ReEDS Capacity Expansion Model and the Value of Efficiency in Long Range Planning Scenarios

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ABSTRACT

The National Renewable Energy Laboratory's (NREL) Regional Energy Deployment System (ReEDS) is a linear programming model designed to analyze the investment and operational needs of the U.S. electricity system over 40 years. ReEDS's regional structure was developed to explicitly address a variety of issues related to renewable energy technologies, including accessibility and cost of transmission, regional quality of renewable resources, seasonal and diurnal generation profiles, variability of wind and solar power, and the influence of variability on the reliability of the electrical grid (Short, et al. 2009). By minimizing costs while meeting system constraints, the linear program determines which types of new capacity are the most economical to add and operate at a balancing authority spatial resolution.

While it was developed to address supply-side capacity expansion, ReEDS is also a powerful resource planning tool for delivering of energy efficiency at high percentages of load. For this paper, we use ReEDS to understand how meeting Energy Efficiency Resource Standards (EERS) around the United States can help drive investment in renewables. Results from long-term planning simulations illustrate efficiency as an invaluable driver for renewables, while maintaining low system cost.

Introduction

Across the country, the past five years have been a fruitful time for both renewables and efficiency. Great progress has been made in both legislative actions and detailed analysis.

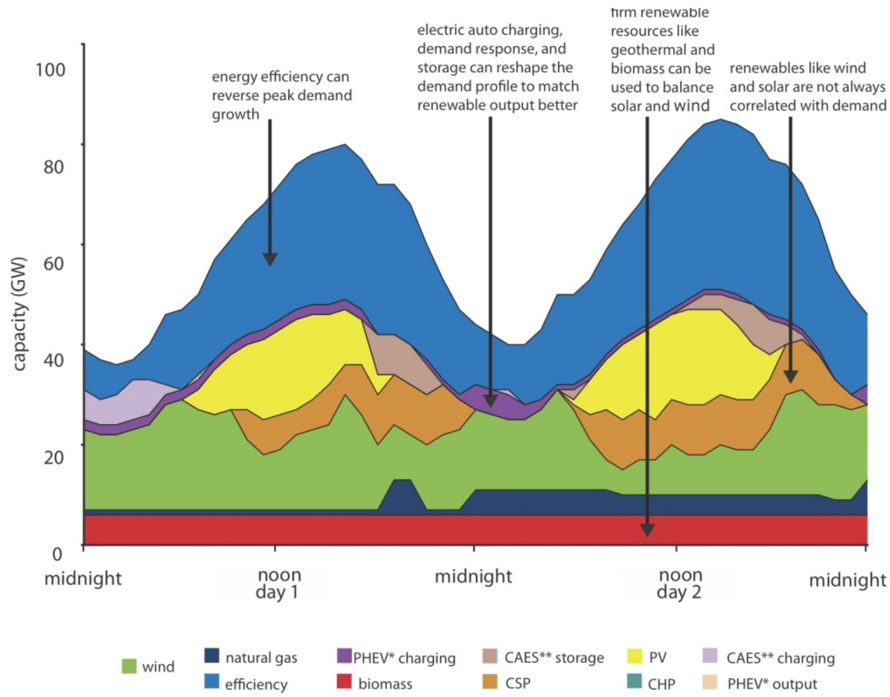
As of March 2012, 30 states have adopted Renewable Portfolio Standards (RPS) mandating a specific percentage of total retail sales come from renewable sources. California has a well-publicized 33% by 2020 target. Colorado and Hawaii also have ambitious goals, with 30% and 40% of retail sales, respectively by 2020. RPS proceedings have generated a wealth of planning and analytical tools. These tools, such as the CPUC's *33% RPS Calculator*, have been indispensable in demonstrating that goals can be met at reasonable cost and allow comparison of resource procurement strategies under different market and regulator conditions (CPUC 2009).

Energy Efficiency Resource Standards (EERS) continue to ratchet up to higher levels of demand-side savings. While not all states are planning to turn down load growth like Vermont, many of these targets are aggressive. As of October 2011, there are 24 states with EERS standards, with Arizona leading the way of states with specific percentage savings goals at 22% of load by 2022 (Sciortino, et al. 2011).

Analysis supporting EERS standards is equally sophisticated to its supply-side counterparts. Extremely detailed demand-side studies in California and the Pacific Northwest have determined the technical, economic, and achievable energy efficiency in the state. Newer studies have increasingly innovative approaches to quantifying potential savings from codes and standards and behavioral programs.

While analytical tools for both supply- and demand-side resources have greatly improved, utilities and states often treat generation procurement and energy efficiency independently and the two are rarely synched up for long-range planning. There's a real need for a more unified approach, as supply- and demand-side resources can complement each other and offer a range of mutual benefits. Energy efficiency at 20% of retail sales is a *bona fide* resource and should be modeled as such. See example in Figure 1 below:

Figure 1. Hourly System Operability Example Under High Penetrations of Energy Efficiency (Blue)



RMI attempted to bridge efficiency planning and renewables planning using the National Renewable Energy Laboratory's Regional Energy Deployment System (ReEDS) model as part of our *Reinventing Fire* publication, a roadmap for getting the U.S. off of coal and oil. Though ReEDs was developed to explicitly address a variety of issues related to renewable energy technologies, it also highlights impacts of energy efficiency at levels mandated by EERS, as of May 2011.

ReEDS Model

To assess the implications of possible future paths for the U.S. electricity sector, RMI developed analysis for four *Reinventing Fire* scenarios or "cases" based on differing assumptions about how electricity might be generated, delivered, and used from 2010 to 2050. In particular, ReEDS acknowledges the variability in energy efficiency procurement and quantifies energy efficiency's importance to renewables development.

We develop input assumptions for each case based on five criteria:

- **Technical feasibility**
  Is there sufficient resource available, do the technologies exist commercially, and is the required scaling realistic?
- **Affordability**
  How does cost compare with business-as-usual, and does electricity remain reasonably priced?
- **Reliability**
  Can the system be operated reliably? How vulnerable is the system to natural or deliberate disruption, and can it bounce back quickly?
- **Environmental responsibility**
  Does the case minimize health and environmental impacts?
- **Public acceptability**
  Could this case actually be built under realistic political conditions?

We analyzed the performance of the U.S. electricity system using two models. First, for distributed renewable resources[1], RMI's own electricity-dispatch model calculated the costs of meeting hourly electricity demand throughout any particular year, dispatching the lowest-cost, reliable mix of resources at an hourly time scale within the assumed portfolios. Second, we determined the total cost, generation, capacity and emissions of each case using ReEDS.

ReEDS is a system-expansion model designed to build and operate new generators and transmission in 23 two-year periods from 2006 to 2050 while minimizing system costs and meeting reserve and emission requirements. The primary outputs of ReEDS are the amount of capacity and generation of each type of generating resource (coal, gas nuclear, wind, etc) in each year of each 2-year period. It includes all major conventional thermal generation types. However, renewable and carbon-free energy technologies are a focus. There are also four storage options (pumped storage, batteries and compressed air and ice storage) allowed in the ReEDS model. Batteries and PSH can contribute to planning and operating reserves, CAES only to planning reserves. The demand forecast is highly customizable for different energy efficient procurement scenarios at the resolution of a balancing authority.

The objective function is a minimization of all the costs of the U.S. electric sector. Costs are inclusive of:

- the present value of the cost for both generation and transmission capacity installed in each period
- the present value of the cost for operating that capacity during the next 20 years to meet load, i.e., fixed and variable operation and maintenance (O&M) and fuel costs
- the cost of several categories of ancillary services and storage.

Major constraints to ReEDS are characteristics of the generating resources, transmission, load to meet, reserve margin, operating reserves, wind surplus, emissions, and renewable portfolio standards.

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[1] At present, distributed wind and solar PV are not included in NREL's ReEDS model, so our independent dispatch model was required.

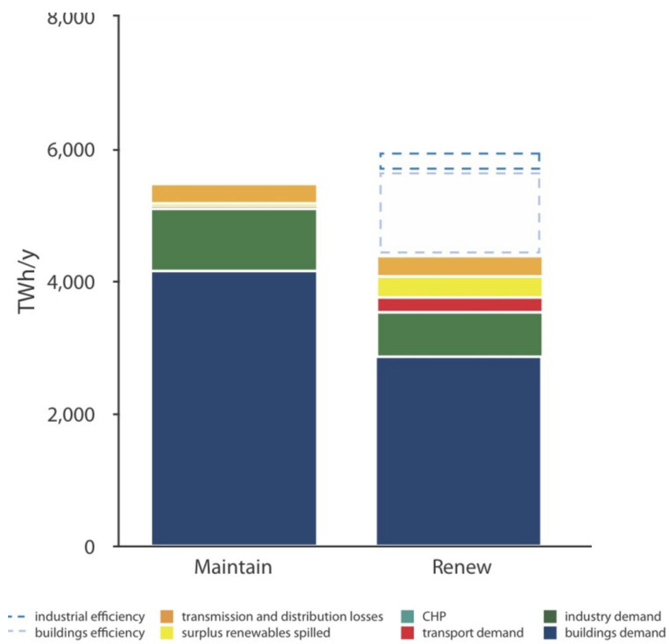
For this paper, we have chosen to highlight just two of these scenarios in order to show the impacts that high levels of efficiency adoption can have on long-term planning. For more information on RMI's scenarios for *Reinventing Fire*, go to www.reinventingfire.org.

Inputs

Case Study Summaries

Three end-use sectors demand electricity: transportation, buildings, and industry. From the perspective of the electricity system, demand from the transportation sector increases with the adoption of electric vehicles; demand from the buildings and industrial sectors decreases with the adoption of efficient technologies and combined heat and power (CHP). The relative contribution to final demand by case is shown in Figure 2. An overview of the two cases selected to compare high penetrations of efficiency follow.

Figure 2. 2050 Electricity Consumption by Scenario



Case 1 (*Maintain*) expands a system much like today's in both demand and generating technologies. As such, build out of central renewables, coal, IGCC, distributed wind and nuclear were unconstrained. Business as Usual (BAU) energy savings was assumed, which are explained in further detail below. Demand response was assumed to be 6% of peak demand in 2050. There was no incremental CHP or PHEV demand relative to BAU baseline. Distribution cost was assumed to be $41.76/MW, with an adder for Smart Grid development of 1.5B per year through 2030, 0.9B per year 2030-2050 ($2009).

Case 3 (*Renew*) examines a future in which centralized renewables like solar, wind, geothermal, biomass, and small (plus existing big) hydro provide at least 80% of U.S. 2050 electricity. There were much more significant constraints imposed in this case. Coal was eliminated by 2050. IGCC and nuclear, however, were unconstrained. Incremental energy savings were 1569 TWh over the *Maintain* case. Demand response was assumed to be 14% of peak demand in 2050. There was no CHP relative to BAU baseline, but there was 225.6 TWh of PHEV. Distribution cost was assumed to be $41.76/MW, with an adder for Smart Grid development of $3.7B per year through 2030, $2.2B per year 2030-2050 ($2009).

Renewables

Resource potentials for wind, solar photovoltaic, geothermal, hydropower, storage, and concentrated solar power were calculated by NREL for each technology (Short et al., 2009). The other two major drivers for renewables development are technology cost and RPS standards. Figure 3 shows RMI's learning curves for each generation technology. For consistency, these values were used in every case. Table 1 shows the RPS standards included in the analysis. Note that the standards used in ReEDS are not current for all states, but accurate for March of 2011.

Figure 3. Learning Curves

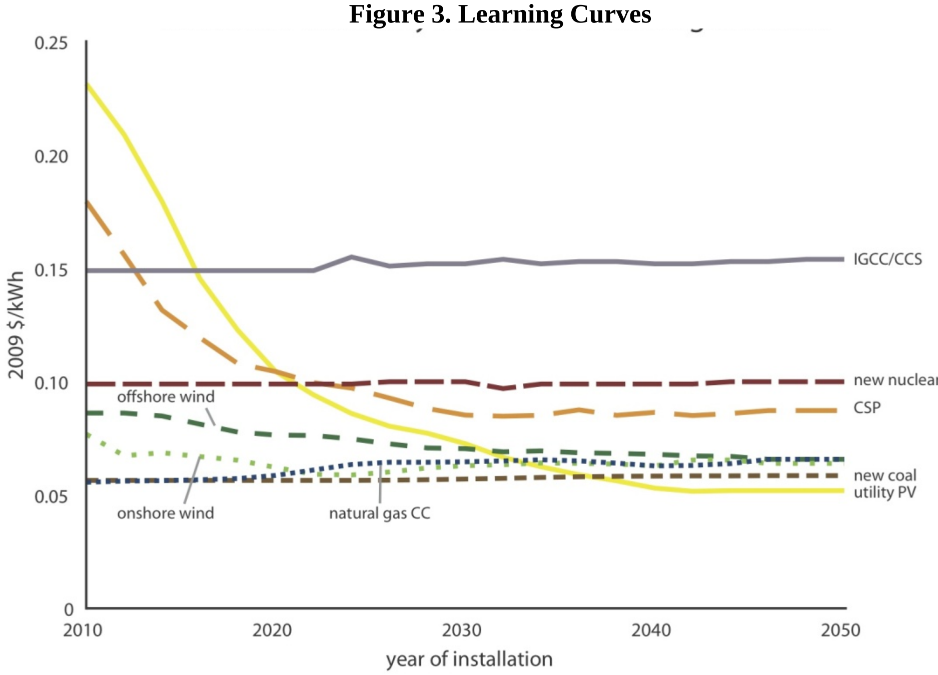


Table 1. Renewable Portfolio Standards

State	RPS Start	Full Implementation	Penalty ($/MWh)	Assumed RPS (%)	Legislated RPS (%)	Load Fraction
Arizona	2001	2025	5	15	15	0.59
California	2003	2011	50	20	20	0.75
Colorado	2007	2015	5	30	30	0.51
Connecticut	2004	2020	55	23	27	0.93
Delaware	2007	2020	5	36	40	0.36
Illinois	2004	2025	5	25	25	0.46
Iowa	1999	1999	5	105 MW	105 MW	1
Massachusetts	2003	2020	59	15	15	0.85
Maryland	2006	2022	20	20	20	0.97
Michigan	2007	2015	5	10	10	1
Minnesota	2002	2025	5	55	55	0.5
Missouri	2007	2021	5	15	15	0.7
Montana	2008	2015	10	15	15	0.67
Nevada	2003	2015	5	20	20	0.88
New Hampshire	2008	2025	54	23.8	23.8	1
New Jersey	2005	2021	50	22.5	22.5	0.98
New Mexico	2006	2020	5	29.4	30	0.52
New York	2006	2013	5	23.7	23.8	0.73
North Carolina	2007	2021	5	21	22.5	0.53
Ohio	2007	2024	45	12.5	12.5	0.89
Oregon	2003	2025	5	40	40	0.51
Pennsylvania	2007	2021	45	17.5	18	0.97
Rhode Island	2007	2019	59	16	16	0.99
Texas	2003	2015	50	5880 MW	5880 MW	1
Washington	2007	2020	50	15	15	0.85
Wisconsin	2001	2015	10	10.1	10.1	1

Energy Efficiency

For our *Reinventing Fire* scenarios, our assumptions for demand vary widely between the *Maintain* and *Renew* cases (Table 2). The *Maintain* case assumes the U.S. continues to capture efficiency at the same rates it has over the past twenty years while *Renew* assumes that the U.S. comes close to capturing all cost-effective energy efficiency available.

Demand in the *Maintain* case is largely based off of the Energy Information Administration's (E.I.A.) *Annual Energy Outlook*. This forecast uses estimates of stock turnover, code adoption, and price elasticity to determine future energy consumption. *Maintain* projects very little change from today in infrastructure, policy, and regulatory structure. As a result, demand grows at around 1% per year for the next 40 years and this demand is largely met by increased gas- and coal-fired generation.

The energy efficiency that is captured in the *Renew* case is based off of the economic potential in the National Academy of Sciences study, "Real Prospects for Energy Efficiency." (NAS 2010) To capture all cost-effective efficiency, there need to be new policies (such as aggressive codes and standards and disclosure at point of sale) but utility programs must achieve unprecedented levels at the national level. While there has been significant progress in some states to incentivize utilities to invest in energy efficiency, *Renew* assumes that all utilities will be incentivized to invest and will drive broader (more customers) and deeper (more savings per customer) savings through their programs.

We made four changes to the supply curves for associated costs provided in the National Academy's study:

- 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.

Table 2. Total Demand in TW for Each Case

	TW				
	2010	**2020**	**2030**	**2040**	**2050**
Case 1	***3,584***	***4,056***	***4,438***	***4,801***	***5,152***
Case 3	***3,584***	***3,952***	***3,917***	***3,746***	***3,563***

To convert our efficiency scenarios in Table 2 to ReEDS timeslices in Table 3, we used the following methodology:

1) We assume the default ReEDS high demand case by NERC region, and timeslice is the same as *Maintain* case, but scaled to match our total annual consumption numbers. This is a very minimal (~1%) change from the default ReEDS inputs.
2) We calculate the full savings from potential in each timeslice for each year, based on annual end-use growth and hourly end-use demand split calculations that are internal to RMI's *Reinventing Fire* analysis.
3) We convert those savings to timeslice percent values by NERC region.
4) We scaled those savings a variable annual percent in *Renew* to match NREL’s low-demand projections.

Table 3. Timeslice Periods

Time Slice	Number of Hours Per Year	Season	Time of Day	Time Period
H1	736	Summer	Night	10:00 p.m. to 6:00 a.m.
H2	644	Summer	Morning	6:00 a.m. to 1:00 p.m.
H3	328	Summer	Afternoon	1:00 p.m. to 5:00 p.m.
H4	460	Summer	Evening	5:00 p.m. to 10:00 p.m.
H5	488	Fall	Night	10:00 p.m. to 6:00 a.m.
H6	427	Fall	Morning	6:00 a.m. to 1:00 p.m.
H7	244	Fall	Afternoon	1:00 p.m. to 5:00 p.m.
H8	305	Fall	Evening	5:00 p.m. to 10:00 p.m.
H9	960	Winter	Night	10:00 p.m. to 6:00 a.m.
H10	840	Winter	Morning	6:00 a.m. to 1:00 p.m.
H11	480	Winter	Afternoon	1:00 p.m. to 5:00 p.m.
H12	600	Winter	Evening	5:00 p.m. to 10:00 p.m.
H13	736	Spring	Night	10:00 p.m. to 6:00 a.m.
H14	644	Spring	Morning	6:00 a.m. to 1:00 p.m.
H15	368	Spring	Afternoon	1:00 p.m. to 5:00 p.m.
H16	460	Spring	Evening	5:00 p.m. to 10:00 p.m.
H17	40	Summer	Peak	40 highest demand hours of summer 1:00pm-5:00pm

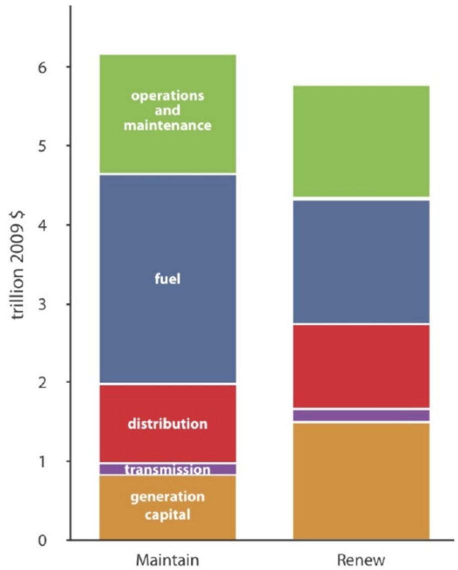
Results

The primary output of the ReEDS model is the generation and capacity build by technology out for each *Reinventing Fire* case. However, also included are:

- **Electricity price**: national average in $2009/MWh with a 30-year rate base. This was $120.83/MWh for *Maintain* $129.04/MWh for *Renew* in 2050.
- **Cash Flows**: bi-annual cash flow values for conventional capital cost, conventional O&M, convention fuel cost, renewables capital, renewables O&M, renewables fuel, storage capital cost, storage O&M, transmission capital cost, and transmission O&M. Cashflow values were used to determine PV system costs in Figure 4.
- **New Transmission:** 354 millions MW miles in *Maintain* and 833 million MW miles in *Renew*.
- **Carbon Emissions:** 49,520 million tons in *Maintain* and 26,473 million tons in *Renew*.
- **Fuel Consumption**: Both coal and natural gas consumption and cost are outputs, in quads and $2009/MMBTU, respectively.

For this analysis, the primary output relevant to energy efficiency is system cost, which is shown in Figure 4. In our analysis, the costs of the highly renewable *Renew* case are lower than the reference case, *Maintain*. The reasons for the lower costs are two-fold. One, the price of cost effective efficiency is lower than any new supply-side resources, whether they're conventional fossil fuel plants or renewables. Two, we expect the cost of renewables to rapidly decline as the installed capacity continues to increase. Given the uncertainty of the future costs for renewables though, efficiency should be leveraged as much as possible because there is a much longer history of deploying the resource and the costs are better-known than for renewables.

Figure 4. Cost Results



Our research shows that from a systems planning perspective, energy efficiency plays a key role in building out a highly renewable national grid. There are many reasons why utilities and policymakers should continue to pursue energy efficiency as part of their clean energy goals:

Keeps the costs of the system low as long as the efficiency is cost-effective.

Changes future load shapes as utilities deploy efficiency to match their load shapes to the renewables on their system

Maintains option value in long-term planning by deferring or reducing the need for conventional power sources while the cost of most renewables continue to decrease over time

Reduces financial risk associated with larger scale investments because its short lead time and small unit size lets utilities reduce financial risk by installing measures in increments more closely matched to changing customer demand

Increasing efficiency to enable more renewables

In order to capture the levels of efficiency in the *Renew case,* the U.S. must start capturing efficiency savings more aggressively today.

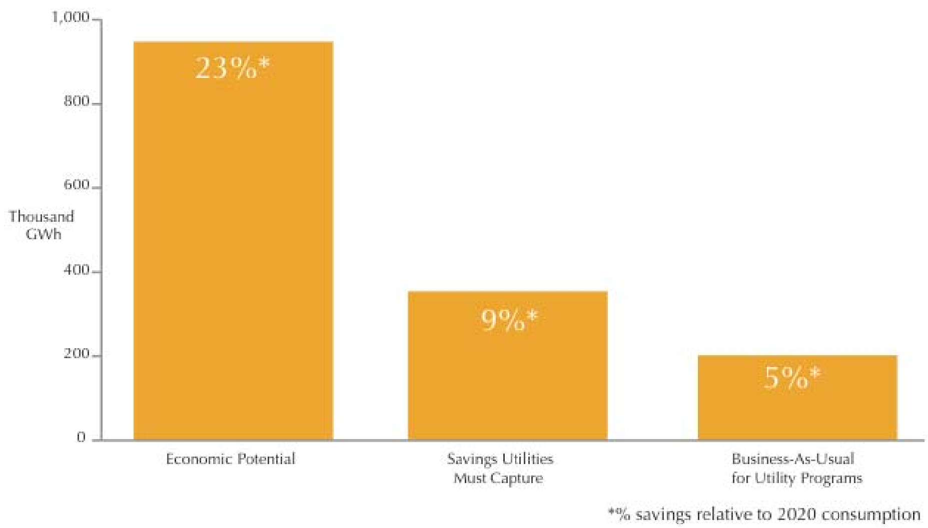
Utilities are now poised to achieve unprecedented levels of savings. Policymakers in many states require utilities to save the equivalent 20% of their sales in 2020 with Energy Efficiency Resource Standards (EERS) over the next decade, and regulators are allowing utilities to recover lost revenues and earn returns for shareholders on par with supply resources. Investments in efficiency are growing significantly due to these new goals, requirements, and incentives.

Though this progress is significant, there are two critical gaps that policymakers, regulators, and utilities in the U.S. still need to address (Figure 5).

The first gap is between the economic potential from the National Academy and what utilities are required to achieve (NAS 2010). More than half the states have mandated energy efficiency goals that will require utilities on the whole to achieve unprecedented levels of savings. But utilities can achieve more. Trending states that have begun to invest can match the savings levels of leading states over time (~203% of total electricity demand annually). Laggard states with little or no program budget for efficiency can begin to make significant investment.

The second gap is between what utilities are required to achieve over the next decade and their current pace for savings. Most utilities have either met or exceeded their goals to date. But these goals are only beginning to ramp up and as they become more substantial, conventional programs will not be sufficient. If utilities are to capture a greater portion of the economic potential over time, they will have to meet current savings goals first.

Figure 5. Energy Efficiency Savings Gap



To meet these current savings goals, utilities can increase the effectiveness of their programs. The leading utilities have recognized that conventional tactics will be insufficient and are already looking for new ways to deliver savings. As other utilities begin to build up their program departments or third party providers to achieve higher levels of savings, they too will have to look to find ways to capture more savings from their programs.

While we know the options in our toolkit, correctly timing and organizing the sequence of applying the right tool to the unique situation of each city, building owner, or business leader is not so easy. There is no one-size-fits-all approach. Experimentation, reorganization, reprioritization, and in some cases complete transformation will be required.

Based on our *Turbocharging Energy Efficiency Programs* report (Bell & O'Donnell 2011), here are four broad elements that we believe are critical for making efficiency more effective at delivering high levels of savings:

Making marketing work. By understanding and influencing consumer opinions about energy efficiency, utilities can align good technology with good messaging. The leading utilities do not simply publicize their programs and incentives. They understand their consumers' needs, values, and desires, and use this information for messaging their programs. To improve marketing efforts for programs, utilities can segment their customers, customize messaging to them, and continue to build relationships and trust with their customers over time.

Improving sales execution. Utility programs can pursue significant opportunities to raise conversion rates from prospective participants to actual participants. The leading utilities have embraced strategies that allow for easy adaptation to customer demands and have been open to new program ideas. Some of these strategies include being dynamic and flexible with how programs are structured, approaching customers from different angles, and recognizing patterns among customers to take efficient design to greater scale. These sales strategies can increase the number of participants and the likelihood of repeat participants.

Driving down transaction costs. Since the average costs of programs have been so low, utilities have not had to run their efficiency programs as leanly as they could. As policymakers continue to ratchet up goals, and utilities focus on going broader and deeper, they will have to find ways to cut out unnecessary costs and increase the productivity of their program portfolios in order to maintain cost-effectiveness. There are many new, promising tools that the leading utilities are using to drive down transaction costs, including faster and simpler audits, moving upstream to vendors and manufacturers, and using the web effectively to drive participation rates.

Embracing collaboration. Stakeholders in the utility energy efficiency program process include regulators, non-profit organizations, architectural and engineering firms, contractors, auditors, and customers, among others. To achieve higher levels of savings, all of these parties can work more closely together. For utilities, there are many benefits for working with other stakeholders, such as finding new ideas for programs, getting credit for codes and standards, and increasing "buy-in" among regulators who many not favor program innovations.

Beyond improving utility program performance over the next decade, to attain the highly renewable scenario we have described, there will need to be more work focused on increasing the efficiency potential. There will have to be significantly more research and innovation to decrease the costs of promising technologies that currently are not cost-effective (like aerogels for insulation and phase-change materials for windows). Furthermore, architects and engineers will have to leverage best practices in integrative design to improve the efficiency of their designs while keeping their costs low.

Conclusion

Efforts to integrate demand-side options with traditional supply-side operations are becoming more common. Regional studies, chiefly the 6th Power Plan in the Pacific Northwest, have taken a more comprehensive approach to valuing supply- and demand-side options. Several Integrated Resource Plans (IRP), including Long Island Power Authority, used a potential power plan as a benchmark and went after the load with efficiency (Voltz 2011). Other utilities, such as Con Edison, have looked into substation-level impacts of efficiency resources (Gazze 2011). Additionally, aggregators can make bids with demand response into the PJM market, which is lowering system costs (Walawalkar, et al. 2010).

As energy efficiency savings ratchet up to high percentages of load, there is a need for more sophisticated analytical tools like ReEDS that can accommodate a variety of demand-side scenarios. While cost effectiveness is an effective tool for measure screening, it does not account for the other ways efficiency can provide value to the system. While our modeling shows that efficiency can be used as a resource to drive down the costs of a highly renewable system, it does not explicitly intermingle supply and demands-resources. Therefore, much more work can be done to show just how valuable efficiency can be at a system level.

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