2024 IRP Working Group

Meeting 2: August 28-29, 2023
Norris, TN and Knoxville, TN

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Welcome and Safety Moment

Jo Anne Lavender; IRP Facilitator
Hunter Reed, IRP Project Manager

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Safety Moment

EMERGENCY EXITS

In case of Building Emergency ….

In case of Severe Weather ….

TVA's Integrated Resource Plan

The IRP is a study of how TVA could meet customer demand for electricity between now and 2050 across a variety of future environments.

A programmatic Environmental Impact Statement (EIS) accompanies the IRP to address its environmental effects.

An updated IRP is needed in order to:

- Proactively establish a strong planning foundation for the 2030s and beyond
- Inform TVA's next long-range financial plan

The IRP provides strategic direction on how TVA will continue to provide low-cost, reliable, and increasingly cleaner electricity to the 10 million residents of the Tennessee Valley.

Overarching Objective of the IRP-WG

To provide stakeholder input to the framing and evaluation included in TVA's next IRP, which establishes TVA's resource strategy in developing the energy system of the future.

Agenda – August 28, 2023

Topic	Time (ET)	Presenter(s)	Notes
Lunch, with welcome, safety moment, and climate change and extreme weather overview	12:00-1:15	Jo Anne Lavender; Hunter Reed; Nathan Donahoe; Scott Jones	
Public Scoping summary and discussion	1:15-2:00	Kelly Baxter	Review of public comments and discuss WG member reactions
Break	2:00-2:15		
Peer IRP Benchmarking	2:15-3:20	Howard Friedman	Deloitte presentation
Wrap-up and day two preview	3:20-3:25	Jo Anne Lavender	
Travel to Norris Dam	3:25-3:45		
Norris Dam tour	3:45-5:00		

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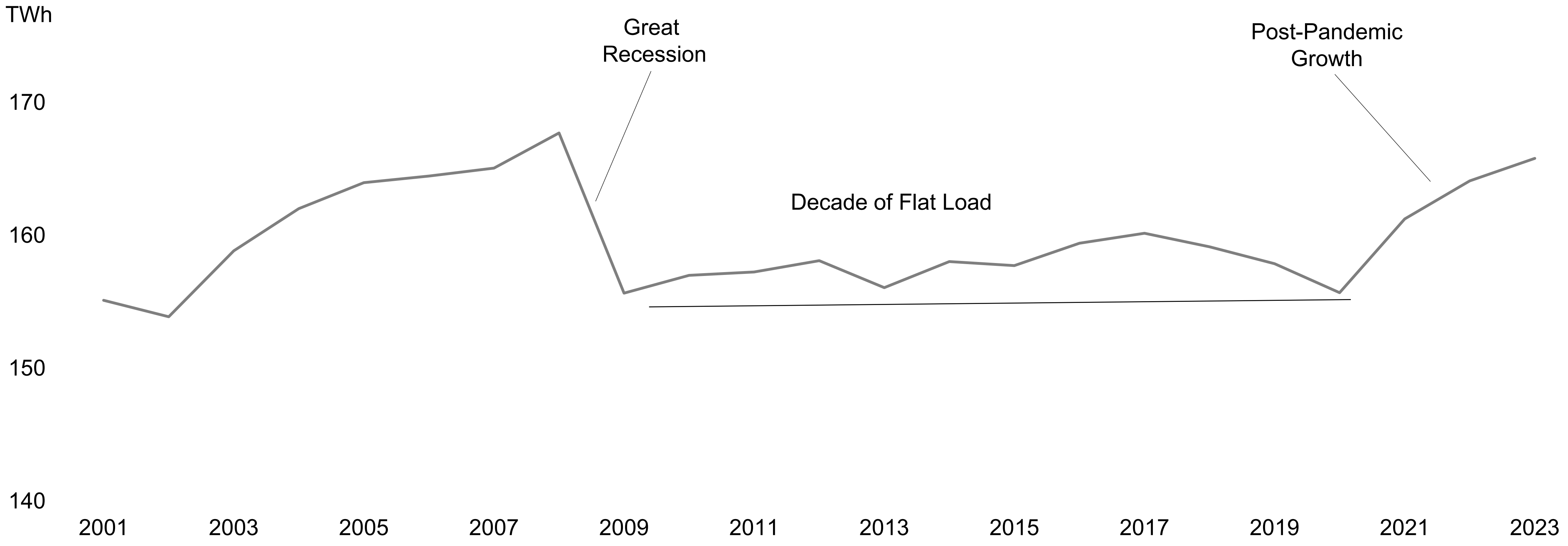
Climate Change and Extreme Weather

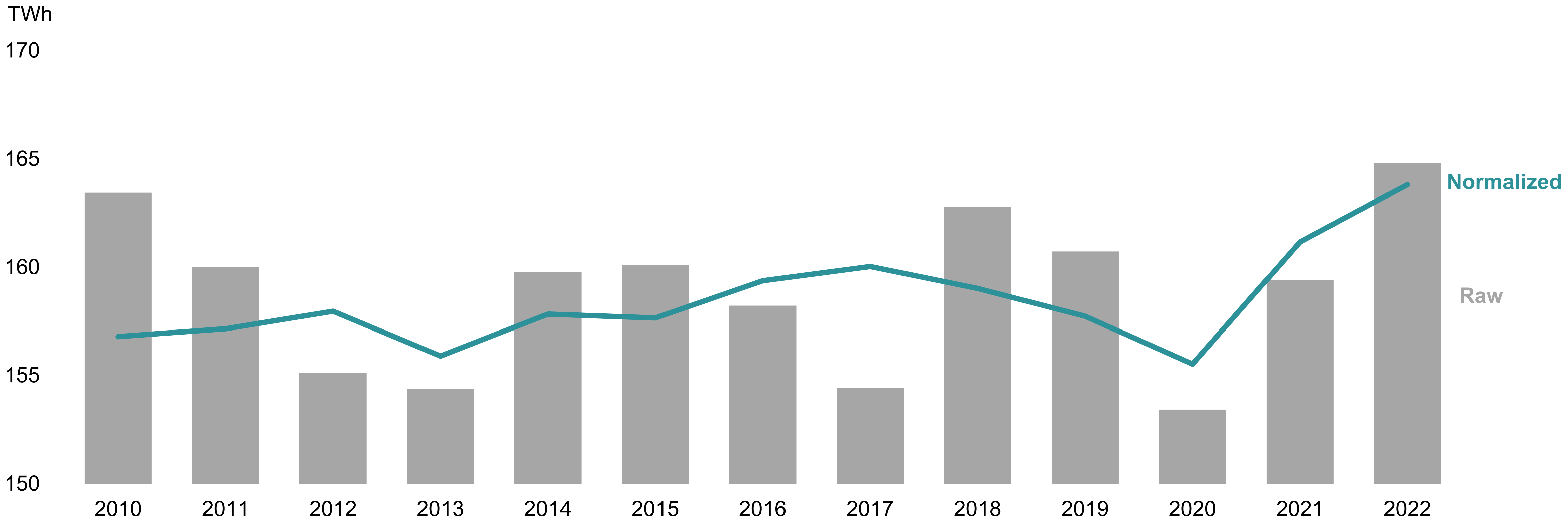
Nathan Donahoe; Sr. Manager, Enterprise Forecasting
Scott Jones; Sr. Specialist, Resource Strategy
Hunter Reed; IRP Project Manager

Load has Recovered from a Lost Decade



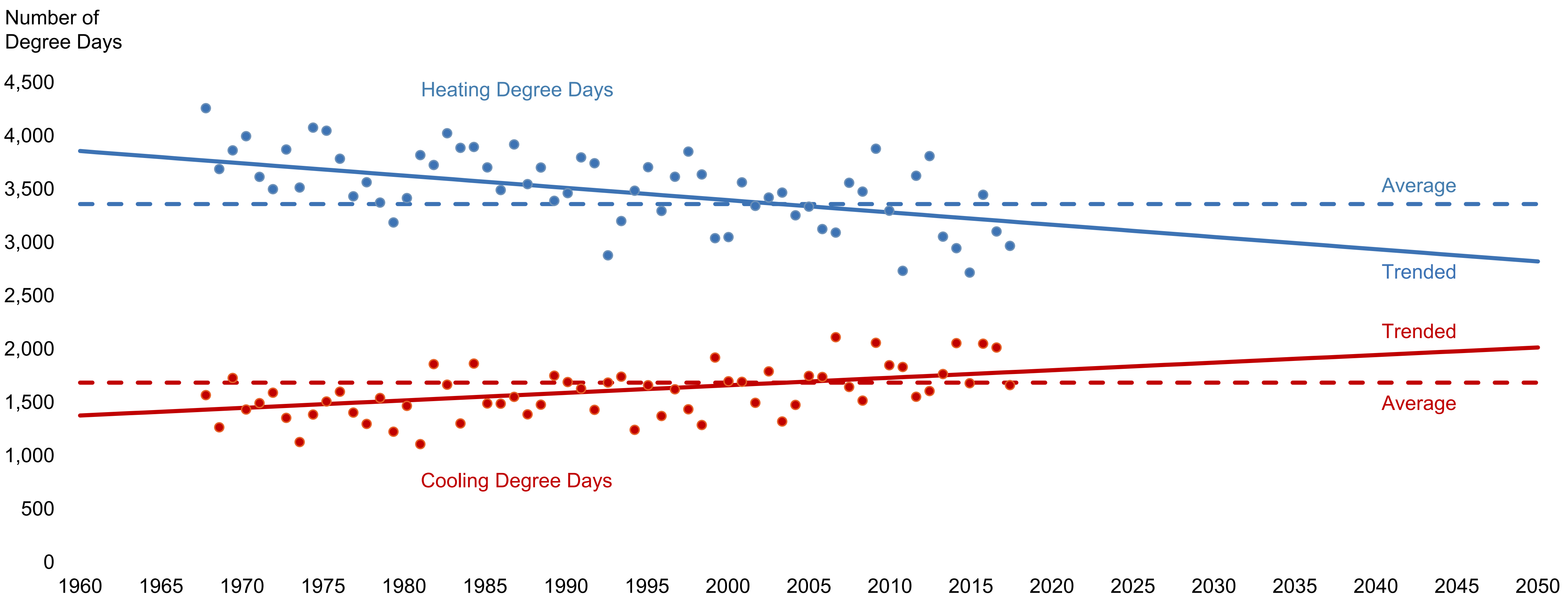
*Adjusted for weather and excludes USEC

Loads are Weather Normalized to Isolate Trends



*Excludes USEC

Trended Degree Days Sets Future Expectations



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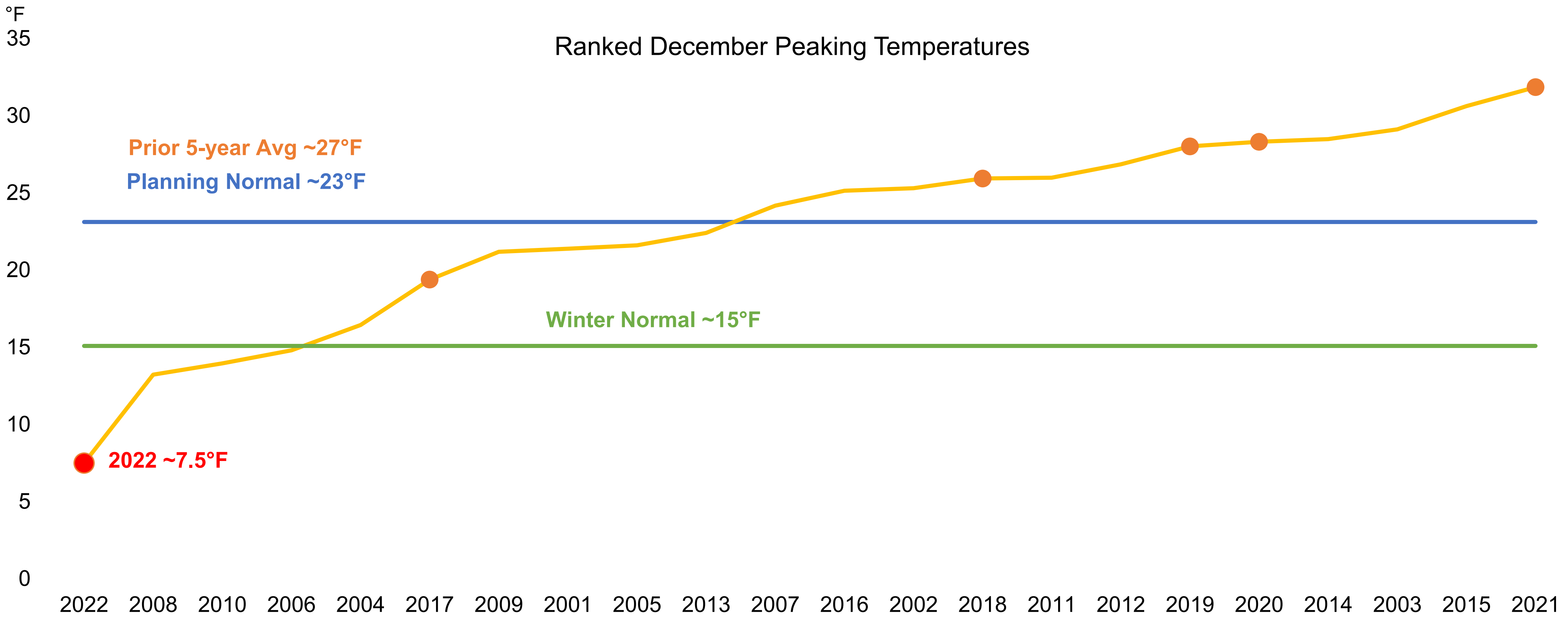
Coldest December Temperatures in Recent Years

More than 15 °F below normal December peak



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Reserve Margin

Reserve margins account for the risk of unplanned events, targeting an industry best-practice one-in-ten-year loss of load event (LOLE)

Weather

Variability from normal
- Temperatures / Load
- Hydrology
- Solar and wind
- Cold weather impact to outages and capacity

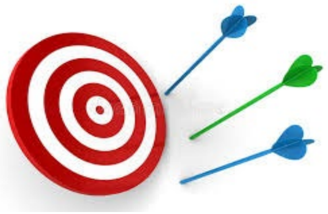
Forecast Error

Non-weather variability
- Economic cycles
- Consumer behavior

Availability

- Planned outages
- Forced outages
- Renewable performance
- Firm transmission
- Capacity Benefit Margin

Hour-ahead Forecast Error



Performance Uncertainty
- Wind
- Solar
- Load

Climate Change and Extreme Weather – Path Forward

TVA staff recommends a combination approach to modeling the impacts of climate change and extreme weather:

1. Scenarios will include trended weather normal forecasts which will influence seasonal energy trends within the load forecast (more cooling degree days, fewer heating degree days)

2. Stochastic analysis will capture each portfolio's ability to serve extreme peak load

3. In conjunction with the IRP-WG, develop a sensitivity to capture additional potential impacts of climate change (e.g., faster warming trend, seasonal rainfall differences, thermal derates in summer due to drought conditions) [Expected early 2024]

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Public Scoping Summary and Discussion

Kelly Baxter
NEPA Project Manager

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Public Scoping

Public scoping is the process to define how the IRP study will be done with help from the general public, TVA customers, organizations and agencies.

Scoping meeting presentations included:

An overview of the IRP Process
- TVA’s methodology for resource planning
- Why resource planning is important
- Rationale for 2024 IRP
- How IRP results will be used

Schedule for 2024 IRP study
Overview of the environmental impact assessment method

Results

Scoping results are used to help define:

The sources TVA will use to generate power
How TVA will manage the demand for power
How conditions in the TVA territory could change during the planning period
The important environmental topics to be evaluated

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NOI Scoping Questions

How do you think **energy demand** will **change** between now and 2050 in the TVA region?

Should the **diversity** of the current power **generation mix** (e.g., coal, nuclear, power, natural gas, hydro, renewable resources) **change**? If so, how?

How should **Distributed Energy Resources** (DER) be considered in TVA planning?

How should **energy efficiency and demand response** be considered in planning for **future energy needs?**

How will the resource decisions discussed in the NOI affect the **reliability, dispatchability** (ability to turn on or off energy resources) and **cost of electricity**?

And how can TVA **directly affect electricity usage** by consumers?

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Public Scoping Summary

Scoping Period: May 12 – July 3, 2023

Outreach methods:

- Media outlets received news releases throughout TVA region
- Social media advertisements on multiple platforms
- Emails to individuals, agencies, and organizations

Scoping webinar 1: May 23, 2023 5:30 p.m.	Scoping webinar 2: June 7, 2023 12:00 p.m.	115 Participants 34 Clarifying Questions

How many comments?	**Who made the comment?**	**Where are commenters from?**
43 Official comments via email, online portal, mail Over 300 unofficial comments via social media	13 businesses 20 self / individuals 2 government agencies 11 non-gov organizations	4 Valley states (86% in-Valley) 4 other states and Washington, D.C.

Common Themes

General support and opposition to various generation options

Increase decarbonization efforts and to promote distributed energy resource options

General interest in energy efficiency measures and energy storage alternatives

Feedback on IRP process, modeling, evaluation criteria, and need for transparency

Concerns and general comments on reliability, resilience, and increased demand

Requests for more attention to environmental justice communities

Climate change and need to reduce/eliminate use of fossil fuels in the near-term

Scoping Advice

Increase decarbonization efforts and faster.

Consider resources from outside the Valley.

Climate change impacts and risks.

General scenario design ideas.

Consider existing and emerging generation and storage technologies.

Consider improving rates.

Recognition of socioeconomic and environmental justice strategies.

Interest in various types of generation options.

Suggestions to increase public outreach and stakeholder involvement.

Comment Categories

- Increase Decarbonization
- Demand, Resilience and Reliability
- Scenarios / Strategies
- Process and Transparency

Energy Resources

- Solar
- Coal
- Natural Gas
- Nuclear
- Energy Efficiency / Demand Response
- Energy Storage
- Distributed Energy Resources
- Biomass

Environmental Impact Statement

- Air and Water Quality
- Land Use
- Environmental Justice
- Threatened and Endangered Species

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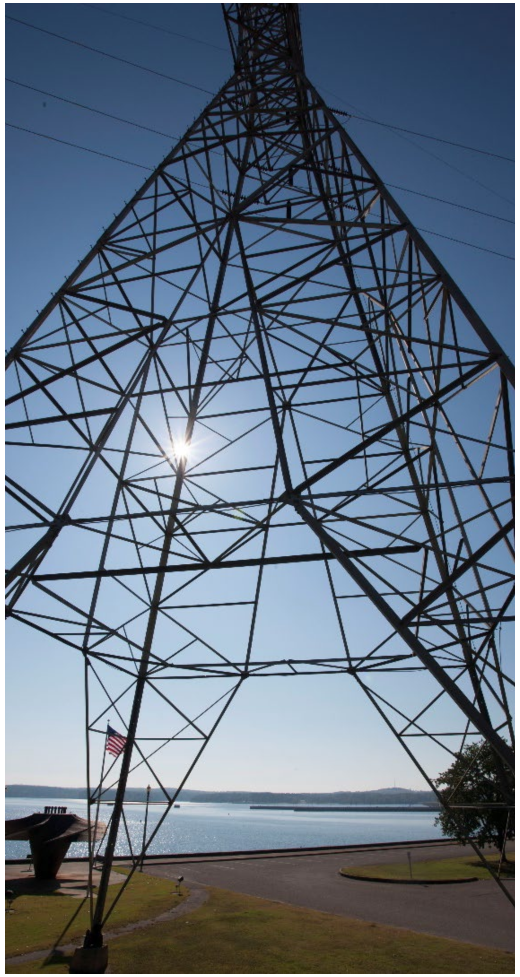
Scoping Report



TVA is compiling a report summarizing the scoping input

The scoping report will:

- Document the comment themes and comments received
- Include how TVA intends to consider the comments
- Describe how IRP process considers scoping input during the development of the IRP and the EIS
- Describe scenarios, strategies, and energy resources being carried forward in the IRP and IRP EIS analysis.

The scoping report is scheduled for posting to the IRP website in the fall

2024 IRP Public Scoping – IRP-WG Discussion

What comments surprised you?

What did you expect to see that was not mentioned?

Any additional suggestions on how TVA can better engage the public, we'd love to hear those ideas.

Appendix – Public Scoping

Agency and NGO Commenters

Agencies	
Environmental Protection Agency	Tennessee Dept. of Environment and Conservation
Environmental NGOs	**Energy NGOs**
Center for Biological Diversity	Southeast Sustainability Directors Network
Sierra Club	Southern Alliance for Clean Energy
Southern Environmental Law Center et al.*	Southern Renewable Energy Association
Tennessee Wildlife Federation	Vote Solar

*Appalachian Voices, Center for Biological Diversity, Memphis Community Against Pollution, Protect Our Aquifer, and Sierra Club

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Break

Peer IRP Benchmarking

Howard Friedman; Managing Director
Regulatory & Legal Services
Deloitte

Wrap-up and Day Two Preview

Jo Anne Lavender; IRP Facilitator

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Welcome

Jo Anne Lavender; IRP Facilitator

Safety Moment

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Agenda – August 29, 2023

Topic	Time (ET)	Presenter(s)	Notes
Breakfast	8:00-8:30		
Agenda and welcome	8:30-8:40	Jo Anne Lavender	
Reference Case forecasts	8:40-10:30	Bob Roth; Nathan Mathis; John Collins	Review current outlook on economics, load, and commodities forecasts
Break	10:30-10:45		
Scenarios review and discussion	10:45-11:45	Daniel Woolley; Jo Anne Lavender	Review of feedback, updates, and discussion
Lunch	11:45-12:30		
Resource Overview	12:30-1:15	Hunter Reed	Overview of expansion resources
Break	1:15-1:30		
Scenarios discussion (cont.)	1:30-2:15	Jo Anne Lavender; Daniel Woolley	
Emerging tech overviews, including break	2:15-4:50	Daniel Sipe	I&R/EPRI presentations/ discussion on CCS, hydrogen, and storage
Wrap-up	4:50-5:00	Jo Anne Lavender	

2024 IRP Reference Case

Bob Roth; Sr. Specialist, Enterprise Forecasting
Nathan Mathis; Manager, Load Forecasting
John Collins; Sr. Specialist, Enterprise Forecasting

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Reference Case Forecasts – Economic Forecast

Bob Roth; Senior Specialist, Enterprise Forecasting

Summary

Core inflation, along with economic activity, has proven to be very resilient in 2023. Rate hikes are expected to slow inflation and growth, especially in 2024.

The Federal Open Market Committee (FED OMC) has raised interest rates by 5.25% over the past 17 months and plans to add another 25 basis points to the federal funds rate (FFR) prior to year-end.

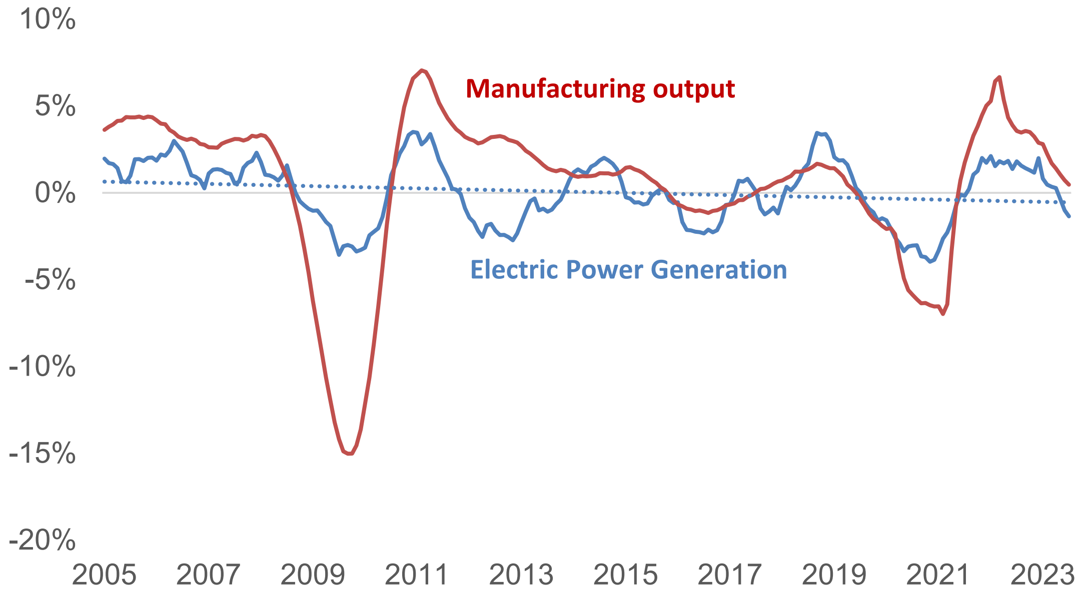
Expected downside to employment should be modest due to tight labor markets.

Reference Case forecast reflects post-pandemic population/migration data from the Bureau of the Census.

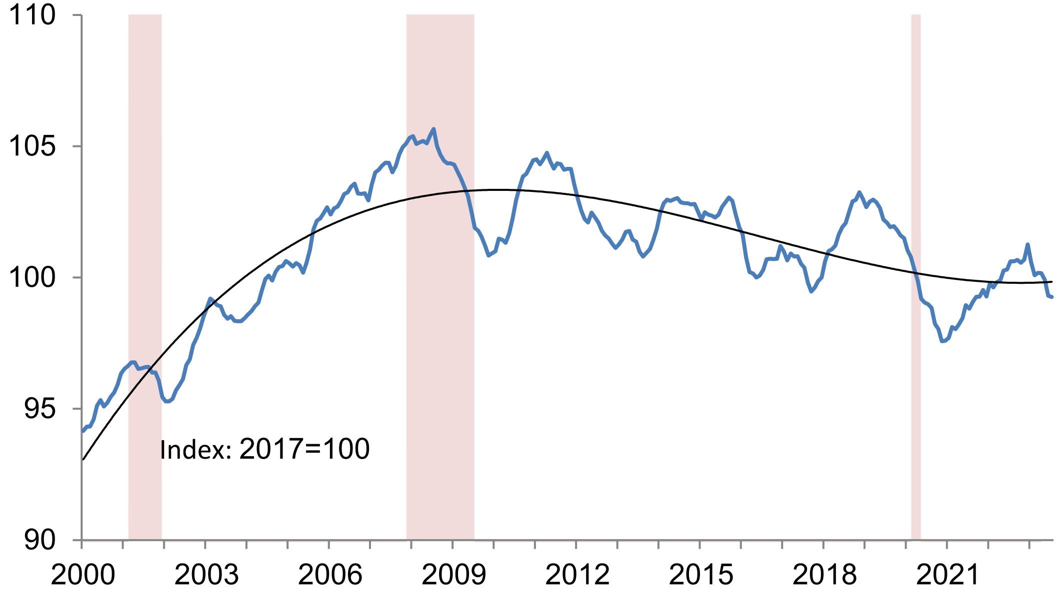
U.S. Electric Power Generation (IP)

Electric power demand has been declining since the Great Recession (2008 - 2009) due to efficiency gains and an increasing shift to a service-sector oriented economy which is less energy-intensive. Generation output rose 2% in CY-2022 but is off 3.4% YTD-July-2023 with manufacturing slowing.

Electric Power Generation vs. Manufacturing Output year-on-year change in 12-month-rolling average



Electric Power Generation – 12-month-rolling-average



Source: U.S. Federal Reserve Board, not adjusted for weather impacts

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Reference Case Forecasts – Load Forecast

Nathan Mathis; Manager, Load Forecasting

Agenda

Load History and Context

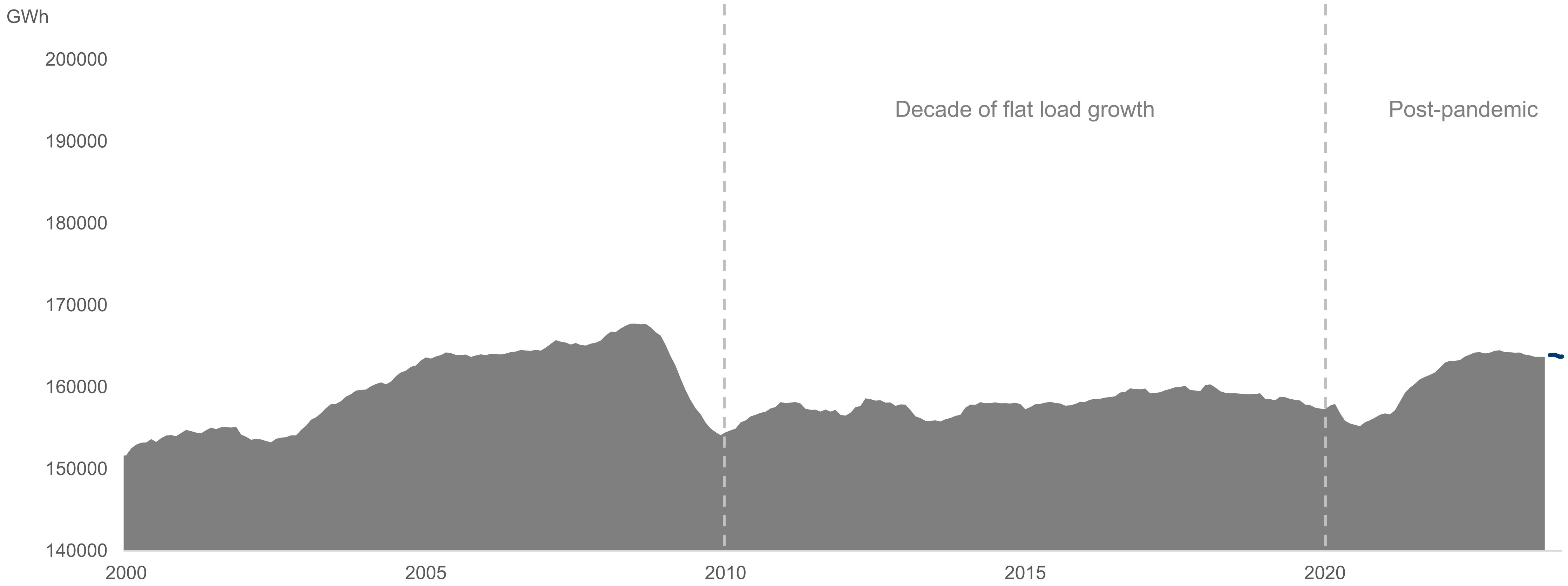
Load Forecasting Process Overview

Reference Case Load Forecast

- Net System Energy
- Net System Demand
- Local Power Company Served Load
- Directly Served Load
- Electric Vehicle Forecast
- Behind-the-Meter Solar

Key Takeaways

Decade of flat load followed by post-pandemic growth



* Weather normalized rolling 12-month energy. Excludes USEC

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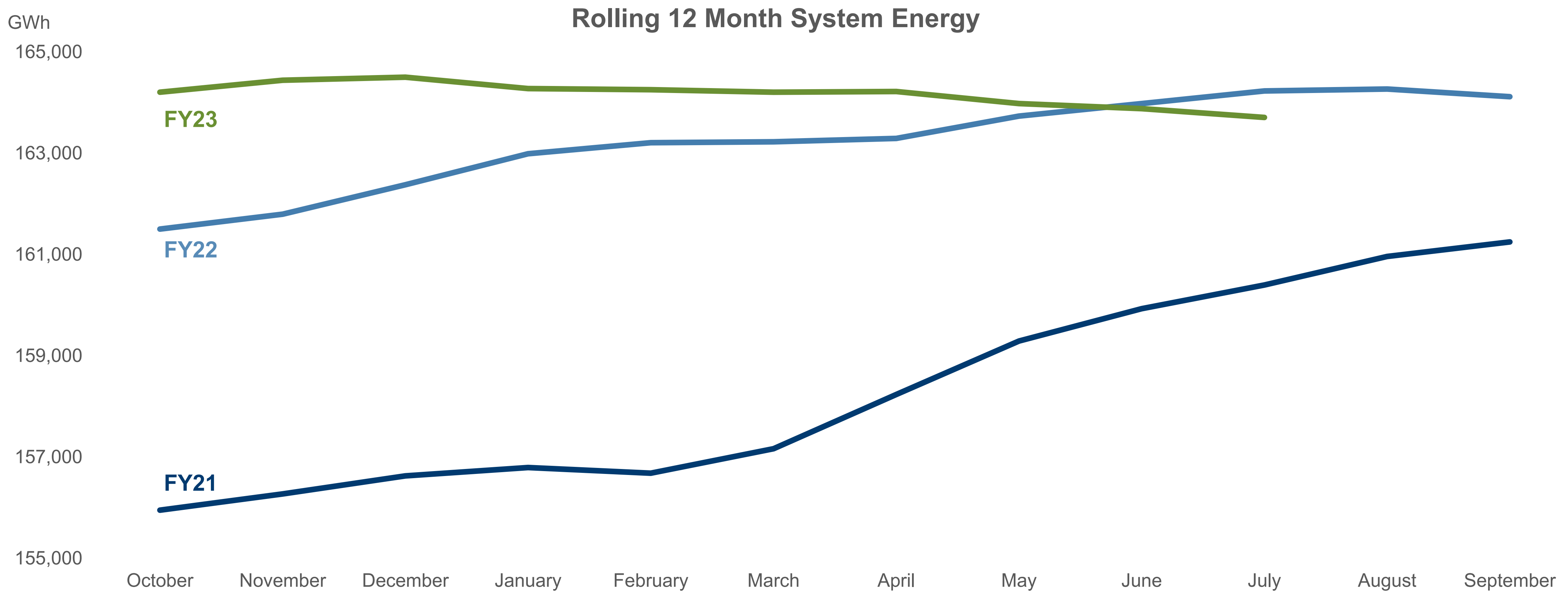
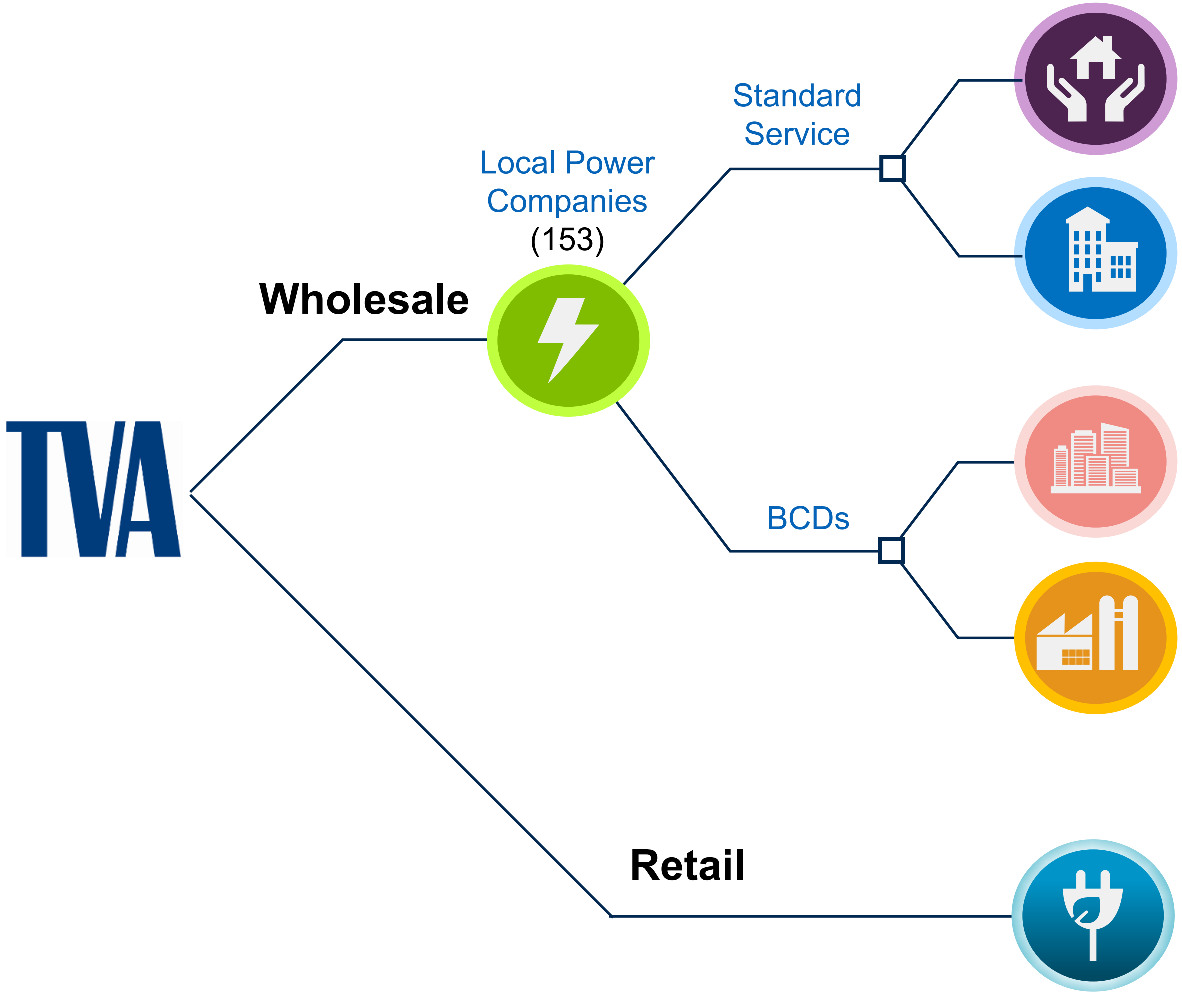
Recent trends show rapid post-pandemic growth followed by a sluggish FY23

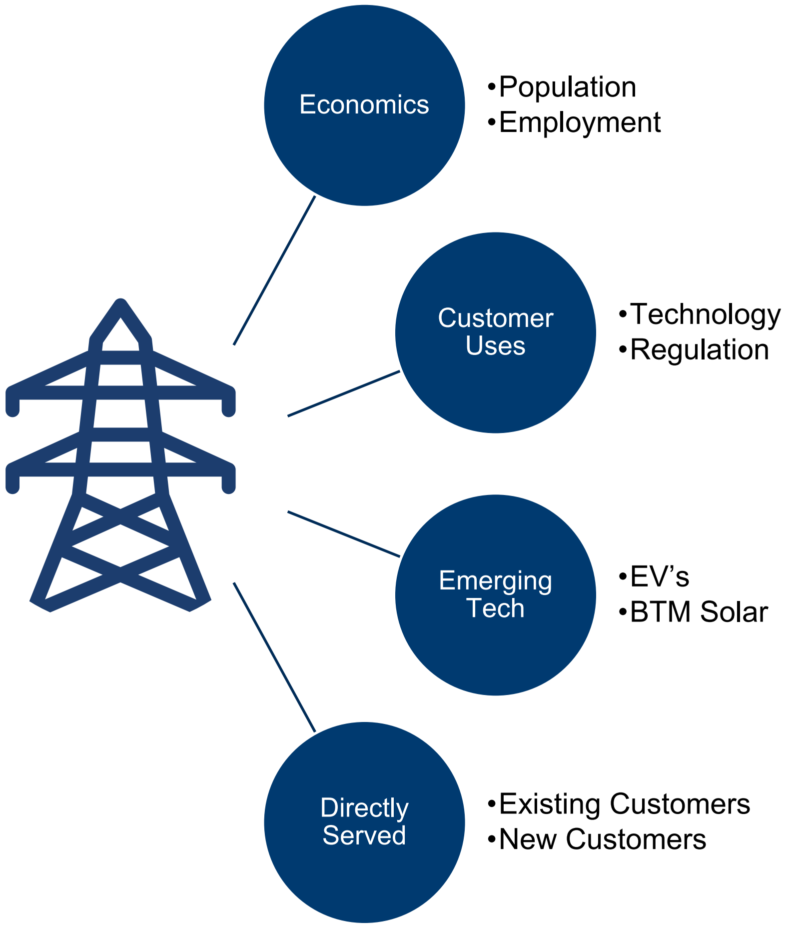


Breakdown of TVA's Load



	Accounts	% of Energy Demand
Residential	4 Million	40%
Small Commercial & Industrial	700,000	33%
Large Commercial	~100	2%
Large Industrial	~400	12%
Directly Served	~60	13%

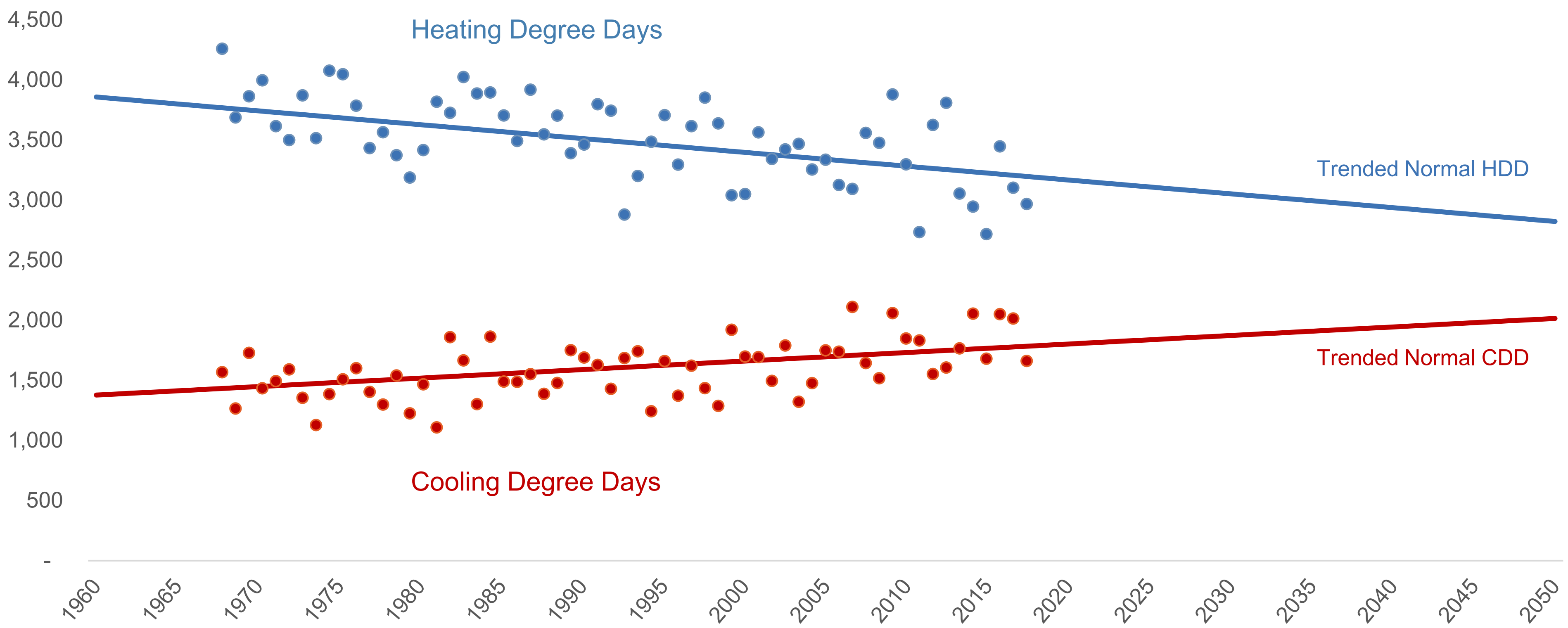
Load Forecasting Process



TVA compares favorably with peer utilities, and uses industry best practices for forecasting techniques

- County level economics and demographics
- Residential and Commercial end-use intensities and saturations
- Appliance efficiency codes and standards
- Light and medium/heavy duty EV market adoption with usage data and charging patterns
- PV market adoption and technical specifications
- Discrete customer forecasts for each directly served customer
- Large industrial customer expansions and additions
- Hourly regional and customer level load data capturing behavioral patterns, levels, and trends
- 23 weather stations across the Valley with proportional load weights

Reference case uses trended climate assumptions



Key Takeaways

This forecast represents the Reference Case for the IRP. Additional scenarios will explore alternative assumptions and associated TVA system growth rates.

TVA's load forecasting process provides many opportunities to calibrate key scenario assumptions and explore associated load growth impacts.

TVA experienced a decade of flat loads followed by rapid post-pandemic growth. Recent data indicates slowing over the past year. Load growth expected to return in the following years driven by:

- Higher employment and population forecasts
- Large industrial expansions and additions
- Electric vehicle market adoption

Climate trends are shifting season energy patterns

Increasing efficiency standards and behind-the-meter solar will dampen growth rate

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Reference Case Forecasts – Commodity Forecast

John Collins; Senior Specialist, Enterprise Forecasting

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Commodity Forecasting Methodology

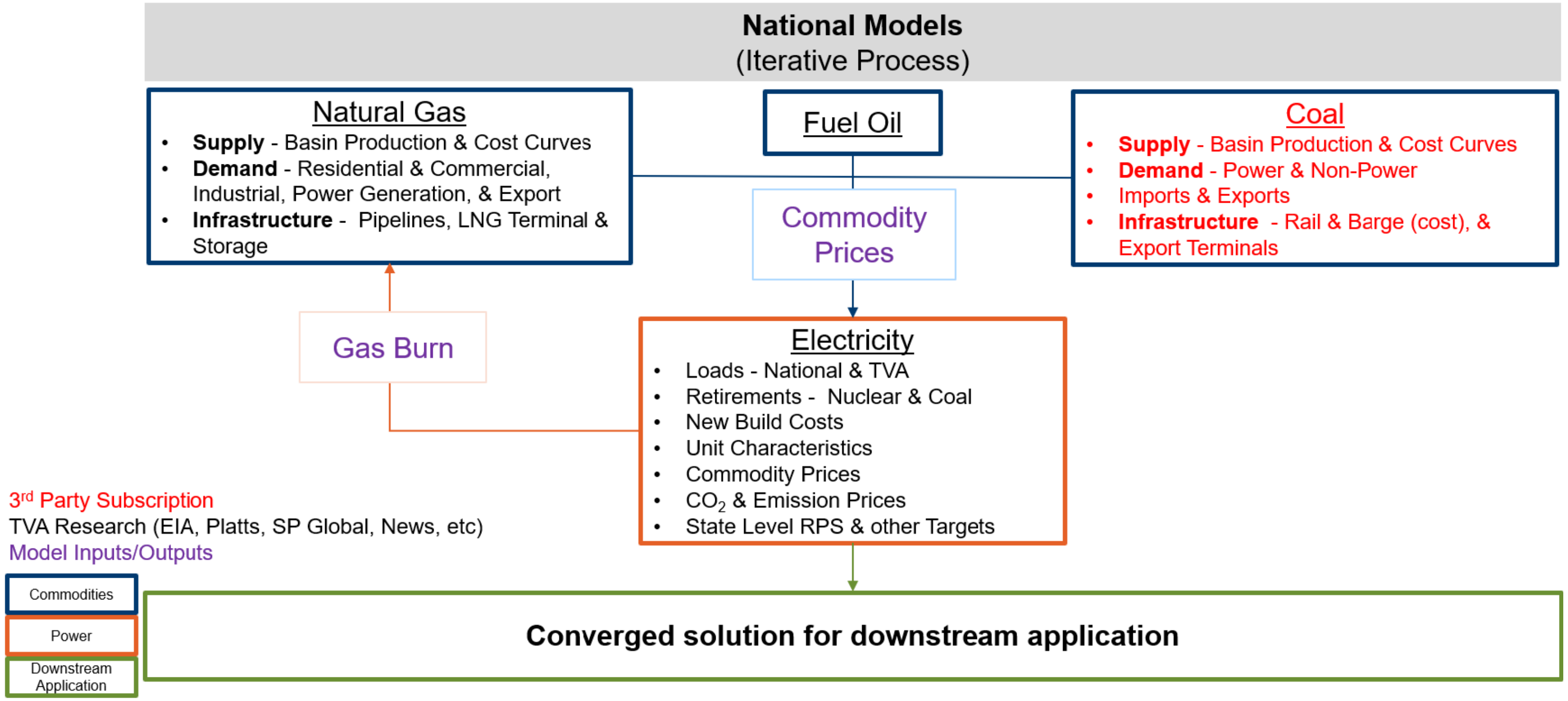
TVA utilizes industry standard modeling systems for gas and power markets

Commodity price forecasts are model outputs

Co-optimization process ensures consistency across gas and power models

First three years of forecast are market data, followed by a two-year blending period with model output

Fuel oil and coal are 3rd party forecasts



Key Natural Gas Model Inputs

Supply
Supply plays/basins
Pipeline availability
Pipeline capacity

Demand
Residential
Commercial
Industrial
Electric
Liquefied Natural Gas (LNG)

LNG
Global demand
LNG facility availability
LNG facility capacity

Key Power Model Inputs

Internal

- TVA Load Forecast
- Natural Gas Prices
- Inflation
- Nuclear Retirement Dates
- TVA Generating Capacity
- Public Policy Assumptions
- Capital Cost of New Generation

External

- National Load Forecast
- Coal Prices
- Fuel Oil Prices
- Generation Resources
- Transmission Limits
- Renewable Generation Profiles
- Capital Cost of New Generation

Executive Summary

Natural gas price increases in the future primarily due to growing exports

LNG export capacity expected to nearly double by 2027, which further links U.S. to global markets

Despite these increases, price expectations remain comparable to shale era when adjusted for inflation

Gas-fired units are frequently the marginal generation source throughout the U.S.

Public policy is a key determinant of future generation capacity additions

Solar and wind generation is expected to comprise the majority of future national capacity additions

Natural gas remains an important power sector fuel even with major renewable additions

Volatility expected to increase in both power and gas markets

Outlook Risks and Uncertainties

- Load growth
- Infrastructure development
- Materials and mineral availability
- Global energy demand
- Public policy
- Technological change

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Break

Scenarios Review

Daniel Woolley; Sr. Specialist, Resource Strategy
Jo Anne Lavender; IRP Facilitator

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Lunch

Resource Overview

Hunter Reed; IRP Project Manager

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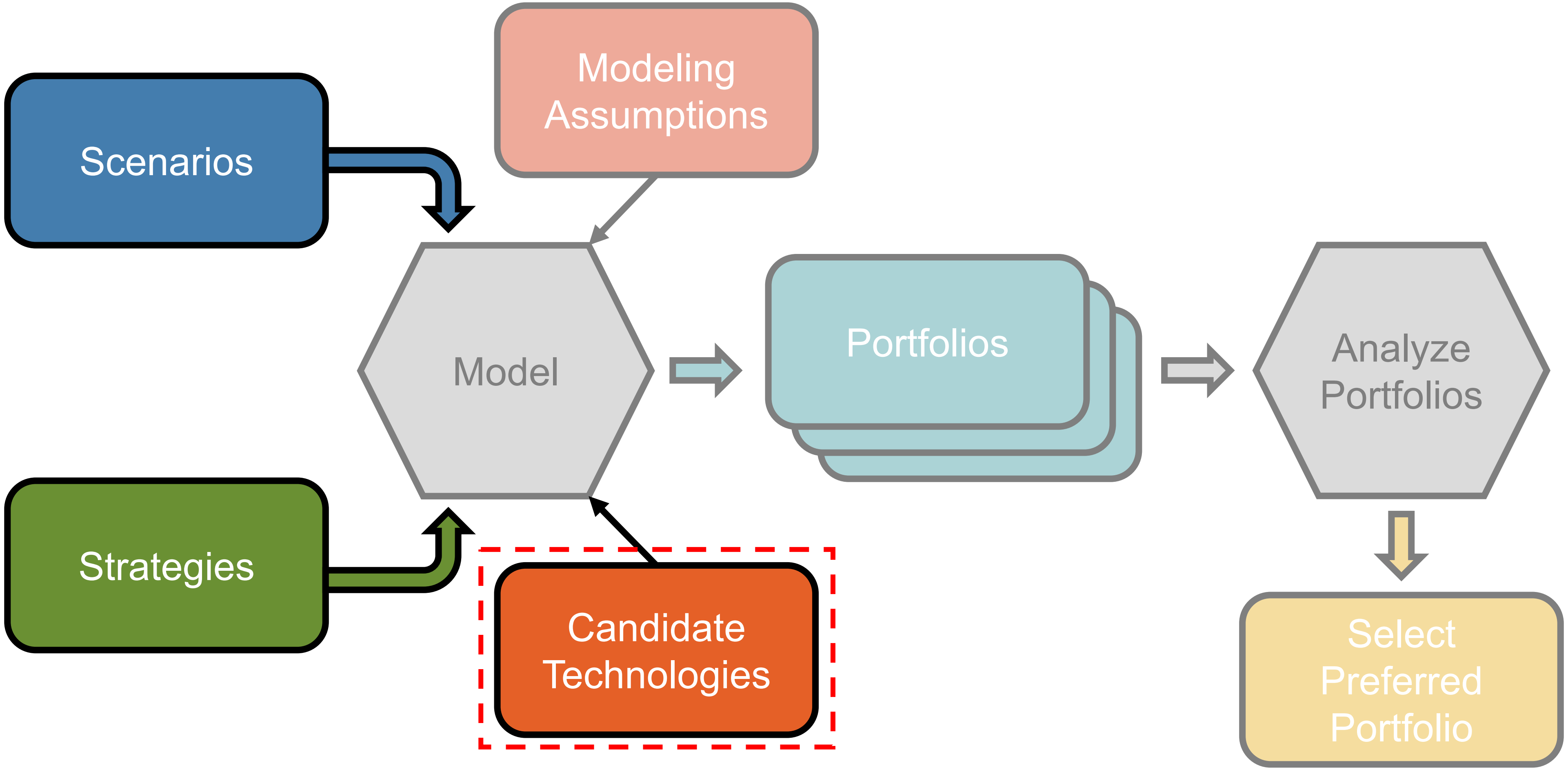
How the Integrated Resource Planning Process Works



Stakeholder feedback is a key component in the development of all model inputs

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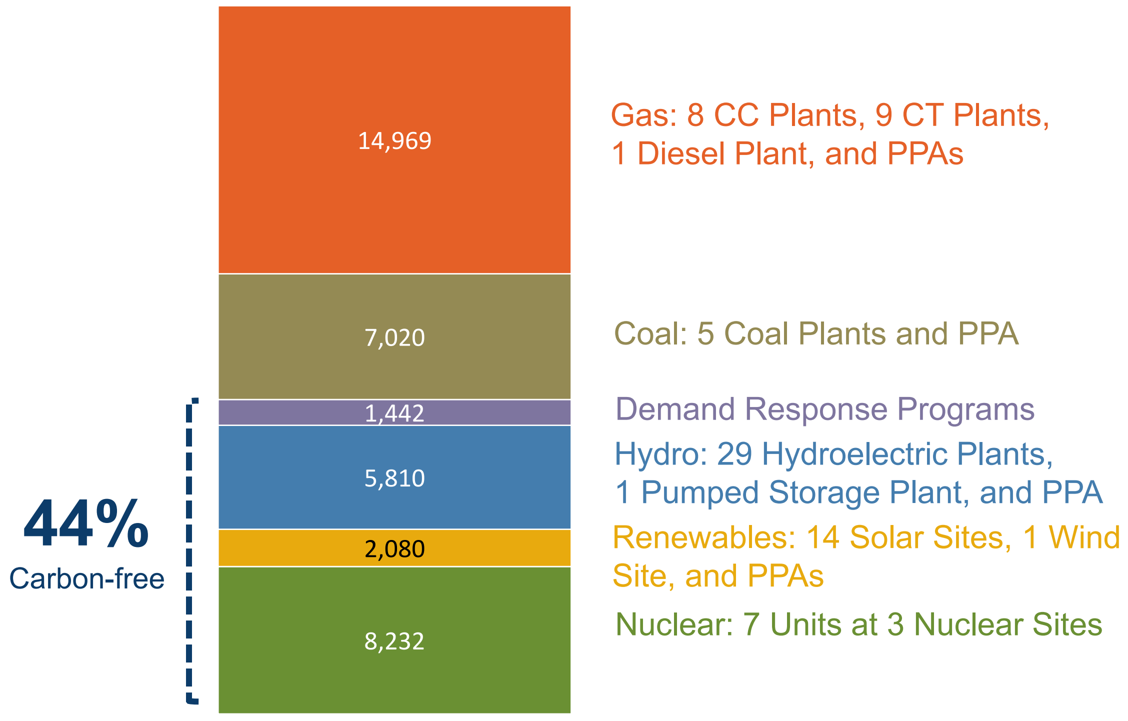
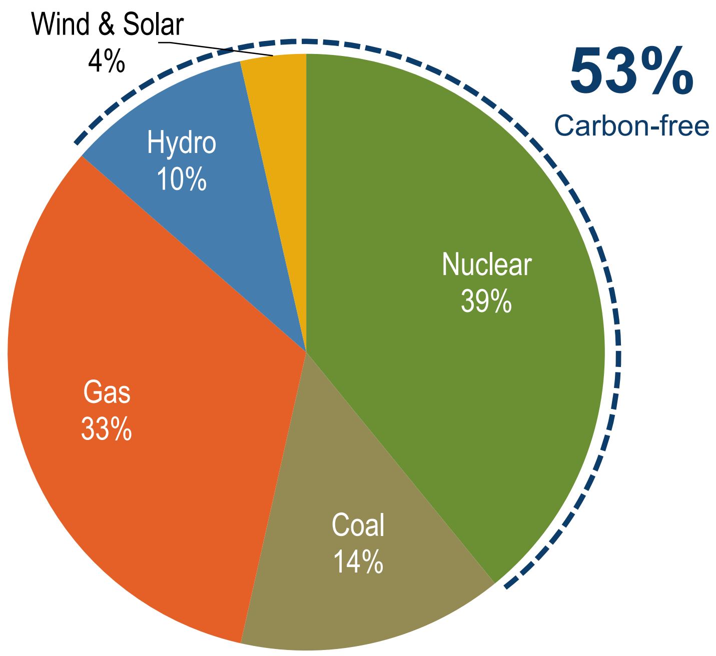
Today's Resource Portfolio

FY22 Capacity
39,553 MW



Capacity aligns to FY22 10-K Net Summer Capability, adjusted to include demand response programs. Planning capacity is lower, as it accounts for Hydro and Renewable expected generation at peak, fuel blend derates, and other factors.

FY22 Energy
165 TWh



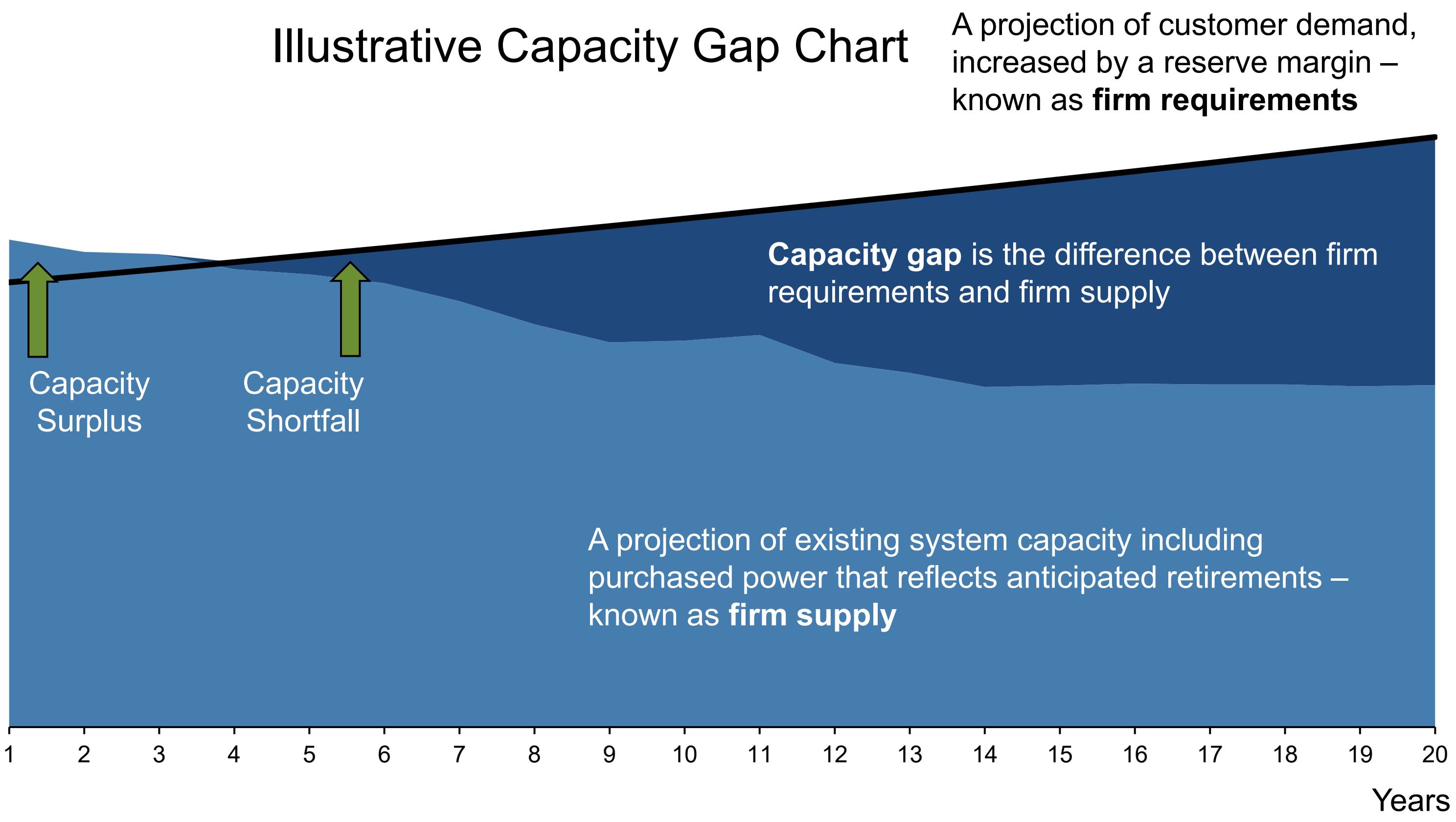
In addition to power supply sources included here, TVA offers energy efficiency programs that effectively reduced 2022 energy needs by about 2,200 GWh or 1.3% (Net Cumulative Realized at System basis, 2007 base year).

Resource Planning for Future Capacity Needs

Resource planning is about optimizing the mix of future capacity.

Projections of capacity needed are filled by the most cost-effective resources.

Illustrative Capacity Gap Chart



Recommended path provides low cost, reliability, diversity and flexibility

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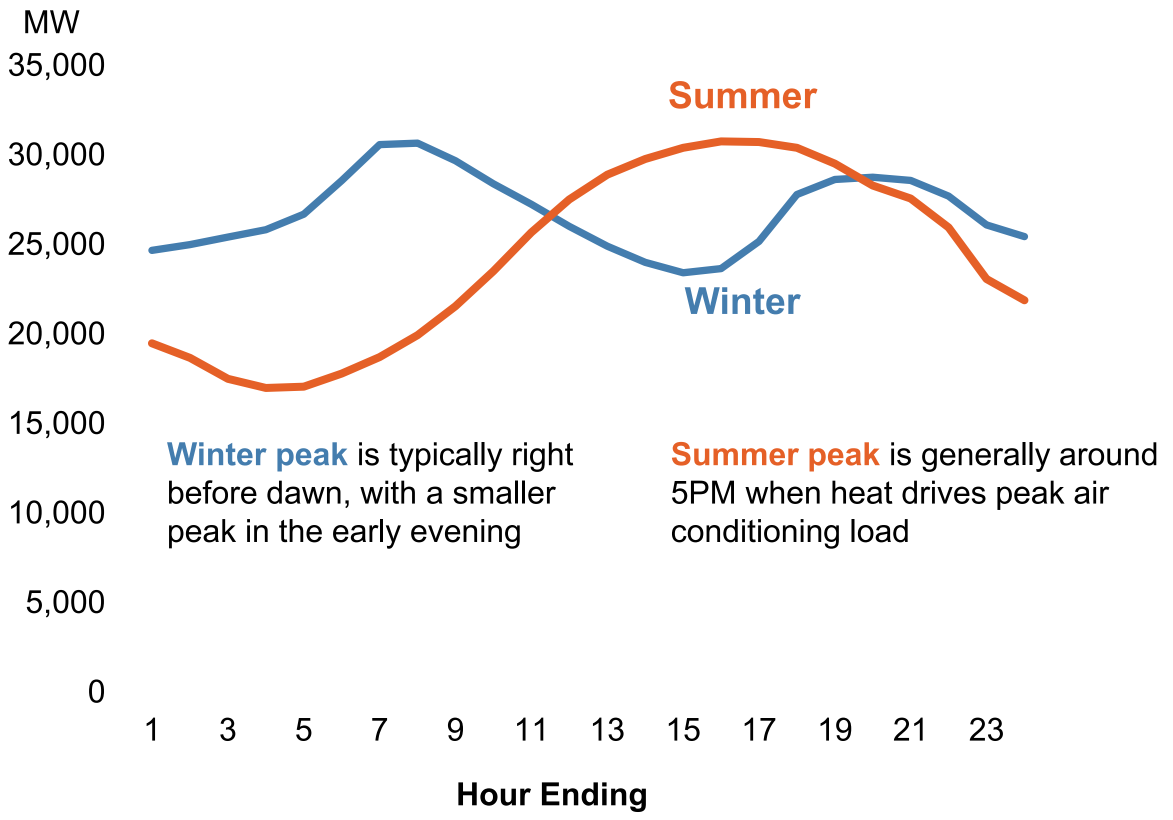
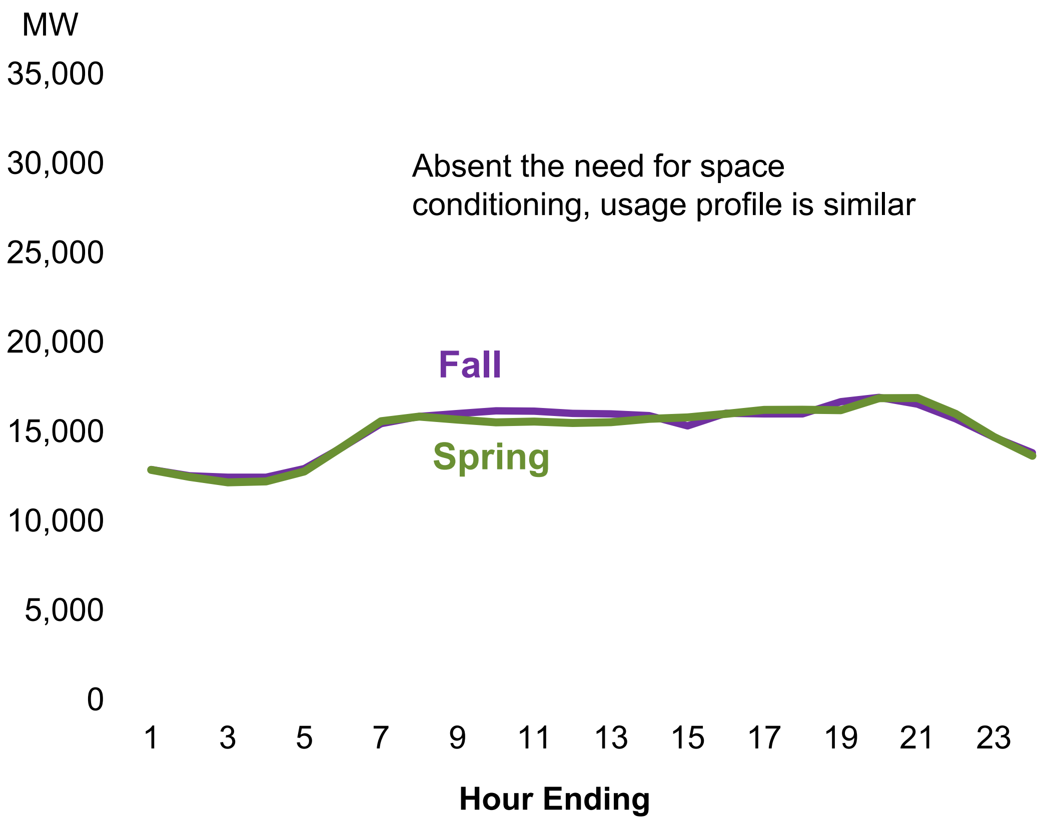
Winter and Summer Have Distinct Profiles





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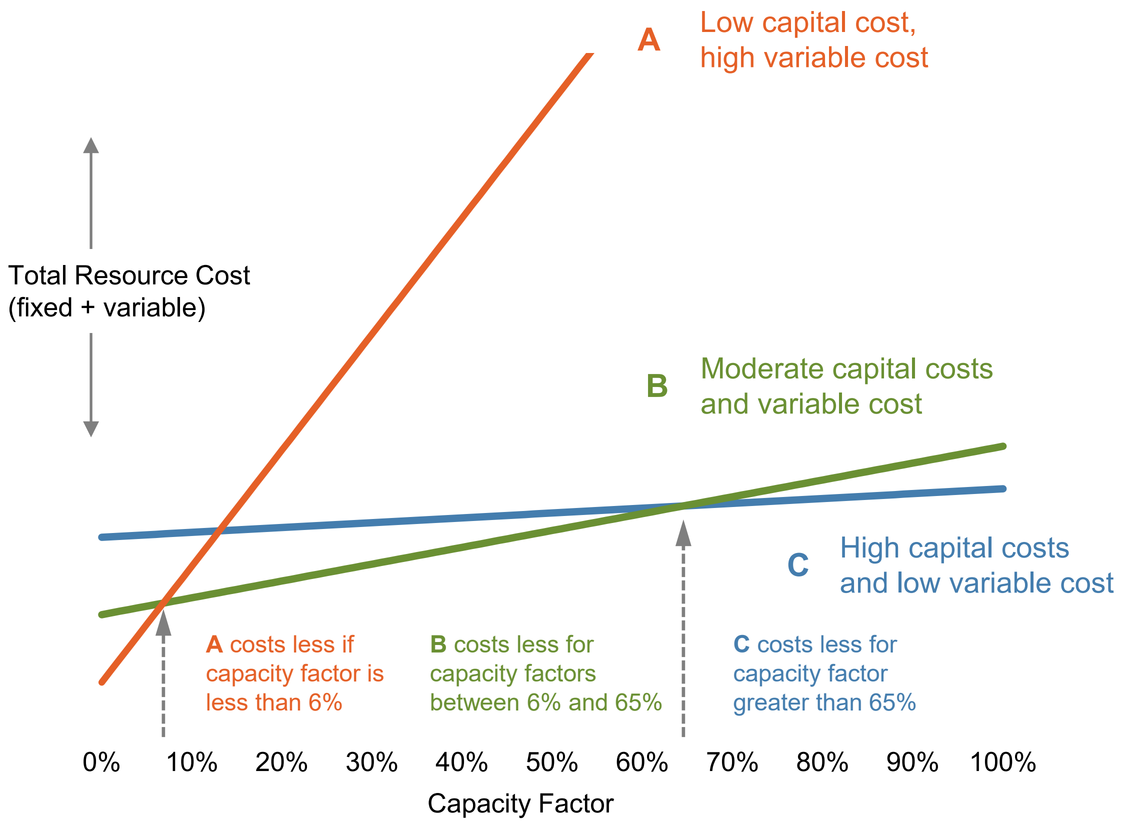
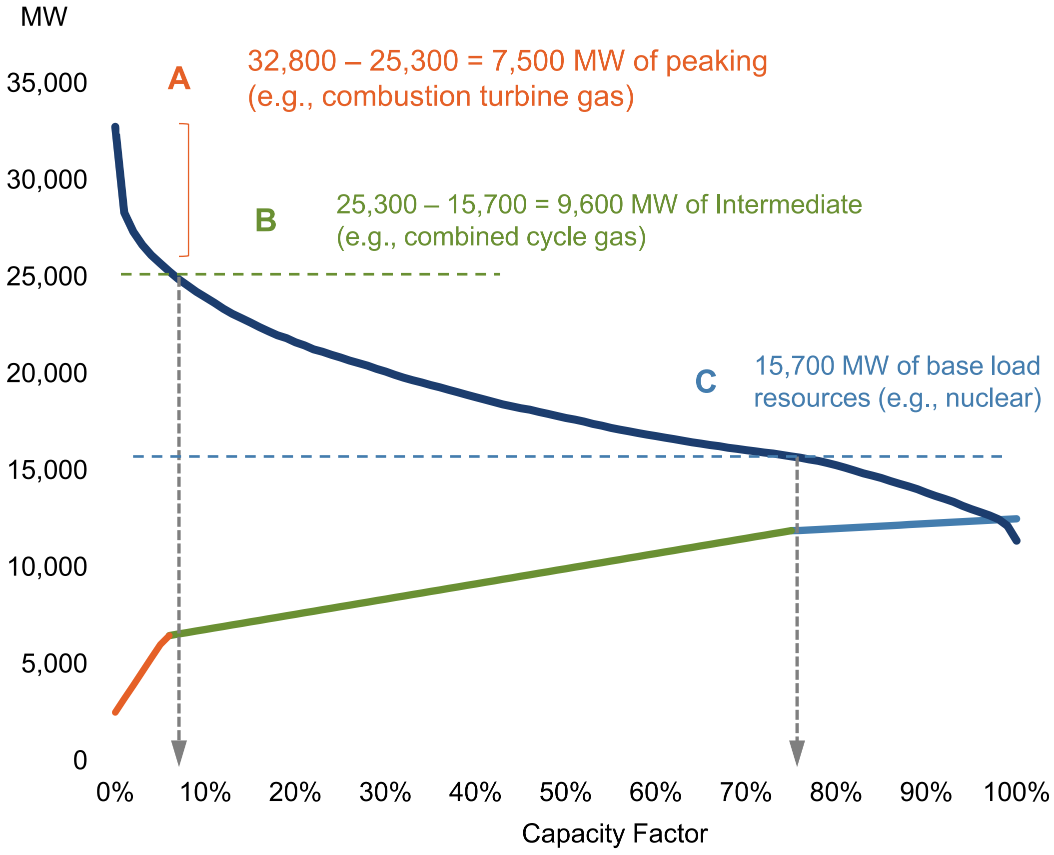
Selecting Appropriate Resource Type

Resource selection is complex and considers physical and cost characteristics and portfolio fit





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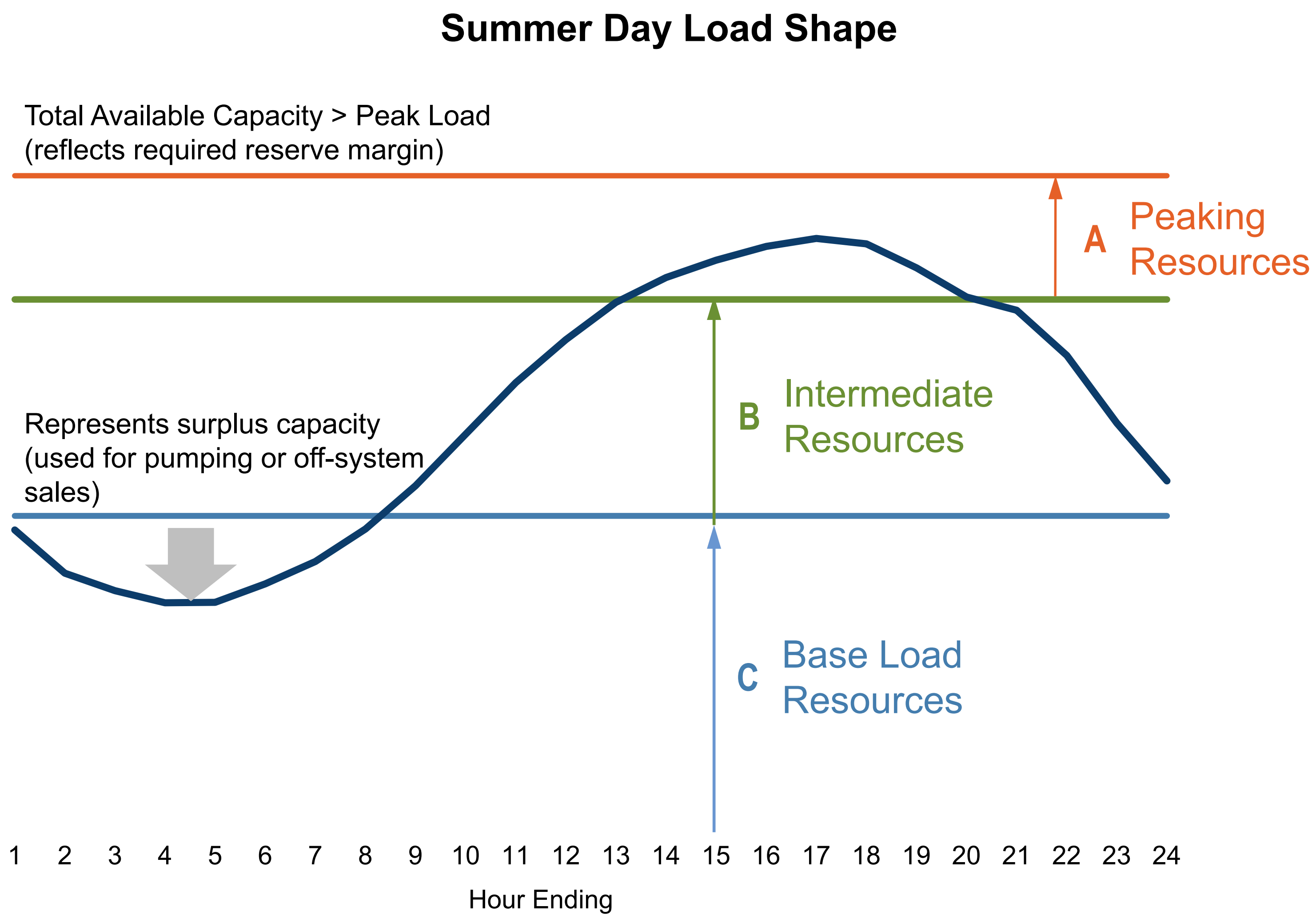
Daily Load Shape and Resource Dispatch



Resource Characteristics

Physical and economic characteristics matter for resource evaluation and portfolio fit

Physical

Item	Measure
Output (capacity)	MW (max dependable) MW (minimum)
Availability	Outage rates
Flexibility	Ramp rate
Duty Cycle	Base, intermediate, peaking
Dispatchability	Dispatchable, intermittent
Fuel	Types of fuel, limits
Emissions	Lbs./kWh
Other	Regulations, constraints

Economic

Item	Measure
Capital Cost	Installed cost ($), including transmission
Efficiency	Heat rate (Btu/kWh)
Operating Cost	Fixed ($) Variable ($/kWh)
Fuel Cost	$/Btu
Emissions Cost	$/lb. (as applicable)
Build Schedule	Years
Book life	Years

TVA Operates in Multidirectional Environment

Capacity (kW) and Energy (kWh)

Demand Side

Supply Side

Load Management Demand Reduction and Generation

Supply Side Resources

Nuclear

Coal

Gas

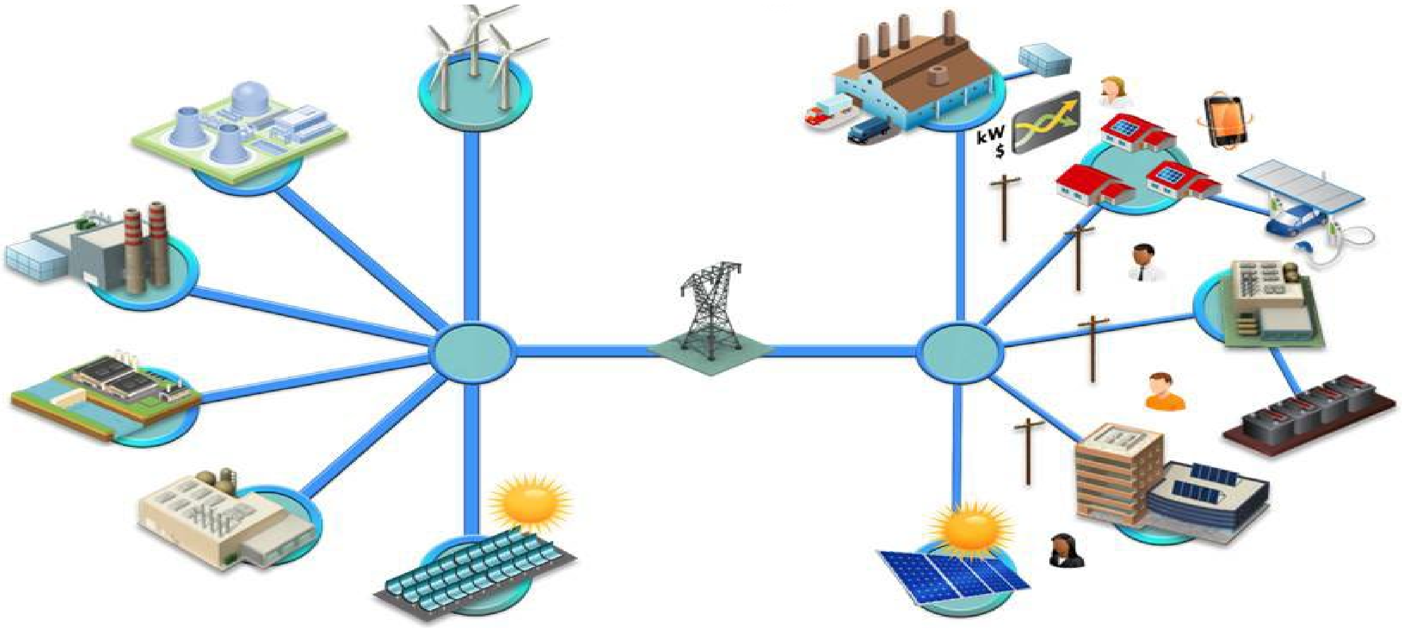
Purchased Power

Renewables

Hydro

Storage

Other Assets



Demand Side Resources

Energy Efficiency

Demand Response

Energy Services

Distributed Generation

Nuclear

Nuclear power generates large amounts of electricity that's safe, clean, reliable, and cost-effective. TVA continues to evaluate emerging nuclear technologies, including small modular reactors, as part of technology innovation efforts aimed at developing the energy system of the future.

Advantages:

- Dispatchable and carbon-free
- Low production/operating costs

Considerations:

- Relatively high construction and fixed costs
- Cost and timeline uncertainty associated with new nuclear

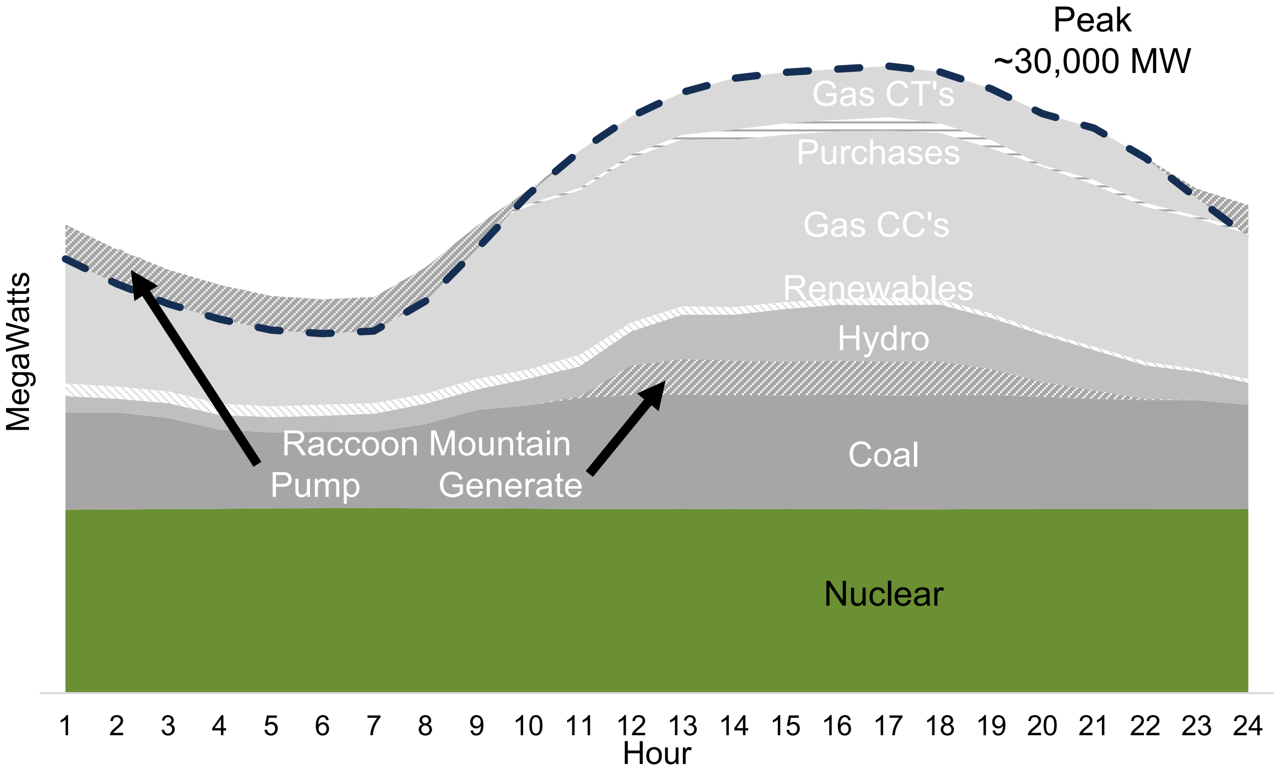


Chart is illustrative and for educational purposes only;
Reflects a typical summer day

Coal

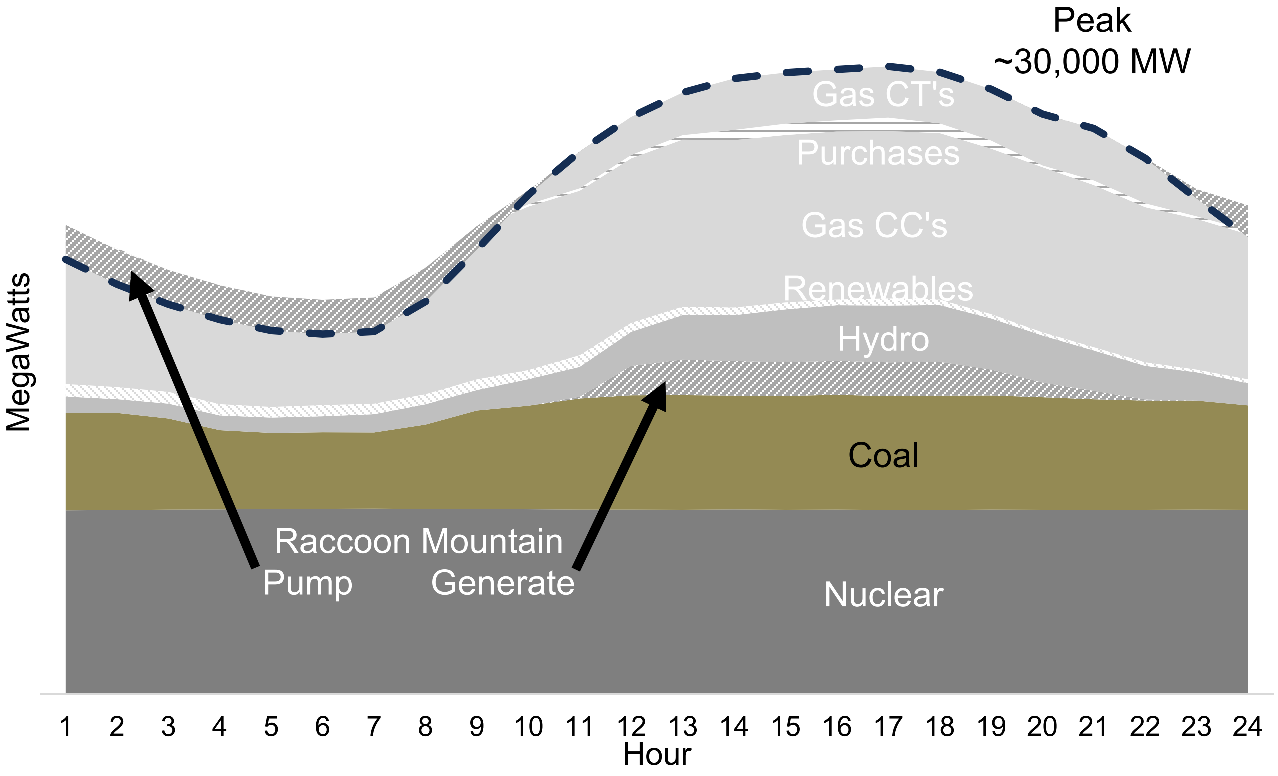
Coal-fired plants have formed the backbone of the TVA power system since it first started using them in the 1950s. TVA's coal fleet is one of the oldest in the nation and TVA has already retired over half of the units it once operated with plans to retire all remaining units by 2035.

Advantages:

- Serves large energy across many hours
- Provides regional grid support

Considerations:

- Carbon-emitting
- Waste disposal (Coal combustion residuals, wastewater)
- Economic and environmental risks



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Hydro

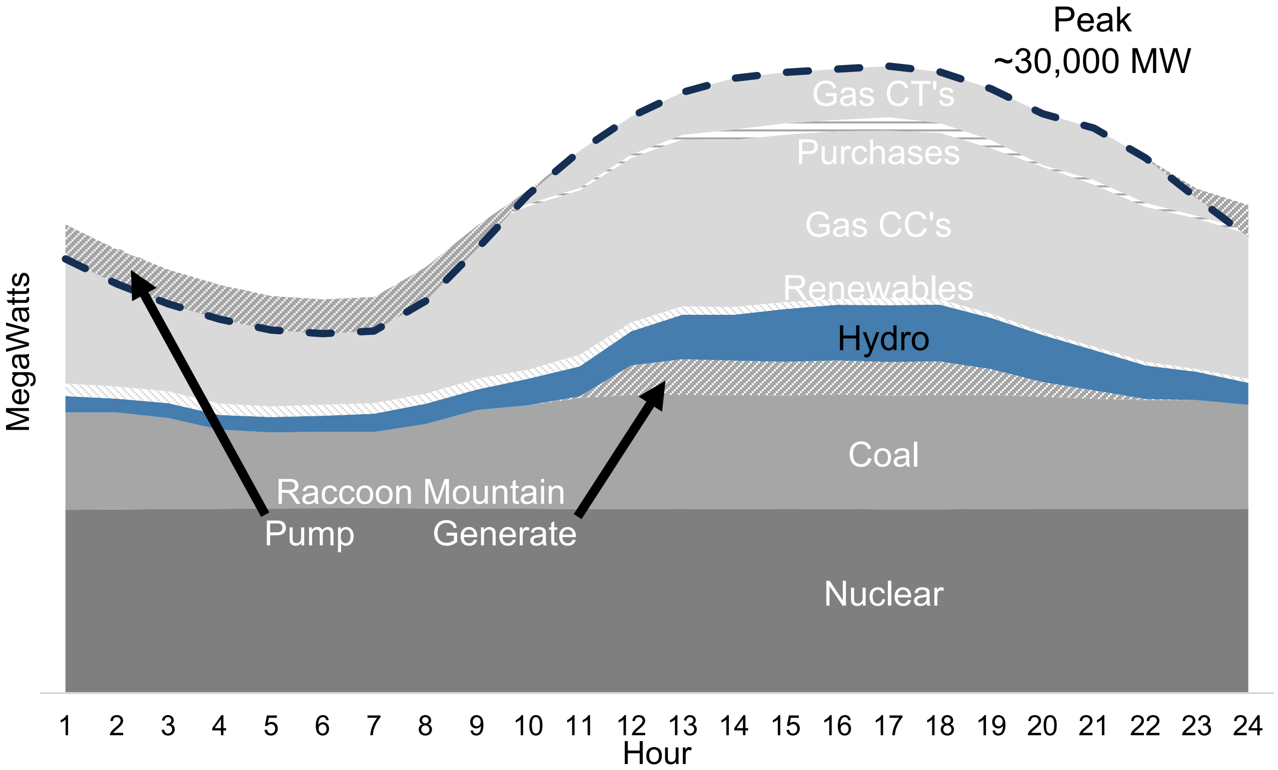
Hydroelectric power is TVA's original, and largest source of renewable energy. Dams operated by TVA along the Tennessee River system serve multiple missions, including flood control, navigation, generation of electricity, and recreation.

Advantages:

- Dispatchable and carbon-free
- Low variable costs and zero fuel cost

Considerations:

- Energy limited due to water availability and multi-function mission
- Relatively high construction cost



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Solar

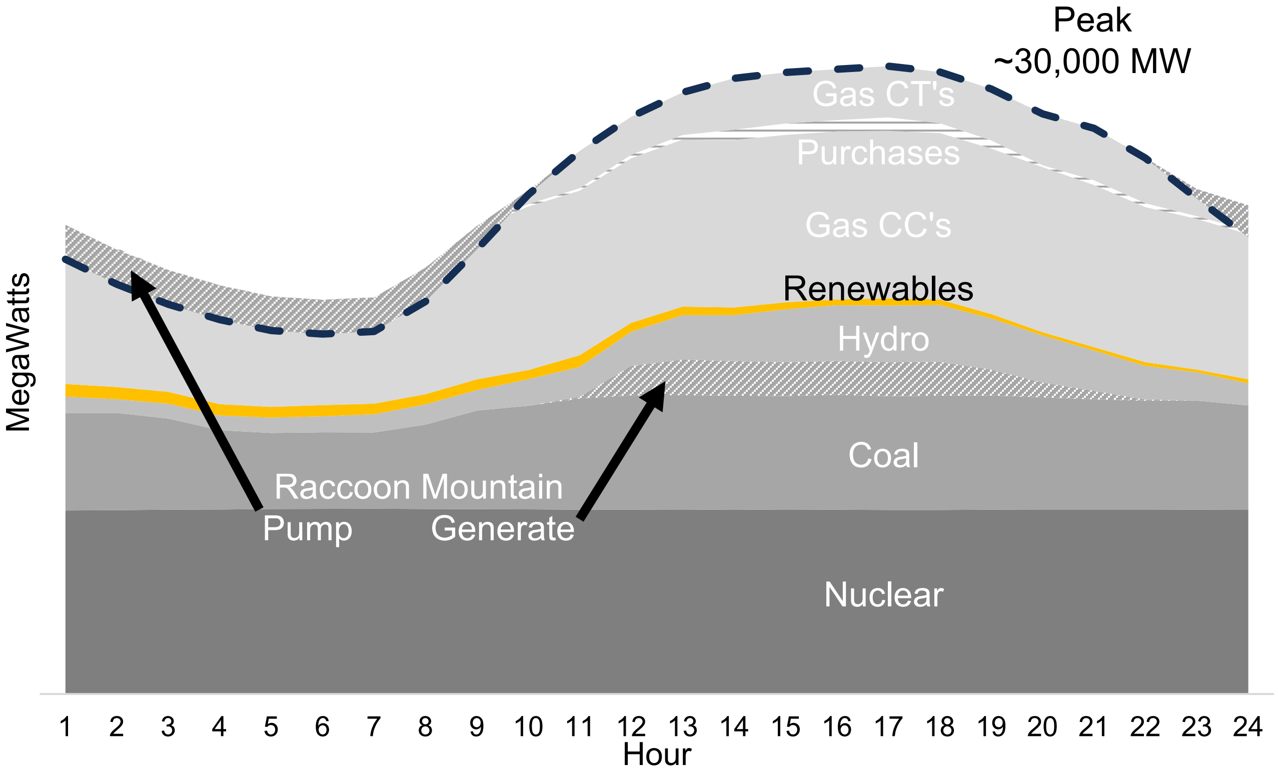
Solar is a growing component of TVA's renewable portfolio, being added to meet customer and system needs. Solar is becoming a cost competitive source of carbon-free energy; however, generation is restricted to daylight hours and intermittent in nature which limits its firm capacity contribution.

Advantages:

- Carbon-free
- Zero fuel cost

Considerations:

- Non-dispatchable
- Supply chain and permitting challenges



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Reflects a typical summer day

Wind

Wind energy is a major source of renewable energy and TVA's second largest source of renewable energy today. Lower wind speeds in the Tennessee Valley have traditionally required TVA to utilize imports from neighboring systems, however technology advancements are improving in-Valley prospects.

Advantages:

- Carbon-free
- Low variable costs and zero fuel cost

Considerations:

- Non-dispatchable
- Valley weather and topography traditionally not well-suited to wind
- Importing to the Valley requires additional infrastructure and reliance on outside resources

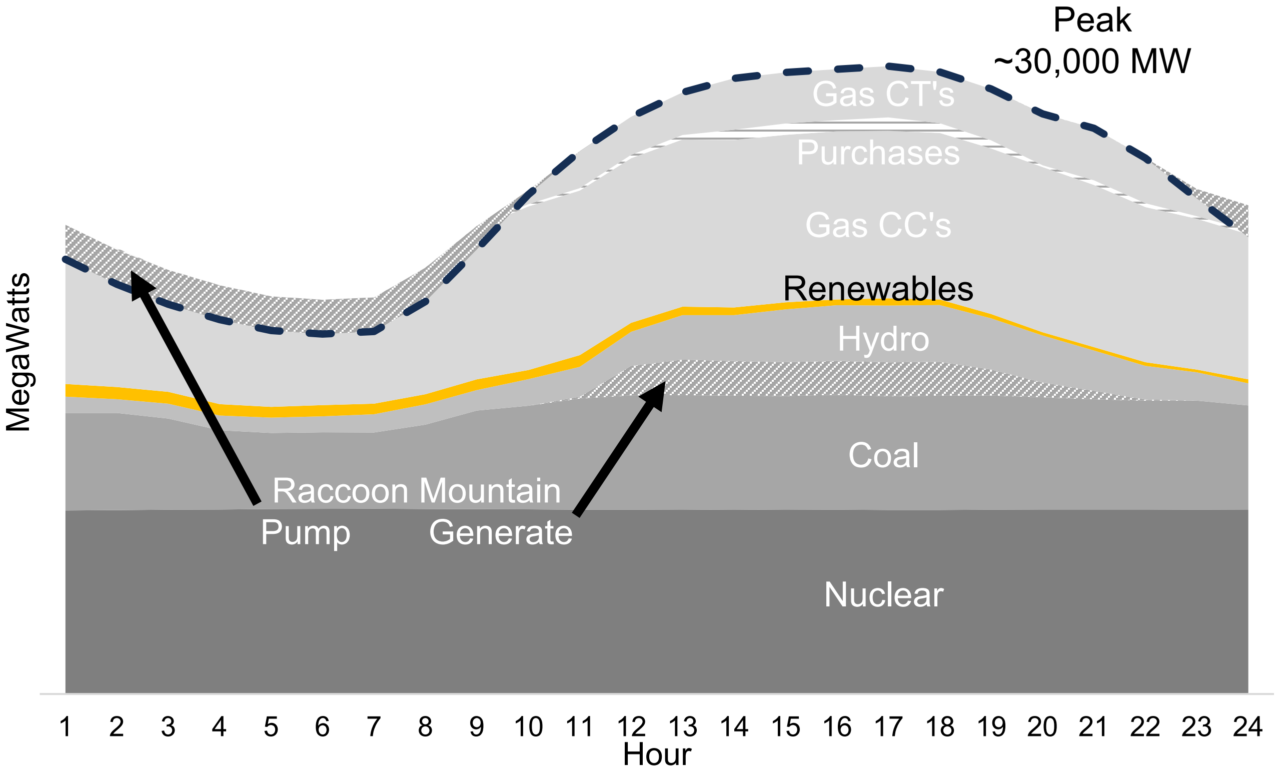

Chart is illustrative and for educational purposes only; Reflects a typical summer day

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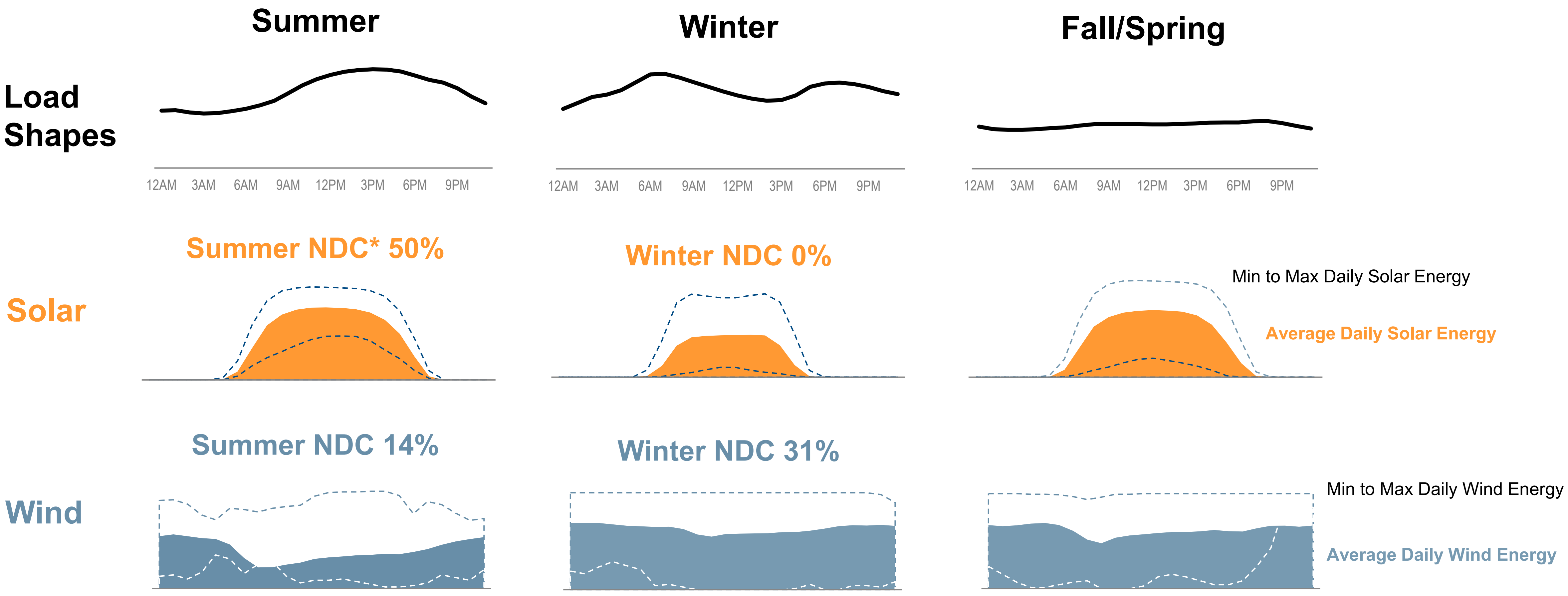
Solar and Wind Generation Profiles



*Net Dependable Capacity

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Natural Gas

Natural gas serves an increasingly important role in TVA's mission to provide clean, reliable energy to the people and businesses of the Tennessee Valley. Natural gas produces far lower levels of emissions than coal, helping TVA to improve air quality while meeting the growing demand for power in our region.

Advantages:

- Serves large energy across many hours (Combined Cycle)
- Helps quickly meet demand during peak periods (Combustion Turbine)
- Enables renewable integration and grid support

Considerations:

- Carbon-emitting
- Increasing challenges to procuring air permits and pipeline development

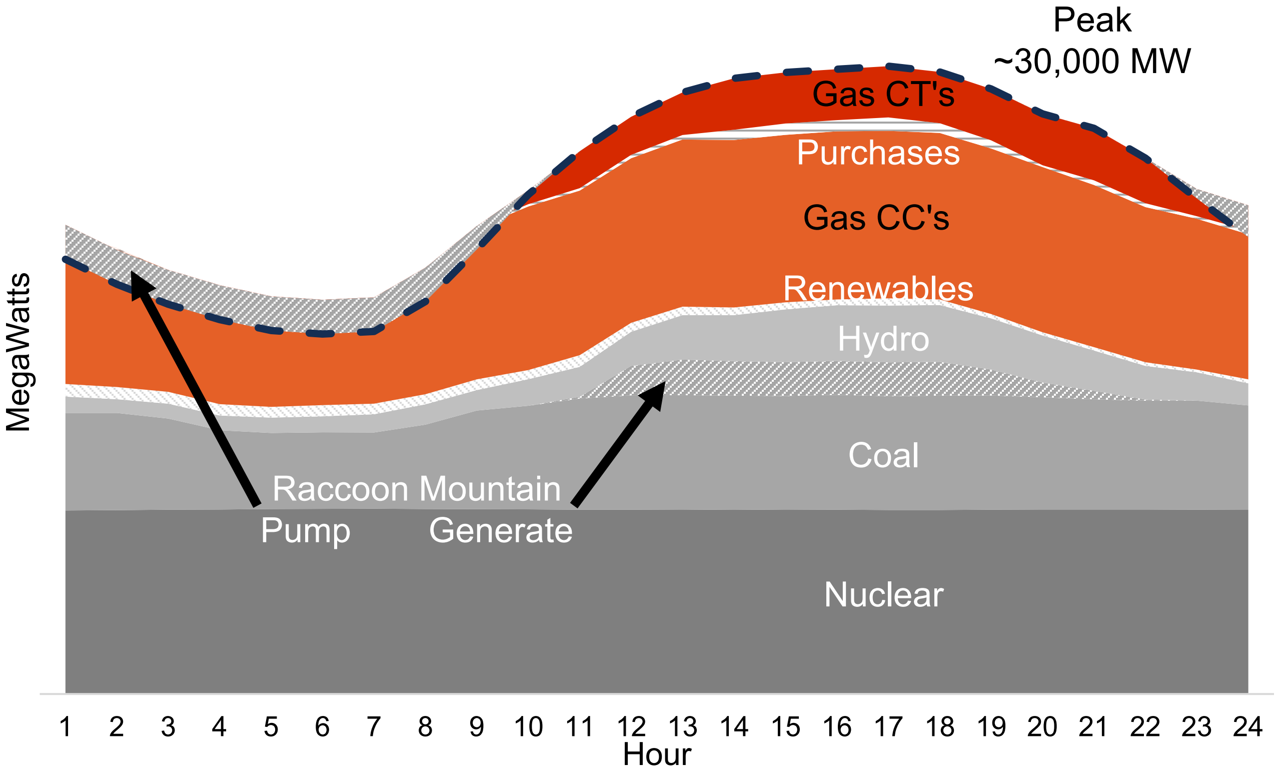

Chart is illustrative and for educational purposes only;
Reflects a typical summer day

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Storage

Storage resources act as a buffer between electricity supply and demand variations, increasing the flexibility of the grid and helping to enable use of renewable resources like solar, wind and other forms of distributed generation. TVA has a long history of bulk energy storage with its Raccoon Mountain pumped storage facility and has several battery storage projects under construction.

Advantages:

- Allows for more efficient system operation
- Enables intermittent resources

Considerations:

- Energy-limited based on hours of duration
- 10-15% efficiency loss

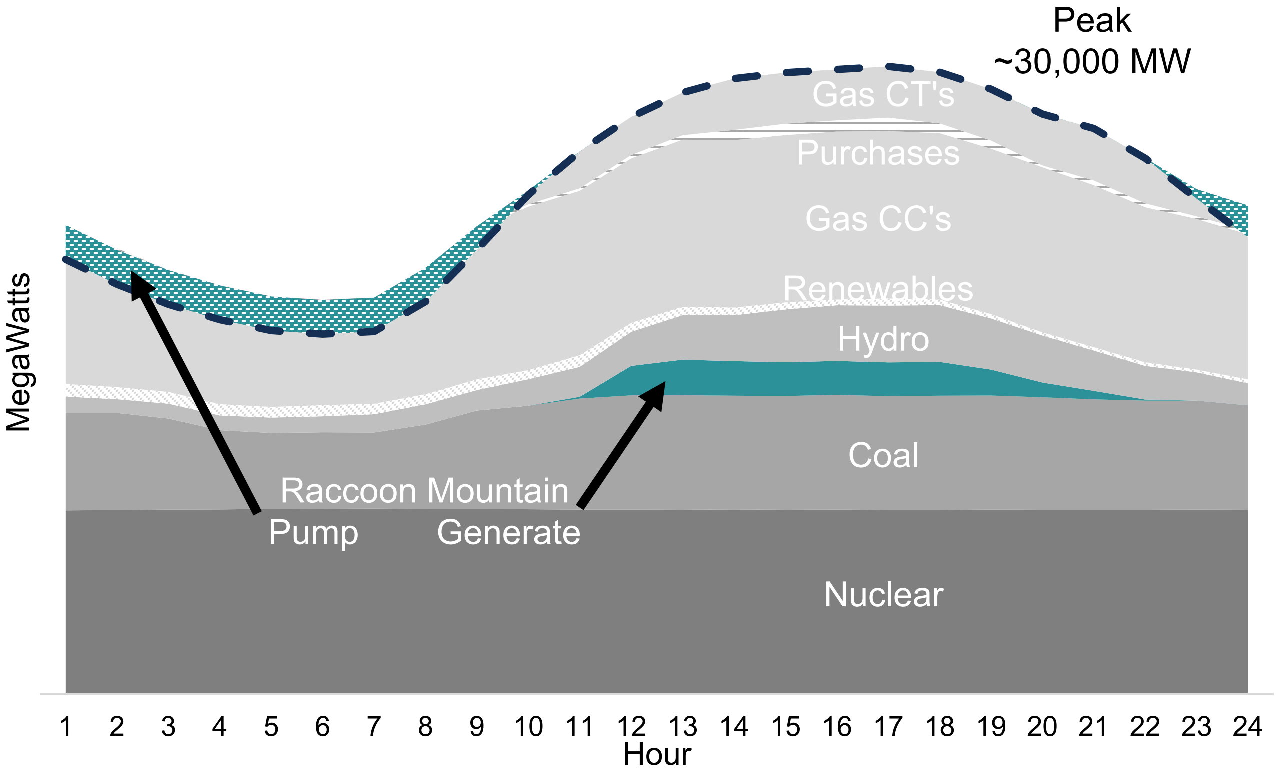


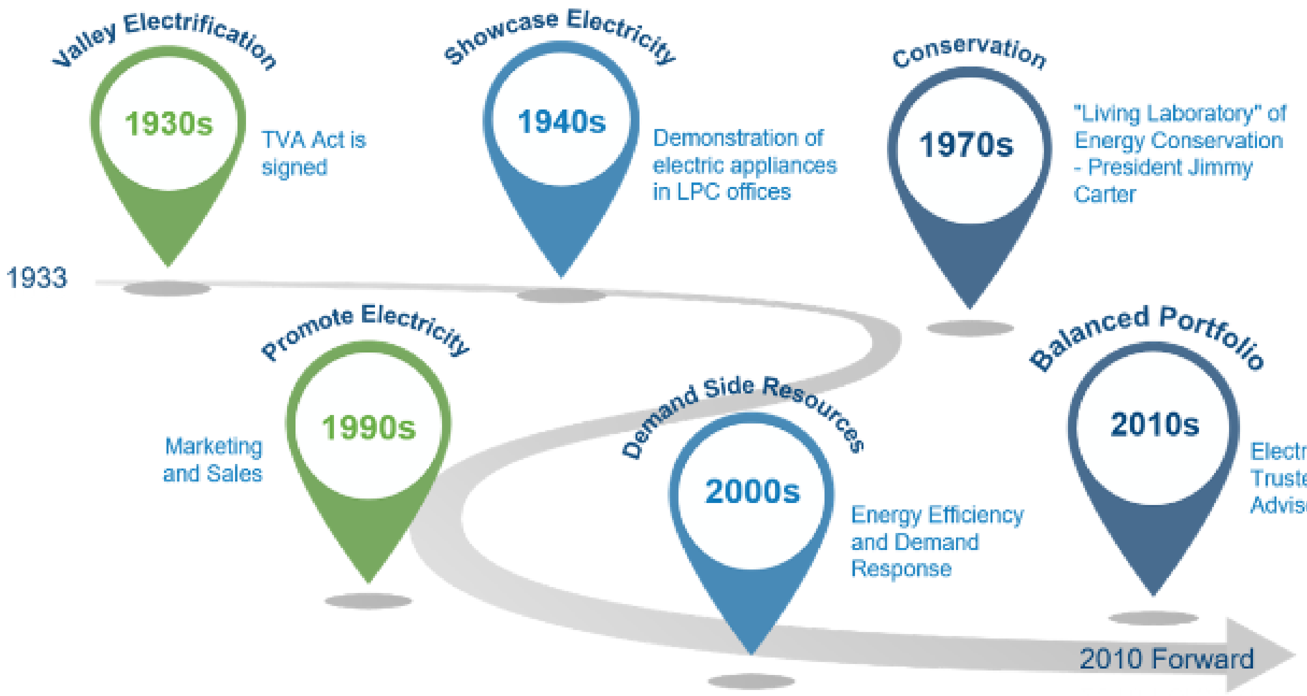
Chart is illustrative and for educational purposes only; Reflects a typical summer day

Demand-Side Management – Energy Programs

Energy Programs, such as energy efficiency and demand response, are an important part of a diverse portfolio of energy resource options.

These offerings can include incentive programs, pricing products, and educational efforts to encourage informed consumer choice.

At TVA, programs are offered under the EnergyRight® Solutions (ERS) brand and span residential, commercial and industrial sectors.



TVA EnergyRight®

Energy Efficiency

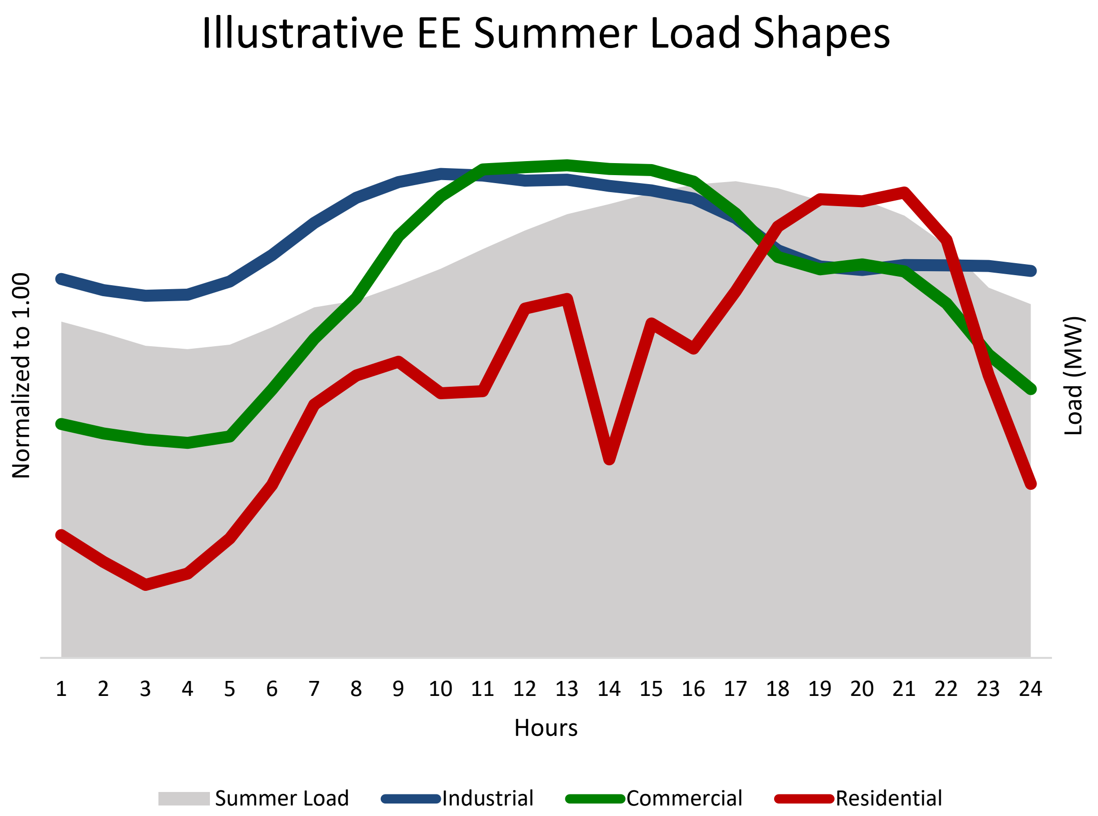
Energy Efficiency (EE) programs target efficiency upgrades and improvements to reduce system load across many hours. Programs provide incentives or educational opportunities to consumers to spur efficiency improvements in their homes or businesses above and beyond current codes and standards.

Advantages:

- Carbon-free
- Reduces energy generation and can offset new capacity needs

Considerations:

- Programs take time to market and scale
- Market-driven effects, free-ridership, and evolving codes and standards can decrease effectiveness



Demand Response

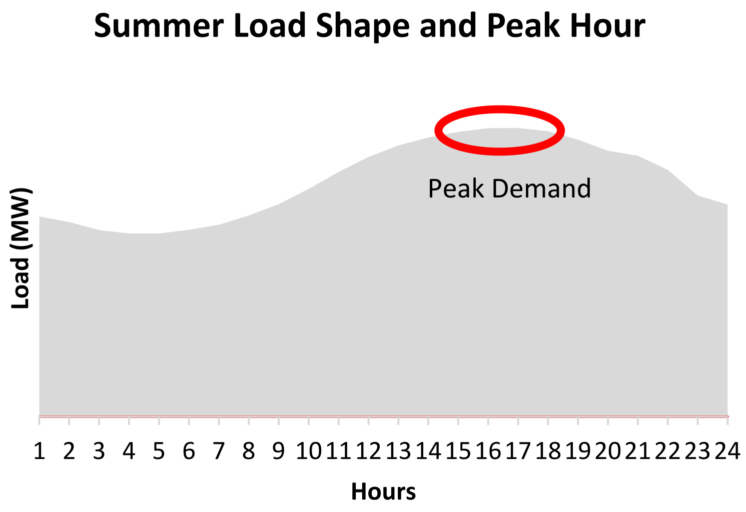
Demand Response (DR) programs reduce system load at peak hours and potentially offset or delay the need for more expensive peaking generation. Various programs provide incentives or price structure changes to customers in exchange for them suspending a portion of their load during peak periods.

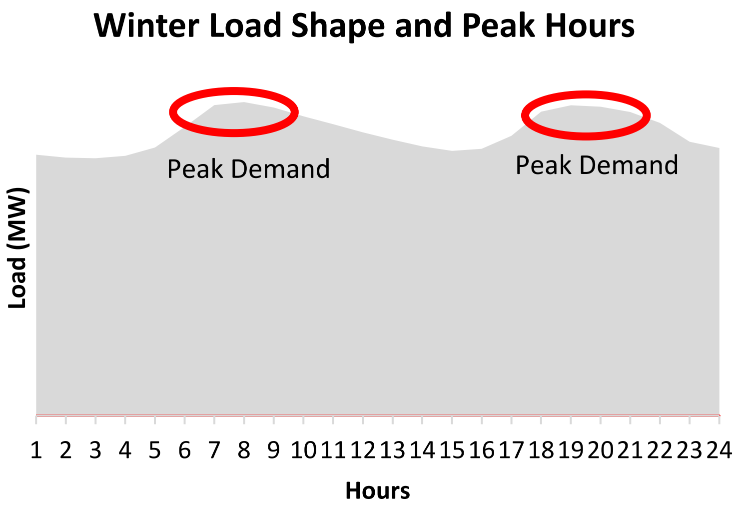
Advantages:

- Carbon-free
- Reduces physical dispatchable capacity needs

Considerations:

- Limited number of callable hours, outside of reliability events
- Frequent use of reliability events can discourage participation





Expansion Resource Technologies

Earliest Deployment Year for Additional Resources

2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 +

|--------------- Technologies Deployable by 2030 ----------------| |------------ Technologies Deployable after 2030 -----------|

Technologies Deployable by 2030

Energy Efficiency and Demand Response Programs

Natural Gas

Solar

Wind

Lithium-Ion Battery Storage

Technologies Deployable after 2030

Pumped Storage

Advanced Storage

Carbon Capture Combined Cycle

Alternative Fuels / Hydrogen

Small Modular Reactors

Emerging technology timelines have more uncertainty

Expansion Resource Options – Next Steps

Complete third-party review of resource cost assumptions (Horizons Energy)

Share costs and findings of third-party review at September IRP Working Group meeting

Review and incorporate IRP-WG feedback

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Break

Emerging Technology Overviews

Daniel Sipe; Manager, Generation Research

TENNESSEE VALLEY AUTHORITY

Emerging Technologies

Daniel Sipe
Innovation & Research

TENNESSEE VALLEY AUTHORITY

Outline

TVA’s Approach to Emerging Technologies

EPRI collaboration

Technology Discussions

Why are Emerging Technologies important to TVA?

Technology advancements are needed for the future energy system to provide **affordable**, **reliable**, and **clean** electricity

Energy Usage

- Electrification and EVs
- Energy efficiency and demand response
- Grid modernization

Portfolio Diversification

- Continue to leverage multiple resources types

Sustainability

- Leadership in carbon reduction, environment, economic development, community, and governance

Innovation and Research

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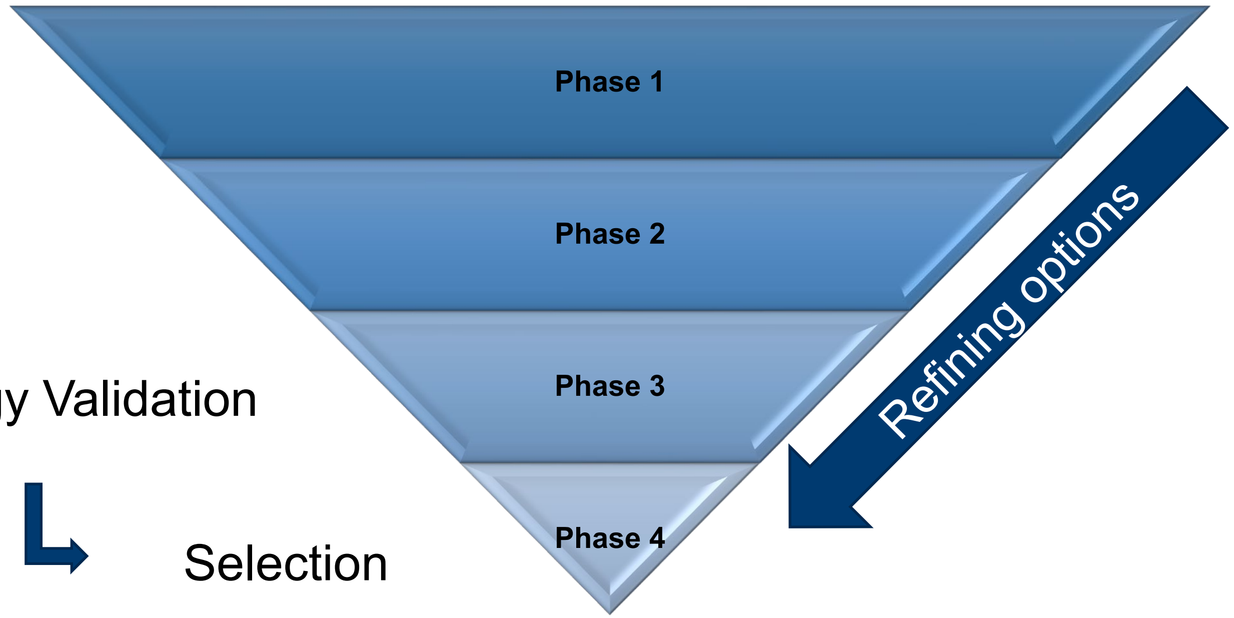
TVA Technology Screening Process for IRP

Research

Initial Screening

Technology Validation

Selection



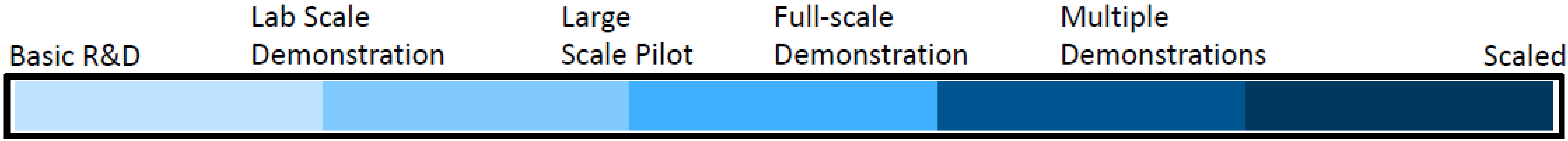
Phase 1: Identify potential future commercially viable technologies

Phase 2: Rank and characterize high potential technologies

Phase 3: Assemble characteristics and supporting documentation

Phase 4: Evaluate technologies in planning and/or analysis tools

Technology Readiness Level



Technology Development	Pilot & Demonstration	Ready to Scale / Scaled
TRL 1 to 4	TRL 5 to 7	TRL 8 to 9
Not included	**Maybe**	**Likely to include**

Source: EPRI LCRI

R&D Approach and Key Inputs

- Use of R&D sources (e.g. DOE, NREL, EPRI, University)
  - Performance and cost assessments
  - OEM (Original Equipment Manufacturer)
  - 3rd party engineering studies
  - FEED (Front End Engineering Design)

- Utility expertise and market intelligence

- Stakeholder/expert input

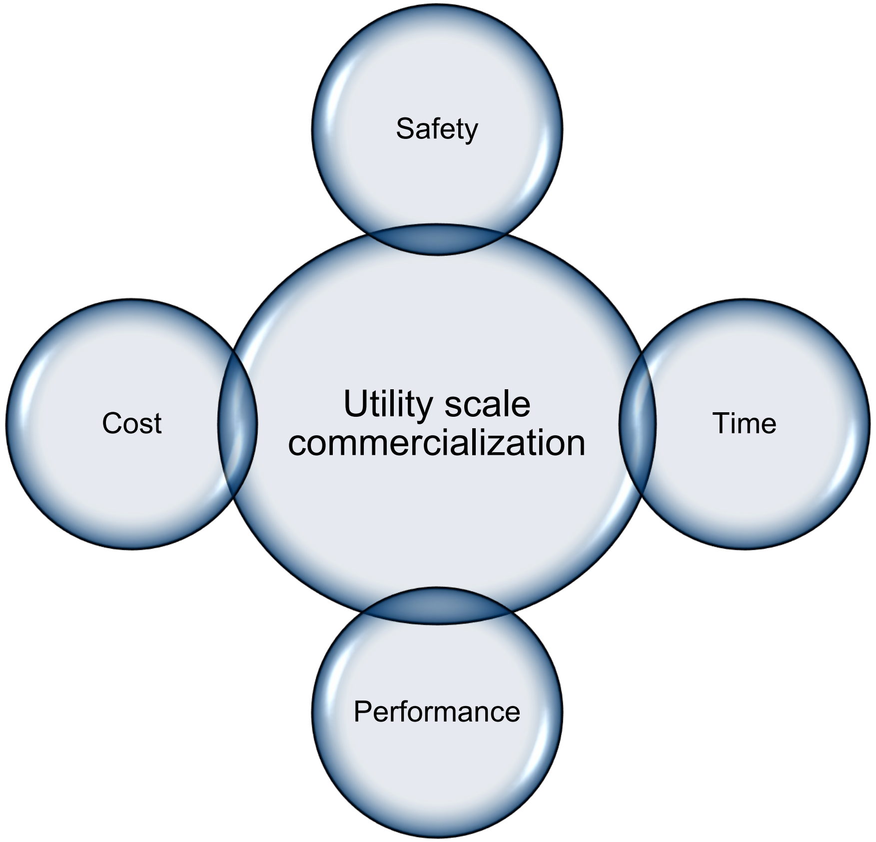
Uncertainty of Commercialization

Is this in the planning horizon?

What cost and performance insight is available?

What technical issues might delay?

How do alternatives impact?



Robustness of answers informs commercialization potential

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Overview of Emerging Energy System Technologies

Integrated Resource Plan Working Group
Tennessee Valley Authority

Romey James
Project Set Manager
EPRI 178A: Energy System Technology Cost, Performance, and Technoeconomic Analysis

August 29, 2023

Who is EPRI?

EPRI

KEY ASPECTS

Nonprofit

Chartered to serve the public benefit, with guidance from an independent advisory council.

Thought Leadership

Systematically and imaginatively looking ahead to identify issues, technology gaps, and broader needs that can be addressed by the electricity sector.

Independent

Objective, scientific research leading to progress in reliability, efficiency, affordability, health, safety, and the environment.

Scientific and Industry Expertise

Provide expertise in technical disciplines that bring answers and solutions to electricity generation, transmission, distribution, and end use.

Collaborative Value

Bring together our members and diverse scientific and technical sectors to shape and drive research and development in the electricity sector.

Explore EPRI's research across the Nuclear, Generation, and Power Delivery and Utilization sectors ranging from decarbonization to grid modernization to low carbon resources.

COLLABORATION

EPRI's collaborative platform is unrivaled. Our R&D:

- Leverages member research dollars
- Connects members to a global network of peers
- Accelerates deployment of technology
- Mitigates the risk and uncertainty of going it alone
- Positions members as leaders in addressing industrywide challenges

CREDIBILITY

EPRI's independent research is guided by our **mission to benefit the public**. We offer:

- Objective solutions
- A proven track record
- Scientifically based research you can trust

EXPERTISE

For more than 50 years, EPRI has been applying R&D to help solve real challenges. With EPRI, members can:

- Reduce expenses and increase productivity
- Be more resilient today and better prepared for tomorrow
- Access an industry repository of collective experiences, technical expertise, and training resources
- Extend member staff and make teams more robust and more confident
- Benchmark, learn and share best practices
- Increase awareness of challenges that others are facing and alternate solutions to challenges faced
- Save time and money troubleshooting problems EPRI and its stakeholders have seen before

Who We Are

Founded in 1972, the Electric Power Research Institute (EPRI) is the world's preeminent independent, non-profit energy research and development organization, with offices around the world.

Our Experts

EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe.

Program 222: Advanced Generation & Carbon Capture and Storage

- **Program 222 - Annual Research Portfolio**
  - Focus is on power generation
  - Covers novel power cycles, oxy-combustion, pre-combustion, and post-combustion carbon capture
  - Covers CO_2 transport and storage
- **Low Carbon Resources Initiative (LCRI)**
  - Focus is on alternate energy carriers (H_2, NH_3), industrial sources, and the last 20% of economy-wide decarbonization
  - CCS related to H_2 production, e.g., steam methane reforming (blue H_2), transport and storage of CO_2 and H_2.
  - CCS related to industrial sources, Direct Air Capture

- **Technology Innovation**
  - 14+ years of continuous TI support (early-stage) for CCS
  - Developed extensive internal capability, especially modeling of power plants, post-combustion CO_2 capture (solvents, membranes, adsorbents, cryogenic, others), and more recently CO_2 storage
  - Launched CO_2 capture database, early-stage technology investigations, academic networking, long-term projects
- **U.S. Department of Energy**
  - Started working with DOE on CCS 15+ years ago
  - The largest DOE-funded area at EPRI
  - Between 6-10 DOE projects at any given time in capture and storage
  - Member of P222 for the past 5+ years
- **Supplemental Projects**
  - CO2DA
  - Allam Cycle Pilot
  - Frost CC
  - DOE Funded



P221: Bulk Energy Storage

Mission

Provide actionable research to advance larger-scale, longer-duration energy storage with focus on chemical, mechanical, and thermal types

Why EPRI's Bulk Energy Storage (BES)?

Value of Collaboration

The BES program works closely with multiple programs in the Generation and PDU sectors, 100+ energy storage developers, and leading R&D and government teams in the energy storage space.

Program Manager
Andrew Maxson
+1 650-862-7640
amaxson@epri.com

www.epri.co/bes

Research Focus Areas

- Assessment and comparison of energy storage technologies
- Design and safety reviews
- Energy storage integration to thermal power plants
- Energy storage roadmaps
- O&M and testing support
- Participation in field demonstrations
- Seasonal energy storage
- Techno-economic and benefit assessments

Unique Insights

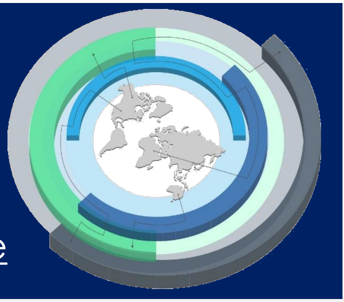
- 9 staff (3 Technical Executives) with 9 advanced degrees and 85 years experience combined at EPRI
- 500+ member meetings on energy storage in 2023
- 600+ papers, articles, and other published works

Impactful Content

- **Web-based software:** Energy Storage Technology Database
- **Benefits assessments:** 3002019890, 3002021099, 3002024309
- **Cost and performance studies:** 3002022615, 3002022120, 3002021098, 3002024283

Technology Application

- Concrete thermal energy storage pilot
- Seasonal energy storage
- Thermal energy storage repowering
- Bulk energy storage costs and performance



Program 94 Energy Storage & Distributed Generation Project Set Structure

P94A: Strategic Intelligence and Industry Collaboration

Industry developments and technology transfer

P94B: Energy Storage Technology and Analytics

Non-application specific topics: technology, cost, valuation, and controls

P94C	P94D	P94E	P94G
Distribution Energy Storage Applications	**Transmission Energy Storage Applications**	**Customer-sited Energy Storage Applications**	**Distributed Generation and Microgrids**
Application and asset management	Application and asset management	Application and asset management	Technologies, modeling, and deployment

Low-Carbon Resources Initiative

Mission

Evaluating pathways for deployment of low-carbon fuels and energy carriers in support of net zero decarbonization across the energy economy. Focused on a vision of the future global energy system that is decarbonized, consumer-focused, sustainable, and resilient.

Why LCRI?

Value of Collaboration

- Expanding the Body of Knowledge
- Leading Efforts to Advance Technology
- Strengthening Stakeholder Engagement
- Creating Resources to Inform Strategies

Neil Kern
Program Manager
nkern@epri.com

Jeffery Preece
Director, R&D
jpreece@epri.com

www.LowCarbonLCRI.com

Research Focus Areas

- Understanding impacts and potential of low-carbon fuels & energy technologies
- Accelerating technology deployment
- Energy system value chain from production to end use
- Integrated system analysis to understand adoption pathways and interactions
- Environmental impacts, health and safety requirements, and equitable decarbonization

Unique Insights

- 100+ technical experts contributing to understand the impacts of the energy transition for customers and electric and gas infrastructure.
- Participation and engagement with 53 organizations comprising of electric, gas, and energy supply and delivery from around the world.
- Resource library with technical reports, techno-economic analyses, technology evaluations, training material, and more.

Impactful Content

- Low-Carbon Resources Initiative Research Vision [link]
- Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis [link]
- A Value Chain Approach to Energy Systems [link]

Technology Applications

- Hydrogen Cofiring Demonstrations for Power Generation [link 1, link 2, link 3]
- DOE H2@Scale – NREL Performance Testing [link]
- A Community Approach to Infrastructure Development [link]

Energy Systems and Climate Analysis Research Areas

Website

Newsletter

See all public research on our website:

esca.epri.com

Decarbonization

Electrification

Economics of Emerging Technologies

Policy Analysis

Technoeconomics

Energy Systems Analysis

ESCA

Technology Costs, Performance, and Trends

Greenhouse Gas Accounting and Offsets

Integrated Strategic System Planning

Climate Impacts, Resilience, and Climate-Related Risks

Resource Planning for the Electric Sector

Equity & Distributional Impacts

Climate Impacts, Resilience, and Climate-Related Risks

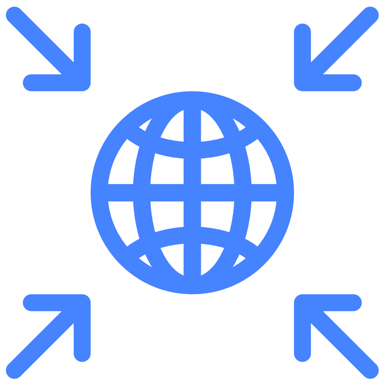
Global Drivers

Carbon Capture and Storage

CCS consists of three major components

Capture

Transportation

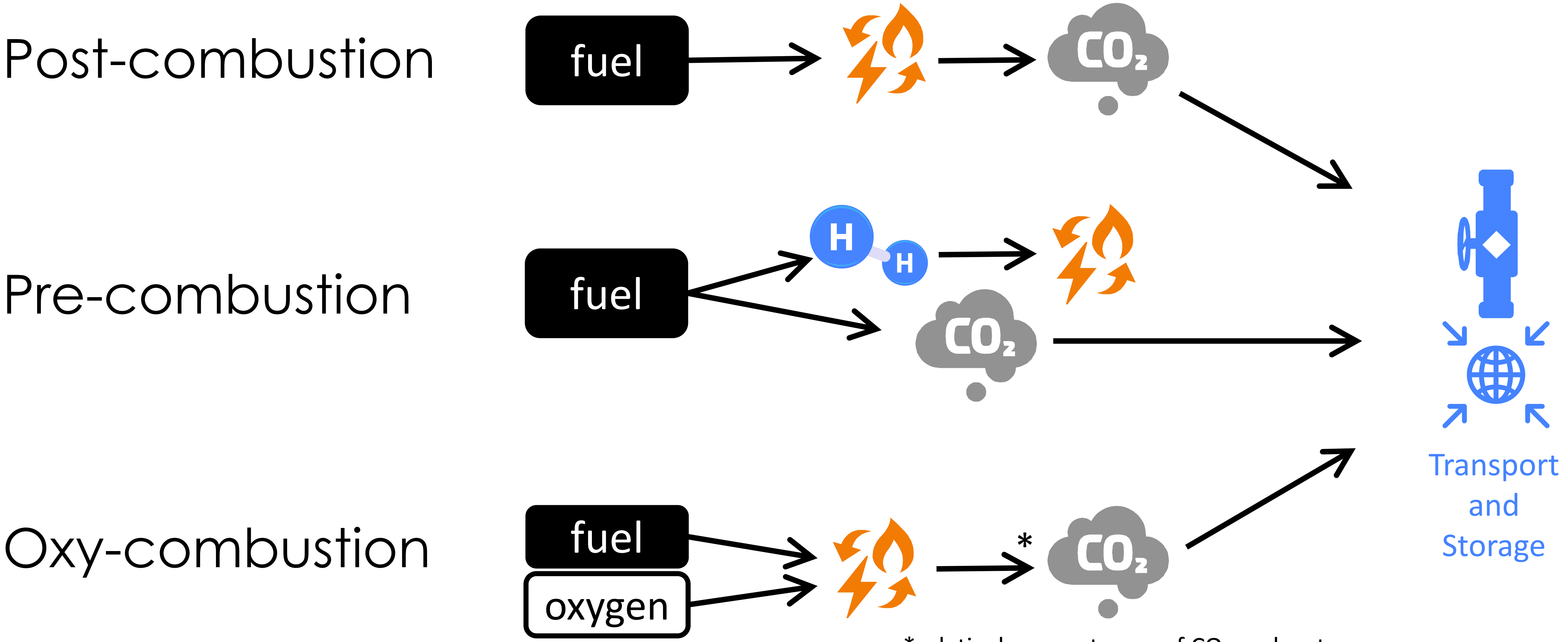


Storage

Each part of the process presents unique considerations and potential challenges.

Different Approaches to Capturing Carbon

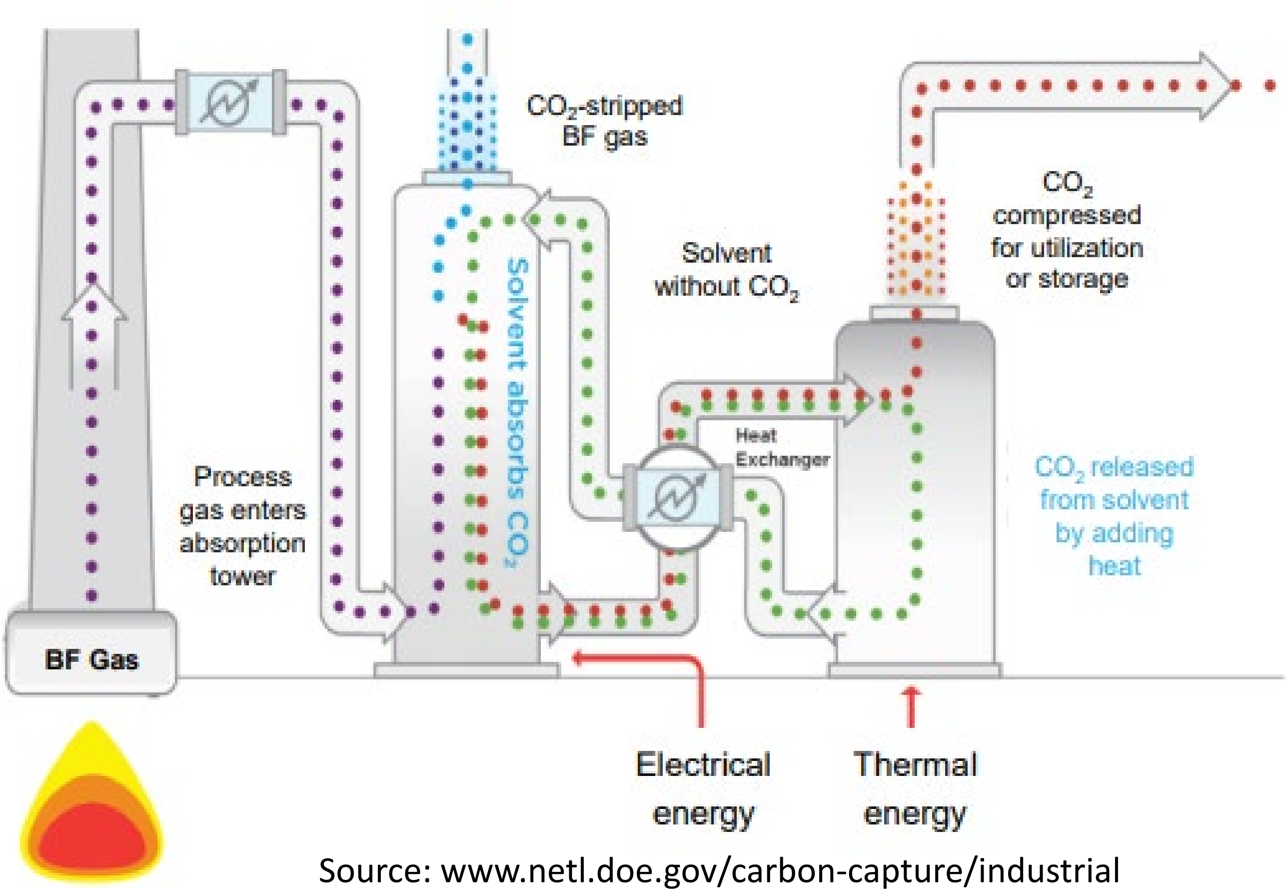
Simplified representations



*relatively pure stream of CO_2 and water vapor

Post-combustion Carbon Capture

- Post-combustion carbon capture technologies include
  - Absorption
  - Adsorption
  - Membranes
  - Cryogenic processes
- Absorption is technologically mature
  - Contact the flue gas with an amine-based solvent which absorbs the CO_2 , then
  - Heating the solvent to release the CO_2 as a relatively pure stream.



Source: www.netl.doe.gov/carbon-capture/industrial

Chemical absorption is the most technologically mature post-combustion technology.

2025 Commercialization

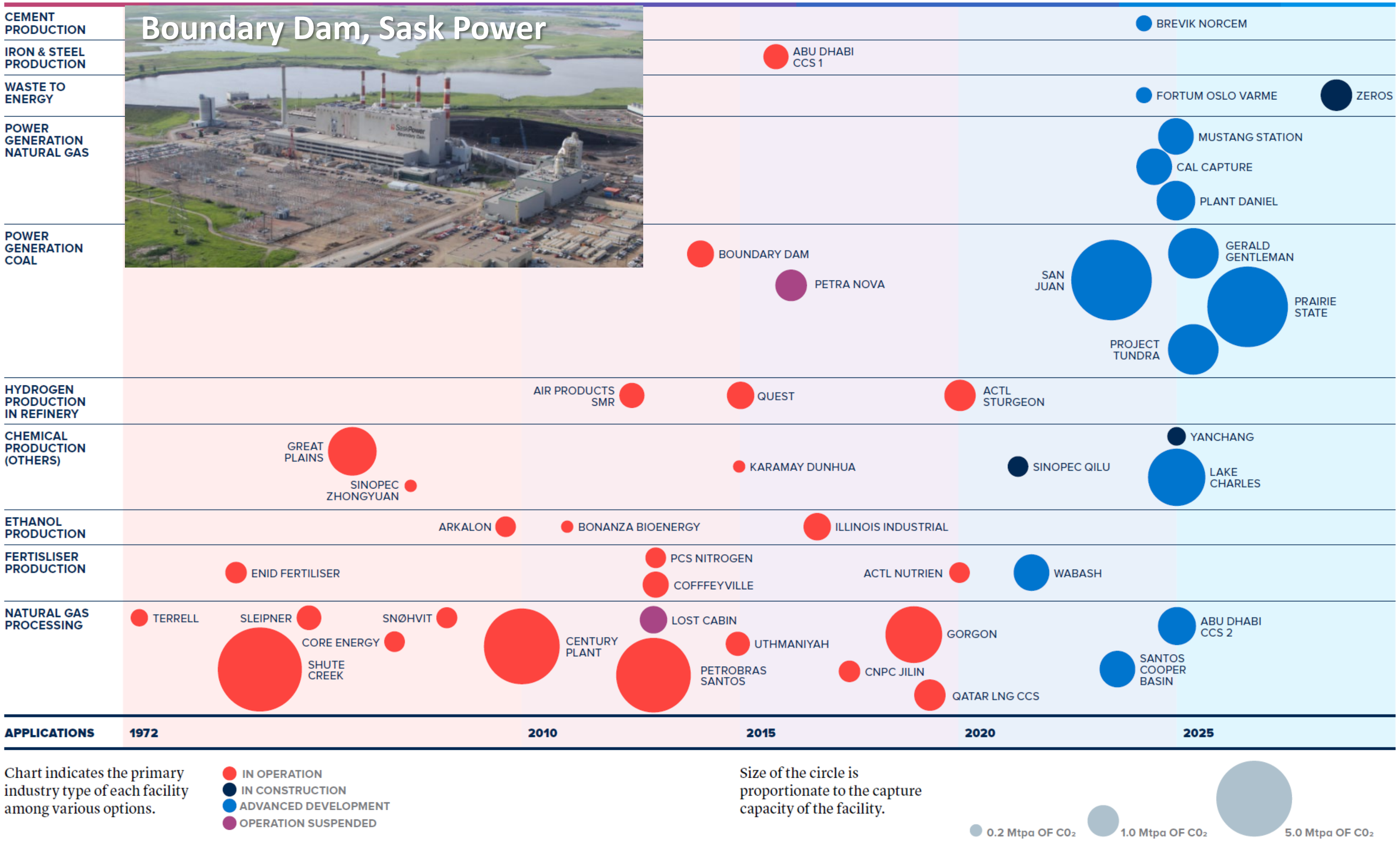
Largest Power Plants in the World

Coal
6,720 MW
59 Mt/yr*

Gas
5,597MW
25.5 Mt/yr*

A typical new combined cycle gas power plant is about 1,000 MW

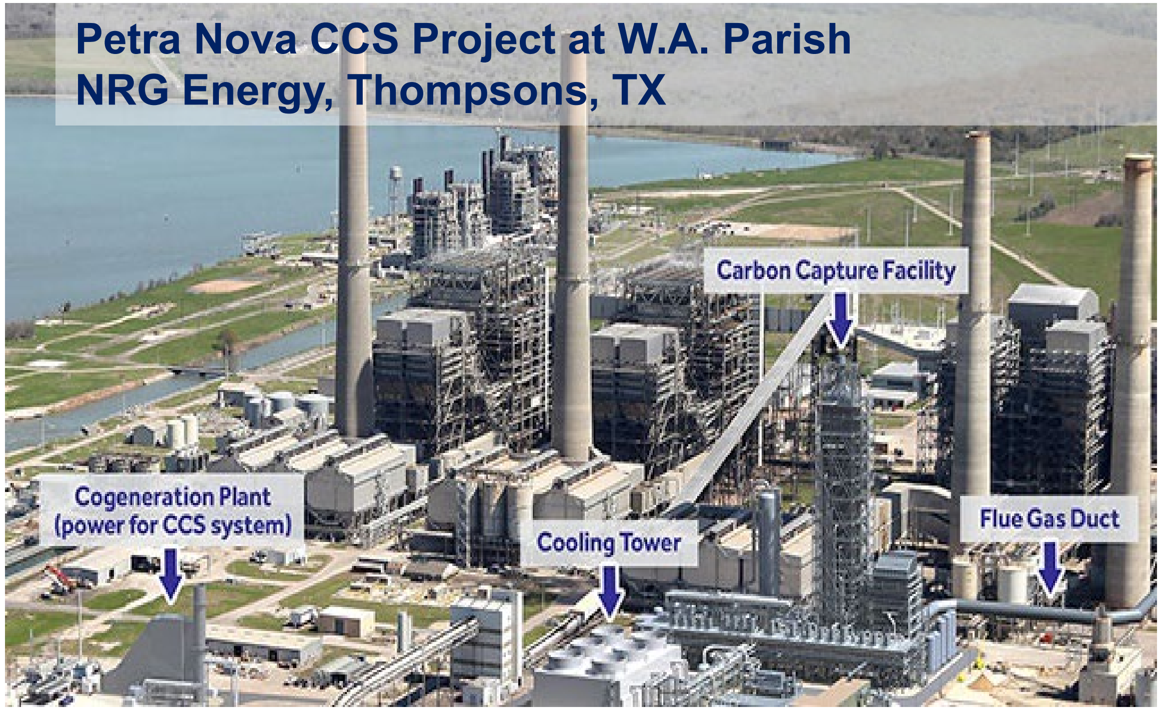
* Calculated emissions using average CO_2 emission intensity for the US fleet. Actual plant emission intensity may differ.



Source: Global CCS Institute

At Scale Post-Combustion Capture on Power Plants

Source: SaskPower

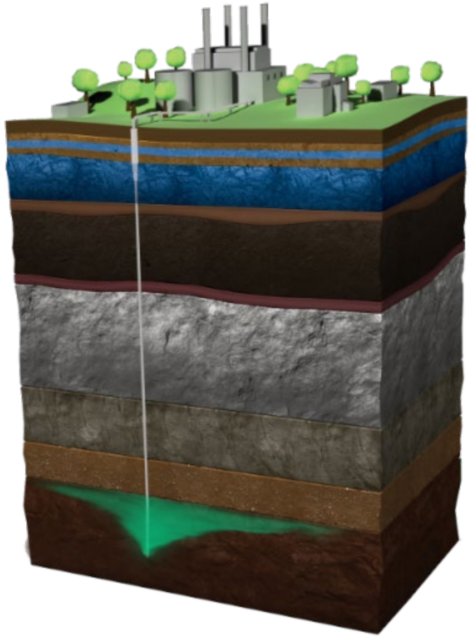


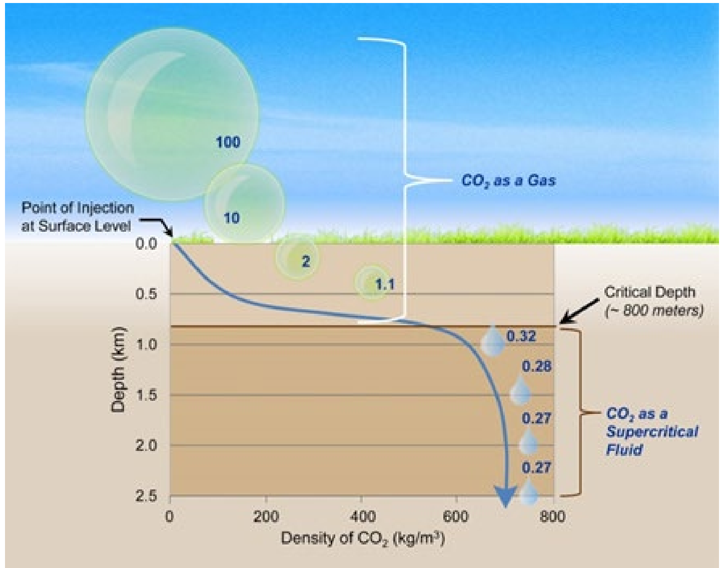
Source: NRG

Start up in 2014	Start up in 2016, shut down 2020, restart announced
1.0 Mt CO_2/yr design	1.4 Mt CO_2/yr design
~139 MWe flue gas slipstream out of 730 MWe Coal	~250 MWe gross out of 650 MWe Coal
Shell Cansolv Aqueous Amine Process	Mitsubishi Heavy Industries Aqueous Amine Process
41 mile pipeline to Weyburn oil field EOR	82 miles pipeline for EOR
1.2 miles to Aquistore geological storage (minor)	West Ranch Oil Field, Texas

Transportation and Storage

- Once captured, CO_2 must be transported to a storage site with an injection well.
  - Pipelines are the only economically feasible way to transport large quantities of CO_2.
- The CO_2 is injected deep below the surface.
  - The high temperatures and pressures cause it to behave as a supercritical fluid, allowing for much greater storage than if it were a gas.
  - The CO_2 becomes trapped for storage.
- Challenges could arise with the permitting and development of pipelines and injection wells.





Source: https://www.netl.doe.gov/carbon-management/carbon-storage

CO_2 transportation and storage is technologically feasible but carries risks with permitting and development.

Utilization

- CO_2 could be utilized instead of stored underground.
- It is currently utilized by several industries.
  - Enhanced oil recovery
  - Food freezing
  - Beverage carbonation
  - Fire suppressant

- The potential supply of captured CO_2 is much greater than current demand.

- New demand may develop in new industries.
  - Synthetic hydrocarbon fuels

  - Building materials

- New industries not unexpected to provide a significant sink for captured CO_2.

Utilization is expected to play a small role in CO_2 management.

Inflation Reduction Act

- The IRA increased existing 45Q tax credits for carbon captured from point sources to:
  - **$85/tCO_2$** for storage and
  - $60/tCO_2$ for utilization
  - if labor criteria are met.

- If cost reductions to n^{th}-of-a-kind costs are achieved, the net cost of capturing CO_2 from concentrated sources like coal plants in favorable locations could be near zero.

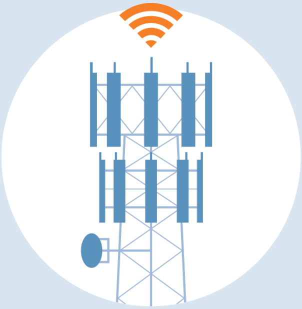
TVA Carbon Capture

Daniel Sipe
Innovation & Research

TENNESSEE
VALLEY
AUTHORITY

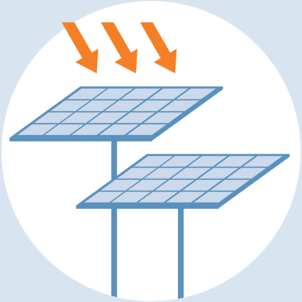
How could Carbon Capture & Storage (CCS) be beneficial to TVA?

CCS can enable TVA to continue operation of Combined Cycle plants which provide significant **flexibility** and **reliability** to the grid.



Dispatch capability

- Maintaining dispatchable resources provides critical flexibility



Portfolio Diversification

- Continuing to leverage multiple resources types

Environmental Stewardship

- can potentially dramatically reduce carbon emissions

Discussion Carbon Capture

10 minutes

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Energy Storage

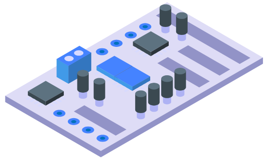
Legacy Energy Storage

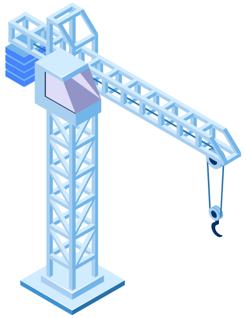
New Energy Storage

Types of Energy Storage

Electrochemical	Thermal	Mechanical	Chemical
Reversible chemical reaction generates an electrical potential difference	Energy storage achieved by heating bulk media	Kinetic or potential (compression or gravitational)	Reaction produces product that can generate heat or power

Considerations for Energy Storage

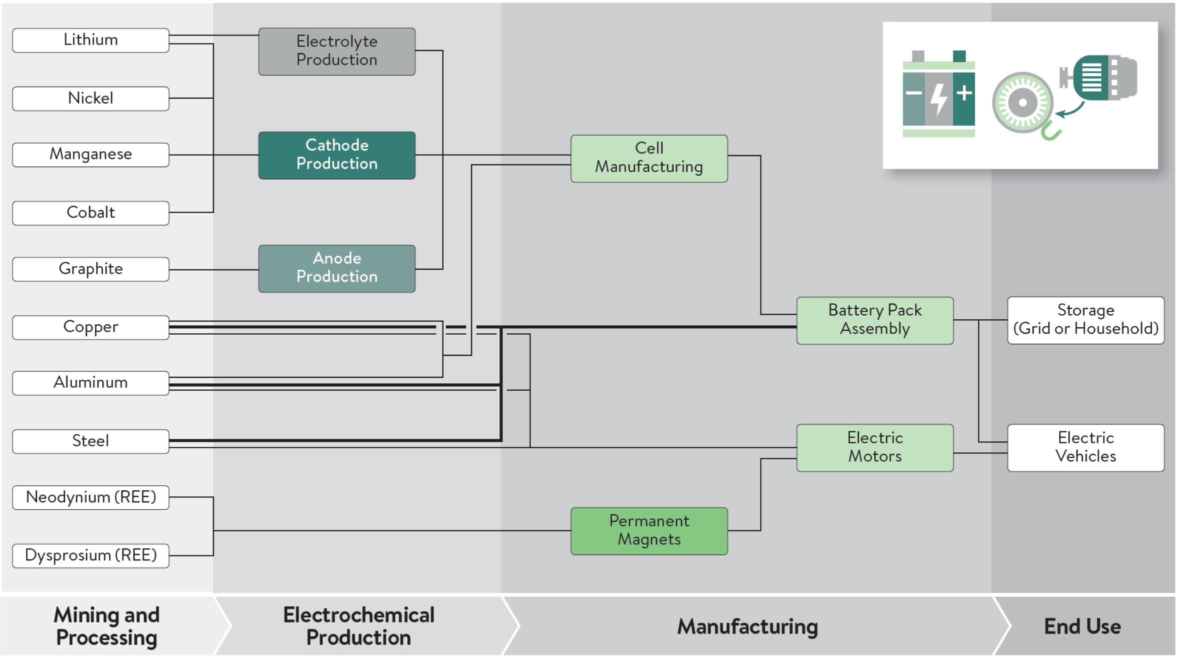


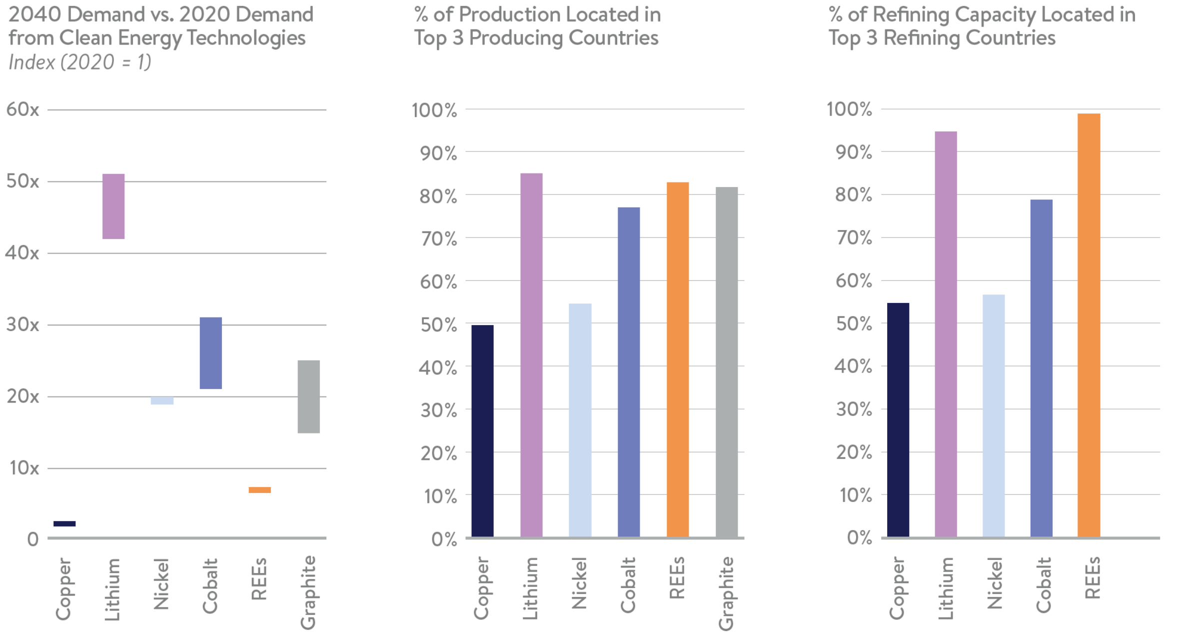


- Technology Readiness Level (TRL)
  - A measure of the technical maturity
  - Lithium-ion batteries and pumped storage hydro are high TRL
- Siting
  - Technologies with higher energy densities with no geological or geographical needs can be sited in a wider range of potential locations
- Duration
  - Technologies that can economically store energy for ten or more hours out to seasonal periods are receiving investment and research attention
- Round-Trip Efficiency
  - Ratio between energy discharged by an energy storage system and the energy used to charge it
  - Lithium-ion batteries and gravitational systems are higher, while chemical and certain forms of thermal energy storage are lower
- Scaling
  - Some technologies are more viable at larger scales while others are more viable at smaller scales
- Costs
  - Technologies are vying to be lower cost by using cheaper materials and components and simpler designs

Critical Minerals

- Lithium-ion batteries require a number of critical minerals with
  - demand expected to rise, and
  - production and refining concentrated in a small number of countries.
- Alternative battery chemistries are increasing TRL.
  - Some rely on less critical minerals.
  - Some offer other operational advantages or potentially lower costs.





Source: www.epri.com/research/products/000000003002023228

Inflation Reduction Act

- The IRA makes investment tax credits (ITC) available to standalone energy storage projects.
- Previously, energy storage was only eligible for the ITC if coupled with solar.
- Storage projects are now eligible for a **30% ITC** if labor requirements regarding prevailing wages and apprenticeships are met
  - plus stackable bonuses of an additional
    - 10% for domestic content
    - 10% for energy communities

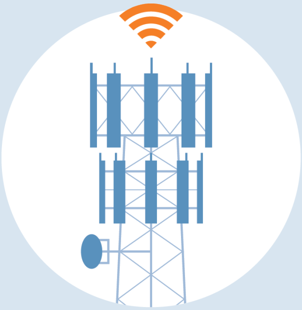
TVA Storage

Daniel Sipe
Innovation & Research

TENNESSEE VALLEY AUTHORITY

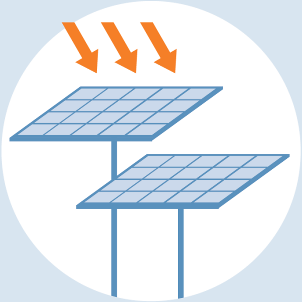
What’s Driving Energy Storage Adoption at TVA?

Energy storage enables TVA to include higher levels of intermittent resources into TVA’s portfolio, manage load characteristics, and improve **reliability** and **resiliency**.



Grid Modernization Efforts

- Future integration at utility, industrial, commercial, and residential at scale



Renewable Generation Integration

- Intermittent resources require balancing

Environmental Stewardship

- Energy storage can shift zero carbon energy to maximize value

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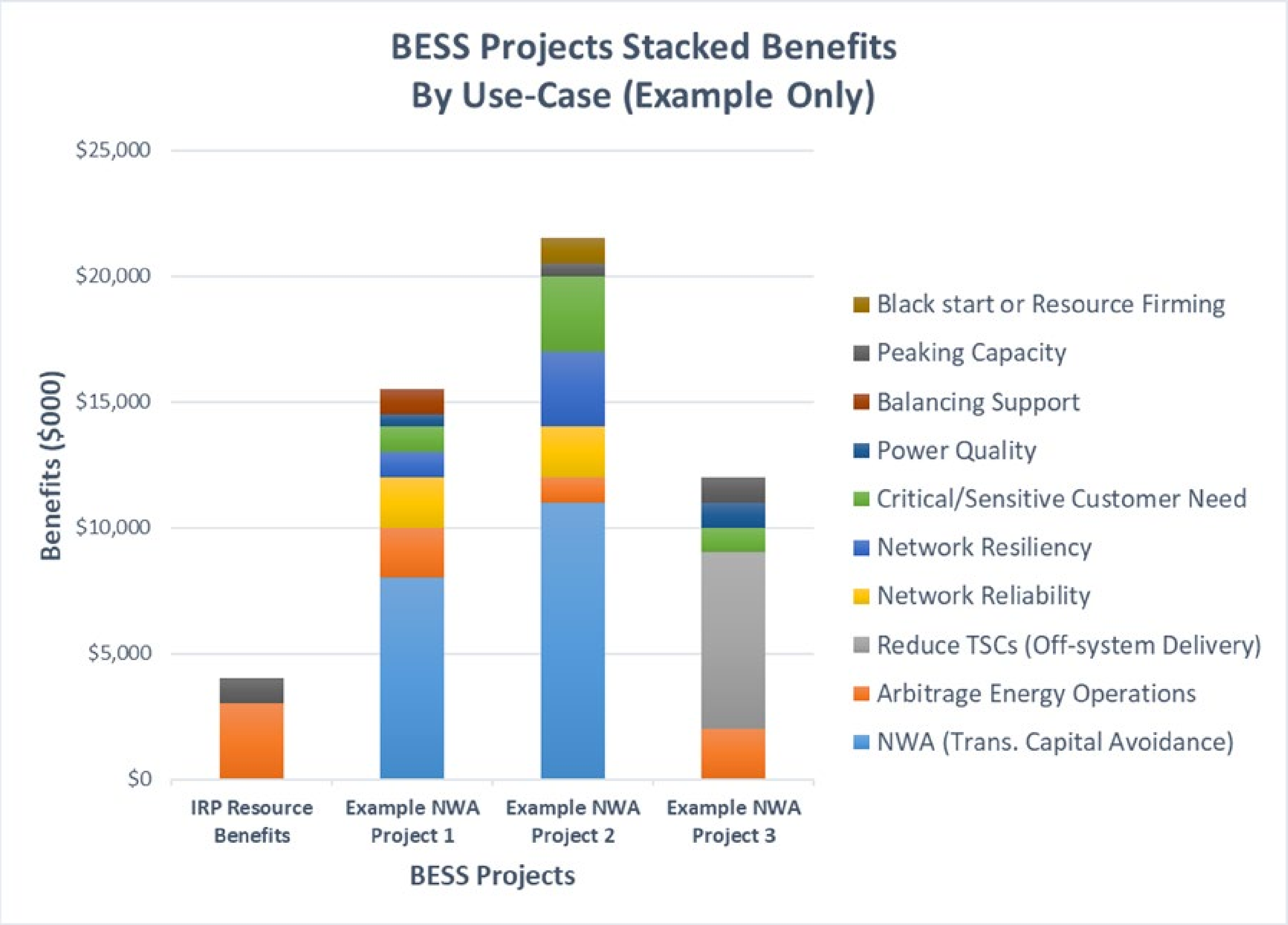
TVA Battery Technology

Vonore is TVA's first utility scale battery with expected commercialization by 2024



Learn to manage a new resource type

Provides stacked value –locational and non-locational

Battery Costs

Lithium ion maintains advantage over alternative chemistries, but competition expected

Cost reductions hampered by demand and supply chain

Demand continues to explode particularly through EVs

Costs are expected to decline

When?

How much?

How do other technologies compete?

Battery Cost Decline

National Renewable Energy Laboratory

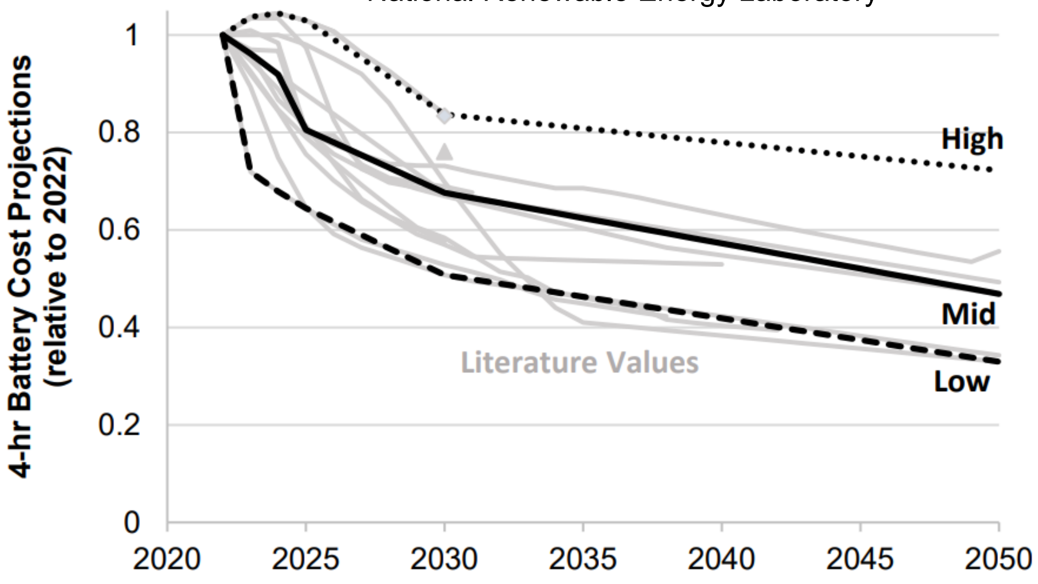


Figure ES-1. Battery cost projections for 4-hour lithium-ion systems, with values normalized relative to 2022. The high, mid, and low cost projections developed in this work are shown as bolded lines.

Source: “Cost Projections for Utility-Scale Battery Storage: 2023 Update, NREL, June 2023

TVA Pump Storage

Curt Jawdy
Innovation & Research

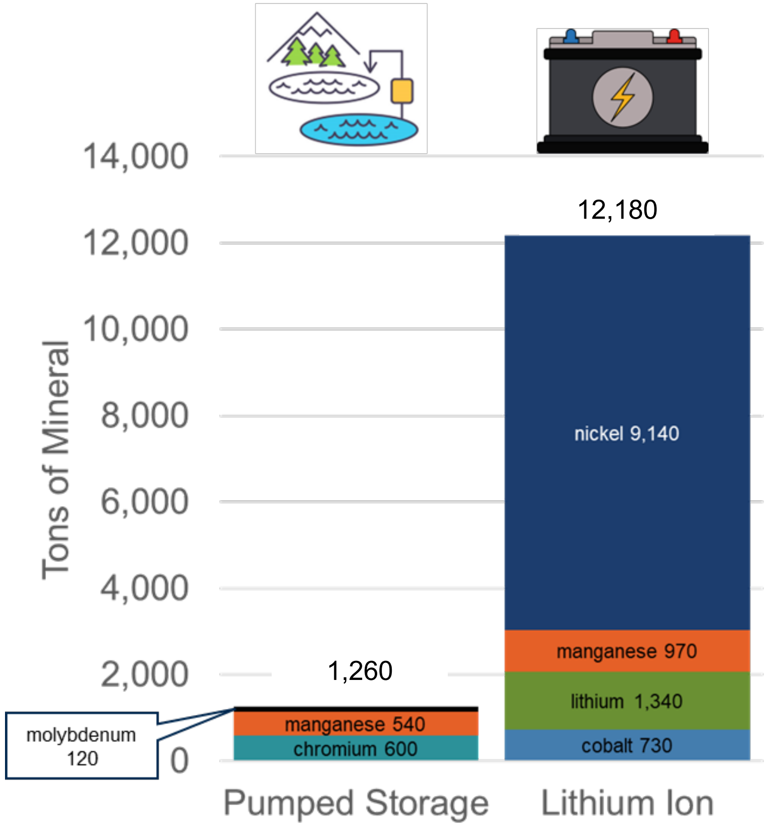
TENNESSEE VALLEY AUTHORITY

Pumped Storage and Battery Considerations

Pumped Storage	Batteries
Long-term storage	More appropriate for **four hours or less**
Requires **less** critical minerals and has a more **domestic** supply chain	Requires **more** critical minerals and a variable supply chain (**domestic and international**)
Requires a substantial amount of land and is **more** environmentally and community friendly	Requires a substantial amount of land and is **less** environmentally and community friendly
Large **single** installation	**Multiple** installations distributed across the grid
Lengthy deployment timeframe	**Shorter** deployment timeframe
Longer life of ~100 years	**Shorter life** of ~15 years
Cheaper in $/**MWh**	Cheaper in $/**MW**

How does life cycle analysis (LCA) compare?

Earth Mineral Composition for 16,000 MWH



Source Data Li-ION Battery versus Pumped Storage – A Comparison of Raw Material, Investment Costs and CO2 Footprint – Dr. Klaus Kruger, et. al

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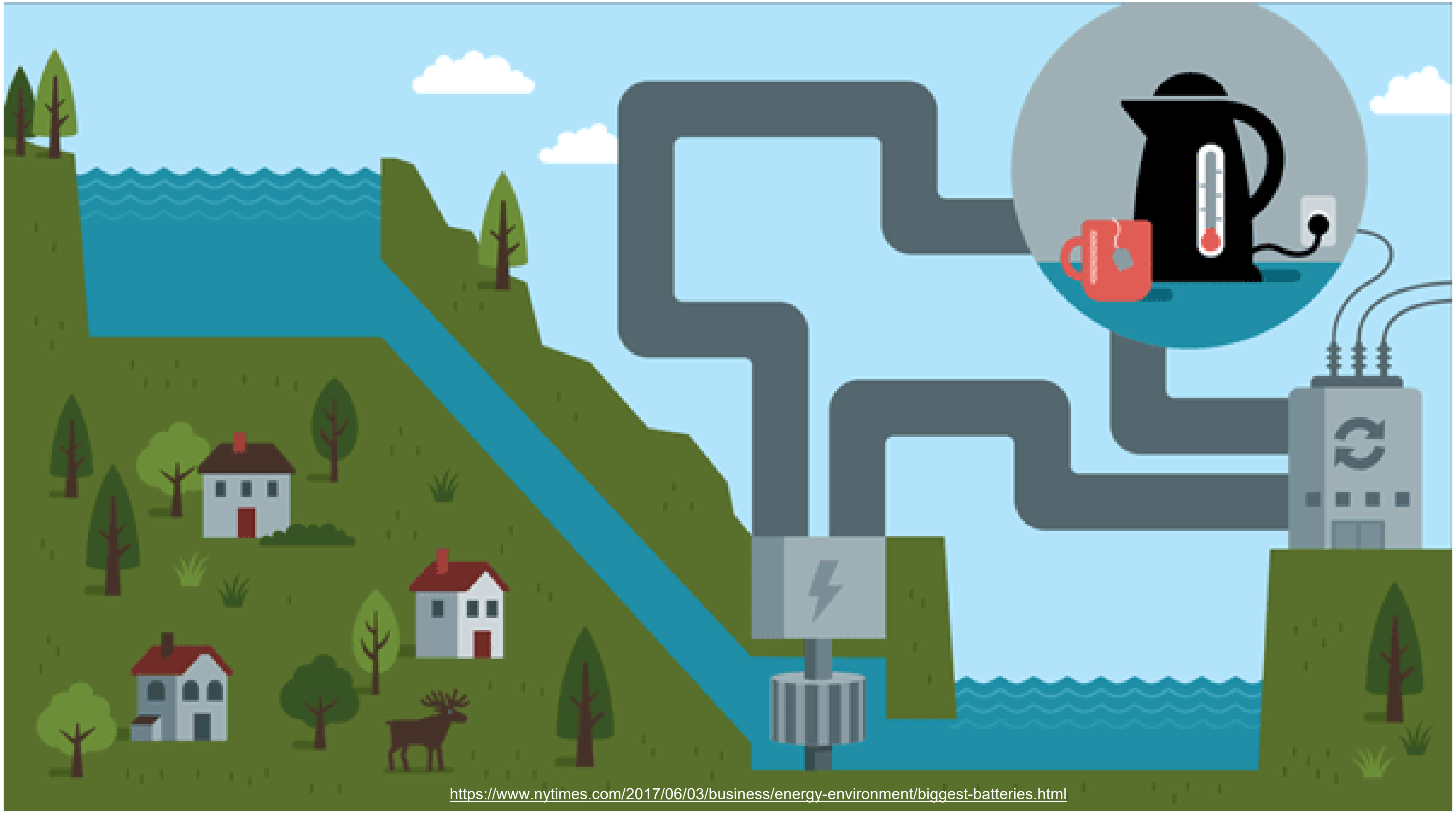
How Pumped Storage Works



https://www.nytimes.com/2017/06/03/business/energy-environment/biggest-batteries.html

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Discussion Storage

10 minutes

Hydrogen

Hydrogen Production Pathways

Green Hydrogen
Electrolysis powered by carbon-free renewable energy, such as wind or solar

Blue Hydrogen
Steam methane reforming or other fossil fuel derivation with CCS

Grey Hydrogen
Steam methane reforming or other fossil fuel derivation without CCS

Turquoise Hydrogen
Methane pyrolysis, generating solid carbon black rather than CO_2

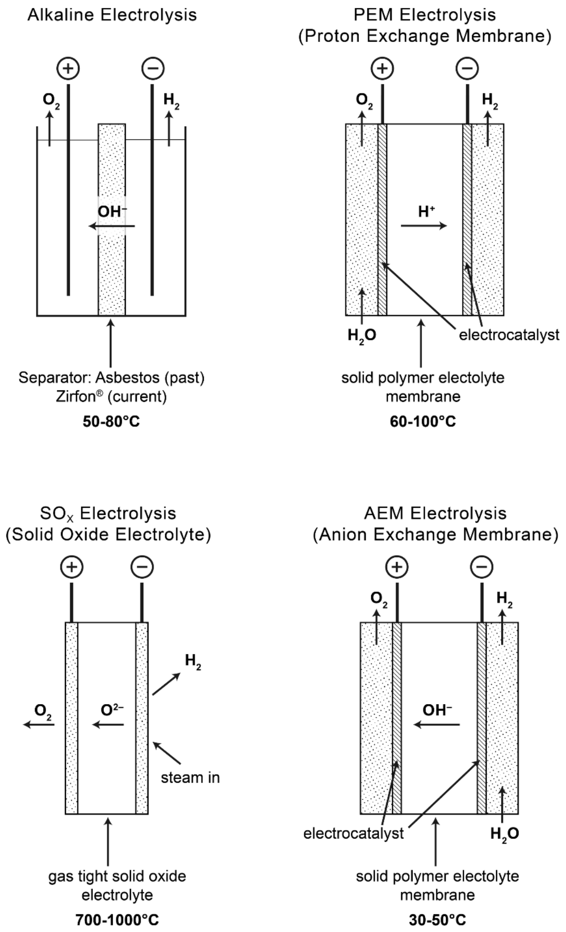
Pink Hydrogen
Electrolysis powered by nuclear energy

The optimal production pathway would depend on local factors such as availability of renewable energy, water, and favorable geology for CO_2 sequestration.

EPRI

Hydrogen from Electrolysis and Natural Gas

- Electrolysis
  - Uses electricity to split water molecules (H_2O) into hydrogen (H_2) and oxygen (O_2)
  - Several distinct technologies exist.



Source: https://www.epri.com/research/products/000000003002014766

- Steam methane reforming
  - Mature technology currently used to supply most of the world's existing demand for hydrogen.

$$CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$$

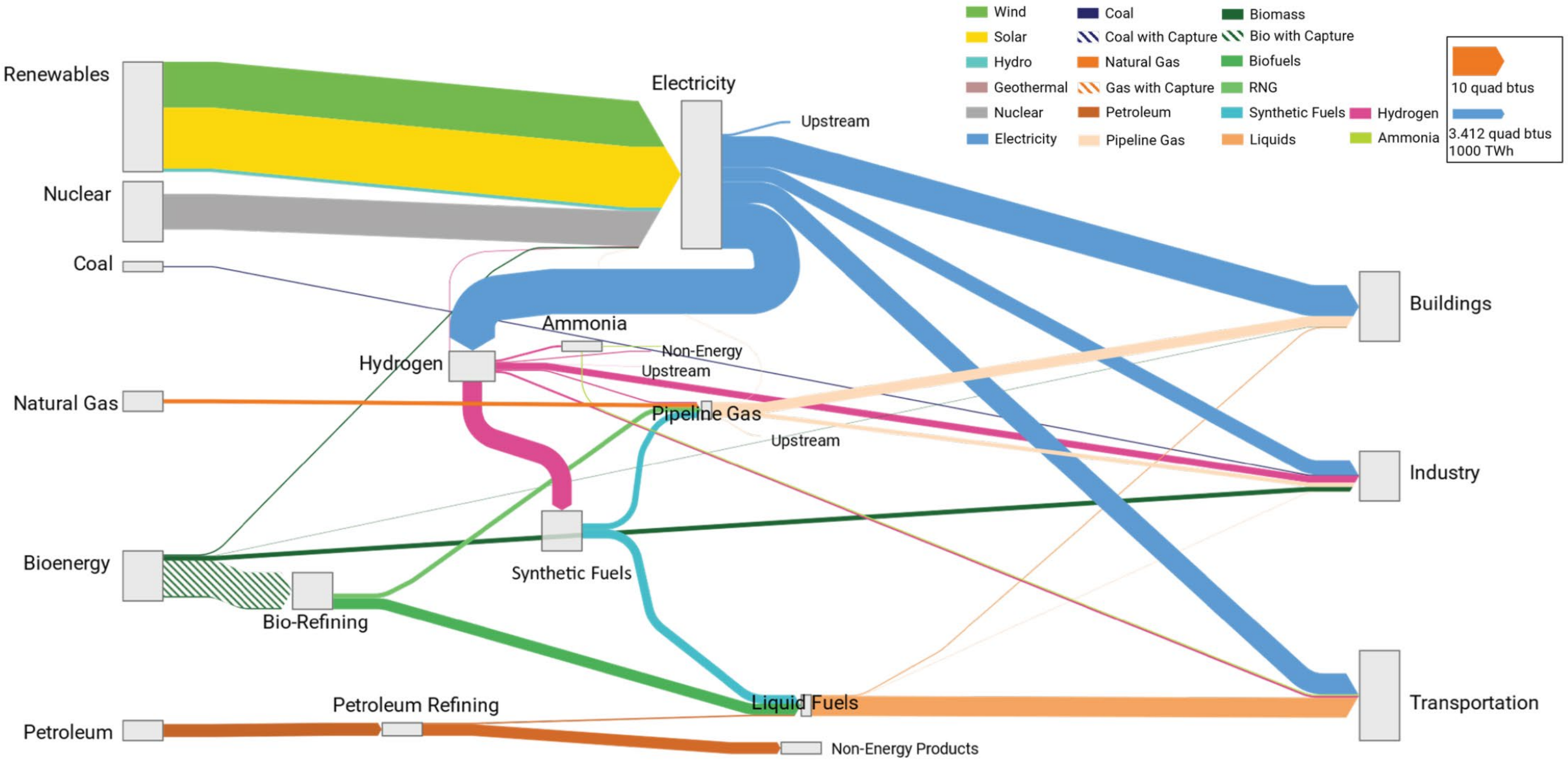
- Methane pyrolysis
  - Less mature technology that hydrogen produces solid carbon black from natural gas.

$$CH_4 \rightarrow 2H_2 + C$$

Hydrogen Economy

- EPRI modeling has shown that hydrogen may see more/sooner adoption in sectors other than power generation.
  - The diagram shows economy wide energy flows in 2050 under a net-zero limited options scenario (no CCS).
  - Note hydrogen (in pink) with only a small line to electricity.
  - This analysis did not include IRA incentives.
- This would allow sharing of transportation and storage infrastructure costs.

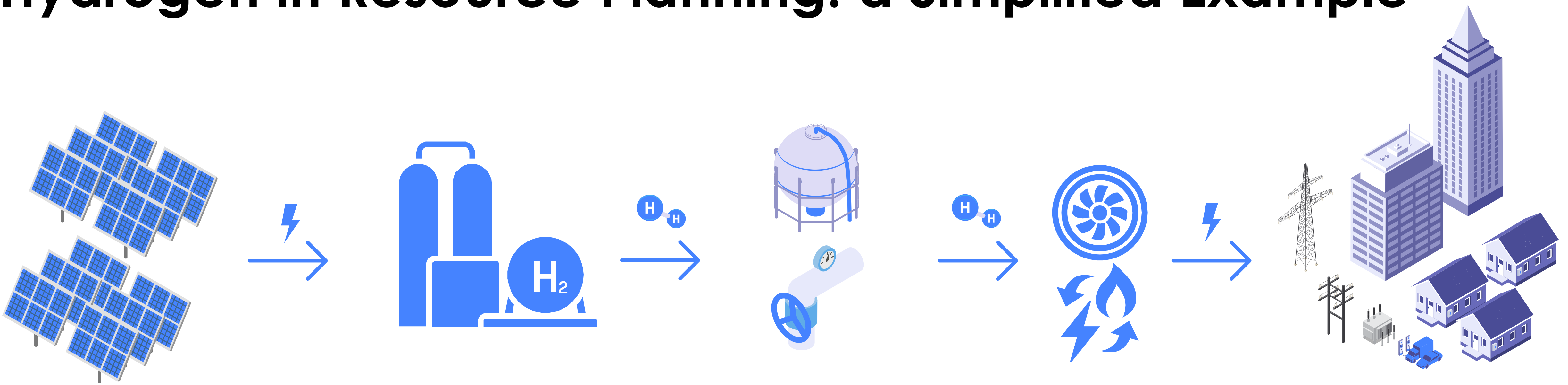
NET-ZERO LIMITED OPTIONS SCENARIO



Source: https://www.epri.com/research/products/000000003002024993

A hydrogen economy led by other sectors could reduce transportation and storage costs for hydrogen used for power generation.

Hydrogen in Resource Planning: a Simplified Example



Solar generation
Generates **382 GWh/year**.
Capacity of about 200 MW.
Requires about 600 acres.

Hydrogen production
Electrolysis produces
2,663 tonnes H_2/year.
About 300k MMBtu LHV.

Transport & storage
Transported by
pipelines and stored
underground.

Power generation
Generates **86 GWh/year**
at peak load hours.
100 MW turbine, 10% CF.

End use
Electricity
delivered to
customer

Using hydrogen for power generation would require significant new upstream generation. Investment in hydrogen transportation and storage infrastructure would also be necessary.

CF = capacity factor

Inflation Reduction Act

- The IRA offers a tax credit for hydrogen production up to **$3/kg H_2** including a bonus dependent on carbon intensity.
- Even including this bonus, hydrogen today would be more expensive than natural gas.

- Research and development in the electrolyzer industry could lead to cost reductions in coming years, resulting in lower costs of hydrogen.

TVA Hydrogen

Daniel Sipe
Innovation & Research

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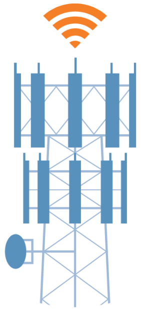
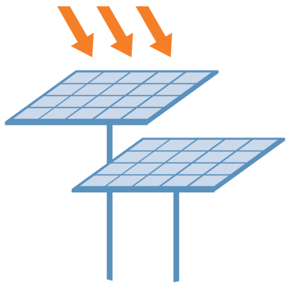
How could Hydrogen be beneficial to TVA?

Hydrogen is an alternative fuel providing carbon free energy which can support Valley **decarbonization**



Hydrogen Economy

- Development informs how TVA may support energy usage



Portfolio Diversification

- Continue to leverage multiple resources types

Environmental Stewardship

- Could support reduction of carbon emitting resources

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What are TVA’s alternative fuel options?

Alternative fuels are liquid or solid fuels that do not contribute to atmospheric carbon dioxide levels.

Volume, **cost**, and **energy efficiency** are key to a transition

- Biomass and biofuels are possible but scale is small
- Hydrogen is the a primary candidate with DOE significant momentum

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

1 Dollar 1 Kilogram 1 Decade

U.S. DEPARTMENT OF ENERGY · LCRI LOW-CARBON RESOURCES INITIATIVE · Southern Company · DUKE ENERGY · Dominion Energy · LG&E KU PPL companies

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Hydrogen Hub Update

Andrew Campbell
Innovation & Research

TENNESSEE
VALLEY
AUTHORITY

Hydrogen Economy Development

Need tremendous development

- Production capacity
- Pipeline transportation
- Competitive costs to gain market share.

Non-power sector will lead

Excess renewables leading to power generation hard to see.

Nuclear power maximizes efficiency of electrolyzer

Southeast Hydrogen Hub Update

Concept Paper Received Encouragement from the DOE

- Concept Paper was evaluated based on OOE scoring criteria
- Of 79 concepts, 33 were encouraged and 46 discouraged

Full application submitted

- DOE notifications expected Fall 2023
- MOU between parties complete, includes shared cost for support services

State and Federal Support

- Bipartisan Senate
- Governors

Discussion Hydrogen

15 minutes

General Technology Discussion

15 minutes

What feedback do you have or areas we should look further?

Meeting Wrap-Up

Jo Anne Lavender; IRP Facilitator

For Review: Strategies Update

Daniel Woolley; Sr. Specialist, Resource Strategy