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U.S. DEPARTMENT OF ENERGY

Building Performance Standards:

Cost-Benefits Analysis Briefing

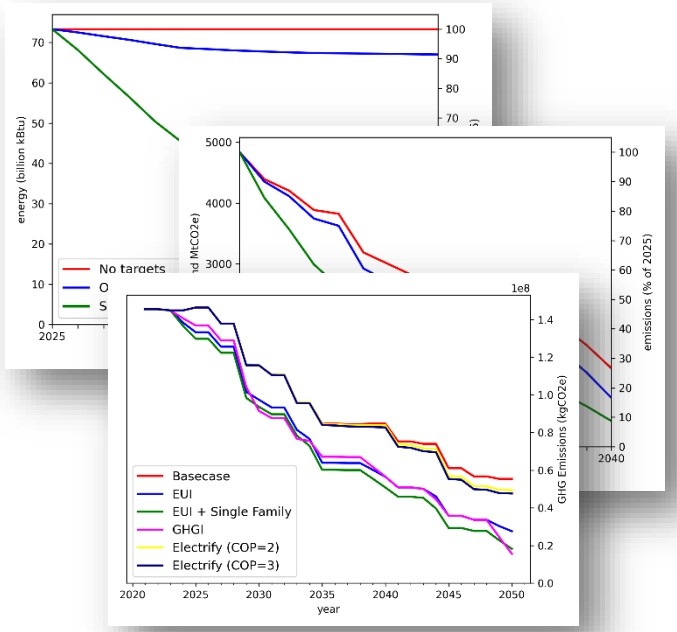
Agenda

- LBNL Initial Impact Analysis for MDE and Background
- PNNL BPS Retrofit Costs Meta-Study
- Combined Cost-Benefit Analysis
- Discussion of Results

What are BPS Impact / Stock Analyses?

- Building Stock Analysis / Energy + Carbon Baselining
  - **Fill the gap of unknown energy+carbon data** for existing buildings
  - Support jurisdictions at **any phase of policy development**
  - **Leverage all existing data**, regardless of format or quality

- Impact Analysis
  - **Model policy-driven scenarios** for energy/carbon reduction for any jurisdiction, tailored to their policy framework
  - **Support policy standardization** without sacrificing accuracy of scenario simulation

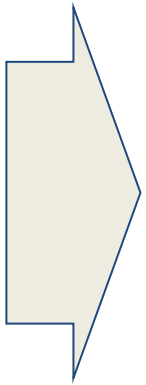


Data-driven BPS Policy Analysis

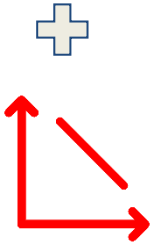
Building Type, Size, Age
Tax database

Energy/Emissions
Bx data, utility bills
Est. via EIA,BPD,...

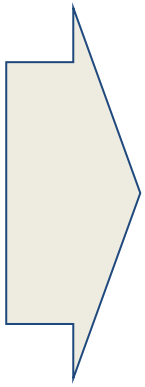
Asset characteristics
Audits, permit data
Est. via EIA,BPD,...



Current Stock
Energy/Emiss.



BPS targets
scenarios



Future Stock
Energy/Emiss.

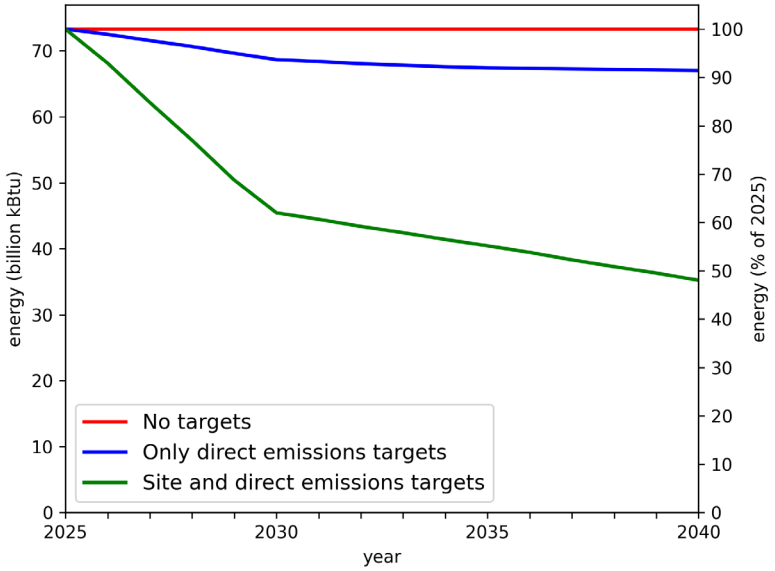
MDE – Baseline Data Sources and Modeling Methodology

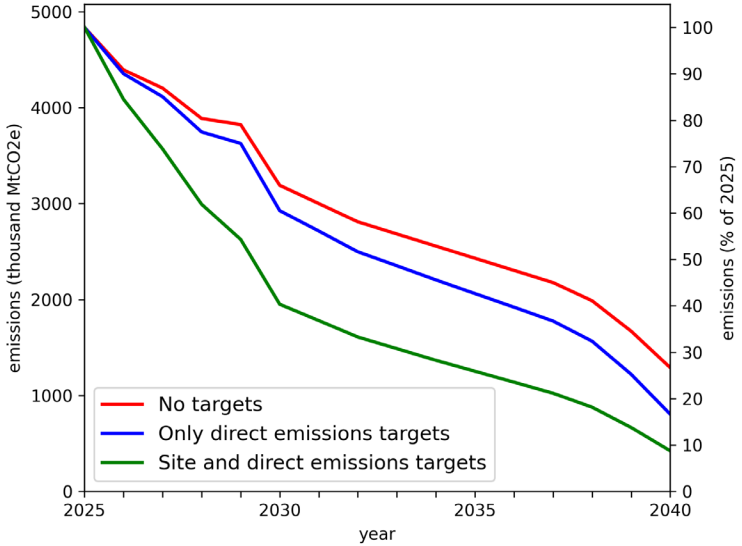
- Data Sources
  - Building types + sizes from draft Maryland Covered Building List (CBL) (~9300 bldgs >35k sqft)
  - Site EUI and electric/site ratio from EPA ESPM dataset
  - Ratio of fuel used for space and water heating from Com/ResStock/CBECS
  - Projected grid emissions factors from Maryland analysis

- Impact Model: Reduce energy use to meet targets
  - First: Try to meet direct emissions target with efficiency
  - Next: Electrify space heating, water heating, other uses, until direct emissions target met
  - Last: Reduce electric use until site energy use intensity (EUI) target met

MDE - Energy and Emissions Reductions

- Emissions savings aggregate of cleaner projected grid, electrification, and efficiency





PNNL – BPS Retrofit Costs Meta-Study

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PNNL – BPS Retrofit Costs Meta Study

- The cost analysis began with a broad literature search to compile a list of existing BPS cost studies and potential energy efficiency and electrification measures with associated costs and savings.
  - This review was not limited to Maryland only but included some Maryland-related examples, such as Steven Winter's Building Energy Performance Standard (BEPS) Technical Analysis report for Montgomery County
  - The measures were translated into a common framework (i.e. similar measure types, similar building types, etc.) to be able to compare across jurisdictions.
  - Costs from other locations adjusted using RSMeans Location Factors to obtain national average costs
- The Maryland-specific analysis included three components:
  - Energy efficiency retrofit costs
  - Electrification of traditionally fossil fuel-fired systems
    - ✓ Space heating
    - ✓ Domestic/service water heating
    - ✓ Other equipment (e.g., cooking or clothes drying)
  - Normal, same-fuel, replacement costs for fossil fuel-fired systems and equipment

PNNL – Maryland Analysis

The analysis for Maryland leverage the literature search previously described, and included the development of cost curves that could be applied to each building individually. The process included the following:

1. Reviewed list of measures from literature search, selected measures applicable to the Maryland region, and sorted them by the building types in which they would be appropriate.
   - The list includes 27 measures for multifamily buildings for example.
2. Identified additional applicable measures from other existing research, such as energy credit measure studies conducted for the development of model energy codes.
3. Given the wide range of energy savings that is being proposed for Maryland buildings (some are expected to reduce their EUI by up to 80%), generic measure packages that could apply to a specific building type could not be developed without additional building information. A different approach was used: developing cost curves using the cost per unit of savings as a measure of cost-effectiveness.
   - This approach considers that building owners will likely implement energy efficiency improvements starting with the most cost-effective measures and ride the curve upward, implementing the least cost-effective measures as needed.
4. Cost curves were only developed for electricity use since gas will be eliminated through electrification requirements.
5. Different curves were developed for multifamily, office, and warehouse buildings (the most common typologies covered by Maryland's BPS).

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Example ECM (Energy Conservation Measure) List by Loading Order

- Multifamily

Measures sorted by loading order	Cost / kBtu_savings	Electric Portion of WB EUI (%)	W/B Site EUI (kBtu/sf)	W/B Site EUI Savings %	W/B Site EUI Savings (kBtu/sf)	Electric Site EUI Savings (%)	Electric Site EUI Savings (kBtu/sf)	Electric Site EUI Savings (%) normalized to EUI 40	Electric Site EUI Savings (kBtu/sf) normalized to EUI 40	Cost per SF	Electric EUI Savings (%) cumulative	Electric EUI Savings (kBtu/sf) cumulative	Cost/sf cumulative
Commissioning: Stage 1: 1-month payback	$0.006	100%	113	6.2%	7.00	6.2%	7.00	2.2%	2.48	$ 0.014	2.2%	2.48	$ 0.01
Add Plug Load Control	$0.021	100%	120	2.0%	2.40	2.0%	2.40	0.7%	0.80	$ 0.017	2.9%	3.28	$ 0.03
Envelope Leakage Reduction	$0.022	70%	32	2.5%	0.80	1.8%	0.56	2.2%	0.70	$ 0.016	5.1%	3.98	$ 0.05
Install variable frequency drives on central distribution pumps	$0.059	100%	75	2.7%	2.05	2.7%	2.05	1.5%	1.09	$ 0.064	6.5%	5.08	$ 0.11
Commissioning: Stage 2: 1-year payback	$0.067	100%	113	5.3%	6.00	5.3%	6.00	1.9%	2.12	$ 0.141	8.4%	7.20	$ 0.25
Install variable frequency drives on heating hot water pumps	$0.175	95%	120	1.8%	2.16	1.7%	2.05	0.6%	0.68	$ 0.120	9.0%	7.88	$ 0.37
Residential HVAC control	$0.185	100%	39	2.1%	0.80	2.1%	0.80	2.1%	0.83	$ 0.153	11.1%	8.71	$ 0.52
Commissioning: Stage 3: 3-year payback	$0.189	100%	114	3.5%	4.00	3.5%	4.00	1.2%	1.40	$ 0.265	12.3%	10.11	$ 0.79
SHW shower drain heat recovery	$0.222	100%	33	2.7%	0.89	2.7%	0.89	3.3%	1.08	$ 0.240	15.6%	11.19	$ 1.03
Install variable frequency drives on domestic water booster pumps	$0.273	100%	75	0.4%	0.28	0.4%	0.28	0.2%	0.15	$ 0.040	15.8%	11.34	$ 1.07
Install variable frequency drives on condenser water pumps	$0.343	100%	75	0.4%	0.26	0.4%	0.26	0.2%	0.14	$ 0.048	16.0%	11.48	$ 1.12
Central Temperature Controls	$0.395	100%	86	2.1%	1.81	2.1%	1.81	1.0%	0.84	$ 0.332	17.0%	12.32	$ 1.45
Light power reduction	$0.424	100%	39	0.6%	0.25	0.6%	0.25	0.7%	0.26	$ 0.110	17.6%	12.58	$ 1.56
Residential light control	$0.569	100%	39	0.6%	0.23	0.6%	0.23	0.6%	0.24	$ 0.136	18.2%	12.81	$ 1.70
Thermostatic balancing valves	$0.727	5%	33	0.3%	0.10	0.0%	0.01	0.0%	0.01	$ 0.005	18.3%	12.82	$ 1.70
Upgrade Exhaust Fans	$0.787	100%	86	1.4%	1.20	1.4%	1.20	0.7%	0.56	$ 0.441	18.9%	13.38	$ 2.14
Install an exhaust recovery ventilation unit	$0.803	100%	75	7.9%	5.93	7.9%	5.93	4.2%	3.16	$ 2.536	23.1%	16.54	$ 4.68
Upgrade In-Unit Appliances	$0.817	100%	86	1.8%	1.55	1.8%	1.55	0.8%	0.72	$ 0.588	24.0%	17.26	$ 5.26
Close Shaft Vents	$0.968	100%	38	0.2%	0.07	0.2%	0.07	0.2%	0.07	$ 0.069	24.2%	17.33	$ 5.33
Add R-5.0ci Wall Insulation	$1.075	60%	38	0.8%	0.32	0.5%	0.19	0.5%	0.20	$ 0.213	24.7%	17.53	$ 5.55
Fault Detection and Diagnosis	$1.292	80%	39	0.2%	0.08	0.2%	0.06	0.2%	0.06	$ 0.080	24.8%	17.59	$ 5.63
Add programmable thermostats to apartments, provide instructions to occupants on u	$1.496	100%	55	0.8%	0.44	0.8%	0.44	0.6%	0.32	$ 0.479	25.4%	17.91	$ 6.11
Improve Fenestration	$1.689	60%	39	2.2%	0.83	1.3%	0.50	1.3%	0.52	$ 0.872	26.7%	18.43	$ 6.98
Add R-10 Roof Insulation	$1.873	60%	38	0.5%	0.18	0.3%	0.11	0.3%	0.11	$ 0.210	27.0%	18.54	$ 7.19
Heat pump clothes dryer	$2.072	100%	75	0.2%	0.18	0.2%	0.18	0.1%	0.10	$ 0.200	27.2%	18.64	$ 7.39
SHW pipe insulation	$2.470	5%	33	0.8%	0.26	0.0%	0.01	0.0%	0.02	$ 0.039	27.2%	18.65	$ 7.43
Install low flow aerators in faucets and showers	$2.731	10%	86	0.4%	0.37	0.0%	0.04	0.0%	0.02	$ 0.046	27.2%	18.67	$ 7.47

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Example ECM List by Loading Order

- Office

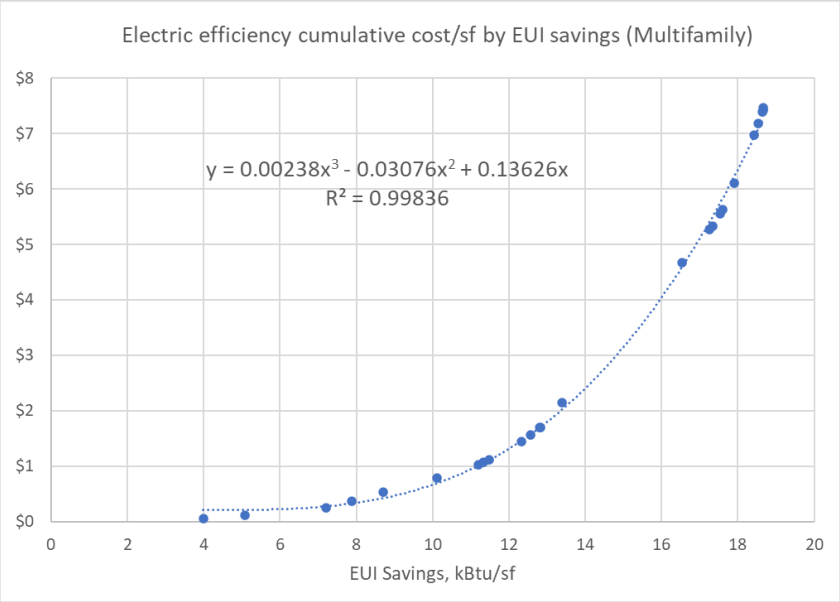
Measures sorted by loading order	Cost / kBtu_savings	Electric Portion of WB EUI (%)	W/B Site EUI (kBtu/sf)	W/B Site EUI Savings %	W/B Site EUI Savings (kBtu/sf)	Electric Site EUI Savings (%)	Electric Site EUI Savings (kBtu/sf)	Electric Site EUI Savings (%) normalized to EUI 40	Electric Site EUI Savings (kBtu/sf) normalized to EUI 40	Cost per SF	Electric EUI Savings (%) cumulative	Electric EUI Savings (kBtu/sf) cumulative	Cost/sf cumulative
Adjust existing HVAC schedules to align with occupancy	$0.004	100%	85	7.4%	6.27	7.4%	6.27	3.5%	2.95	$0.012	3.5%	2.95	$ 0.01
Commissioning: Stage 1: 1-month payback	$0.006	100%	113	6.2%	7.00	6.2%	7.00	2.2%	2.48	$0.014	5.7%	5.43	$ 0.03
Envelope Leakage Reduction	$0.044	70%	35	0.8%	0.28	0.6%	0.20	0.7%	0.23	$0.010	6.3%	5.66	$ 0.04
Commissioning: Stage 2: 1-year payback	$0.067	100%	113	5.3%	6.00	5.3%	6.00	1.9%	2.12	$0.141	8.2%	7.78	$ 0.18
Fault Detection and Diagnosis	$0.079	80%	35	0.2%	0.08	0.2%	0.06	0.2%	0.07	$0.006	8.4%	7.85	$ 0.18
Commissioning: Stage 3: 3-year payback	$0.189	100%	114	3.5%	4.00	3.5%	4.00	1.2%	1.40	$0.265	9.6%	9.25	$ 0.45
Install smart plug load management tools	$0.197	100%	82	1.4%	1.14	1.4%	1.14	0.7%	0.56	$0.110	10.3%	9.81	$ 0.56
DOAS/fan control	$0.252	100%	35	3.5%	1.21	3.5%	1.21	4.0%	1.39	$0.350	14.3%	11.20	$ 0.91
Add R-5.0ci Wall Insulation	$0.452	60%	35	0.5%	0.19	0.3%	0.11	0.4%	0.13	$0.058	14.7%	11.33	$ 0.97
Install variable frequency drives on condenser water pumps	$0.475	100%	85	0.4%	0.34	0.4%	0.34	0.2%	0.16	$0.076	14.8%	11.49	$ 1.04
Increase occupancy sensor	$0.694	100%	35	0.6%	0.20	0.6%	0.20	0.7%	0.23	$0.159	15.5%	11.71	$ 1.20
Install primary chilled water pump variable frequency drives	$0.700	100%	85	0.1%	0.09	0.1%	0.09	0.0%	0.04	$0.028	15.6%	11.75	$ 1.23
Install an exhaust recovery ventilation unit	$0.708	80%	85	8.3%	7.06	6.6%	5.64	3.1%	2.66	$1.880	18.7%	14.41	$ 3.11
Light power reduction	$0.764	100%	35	1.5%	0.52	1.5%	0.52	1.7%	0.60	$0.457	20.4%	15.01	$ 3.57
Efficient Elevator	$1.348	100%	35	0.5%	0.17	0.5%	0.17	0.6%	0.20	$0.264	21.0%	15.20	$ 3.83
LED conversion	$1.479	100%	85	1.4%	1.19	1.4%	1.19	0.7%	0.56	$0.828	21.6%	15.76	$ 4.66
Install submeters to incentivize tenants to reduce their energy use	$1.490	100%	85	1.0%	0.85	1.0%	0.85	0.5%	0.40	$0.596	22.1%	16.16	$ 5.25
LED conversion for parking garage	$1.600	100%	85	0.3%	0.26	0.3%	0.26	0.1%	0.12	$0.192	22.2%	16.28	$ 5.45
Add R-10 Roof Insulation	$2.655	60%	35	0.3%	0.09	0.2%	0.05	0.2%	0.06	$0.162	22.4%	16.35	$ 5.61

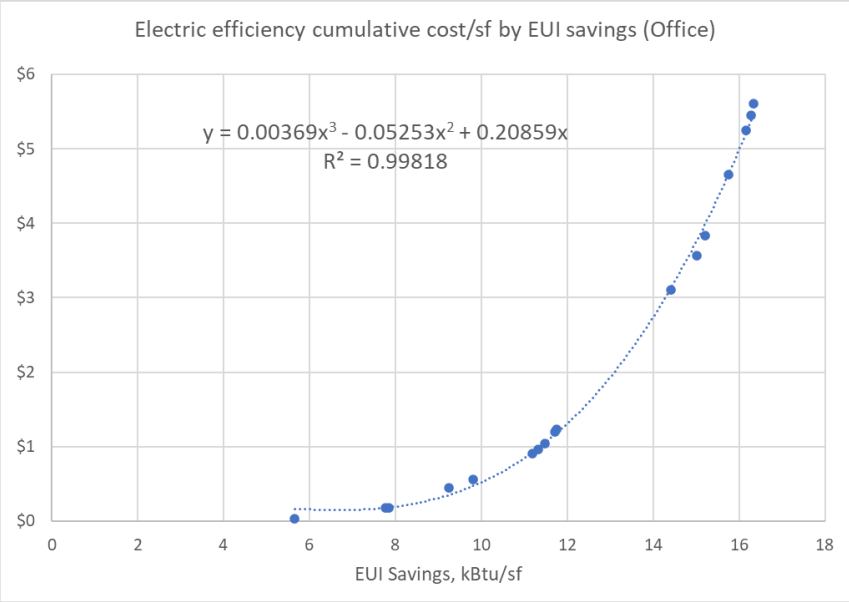
Example ECM List by Loading Order

- Install smart plug load management tools
- DOAS/fan control
- Add R-5.0ci Wall Insulation
- Install variable frequency drives on condenser water pumps
- Increase occupancy sensor
- Install primary chilled water pump variable frequency drives
- Install an exhaust recovery ventilation unit
- Light power reduction

	Electric EUI Savings (kBtu/sf) cumulative	Cost/sf cumulative
5%	2.95	$ 0.01
7%	5.43	$ 0.03
3%	5.66	$ 0.04
2%	7.78	$ 0.18
4%	7.85	$ 0.18
6%	9.25	$ 0.45
3%	9.81	$ 0.56
3%	11.20	$ 0.91
7%	11.33	$ 0.97
8%	11.49	$ 1.04
5%	11.71	$ 1.20
6%	11.75	$ 1.23
7%	14.41	$ 3.11
4%	15.01	$ 3.57
0%	15.20	$ 3.83
6%	15.76	$ 4.66
1%	16.16	$ 5.25
2%	16.28	$ 5.45
4%	16.35	$ 5.61

Cost Curves by Property Type





PNNL – BPS Retrofit Electrification Costs

- Costs to replace common fossil fuel-fired equipment with electric equipment
- Sources of reference cost values
  - Cost and Benefit Impact Study of the Washington D.C. Building Energy Performance Standards Program
  - Steven Winter pilot study investigating costs for electrification of a sample of existing buildings in Montgomery County, Maryland
  - E3 Building Decarbonization Study for the State of Maryland
- Costs are normalized by square foot of floor area due to limited information regarding installed equipment capacities in the studies referenced

Base Case Gas Systems

- Purpose: Cost estimates for normal replacement of gas equipment are needed as a baseline for determining incremental capital costs of electrification
- Methodology:
  1. Use PNNL's cost analysis data and calculations used to support ASHRAE 90.1 updates
  2. Retrieve gas equipment costs specific to Maryland construction
     a. Modeled capacities by prototype buildings: small office; large office; midrise apartment; stand-alone retail
     b. Include regional cost adjusters for labor and material
  3. Costs normalized to results from 90.1-2019 prototype simulations:
     a. Annual end use energy consumption; Units = $/kBtu-yr
     b. Simulated equipment capacity (furnace, boiler or water heater); Units = $/kBtu-hr Capacity
     c. Prototype floor area; Units = $/sf

Base Case Gas Systems – Boiler Example

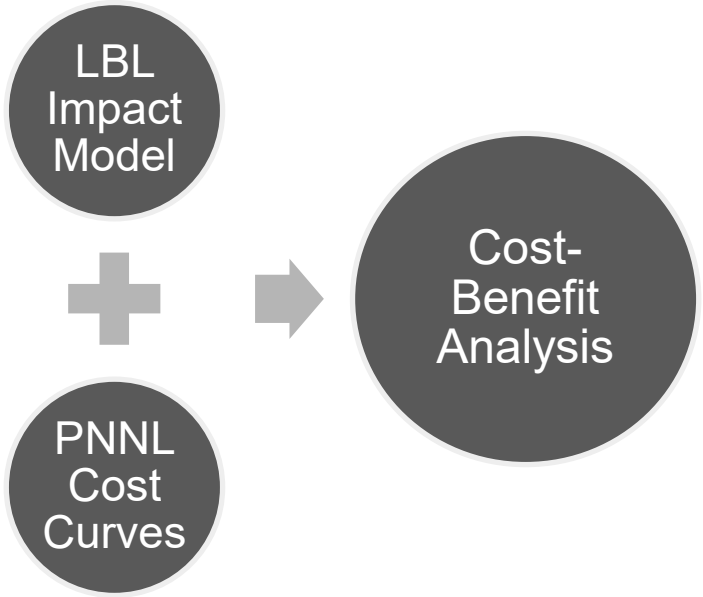
- Large Office Simulation Prototype (498,588 ft^2)
  - 90.1-2019 minimally compliant
  - Boiler capacity: 3,599 kBtu/hr
  - Modeled annual heating energy: 600,499 kBtu
  - Boiler cost: $ 78,490, adjusted for:
    - ✓ 90.1 cost vs. capacity relationship
    - ✓ regional labor and material variations

- Normal Replacement Costs
  - $78,490 / 3,599 = $21.80 / kBtuh of boiler capacity
  - $78,490 / 600,499 = $0.13 / kBtu of annual gas heating energy consumption
  - $78,490 / 498,588 = $0.16 / ft^2 of conditioned floor area

Integrating Costs into Impact Modeling

- Utilizing PNNL data on implementation costs for various energy retrofits at buildings, developing region-specific cost curves to help quantify **state-wide** magnitude of investment costs

- Integrated into LBNL impact model to quantify cost-benefit and model compliance rates



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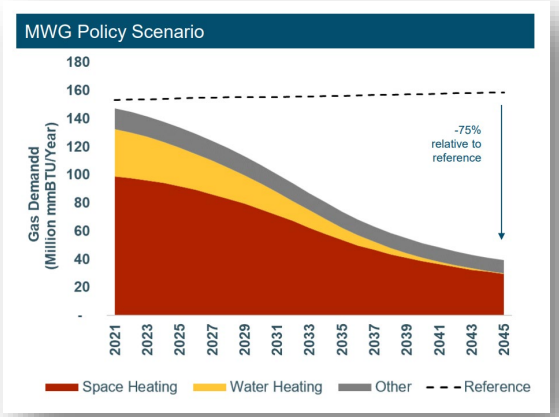
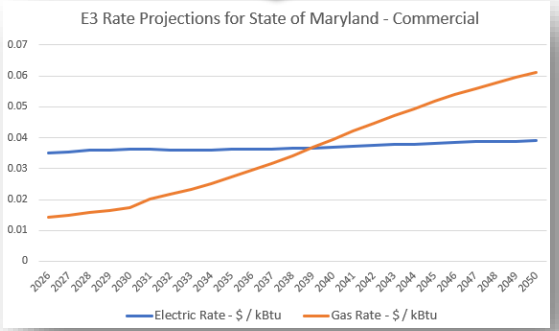
Rate Projections – State of Maryland

- Rate projections were taken from the “Maryland Building Decarbonization Study” released by E3 on October 21st, 2021.
- MDE and MWG designed a “Residential Electrification and Commercial Emissions Standard” scenario (referred to as “MWG Policy Scenario”), based on feedback from the MWG participants for the E3 study
- Key assumptions for the MWG Policy Scenario include:
  - All-electric new construction
  - High electrification retrofits for existing residential buildings
  - Dual-fuel retrofits for existing commercial buildings, reflecting a Building Emissions Standard targeting net-zero emissions for commercial buildings by 2040 proposed in the draft Building Energy Transition Plan

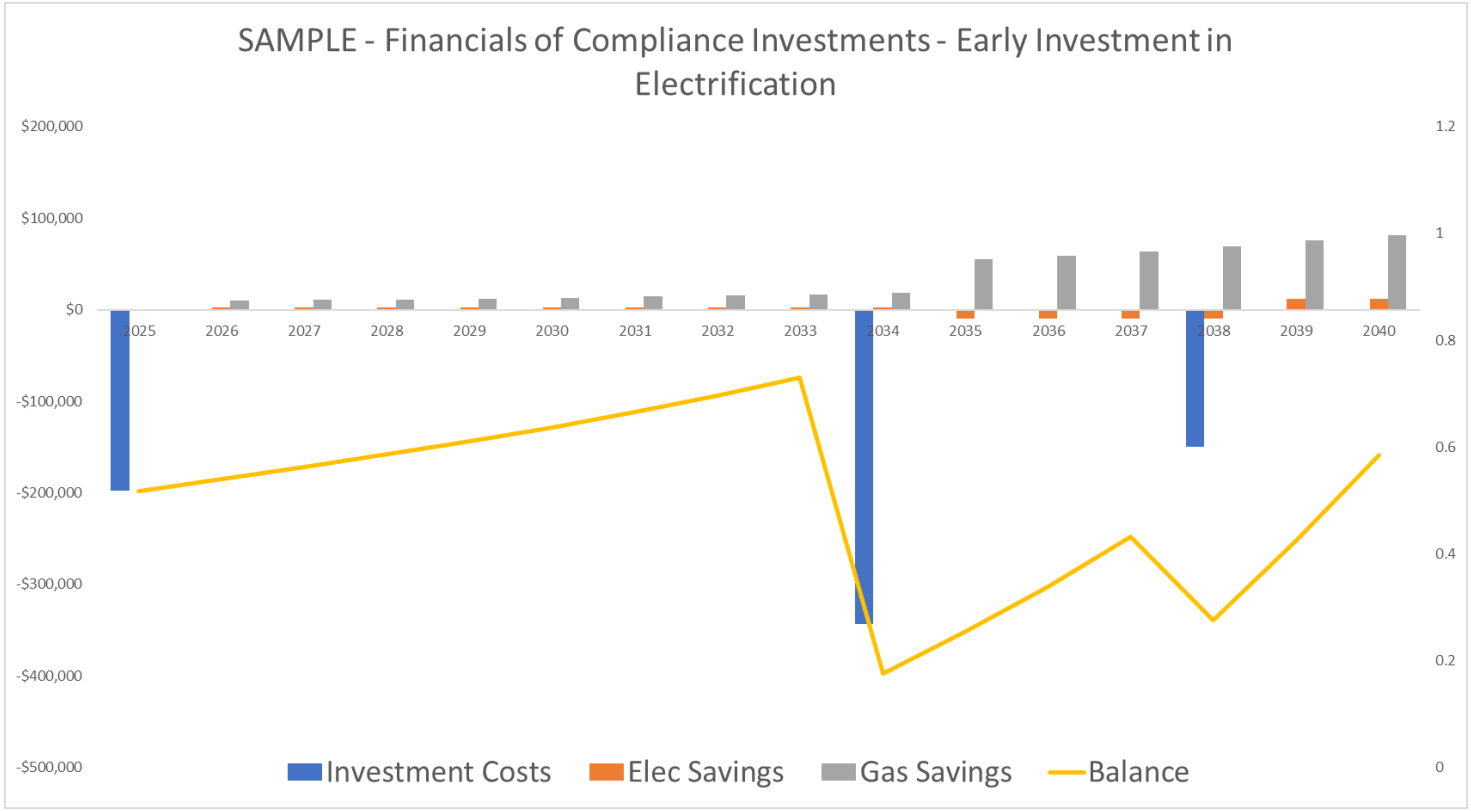




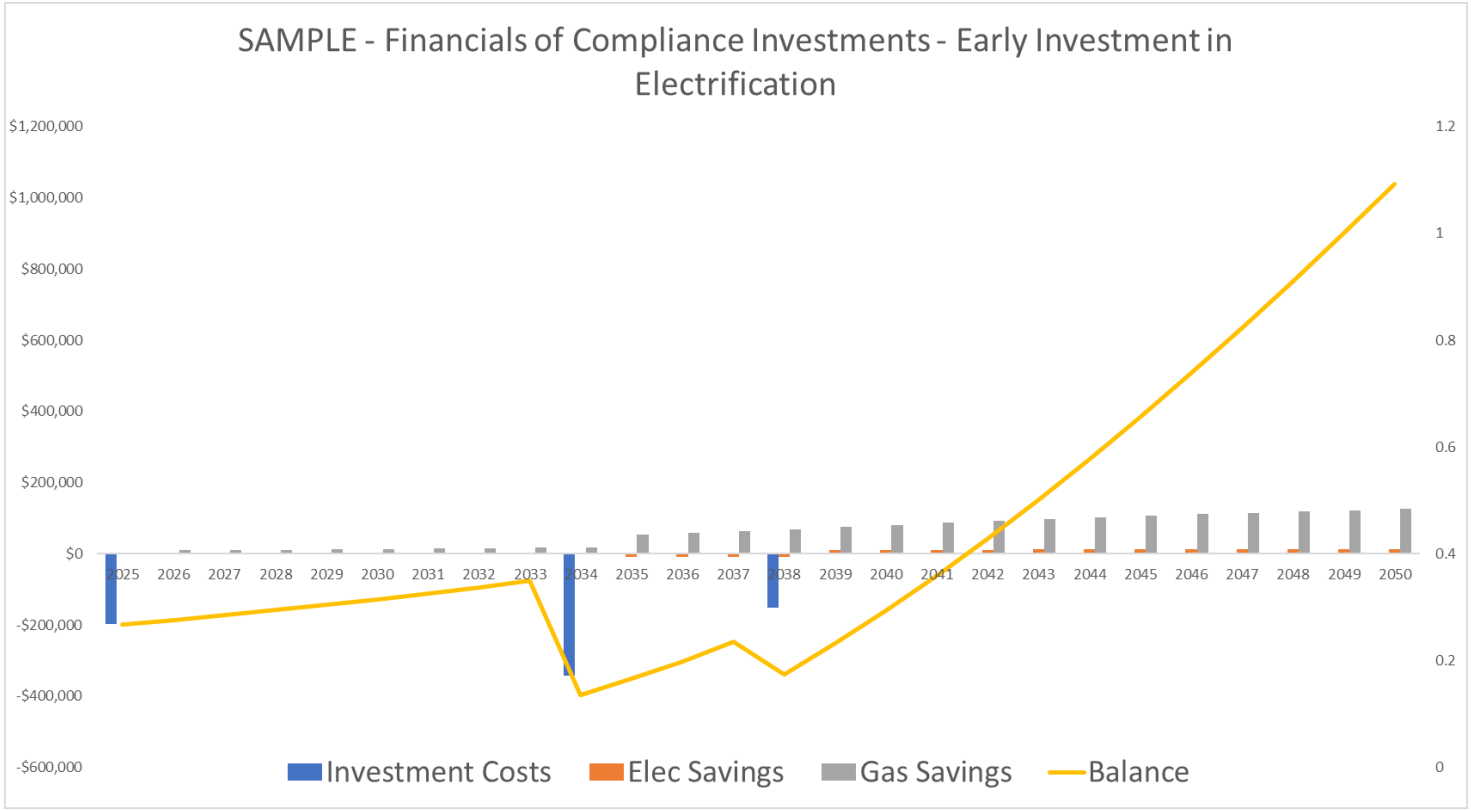
Cost Inputs to CBA

- Capital Cost Categories
  - Electric Efficiency
  - Gas Efficiency
  - Electrification
- Ongoing Cost Buckets
  - Electric Cost (Savings from efficiency, increases from electrification)
  - Gas Cost (Savings from efficiency + electrification)
  - Site EUI ACP (most recent iteration)
  - Direct GHG ACP (most recent iteration)

Example Building



Example Building – Longer Outlook



State-wide Results: 2025 – 2050*

- Total Building Area Covered: ~990MM SqFt
- Baseline Energy Costs: $68.9B
- BAU System Replacement Costs: $0.9B
- Total Efficiency Investments: $8.8B
- Total Electrification Investments: $6.4B
- Total Energy Cost Savings from Baseline: $22.3B
- **Net Cost Savings of All Investments: $4.5B**

*All metrics shown aggregated over 2025-2050 time period
Does not include any energy efficiency/electrification incentives

State-wide Results: 2025 – 2050*

- Baseline Energy Costs: $69.60 / SF ($2.80/SF/Year)
- BAU Gas System Replacement Costs: $0.91 / SF
- Total Efficiency Investments: $8.97 / SF
- Total Electrification Investments: $6.48 / SF
- Total Energy Cost Savings from Baseline: $22.56 / SF ($0.90/SF/Year)
- **Net Cost Savings of All Investments: $4.47 / SF**

45% (including 65% in the 1st compliance period) of all interventions could be considered 'financeable', per rough assumptions regarding IRR (Internal Rate of Return) thresholds by property type.

*All metrics shown aggregated over 2025-2050 time period unless otherwise specified
Does not include any energy efficiency/electrification incentives

Maryland Cost Analysis Caveats

- The costs provided are high-level and should not be used to estimate the costs of retrofits at any individual building
- The list of energy efficiency measures is not exhaustive and does not represent a complete list of all potential retrofits that may be possible within Maryland buildings
- The capacity-based costs ($/kBtu-yr) provided for the base case gas systems assumes that capacity is scalable with annual energy use which means that buildings with longer operating hours may have underestimated costs and buildings with shorter operating hours may have the opposite
- The square foot-based costs ($/SF) provided for the base case gas systems will underestimate costs for less efficient buildings since the costs are tied to 2019 code compliant buildings which will have many non-HVAC efficiencies that reduce overall energy consumption. However, given that electrification costs could only be obtained on a per square foot basis due to data availability, this normalized cost was used for comparison

LBNL Impact Analysis Caveats

- Due to limited data availability, all results should be considered rough and best-available estimates for costs and savings. Analysis may be refined and is subject to change as more empirical data becomes available.
- ECM Measure Life was not taken into account for this analysis. Costs assume no net changes in maintenance or upkeep of systems pre- and post-implementation.
- Like-for-Like system replacement costs in the baseline scenario were assumed to occur once per system for each building otherwise undergoing electrification retrofits in the compliance scenario.
- Results not adjusted for inflation, and do not take into account future efficiency/electrification technologies not currently on the market.

Contacts

Joshua Kace
jkace@lbl.gov

Travis Walter
twalter@lbl.gov

Andrea Mengual
andrea.mengual@pnnl.gov

Kevin Madison
kevin.j.madison@pnnl.gov