Beyond ZNE: The Carbon Mitigation Potential of California Buildings

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Getting to Zero Forum

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RESOURCE REFOCUS

Zero-Carbon Buildings in California: A Feasibility Study

Conducted on behalf of the California Air Resources Board and the California Environmental Protection Agency

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  - Water -- Prof. Arpad Horvath, Dr. Jennifer Stokes-Draut, and Fiona Greer
  - Operational Energy -- Resource Refocus: Anna LaRue, Carrie Brown, Margaret Pigman, and Vrushali Mendon
  - Community scale energy -- Energy Solutions
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Zero-Carbon Buildings in California: A Feasibility Study

Research Need

- In order to meet the ambitious statewide GHG emissions reduction targets recently put in place -- a 40% reduction of GHG emissions below 1990/2020 levels by 2030 (under SB 32), and achieving carbon neutrality statewide by 2045 if not before (under E.O. B-55-18) – the State must assess the feasibility of buildings that generate zero, or nearly zero, emissions from their ongoing operations.

This research explores the feasibility of zero carbon residential and commercial new buildings to support the development of state targets and policy frameworks on zero carbon building.

Zero-Carbon Buildings in California: A Feasibility Study

Phase 1 assessed the feasibility of **building-scale** transportation, water, solid waste, and operational energy management strategies to supplement existing ZNE goals to achieve ZC in new construction in California.

- For each of six building types (single-family residential, multi-family residential, large office, strip mall, school, and warehouse), the research team quantified the potential for each identified building-scale strategy to reduce greenhouse gas (GHG) emissions below anticipated future baseline levels and then assembled those strategies as graphical “wedges” in a dynamic spreadsheet tool that can quantify zero carbon building potential for any location in California.

Zero-Carbon Buildings in California: A Feasibility Study

Phase 2 identified and assessed the GHG reduction potential of **existing buildings** at the community scale to complement the building scale analysis

- Leveraged existing Richmond AEC project to create a GHG mitigation framework for zero net carbon communities
- Conducted place-based analysis of Richmond with transferability to other municipalities in CA

Zero-Carbon Buildings in California: A Feasibility Study

While the overall study also explores emissions due to transportation, water, and solid waste both at the building and community level, **this presentation will focus specifically on operational energy methodologies and results at the building level for new and existing buildings.**

Zero-Carbon Buildings in California: A Feasibility Study

This ZC analysis builds on the ZNE exemplar building packages developed through the Technical Feasibility of Zero Net Energy Buildings in California (Arup 2012).

The Technical Feasibility of ZNE Buildings in CA (Arup 2012)

Figure 10 – Statewide Technically Feasible **EUIs without Solar** (TDV$) distributed by Projected 2020 Construction Volume

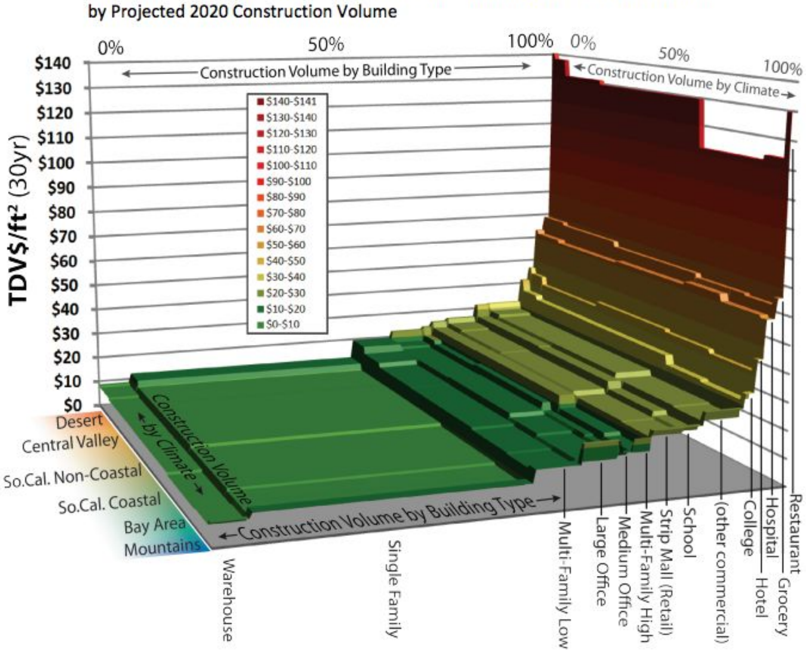
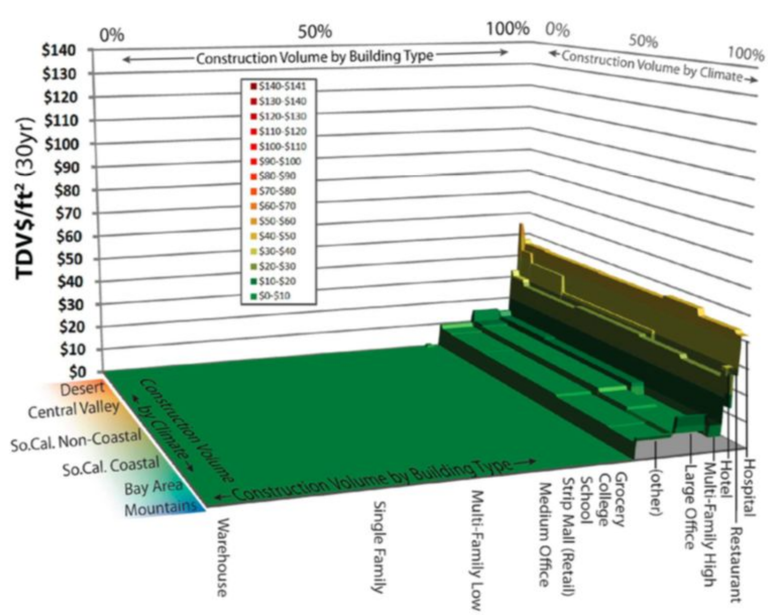


Figure 2. Modeling results for feasibility of zero net energy construction of major building types across California climate zones. Building types on the flat green plane reach ZNE. From Arup (2012)



Phase 1: Carbon Mitigation Potential of New Construction

Task 1: Quantify Gap between ZNE and ZC

Task 2: Quantify Carbon Wedges

- PV
- Fuel Switching
- Plug Load Management

Building Types

4 Commercial

- Large office
- Strip mall
- School
- Warehouse

2 Residential

- Single-family residential
- Multi-family residential (low-rise)

Selected building types represent:

- Over 75% of anticipated CA construction volume in 2020
- 5 of 6 can meet ZNE across all climate zones
- Diversity of occupant densities, resource usage

CA Climate Zones (CZs)

The Tech Feasibility analyzed 7 of 16 California CZs.

For this study:

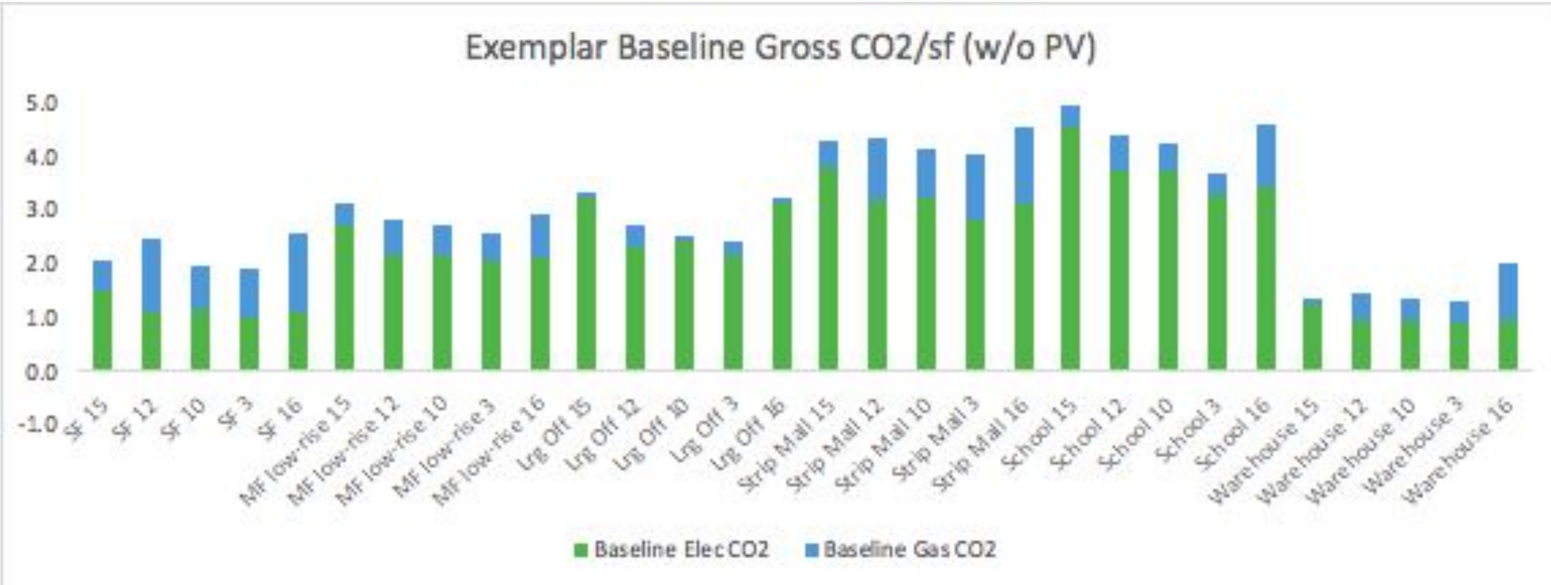
- To cover a large percentage of construction volume:
  - CZ 3 (Bay Area)
  - CZ 10 (Riverside)
  - CZ 12 (Sacramento)
- To illustrate bounding cases that will be more challenging to achieve zero carbon
  - CZ 15 (low desert, very hot, dry summer, moderate winter)
  - CZ 16 (high mountains, largest annual temp swings)

Task 1: Quantify Gap between ZNE and ZC

Baseline: Assume that the Tech Feasibility exemplar buildings approximate a 2020 ZNE baseline.

- Exemplar Building data available
  - Data by building type and climate zone. Includes:
  - sf, # floors, available roof space, % roof space used for PV, gross and net consumption,
  - Gross and net emissions using static annual multipliers to begin
    - 1 kWh = 0.59508 lbs CO_2 and
    - 1 Therm = 13.224 lbs CO_2

Task 1: Quantify Gap between ZNE and ZC



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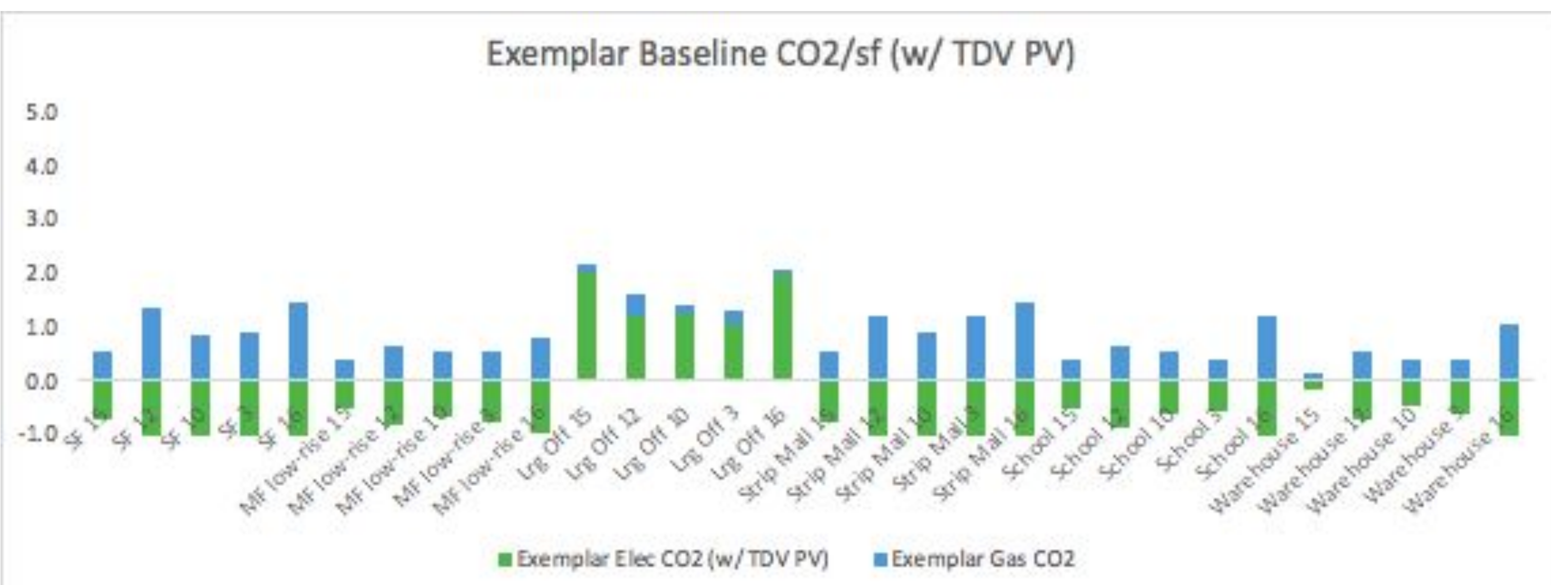

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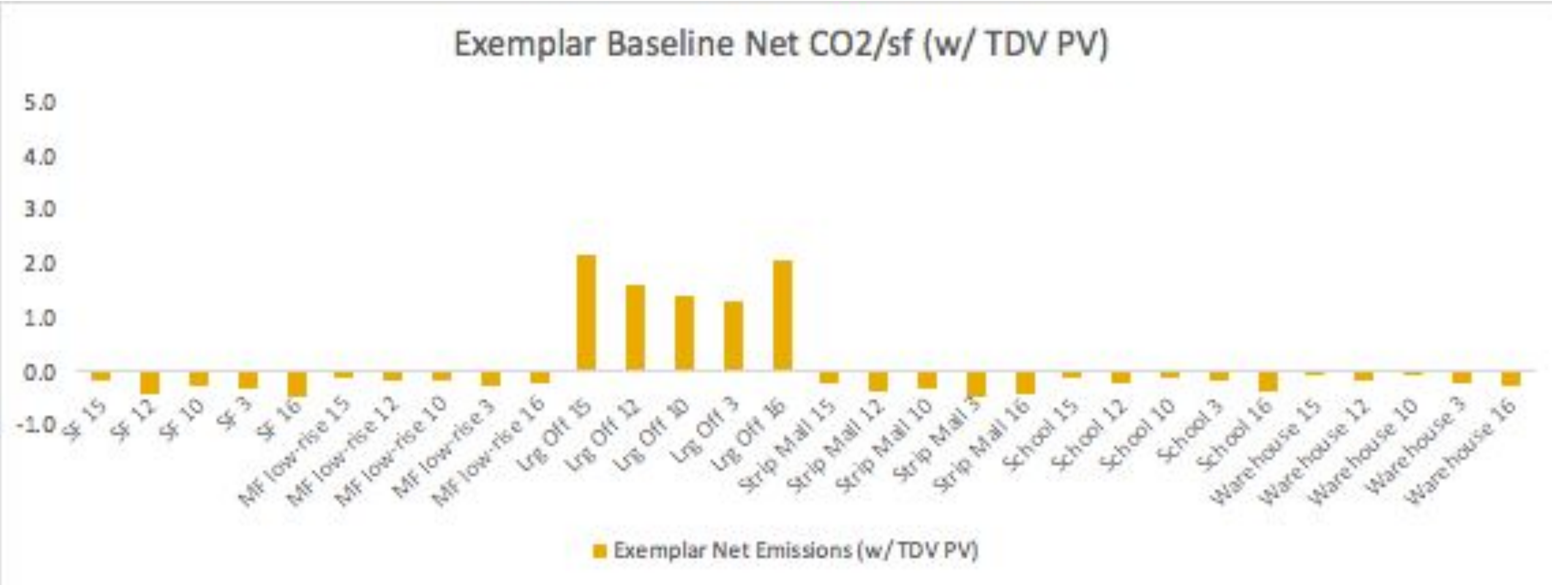


Task 2: Quantify Carbon Wedges

- Wedge 1 -- PV:
  - Both surplus PV (max rooftop, parking lots) and PV efficiency improvements.
- Wedge 2 -- Fuel switching:
  - For end uses such as domestic hot water and space conditioning.
- Wedge 3 -- Plug loads:
  - Typically not regulated under T-24 or T-20, and are likely to see the widest variation. In a new residential construction, they can represent up to up to 50% of the building’s energy use as envelopes and appliances continue to be more efficient. Without careful attention, this end use could have growth in carbon emissions.

PV Wedge

- Identification of building types/CZs that are potential carbon sinks using 100% available roof space and parking lot area.

- Tech Feasibility assumptions
  - Roof area: 80% roof area “available”
  - Parking lot area:

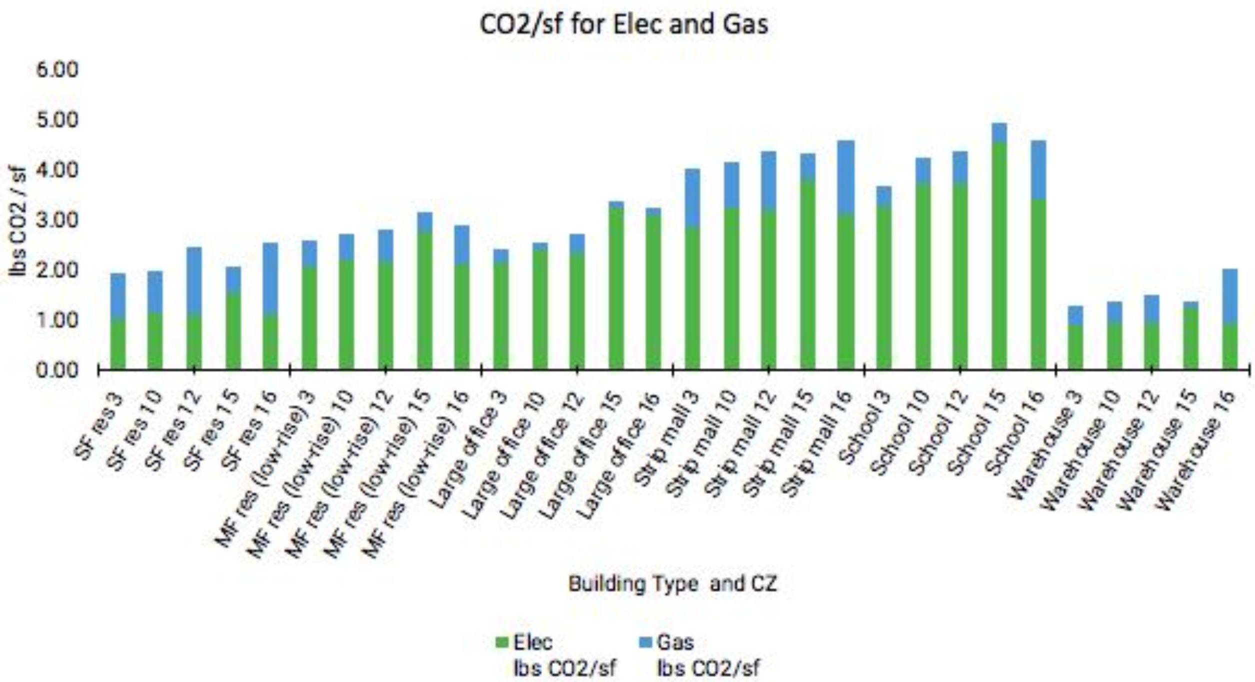
Parking Lot PV	Total Building Area sf	Avg Parking Spaces	kWh / building sf
Single-Family Residential	2100	0	0
Multi-Family Residential	14700	20	5.8
Large Office	498600	750	7.1
Strip Mall	22500	120	25.9
Warehouse	49495	50	4.5
School	210900	280	6.3

PV Wedge

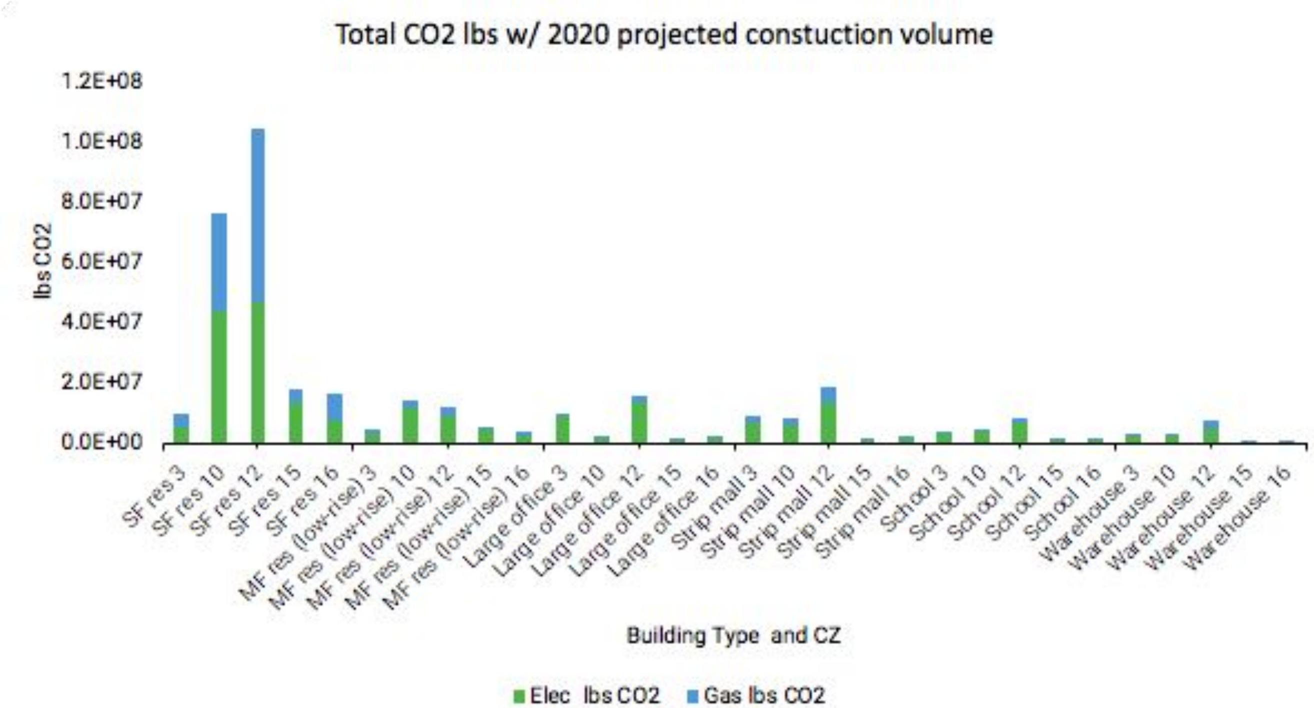
PV wedge: Incorporates the production potential from both efficiency improvements and surplus roof and parking lot area.

- “Low” wedge assumes 15% panel efficiency, representing a worst case scenario with an efficiency level readily available today.
- “High” wedge followed the Tech Feasibility assumption of 20% efficient panels, and assumed a further 20% increase (to 24% efficiency) by 2020.

Fuel Switching Wedge



Fuel Switching Wedge



Fuel Switching Wedge

Fuel switching wedge: Converts gas usage to electricity for end uses such as domestic hot water and space conditioning.

- Bounding cases: straight energy conversion of all exemplar baseline gas to electricity (1 therm = 29.30 kWh) using COP 1 “low” and COP 3 “high”

Plugs Loads Wedge

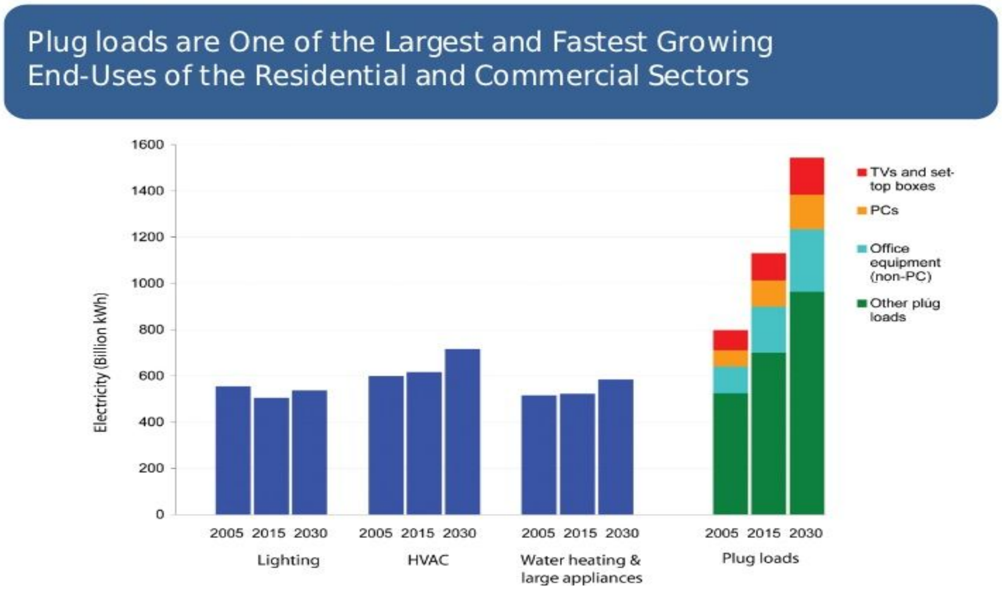
- In the United States in 2016, plug loads represented about 30% of the primary energy used in residential buildings and 36% used in commercial buildings (DOE 2016). Plug loads continue to be the fastest growing end use in these sectors (Kwatra 2013, EIA 2018).

- From 2016 to 2030, they are expected to grow by 13% in residential buildings and 27% in commercial buildings (DOE 2016).

- With higher plug load consumption and increased efficiencies in other end uses, the percent of total building energy that plug loads represent is expected to increase from 30 to 34% in residential buildings, and 36 to 43% in commercial buildings during this time (DOE 2016).

Plugs Loads Wedge

Without careful attention, this end use could have growth in carbon emissions. Task is to quantity reasonable range in plug load over time.



Source: Office Plug Loads: Energy Use and Savings Opportunities, CEC 2012.

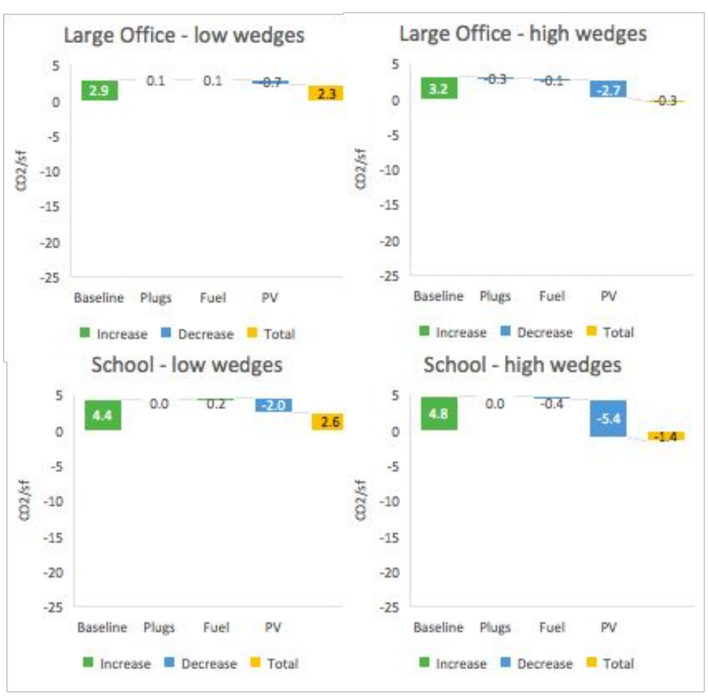
Plugs Loads Wedge

Plug load management wedge:

- "Low" wedge: Exemplar building with 50% of DOE expected 2030 plug growth. Residential growth is reduced from 13% to 6.5%, while commercial is reduced from 27% to 13.5%.
- "High" wedge: Exemplar building with plug load savings doubled.

Phase 1 Results

Phase 1 Results



Phase 1 Results

The results show that **zero carbon new construction is generally feasible for warehouses, strip malls, and both types of residential buildings across California** in the next decade when the building-scale strategies are combined with modest investments in carbon offsets.

For large offices and schools, much larger investments in offsets, slower implementation schedules, and/or new strategies and technologies are needed to achieve zero carbon performance.

Phase 2: Carbon Mitigation Potential of Existing Buildings

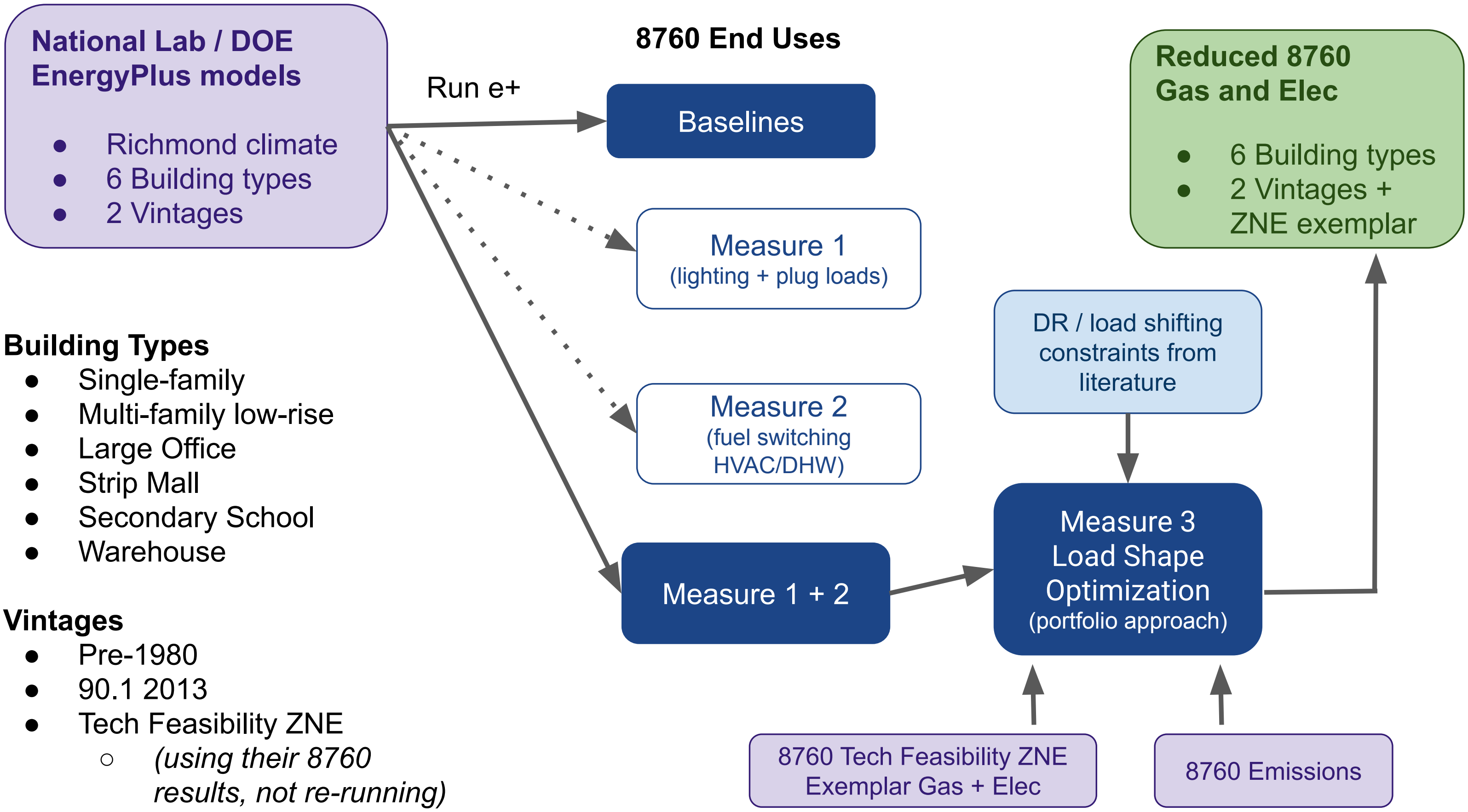
Community Scale Study in Richmond, CA
Existing Buildings: Simple retrofits, no gut rehabs

Step 1: Modeled Load Reduction -- Measures 1 & 2
(within EnergyPlus)

- Combined plug load + lighting
- HVAC / DHW fuel switching

Step 2: Load Shape Optimization -- Measure 3

- Portfolio approach
- Use existing DR and storage literature to set high-level constraints on magnitude and duration of energy use shifts
- Essentially rate arbitrage with emissions



Energy Modeling -- Measure 1: Plugs + Lights

Residential:

- Lighting - 100% LED for interior and exterior
- Plug Loads - 25% reduction from Building America default

Commercial:

- No change to baseline envelope (skylights) or daylighting controls
- LPD: reduced 50-70% from 2013 baseline
- EPD: reduced to 0.5 W/sf outside of data centers, or reduced by 10-30% from 2013 baseline
- Controls: unoccupied hours (8pm-6am) reduced to 15% of EPD, except in the data center and basement (2013 only) which are always on

Energy Modeling -- Measure 2: Fuel Switching

Residential:

- Heating
  - Variable speed heat pump
- Water Heating
  - 50 gallon HPWH per unit

Warehouse and Strip Mall:

- Heating
  - Replace PTAC with PTHP
- Water Heating -- No changes
  - Warehouse: already electric
  - Strip Mall: No water heating in pre-1980s model; didn't add any; 2013 already electric

Energy Modeling -- Measure 2: Fuel Switching

Secondary School:

- Heating
  - Replace PTAC with PTHP in kitchen, gym, auditorium, cafeteria. Add PTHP to classrooms, library, offices.
  - Boiler serving VAV system (bathrooms and corridors) converted to electric.
- Water Heating: Converted to electric.
- Left gas in the kitchen.

Office:

- Heating
  - Pre-1980s
    - Replace DOAS with WSHP. Replaced the gas in the DOAS with DX heating.
  - 2013: Boiler serving the VAV system converted to electric.
- Water Heating: Converted to electric.

Energy Modeling -- Measure 3: TOU

Load Shape Optimization:

- Portfolio approach
- Use existing DR and storage literature to set high-level constraints on magnitude and duration of energy use shifts
- Essentially rate arbitrage with emissions

Energy Modeling -- Measure 3: TOU

Optimization Formulation: (Linear Constrained)

- Objective Function J(X, P) for hours 1 to 8760 = **Minimize sum of hourly GHG**
- Such that
  - X : Design variables = Hourly % Shift
  - P : Design parameters (constants)
    - Pre-1980 and 2013 hourly kWh from modeling runs
    - Hourly GHG Factors
  - H : Equality constraints
    - Daily sum of Hourly % Shifts = 0
  - LB, UB : Upper and lower bounds for design variables
    - -5% <= Hourly % Shift <= 5% (*will do sensitivity analysis here*)

SLIDE EDIT: REFORMAT AS EQUATION

Energy Modeling -- Measure 3: TOU

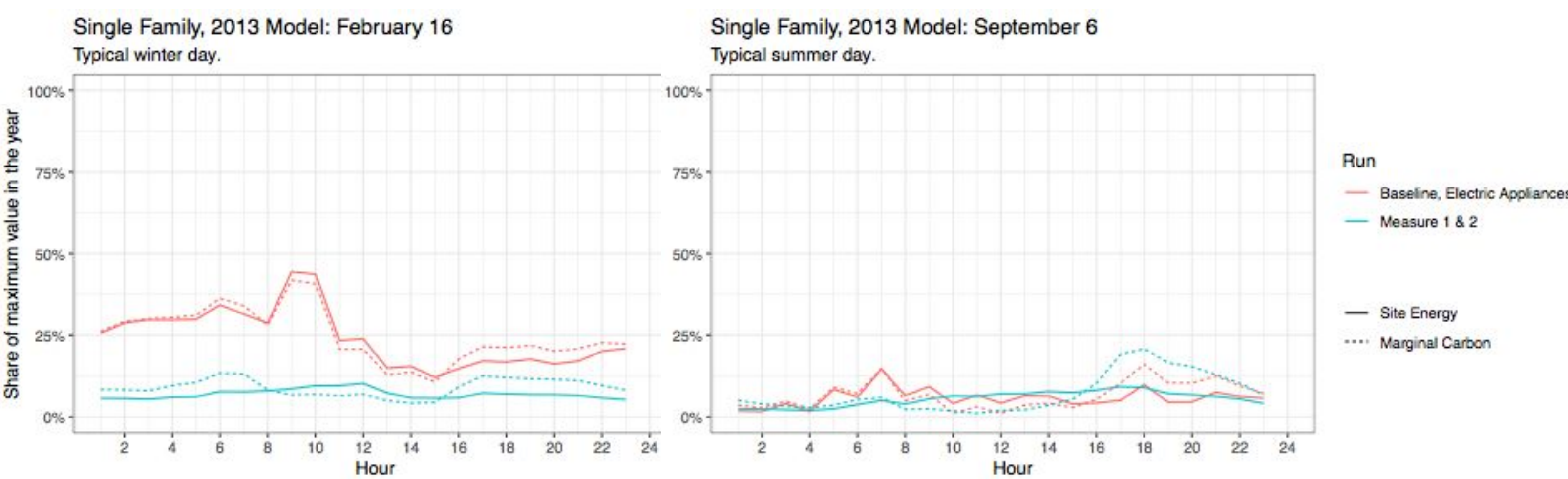
(Some) hourly GHG metrics considered:

- CAISO
- Watttime
- SB 1477 hourly average emissions
- E3's new metrics work will be completed later

Final selection:

- **Long run marginal emissions from CEC**
  - Also proposed in CEC/CPUC BUILD and TECH *draft* programs

Phase 2 **Preliminary** Results



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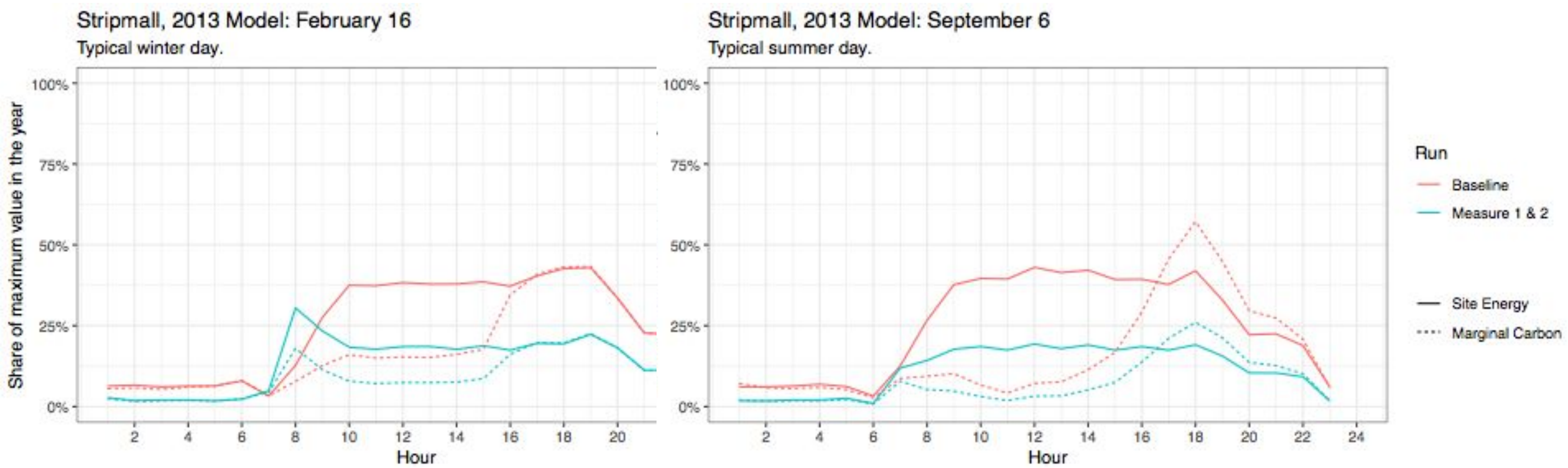

Phase 2 **Preliminary** Results

CHART OF MEASURE 1+2+3 SAVINGS

Conclusions

THANKS!

Any questions?

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