Seminar Series Summary

Wednesdays at noon from now through early January
Six sessions (possibly more to come)
Focus on sharing practical experiences

Topics:
• Cost analyses
• Can you DIY home electrification?
• How to Electrify Your Home Without Panel Upgrades
• Planning, Designing and Installing Home Electrification
• Rapid Electrification of Existing Buildings: Problems and Opportunities
• Trials and Tribulations of Home Electrification

LBNL Staff

Practitioners

Alan Meier  Steve Greenberg  Howdy Goudey  Sean Armstrong  Tom Kabat
Gerald Robinson  Spencer Dutton  Bruce Nordman  Ann Edminster  Keith O’Hara
Brennan Less  Nuria Casquero Modrego  Iain Walker  Chris Stratton  Josie Gaillard
Jonathan Wooley
The Cost of Decarbonization and Energy Upgrade Retrofits for US Homes

Brennan D. Less, Iain S. Walker, Núria Casquero Modrego

2021-11-17
Emerging Changes in Residential Construction

Think about it as the completion of the electrification program begun in the US 100 years ago.
New Policies

100 percent clean policies by state as of April 2020

Action taken at:
- State level
- City/County level
- No action taken

*Hover or click on states for more information.*

Three Principles for Home Decarbonization

Principle #1: We can’t efficiency our way to zero emissions

Principle #2: Homes will have to be electrified

Principle #3: Solutions need to be affordable
What are the main motivations of homeowners / building owners when seeking to perform an energy upgrade project?

- Improve comfort: 48
- Save money on energy bill: 42
- Make home sustainable / green: 32
- Reduce carbon emissions: 22
- Reduce use of on-site fossil fuel: 13
- Other: 7
- Upgrade for modern convenience (e.g., car charging): 7
- Address existing moisture / mold problem: 7
- Increase home value: 6
- Increase resilience (e.g., hurricane, power outage): 5
- Address existing odor / IAQ problem: 5
- Upgrade for lifestyle changes (e.g., aging in place): 4
- Address home safety issues: 3
- Address existing noise problem: 0

Customer Motivations

Residential <> Commercial

Profit is not the motive

ROI, payback and other traditional investment metrics are misleading and the wrong ones to use

“Affordability” and financing are key

Address existing noise problem
While we focus on costs today important to note other important factors to get to scale
Deep Retrofit Database Summary

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

Data included:
- Costs - broken down by measure
- Energy (and calculated CO₂) savings

12 Programs | 1,739 Projects | 10,512 Measures | 3,294,946 ft² | $24,689,213
Measure Breakdown

- HVAC (n=2,298) (Cost: $14.24)
- Attic (n=1,061) (Cost: $2.71)
- Electrical (n=360) (Cost: $2.45)
- House (n=1,391) (Cost: $1.97)
- Walls (n=289) (Cost: $1.1)
- Windows (n=76) (Cost: $0.77)
- Foundation (n=274) (Cost: $0.65)
- Plumbing (n=274) (Cost: $0.62)
- Appliance (n=100) (Cost: $0.12)
- Doors (n=42) (Cost: $0.06)
Costs of Most Frequent Upgrade Measures
Median Total Cost ($ per ft\(^2\))

- **Median Cost >$5,000**
  - HVAC, install, fueling, m\(^2\): $27,184 ($13.58)
  - Windows: $8,027 ($5.44)
  - HVAC, install, full framing: $6,464 ($4.94)
  - Blast walls: $5,883 ($2.93)
  - Electrical, install, JP: $5,096 ($2.77)

- **Median Cost $1,000-$5,000**
  - HVAC, install, fueling, m\(^2\): $2,016 ($0.96)
  - Windows: $1,544 ($0.82)
  - HVAC, install, full framing: $1,578 ($0.88)
  - Blast walls: $1,827 ($1.11)
  - Electrical, install, JP: $1,092 ($0.86)

- **Median Cost $250-$1,000**
  - HVAC, install, fueling, m\(^2\): $789 ($0.93)
  - Windows: $733 ($0.41)
  - HVAC, install, full framing: $730 ($0.41)
  - Blast walls: $714 ($0.46)
  - Electrical, install, JP: $740 ($0.31)

- **Median Cost < $250**
  - HVAC, install, fueling, m\(^2\): $298 ($0.14)
  - Windows: $109 ($0.07)
  - HVAC, install, full framing: $143 ($0.09)
  - Electrical, install, JP: $229 ($0.13)

Source: 11homes.lbl.gov
Heat Pump Costs

Some measures broken down by size, for example, heat pump costs per ton

This allows tradeoffs e.g., Balance cost of envelope load reduction with reduced heat pump cost

Heat Pump installation costs per ton

- **Ground Source Heat Pump**: $9,770, n=28
- **Unknown**: $6,457, n=73
- **Ductless mini-split**: $4,421, n=180
- **Air Source Heat Pump**: $2,481, n=317

homes.lbl.gov
Comparing Median Measure Costs Against NREL EMDB

Most reported costs higher than NREL database

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

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

- >$40: >50% Carbon reductions currently cost $20-30+ per ft² (62% of projects, n=21)
- $30-40: 61% of projects (n=20)
- $20-30: 49% of projects (n=48)
- $10-20: 33% of projects (n=158)
- <$10: 25% of projects (n=914)

Higher cost projects have diminishing returns.
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 based on total project costs.
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

$ - Total Cost
(% - CO₂e reduction)

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

$3,849 (18%)
$10,105 (31%)
$26,228 (25%)

Basic
HVAC
Advanced HVAC
Large Home Geothermal
Superinsulation
Electrification with PV

n=671
n=857
n=136
n=14
n=15
n=13
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
Clustered Projects: Required Cost Compression

Terms: 30-year, 3% interest

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Basic</th>
<th>HVAC</th>
<th>Advanced HVAC</th>
<th>Geo-thermal</th>
<th>Super-insulation</th>
<th>Electrification with PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Supported by Savings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>$-1,149</td>
<td>$-1,215</td>
<td>$20,694</td>
<td>$65,816</td>
<td>$91,112</td>
<td>$19,867</td>
</tr>
<tr>
<td>$</td>
<td>$5,443</td>
<td>$11,321</td>
<td>$5,705</td>
<td>$21,057</td>
<td>$17,947</td>
<td>$34,232</td>
</tr>
<tr>
<td>$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

CO₂ Reduction

- Basic: 18%
- HVAC: 31%
- Advanced HVAC: 25%
- Geo-thermal: 39%
- Super-insulation: 51%
- Electrification with PV: 68%
Cost Compression - Pathways

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

Cost Supported by Savings
Required Cost Compression
25% Rebate

Cluster: Basic, HVAC, Advanced HVAC, Geo-thermal, Super-insulation, Electrification with PV

CO₂ Reduction: 18%, 31%, 25%, 39%, 51%, 68%

Terms: 30-year, 3% interest

More feasible cost compression
Cost Compression – Package Optimization
Archetypal Upgrade Packages

Archetypes Created from 4 envelope, 3 HVAC & DHW and 3 PV options

Costs and CO₂ reduction predicted using random forest regression models for each individual measure
Mild Envelope upgrades + PV gives good carbon savings at least cost
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

Target Cost

Ductless Heat Pump Installed Cost per Ton (2019 $USD)

23 homes.lbl.gov
Cost Compression - Heat Pump Water Heater, 50-Gal

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

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

Low  Average Cost  High
$800  $2,500  $4,500

(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
- Project design
## Cost Compression – Soft Costs

<table>
<thead>
<tr>
<th>Outsource customer acquisition to programs with marketing and sales expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>CURRENT</td>
</tr>
<tr>
<td>$1,000-2,500 per project</td>
</tr>
<tr>
<td>COMPRESSED</td>
</tr>
<tr>
<td>$700</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reduce diagnostic testing and commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>CURRENT</td>
</tr>
<tr>
<td>Combustion: $387</td>
</tr>
<tr>
<td>COMPRESSED</td>
</tr>
<tr>
<td>$0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Remote approaches to customer acquisition, management and sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>CURRENT</td>
</tr>
<tr>
<td>Remote audits: 40% cost savings for individual projects</td>
</tr>
<tr>
<td>COMPRESSED</td>
</tr>
<tr>
<td>60% savings for executed projects</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Automated, rapid HVAC equipment sizing</th>
</tr>
</thead>
<tbody>
<tr>
<td>CURRENT</td>
</tr>
<tr>
<td>$564</td>
</tr>
<tr>
<td>COMPRESSED</td>
</tr>
<tr>
<td>$100</td>
</tr>
</tbody>
</table>
Cost Compression – Soft Costs – Real Life Examples
DIY Solar PV and Heat Pump

• 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.

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

Custom design
• Pre-insulated line sets
• Simplified fittings
• Strong advertising

- Strong advertising

Never Stop Dreaming
Innovative Heating & Air for Your Family
Cost Compression – No- and Low-Cost
Automated emission reductions

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

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

Homelintel 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 Homelintel.

1. Old baseboard heaters costing $100 per month
2. Continuous hot water recirculation pump costing $50 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
Decarbonization Costs – New Metrics
Using Electric Heat Pumps Instead Of Gas Furnaces

CO₂ Emissions Neutrality

80 AFUE

Energy Cost Neutrality

80 AFUE

CO₂ Emissions Neutrality

95 AFUE

Energy Cost Neutrality

95 AFUE

Heat Pump COP required to break even with a gas furnace
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.

Current COP of high performance heat pumps.
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
What’s Next: Transportation

- Current poor public charging infrastructure:
  - Need to be able to charge at home
- Need a spare circuit or new panel/rewiring
- EV could easily be the biggest home load: up to 50 kW
  - Need to restrict power requirement to 7.2kW (or less?)
  - Use timers/smart circuit sharing
- How to make this affordable for everyone?
What’s Next: Time shifting using storage

Can be charged from onsite solar or low-cost mid-day grid power

Good for disadvantaged/low income communities: avoid peak pricing and demand charges

Offset cost with downsized heat pump

Electric Battery
  • 3 to 5 kWh in every home

Thermal Storage
  • Safe, common, phase change materials
  • 10.5 kWh in same space as 50 gallon tank

• How to make this affordable for everyone?
What’s Next?

• Data gathering and analysis for multifamily and manufactured homes
• R&D directed at cost compression – both soft and hard costs
• R&D supporting financing mechanisms for affordability and decarbonization program development
• Develop guidance for industry on most effective approaches
• Stakeholder meetings and other industry engagement
Next Seminar

December 1st

Can you DIY Home Electrification?

Howdy Goudey
Spencer Dutton
Jonathan Wooley
Bruce Nordman