Multifamily Net Zero Retrofit Market:

Technical and Cost Benchmarks for San Francisco

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Acronym Key

ACEEE – American Council for an Energy Efficient Economy

ACH50 – Air Changes Per Hour Taken at 50 Pascals

AFUE – Annual Fuel Utilization Efficiency

ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers

BAU – Business As Usual

BB – Baseboard

BEopt – NREL's Building Energy Optimization Model

CFL – Compact Fluorescent Lamp

CO_2 – Carbon Dioxide

DHW – Domestic Hot Water

ECM – Energy Conservation Measure

EE – Energy Efficiency

EIA – Energy Information Administration

EUI – Energy Use Intensity

GPM – Gallons Per Minute

HP – Heat Pump

HPHW – Heat Pump Hot Water

HSPF – Heating Seasonal Performance Factor

HVAC – Heating Ventilation and Air Conditioning

HW – Hot Water

ITC – Solar Investment Tax Credit

kBTU – Kilo British Thermal Unit

kW – Kilo Watt

LB - Pound

LED – Light Emitting Diode

LIHTC – Low Income Housing Tax Credit

Low-E – Low-emittance

NREL – National Renewable Energy Lab

NZE_c – Net Zero Carbon

NPV – Net Present Value

PG&E MUP – Pacific Gas & Electric Multifamily Upgrade Program

PV – Present Value

SAM – System Advisor Model

SEER – Seasonal Energy Efficiency Ratio

SF – Square Foot

Solar PV – Solar Photovoltaic

STD – Standard

YR - Year

Analysis Process

Retrofit Technical and Cost Benchmark Process

A detailed “how-to” guide is available that explains key considerations and gives resources to complete each step

Step 1: Determine Scope of Project

Affordable multifamily buildings in greater San Francisco were analyzed for net zero carbon

Step 2: Identify Appropriate Modeling Tools and Data Sets

Building Energy Optimization (BEopt) and System Advisor Model (SAM) were the modeling tools used

Step 3: Select Prototypical Buildings

Three prototype buildings were selected: 6 unit, 15 unit, and 65 unit

Step 4: Energy Conservation Measures

Included envelope, lighting, HVAC, rooftop PV, offsite renewables, and appliances in analysis

Step 5: Solar Analysis

Used SAM to determine carbon offset of solar arrays with different efficiency and racking configurations

Step 6: Utility Economics

Determined utility escalation rates, typical rate structure, and carbon produced from electricity and natural gas

Step 7: Financing

Used a 15 and 25 year analysis period and 5% discount rate; incentives included LIHTC, PG&E MUP, and ITC

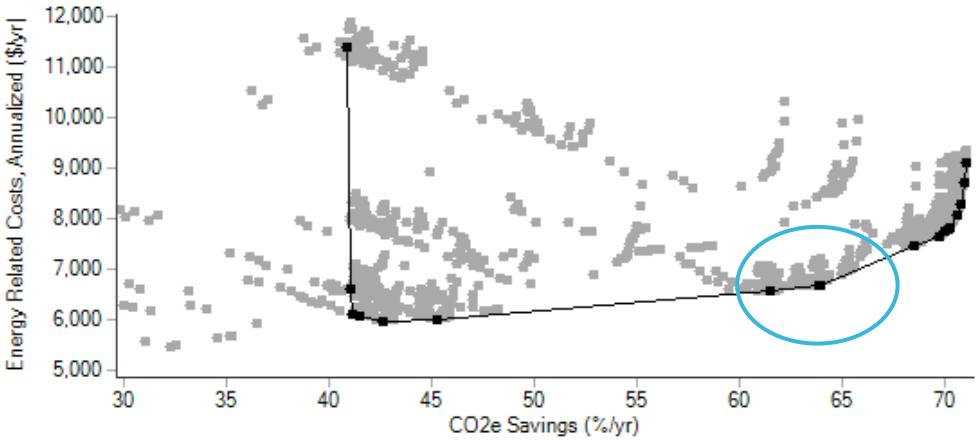
Step 8: Optimize Analysis To Hit Net Zero In The Most Cost Effective Way

Used BEopt to optimize efficiency package

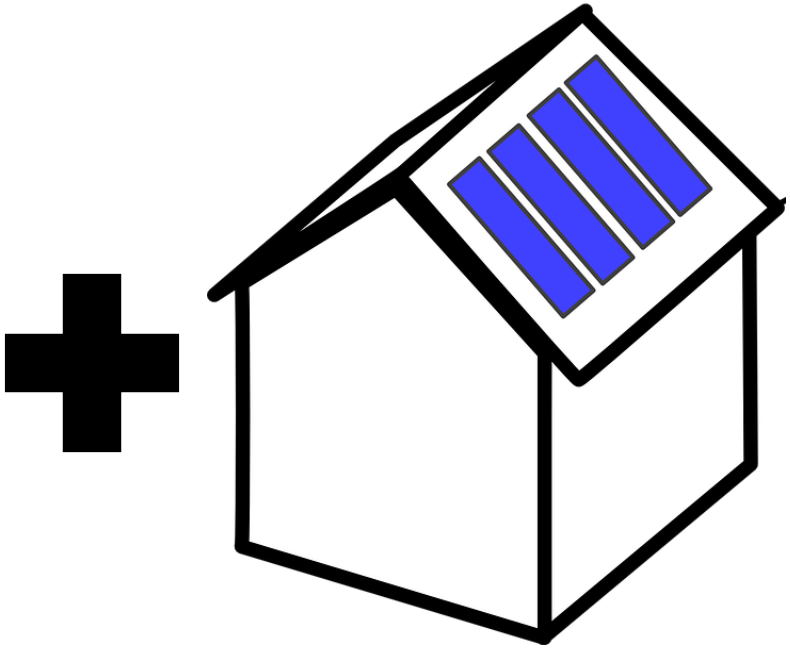
Modeling Tools Used

BEopt was used to optimize EE measures and SAM was used to do a detailed solar analysis. Because these were done in two separate programs a degree of manual optimization was required.

Building Energy Optimization (BEopt)



System Advisor Model (SAM)

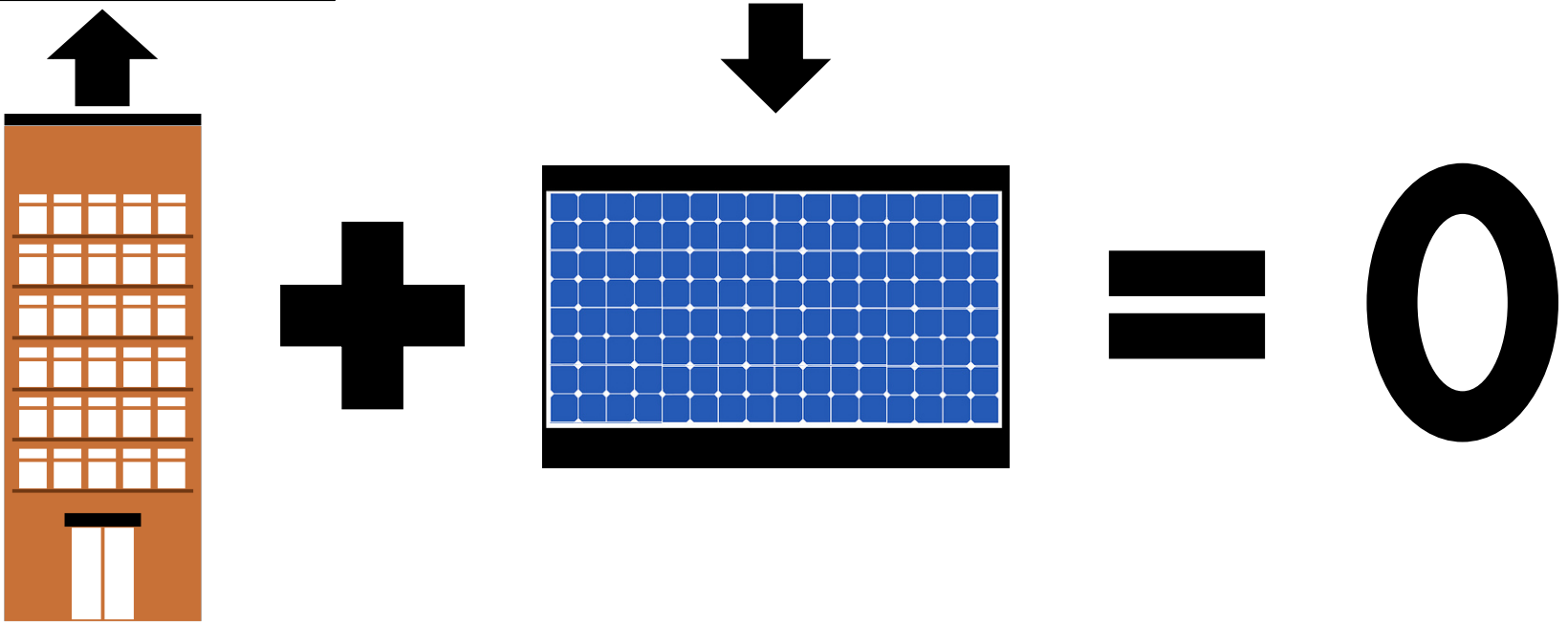


Defining “Net Zero”

This analysis defined net zero as net zero carbon, which is achieved when an equivalent unit of carbon-free renewable energy is produced (on or off site) to offset each unit of fossil fuel energy used by the building.

Building CO_2 Production:
Electricity: 36 tons/yr
Gas: 4 tons/yr

Renewable CO_2 Offset:
40 tons/yr



BEopt uses site energy to calculate carbon
Electric: Carbon Factor: 0.427 lb/kWh from PG&E 2013 (last verified)
Gas: Carbon Factor: 14.150 lb/therm from ASHRAE STD 105

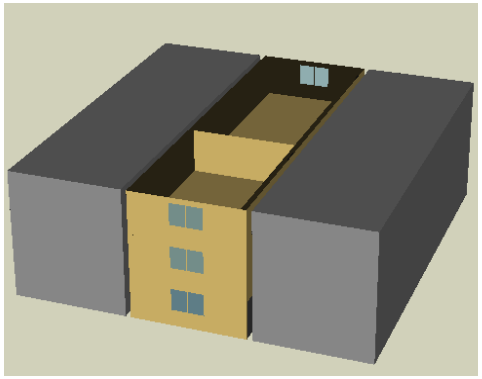
Three Prototypical San Francisco Building Types

The majority of affordable multifamily buildings in San Francisco were constructed prior to 1980, have gas furnace heating, and are three stories or less.

Category: 5-9 unit buildings
Market Share+: 8.9% (~6.2K units)

6 Unit Prototype

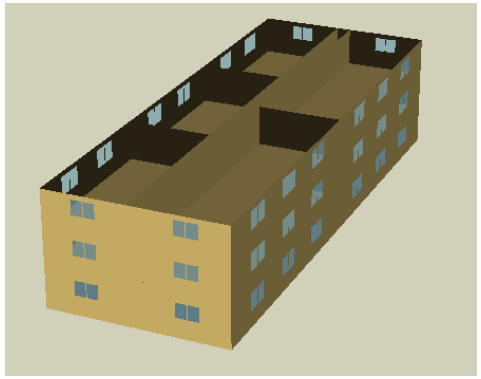
- Built pre-1980s
- 4,725 sf
- 3 stories
- Row home
- Furnace, no cooling*
- Individual gas HW heater



Category: 10-19 unit buildings
Market Share+: 22.5% (~16K units)

15 Unit Prototype

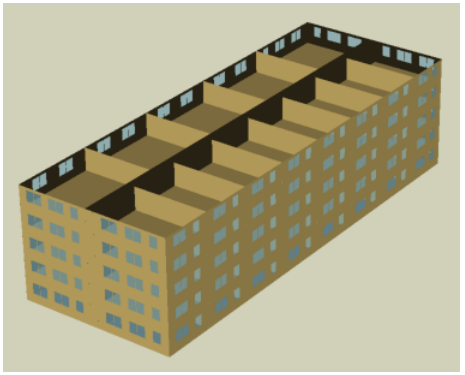
- Built pre-1980s
- 11,270 sf
- 3 stories
- Stand alone building
- Furnace, no cooling*
- Central gas HW heater



Category: 20+ unit building
Market Share+: 66.2% (~46K units)

65 Unit Prototype

- Built pre-1980s
- 40,900 sf
- 5 stories
- Stand alone building
- Central boiler, no cooling*
- Central gas HW heater

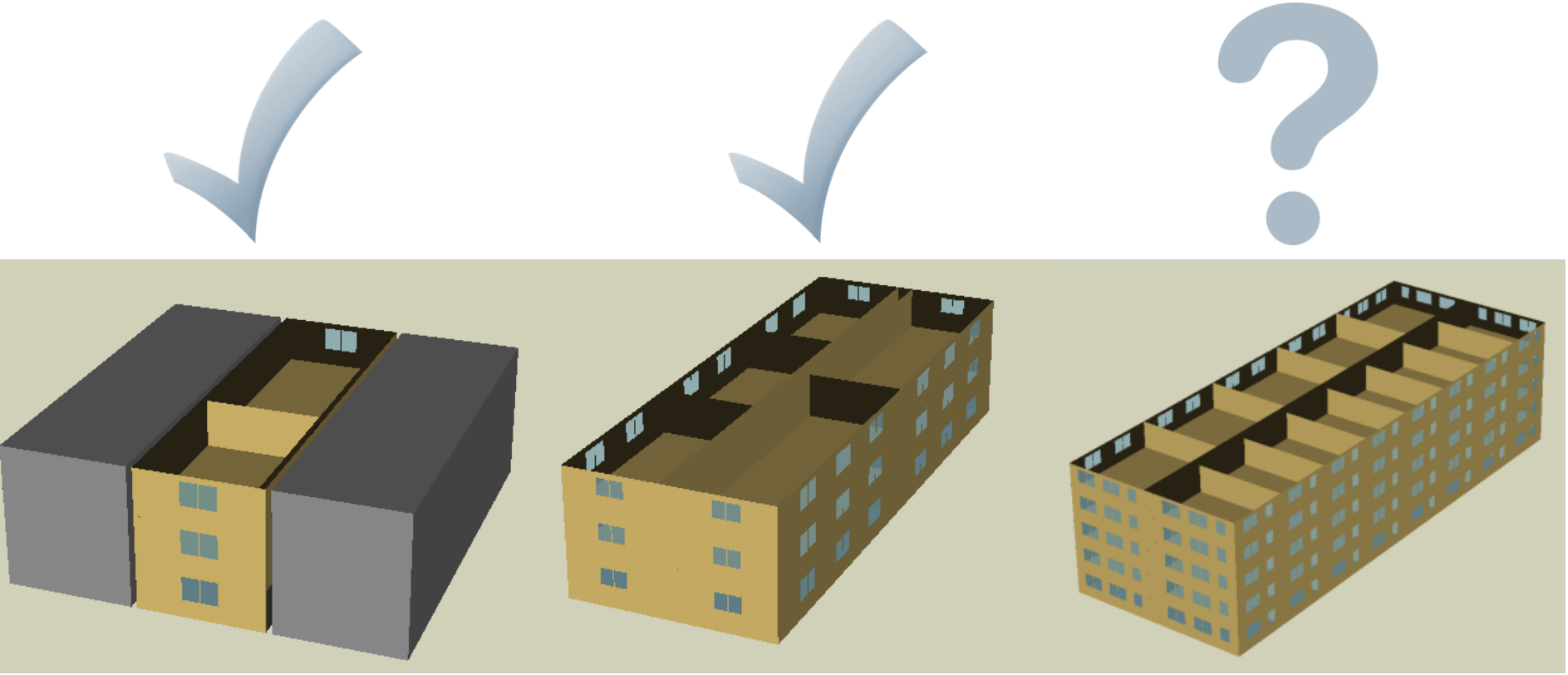


+ Greater San Francisco Bay Area has 69,857 affordable housing units
** 58% of San Francisco homes use natural gas, 36% electricity according to an ACEEE 2017 report*

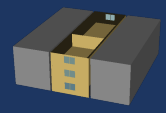
Retrofit Economics

Results Summary

For the 6 and 15 unit prototypes, there are many existing cost-effective paths to net zero via custom retrofits. Net zero is technically feasible for 65 units, but not cost effective.



6 Unit Prototype: Analysis Key Take-aways



Several retrofit paths to net zero are cost effective now. Further cost-reduction would be helpful to make the business case even more compelling.

NZE_c Mini-Split Retrofit

- Site EUI of 17.6 kBtu/sf
- No offsite renewables required
- No envelope upgrades required; great for buildings with complex envelope
- Provides optional cooling
- Market-ready technology
- All electric solution
- 25 YR NPV* with incentives: $61,200
- 8.7 year simple payback period

NZE_c Baseboard + Envelope Retrofit

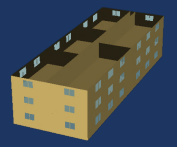
- Site EUI of 17.4 kBtu/sf
- No offsite renewables required
- Great for buildings that want to electrify
- Market-ready technology
- All electric solution
- 25 YR NPV* with incentives: $64,400
- 8.1 year simple payback period

NZE_c Envelope Retrofit

- Site EUI of 17.8 kBtu/sf
- No offsite renewables required
- No HVAC upgrade required; great for buildings with recently replaced HVAC or improving aesthetics
- Market-ready technology
- 25 YR NPV* with incentives: $62,900
- 8.2 year simple payback period

**Energy savings PV calculated using a 5% discount rate and an escalation rate of 2.35%, which is a blended average based on 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. Water and sewage savings calculated assuming 5% discount rate and 5% escalation rate.*

15 Unit Prototype: Analysis Key Take-aways



Several retrofit paths to net zero are cost effective now. Further cost-reduction would be helpful to make the business case even more compelling.

NZE_c Mini-Split Retrofit

- Site EUI of 19.5 kBtu/sf
- No offsite renewables required
- No envelope upgrades required; great for buildings with complex envelope
- Provides optional cooling
- Market-ready technology
- All electric solution
- 25 YR NPV* with incentives: $187,000
- 8.5 year simple payback period

NZE_c Baseboard + Envelope Retrofit

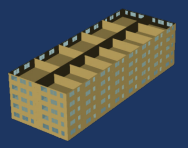
- Site EUI of 20.9 kBtu/sf
- No offsite renewables required
- Great for buildings that want to electrify
- Market-ready technology
- All electric solution
- 25 YR NPV* with incentives: $213,000
- 7.1 year simple payback period

NZE_c Envelope Retrofit

- Site EUI of 20.6 kBtu/sf
- No offsite renewables required
- No HVAC upgrade required; great for buildings with recently replaced HVAC or improving aesthetics
- Market-ready technology
- 25 YR NPV* with incentives: $189,000
- 8.1 year simple payback period

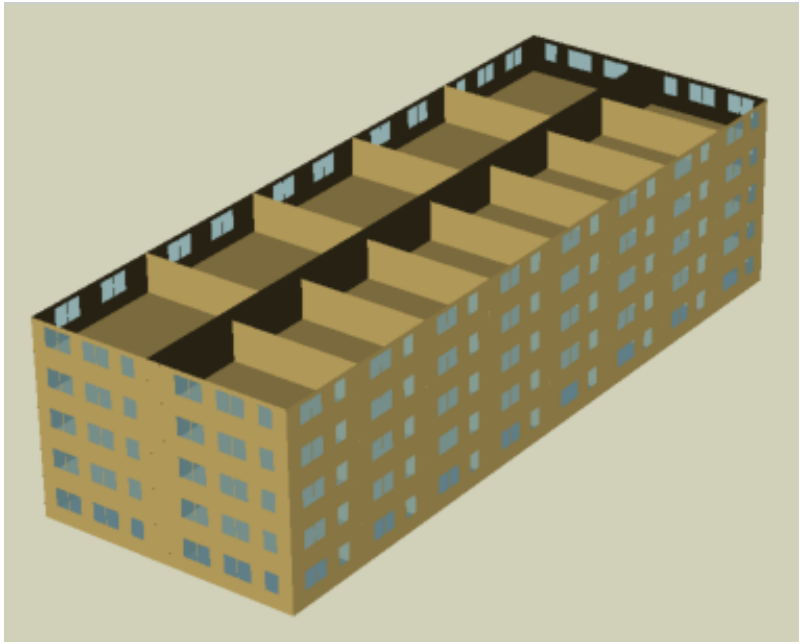
**Energy savings PV calculated using a 5% discount rate and an escalation rate of 2.28%, which is a blended average based on 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. Water and sewage savings calculated assuming 5% discount rate and 5% escalation rate.*

65 Unit Prototype: Analysis Key Take-aways



Net zero retrofits for this prototype require cost reductions in order to achieve payback during a typical investment cycle of 15 years, but are cost effective in a 25 year analysis.

- Site EUI is 16.8 kBtu/sf
- Can achieve NZE_c with efficient rooftop solar PV
- Measures less cost effective than solar PV required to reduce load
- All electric solution
- 25 YR NPV* with incentives: $295,000
- 14.9 year simple payback period



**Energy savings PV calculated using a 5% discount rate and an escalation rate of 2.48%, which is a blended average based on 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. Water and sewage savings calculated assuming 5% discount rate and 5% escalation rate.*

NZEc Retrofit Cost Benchmarks and Targets

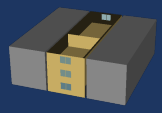
Benchmarks and targets were determined by averaging results from the selected net zero carbon retrofit packages for each prototype.

	6 Unit Prototype	15 Unit Prototype	65 Unit Prototype
Current Net Zero Carbon Retrofit Cost ($/Unit)	$19,013	$22,255	$22,296
Cost With Current Incentives ($/Unit)	$7,527	$8,985	$11,329
Price Point Using 25 Year Present Value* Utility Bill Savings ($/Unit)	$17,997	$22,053	$12,189
Cost Reduction Required to be Paid for Through 25YR Utility Bill Savings (Without Incentives/With Incentives)	5.34% / 0%	0.9% / 0%	45.3% / 0%
Price Point for 10 Year Simple Payback Period ($/Unit)	$9,045	$11,371	$5,867
Cost Reduction Required for 10 Year Simple Payback Period (Without Incentives/With Incentives)	52.4% / 0%	48.9% / 0%	73.7% / 48.2%

**Energy savings PV calculated using a 5% discount rate and an escalation rate of 2.35% for the 6 unit prototype, 2.28% for the 15 unit prototype, and 2.48% for the 65 unit prototype. Escalation rates are a blended average based on 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. Water and sewage savings calculated assuming 5% discount rate and 5% escalation rate.*

Technical Analysis Details

6 Unit Prototype: Retrofit Packages



NZE_c Mini-Split Retrofit

- No wall upgrades
- No roof upgrades
- No air sealing improvements, no mechanical ventilation added
- No window improvements
- Mini-split HP, 29.3 SEER, 14 HSPF
- Heat pump hot water heater, individual
- 100% LED lights
- Low flow water fixtures (1.8 gpm shower, 1.5 gpm sink)
- ENERGY STAR clothes washer
- 17.8 kW rooftop solar PV
- Electric cooking range

NZE_c Baseboard + Envelope Retrofit

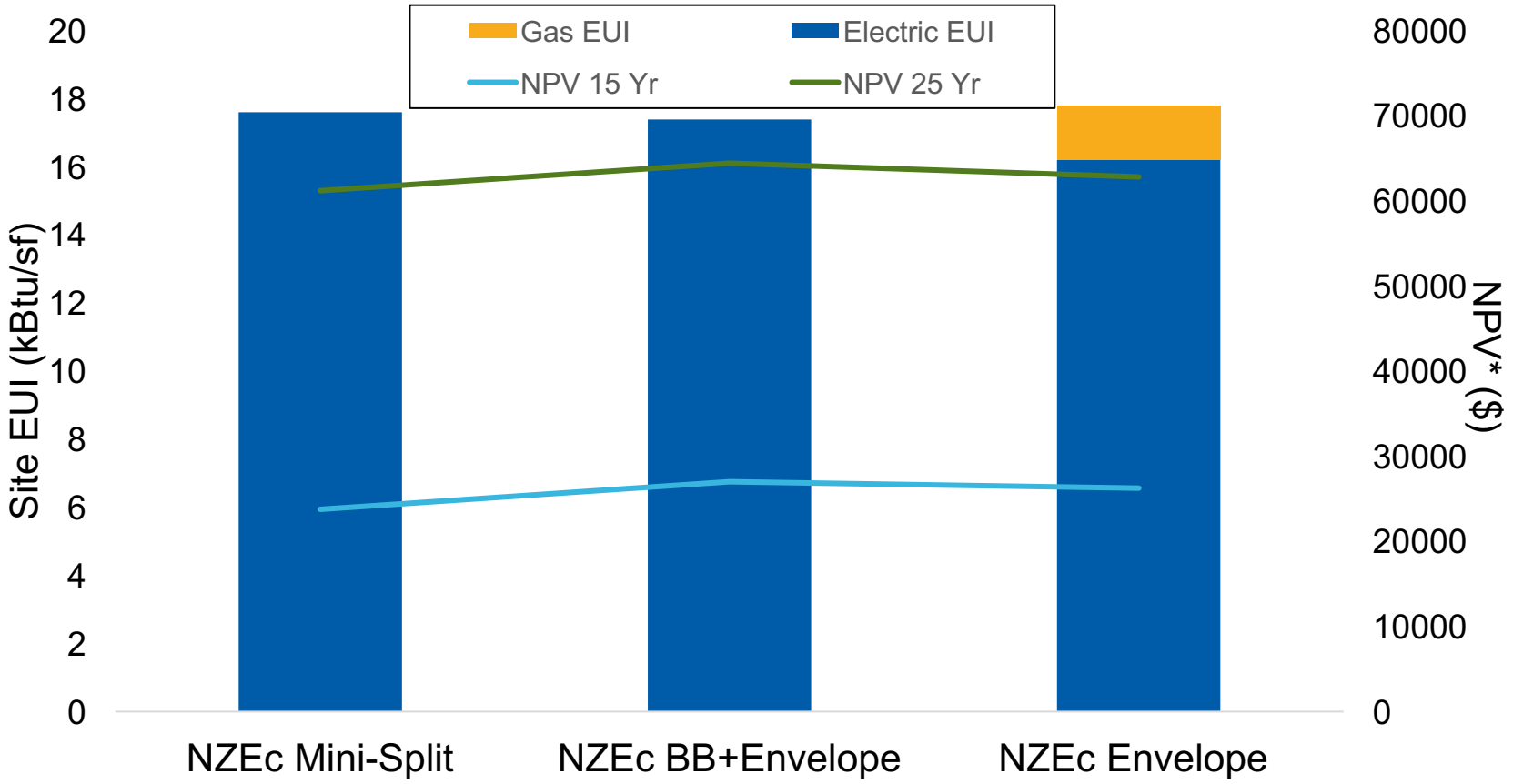
- R-15 wall insulation
- R-15 roof insulation
- 6 ACH50 air leakage, no mechanical vent
- Single pane windows
- Electric baseboards
- No cooling
- Heat pump hot water heater, individual
- 100% LED lights
- Low flow water fixtures (1.8 gpm shower, 1.5 gpm sink)
- ENERGY STAR clothes washer
- 17.5 kW rooftop solar PV
- Electric cooking range

NZE_c Envelope Retrofit

- R-15 wall insulation
- R-15 roof insulation
- 4 ACH50 air leakage, no mechanical vent
- Single pane windows
- Keep existing furnace, natural gas, 72% AFUE
- No cooling
- Heat pump hot water heater, individual
- 100% LED lights
- Low flow water fixtures (1.8 gpm shower, 1.5 gpm sink)
- ENERGY STAR clothes washer
- 18.2 kW rooftop solar PV
- Electric cooking range

6 Unit Prototype: Retrofit Package Comparison

All three packages are comparable. The baseboard + envelope package would be the most cost-effective maximizing financial benefits of solar under CA NEM, with lowest total cost. However, California Energy Code discourages electric resistance heating due to cost of grid electricity during peak periods (i.e. Time Dependent Valuation), so this solution may not be permitted.



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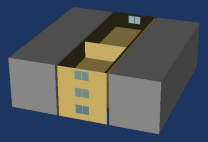
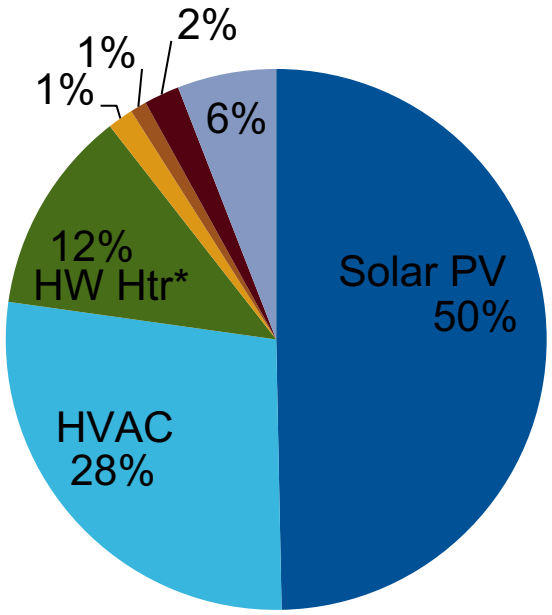
6 Unit Prototype: Cost Comparison

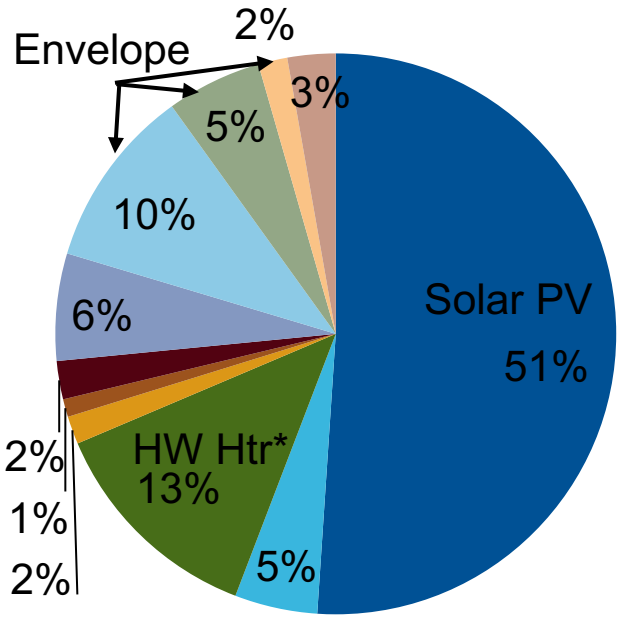


Solar, HVAC, envelope, and hot water heater are the biggest cost drivers, and, therefore, are likely the best targets for cost savings through industrialized solutions.

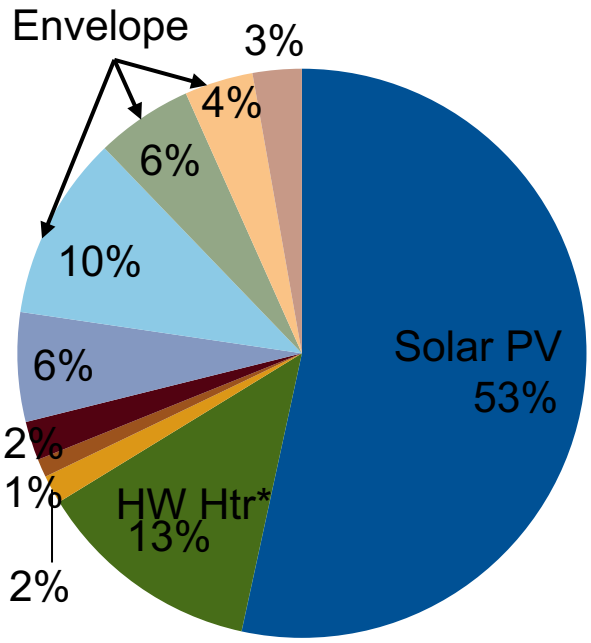
NZE_c Mini-Split Retrofit



NZE_c Baseboard + Envelope Retrofit



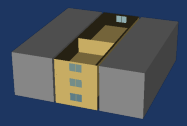
NZE_c Envelope Retrofit



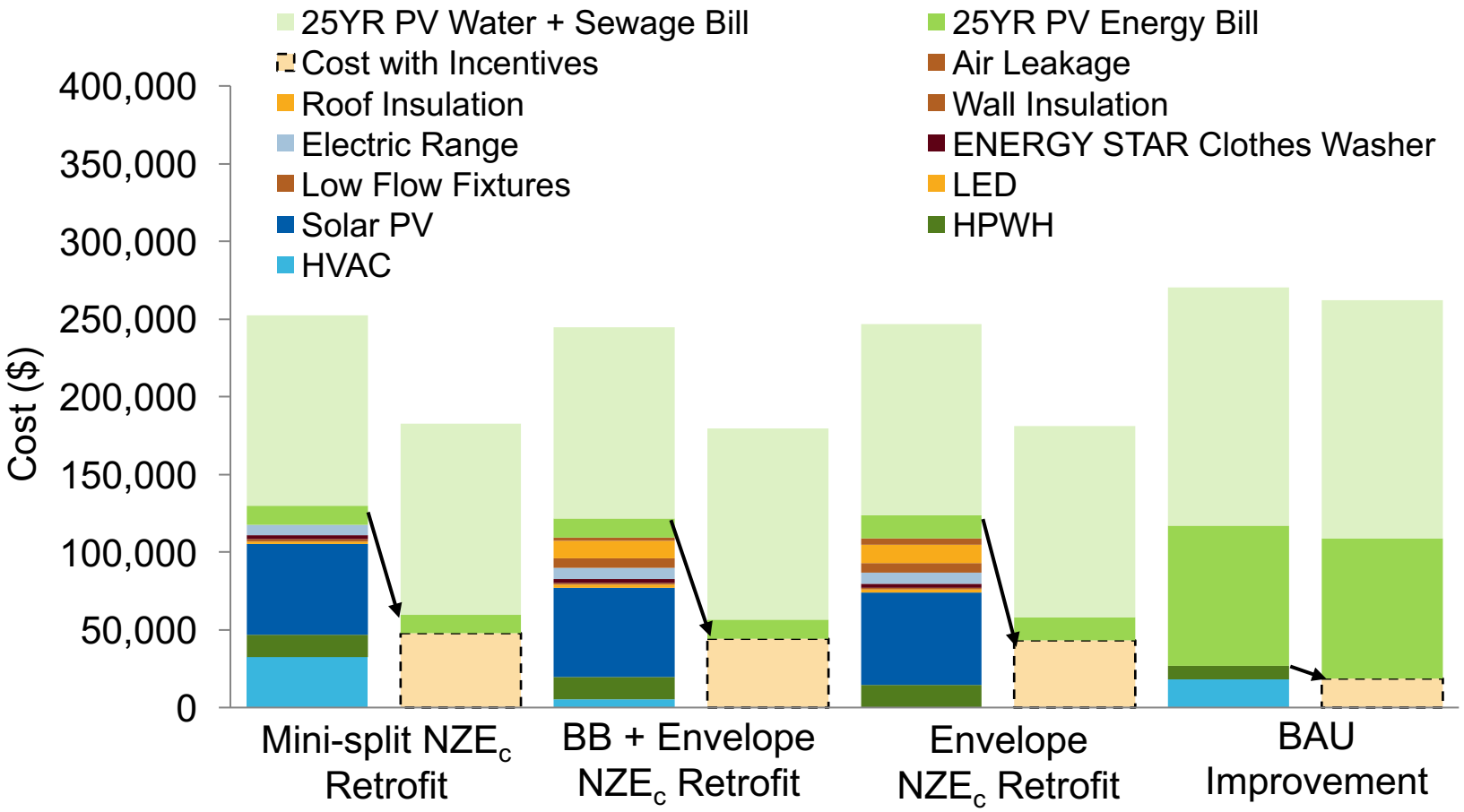
- PV Solar
- HPWH
- Low Flow Fixtures
- Electric Range
- Wall
- Smart Thermostat
- HVAC
- LED
- ENERGY STAR Clothes Washer
- Roof
- Air Leakage

*Htr - Heater

6 Unit Prototype: NZE_c Retrofit vs. BAU



With existing incentives, the NZE_c retrofits are more cost effective than business as usual.



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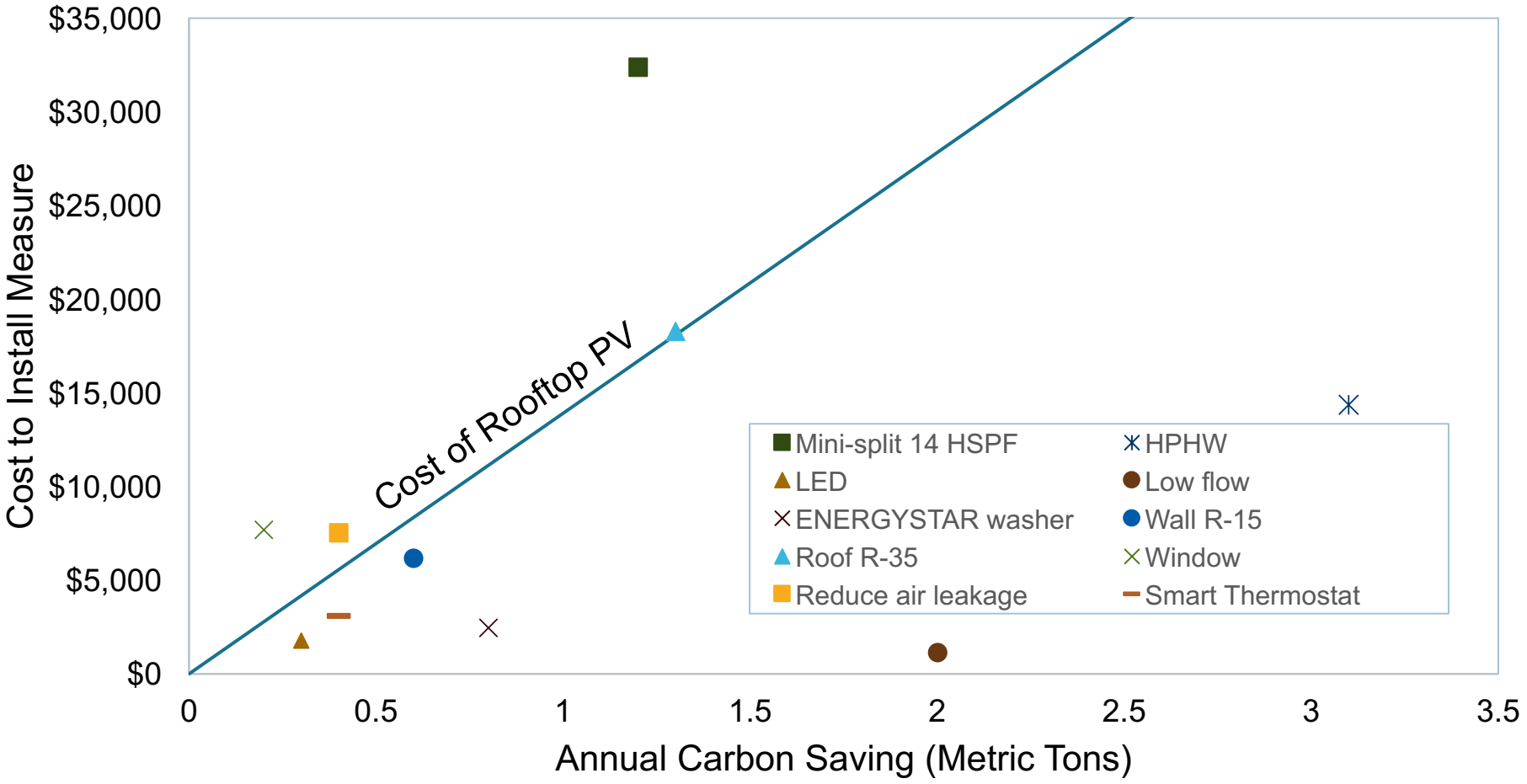
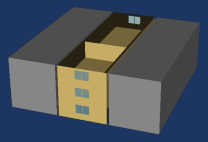
6 Unit Prototype: ECMs Savings And Cost

The most cost effective measures reduce DHW load and heating load. These independently modeled measures don't account for reduced carbon savings from interactive effects.

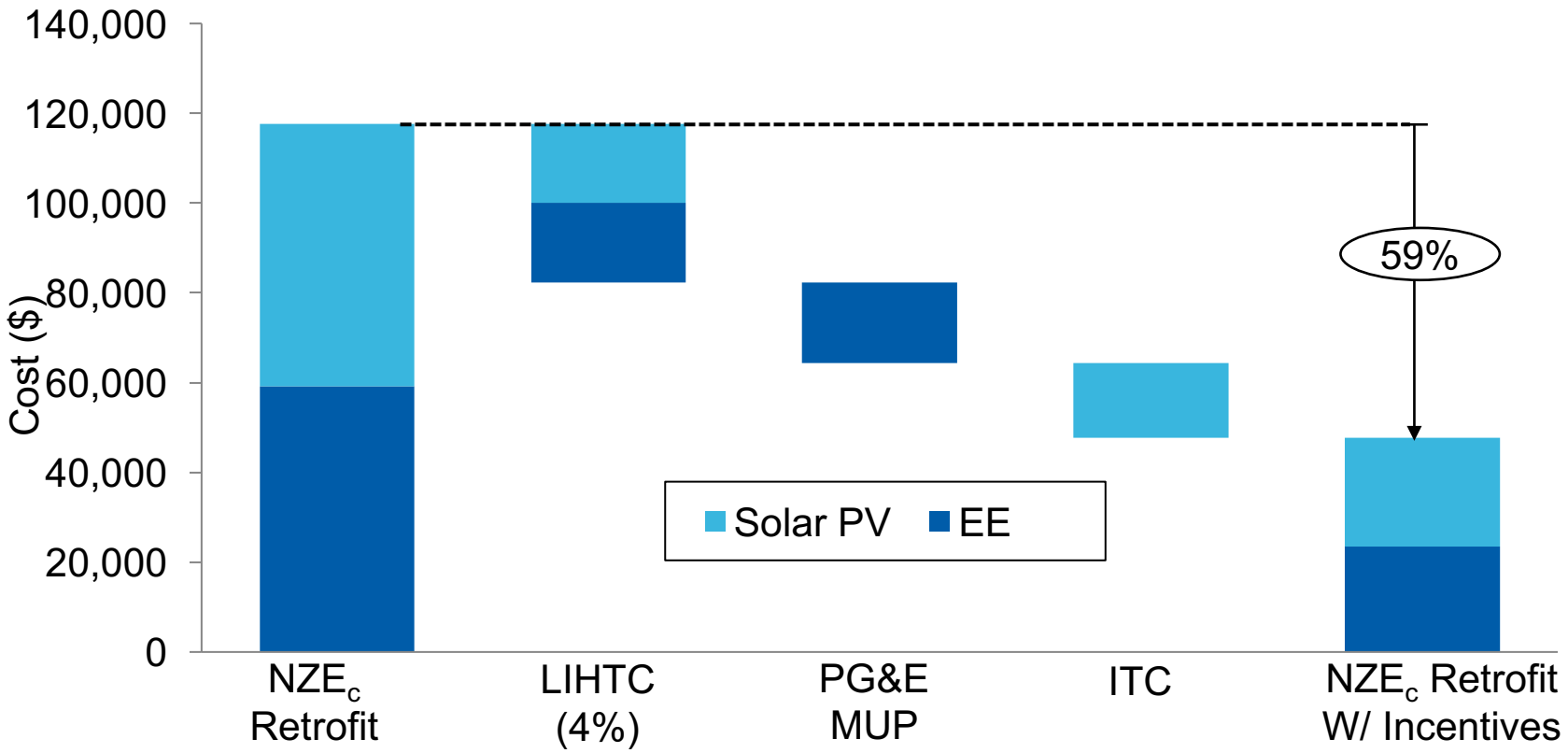


Note: All measures compared to baseline building with furnace. Does not take into account interactive effects of each measure.

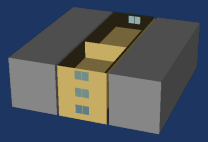
6 Unit Prototype: Incentives Available



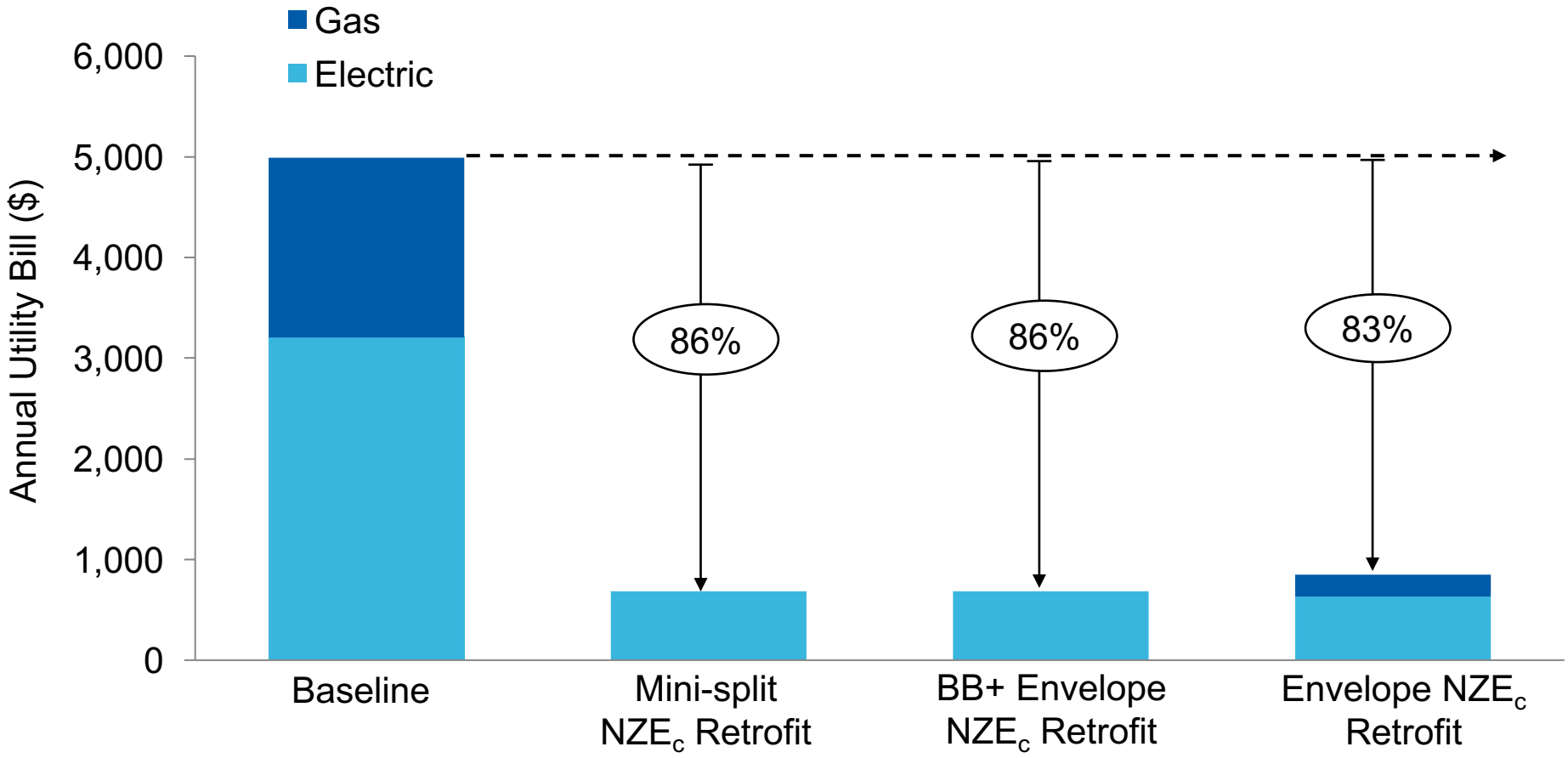
Currently, incentives cut cost of net zero retrofit by almost two thirds.



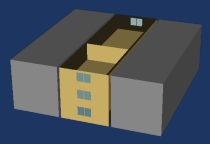
6 Unit Prototype: Utility Bill Savings



The net zero retrofits eliminate the annual energy utility bill, except for fixed costs.

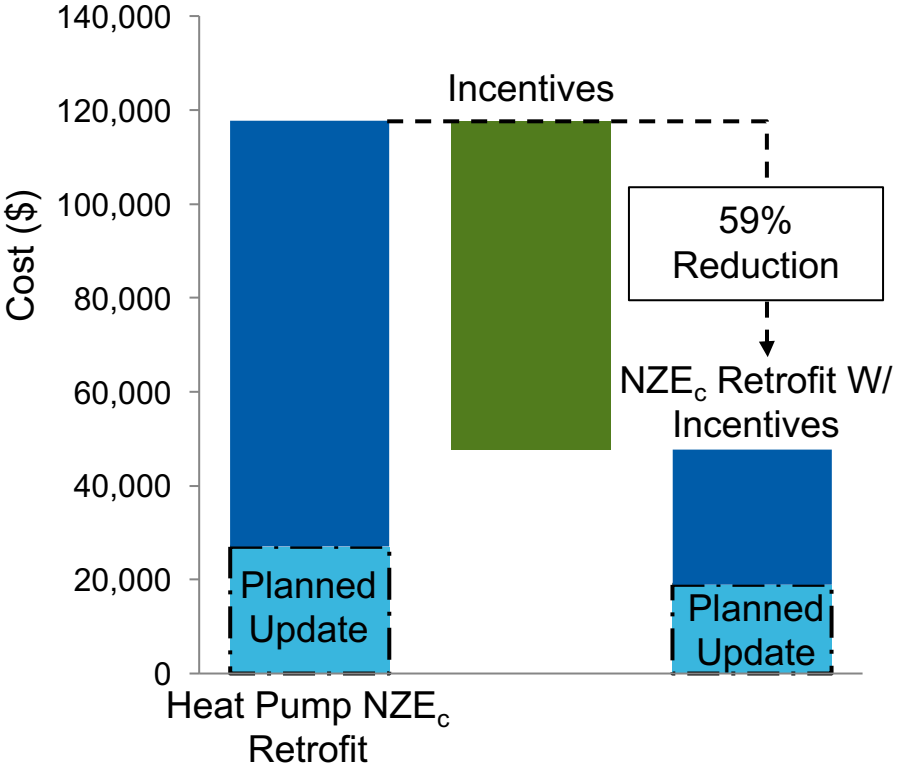


6 Unit Prototype: Summary Mini-split Package

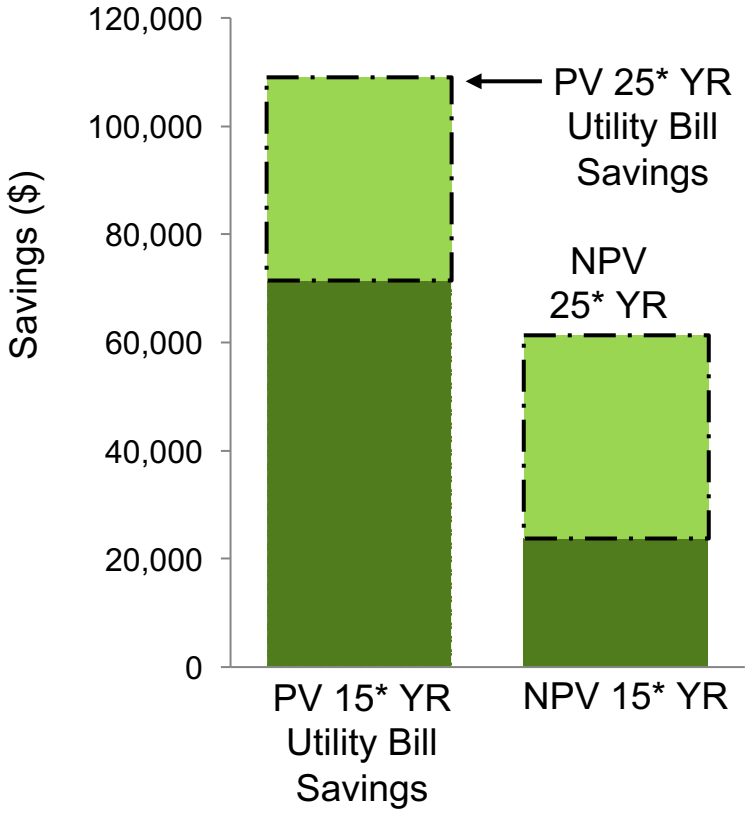


The NPV of the net zero retrofit will result in positive savings in the typical 15 year investment cycle.

COST



SAVINGS



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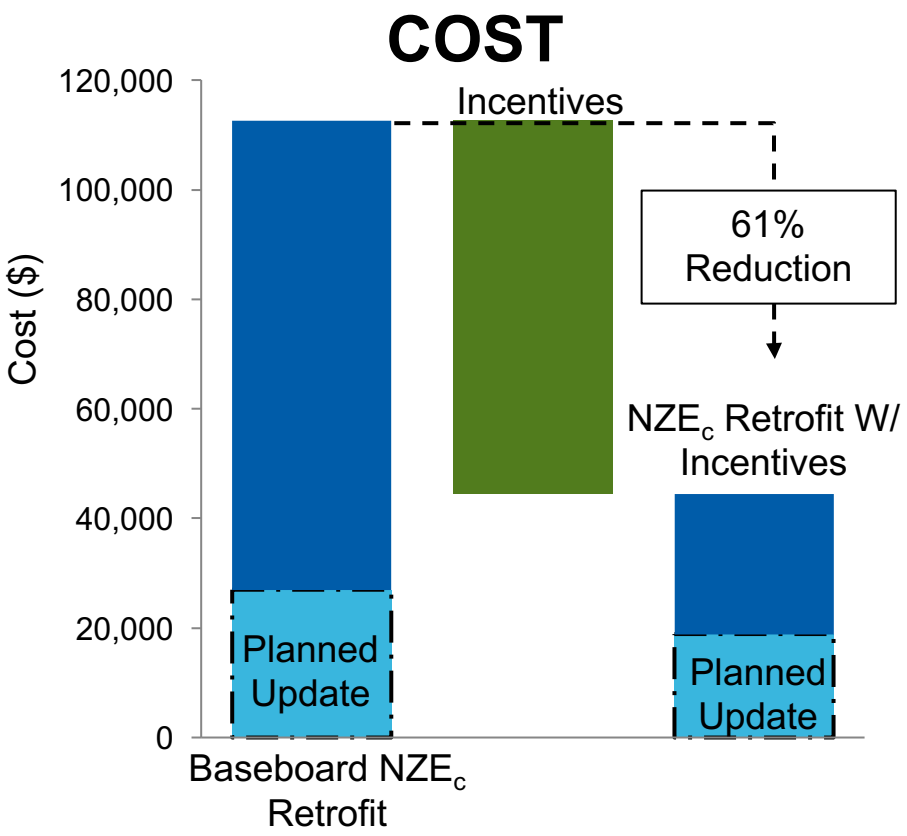
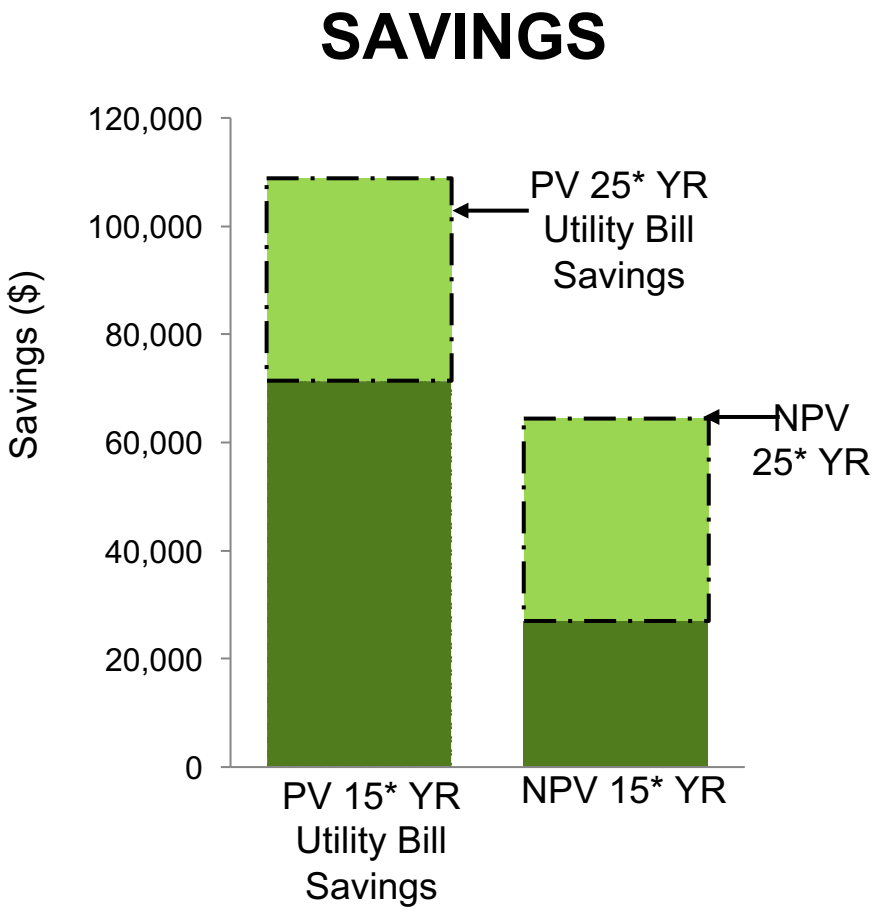
6 Unit Prototype: Summary Baseboard Package

The NPV of the net zero retrofit will result in positive savings in the typical 15 year investment cycle. As noted previously, this solution may not pass Title 24 Energy Code, which discourages electric resistance heating.





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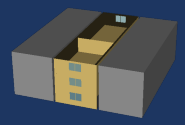
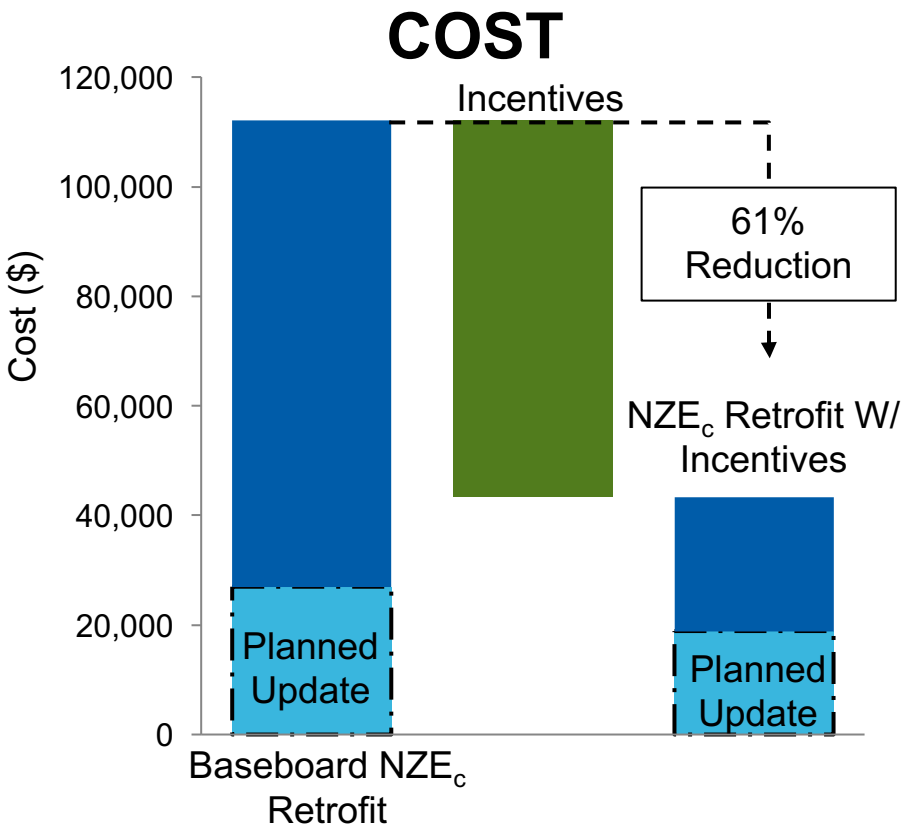
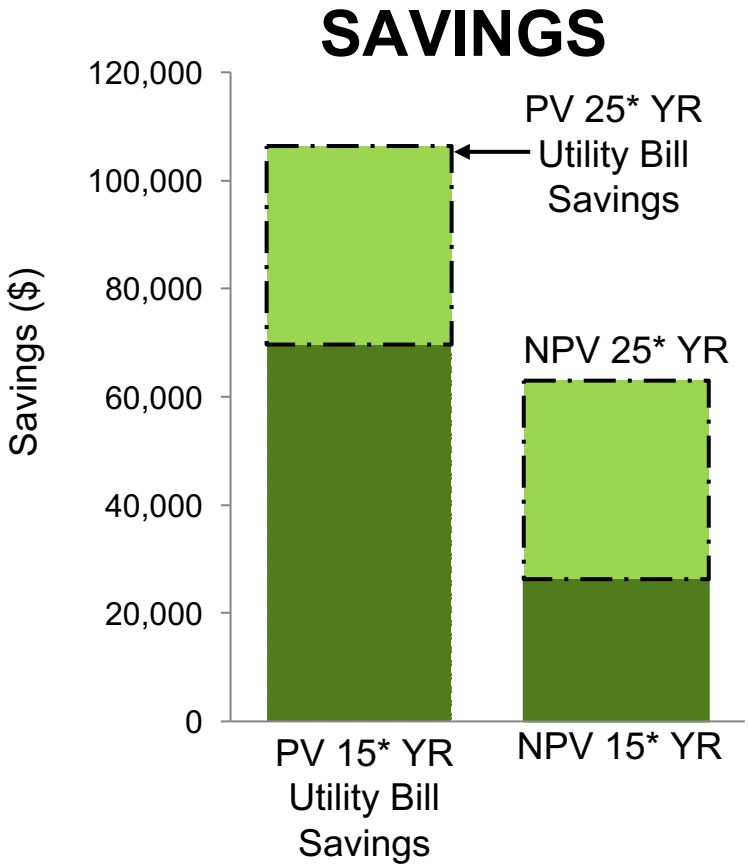
6 Unit Prototype: Summary Envelope Package



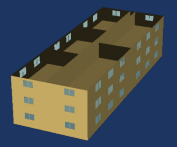
The NPV of the net zero retrofit will result in positive savings in the typical 15 year investment cycle.





**Energy savings PV calculated using a 5% discount rate and an escalation rate of 2.35%, which is a blended average based on 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. 15 years selected as typical investment cycle for affordable housing. Water and sewage savings calculated assuming 5% discount rate and 5% escalation rate.*

15 Unit Prototype: Retrofit Packages



NZE_c Mini-Split Retrofit

- R-12 Wall Insulation
- No roof upgrades
- No air sealing improvements, no mechanical ventilation added
- No window improvements
- Mini-split HP, 29.3 SEER, 14 HSPF
- Smart thermostat
- Heat pump hot water heater, central
- 100% LED lights
- Low flow water fixtures (1.8 gpm shower, 1.5 gpm sink)
- ENERGY STAR clothes washer
- Electric cooking range
- 51.9 kW rooftop solar PV

NZE_c Baseboard + Envelope Retrofit

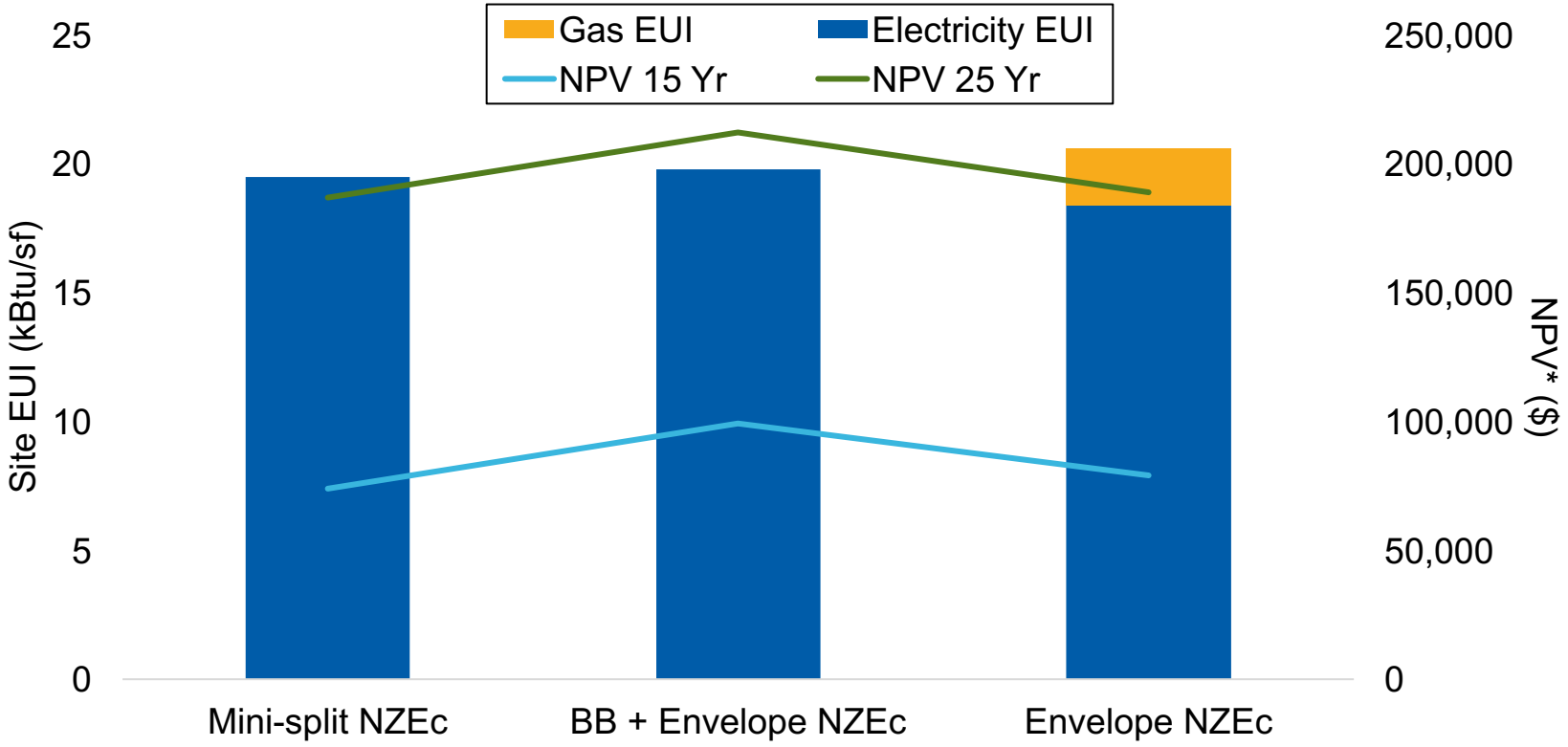
- R-12 wall insulation
- R-15 roof insulation
- No air sealing improvements, no mechanical ventilation added
- No window improvements
- Electric baseboards
- No cooling
- Heat pump hot water heater, individual
- 100% LED lights
- Low flow water fixtures (1.8 gpm shower, 1.5 gpm sink)
- ENERGY STAR clothes washer
- Electric cooking range
- 55.6 kW rooftop solar PV

NZE_c Envelope Retrofit

- R-15 wall insulation
- R-15 roof insulation
- 5 ACH50 air leakage, no mechanical vent
- No window improvements
- Keep existing furnace, natural gas, 72% AFUE
- No cooling
- Heat pump hot water heater, individual
- 100% LED lights
- Low flow water fixtures (1.8 gpm shower, 1.5 gpm sink)
- ENERGY STAR clothes washer
- Electric cooking range
- 55.6 kW rooftop solar PV

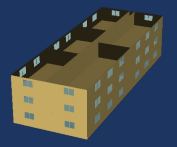
15 Unit Prototype: Retrofit Package Comparison

All three packages are comparable. The baseboard + envelope package would be the most cost-effective – maximizing financial benefits of solar under CA Net Energy Metering, with lowest total cost. However, California Energy Code discourages electric resistance heating due to cost of grid electricity during peak periods (i.e. Time Dependent Valuation), so this solution may not be permitted.



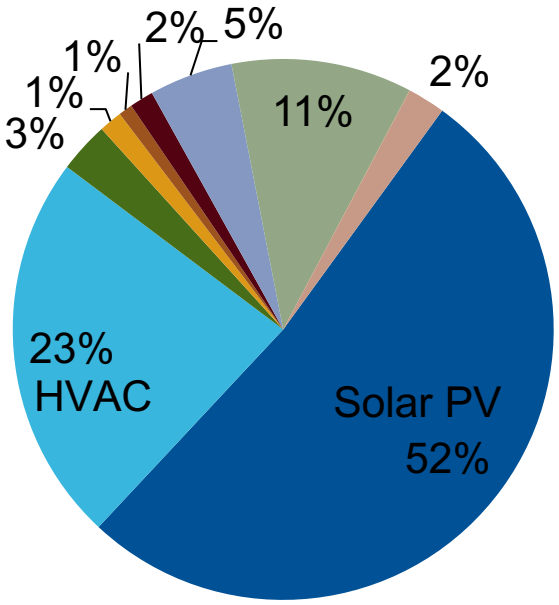
**Energy savings PV calculated using a 5% discount rate and an escalation rate of 2.28%, which is a blended average based on 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. 15 years selected as typical investment cycle for affordable housing. Water and sewage savings calculated assuming 5% discount rate and 5% escalation rate.*

15 Unit Prototype: Cost Breakdown

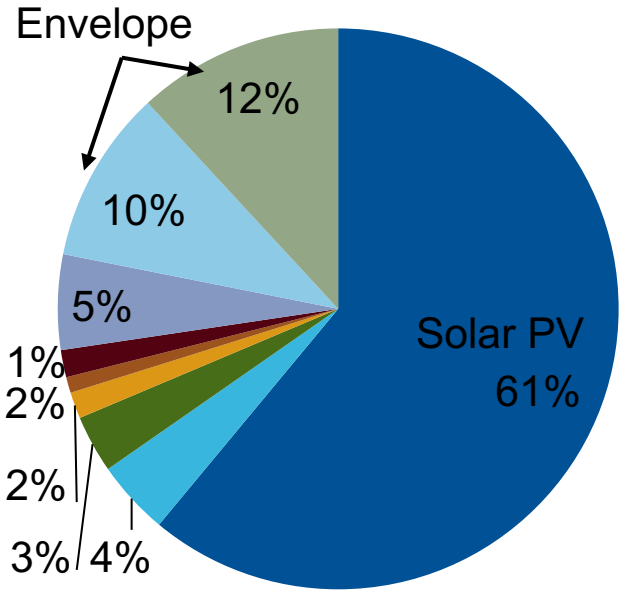


Solar, HVAC, and envelope are the biggest cost drivers, and, therefore, are likely the best targets for cost savings through industrialized solutions.

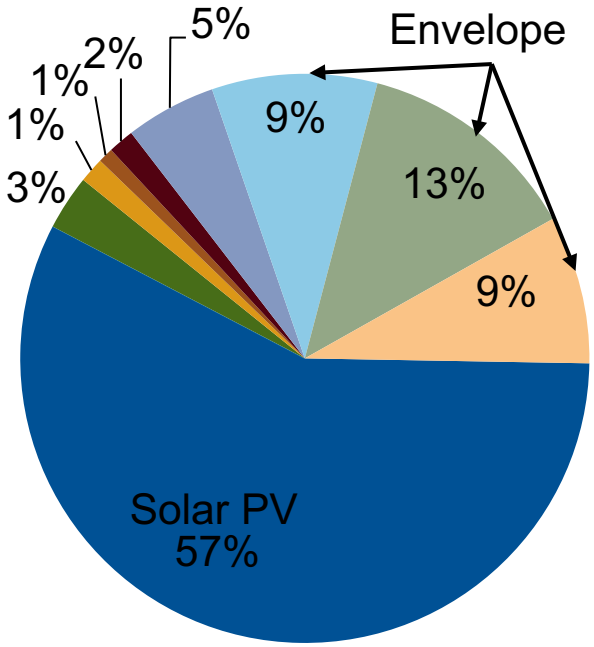
NZE_c Mini-Split Retrofit



NZE_c Baseboard + Envelope Retrofit



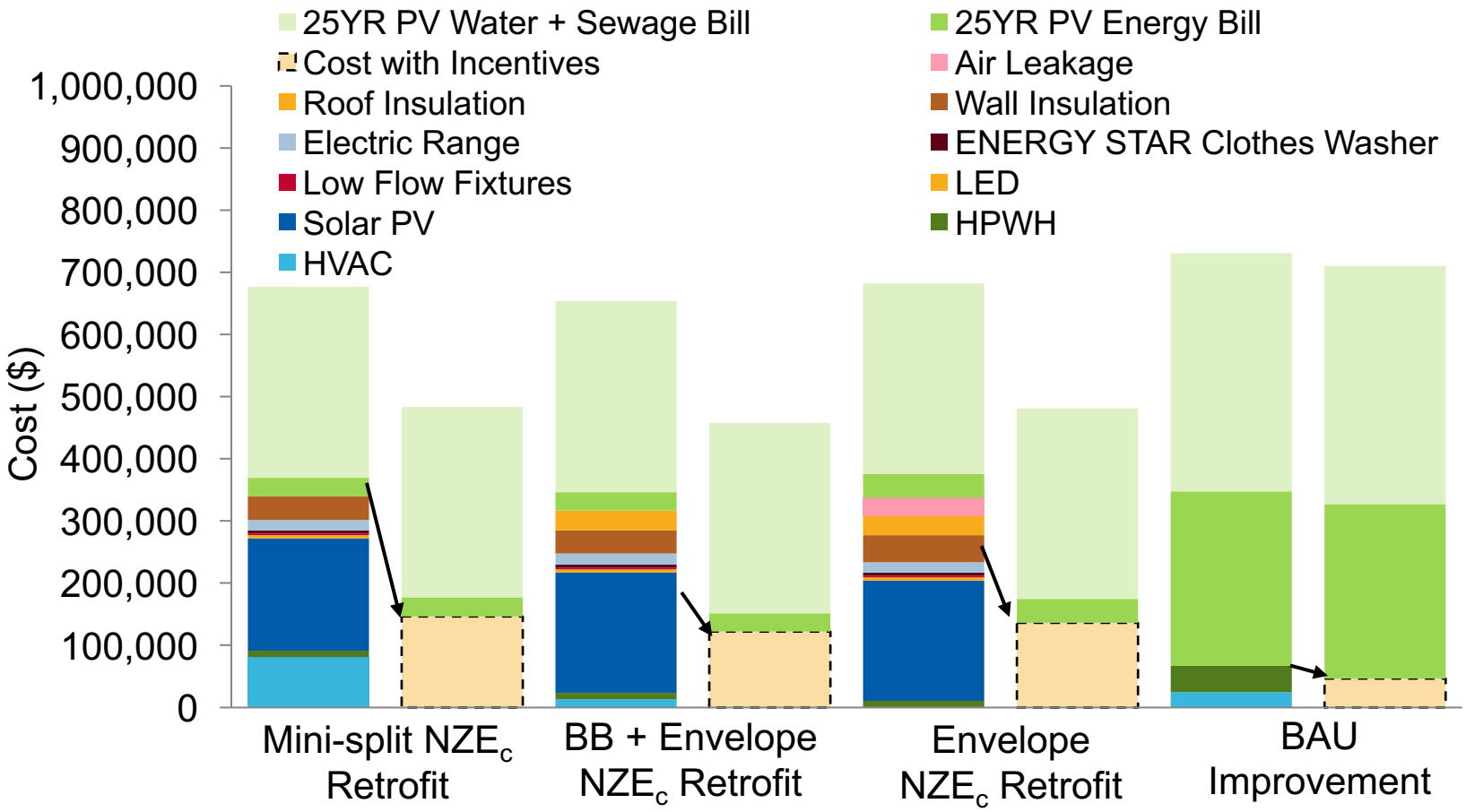
NZE_c Envelope Retrofit



- PV Solar
- HPWH
- Low Flow Fixtures
- Electric Range
- Wall
- Smart Thermostat
- HVAC
- LED
- ENERGY STAR Clothes Washer
- Roof
- Air Leakage

15 Unit Prototype: NZE_c Retrofit vs. BAU

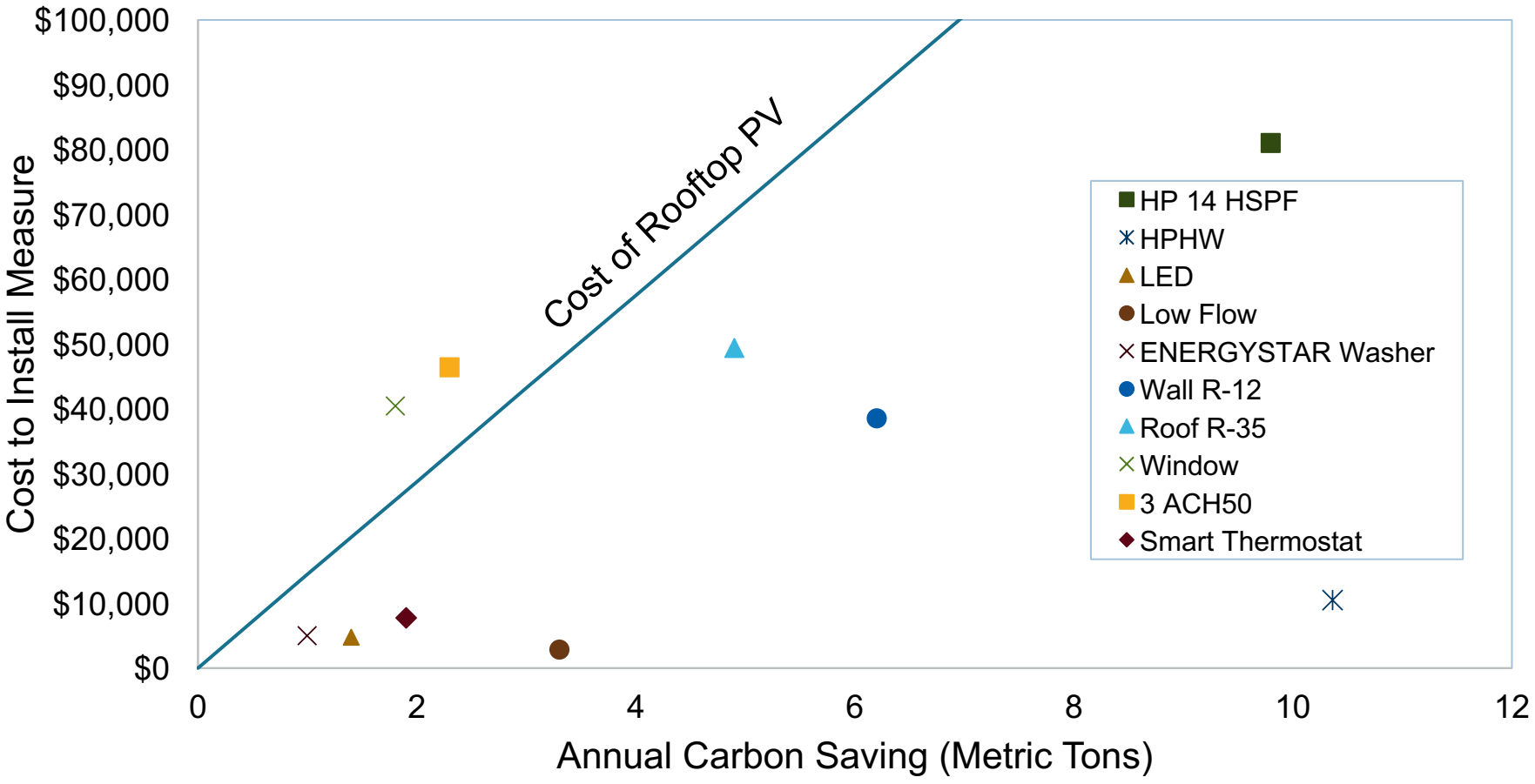
With current incentives, the NZE_c retrofits are more cost effective than business as usual.



**Energy savings PV calculated using a 5% discount rate and an escalation rate of 2.28%, which is a blended average based on 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. Water and sewage savings calculated assuming 5% discount rate and 5% escalation rate.*

15 Unit Prototype: EE With Furnace Baseline

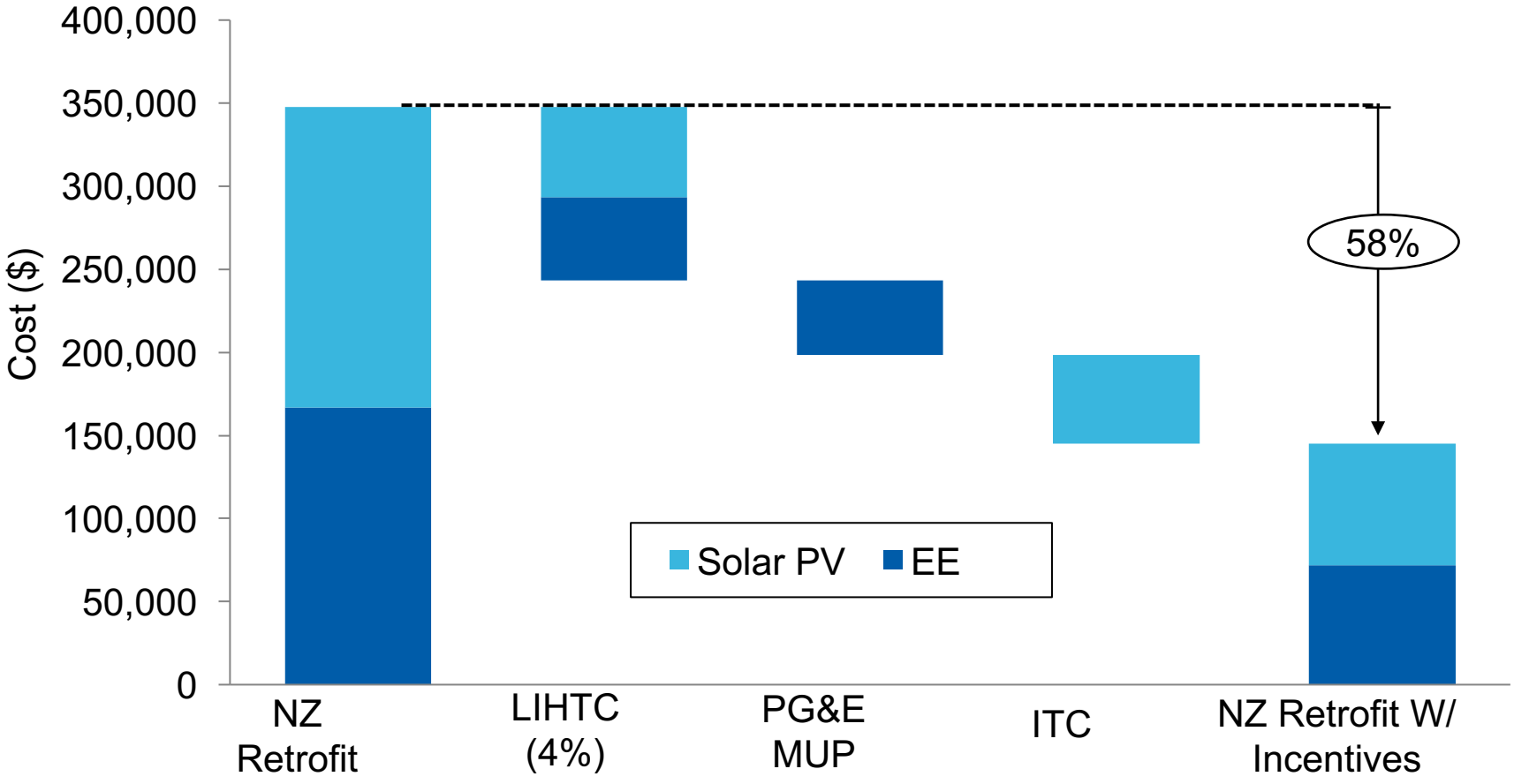
The most cost effective measures reduce DHW load and heating load. These independently modeled measures don't account for reduced carbon savings from interactive effects.



Note: All measures compared to baseline building with furnace. Does not take into account interactive effects of each measure.

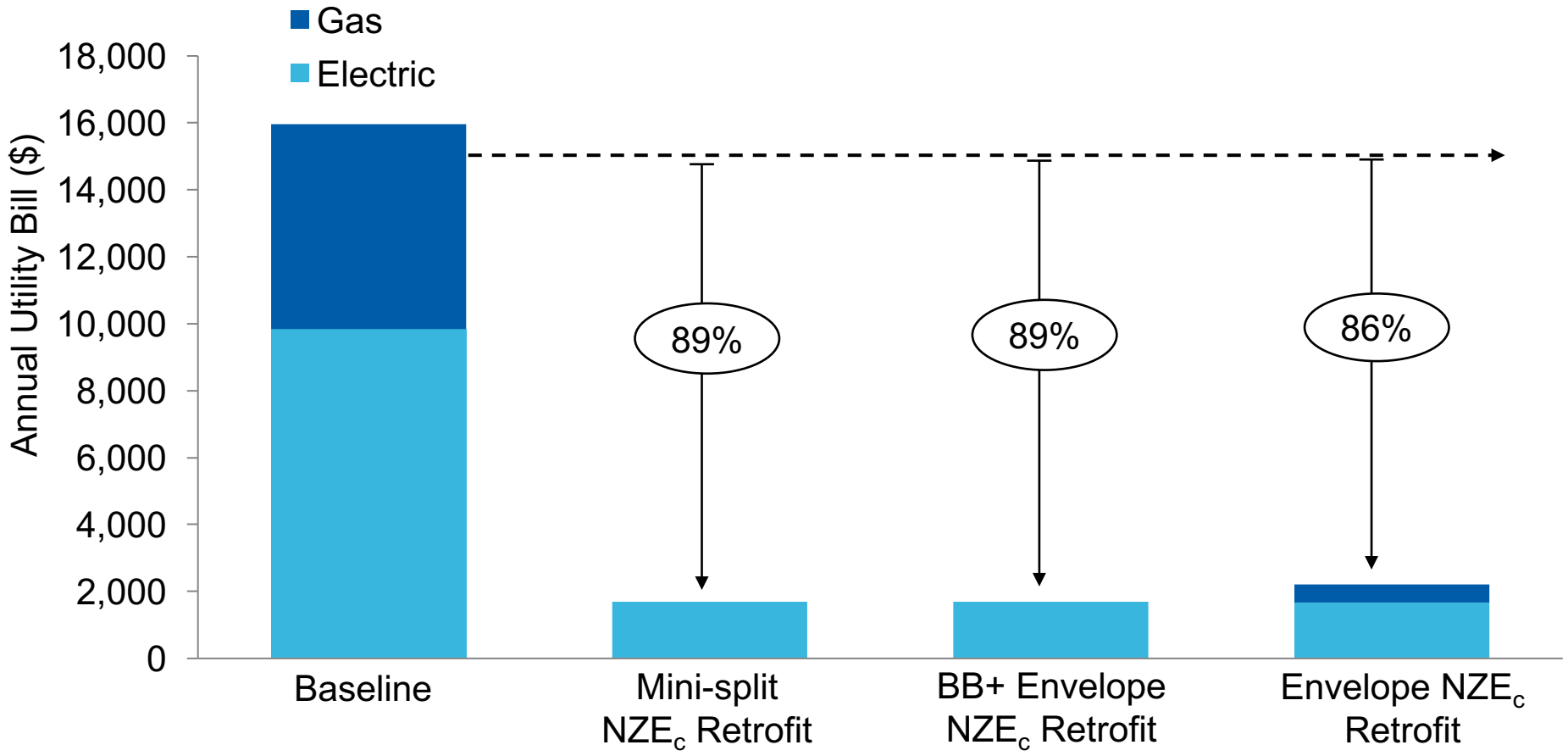
15 Unit Prototype: Incentives Available

Current incentives drastically reduce the cost of net zero retrofits.

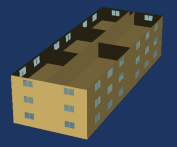


15 Unit Prototype: Utility Bill Savings

The net zero retrofits eliminate the annual energy utility bill except for fixed costs.

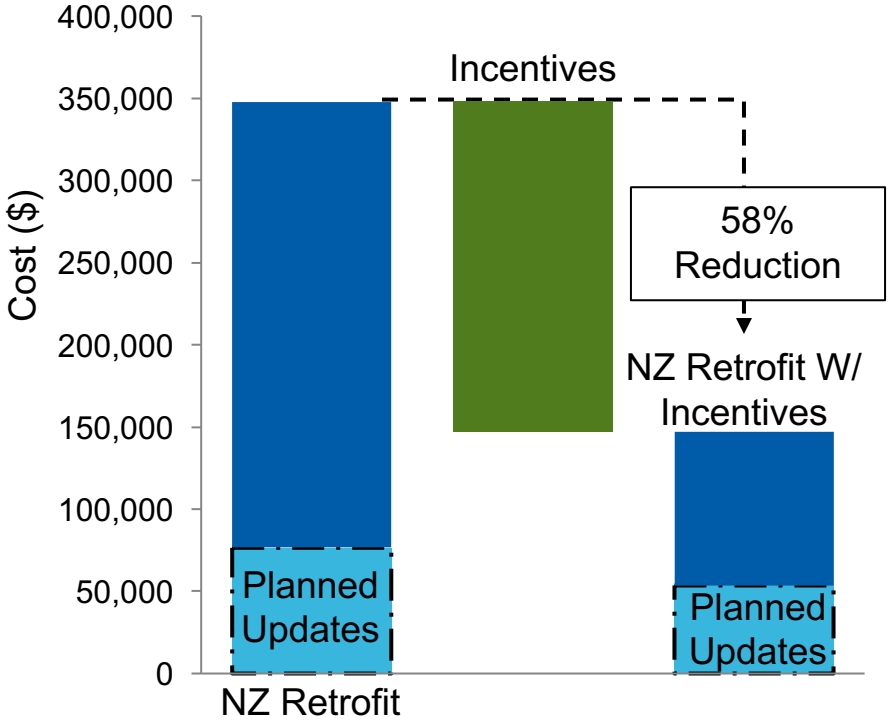


15 Unit Prototype: Summary Mini-split Package

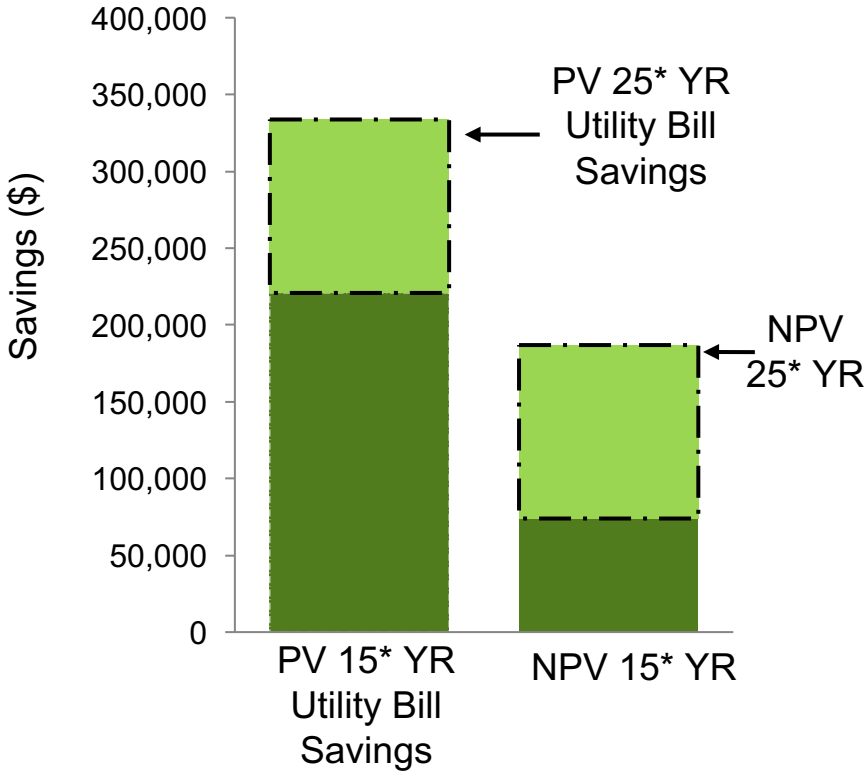


The NPV of the net zero retrofit will result in positive savings in the typical 15 year investment cycle.

COST



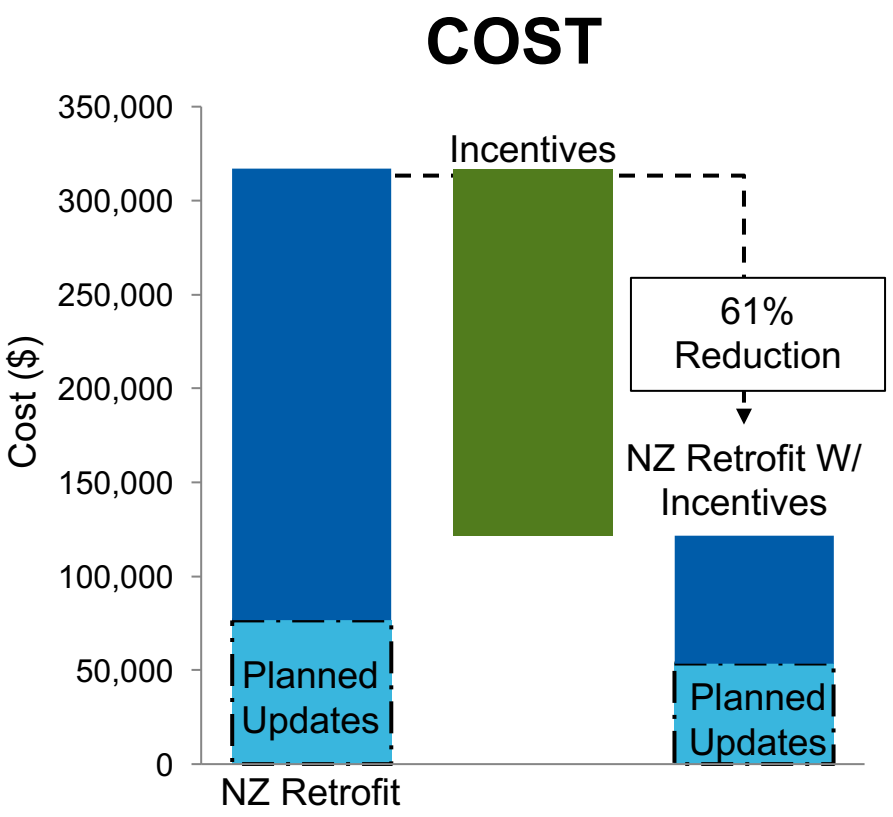
SAVINGS

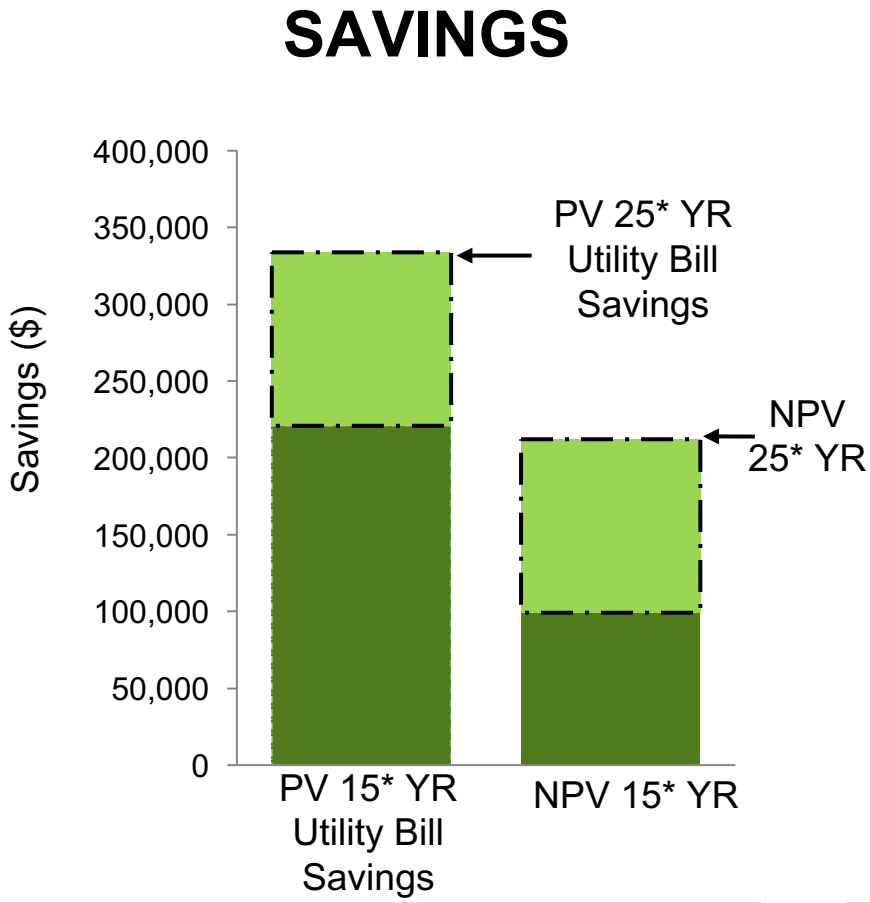


**Energy savings PV calculated using a 5% discount rate and an escalation rate of 2.28%, which is a blended average based on 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. 15 years selected as typical investment cycle for affordable housing. Water and sewage savings calculated assuming 5% discount rate and 5% escalation rate.*

15 Unit Prototype: Summary Baseboard Package

The NPV of the net zero retrofit will result in positive savings in the typical 15 year investment cycle. As noted previously, this solution may not pass Title 24 Energy Code, which discourages electric resistance heating.



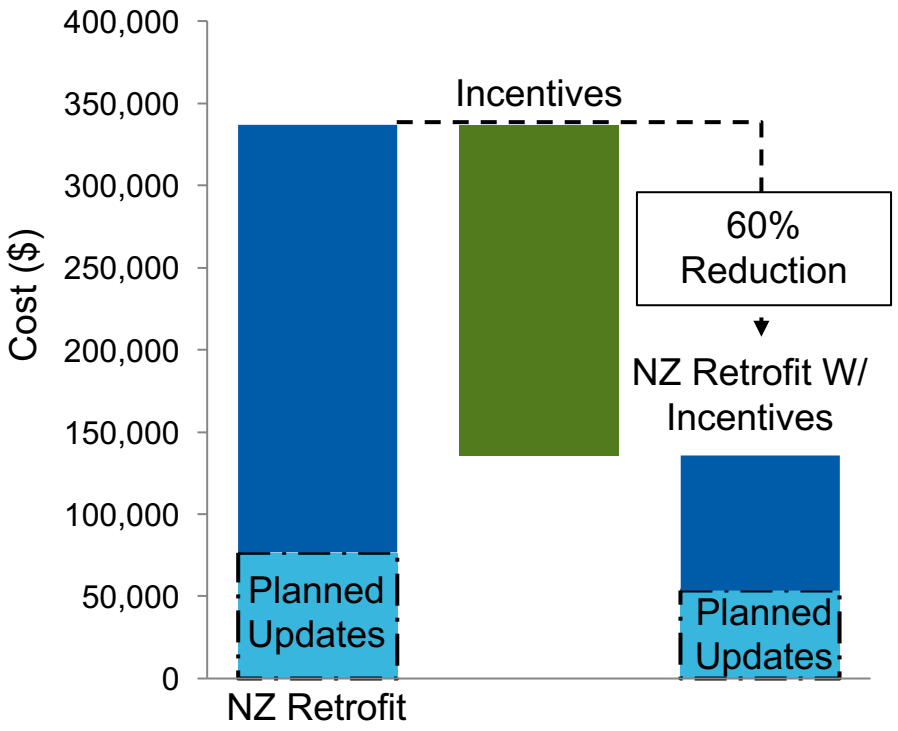


**Energy savings PV calculated using a 5% discount rate and an escalation rate of 2.28%, which is a blended average based on 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. 15 years selected as typical investment cycle for affordable housing. Water and sewage savings calculated assuming 5% discount rate and 5% escalation rate.*

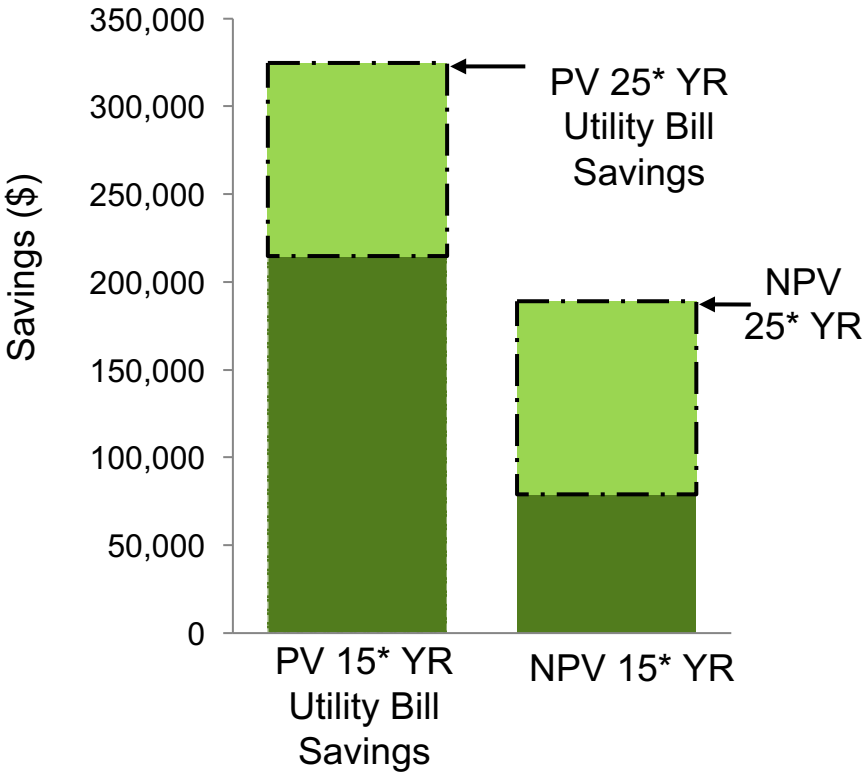
15 Unit Prototype: Summary Envelope Package

The NPV of the net zero retrofit will result in positive savings in the typical 15 year investment cycle.

COST



SAVINGS



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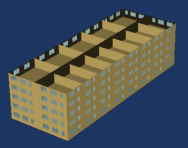
65 Unit Prototype: Retrofit Package



Baseline Building

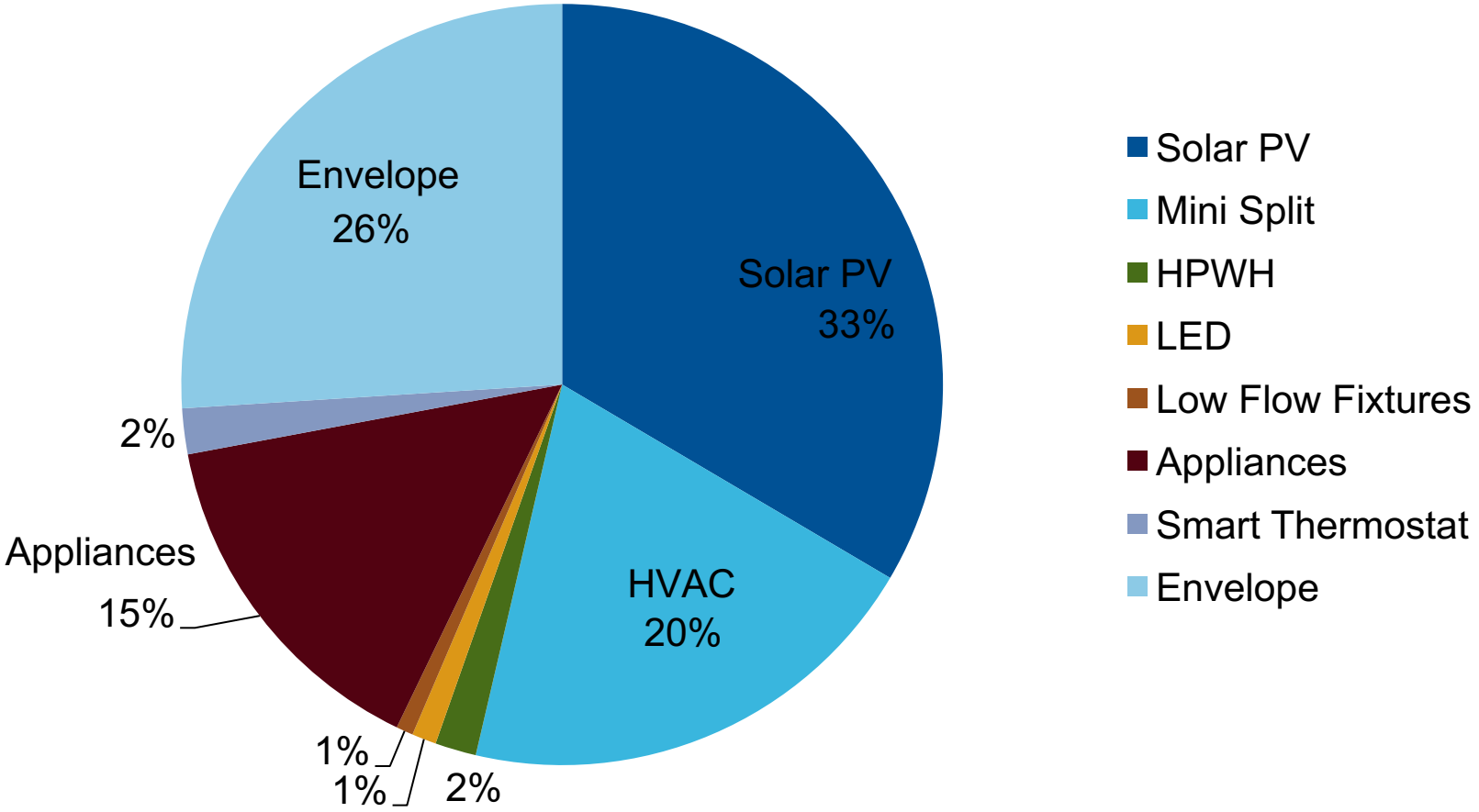
- Masonry walls, uninsulated
- 2x6 wood framed roof
- 7 ACH50 air leakage, no mechanical vent
- Single pane windows
- Central hot water boiler serving radiators
- No cooling
- Non-programmable thermostat
- Hot water heater, natural gas, central
- 67% incandescent, 33% CFL lights
- Standard water fixtures (2.5 gpm shower, 2.2 gpm sink)
- Conventional appliances
- Gas cooking range

Proposed Net-Zero Retrofit

- R-15 continuous exterior insulation
- R-35 roof
- 4 ACH50 air leakage, no mechanical vent
- Low-E, double pane windows
- Minisplit HP, 29.3 SEER, 14 HSPF
- Smart thermostat
- Heat pump hot water heater, central
- 100% LED lights
- Low flow water fixtures
- ENERGY STAR clothes washer
- ENERGY STAR refrigerator
- Heat pump dryer
- Electric induction cooking range
- 167 kW rooftop solar PV or 208,000 kWh from community choice aggregator

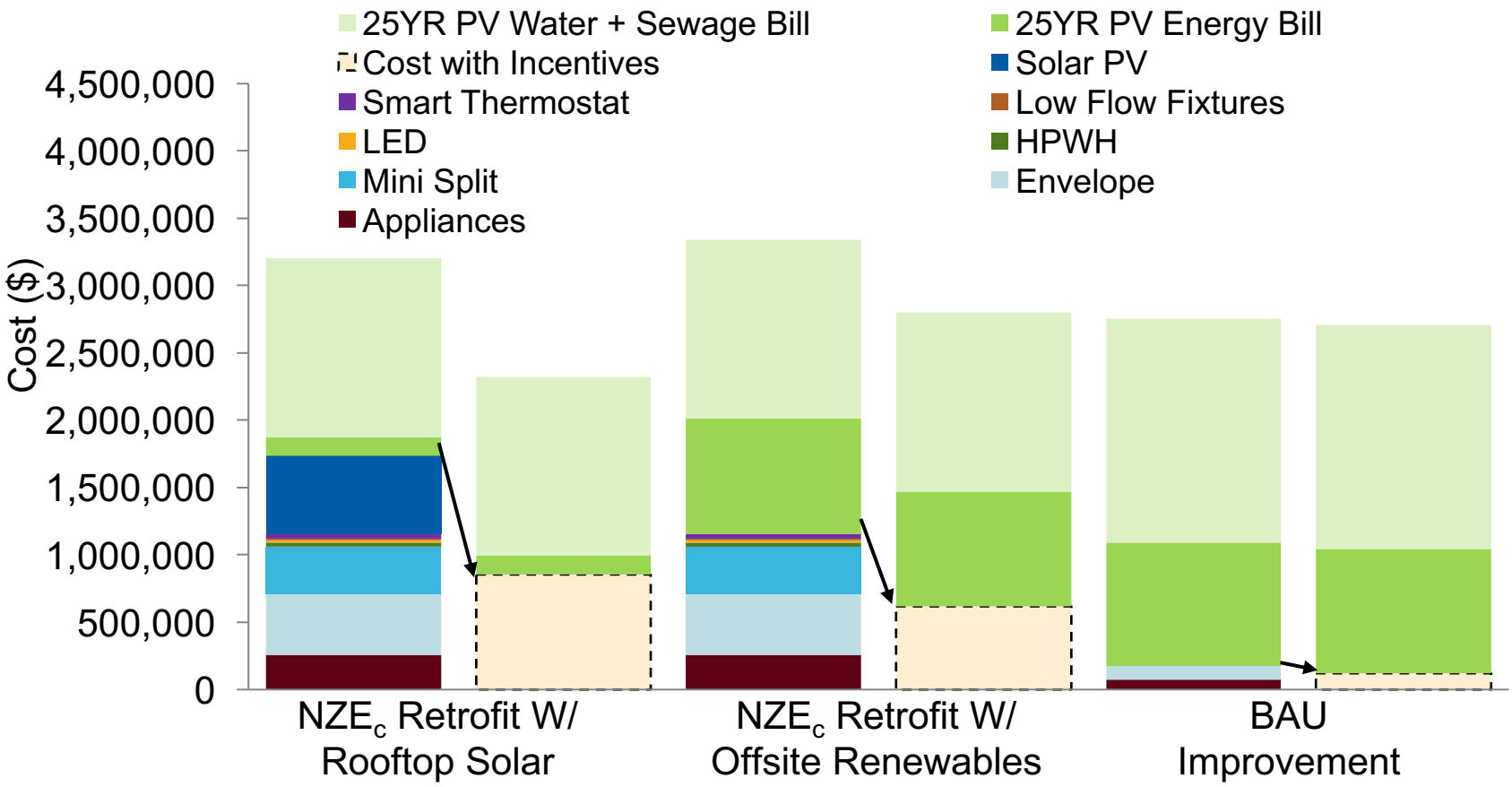
65 Unit Prototype: Cost Breakdown

Solar, HVAC, envelope, and appliances are the biggest cost drivers, and, therefore, are likely the best targets for cost savings through industrialized solutions.



65 Unit Prototype: NZE_c Retrofit vs. BAU

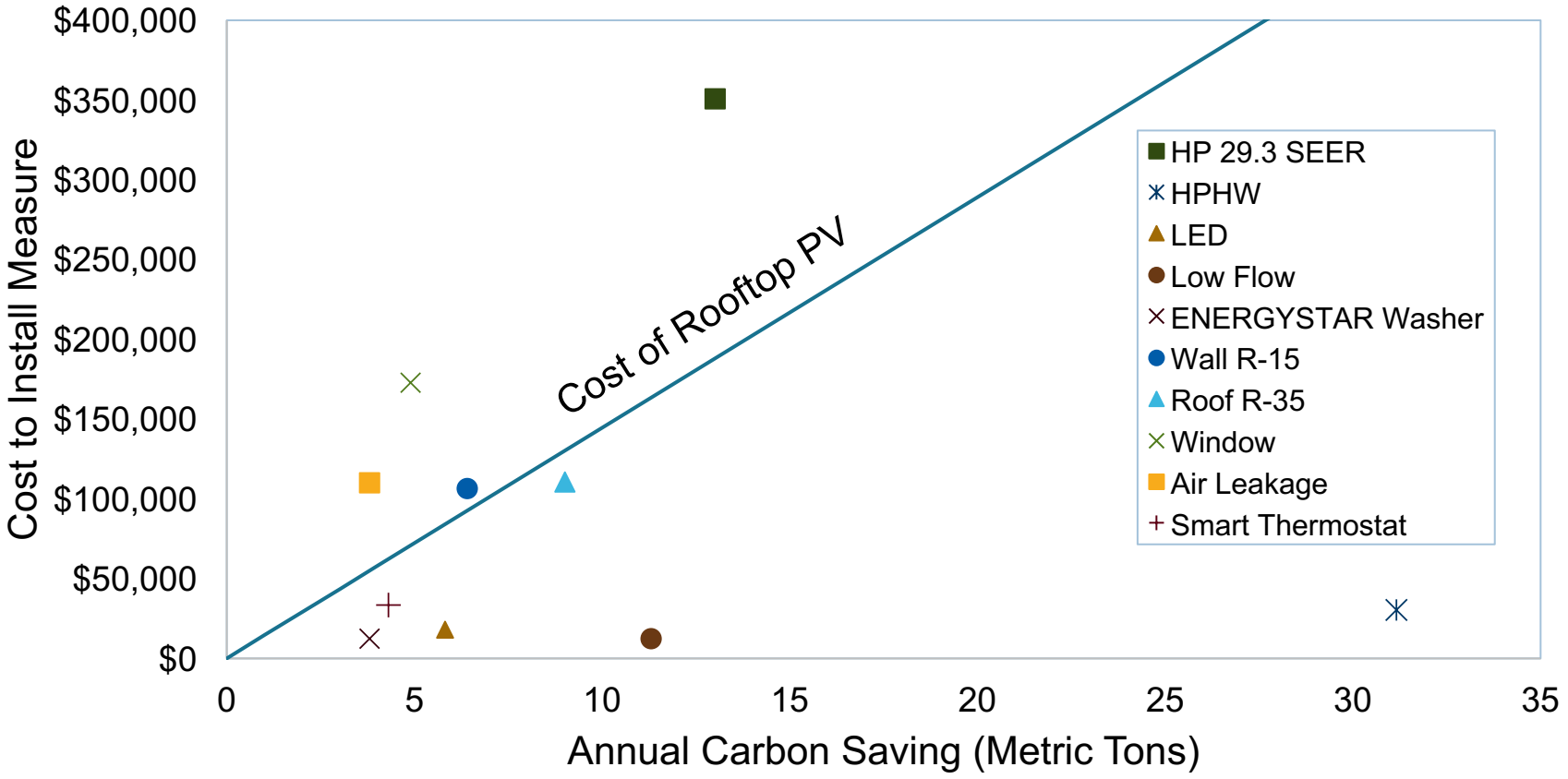
The NZE_c retrofits are comparable to business as usual during the life of the retrofit package.



**Energy savings PV calculated using a 5% discount rate and an escalation rate of 2.48%, which is a blended average based on 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. Water and sewage savings calculated assuming 5% discount rate and 5% escalation rate.*

65 Unit Prototype: ECMs Savings And Cost

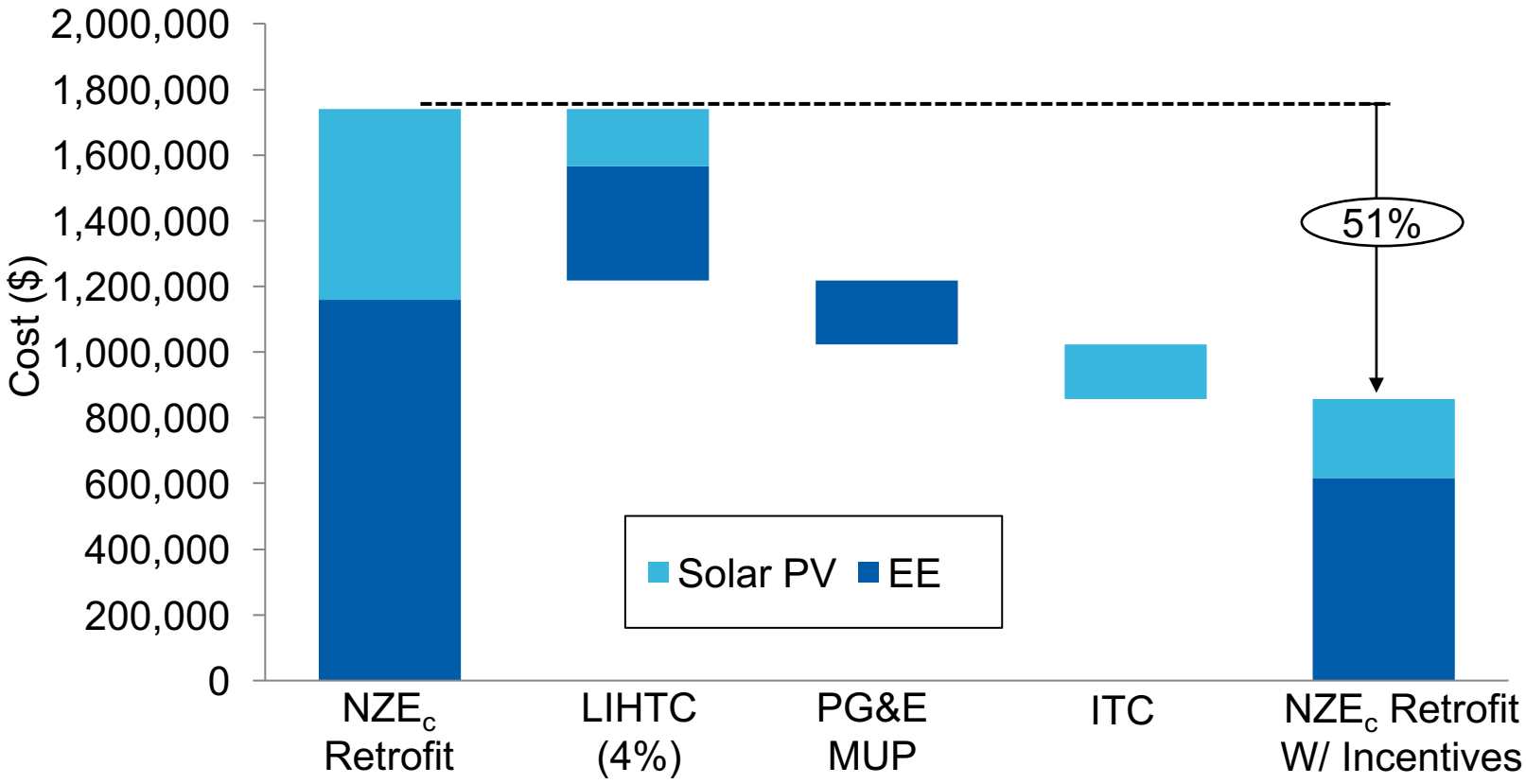
The most cost effective measures reduce DHW load and heating load. These independently modeled measures don't account for reduced carbon savings from interactive effects.



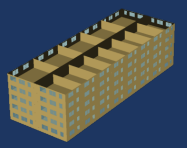
Note: All measures compared to baseline building with furnace. Does not take into account interactive effects of each measure.

65 Unit Prototype: Incentives with Rooftop PV

Incentives cut the cost of a net zero retrofit by half.



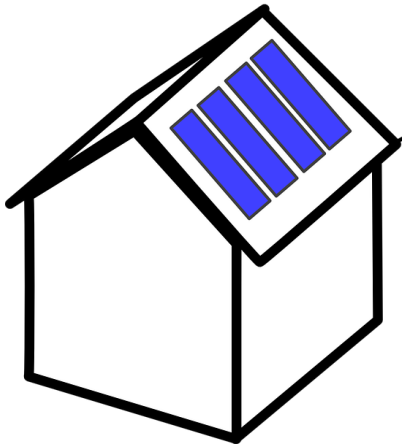
65 Unit Prototype: Renewable Program vs. Rooftop Solar PV



CleanPowerSF allows for lower upfront costs and rooftop solar PV provides lower total cost of ownership.

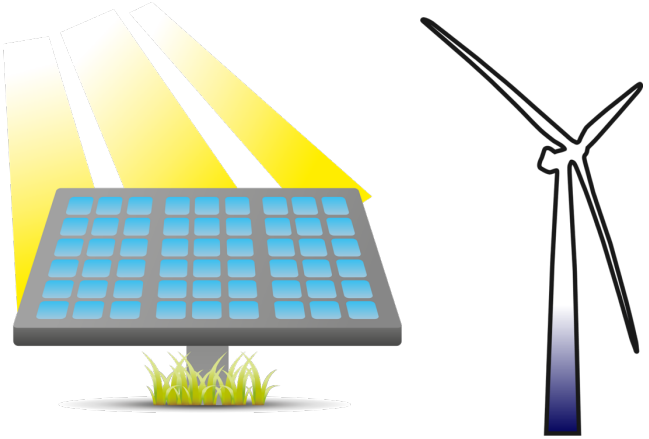
Approach 1: Rooftop Photovoltaics

Using this approach requires investment in deep energy efficiency measures and rooftop solar



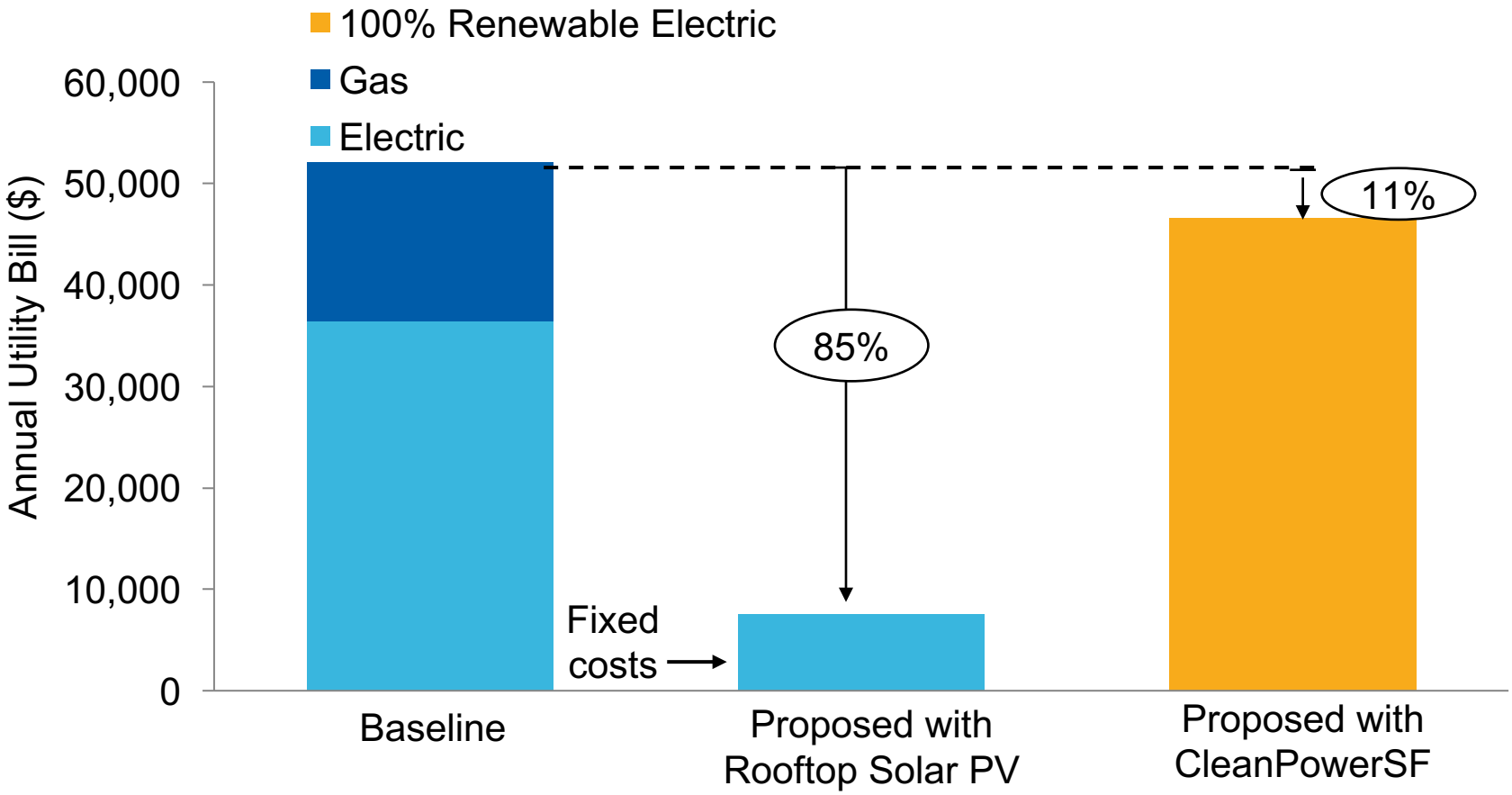
Approach 2: CleanPowerSF (Offsite Renewables)

CleanPowerSF avoids upfront cost of rooftop PV, creating a fairly easy path to NZE_c even in high rise buildings, but adds ~2 cents/kWh to utility bill

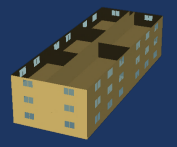


65 Unit Prototype: Energy Utility Bill

Renewable power programs almost eliminate utility bill savings from energy efficiency.

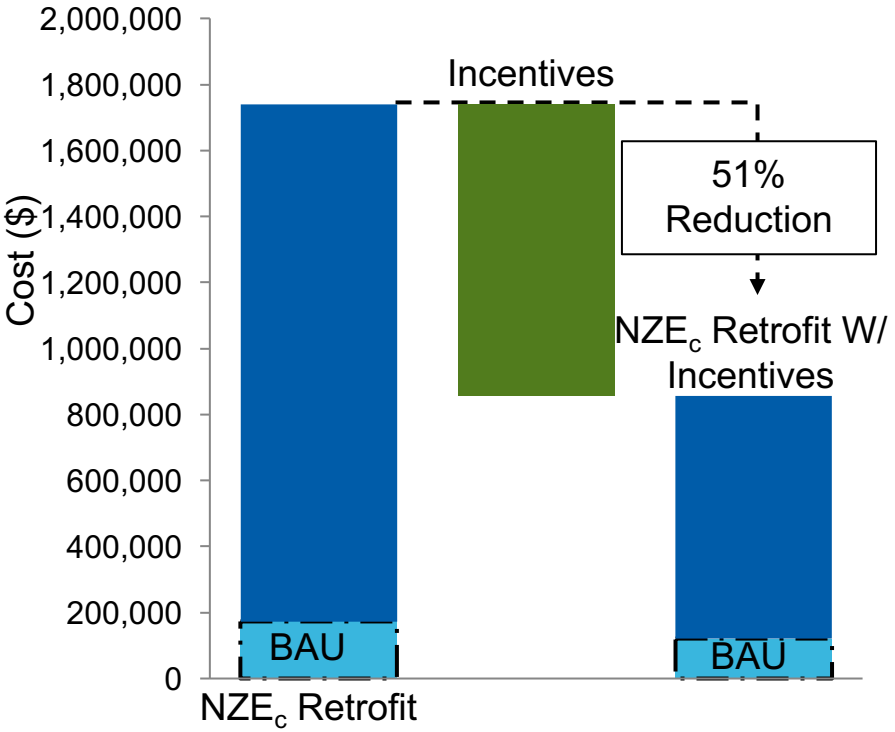


65 Unit Prototype: Summary Rooftop Solar PV

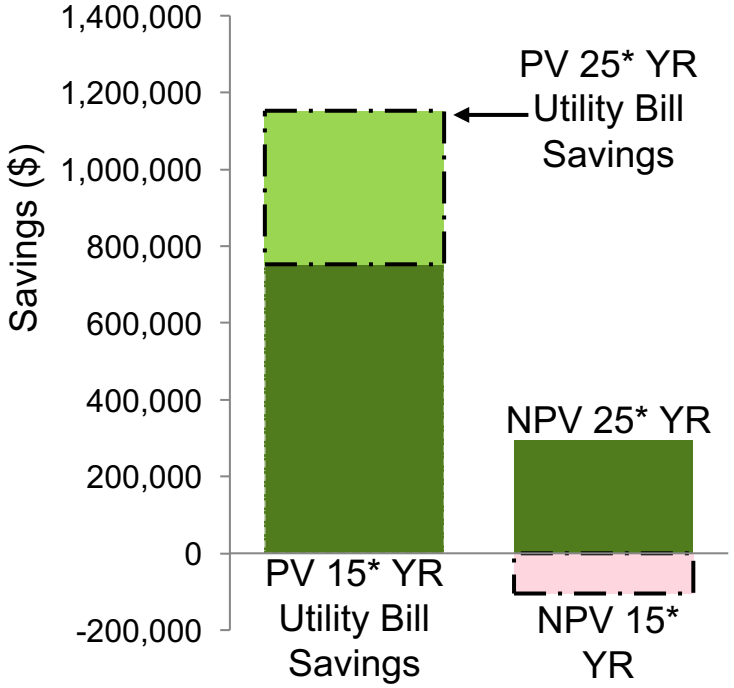


The NPV of the net zero retrofit will not break even in the typical 15 year investment cycle, but saves money over life of the retrofit.

COST



SAVINGS

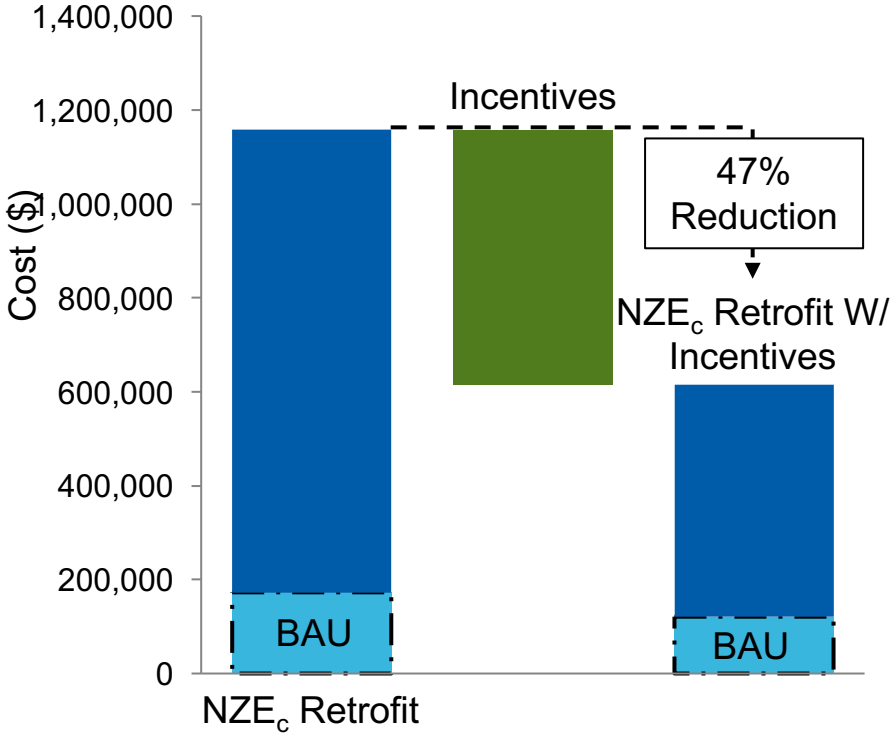


**Energy savings PV calculated using a 5% discount rate and an escalation rate of 2.48%, which is a blended average based on 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. 15 years selected as typical investment cycle for affordable housing. Water and sewage savings calculated assuming 5% discount rate and 5% escalation rate.*

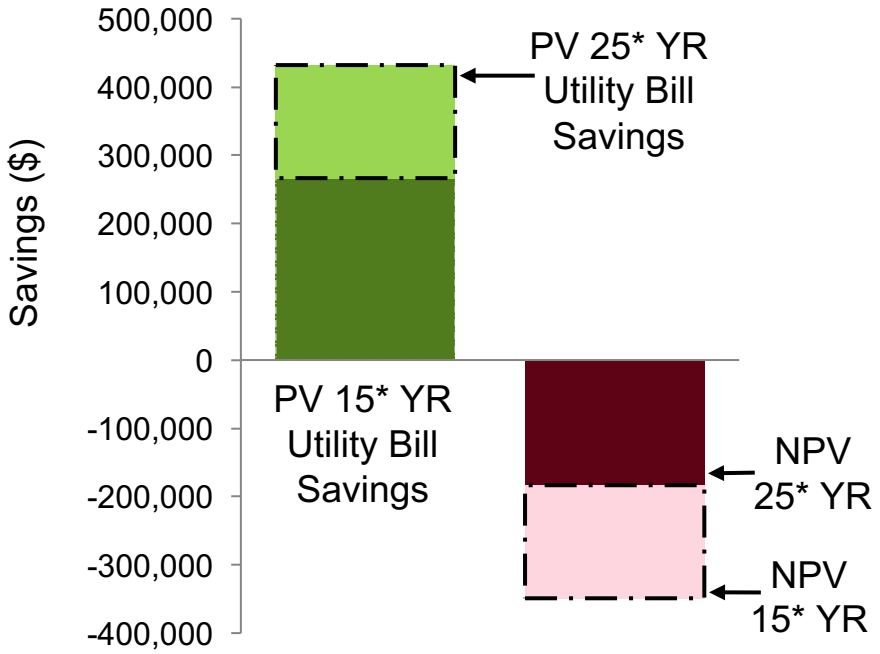
65 Unit Prototype: Summary Offsite Renewables

Although CleanPowerSF allows for lower upfront costs, the reduction in energy savings make it far less cost effective than rooftop solar PV.

COST



SAVINGS



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