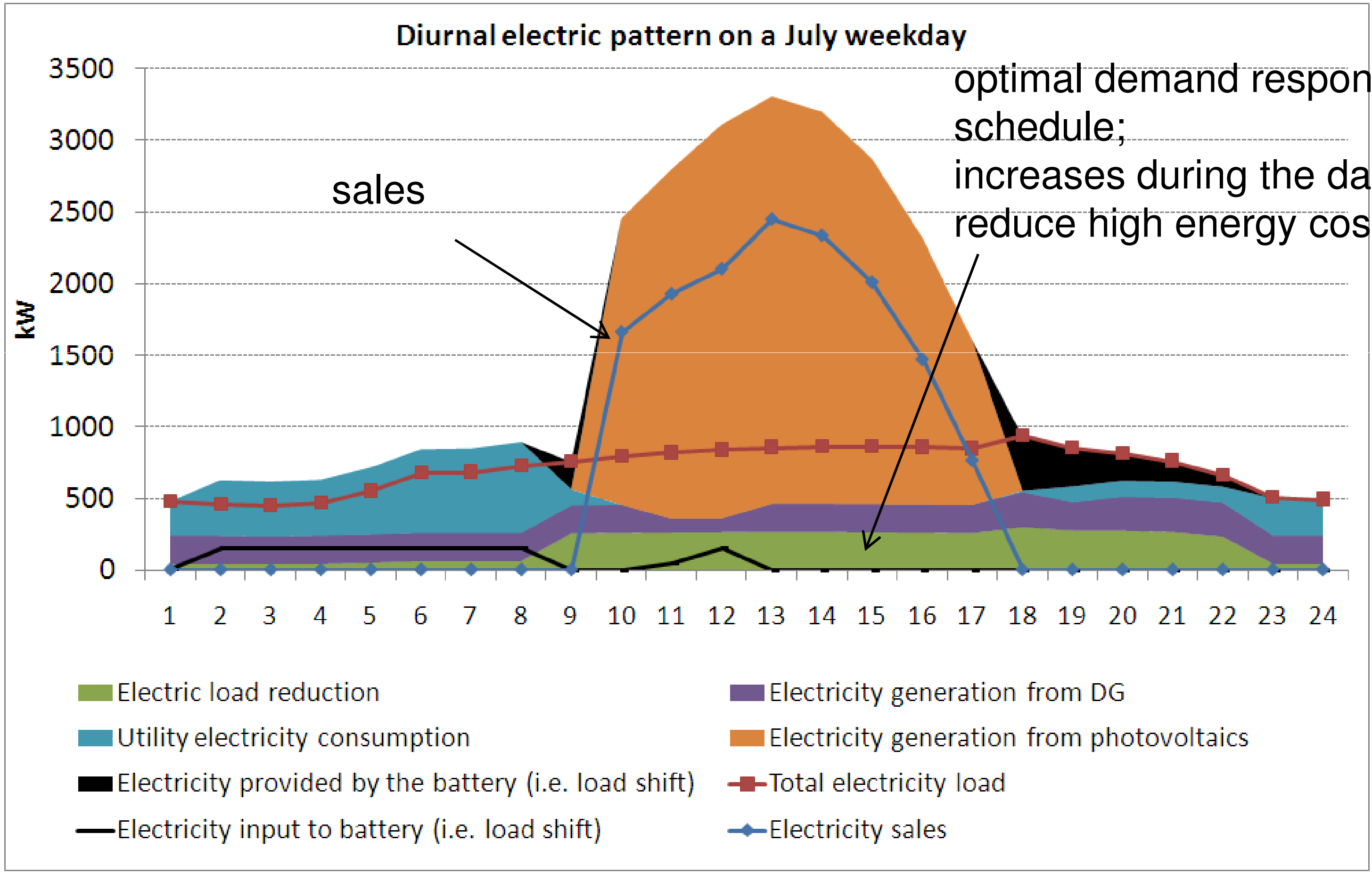
ZNEB

- ZNEB constraint: purchased energy = sold energy
- Energy must be in common units (heat equivalent)
- Footprint constraint: the possible space for PV and solar thermal adoption must be restricted
- Multiple possible minimization objectives:
  - total energy bill
  - carbon emissions
  - combination
- Consideration of DSM:
  - load <u>shifting</u> measures represented by storage, and
  - load <u>reduction</u> measures represented by abstract “low”, “mid”, and “high” measures for electricity-only and heating loads

ZNEB - CA Nursing Home

- Strategy: cost minimization
- Reduced technology costs (due to subsidies) for PV and storage (case E from slide 12)
- Total energy bill: - 15% (compared to do-nothing)
- Annual carbon emissions: - 36% (compared to do-nothing)
- Installed Equipment:
  - 200 kW of ICE with heat exchanger
  - 1514 kWh of electric storage
  - 3156 kW of PV (ca. 22000m^2)
- Carbon reduction costs of ca. $950/tC (compare this to $150/tC at EEX in Germany)

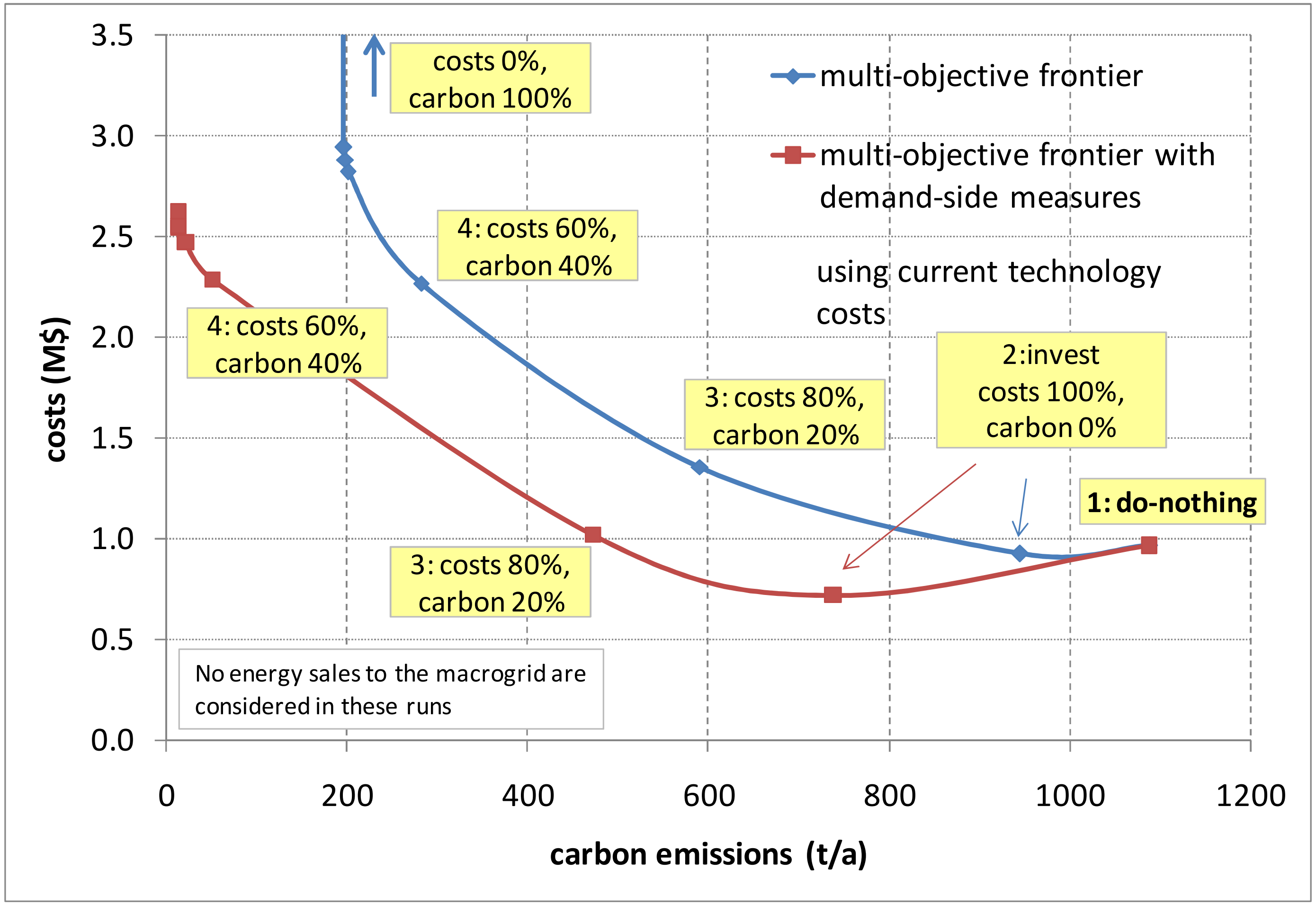
ZNEB - CA Nursing Home



sales

optimal demand response schedule; increases during the day to reduce high energy costs

CA Nursing Home Multi-Objective Frontier



CA Nursing Home Multi-Objective Frontier

multi-objective frontier	ICE (kW)	abs. chiller (kW)	electric storage (kWh)	heat storage (kWh)	PV (kW)	solar thermal (kW)
1: do-nothing	0	0	0	0	0	0
2: invest	300	48	0	0	0	134
3: (80%cost, 20% carbon)	100	238	0	12293	754	4445
4: (60%cost, 40% carbon)	0	250	7900	19577	2074	5595
5: (40%cost, 60% carbon)	300	156	14299	9517	2914	2364
6: (20%cost, 80% carbon)	300	0	15262	10013	2951	2222

multi-objective frontier ***with DSM***	ICE (kW)	abs. chiller (kW)	electric storage (kWh)	heat storage (kWh)	PV (kW)	solar thermal (kW)
1: do-nothing	0	0	0	0	0	0
2: invest	300	0	0	0	0	0
3: (80%cost, 20% carbon)	0	238	0	9911	459	3984
4: (60%cost, 40% carbon)	0	246	9982	16438	2305	4705
5: (40%cost, 60% carbon)	0	191	12931	11604	2614	3517
6: (20%cost, 80% carbon)	100	173	13427	11239	2709	3152

CA Nursing Home Multi-Objective Frontier

- Electric storage as well as PV adoption increases with increasing carbon minimization level

→ PV will be “oversized” and used to charge electric storage systems (since costs are not important)

- ICEs with heat recovery seem to play a role at high carbon reduction goals
- DSM seems to reduce that need for ICEs
- Those ICE results need more in depth research considering more DER technologies and different building types as well as different tariff regimes.

Conclusions & Future Work

- Passive and demand-side measures, better boxes
- Forecasting, uncertainty, thermodynamics, mobile sources
- Consideration of grid losses and thermodynamics to consider widespread microgrids and communities
- Open source data base of tariffs, equip. perform., etc.
- Advanced financial methods, options, sequencing
- Integration of DER-CAM into building energy managements systems to enable “realtime” optimizations
- Related studies: ZNEB (less silly), standard blgs., residential buildings and communities

DER-CAM

Thank You!

Comments and Discussions are Welcome!