The Cost of Decarbonization and Energy Upgrade Retrofits for US Homes

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2021-11-04
Database Summary

Sample of convenience:
• Most data voluntarily provided by energy programs
• Paid contributions for 475 homes

Data included:
• Project meta-data
• Costs broken down by measure
• Energy (and calculated CO₂) savings for whole project

12 Programs  1,739 Projects  10,512 Measures  3,294,946 ft²  $24,689,213
Costs of Most Frequent Upgrade Measures
Median Total Cost ($ per ft$^2$)
Heat Pump Costs

Some measures broken down by size, for example, heat pump costs per ton.
Comparing Median Measure Costs Against NREL EMDB

Most reported costs higher than NREL database

LBNL & NREL collaborating to update database
Project Cost vs. Carbon Savings

How much does it cost to get to 50% savings?

- Higher cost projects have diminishing returns

>50% Carbon reductions currently cost $20-30+ per ft²

- Total Project Gross Cost ($ per ft²)
  - >$40: 62% (n=21)
  - $30-40: 61% (n=20)
  - $20-30: 49% (n=48)
  - $10-20: 33% (n=158)
  - <$10: 25% (n=914)

Carbon Savings (%)
Unsupervised Machine Learning approach that groups similar objects such that the objects in the same group are more similar to each other than to objects in the other groups.

Upgrade projects were clustered according to how money was spent.
Clustered Project Cost Stacks

BASIC
Low-cost, basic projects with mostly envelope and limited HVAC work

HVAC
HVAC projects with standard equipment (~1/2 heat pumps), including some envelope work

ADVANCED HVAC
Advanced, higher-cost HVAC projects (>2/3 heat pumps), including some envelope work

LARGE HOME GEOTHERMAL
HVAC-focused projects in large homes with geothermal heat pumps (90%) and some envelope and PV work

SUPERINSULATION
Comprehensive deep retrofits focused on aggressive envelope upgrades (e.g., exterior wall insulation, triple pane windows, etc.) with some gas equipment and little or no PV

ELECTRIFICATION WITH PV
Equipment electrification projects that include moderate envelope upgrades and PV in all cases

Costs remain too high

Total Cost ($) - $150,000

$120,802 (39%)
$109,059 (51%)
$54,098 (68%)

Envelope
Equipment
PV
Affordability, Cash Flow and Cost Compression – Schematic

Upfront costs are a major barrier to getting to scale with decarbonization

Focus on AFFORDABILITY
• Requires access to easy financing

Utility Bill Savings ($)

Loan Payment ($)

Loan Supported by Savings ($)

Actual Project Cost ($)

Required Cost Compression ($)

Loan Terms
(Period and interest rate)
Clustered Projects Required
Cost Compression

Terms: 30-year, 3% interest

Cost reductions needed to be cost-effective
Clustered Projects Saving > 50% Compressed Cost Stacks

Electrification with PV
n=43

Superinsulation
n=15

Terms: 30-year, 3% interest
Clustered Projects
Compressed Cost Stacks – Varying Financing Terms

Required cost compression depends on available financing.
Cost Compression - Pathways

- Rebates and Incentives
- Upgrade Package Optimization
- Technology Innovation
- Soft Cost Reductions
- New Metrics
- No- and Low-Cost Methods
Cost Compression - Rebates

Terms: 30-year, 3% interest
Archetypal projects created to find the lowest cost approaches for typical house (1,768 ft², 1-story, 1970’s home). Costs predicted using random forest regression models for each individual measure, then assembled into prescriptive packages.

### Envelope upgrade packages:

1. None – no envelope or HVAC upgrades
2. Weatherization (Wx) – typical for DOE Wx program
3. Home Performance (HP) – typical for a home performance contractor
4. Deep Energy Retrofit (DER) - typical high performance envelope

### Equipment (HVAC & DHW):

1. Gas
2. Gas + cooling (Air Conditioning)
3. All Electric

### PV:

1. Small
2. Medium
3. Large
Cost Compression – Package Optimization
Archetypal Upgrade Packages

4 envelope, 3 HVAC & DHW and 3 PV options permutated to look for optimum solutions
Cost Compression – Package Optimization
Archetypal Upgrade Packages

50-60% CO₂e Savings

$\text{Carbon savings and costs predicted by regression models}$
Cost Compression – Ductless Heat Pumps

Ductless Heat Pump Cost Compression

- Current Cost: $4,397
- Automated HVAC sizing calculations: $250
- Bundled measures soft cost savings: $220
- Volume purchasing discount: $220
- Automated fault detection and commissioning: $250
- Electrical savings from 120V plug-in tech: $350
- Target Cost: $3,107
Cost Compression – Ductless Heat Pumps

$875 equip mark-up

$300-700 equip mark-up

Navigant 2018

- Labor: $1,319
- Equipment: $2,418
- Supplies: $440
- Other: $220
- Permits: $125
- Electrical: $800
- Margin: $1,666

Armstrong et al 2021

- Labor: $300
- Equipment: $1,666
- Supplies: $208
- Other: $1,666
- Permits: $125
- Electrical: $800
- Margin: $0

Heat Pump Water Heater Cost Compression

Current Cost: $3,828

- Bundled measures soft cost savings: $2,242
- Volume purchasing discount: $112
- Electrical savings from 120V plug-in tech: $700
- Target Cost: $1,318

80-Gal HPWH
Cost Compression - Heat Pump Water Heater, 50-Gal

80-Gallon 120F = 50-Gallon 140F + Mixing Valve
Cost Compression – Low Power Electrification
Avoiding Panel Upgrade Costs

Contractor’s Pricing Guide: Residential Repair & Remodeling Costs
with RSMeans data

Average range: $1,500 - $4,000

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<thead>
<tr>
<th>Low</th>
<th>Average Cost</th>
<th>High</th>
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<tbody>
<tr>
<td>$800</td>
<td>$2,500</td>
<td>$4,500</td>
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(replace an existing panel with a new model with new housing)

https://www.fixr.com/costs/install-electrical-circuit-panel-upgrade
Cost Compression – Low Power Electrification
Avoiding Panel Upgrade Costs

Smart Circuit Splitters and Sharing

Programmable Subpanels

Power-efficient Appliances (120V)

Watt Diet Calculator

Source - Sean Armstrong, Redwood Energy (2020)
Need to reduce Soft Costs:

- Customer acquisition
- Testing
- Program participation
- Load calculations
- Project design
Cost Compression – Soft Costs

Outsource customer acquisition to programs with marketing and sales expertise

- CURRENT
  - $1,000-2,500 per project
- COMPRESSED
  - $700

Reduce diagnostic testing and commissioning

- CURRENT
  - Combustion: $387
- COMPRESSED
  - $0

Remote approaches to customer acquisition, management and sales

- Remote audits: 40% cost savings for individual projects
- Remote audits: 60% savings for executed projects

Automated, rapid HVAC equipment sizing

- CURRENT
  - $564
- COMPRESSED
  - $100
Cost Compression – Soft Costs – Real Life Examples
DIY Solar PV

- Eliminate overhead with online experience
- Flat pricing across the US
- DIY or full-service options

Want to DIY? You put up the panels, we do the rest.

Forget Everything You’ve Heard About Solar
Same Equipment. Same Warranty. Lowest Price.

Transparent Pricing
Lowest Guaranteed

Equipment + Permits & DIY Support
$0.90-$1.20 /watt

Ground Mount + Installation
$0.30* /watt

Full Service Install + Warranty
$0.37* /watt

*Pricing reflected as after incentive pricing.
Cost Compression – Soft Costs – Real Life Examples

DIY/very simple install:
- Custom design
- Pre-insulated line sets
- Simplified fittings
- Strong advertising
Decarbonization Costs – New Metrics
Using Electric Heat Pumps Instead Of Gas Furnaces

Heat Pump COP required to break even with a gas furnace

CO₂ Emissions Neutrality 80 AFUE

Energy Cost Neutrality 80 AFUE

CO₂ Emissions Neutrality 95 AFUE

Energy Cost Neutrality 95 AFUE
Decarbonization Costs– New Metrics
Using Electric Heat Pumps Instead Of Gas Furnaces

What Heat Pump performance is required to be carbon and /or cost neutral?
Gas Furnace: 80 AFUE

Points scaled according to count of natural gas heating appliances in each state
Cost Compression – New Metrics
Using Electric Heat Pumps Instead Of Gas Furnaces

What are the carbon and cost savings?

Gas Furnace: 80 AFUE
Heat pump: 3.0 COP

Points scaled according to count of natural gas heating appliances in each state
Cost Compression – No- and Low-Cost
Automated emission reductions

Small – but easy and low cost
Should be part of every project

WattTime™

Forecasting

Marginal Emission Rate

Optimization

Reporting

"We cut our bill in half and are on track to save over $2,000 after the changes we made with HomeIntel's help."
HomeIntel customer

Their story: This couple has lived in their 3,000sqft home in Stanford, CA for 30 years.

Despite completing HVAC upgrades, they still had high energy use.

Their results: Saving $220 per month and over $2,500 annually.

The customer above found 4 Energy Hogs using HomeIntel.

1. Old baseboard heaters costing $100 per month

2. Continuous hot water recirculation pump costing $65 per month

3. 20 year old wine cellar (cooler pictured) costing $120 per month

4. Instant hot water dispenser under the sink costing $30 per month
What’s Next?

• Cost Compression
  - Financing – reduce “sticker shock”
  - Technology – affordable, low-power HVAC/DHW/Cooking/clothes dryer appliances
  - Soft Costs
    - Streamlining/Reducing installation, code and permitting requirements
    - Standardized packages of upgrades to simplify decision-making process

• Electrification for Low-Income households
  • Drop-in/Plug-in/DIY approaches
  • Transportable technologies

• How to overcome emergency equipment replacement – make lower carbon the lowest cost default option
References

