Exploring Least-Regrets Resource Planning: A Forum on Modeling for Long-Range Power Supply Studies

April 16, 2014 4 — 6 pm

Toyota Auditorium

Howard H. Baker Jr. Center for Public Policy - 1640 Cumberland Avenue

Agenda

◆ Introduction to Resource Planning
— Goals
— Least-Cost planning
— Least-Regrets planning

◆ Modeling Process:
— Concepts in Capacity (Expansion) Planning
— The Optimized Capacity Plan
— Capturing Total Plan Costs

◆ Uncertainty & Plan Costs

◆ Pulling the Findings Together: Scorecards

The Purpose of Resource Planning

The application of economic and engineering analyses to the resource adequacy problem… specifically making investment decisions to minimize fixed and variable costs, while maintaining appropriate resource adequacy.

'Resource adequacy' is typically achieved by maintaining an amount of capacity in excess of forecasted peak demand.

- This "reserve margin" ensures that customer demand for power can be met, with fluctuations in actual demand (weather) and unexpected outages of generating assets.

- The optimum level of reserves balances the cost with the risk of power being unavailable.

Resource Planners Ask Lots of Questions

◆ How much energy will our customers use in the future?

◆ Will we be able to meet the projected energy use?

◆ Are additional resources needed?

◆ What alternatives do we have to meet our resource needs?

◆ Are there strategic considerations that will limit the alternatives we can consider?

◆ How do we properly evaluate all of these resource alternatives?

◆ How do we find the best solution?

Balancing Investment, Expenses & Risk

◆ Identifying the optimum resource mix is complex:
— must balance capital investment, projected expenses and risks that will impact the reliability and/or cost of electricity

◆ Generally utilities seek the most robust long-term resource plan
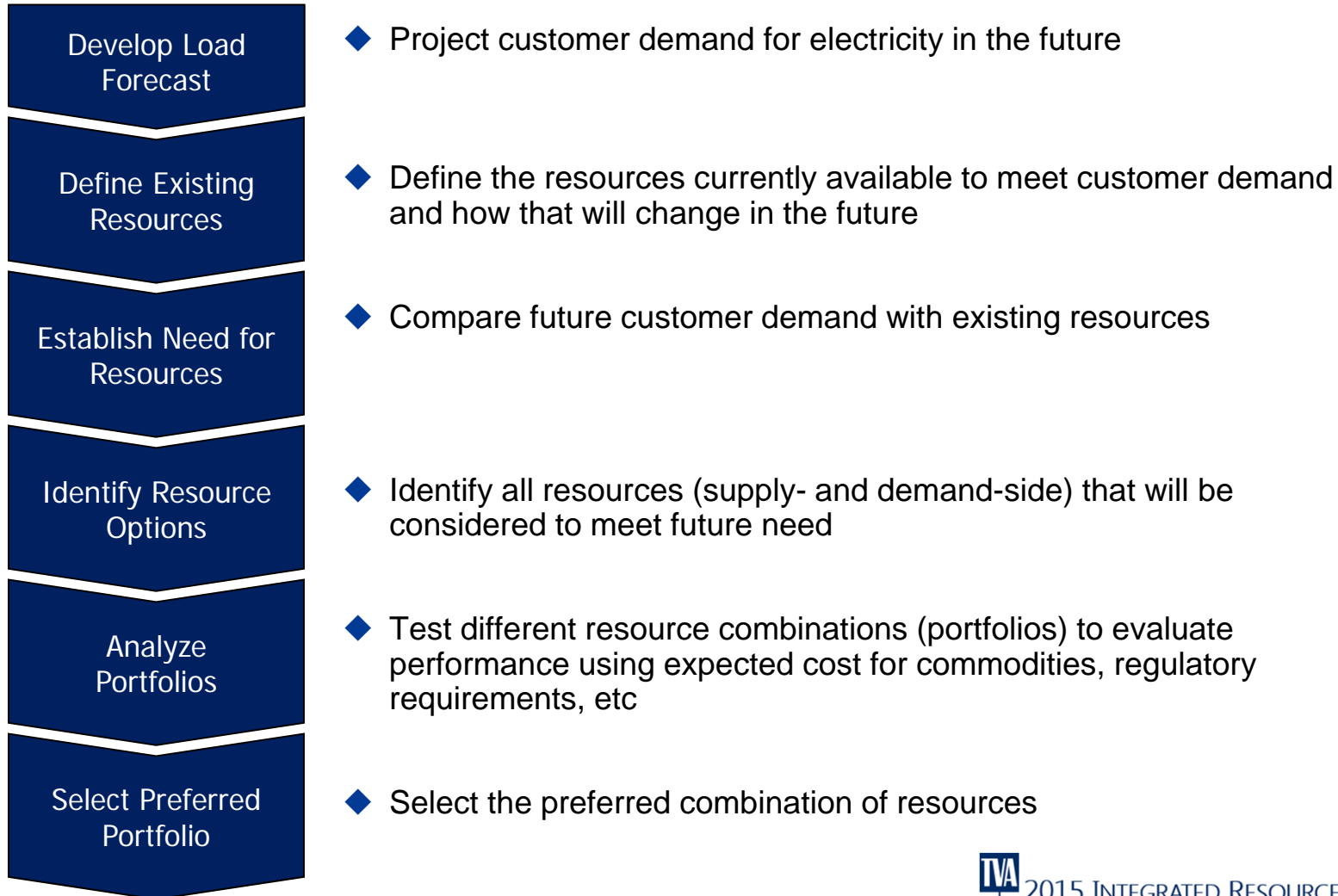— least variation in cost under the broadest set of changing (and uncertain) conditions

◆ Ultimately, the recommended resource mix considers
— capital investments required
— projected operating expenses
— minimizes these costs over the planning horizon

Typical Resource Planning Process

Identifies the least cost solution to meet customer demand over a long horizon (usually 20 years)

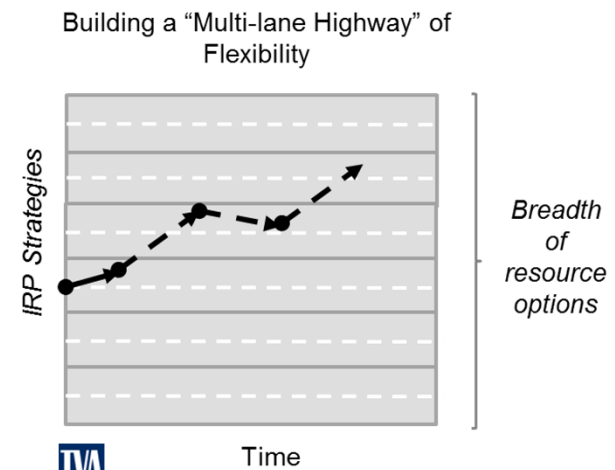| Process Step	Description
Develop Load Forecast	◆ Project customer demand for electricity in the future
Define Existing Resources	◆ Define the resources currently available to meet customer demand and how that will change in the future
Establish Need for Resources	◆ Compare future customer demand with existing resources
Identify Resource Options	◆ Identify all resources (supply- and demand-side) that will be considered to meet future need
Analyze Portfolios	◆ Test different resource combinations (portfolios) to evaluate performance using expected cost for commodities, regulatory requirements, etc
Select Preferred Portfolio	◆ Select the preferred combination of resources

Least-Cost vs. Least-Regrets Planning

Least-Cost Planning

◆ Forecasts of critical variables (i.e. load forecast, fuel prices, etc.) define a <u>single</u> planning "future" as the expected case

◆ Outcome is the portfolio of resources that will produce the least-cost plan over the study period in that expected future

◆ Often stress-tested on key variables (high/low loads, high/low gas prices) done one at a time to identify cost sensitivity (risk).
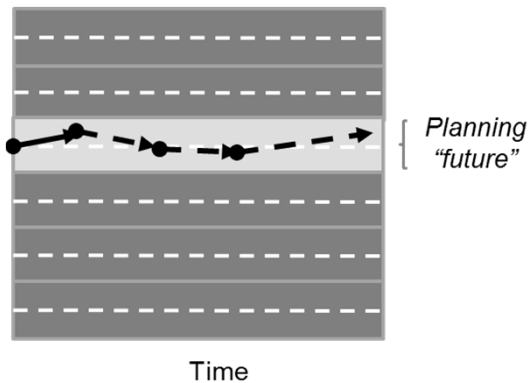
Least-Regret Planning

◆ Two types of "unknowns" are evaluated:
  — The expected case is one of several plausible futures that the utility will need to survive; and
  — Critical variables are random and more than one driver can change simultaneously (e.g. loads and fuel prices)

◆ Outcome is a portfolio with a range of resource additions that will perform well under <u>multiple</u> plausible futures

◆ Risk considered by varying key drivers randomly within the framework of each plausible future

Building a "Multi-lane Highway" of Flexibility

IRP Strategies

Breadth of resource options

Time

Planning "future"

Time

Why use Least-Regrets Resource Planning?

◆ Industry subject to rapid and unpredictable change, driven by many drivers:

— Uncertain growth rates

— A highly volatile regulatory future

— Maturity of new generation technologies

— Fuel costs

— Uncertainty over nuclear generation

— Growth of demand-side resources

◆ Drivers interact with each other and with emerging drivers, creating a business environment that could evolve along different paths

◆ In the face of complexity and uncertainty, the temptation could be to gravitate around the path that seems the most likely

◆ This approach is fraught with risks; commitment to a single forecast could serve as a straitjacket for strategic thinking and significant business risks could be ignored
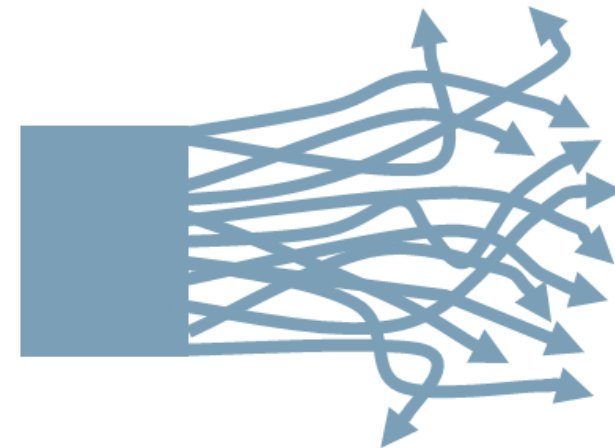
Adopting this single path forward could be the right choice, but if the future evolves along one of the other paths, we will be locked in with few alternatives
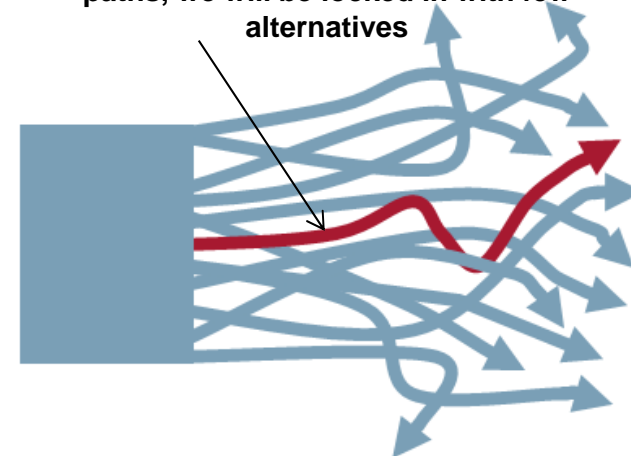
Scenarios Are Key to Least-Regrets Planning

◆ Scenarios allow us to bound key uncertainties to create a wide range of possible outcomes to test individual portfolio strategies

◆ Scenario analysis looks at a set of "plausible futures,"
— They do not cover the universe of unpredictable possibilities and are **not intended to predict the future**

◆ Analysis of portfolio strategies within these futures show how the outcomes of near-term and future decisions would differ as the world changes

◆ Scenario analysis **does not** model the annual planning process

◆ Optimization models process as if they have perfect foreknowledge of all demands, costs, and conditions

◆ Scenario analysis can help planners understand optimal responses to significant changes that occur midstream; make planning more proactive, dynamic, adaptive
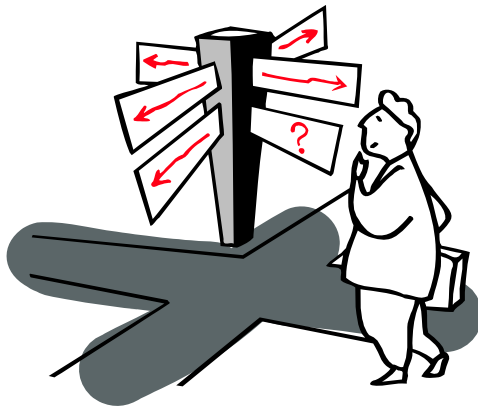
Capacity (Expansion) Planning

◆ Goal of the process is to develop a preferred power supply plan that is subject to a set of constraints:

— Required System Reliability (reserve margin)

— Available Supply options and/or conservation measures

— Constructability of assets

— Environmental compliance targets

— Financial targets

◆ That plan is identified through a process known as capacity planning (or expansion planning)

◆ Preferred resource portfolio is selected to minimize the present value of revenue requirements (PVRR).

— Revenue requirements are used because utilities are funded from rate revenues.

Capacity Plan Optimization

◆ The planning model has the objective of minimizing the present value of revenue requirements (PVRR) for the portfolio or system

◆ While the model has one objective function, it may be regarded as having integrated but separable short-term and long-term sub-objectives:

— In the short run (within any model year), minimize total costs subject to system and unit constraints

— In the long run (over all years of the study), determine an optimal system-wide expansion plan (new plants, contracts, and unit retirements) given a set of supply and demand-side resources.
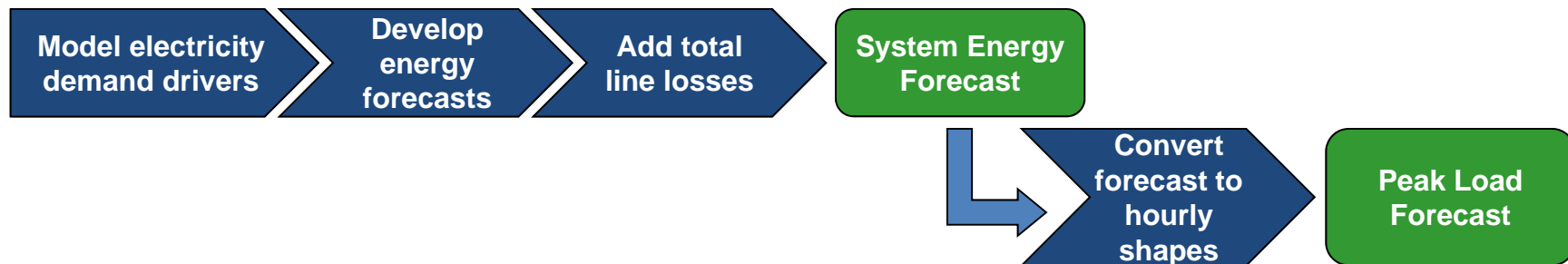
Capacity Expansion Algorithm

These steps represent the recursive calculations applied for each year of the study period

1	2	3	4	5	6
Check Capacity Balance	Identify Resource Combinations	Compute Capital Investment	Compute Operating Expenses	Retain Lowest Cost Combination	Update System Capability
Is system capacity enough to meet projected demand plus reliability margin in this year? If not, resources must be added.	Find combinations of new resources for additional capacity needed *(includes purchased power and conservation programs)*	Annual capital for these new resource combinations based on amortized payment or annual carrying cost for market purchases or conservation measures	Operating costs for the entire electric system including each of the proposed additional resource combinations	The annual system cost (capital plus operating) is used to identify the least cost option for the given year	The least cost combination of new resources is added to the existing system and becomes the basis for the capacity balance check in the following year

Load Forecasting Methodology

Model electricity demand drivers ▷ Develop energy forecasts ▷ Add total line losses ▷ **System Energy Forecast**

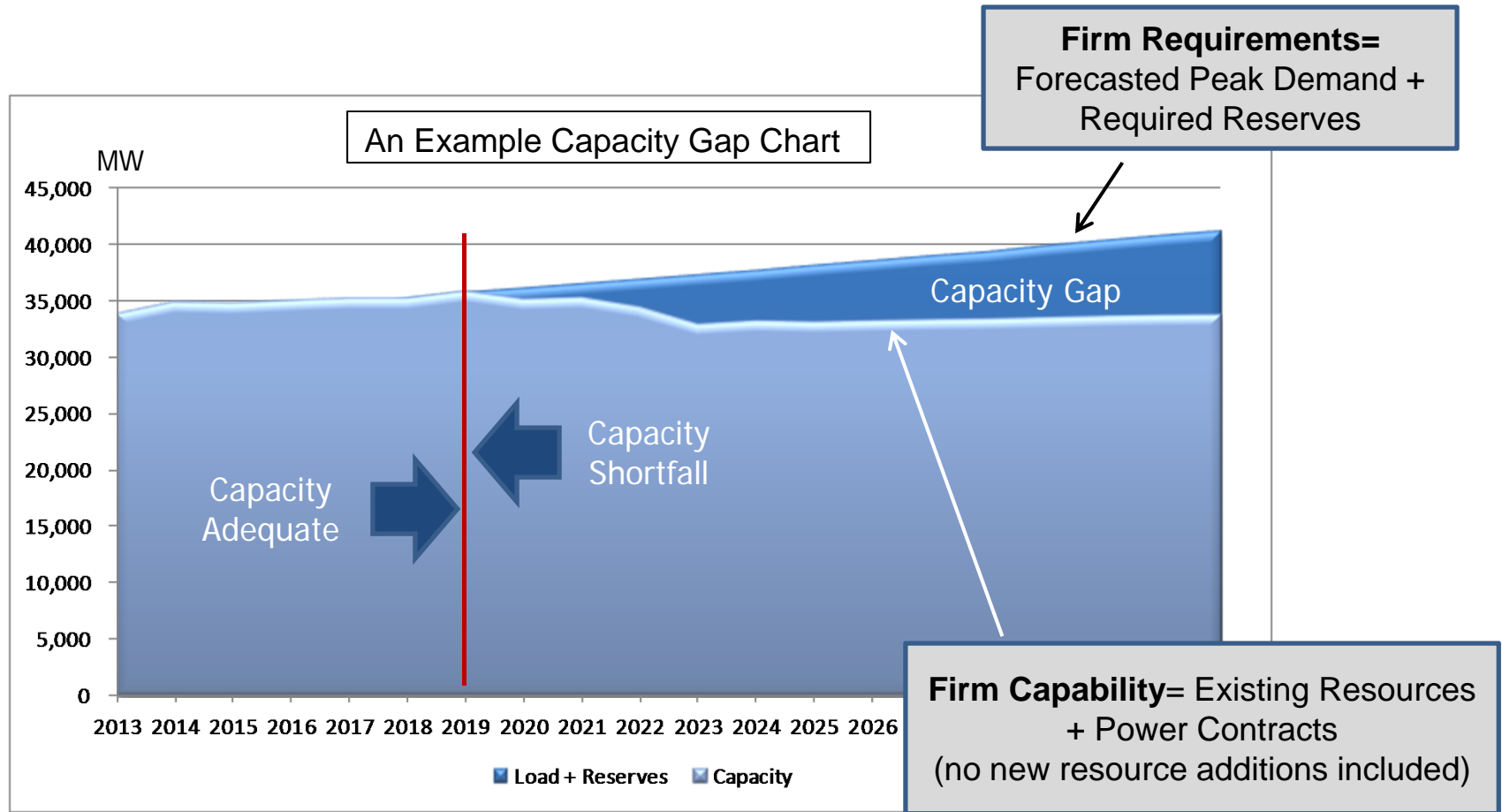**Convert forecast to hourly shapes** ▷ **Peak Load Forecast**

◆ **System energy forecast** is developed by:

— Modeling drivers that relate historical sales to future energy consumption

— Developing energy forecasts for each customer sector based on inputs from electricity demand drivers

— Adding in total transmission and distribution line losses

◆ **Peak load forecast** is created by:

— Converting energy forecast to hourly load shapes for 8,760 hours of each year. Load shapes are based on typical weather patterns and reflect typical hourly usage for TVA customers

— Identifying the highest hourly load, which becomes the peak forecast for each year

Checking the Capacity Balance is the First Step

An Example Capacity Gap Chart

Firm Requirements=
Forecasted Peak Demand +
Required Reserves

MW

Capacity Gap

Capacity
Shortfall

Capacity
Adequate

45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0

2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026

■ Load + Reserves   ■ Capacity

Firm Capability= Existing Resources
+ Power Contracts
(no new resource additions included)

The **Capacity Gap** is the amount of capacity needed to ensure reliability.
Planners seek to optimize the combination of resources needed to close this gap.

Balancing Resource Options & Model Runtime

◆ Model constraints carefully applied to manage computer processing time

◆ Number of resource options considered is a key constraint

◆ Potential resource options are screened using four key metrics:
  — Policy Goals (Strategic)
  — Environmental Footprint
  — Technology Maturity/Viability
  — Cost

Strategic

Environmental

Viability

Cost

Choosing a Resource Depends on Life Cycle Costs
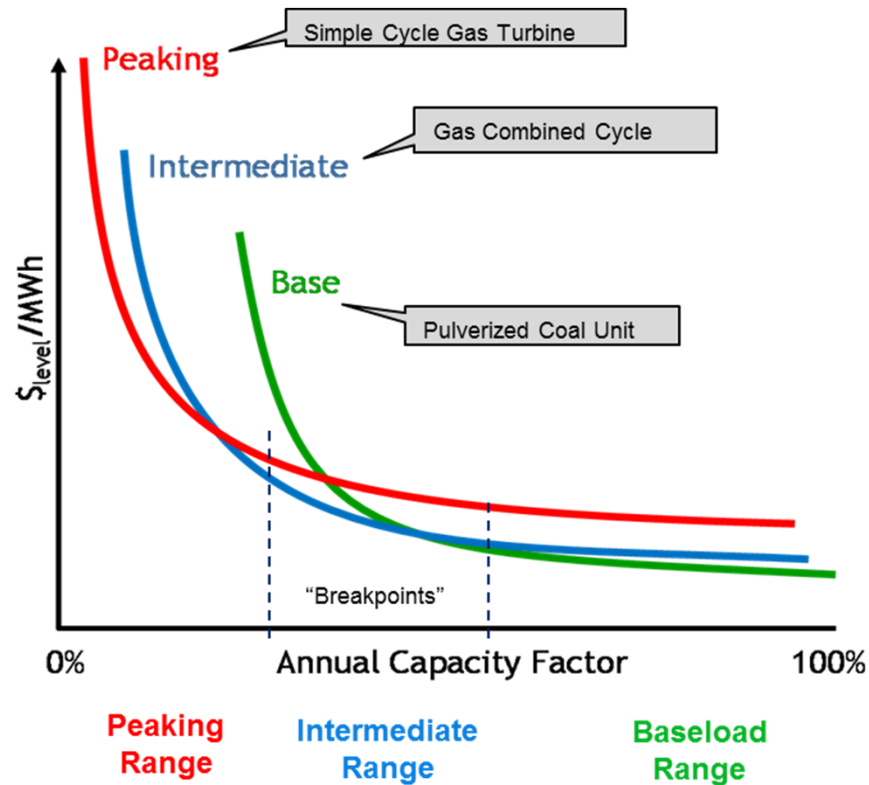
Base load resources – lowest overall operating costs (low heat rate and variable cost), units designed to remain online virtually around the clock

Intermediate resources – moderate operating costs and the ability to "swing" with changes in load

Peaking resources – highest operating costs, designed to be used only when loads are highest and other resources already committed

◆ Resources are chosen based on matching unmet needs with the capacity and energy supply characteristics of a given resource, including both supply-side and demand-side alternatives that are modeled as a resource

◆ In evaluating resources, the model considers the full life cycle cost of each resource

Example: Closing the Capacity Gap

Example: Suppose that in a given year the **capacity shortfall** between projected demand and system capability is **400 MW**

1. Resource options available to the utility include:

◆ 300 MW coal plant

◆ 200 MW gas plant

◆ 100 MW peakers

◆ Market purchases

2: So the possible combinations to close this gap are:

◆ 1 coal plant and 1 peaker

◆ 2 gas plants

◆ 1 gas plant and 2 peakers

◆ 4 peakers

◆ 1 coal plant and market

◆ 1 gas plant and market

◆ 1 gas plant, 1 peaker & market

◆ 1, 2 or 3 peakers with market

◆ All market purchases

All possible combinations will be evaluated to determine the least cost combination in that year

Projections of Plant Capital

◆ Capital investment (build cost) varies considerably across different types of power plants (nuclear, coal, combined cycle, solar)

◆ Build costs can also be influenced by environmental regulations, site constraints, and fuel supply & deliverability

◆ In resource planning, capital costs are typically evaluated as an **amortized cost that represents the debt service** on the plant rather than a single value (the purchase price)

Computing Capital Costs

For each combination of resources that can fill the capacity gap, an amortized capital cost must be computed

Amortized costs are based on a capital recovery factor (real economic carrying cost method):

$$CRF_1 = \frac{(d - g)(1+d)^n}{(1+d)^n - (1+g)^n}$$

d = discount rate
g = growth (inflation) rate
n = asset life

$$CRF_n = CRF_1 (1+g)^{n-1}$$

A real economic carrying cost method is used to minimize "end effects"

Capital Cost Recovery and End Effects

◆ If the study period is less than the resource life span, the model needs to capture the profit or loss and investment recovery for the remaining resource life span

◆ The impact of the profit or loss and investment recovery in the time period outside of the study period is called the **"end effect."**

◆ The end effects bias is most pronounced for selection of capacity needed in the later years of the study horizon, and is mainly caused when

— one project is more capital intensive than another, or

— has a longer service life than another.

	Build (yrs)	Book Life (yrs)
Nuclear	12	40
Coal	10	40
NGCC	5	30
NGCT	4	30

Amortized Capital Costs

◆ Models minimize the end effects bias, with a variety of approaches, including **annual capital recovery factors**

◆ At TVA, we use a real levelized capital recovery method, also known as the **real economic carrying cost** method

debt	6%		$1,000	build cost/kW
discount	8%		100	plant size (MW)
growth	2.70%		$100,000,000	capital cost
life	40			
			Amortized	Level Debt
Year	CRF		Capital (ECC)	Payments
1	0.06117	$	6,117,399	$ 6,646,154
2	0.06283	$	6,282,569	$ 6,646,154
3	0.06452	$	6,452,199	$ 6,646,154
4	0.06626	$	6,626,408	$ 6,646,154
5	0.06805	$	6,805,321	$ 6,646,154
6	0.06989	$	6,989,065	$ 6,646,154
7	0.07178	$	7,177,769	$ 6,646,154
8	0.07372	$	7,371,569	$ 6,646,154
9	0.07571	$	7,570,602	$ 6,646,154
10	0.07775	$	7,775,008	$ 6,646,154
11	0.07985	$	7,984,933	$ 6,646,154
12	0.08201	$	8,200,526	$ 6,646,154
13	0.08422	$	8,421,940	$ 6,646,154
14	0.08649	$	8,649,333	$ 6,646,154
15	0.08883	$	8,882,865	$ 6,646,154
		$ 111,307,507		$99,692,304

Amortized Capital cost stream used by the model to represent the capital investment
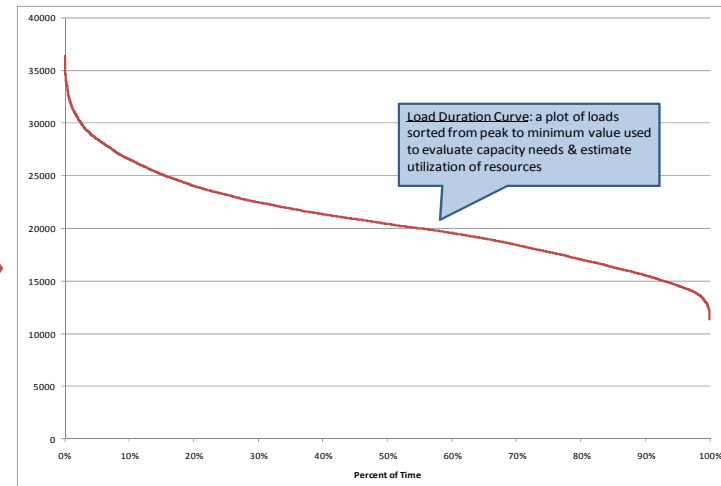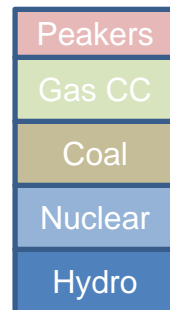
By comparison, this capital stream represents a standard level debt payment method

Operating (Dispatch) Costs

◆ A total cost of power is calculated for each possible combination

◆ Operating costs are estimated using a dispatch stack of resources and a load duration curve representation of customer demand *(each calendar month in each year of the study is represented by a "typical week")*

Dispatch Stack (merit order) ranks all available resources on the basis of cost. Units are committed to serve load in order of cost.

$$

Peakers

Gas CC

Coal

Nuclear

Hydro

Load Duration Curve: a plot of loads sorted from peak to minimum value used to evaluate capacity needs & estimate utilization of resources

Time Periods = Years x Months x DayTypes x TimeOfDayBlocks

Optimized Capacity Expansion
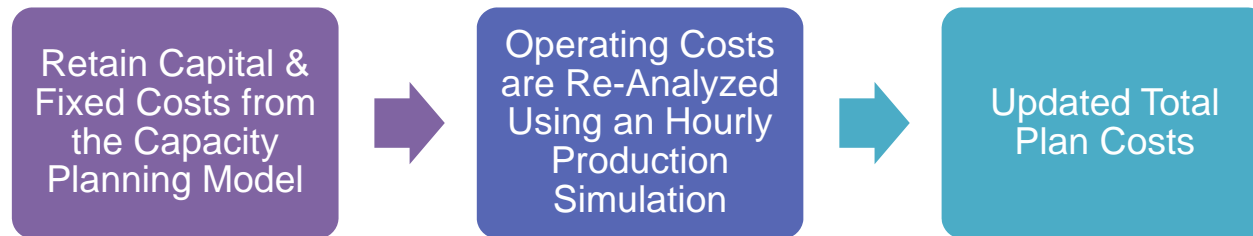
Retain Lowest Cost Combination

Update System Capability

◆ Combining the capital and estimated operating cost for each resource combination produces a **total system annual cost**

◆ The resource combinations are ranked on this cost and the least cost combination is retained as the solution for that year

◆ These additional resources (and their costs) are added to the existing system to form the basis for the capacity gap analysis for the subsequent year

◆ Multiple runs of the annual resource optimization algorithm finds the least cost pathway over the study horizon

◆ The annual system costs are summed over the study horizon and expressed on a present value basis to for comparison between plans with differing resources choices

◆ A resource addition schedule is also prepared that identifies the type of resource and the in-service year

Finalizing the Plan Cost

Retain Capital & Fixed Costs from the Capacity Planning Model	→	Operating Costs are Re-Analyzed Using an Hourly Production Simulation	→	Updated Total Plan Costs

◆ Since the capital investment decisions are influenced by cost recovery, an accurate estimate of operating cost savings is critical

◆ Detailed accounting of operating costs is done to confirm the proposed capacity expansion is a least cost plan

◆ The total plan costs are updated by replacing the estimated operating expenses computed in the capacity planning model with hourly operating costs.
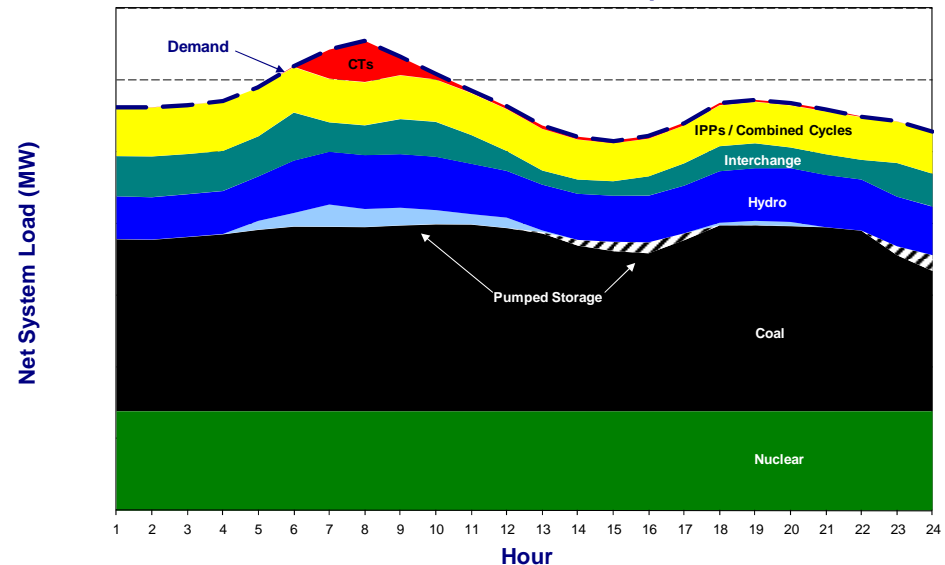
Computing the System Production Cost

Total Cost of a Resource Plan = capital & fixed costs of the assets + the cost to produce the electricity required to serve customers

- Capacity planning models use simple production cost; to fully assess the cost of the resource plan a **revised estimate of the operating costs is needed**

- Detailed (chronological) modeling estimates these costs using unit characteristics & constraints, commodity & market prices, and hourly load data.

Demand Load Chart with Dispatch Stack

Key unit characteristics used in determining a more accurate production cost include:
- Start costs
- Ramp rates
- Minimum
- Minimum up and down times
- Additional ancillary services
- And many more– reliability, steam sales, …

Example: Retaining the Least Cost Resource Combination

◆ In a given year, the sum of capital for each combination of new resources + operating expenses for the total power system with each combination of new resources is determined. The lowest annual cost combination is retained

◆ The table below shows a portion of the combinations under consideration:

M$	1 coal + 1 pkr	2 gas	1 gas + 2pkr	4 peakers	
Capital	200	100	100	100	….
Operating Exp	175	267	320	400	
Annual Cost	375	367	420	500	

	Capital	CRF	Op Cost
	M$	M$	$/MWh
Coal	2900	175	60
Gas	800	50	100
Peaker	400	25	150

Considering Uncertainty in Resource Planning

Forecasts will inevitably be wrong! Variability is a result of supply/demand disruptions, weather, market conditions, technology improvements, and economic cycles
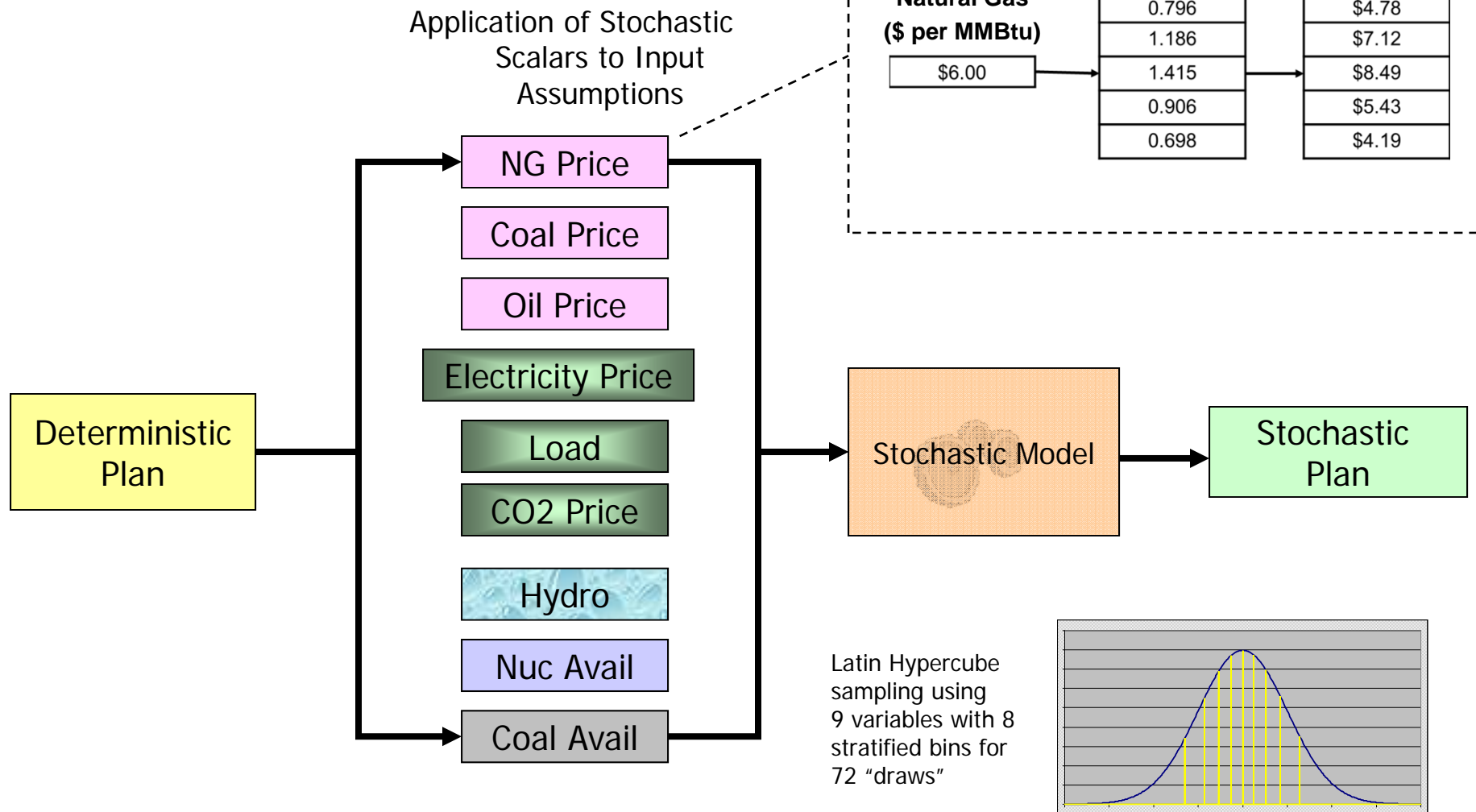
Monte Carlo simulation allows for a better understanding of the richness of possible futures, as well as their likelihoods, so that plans can be made proactively, as opposed to reactively

Portfolio Stochastic Analysis

Application of Stochastic Scalars to Input Assumptions

Natural Gas ($ per MMBtu)	5 Scalars	5 Prices
	0.796	$4.78
	1.186	$7.12
$6.00	1.415	$8.49
	0.906	$5.43
	0.698	$4.19

Deterministic Plan

- NG Price
- Coal Price
- Oil Price
- Electricity Price
- Load
- CO2 Price
- Hydro
- Nuc Avail
- Coal Avail

Stochastic Model

Stochastic Plan

Latin Hypercube sampling using 9 variables with 8 stratified bins for 72 "draws"
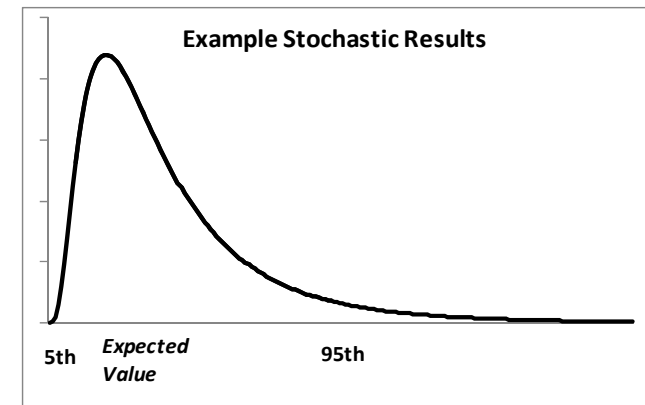
Considering Uncertainty in the IRP Study

Stochastic Analysis of Production Cost and Financials Bound Uncertainty

◆ A stochastic model estimates probability distributions of potential outcomes by allowing for simultaneous random-walking variation in many inputs over time

◆ For the 2011 IRP, a representative monte-carlo distribution using 72 stochastic iterations was developed for each of the portfolios
— A sample stochastic result is shown to the right

◆ The following uncertainties varied in each stochastic run
— Gas price
— Coal price
— CO_2 allowance price
— SO_2 allowance price
— NOx allowance price
— Electricity demand
— Electricity price
— Interest rates
— O&M costs
— Capital costs
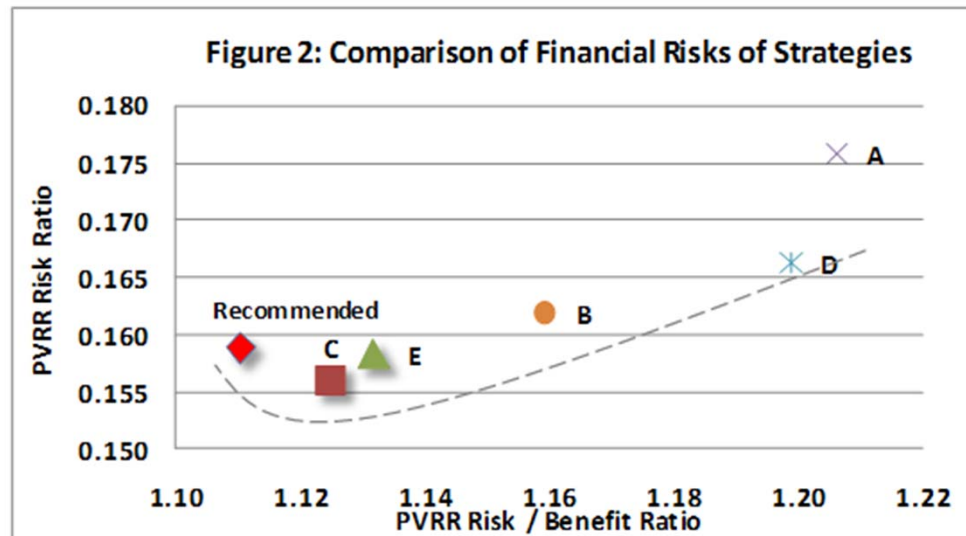— Hydro generation
— Fossil availability
— Nuclear availability

◆ Ranking metrics (cost and risk) were computed based on the expected values produced from these stochastic iterations

Example Stochastic Results

5th   *Expected Value*   95th

Balancing Cost & Risk: The Efficient Frontier

◆ Balancing cost and risk is a key task in least-regrets planning

◆ The Efficient Frontier (from financial theory) defines a set of optimal portfolios that offers the lowest risk for a given level of expected return.

◆ TVA employed a modified version of an efficient frontier graph (Figure 1) to communicate the cost/risk tradeoff in the 2011 IRP study

◆ In Figure 2, the tradeoff under consideration is between two types of risk metrics

Figure 1: Plan Costs vs. Financial Risk

Figure 2: Comparison of Financial Risks of Strategies

◆ The challenge is not insufficient data, but rather sorting through all the results to identify the preferred resource plan

◆ So how do you know when the plan is "good"? When is it "best" or "preferred"?

◆ And who decides that? Are the decision-makers well-grounded in the fundamentals of resource planning? In the assumptions and uncertainties around input data? Will stakeholder opinions be considered in the final selection of a resource plan?

◆ The solution to this dilemma is – METRICS!

To Be Effective, Metrics Need a Scorecard

◆ Metrics facilitate discussion/debate about trade-offs that lead to the selection of the preferred resource plan

◆ At TVA, we use a scorecard approach to packaging the metrics, so that stakeholders and decision-makers can be fully engaged in the identification of what makes a resource plan "preferred"

◆ IRP scorecards were developed to reflect components of TVA's mission and strategic principles

— Cost and risk metrics evaluated quantitative values that reflect traditional utility measures

— Environmental and economic metrics considered possible impacts of both quantitative and qualitative assessments

◆ No regrets considerations were used in addition to the scorecard to represent broader implications that can be described, but are not fully represented in the analysis

Scenario Analysis

		Scenarios						
		#1	#2	#3	#4	#5	#6	#7
Strategies	A							
	B							
	C							
	D							
	E							

Scorecards evaluate the performance of a strategy across many different scenarios

- Ranking metrics were expressed in terms of a 100 point score to ensure that the *relative* relationships between metrics of each portfolio strategy were maintained.

Raw ranking metric value for short-term rate impacts in Scenario 1 are shown to right

Ranking Metric Scores

	Strategy	Scenario 1
Average of ST Rates $/MWh (level 2011-18)	A	76.82
	B	78.67
	C	79.95
	D	84.61
	E	80.41

The "best" (in this case lowest) value within a scenario gets a score of 100

Strategy D is 10.13% higher than the "best" value and receives a score of 89.87

Scores are converted from the raw scores as shown and are included in the planning strategy score cards

Converted Ranking Metric Scores

	Strategy	Scenario 1
Average of ST Rates (level 2011-18)	A	100.00
	B	97.59
	C	95.93
	D	89.87
	E	95.34

All other scores are assigned a value based on their relative position to the "best" score

PVRR P(95) = 95th Percentile of PVRR

$$\text{Risk/Benefit Ratio} = \frac{95^{th} - \text{Expected Value}}{\text{Expected Value} - 5^{th}}$$

$$\text{Risk Ratio} = \frac{95^{th} - \text{Expected Value}}{\text{Expected Value}}$$

- Tail risk was measured using the 95th percentile of the PVRR distribution from a stochastic analysis and represents the value that we would expect total cost to exceed just 5% of the time

- The risk/benefit ratio captures the *risk-reward tradeoff* of a portfolio by examining the likelihood of exceeding the expected PVRR compared to the that of being below the expected PVRR, expressed as a ratio

The Scorecard Gets Key Metrics Together

		Ranking Metrics					Strategic Metrics				
		Energy Supply					Environmental Stewardship			Economic Impact	
Scenarios	PVRR	Short-Term Rate Impact	PVRR Risk/Benefit	PVRR Risk	Total Plan Score	CO$_2$ Footprint	Water	Waste	Total Employment	Growth in Personal Income
1	99.00	95.13	100.00	99.53	98.36	◗	◗	◖	0.9%	0.7%
2	100.00	95.58	99.40	95.30	97.85	◗	◐	◐		
3	100.00	100.00	99.81	89.37	97.56	◗	◗	◗		
4	100.00	97.40	100.00	95.37	98.36	●	◗	◗		
5	100.00	96.43	100.00	100.00	99.19	◗	◗	◐		
6	100.00	100.00	100.00	86.69	96.97	◗	◗	◗	0.2%	0.1%
7	100.00	97.24	100.00	97.03	98.70	◗	◗	◗		
8	99.84	96.66	98.35	97.93	98.50	◗	◗	◐		
				Total Ranking Metric Score	**785.49**					

Legend

(red)	
(orange)	
(yellow)	↓
(light green)	
(green)	*Better*

Legend

○	
◔	
◐	
◗	↓
●	*Better*

◆ The scorecard facilitates discussion about trade-offs and identified the strengths & weaknesses of various resource planning strategies

◆ Using this type of scorecard allows stakeholders and decision-makers who are not technical experts to participate more fully in the debate around selecting a preferred resource plan

Exploring Least-Regrets Planning: Concluding Remarks

◆ How does a large electric utility decide how to structure its energy portfolio to make the most economic sense while recognizing future uncertainty?

◆ TVA believes that the most effective method to develop a robust resource portfolio is to use least-regrets planning methods

◆ This method allows the utility to consider a number of uncertainty factors in a systematic way that minimizes risk impacts regardless of how the future may unfold.

◆ This method is at the heart of TVA's IRP process

Questions?

For information about the 2015 IRP,
go to www.tva.gov/irp