Reinventing Fire Buildings Sector Methodology

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METHODOLOGY FOR REINVENTING FIRE BUILDINGS CHAPTER ANALYSIS

The *Reinventing Fire* (RF) buildings analysis seeks to provide a rigorous, credible, and ambitious vision for the energy consumption of the U.S. buildings sector between now and 2050. Though many other organizations have conducted similar work, we have chosen to conduct this analysis for three reasons:

- To better understand buildings' ability to contribute to the reduction of nation-wide fossil fuel consumption
- To be able to adjust our assumptions and conduct sensitivity analyses for different scenarios
- To integrate the results and findings of the buildings research with the other RF sectors (electricity, transportation, and buildings.)

The RF buildings analysis estimates the capital investment, the energy and fossil fuel savings, and the energy cost reductions available from energy efficiency in the U.S. built environment between 2010 and 2050. To estimate these impacts, we employed our own bottom-up model to generate energy efficiency supply curves (marginal cost *vs.* marginal savings) based on empirical data for existing technologies. This approach is similar to how most utility demand-side potential studies, including recent efforts by McKinsey and EPRI, have analyzed the efficiency potential in the buildings sector. Our analysis examines four sub-sectors (new commercial, existing commercial, new residential, and existing residential), then aggregates them to estimate the overall building-sector effect.

This document describes in detail how we:

1. projected building energy consumption,
2. estimated the cost-effective energy efficiency opportunity for different technology and design approaches, and
3. assessed the impacts of high-levels of adoption for energy efficiency

1. USING ENERGY FORECASTS

We used two forecasts to help us understand how U.S. building sector's energy consumption will change over the next forty years:

- **Business-as-usual (BAU) forecast**

The BAU case is based on the U.S. Energy Information Administration's (EIA) *Annual Energy Outlook 2010* (AEO 2010), whose Reference Case is segmented by building type, fuel shares, and end uses. The AEO 2010 forecast ends in 2035, so we extrapolated the EIA projections through 2050 using the average annual percentage growth from 2010 to 2035. We also analyzed the EIA data used for the National Energy Modeling System (NEMS) to determine how end-use energy intensities are forecasted to change, and extrapolated those trends to 2050. All efficiency measure costs and savings are calculated against the AEO 2010 Reference Case.

- **Frozen efficiency forecast**
  The "frozen efficiency" forecast represents what consumption would be if the physical energy use intensity of the existing building stock and all new construction stayed constant at 2009 levels over the next 40 years. The physical energy use intensity, as well as the building stock data, are from AEO 2010. In this forecast, existing buildings are still replaced by new construction as the older buildings retire, so the natural rate of stock turnover is captured.

2. Identifying the cost-effective efficiency potential

The opportunities for reducing energy consumption in buildings are countless. Everything from today's most simple insulation measures to the most advanced technology in research labs could be used to save energy over the next forty years.

Our approach captures many of the opportunities we have identified from a large body of research and structures them into three categories that the U.S. can apply to achieve the RF results we model:

- Efficient technologies
- Smart controls
- Integrative design

Efficient technologies

To determine how much energy can be saved and at what cost, we needed to create efficiency supply curves showing the techno-economic potential. The energy efficiency supply curves for our analysis are based on a 2008 Lawrence Berkeley National Laboratory (LBNL) report[1,2], which

[1] R. Brown et al., *US Building-Sector Energy Efficiency Potential* (Berkeley, CA: LBNL, 2008).
[2] The LBNL 2008 report is largely based on: M. A Brown, M. D Levine, and J. G Koomey, "Scenarios for a Clean Energy Future," *Energy Policy* 29, no. 48031 (2001).

also served as the basis for the buildings analysis in the National Academy of Sciences' *America's Energy Future: Technology and Transformation*.[3]

We made four changes to the supply curves provided in the 2008 LBNL report:

- For both residential and commercial, the energy use and cost savings data for new and existing buildings had been aggregated and had to be separated. Having both new and existing buildings data allowed us to apply different levels of savings to new and existing buildings over time.

- We adjusted the cost of conserved energy (CCE) for inflation. The CCE spreads the incremental capital cost over the lifetime of the measure into equal annual payments at a certain discount rate, and then the annual payment is divided by the average annual savings. Our analysis makes no assumptions about program costs or the transaction costs of implementing the measures (both are quite small in mature programs). Our cost of conserved energy uses a 7%/y real discount rate. All values were adjusted to 2009 dollars using the GDP implicit price deflator from the federal Bureau of Economic Analysis (BEA).

- We extended the analysis from 2030 to 2050 to match the *Reinventing Fire* time horizon. This obviously entails uncertainties, though their economic importance diminishes with time due to discounting. We chose to hold the potential percentage energy efficiency savings constant over time because energy efficiency is not a diminishing resource: as the U.S. captures energy efficiency, the energy efficiency resource will also continue to grow over time. We conclude from that information that the percentage savings available today compared to the BAU forecast will also be available in 2050 compared to the BAU forecast, and at the same real cost. *Reinventing Fire* presents substantial evidence of sustained significant technology development (costs of manufacturing decreasing due to economies of scale and many more advanced technologies coming to market) to justify this assumption.

- To eliminate the modest use of oil in the building sector, heating and hot water equipment that uses oil is replaced with high-efficiency heat pumps. Since the NAS analysis did not have fuel-switching measures for oil, we had to substitute the NAS efficiency measures for oil with our own estimates for fuel-switching. These fuel-switching calculations were based largely on building models in DOE-2 eQuest that have

[3] National Academy of Sciences, *Real Prospects for Energy Efficiency in the United States* (The National Academies Press, 2010).

been used in past RMI efficiency analyses.[4,5] Of course, many other low- or no-carbon substitutions for oil furnaces and boilers would also be feasible and are widely used today, including active and passive solar techniques and biofuel combustion.

Smart Controls

Smart controls are an additional energy-saving opportunity not included in the cost-effective efficiency levels determined in the 2008 LBNL and *National Academy of Sciences* report.

A report published in 2010 by the American Council for an Energy-Efficient Economy analyzed the results of 36 pilot programs directed at changing residential customer behavior. [6] ACEEE documented four separate types of programs that can be implemented with various levels of savings: enhanced billing, real-time (opt-in), real-time (opt-out) and well-designed, behavior-savvy programs.

Our analysis focused on implementing the programs ACEEE categorizes as "well-designed, behavior-savvy." ACEEE describes these types of programs as effectively integrating multiple, non-economic motivational strategies and including both direct and indirect forms of feedback and real-time, appliance-level feedback.

Besides these behavioral change programs, commissioning and retrocommissioning can achieve important operational savings. A 643-building study found commissioning saved 13% with a 4-year payback in new buildings, while retrocommissioning saved 16% with a 1-year payback in existing buildings.[7] These too are not included in the NAS and LBNL analyses.

According to ACEEE, all these programs are expected to have a CCE of ~$0.035/kWh. For the RF buildings analysis, we adopt this as an average cost for smart controls and assume, probably conservatively given the pace of technological progress and delivery maturation, that it remains static between 2010 and 2050. These types of programs are expected to save on average 12.2% per building, but are can only be obtained in 80% of the building stock. Though the ACEEE report

[4] Kendra Tupper and Kitty Wang, "Economic Efficiency Potential of New and Existing Buildings" (presented at the ACEEE National Conference on Energy Efficiency as a Resource, Chicago, IL, September 2009).
[5] As the U.S. transitions to decarbonized electric power to serve most of its energy needs, there will need to be greater attention paid to what the implications for this higher reliance on heat pumps could be. In the RF Buildings analysis, fuel-switching away from oil does not significantly alter load projections, but if the U.S. were also to start switching natural-gas space- and water-heating to electricity, there would need to be a more detailed analysis for how the switching could affect both total load and the load-duration curve. We did not assume such a switch, so buildings continue to use natural gas, although far more efficiently.
[6] K. Ehrhardt-Martinez, K. A Donnelly, and S. Laitner, *Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities* (American Council for an Energy-Efficient Economy, June 2010).
[7] Evan Mills, "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse-Gas Emissions" (2009), http://cx.lbl.gov/2009-assessment.html.

only examined the opportunity in the residential sector, we believe that approximately the same level of savings at the same cost are available in the commercial sector through improved access to information and commissioning, and we have included these estimates in the commercial analysis.

The 12.2% savings are applied across all end-uses equally because there are few data to show whether the savings are greater for some end-uses than others.

Integrative design

We collected seemingly representative examples of integrative design in the four sub-sectors and then analyzed their energy use savings. From this collection of case studies, we selected a range of savings that we think are feasible if best practices are employed.

To determine the energy use savings achieved, we compare the building's energy use intensity (site kBTU/sf) to the average energy use intensity of the four sub-sectors in 2010 in *AEO 2010*. We use this calculation rather than the percentage savings indicated in the case study because the baselines are too inconsistent between cases to support valid conclusions.

We use these savings calculations to estimate the range of savings that can be attributed to adopting the best practices of integrative design. The high case of this range is based on the average of the top-performing half of the cases for each of the four building categories, while the low case is based on the average of the lower half of the integrative design cases considered. Averaging the cases in these two broad categories seeks to account for the diversity in the building stock (climate, building type, users, etc.), but given the small sample sizes of this case-study analysis, these averages are still far from being truly representative, and narrow the range of integrative-design results from the wider range of best and worst performers.

To apply these overall savings numbers to the end-use level, we proportionally scale specific end-uses affected by integrative design until the total savings are equal to the integrative design total for each sector.

We recognize that the costs of these integrative design savings are uncertain. In some cases, integrative design yields greater savings than standard design with no (or occasionally negative) incremental cost: that is, for the whole building, as some parts may cost more but be offset by making other parts smaller and cheaper or even unnecessary. In other cases, the building may have a cost premium. The wide scatter in reported savings and costs reflects differences in design and execution quality. Rather than trying to assign a CCE, we have excluded cost calculations from this part of the analysis, and concluded only that competent integrative design should not incur higher CCEs than conventional NAS-style efficiency gains.

The analysis for integrative design is intended to stretch our audience's imagination and point out that deeper savings are possible. We acknowledge that there are weaknesses to our approach, but we feel that we are better informing our audience by giving a general, high-level estimate for what can be achieved through integrative design rather than qualitatively discussing the benefits as past reports, as the National Academy of Sciences or McKinsey have done, without including their potential at all in the calculated findings.

3. Modeling approach

Besides using supply curves to understand how much energy the building sector can save at what maximum cost, we also had to estimate the rate of adoption—how much efficiency uptake occurs in a given year. The assumed adoption rates are adapted from experience and research at the Electric Power Research Institute (EPRI) and the Northwest Power Planning Council (NWPPC). The EPRI adoption rate is based on the success of past utility programs and is intended to serve as an estimate for energy efficiency adoption if their trajectory is sustained.[8][9] The NWPPC uses an adoption rate of 85% in its planning, and RMI has adopted those well-validated Pacific Northwest regional goals as long-term goals for the entire U.S.[10]

Like the 2008 LBNL report, adoption is based on a "phased-in" approach, where the implementation and adoption of measures is based on stock turnover using retirement curves for buildings and equipment. This approach is well grounded because it gives us all a greater idea of the constraints to achieving high levels of energy efficiency: the capital stock will be replaced relatively slowly, and few early replacements are expected to occur.

In the RF Buildings model, we do not assume that the U.S. will be able to achieve 85% adoption rates overnight. Rather, we allow twenty years (2011–2030) for the U.S. to ramp up from EPRI's historic adoption rates.

Using building stock data, efficiency supply curves, and adoption rates, our calculations for the impact of the U.S. implementing our vision include:

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[8] EPRI. *Assessment of Achievable Potential from Energy Efficiency Demand Response Programs in the U.S* (Palo Alto, CA: EPRI, 2009).

[9] For this estimate, we averaged the designated 2010 end-use adoption rates of "realistic achievable potential" scenario.

[10] NWPPC. A Retrospective Look at the Northwest Power and Conservation Council's Conservation Planning Assumptions. Council document 2007-13, 2007

- **Capital cost.** Since energy efficiency measures generally have higher initial upfront costs, it is important to calculate how much more capital the U.S. will need to spend if it seeks to achieve higher energy efficiency. The capital costs are based on the incremental cost between the efficient equipment and the equipment that would be installed in the business-as-usual EIA scenario. The incremental capital cost for each year is discounted back to 2010 at a 3%/y real societal discount rate and then summed to provide the present value of the marginal capital costs for transforming the U.S. buildings sector.

- **Energy savings.** We examined several impacts of increased energy efficiency: the overall reduction in site and primary energy use (in quadrillion BTU/y) compared to the BAU forecast; the percentage reduction in energy use compared to the BAU forecast; and the reduction in energy use intensity (kBTU/sf-y) achieved over time in each sub-sector.

- **Energy cost reductions.** Greater energy efficiency leads to lower energy costs in the residential and consumer sectors than those in the BAU forecast. Fuel prices could decline due to overall demand reductions, but we assume that the impact on electricity prices is insignificant because there are so many other factors (disruptions in production, currency exchange rates, inflation, etc.) that have a larger effect on fuel prices.

- **Fossil fuel savings.** Different buildings consume different types of fuels for different end-uses. For instance, a residential home in the Southeast might use electric resistance heating while a commercial office in the Midwest will probably use natural gas. As the energy efficiency measures are adopted, we calculate how fuel consumption will also change. Our analysis tracks fossil fuel consumption year after year, thus creating a profile for how the use of fuels (coal, natural gas, oil, etc.) changes over time.