A National Retrofit Challenge to Meet the Paris Goal of 1.5 Degrees

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ABSTRACT

The United States is one of 190 nations that is committed to pursuing efforts to limit temperature increase to 1.5 degrees C above pre-industrial levels. Even back-of-the-envelope analysis shows that this goal will be impossible to achieve without deep retrofits of almost all buildings. This paper explores how this might be accomplished, exploring several options, given that such a program has never been undertaken at this scale before and inherently requires multiple and simultaneous plans and actions by a wide range of stakeholders.

The paper emphasizes the need to take a "whole building" approach to retrofits rather than more common approaches today which emphasize specific widgets or systems. It also emphasizes the need for new methods of approaching building valuation since energy cost savings alone often will not cover the entire cost of renovations. We consider the need for technical innovation in building construction methods and for electric technologies for supplying heat and hot water to buildings. Finally, we consider the impact of deep retrofits on all buildings to the electricity grid as well as the natural gas system.

The paper seeks to establish pathways to accomplish this goal with the minimal *practical* cost disruption and transfer payments from program administrators to property owners. The scale of this endeavor—very roughly $3-$4 trillion—would strain the budgets of current and prospective administrators. The paper introduces a set of paths that, if rapidly implemented, could set us on a practical rather than political approach to meeting the Paris accord.

Introduction and Problem Statement

The United States is one of 190 nations that is committed to “pursu[ing] efforts” to limit the increase in temperature to 1.5 degrees C above pre-industrial levels. Comprehensive analysis has shown that strong efforts in the areas of efficiency, renewable energy, control of greenhouse gases other than carbon, and increases in carbon sequestration are necessary even to meet the 2-degree goal (IEA 2017; NRDC 2017). For the U.S., this goal requires decreasing emissions by greater than 80% by 2050 or sooner.

Buildings account for more than 35% of climate pollution in the U.S. Similar results are seen in virtually all developed economies. Thus, the 2050 goal of 80% reduction self-evidently cannot be met without dramatic (greater than 50%) reductions in absolute emissions from the buildings sector. Some of this reduction comes about due to cleaning up the electric generation mix, reducing natural gas fugitive emissions and combustion, and replacing fossil fuels with renewable energy. Various models (IEA and NRDC 2017) validate that efficiency plays the largest role in the solution.

But we need to do much more to meet the 1.5-degree target (Goldstein 2018). Achieving the goal will require much faster reductions in emissions, and here the buildings sector has an even larger role to play. The vast majority of the buildings that will exist in 2050 are already built. Even if we were to assure that all new buildings were zero net energy consumers by 2030, existing buildings, even with retrofits of the sort modeled in the IEA and NRDC studies, would still emit too much to meet the goal.

Prioritizing the retrofit of existing buildings, rather than solely relying on progressively improved codes for new construction, is a critical policy solution. Existing buildings have problematic operational carbon footprints that are roughly double of what is needed to reach the 1.5-degree goal. At the same time, these buildings already have high-levels of embodied carbon, mainly in steel and concrete. Wholesale replacement of this building stock would mean additional carbon that would go into replacing them—and that's before they operate. Clearly, public policy around decarbonization should favor preservation and renovation of existing building stock over replacement (Goldstein 2012).

Thus, "pursu[ing] efforts" to keep climate change below 1.5 degrees requires that the U.S. undertake a serious program to realize savings in existing buildings and to do so quickly. This is a difficult task, because relatively little analysis has gone into what we can do with retrofits if our goal is climate protection rather than maximizing internal economic benefits. Deep retrofits of buildings are one of the most expensive efficiency options, and their cost effectiveness relies heavily on non-energy benefits and the potential for cost reductions through competition-driven continual improvement.

But "pursue efforts" does not mean "consider efforts" or "pursue thought"; it requires serious work to determine how best to achieve the prompt and deep retrofits needed to meet the 1.5-degree goal. Retrofits must be pursued quickly because climate pollution is cumulative: emissions savings that start this year continue to create more savings into the future. This effect is amplified by the fact that savings in electricity that occur sooner create fuel savings in a grid that is relatively much dirtier than what the U.S. will likely have in 2030 or 2040. We can easily see in Figure 1 that reducing emissions in 2050 and beyond is less effective at reducing the cumulative total than reducing emissions in 2020.

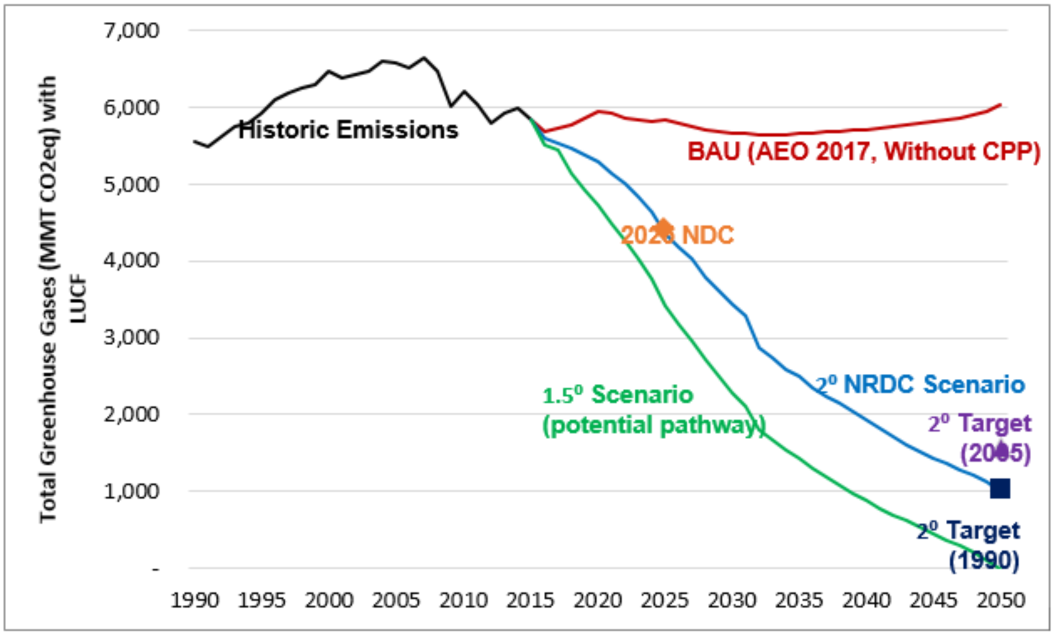

Figure 1. Pathways to climate emissions reduction. (Analysis NRDC 2017 | 1.5° Goldstein 2018)

This paper explores the practical feasibility of implementing prompt, deep retrofits, considering technical issues of measure choice, applicability and cost. It then looks at what the authors believe is the more interesting issue: how to make it happen without relying on politically infeasible mandates or excessive program costs.

It would be easy to say that based on existing research, the goal of 1.5 degrees is impossible to achieve. But the lack of research on how to solve a problem does not mean that the solution is impossible: research can prove the possibility of social and economic change but generally not the impossibility. Indeed, the lack of voluminous research and planning for such a set of solutions is one of the barriers that this paper seeks to overcome.

A Whole Building Approach—Not "Just" the Energy Cost Savings

From our perch in 2018, we know that most new buildings can be constructed to zero energy or zero energy ready performance levels right now at little to no incremental cost—although not mainstream, there are numerous example buildings demonstrating such performance levels without significant added cost. By 2030, it is reasonable to expect such practice to be routine, although vigilance and effort will be required to hit this mark. By far, the larger issue is that on the order of 80% of all buildings today will still be in service in 2050.

For most typical commercial building stock, meaning small- and medium-sized office buildings, schools, warehousing, non-food retail, a ~50% reduction in energy use will result in a site EUI figure in the range of about 17 to 30 kBtu/ft/yr (about 5-9 kWh/ft2/yr for fully electric buildings). And we do know that this can be done: In a 2012 study of nine commercial deep retrofits in the Northwest, New Buildings Institute (NBI) found an average of 52% energy reduction compared to standard benchmarks and their current Getting to Zero list includes dozens of commercial building renovations that have cut energy consumption by typically 50% (Higgins et al. 2012; NBI 2018). PG&E has documented five commercial retrofits which perform in this range (Dean 2016). Likewise, there are examples of savings in the 40%-50% range in residential markets as well.

Our main point to this section is that energy cost savings alone are rarely sufficient to cost-justify what's needed to achieve the 1.5-degree C goal. Within the energy efficiency industry, we hear of many excellent projects where the avoided cost of energy from the energy retrofit pays for the cost of a modest energy retrofit project. These align with dozens of papers presented at previous ACEEE summer studies. However, if our goal is a comprehensive program targeting deep savings in a large percentage of the built environment on a whole building basis, payback math gets problematic for several reasons demonstrated below.

Doing the Math

Consider that energy bills for most of the building stock range from about \$1 to \$3 per square foot per year, with residential buildings trending lower and commercial somewhat higher. To reach the 1.5° C target, we need 50% savings broadly across the *entire* building stock; we cannot select for the "best case." The Present Values of typical savings streams are illustrated in Table 1 on a square foot basis. We have assumed a 30-year project life and a 3% discount rate for simplicity. Although we recognize that individual building economics may vary widely from this example, Table 1 is designed to represent typical conditions across a broad population of buildings:

Table 1. Owner cost savings assuming 50% energy savings, Present Value of savings

Building Type	Typical utility bill, $/sf/yr	Potential Savings $/sf/yr	Present Value/sf of savings stream[1]	Available funds for retrofit based on savings stream	Funds/sf for retrofit based on cost savings[2]
Residential	$1.00/sf/yr	$0.50	$10.00/sf		
Apartment, 1000 sf				$10,000	$10
House, 2000 sf				$20,000	$10
Commercial (light)	$2.00/sf/yr	$1.00	$20.00/sf		
50,000 sf school				$1,000,000	$20
Commercial (moderate)	$3.00sf/yr	$1.50	$30.00/sf		
30,000 sf 0ffice				$900,000	$30

[1]*3% discount rate, and 30-year project life.* [2]*This is below likely cost for deep retrofit of 50+% savings*

Whole building retrofits that save on the order of 50% will, on average, cost more than the present value of the savings stream will cover. For example, to save 50% in a typical single family detached house (2000 sf), substantial shell upgrades (insulation, sealing, fenestration) as well as HVAC and water heating measures will be needed—it will not be possible, on average, to add insulation to the walls and attic, replace the windows, perform air sealing, replace the HVAC system (and ducts) and replace the water heater for $20,000. And it would take 30 years to recover this cost even if it the project could be done for $20,000. In multi-family buildings, the cost will be less but so will the savings since the energy bills are much lower in the first place.

The point is simple: on average, the available savings stream will not support deep retrofits based purely on the value of the energy savings. For the economics to work, the retrofit program must address two other considerations: (1) the improved building valuation from non-energy benefits; and (2) the facilitation of continual improvement in savings and cost over time. The subsequent sections outline shifts needed in markets and programs to get to scale.

Adding Market and Community Value

In private commercial projects we can show examples of renovation work where the enhanced value of the building exceeds the incremental cost of the improvements aligning developers' interest in financial return with energy improvements. For example, a developer chose to invest nearly $50 *more* per sf during renovation to produce a new lease space that was leading-edge in energy systems and a net zero building. The result was a building asset valued at $75 *more* per sf upon leasing and commanding higher rent at nearly $4 *more* per sf - a much bigger deal than the typical $1.50/sf in energy savings (Dean 2016). More efficient buildings simply work better and increase tenant attraction and are thus more valuable from multiple perspectives—the energy savings alone is sometimes the least of it.

This value proposition works differently in other markets. While we can demonstrate the technical feasibility of retrofitting schools and other public buildings to zero-ready condition, there is no "rent premium" available to school districts and government facilities to offset costs. The savings range available to public buildings such as schools is rarely more than $1.00 per sf/ yr. and thus will not fully fund a renovation, even over a 30-year period. However, especially in the case of schools, the district and the students are getting a better learning environment and a healthier building with an extended useful life. To fully address the public market, we will need financial models and financing methods that account for this additional value in public buildings.

This goal is very broad: we are trying to increase the benefits—both energy and emissions savings and comfort and productivity for the buildings' occupants—and reduce the costs—both the societal costs of the retrofits and the costs borne by the program administrator and the utility grid operators—continually over time. This goal suggests that the retrofit program must be sufficiently market-based to generate the competition among contractors and suppliers that leads to continual improvement. Energy ratings can set the stage for that competition.

Add Energy Ratings

A foundational precondition for markets to work is widely available and credible information. Currently there is little to no information at all available on energy performance. A large office building could cost its owner $2 million a year in utility bills or $1 million, and unless it is located in the small number of cities that require transparency with respect to energy consumption, no buyer could tell the difference. Similarly, a house could have energy bills of $4,000 annually or $1,000 and the buyer couldn't tell the difference at purchase.

Energy ratings can set a precondition for making markets pay attention to energy efficiency and make the relatively large cost of retrofits seen as a profit-center to the real estate sector. If energy efficiency as quantified by ratings is reflected in property valuation, appraisals, and lending criteria, competitive forces can start to work.

The next generation of retrofit program should encourage competition at the whole building performance level based on ratings. Since, under today's utility regulatory constructs, whole-building retrofits are one of the less cost-effective efficiency programs, and have been recognized as such for decades, relatively little effort has been expended on optimizing program design and learning from the experience of others. This is why we must encourage different administrators to take different approaches, then be compared annually to see which are more effective, cheaper and faster than another.

Incorporate the Occupant Factor

Another dimension of savings potential comes from occupant behavior opportunities. A rapidly growing group of experts on behavior and human motivations have joined the energy ranks in the last decades with new strategies to influence this factor. Studies range widely on documented savings of 2%-20+% from behavior changes. Yet the methods to reap these savings consistently are works in progress. At the high end, a study for ComEd-Excelon estimated 12%-18% behavioral savings potential in the commercial and industrial sectors (Opinion Dynamics 2013). Even if broadly based programs cannot do this well, a nationwide program can clearly get some of its target savings—and get them sooner than is possible from physical retrofits-- through evolving ways to impact occupant energy use.

In addition to the efficiency measures, solar PV is a viable option that pays for itself in many climates, depending on rate design and other site-specific parameters. Solar has become dramatically less expensive over the past decade because of the continual improvement that results from correcting market failures.

Putting Programs on the Path to Scale

When confronted with an ambitious goal such as 50% savings, analysis finds a paradox: although the costs of whole-building retrofits are much lower than the sum of costs of multiple energy efficiency measures; whole building programs fail regulatory cost-effectiveness tests even as individual measure approaches may pass. One reason is that savings from envelope and lighting measures allow smaller and simpler HVAC systems, and the cost savings on HVAC tends to offset the costs of insulation and lighting measures. A retrofit program needs to encourage and catalyze new and innovative construction methods and product development that can capture deep savings and be credited as a package, not a set of measures within programs. This section looks at the gaps and possible solutions to bring residential and commercial building deep retrofits to scale through programmatic strategies and modifications.

Commercial

Examples of comprehensive retrofit programs that achieve deeper energy savings are few and far between due to the range of issues inherent in both the utility regulatory parameters and the market perception of value in retrofit investments. Still some programs have elevated the approach and the outcomes for retrofits in commercial. The Duke Energy program has verified savings on the order of 20% when addressing just the HVAC component of existing buildings (Duke 2016). Similarly, Towerwise Energy Retrofit Program has demonstrated 20%-30% in the multifamily sector in Toronto Canada (The Atmospheric Fund 2017) and Ecology Action's approach to smaller commercial buildings is yielding an average of 20% from installing a wider range of measures than the typical predominant lighting focused retrofit program (DOE 2016).

A new study provides some compelling financial arguments and data that, if widely applied to a new programmatic method for privately held commercial buildings, could overcome the ignorance of valuation of investment in deep retrofits. A scalable portfolio-based approach to improving a building's energy performance could yield owners a $290 Billion NPV opportunity that has not been available with traditional approaches (RMI 2017). One company worked with Rocky Mountain Institute and could achieve almost 40% savings and prove a financial return that exceeded company targets.

We have found examples of individual projects, but we know of no comprehensive, proven programs that might serve as prototypes for 50% savings. Filling this void by inspiring new work is the goal of this paper. The closest we get to this are individual developers that have built out and replicated a methodology, usually focusing on a single building type. Administrators would do well to examine such efforts and develop methods of scaling them broadly across this sector.

Residential

We already know how to incentivize virtually all homes to undertake deep retrofits, and to do it in just 4 years (a year for planning and 3 years for implementation), because we have already done them as pilot projects (Kinnert 1992; LBNL 2016). These pilots were initiated because the dominant belief among efficiency program administrators at the time was that deep and broad retrofits programs would be impossible. The studies were designed by Pacific Power and Light (PP&L) around 1980 and Pacific Gas and Electric (PG&E) around 1990 to refute that belief, recognizing that the results might also possibly validate it.

These pilots were both very successful. In both cases, some *85% of **all** existing homes* were brought up to the pilot specifications in three years. These pilot programs were operated on the scale of a small community, so the logistical requirements were not difficult. The only direct intervention that the utility managing the earlier program needed was to induce a window company to set up a local factory to produce double-pane storm windows, while the second needed to train air conditioner installers to seal ducts and right-size the new air conditioners.

Clearly it will require more logistical efforts to scale retrofit programs up to a national level. Supplies of insulation materials and efficient windows will need to be scaled up, and manufacturers of climate control equipment will need to adjust assembly lines to upgrade the efficiency so that only the most efficient of the current product line are produced in numbers, and contractors will need to train workers who used to build new homes ten years ago to retrofit existing ones next year.

However, the scale-up does not have to, and indeed should not, occur overnight. We do not want to produce a boom and bust economy of home remodeling: we want to phase the program in over a long enough period that by the end of it the technologies and construction practices will have improved enough that we can go back to the 2018 project and save some half of the *remaining* energy.

It should be achievable within a few years to construct new insulation and window factories, and to adjust product volumes of HVAC production to the higher efficiency options, so a goal of 2030 for completion of Round 1 of retrofits is reasonable from an economic development and jobs perspective as much as a climate perspective.

Lower Program Costs to Increase Scale

The key solution to scaling is reducing administrative cost: the reason for the success of the residential pilot programs is that the utility administering them managed the retrofits from start to finish – from marketing to hiring energy raters to facilitating contractors for owners to inspections and homeowner approval to payment of all the costs: a 'one-stop' approach. We hypothesize that a broad-scale program could mirror this successful method and rely on the administrator to do all of the organizing work—such as arranging the audits, construction, and inspection/rating—but ought not pay much of the retrofit cost.

Almost all retrofits will be cost effective if we can value increased comfort and health. The key here is establishing a dollar value for comfort and health. While this change in the market recognition of value is difficult, it must be part of any program design. Doing this may involve an iterative approach: if all homes post-retrofit are HERS rated, then eventually the savings and comfort will *<u>both</u>* be recognized in the market, and appraisers can develop a formula that translates HERS projections of annual energy costs into increased capital value.

In commercial energy ratings through disclosure ordinances and/or green ratings must be transparent in all business transactions. These are then combined with research documentation on health risk reductions and resiliency improvements in more energy efficiency buildings. The FIRE (Finance, Insurance and Real Estate) industry, that sets costs and values for commercial real estate, can then incorporate the benefits and the energy savings of deeply energy efficiency retrofit buildings, thus increasing the cost-effective equation when evaluating the retrofit.

Finding Funds

Costs for this extensive an effort is substantial: for example, if we retrofit 120 million housing units at a cost of $30,000, each would be $3.6 trillion (assuming $20K for multi-unit and $40K for single family in equal numbers). This is orders of magnitude larger than the amount spent by utilities on retrofit programs, and 80 times higher than the rate of home retrofits in 2016. Thus, a key part of new program will be experimentation with different program approaches that can tap into new sources of funding. Raising the capital would not be difficult if the commitment is made to try. In the market-rate residential sector, the simplest is reforming lending to account for the cash-flow savings from energy (and location) efficiency (Goldstein 2016). This policy would allow retrofits to be financed through conventional mortgages, either by refinancing the original mortgage to add the amount of the retrofit expenses or by using a new retrofit-specific loan or a home equity line of credit.

This is not the only way to handle the financing. Adding a separate secured retrofit loan to the primary loan would increase the security of both, since defaults are strongly correlated to HERS score (Quercia et al. 2013), which the retrofit will reduce substantially. Utilities could also set up arrangements with lenders such that the utility collected the payments through bills and the lender supplied that money at the rates expected for secured debt by qualified borrowers (with qualifications enhanced for this purpose by considering the net decrease in utility bills including on-bill repayment of the loan). Separate types of financing arrangements, including subsidies, are likely to be necessary for rental markets, low-income housing and for commercial.

Jobs in the Equation. This retrofit proposal has strong *societal* non-energy benefits beyond the increases in comfort to the occupants. The worst-performing sector of the economy over the past decade has been housing (Goldstein 2014). Many jobs have been lost as the number of new homes constructed struggles to reach one-half the level it was at before the bubble and crash of 2008-09. The result of the retrofit program would be about 500,000 net new jobs, disproportionately skilled blue-collar jobs, which occur where people already live. Little or no geographic dislocation would be required.

Innovation and “Industrialization” of Renovations

A key to success in retrofits are innovations that lower the costs and increase the benefits over time. “Industrialization” of retrofits is one option that could help. Such methods applied toward common components, such as wall assemblies and mechanical systems, can yield “faster, better, cheaper” product. Our reliance on custom field assembly of buildings is generally viewed as inefficient and antiquated—innovation beyond the status quo is a critical success factor.

Energiesprong, a European approach to retrofitting buildings which began in The Netherlands, has a process for multi-unit residential whole-building renovation which simply places a new building shell over the existing shell, greatly improving the insulative value and reducing air leakage. In one example of a multi-unit retrofit, existing mechanical systems for HVAC and water heating are abandoned and capped in place. New, highly efficient systems are provided that are integrated into the new building shell. The assemblies arrive by truck and are installed with the assistance of a crane. Importantly, the entire process can be completed in a matter of days minimizing the disruption to existing building occupants. In fact, any process requiring the relocation of building occupants for months at a time could easily become a major logistical and cost barrier or even a complete non-starter. Speed counts!

Just as important but a somewhat subtler aspect of Energiesprong is access to capital. The "industrial" approach requires large-scale production facilities, which in turn requires a commitment to large numbers of units which in turn requires access to large amounts of capital. In the U.S., organizations in multiple locations are examining this approach and scoping out pilot projects to try it out in U.S. markets, for example, California Energy Commission EPIC program funding for a similar pilot through Prospect Silicon Valley.

The specific Energiesprong model may or may not carry the day in the U.S., but innovations like those of Energiesprong around large scale "recladding" of buildings, and the related "modularization" of mechanical systems, will be required in any case. Recladding will help with sealing the house against air leakage, which can be the most problematic aspect of home retrofits, and modular mechanical systems can facilitate the use of heat pumps for electrification. Industrial-scale product development, installation and capitalization methods are all needed for success.

Integrating Efficiency and Renewables: Electrification and Demand Response

Retrofits can include electrification of space heating and water heating at an accelerated pace, thus supporting trends toward electrification as an emission reduction strategy and policy. Electrification reduces emissions because the marginal contribution to electric generation is evolving to be more than 50% renewable energy and the rest high-efficiency natural gas in California and is moving that direction nationally – albeit more slowly. The best candidate end uses for electrification are water heaters, space heating systems, and clothes dryers. If we electrify cooking as well, we will eliminate the need to extend gas service to new homes, or to continue to maintain gas lines in existing neighborhoods. Avoiding a gas hookup can save $1,000-$6,000 for a typical new home.

Demand response also saves emissions—it allows more solar and wind generation to be integrated into the grid. There are a few obvious opportunities for demand response, and likely many more when we gain experience with these. Heat pump water heaters already use larger storage tanks because greater storage volume is cheaper than buying a larger heat pump unit. This storage allows hot water to continue to be provided even at system peak or when renewables are not generating much. Conversely, storage allows productive use of electricity to preheat water when renewables would otherwise cause excess generation. Space heating heat pumps can be set to precool in advance of peak loads or periods of low solar or wind availability and then allow the house to float without conditioning. This flexibility is enhanced if extra thermal mass is built into the buildings.

Electrification of transportation increases the efficiency of transport and reduces health-related air pollution emissions. It also helps with renewables integration because charging can be optimized to the times when renewables are most available and curtailed when they are least available. Car batteries could also be used to send power back into the grid if needed.

Overcoming Barriers to Electrify Heating in Existing Buildings

One problem that many successful deep retrofit pilots had to solve was the unavailability of supplies (double-pane storms in Hood River, OR 1978) or contractor skillsets (right-sizing air conditioners and sealing ducts in Delta Project). This is expected to be the case in scaling deep retrofits. There are numerous field conditions in existing buildings where the retrofit program must be designed to bring forth technology that can solve site-related problems that loom large today. Physical size is one example issue: existing heat pump water heaters are generally larger than gas tank heaters. There will thus be costs associated with carpentry needed to accommodate larger units. Perhaps different equipment design can be induced to overcome this limitation.

Another even more significant cost can involve electrical work: products available today require 220 V service and a 40-amp breaker at the electrical panel. Many existing residential units, both single and multi-family, have panels of 100 amps or smaller that usually will not accommodate a 40-amp breaker. The cost of a new run of 220 V from the panel to the install location will likely be far greater than the cost of the heat pump water heater itself. These costs can likely be significantly reduced with new product offerings. For example, the 220V/40-amp requirement is driven entirely by the backup heaters in the heat pump— electric resistance elements in the 4-kW range. In compressor mode, the heat pump draws in the range of just 1 to 1.5 kW and can operated on a 15-amp breaker and 110V. Product innovation focused on higher performance and the elimination of the resistance heaters and smaller physical size are key enablers to product adoption. If an existing home has air conditioning, changing to a heat pump to provide both cooling and heating will not require a panel upgrade in most cases in mild climates since the existing AC unit already requires a 220 V circuit.

In new construction, as well as in the Energiesprong retrofit strategy, mechanical equipment "pods" or modules where HVAC equipment, water heating equipment, PV inverters, batteries, energy management systems, controls and other key features are integrated into a single unit are under development. The challenge of making this strategy work is far greater in renovation, but it seems clear that some version of this approach will be needed to minimize cost and compress project timelines. The elimination of resistance heating elements, which drive the need for both behind-the-meter and grid-side electrical upgrades, will likely be even more important for such systems to become feasible.

Electrification and Grid and Gas Factors

Electrification on a geographical basis where all buildings within an area are converted at approximately the same time will affect the grid and may require upgrades to it. Such upgrades should be considered in an integrated way, looking at Demand Response, distributed renewable energy generation, and the electrification of personal transportation as a package. Efficiency upgrades, together with the elimination of resistance heat strips in both space- and water-heating appliances to the maximum extent possible, will help hold down grid upgrade costs. Pilot projects are needed to examine this issue, determine its magnitude, understand new load shapes and develop cost mitigation strategies so deep retrofits are not deterred by Grid issues.

Electrification of heating and water heating on a retrofit basis raises additional cost effectiveness issues. Despite the lower emissions of heat pumps compared to combustion heaters, the current low unit cost of natural gas implies that the customer annual utility costs for heating may not go down. With existing natural gas service at the building site, costs involved in going off the gas distribution system are not in play until the gas utility confronts the need to replace that part of the gas distribution system.

Thus, the value stream of retrofit electrification involves societal benefits of reducing fossil fuel use throughout the cycle of extraction, transportation, and combustion, including the benefits of reducing fossil fuel use at the power plant. The latter value has substantial public health benefits. The problem that needs solving is how to monetize these societal cost savings so that the money can be applied to supporting electrification as part of a retrofit program.

This discussion raises important issues that are beyond the scope of this paper: how do we deal with the likely eventual costs of abandoning parts of or all of a natural gas distribution system? This includes the societal costs of the gas infrastructure and who pays for gas business assets and infrastructure investments made according to defined statutes, in good faith and under regulatory review and approval. Serious planning needs to be done around how to decommission portions of the gas grid efficiently and at least cost—it's unlikely a piecemeal approach with gradual reductions in throughput across the entire system would make much sense. While in service, the customer-supplied revenue needs to support safe and reliable operation of the infrastructure.

Summary

How can deep energy retrofits be scaled up to a continental level? Key issues within this question are building up the supply chain for physical and human resources for the transition, timescale and sustainability, and financial resources.

This paper has outlined some program and market needs to create national home and commercial building retrofits that would seek to achieve about 50% savings from all buildings by 2030. Key components include the need for: administrators and regulators to focus on the whole building and its footprint; reforms in building valuation, especially regarding the non-energy benefits of high-performance buildings; innovation on construction techniques and for a new generation of heat pump technology; and finally, to consider the impacts of scaling deep retrofits on both the electricity and natural gas infrastructure locally and nationally.

In addition to the job creation and comfort/productivity benefits of this approach the home retrofit initiative would also offer the largest relative benefits to the middle class, renters, and the poor, especially if equity solutions are a part of the fundamental program design. These groups suffer more of the consequences of poor thermal comfort and poor indoor air quality, and pay a larger proportion of their incomes for utility services.

No other summary of how to meet climate goals, to our knowledge, has proposed such a fast or deep set of solutions. Many other analyses of this topic project only 15% savings by 2030—only about a third of what is being proposed here. This roughly tripling of energy savings compared to other studies produces a disproportionately significant reduction in emissions, since the electric grid is a lot dirtier from now until 2030 than it is projected to be from 2030 to 2050. And if we are trying to limit concentrations of greenhouse gases, which are cumulative, fast reductions are especially important because we assure that the worst performing buildings will not continue their elevated level of emissions for more than 15 years.

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