Building the Energy Efficiency Power Plant: Tennessee Valley Authority's 2015 IRP

TVA has a mission of service providing energy, environmental stewardship and economic development to the Tennessee Valley region. Our latest 2015 Integrated Resource Planning (IRP) process included a unique and industry influencing way to incorporate Energy Efficiency as a dynamic selectable resource to help build TVA's Energy Efficiency Power Plant. TVA was one of the first in the nation to model energy efficiency on an equal playing field to traditional resources in an IRP. There is interest across the utility industry to understand this more and potentially replicate it in other regions.

In our prior 2011 IRP, our process was similar to how other Utilities input energy efficiency into planning models - we scheduled energy efficiency (EE) and Demand Response (DR) as fixed supply curves into the resource portfolio and tested multiple portfolios.

With our 2015 IRP, we set a goal to model EE and DR as dynamically selectable resources. We developed a new approach to accomplish this. We defined 10 MW 'blocks' of energy efficiency with specific characteristics (residential, commercial and industrial) and with specific attributes for each block (and designed them to look like thermal resources with nameplate capacities, book lives, $/kW pricing tiers by sector, "Ramp Rates" and unit availability and hourly load shapes).

This approach was a significant challenge both during the development and data population process. TVA engaged stakeholders as part of the process by establishing an 'Energy Efficiency- Information Exchange' (EE-IX) group to provide input and technical expertise into the formation of the EE model inputs. This group which had a broad diversity of subject matter experts, State Energy Offices, Environmental and Energy NGOs, Researchers, Local Power Companies and other Customers, was a significant help to TVA. In addition, TVA's IRP Working Group, also of diverse membership, reviewed and provided input throughout development of the 2015 IRP.

In the end, TVA was able to successfully model EE and DR resources as indicated in our 2015 IRP (Appendix D). Our 2015 IRP recommendation includes achieving between 900 and 1,300 MW's of EE by 2023, and between 2,000 and 2,800 MW's by 2033.

Advantages:

- Allows full portfolio optimization
- More clearly demonstrates value proposition
- Allows flexible, nimble response to changing business environments

Challenges/Considerations:

- Typical EE modeling approach (as a load modifier) doesn't lend itself to an easy transition to supply side modeling
- How to account for cost changes over time
- How to account for uncertainty on load shapes
- How to acknowledge TVA's unique structure as (primarily) a wholesale power company

Key Conclusions:

- Did we change the conversation about EE? *We think so.*
- Did we do it completely correctly? *I doubt it.*
- Was it analytically challenging? *Quite.*
- Did we get stakeholder support for approach, if not on all particulars? *Largely.*
- What did we establish?
    - EE is a competitive resource that introduces unique uncertainties while mitigating others, and that this modeling approach better demonstrates the value EE brings to the portfolio
    - We have additional work to do to leverage this dynamic approach in annual resource planning

The Tennessee Valley Authority is a corporate agency of the United States that provides electricity for business customers and local power distributors serving 9 million people in parts of seven southeastern states. TVA receives no taxpayer funding, deriving virtually all of its revenues from sales of electricity. In addition to operating and investing its revenues in its electric system, TVA provides flood control, navigation and land management for the Tennessee River system and assists local power companies and state and local governments with economic development and job creation.

Appendix D

2015 IRP: Modeling Energy Efficiency

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1 Energy Efficiency in the IRP

One of TVA's goals is to provide low-cost, clean, and reliable electric power to consumers and it does this by maintaining a diverse set of energy resource options. Energy efficiency and demand-side management programs have been part of TVA's energy portfolio since the late 1970s and include incentive programs, price structure changes and educational efforts to encourage awareness and smart consumer choices. TVA continues to offer programs under the EnergyRight® Solutions brand that include residential, commercial, industrial, renewable (end-use-generation), demand response and educational/outreach initiatives.

TVA is currently engaged in evaluating new programs, delivery and impacts as it continues to evolve the demand side management portfolio. These programs help reduce reliance on power purchases from other suppliers, reduce power production environmental impacts and mitigate utility bill pressures by providing benefits to consumers and the TVA system. Refining the characterization of energy efficiency in models will enhance potential for success and assist in keeping electricity costs low.

1.0 Energy Efficiency Modeling

TVA's 2011 IRP used discrete energy efficiency portfolios matched to specific strategies for the modeling effort. The portfolios consisted of detailed program designs for individual energy efficiency and demand response programs that outlined annual costs and demand/energy reductions across a 30-year planning horizon. In the 2011 IRP, energy efficiency consisted of over 20 individual program designs, and the portfolios were considered "must run" components of their respective strategies.

Two significant drawbacks to this approach were the lack of flexibility in the must run nature of the energy efficiency contribution for each strategy design and the staff time required to develop program details for efforts that would not necessarily launch for several years. To address these deficiencies, a different approach was developed in the 2015 IRP to employ "blocks" of energy efficiency impacts and costs that reflect the characteristics of existing programs but do not require the development of detailed program designs.

TVA energy efficiency programs typically address the major components of energy consumption in the areas of lighting, building shell improvements, HVAC/control upgrades, industrial process changes and a newly identified approach, voltage regulation. Assumptions on changes to load shapes and reductions in demand and energy can be derived from the results of existing programs and projected for blocks which serve as proxies of yet-to-be-defined future programs, as well as continuation of existing efforts. This approach greatly reduces the staff time needed to develop modeling inputs and, if designed in small enough blocks, affords the opportunity for the model to select an optimum level of energy efficiency on an annual incremental basis to match the given strategy and scenario inputs in each model run.

1.1 TVA Energy Efficiency Program Characteristics

A variety of delivery methods are used to deliver programs to end-use consumers. Residential programs are delivered through various channels, which include: up-stream incentives to manufacturers and installers; promotion and administration of TVA-designed programs through local power companies (LPCs); turnkey administration of TVA-designed programs through third-party vendors; and design, promotion and administration of programs by LPCs. In the commercial and industrial sectors, programs are offered to large customers directly served by TVA. The majority of promotion and administration duties for LPC commercial and industrial customers are handled by TVA field staff and a third-party administrator under contract to TVA with the collaboration and coordination of the LPCs. The Conservation Voltage Reduction (CVR) program requires the participation of the individual LPCs and does not involve promotion or participation by individual end-use customers.

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Energy efficiency programs impact the system to reduce costs through demand reduction as well as energy savings. As can be seen in Figure 1, on a typical peak day, the energy efficiency resource provides load matching to TVA's overall load requirements for that day. This is due to the EE resource portfolio design having the same system load shape drivers as the system load. The variable EE shape over the majority of the day (Figure 1) and year round EE (Figure 2) demonstrates that EE resembles the cycling nature of an intermediate resource like a natural gas combined cycle unit.

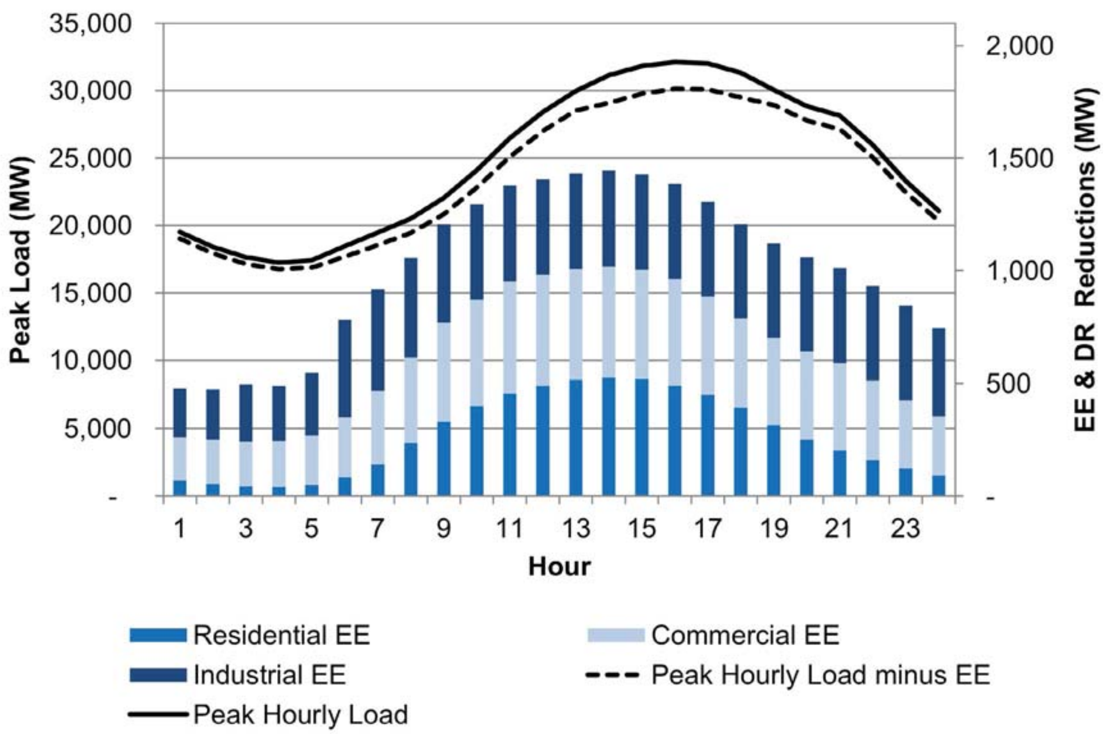

Figure D-1: Energy Efficiency Performance on a Typical Peak Summer Day (2023)

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Looking across a typical year (Figure 2), energy efficiency resources provide fuel and operating cost savings by lowering demand across all months of the year and offsetting the need for base load and intermediate resources. The shapes differ by sector with the residential sector following weather patterns more closely than the commercial or industrial sectors.

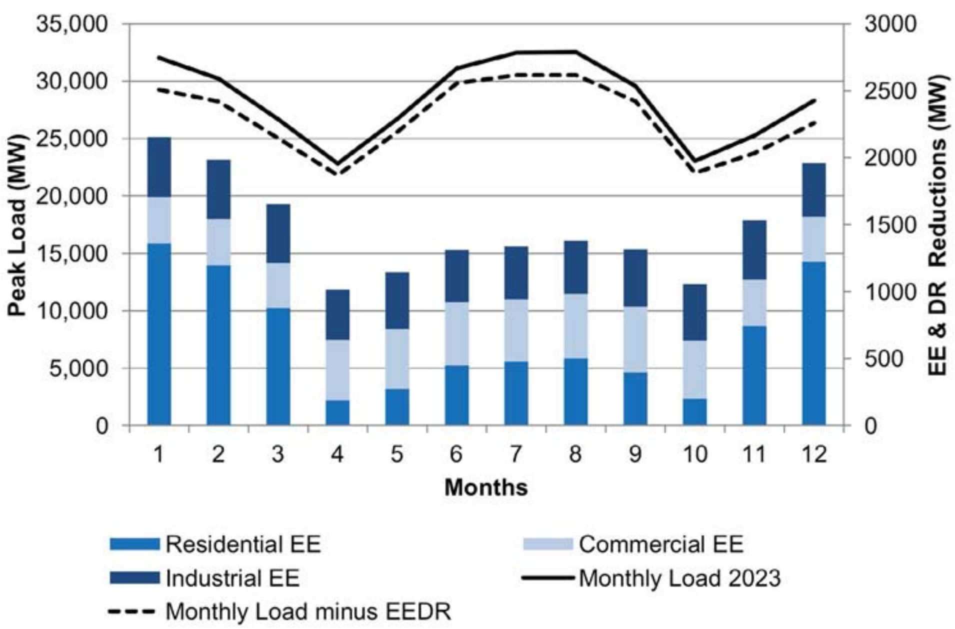

Figure D-2: Energy Efficiency Monthly Profile (2023)

In the block designs used for the 2015 IRP, the residential sector has a defined capacity factor of 57%; the commercial sector has a capacity factor of 68%; and the industrial sector has a capacity factor of 80%. These capacity factors are comparable to other base load and intermediate duty resources with capacity factors typically greater than 40%.

2.0 Model Inputs and Assumptions

For energy efficiency to be a selectable resource option in the optimization model, energy efficiency block characteristics must be developed that are conceptually comparable to other supply side resources.

The Block Concept

Traditional supply side resources have the following characteristics:

- Capacity and energy - typically a known size in MW and MWh respectively
- Install cost - typically a bus bar $/kW
- Construction lead time - years to build from initial project consideration
- Operational characteristics—must run number of hours per year, heat rate (fuel efficiency), capacity factor, etc.
- Service Life - years

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TVA developed energy efficiency options in a similar fashion. Blocks of energy efficiency impacts and load shapes were constructed for three market sectors: residential, commercial and industrial. Each sector has a load shape similar to the weighted average of the end-use load shapes for current EE program within those sectors. For example, a residential EE block has a load shape similar to the weighted average of six residential customer programs' annual load shapes (Table 1). Each of the sectors is comprised of three pricing tiers

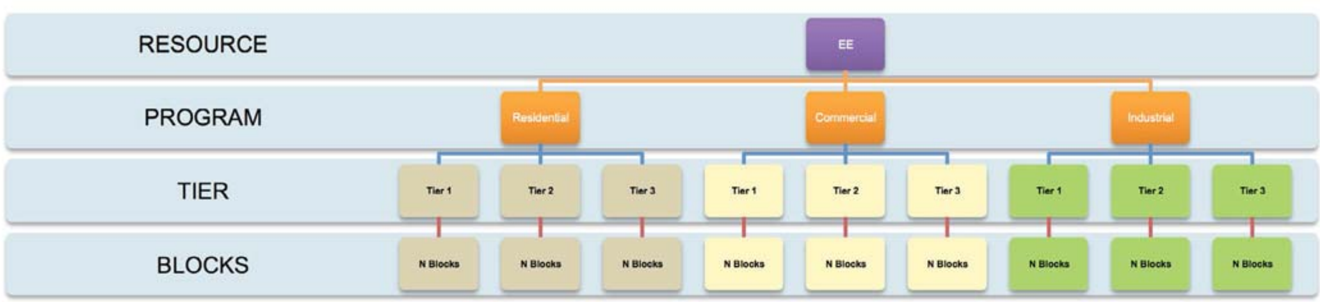

Table D-1: Tier, Sector, and Block Hierarchy

Load shapes, contribution percentages and other program characteristics of the blocks are based on the detailed Program Design Templates developed as part of the FY 2015 TVA budget. Cost and impact estimates for the blocks use an average steady-state, fully-operational estimate of program designs rather than trying to reflect the variation of higher initial/end-of-life program costs.

Blocks were grouped by sector based on commonality of market and similarity of load shape. Each sector's block is composed of different TVA EE programs that carry different weights. Weighting for each sector is found in Table 2 and is based on the past and projected contributions of the various programs.

Residential Programs	Block Weight
New Homes	12%
Self Audit	2%
In Home Energy Evaluation	20%
Manufactured Homes	16%
Heat Pump	10%
eScore	40%

Industrial Programs	Block Weight
Tailored Solutions for Industry	54%
Custom Industrial	10%
Standard Rebate	36%

Commercial Programs	Block Weight
Custom Commercial	10%
Standard Rebate	90%

Table D-2: Weighting of EE Programs

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Each block was developed to be 10MW and between 50-72 GWh in size. This size was chosen to provide flexibility for model selection by being a proxy for EE programs. Current programs each have a net-to-gross (NTG) design assumption (Table 3) which accounts for free-ridership and other aspects of program efficacy and were weighted in the development of the sector blocks. Each existing program also has an associated set of modeled data including the on-peak capacity reduction and associated "operational like" characteristics, which include an 8,760-hour load shape consistent with the sector end-use load shape. Since each EE block occurs at the end use level, the characteristics are "grossed up" for transmission and distribution losses to create a "supply side equivalent" when modeled with other resource options.

Program	Sub Program	Lifespan	NTG
R1	New Homes	15	64%
R2	Kit & Self Audit	6	75%
R3	IHEE	18	80%
R4	Manufactured Homes (VHP)	15	80%
R5	Heat Pump Program	15	67%
R9	ESTAR Man. Homes	15	80%
R14	eScore	18	80%
C1	Tailored Solutions	10	70%
C2	Custom Industrial	10	70%
C3	Custom Commercial	15	76%
C10	Standard Rebate Commercial	15	69%
C11	Standard Rebate Industrial	15	74%

Table D-3: Net to Gross ratios and Lifespans for the EE programs within sectors

2.0.1 Pricing

Once the operational characteristics of each sector EE block was developed, pricing tiers were identified. Pricing tiers were developed to reach more deeply into the pool of potential savings in the Valley; additional costs would need to be incurred to expand delivery system infrastructures and encourage greater participation. Blocks within Tier 1 were priced at the current portfolio of programs for each sector in accordance with the weighting table referenced above.

Tier 2 and Tier 3 consist of programs yet-to-be-developed (some of which represent as-yet-undeveloped technologies) and pricing was based on the step function increase found in Table 4. The breakpoints and step function increase for each of the sectors were developed through consultation with the managers of existing TVA programs and supporting consultants.

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Average Unweighted Increases Relative to Base			
Tier 2	**Residential**	**Industrial**	**Commercial**
ERS Incentives	50%	70%	70%
ERS Variable Costs	26%	70%	70%
ERS Fixed and Low Variable	15%	10%	10%
ERS Other	19%	70%	70%
Tier 3	**Residential**	**Industrial**	**Commercial**
ERS Incentives	100%	200%	200%
ERS Variable Costs	51%	200%	200%
ERS Fixed and Low Variable	25%	20%	20%
ERS Other	29%	200%	200%

Table D-4: Tier Step Changes

The steps in cost for tiers 2 and 3 are similar to a supply stack in which programs with the highest potential are the lowest cost programs, programs with mid-potential are mid cost programs, and programs with lowest to mid potential are at a high program cost. As benefits are exhausted from of the lowest cost programs, it moves down the supply stack to the next lowest cost program.

Levelized costs for each of the tiers within the sectors can be found in Figure 4. Energy efficiency programs are compared against a greenfield combined cycle plant, which energy efficiency tends to closely resemble based on capacity factor. All block costs, including incentives, escalate at inflation (1.8% per year) so that energy efficiency becomes cheaper over time in real terms.

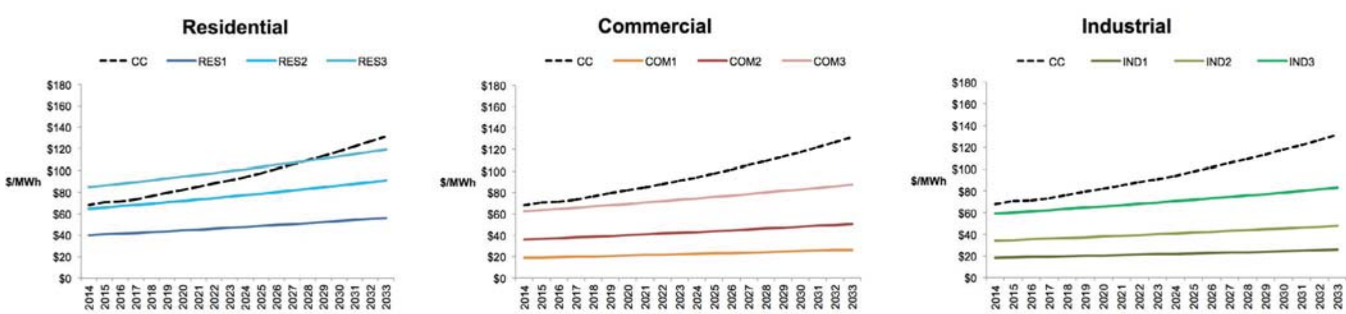

Figure D-3: Levelized EE block cost comparison ($/MWh) compared to a greenfield combined cycle plant over time

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2.0.2 Quantity

Much like the supply side counterparts, EE programs also have operational-like limits on the ramp rate, or year-over-year growth, based on startup time and development of infrastructure. The limits are driven by program development, customer awareness, market penetration, participant acquisition and many other customer and market factors.

Through 2018, TVA has a "required" energy efficiency performance as part of a 2011 EPA settlement. These programs are embedded into the TVA annual business planning cycle and are being modeled as "must run" resources for the IRP resource selection model.

For the selectable blocks, TVA assumed that growth of the total delivered blocks each year cannot exceed 25% when compared to the previous year for years 1-5. For years 6-15, the growth rate was limited to 20%, and then is at 15% per year thereafter. These limits were based on the ability of TVA and program partners to expand the delivery infrastructure from one year to the next and the expectation of increasing consumer/participant awareness.

2.0.3 Block Life

For supply side resources, power contracts expire and power plants reach end of life and are retired. Similarly, energy efficiency resources have useful lifespans (e.g. light bulbs burn out, lighting systems must be upgraded and heating and cooling equipment must be replaced). For the 2015 IRP, TVA has assumed each block of energy efficiency resource can be replaced with a similar block at the available price for that sector's block.

The lifespans for each of the sector blocks were developed based on program composition within each sector, current program lifespan assumptions, and measure lifespan assumptions used by industry standards.

Block Design Parameters	Final		
	Residential	Commercial	Industrial
MW per Block	10	10	10
GWh per Block	50	59	72
Growth Rate (Yr 1-5)	25%	25%	25%
Growth Rate (Yr 6 -15)	20%	20%	20%
Growth Rate (Yr $\geq$ 16)	15%	15%	15%
Max Incremental Blocks per Year Tier 1	9	4	4
Max Incremental Blocks per Year Tier 2	7	4	2
Max Incremental Blocks per Year Tier 3	8	4	2
Max Incremental Blocks per Year Tier Total	22	12	8
Lifespan Tier 1 (Years per Block)	17	15	12
Lifespan Tier 2 (Years per Block)	13	13	10
Lifespan Tier 3 (Years per Block)	13	13	10

Table D-5: Block Characteristics for each sector

Each of the blocks in the different tiers and sectors has differing lifespans. Tier 1 block lifespans were determined using a weighted average based on existing programs. Tier 2 and 3 blocks are made up of programs yet to be developed as well as some potentially unknown technologies, therefore the same estimates could not be applied. TVA instead used an industry average lifespan for each of the sectors. Residential and commercial tier 2 and 3 blocks have a 13 year lifespan and industrial tier 2 and 3 blocks a 10-year lifespan (Table 5).

3.0 Energy Efficiency Methodology within System Planning

3.1 Planning Approach

Energy Efficiency (EE) programs have two basic impacts that are relevant to planners:

1) Avoided energy calculation – Energy not consumed means fuel not burned, resulting in savings in variable costs. Further, since program impacts are felt at the meter, they also avoid transmission and distribution (thermal) losses which can average 6.5% by the time energy reaches an end user.

2) Avoided capacity calculation – Capacity is avoided, because reduced electricity demand translates into reduced need for incremental capacity additions.

Using EE program design parameters, hourly demand profiles are developed via engineering models, such as eQuest, and then calibrated through program evaluation. Inputs to the models include occupancy/utilization profiles and weather data. Each model's key output is an 8,760 hourly profile of a "before" end use shape and an "after" efficient end use shape that are subtracted to get the net savings. The net savings shape is then regressed on weather and calendar variables, revealing the relationship between savings and temperature, day of week, season, etc. The model is then forecast forward using TVA weather and load forecast as inputs. The final result is an hourly energy efficiency savings forecast synched to the TVA load forecast.

There are two basic ways to incorporate the EE shapes into System Planning models:

1) **As a load modifier:** the energy efficiency shapes are subtracted from the original system load and the resulting net system load is fed into the model's "load input."

2) **As a resource (selectable or non-selectable):** consistent with how all other supply side resources are modeled (i.e. nuclear, coal, gas, hydro, etc.). EE resources point to a defined energy pattern (i.e. the EE load shape) similar to a solar resource.

Each approach has pros and cons and the best approach depends on modeling architecture and modeling objectives. For the 2015 IRP, TVA elected to use the model-as-a-selectable-resource approach. This allows TVA to model selectable EE resource units for full optimization. Energy efficiency is non-dispatchable and operates similarly to a number of other non-dispatchable generation resources in that system operators cannot directly control it based on system needs. There are no variable operations and maintenance (VOM) costs nor an emissions penalty (CO_2 costs). Key input parameters are monthly avoided capacity, $/kW (cost divided by summer peak kW) and an hourly energy pattern.

3.2 New Approach to Modeling from 2011 IRP

TVA is taking a new approach to energy efficiency modeling to allow energy efficiency to compete with other resources within each of the IRP cases. This will create an opportunity to allow for full portfolio optimization, to better gauge the impacts of the programs in different situations, and to better demonstrate the value proposition for the resource.

The 2011 IRP study did not contain energy efficiency as a selectable resource. Several different EE portfolios were scheduled as load modifiers in various scenarios. There was no supply stack concept in those portfolios, which in effect reduces model flexibility and limits model outcome. TVA's new modeling approach for

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energy efficiency as a competitive resource attempts to enhance model visibility and potential impacts with regards to least-cost optimization.

3.2.1 Comparability to Other Supply Side Resources

Energy efficiency unit characteristics must be developed that are comparable to other supply side resources. Supply side characteristics that feed the capacity expansion model can be found in Table 6 and are compared against the energy efficiency "power plant."

	SUPPLY SIDE COMPARISON						
	Comm EE	Ind EE	Res EE	New CC	New CT	New Coal w/ CCS	AP 1000
Year Available	2014	2014	2014	2019	2018	2028	2026
Outage Rate				✓	✓	✓	✓
Heat Rate				✓	✓	✓	✓
Fuel Costs				✓	✓	✓	✓
Fuel CAGR				✓	✓	✓	✓
CO_2 Costs				✓	✓	✓	✓
CO_2 CAGR (starts in 2022)				✓	✓	✓	
O&M costs	✓	✓	✓	✓	✓	✓	✓
O&M Escalation	✓	✓	✓	✓	✓	✓	✓
Transmission Contingency Cost				✓	✓	✓	✓
Project Contingency Cost				✓	✓	✓	✓
Capital Costs				✓	✓	✓	✓
Escalation of Capital				✓	✓	✓	✓
Capacity Factor	✓	✓	✓	✓	✓	✓	✓
Technology Shifts	✓	✓	✓				

Table D-6: Resource Characteristic Comparison with EE

For supply side resources in the IRP, unit performance is not expected to be 100%. This delivery risk is captured in an outage rate for the unit. There is not a comparable outage rate for the modeled energy efficiency blocks; rather, the modeling approach assumes the block to be operationally available 100% of the time. Efficiency is dependent on variables such as equipment reliability and service life, operating conditions, etc., that would impact operability similar to an outage rate.

In addition to outage rates, Table 7 shows the potential uncertainties that are captured in cost for supply side resources. Examples include a carbon dioxide emission penalty, fuel cost uncertainty, project cost contingencies and cost escalation uncertainties.

One item unique to TVA's modeling approach on EE blocks is related to technological improvements. Traditional supply side resources do not reflect advancements in technology over time. For example, a combined cycle plant constructed in 2033 possesses the same heat rates, ramp rates, cost of construction (escalated for inflation), etc. as one constructed in 2015 because we do not know what the future technology will be. However, in EE blocks TVA allows for an assumption of technological improvements based on the history of EE deliveries over the past 30 years.

3.3 Modeling Uncertainty

The block design approach is novel and fits well with model architecture, but introduces some uncertainties around design and delivery that are unique relative to other resources. Design uncertainty is introduced by the creation of prescribed blocks of EE meant to reflect bundles of programs over time. Delivery uncertainty exists around claimed versus evaluated measures, the ability to deliver and implement programs though TVA's 155 different local power companies, and risk around EE deliveries relative to future codes and standards.

Uncertainty	
Design	**Deliver**
Proxy Programs in Blocks	*LPC Delivery Risk*
Measure Lifespand Blending	*Codes and Standards*
Unchanging Shapes	*Claimed vs. Evaluated*

Table D-7: Design and Delivery Uncertainties

Uncertainty of all types exists with supply side resources and is modeled in different ways in the analysis, but typically manifest itself as cost. For energy efficiency, TVA considers the two primary categories of uncertainty mentioned above to remain comparable with other supply side resources. In addition, certain variables can be captured directly or indirectly in the stochastic analysis performed in the study. Key uncertainties are discussed in more detail below.

3.3.1 Design Uncertainty

Since the modeled energy efficiency blocks are proxies for technologies and programs not yet developed, there is uncertainty in their design and future composition. Blocks in the study are modeled as 10 MW resources with a defined load shape by sector (residential, commercial, and industrial). The virtual nature of energy efficiency compared with the tangible, physical attributes of supply side resources necessarily introduces a level of uncertainty around certain key design attributes.

3.3.1.1 Measure Life Uncertainty

Measure life or Effective Useful Life (EUL) is the median number of years that the measure after installation is expected to be in place and operable. This includes “equipment life” which is the number of years installed equipment will be operational before it fails, and “measure persistence” which takes into account business turnover, failure or early retirement of the installed equipment.

Each of the energy efficiency blocks contains different programs with different EULs. Tier 1 blocks contain currently developed TVA programs, and the block lifespan was determined using weighted averages. Block lifespans for tiers 2 and 3 were approached differently. Because tiers 2 and 3 contain undeveloped technologies and programs, industry average standards were used for the different sector’s lifespan.

Since the energy efficiency blocks are a mix of differing technologies with differing life measures, potential exists for overestimation or underestimation of energy savings. With respect to the energy shapes, the capacity expansion model uses a repeating annual energy pattern for each block to the end of the lifespan. As programs die off before the expected lifespan, they are replaced with the same technology at no cost until the end of a defined block life.

Figure 5 demonstrates how this applies to a 14-year residential audit program within a residential block that has a lifespan of 17 years. Several technologies die off before the end of life, but the block assumes the energy is still there because the technology is replaced with like kind (solid black line). Notice there is an overstatement of energy for years 6 -17. For the technologies where contribution ends prior to end of block life, it is replaced with a similar block and contributes with the same energy pattern for the remaining block life. The risk in these cases is that we are overstating energy (by having the same energy contribution every year) and underestimating costs (by assuming technology is replaced at no cost to TVA). The blending of programs into blocks creates unique challenges for resource planning in that an average lifespan can create resource adequacy challenges in a particular year.

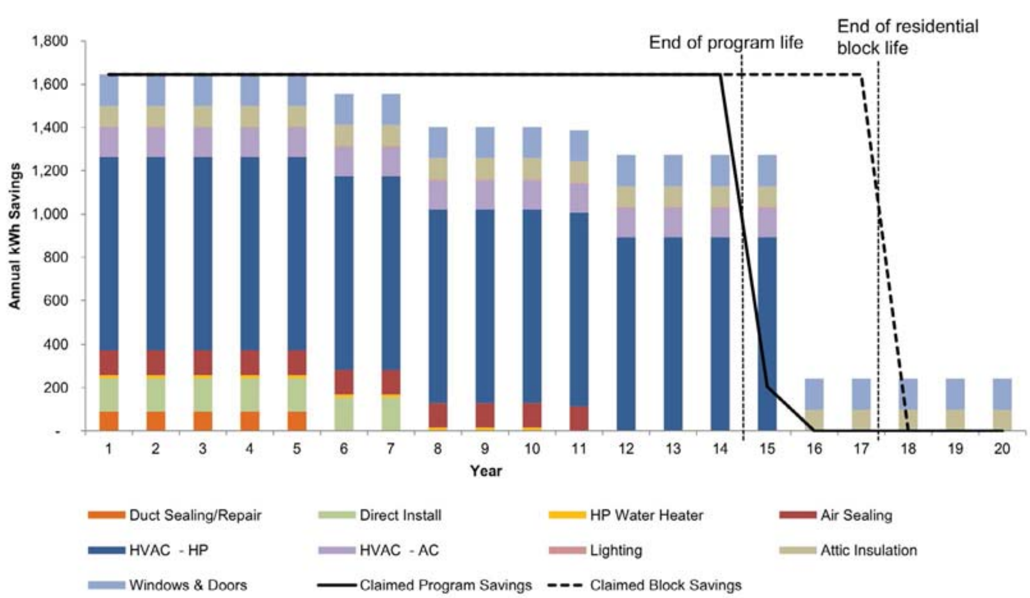

Figure D-4: Example of a residential audit program modeled as part of a residential block

3.3.1.2 Fixed Shape Uncertainty

Each of the energy efficiency sectors has a fixed end use 8,760 load shape. For modeling convenience, the blocks are assumed to have an unchanging composition over time, even though this is unlikely. TVA's stochastic modeling around the overall TVA load shape partially addresses some of this risk but does not address the uncertainty around the shape of the block designs changing over time as programs and technologies evolve and as the "low hanging fruit" of EE is picked off.

3.3.2 Delivery Risk Uncertainty

3.3.2.1 Local Power Company Delivery Uncertainty

Unlike conventional assets that can be constructed, operated and maintained directly by TVA, there is more uncertainty around the ability to implement EE resources in the Tennessee Valley because of the multiple parties involved and coordination around end use customer adoption. The end use providers are made up of the participants and the local power companies. There are currently 155 Local Power Companies (LPCs) in the TVA region consisting of municipal utility companies and cooperatives. Since TVA is not the end-use provider there is risk in how the 155 local power companies would vary in their delivery of EE programs. Additionally, TVA and the LPCs need to establish delivery mechanisms to facilitate larger EE deployment across the region and this takes time and resources which may be different than a comparable, vertically integrated utility might experience.

TVA believes delivery risk will diminish over time as delivery mechanisms are developed and refined with the LPC customers. A 10% adjustment is applied to reflect delivery risk for years 1 through 5. At year 6, this adjustment begins declining at 2% per year.

3.3.2.2 Realization Rate Delivery Uncertainty

The gross realization rate is the ratio of measured energy reduction (actual) to claimed energy reduction (planned). The gross realization rate is typically multiplied by the Net to Gross ratio (a ratio which accounts for attribution) in order to get "the net realization rate." In most studies reviewed by TVA, net realization rates tend to be less than one, although in some jurisdictions realization rates reflecting actual performance exceeding planned savings have been achieved.

Examples of lower realization rates (i.e. realized program impacts) can be seen in more mature markets such as California, Con Edison and Indiana where there are extensive measurement and verification (M&V) data. They illustrate that risk exists with regard to energy and capacity impacts even in these more mature markets. A lot of this is attributable to operational issues, calculation methods, and inappropriate baselines. TVA does not expect to repeat industry experience with regards to claimed and evaluated measured discrepancies since TVA has different market drivers. However, TVA can learn from their experience by noting that there is risk around these future program assumptions. In the IRP case, the risk is primarily around our ability to realize deliveries over the 20-year study period on programs that as-yet have not been designed, undergone M&V and been refined. This uncertainty increases over time.

3.3.2.3 Delivery Risk: Codes and Standards

TVA's modeling approach assumes that selectable EE resource deliveries are over and above any future tightening of efficiency codes and standards. Currently, known codes and standards (C&S) are reflected in the load forecast in the IRP, and future increases in C&S are not assumed.

Treating EE as a supply side resource means that it is available and deliverable in the same way that a conventional resource is, and this creates a risk around C&S tightening. A conventional gas turbine for example, delivers MWs regardless of whether new efficiency standards reduce TVA's sales in year 15 of the study. For EE, there is a risk that future tightening of C&S would reduce the amount of EE available to deploy in the market or increase the cost of deploying the EE resource in the future. As baseline efficiency requirements increase, then either the supply (volume) of EE must decrease or the cost of the next series of measures must increase. TVA's current EE modeling assumes that over the 20-year study period that TVA programs can be developed to exceed whatever the then-current standards may be.

3.4 Recognizing Design & Delivery Uncertainty: Planning Factor Adjustment

Why do all these performance issues and uncertainty matter? Dynamically modeling energy efficiency as a resource means that all variables, including resource costs, shapes and uncertainties, significantly influence the modeled needs for base load, intermediate and peaking generation. There are several possible ways to address this uncertainty analytically, including carrying higher planning reserves, but each increases overall plan costs. To address these uncertainties and allow energy efficiency to compete on the same playing field as a supply side resource, a planning adjustment factor was made to reflect the two categories of design and delivery uncertainty.

Initially, the primary risk TVA faces is delivery risk, largely around the ability to implement programs across our service territory and build the infrastructure with our LPC partners. This is represented as a 10% cost adder in years 1-5 that begins to decline in year 6. The other uncertainties around block design and delivery risk uncertainty are initially zero but begin to grow over time, starting in year 6. The total planning adjustment is shown in Figure 6 and grows to 30 percent over the out years of the study. This planning adjustment reflects the fact that the further out in the future one goes, the more uncertain these proxy EE blocks are. The planning adjustment is an approximation, not a precise calculation, but is meant to reflect how uncertainties increase over time.

In this construct, the uncertainties manifest as cost in the model. The alternate approach was to restrict volumes available in the out years, but TVA chose to keep the volumes consistent to test the model boundaries. Uncertainty manifesting as cost has certain modeling advantages and also allows volumes to be unconstrained. In many case results we can see full selection of EE blocks occur, even in the out years with the uncertainty adjustments, which allows for a more robust range of case results.

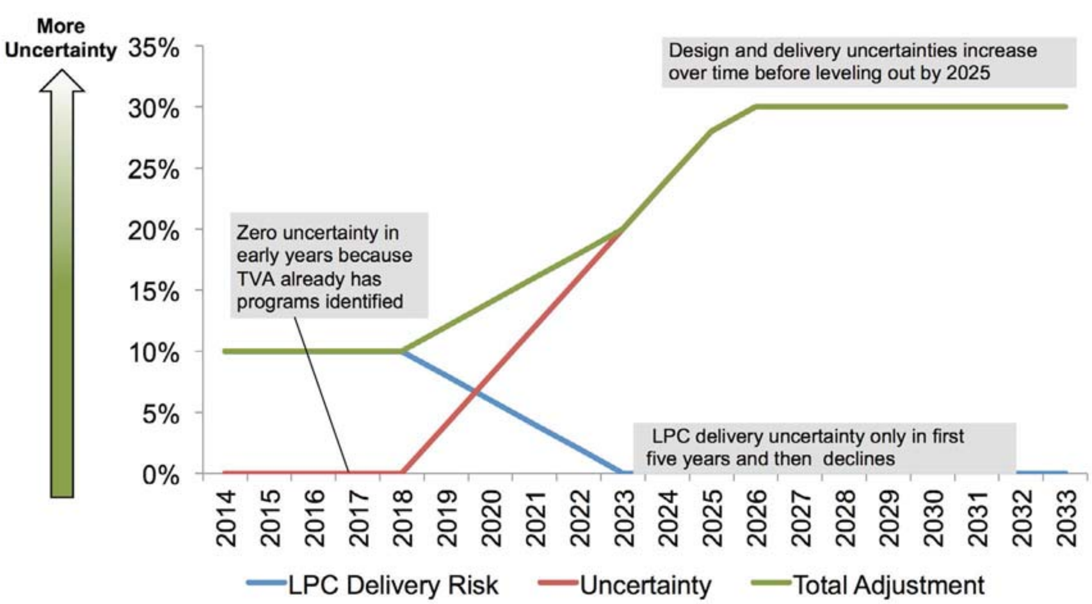

Figure D-5: Planning Factor Adjustment over time

3.5 Recognizing Uncertainty: Stochastic Analysis

While the planning adjustment captures design and delivery uncertainty, TVA's analytical approach also considers stochastic analysis on several key inputs. O&M cost escalations are stochastically varied in the analysis using the same distributions as other O&M costs. Resulting system cost impacts are indirectly varied by demand and weather pattern (i.e. load shape) distributions modeled in the analysis. Traditional supply side resources have other factors that can change both their cost and generation levels: demand, fuel, O&M, capital costs, CO_2 emission penalties, etc. All such uncertainties manifest as cost in the model. Table 8 lists the direct and indirect stochastic variables for several supply side resources as a comparison to energy efficiency.

direct	✓
indirect	✓

Stochastic Variables

	Diesels	CT	CC	Coal	Nuclear	Hydro	Solar	Wind	Energy Efficiency
Gas price		direct	direct	indirect		indirect			
Coal price		indirect	indirect	direct		indirect			
Oil price	direct	indirect				indirect			
CO_2 allowance price	direct	direct	direct	direct					
Electricity price	indirect	indirect	indirect	indirect	indirect	indirect			
Hydro generation		indirect	indirect	indirect	indirect	direct			
Plant availability	direct	direct	direct	direct	direct	indirect			
Load shape year	indirect	indirect	indirect	indirect	indirect	indirect			indirect
Electricity demand	indirect	indirect	indirect	indirect	indirect	indirect			indirect
O&M costs	direct	direct	direct	direct	direct	direct	direct	direct	direct
Interest rates		direct	direct	direct	direct	direct	direct	direct	
Capital cost		direct	direct	direct	direct	direct	direct	direct	

Table D-8: Indirect and Direct Stochastic Variables

Even after accounting for the planning factor uncertainty, EE blocks have a significantly lower range of uncertainty than a comparable combined cycle plant as shown in Figure 7. The uncertainty bands around combined cycle costs are much wider due to fuel, emissions, O&M, capacity factor and capital cost uncertainty. The much narrower EE uncertainty band is driven by the design and delivery uncertainties previously covered, stochastic variations on O&M cost and the indirect effects of the stochastic draws on the overall system load shape.

Appendix D

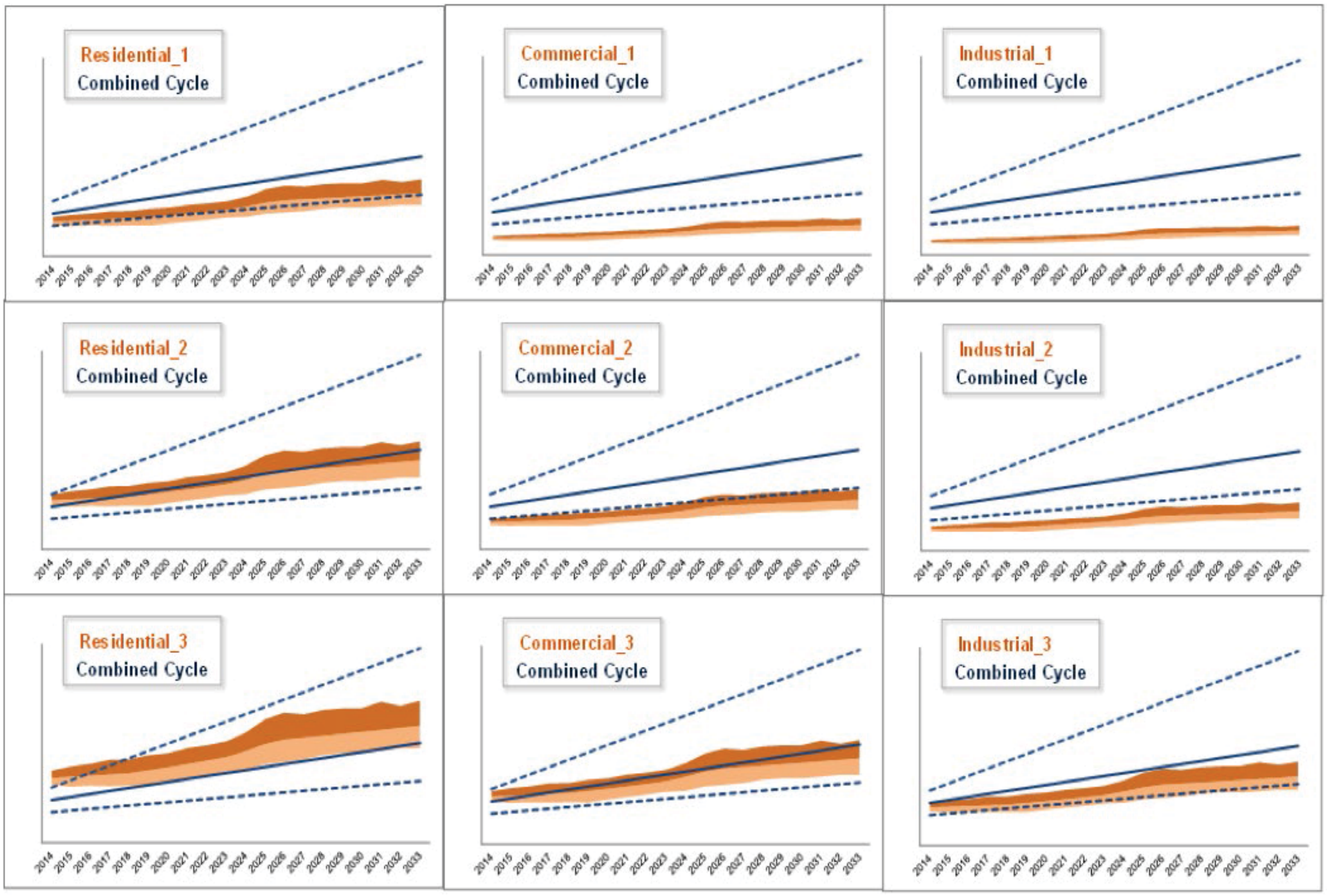

Figure D-6: Uncertainty bands in \$/MWh for each of the EE sector blocks as compared to a greenfield combined cycle plant

3.6 Costs after Planning Adjustment

Levelized Cost of Energy (LCOE) is a common metric to allow comparisons of total resource costs reflective of capital costs, asset lives and expected fuel costs. Looking at the comparison in Figure 8, EE compares favorably with other TVA resources in 2015.

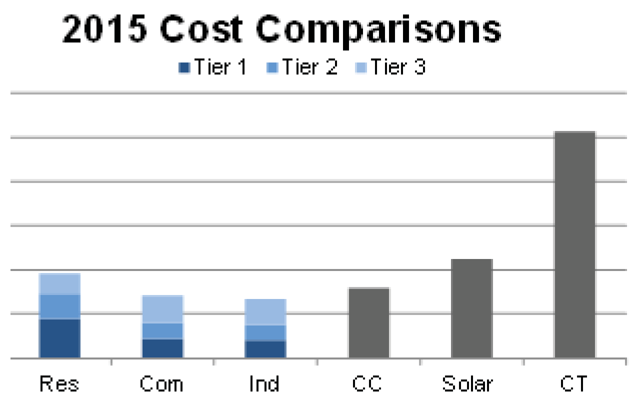

Figure D-7: Levelized Cost comparisons in 2015 (2015$/MWh)

Looking at the LCOE over time with the uncertainty adjustment, most of the EE blocks remain less expensive than a natural gas combined cycle unit through the IRP study period. Only Residential Tier 3 has block costs that are higher in the beginning and end of the study period than a comparable combined cycle.

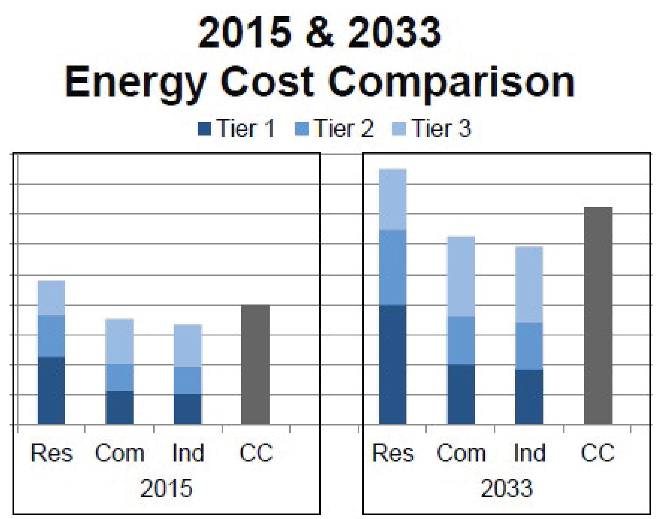

Figure D-8: Levelized cost comparison ($/MWh) of EE tiers in 2015 and 2033

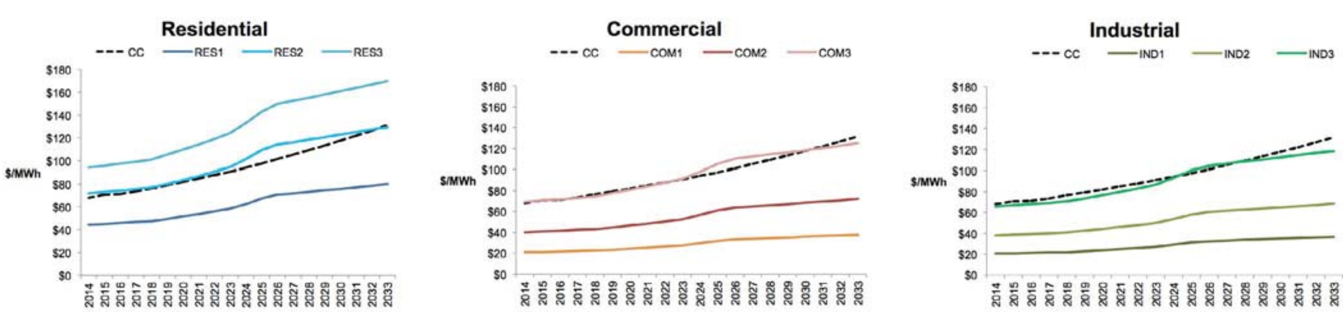

Figure D-9: Levelized Cost Comparison by Sector through time

4.0 Next Steps

Energy efficiency modeling for the IRP was a collaborative effort across TVA and with stakeholders. Modeling energy efficiency as a competitive resource introduces additional uncertainties around design and delivery that are unique from other traditional resources. TVA's approach accounts for these uncertainties with a planning adjustment, which is hoped to refine over time as programs are developed, measured and verified. The modeling framework chosen for use in the 2015 IRP has produced a robust set of results that demonstrate the value energy efficiency brings to the portfolio, including an assessment of the outcome for cases that test the boundaries for EE. TVA's next step is to develop an internal business process to leverage this dynamic approach in resource planning and to revisit the assumptions behind some of the fundamental parameters.