REINHOLD ENVIRONMENTAL ®

2024 Reinhold/PCUG Round Table Presentation

Hosted by LG&E/KU and Co-hosted by Southern Co. and TVA
in The Marriott Resort Lexington Griffin Gate Hotel, Lexington,
KY on June 24-25, 2024

Generation Flexibility Optimization

Thermal Generation Assets

Stephen Storm, EPRI
Program | Area Manager

2024 Reinhold Round Table
June 24,2024

Agenda

1. Introduction
2. Energy Supply Technology Pathway Challenges
3. Common/Emerging Thermal Fleet Challenges
4. Generation Flexibility Management and Optimization

Fleetwide Flexibility Management:

i. Understanding thermal flexibility demands and asset capability
ii. Managing technology benefit vs. challenges for a given region.
iii. Aligning people, process and technologies
iv. Flexibility program management
v. Systematic approach to flexibility assessments
vi. Dispatch optimization
vii. Cost management under flexible operations
viii. Units on a glidepath to retirement
ix. Strategic planning for resiliency
x. Environmental compliance

2024 Generation Portfolio

ARP Program
Supplemental Program
Strategic Supplemental Project

Thermal Fleet

214: Boiler Life and Availability Improvement
215: Power Plant Piping
216: Gas Turbine Life Cycle Management
217: Gas Turbine Advanced Components and Technologies
218: Heat Recovery Steam Generators
219: Steam Turbines and Auxiliary Systems
220: Generators and Auxiliary Systems

Thermal Optimization & Emissions Controls

223: Heat Rate and Flexibility: Generation Fleet Optimization
232: SCR Performance Issues
233: Continuous Emissions Monitoring and Measurements
*Combustion and Carbon Control Issues **(SP254)***
*Emissions Controls **(SP253)***

Renewable Fleet

206: Wind Generation
*Environmental Aspects of Wind **(SP250)***
*Offshore Wind **(SP249)***
207: Solar Generation
*Environmental Aspects of Solar **(SP252)***
208: Hydropower Generation
Geothermal

Water & Land Management

238: Water Treatment Technologies
239: Aquatic Resource Protection
240: Water Quality and Effluent Guidelines
241: Coal Combustion Products Management
242: CCP Land and Groundwater Management

Air Quality & Health

235: Air Quality Assessments and Multimedia Characterization
236: Air Quality, Health, and Communities
*Atmospheric Models and Ambient Measurements **(SP247)***

Next-Generation Fleet

221: Bulk Energy Storage
222: Advanced Generation and Carbon Capture and Storage
*Generation Transitions **(SP248)***
Low-Carbon Resources Initiative
Net-Zero Industrial Clusters

Fleet Management & Operations

224: Integrated Asset Management
225: Plant Management Essentials
226: Boiler and Turbine Steam and Cycle Chemistry
*Plant Decommissioning and Site Redevelopment **(SP255)***

Digitalization

209: Cyber Security for Generation Assets
227: Process Control and Automation
228: Monitoring and Advanced Data Analytics

Materials

229: Materials
Advanced Manufacturing

Research
VISION

Heat Rate and Flexibility: Fleet Generation Optimization

Objectives

Heat Rate:

- Support and compliance with regulations Reduced uncertainty in key performance measurements
- Improved efficiency during startups and load following
- More accurate dispatch order, optimal usage of generation assets
- Technical webcasts on plant performance related topics
- Access to industry expertise, resources, guidance and answers for pressing issues

Flexibility

- Support with implementation of a flexibility program; Placing relevant information in the hands of key staff
- Flexibility assessments and benchmarking on conventional steam units & CCGT units
- Opportunity to demonstrate integration of diagnostics with the existing M&D center models and reliability monitoring tools
- Cost management prioritization
- Input with equipment reliability and risk optimization process and opportunity for demonstration and application with projects that strive to optimize efficient, safe, reliable and environmentally compliant generating assets.

Michael Caravaggio

Director – Thermal Fleet

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Program | Area Manager

Keith Paul

Principal Technical Leader

Grant Lanthorn

Senior Technical Leader

Dr. Lesley Sloss

Senior Technical Leader

Lauren Aiken

Technical Assistant

Patti Logan

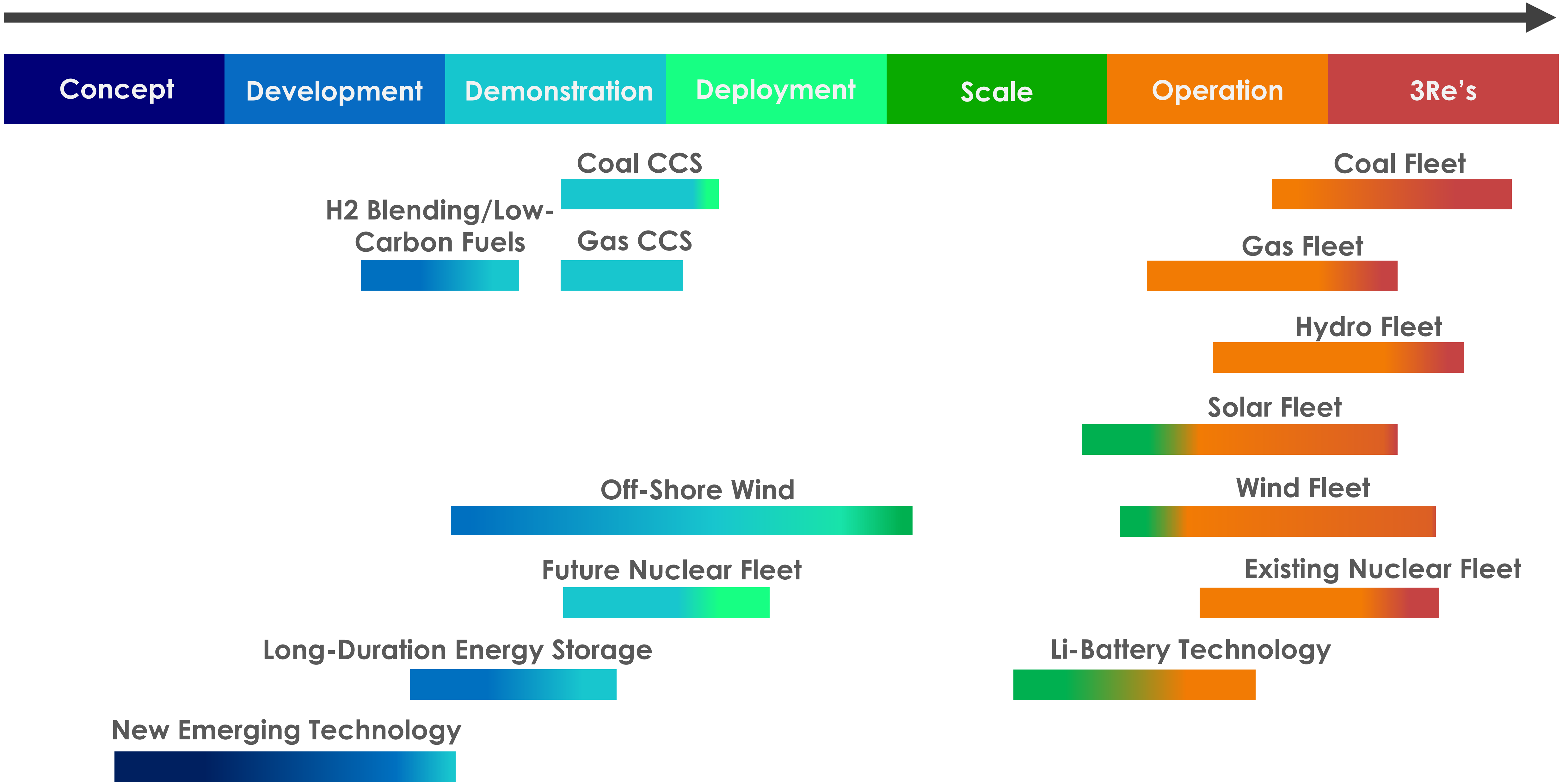
Event Planner

A Perfect Storm

This Decade Represents a Perfect Storm of Challenges and Opportunities.

2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030

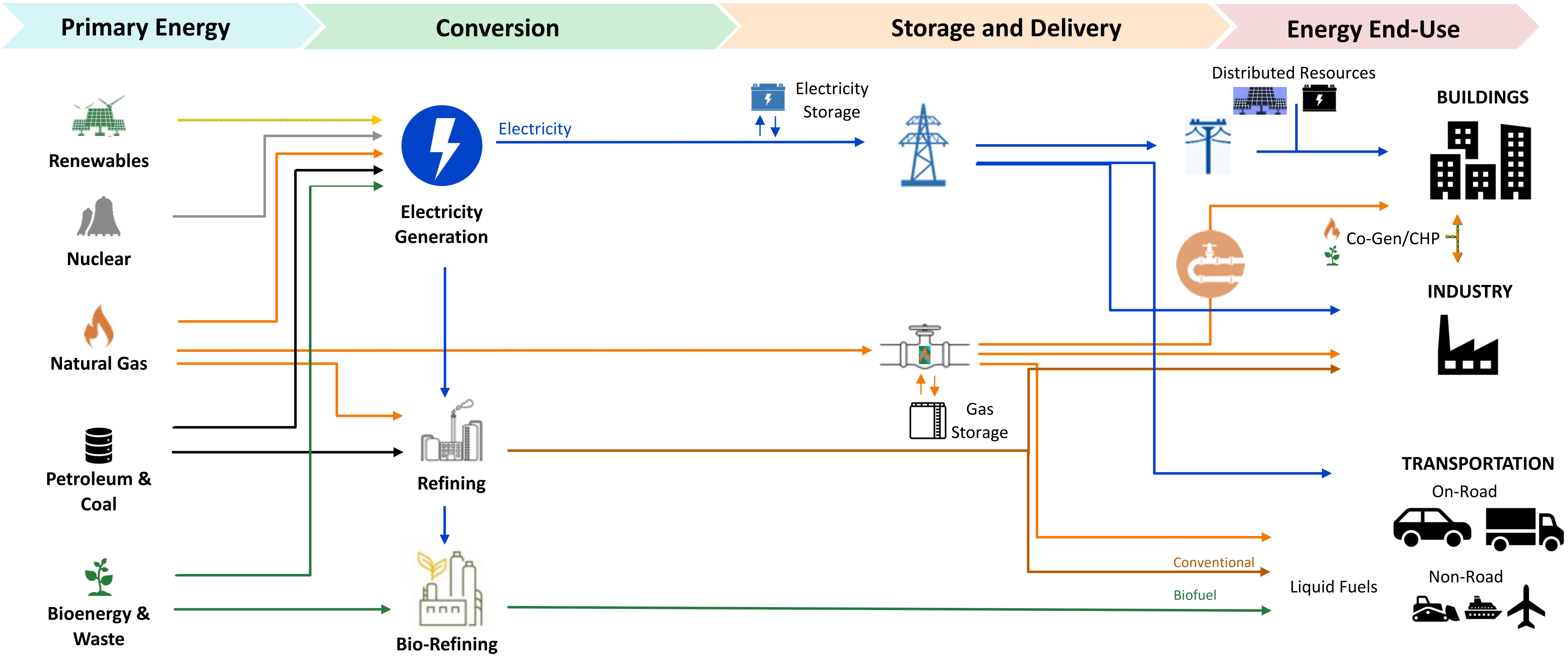
Energy Supply Technology Maturity



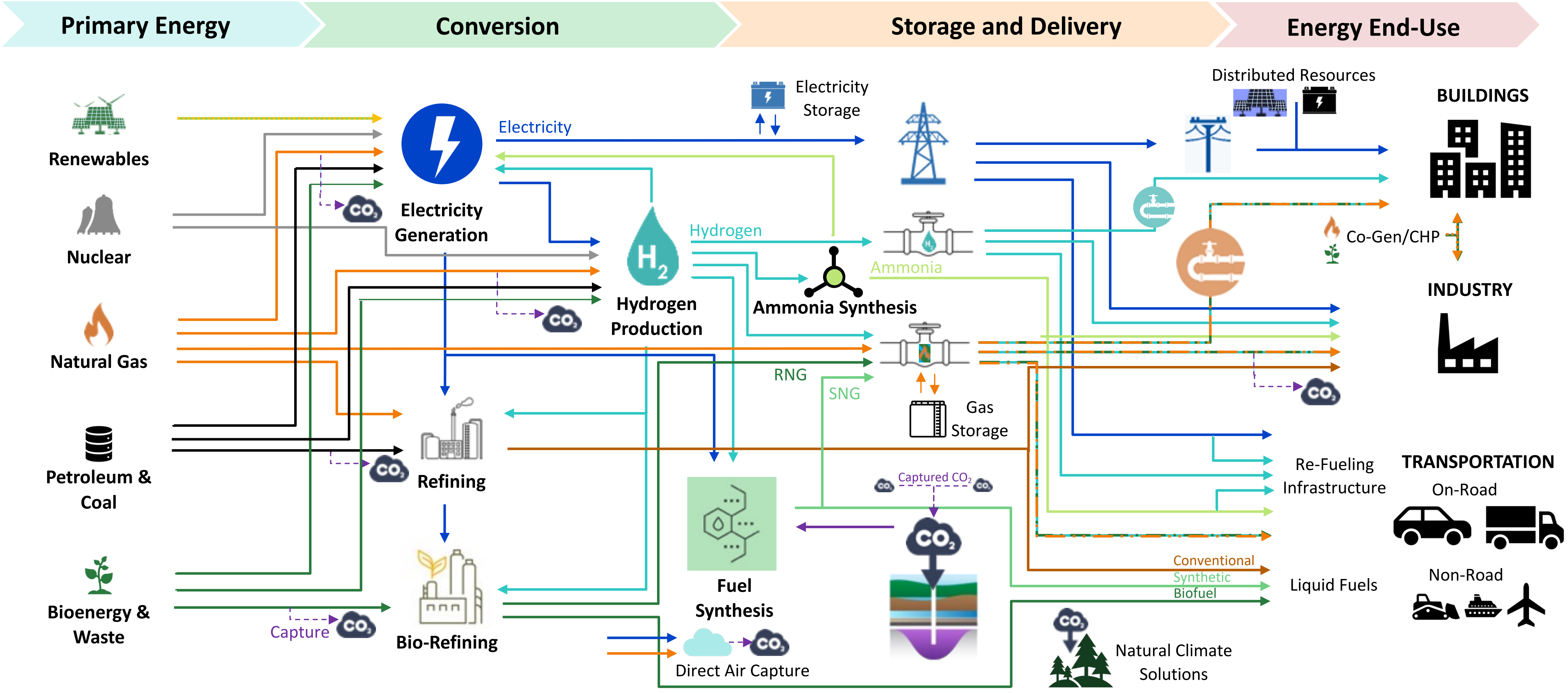
Concept
Development
Demonstration
Deployment
Scale
Operation
3Re's

Coal CCS
Coal Fleet
H2 Blending/Low-Carbon Fuels
Gas CCS
Gas Fleet
Hydro Fleet
Solar Fleet
Off-Shore Wind
Wind Fleet
Future Nuclear Fleet
Existing Nuclear Fleet
Long-Duration Energy Storage
Li-Battery Technology
New Emerging Technology

Energy System Today is Fairly Simple



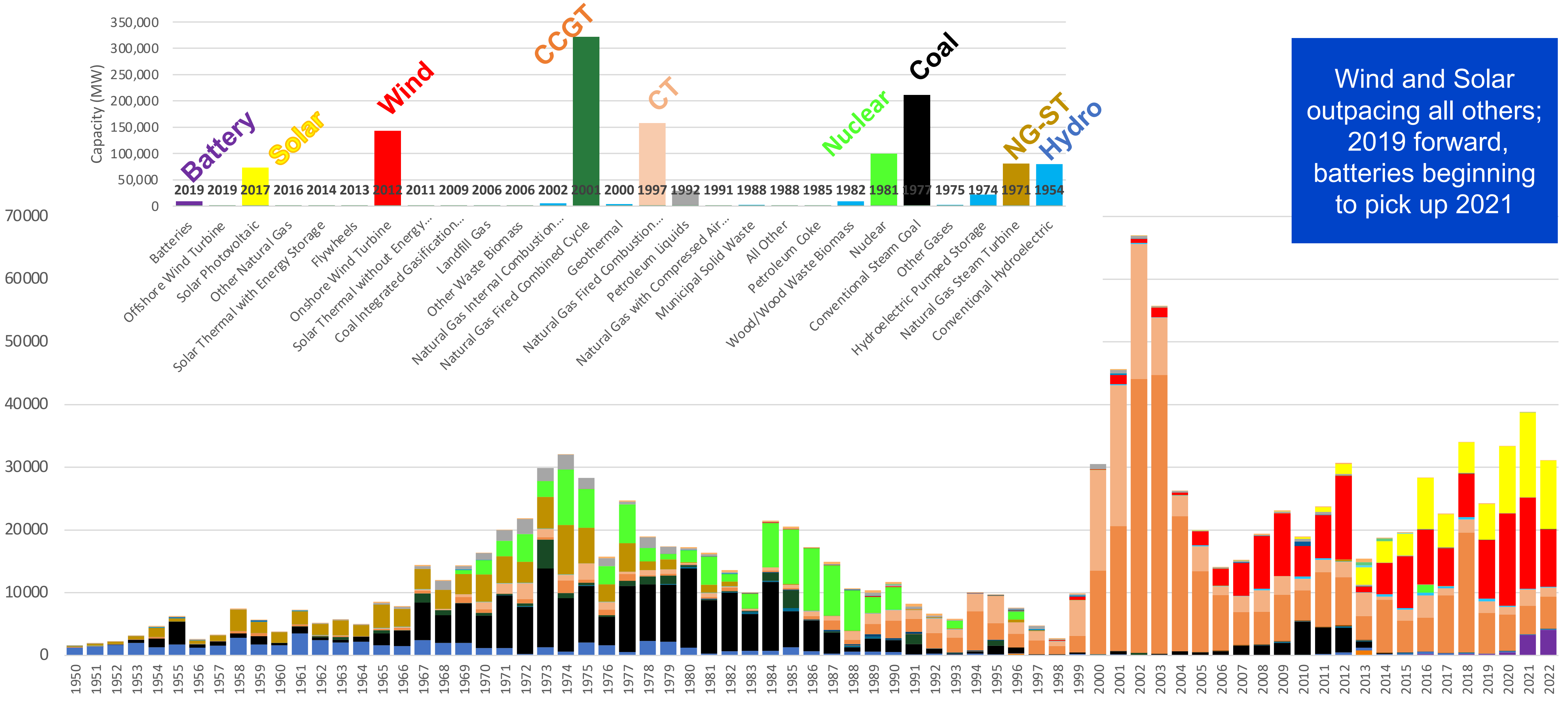
Growing Complexity in the Future Energy System



US Capacity Details

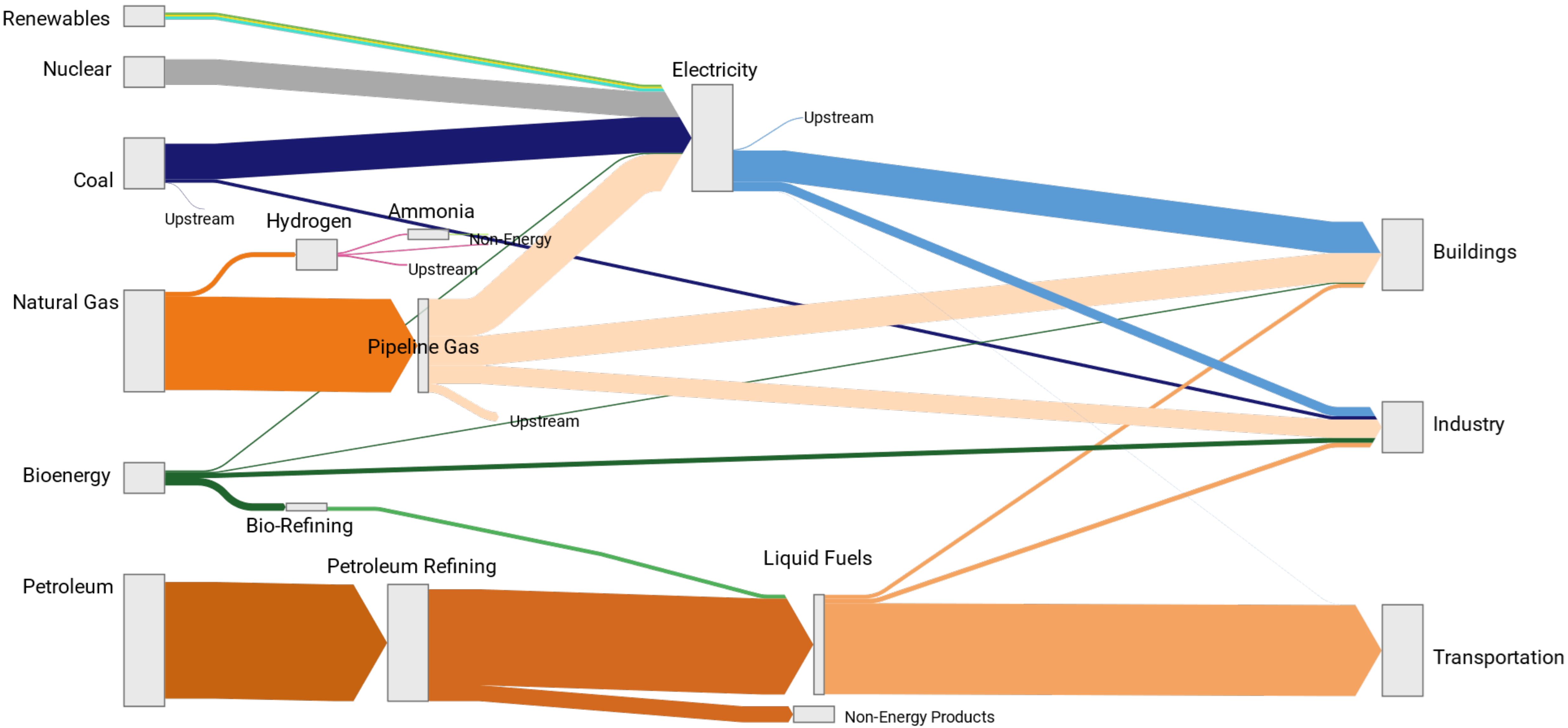
Few New Thermal Asset

New Assets are more Variable

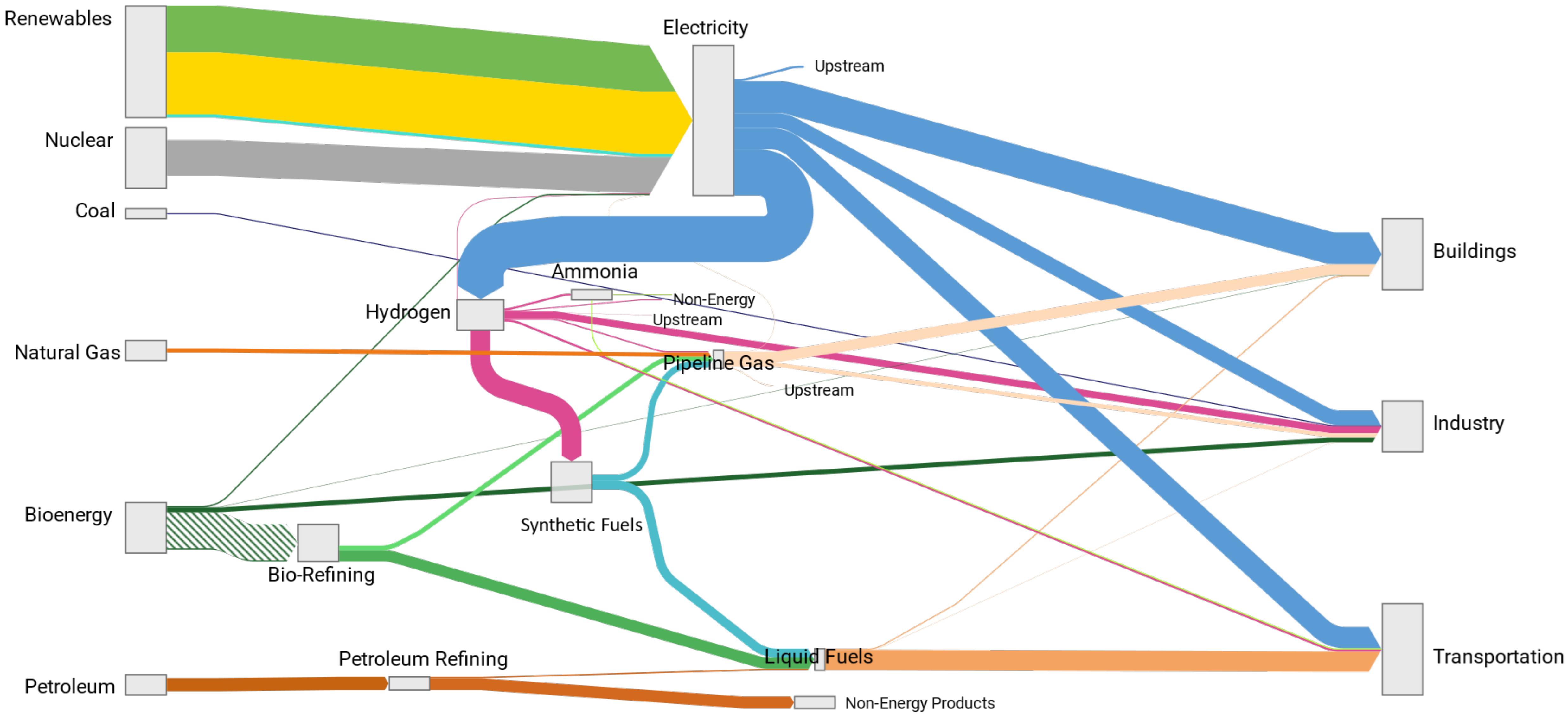


Wind and Solar outpacing all others; 2019 forward, batteries beginning to pick up 2021

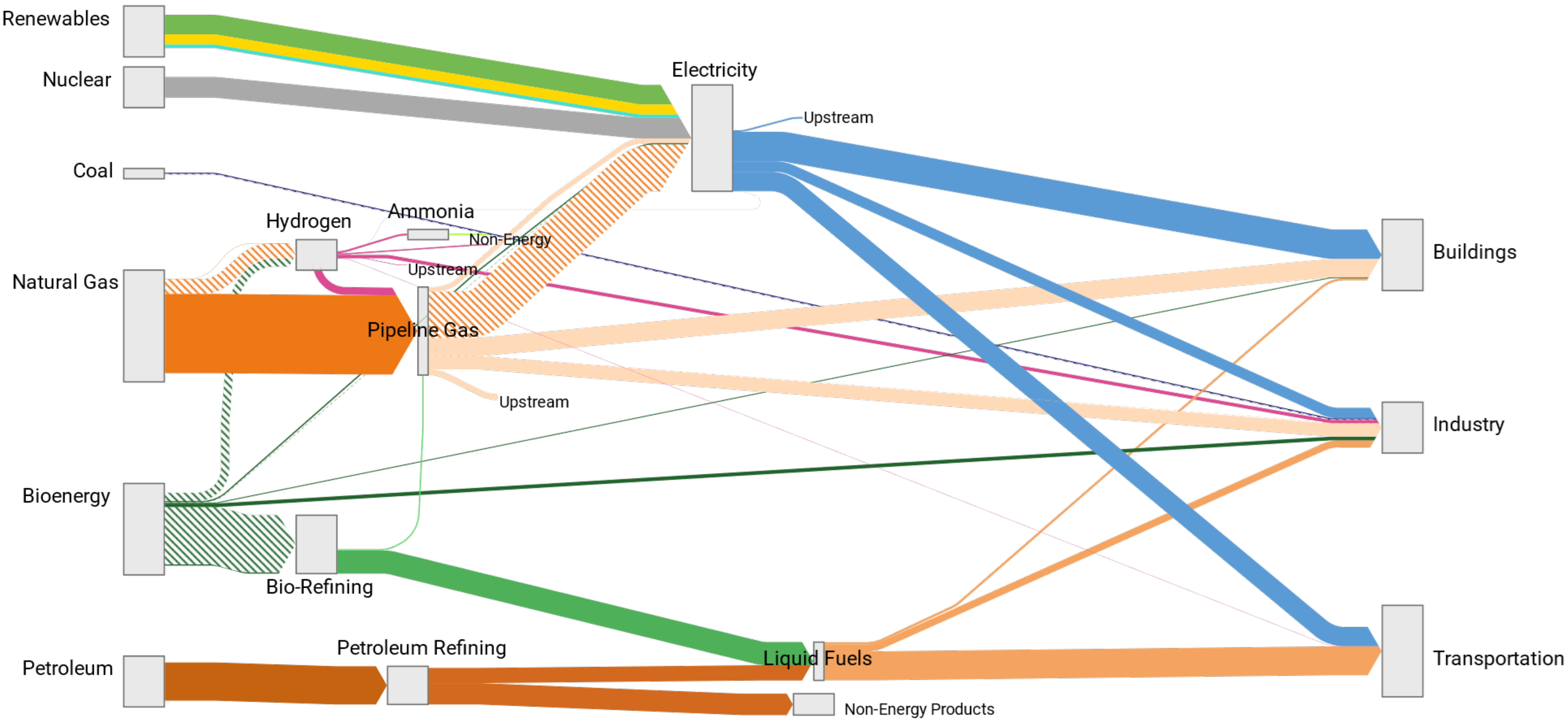
U.S. Current Energy System



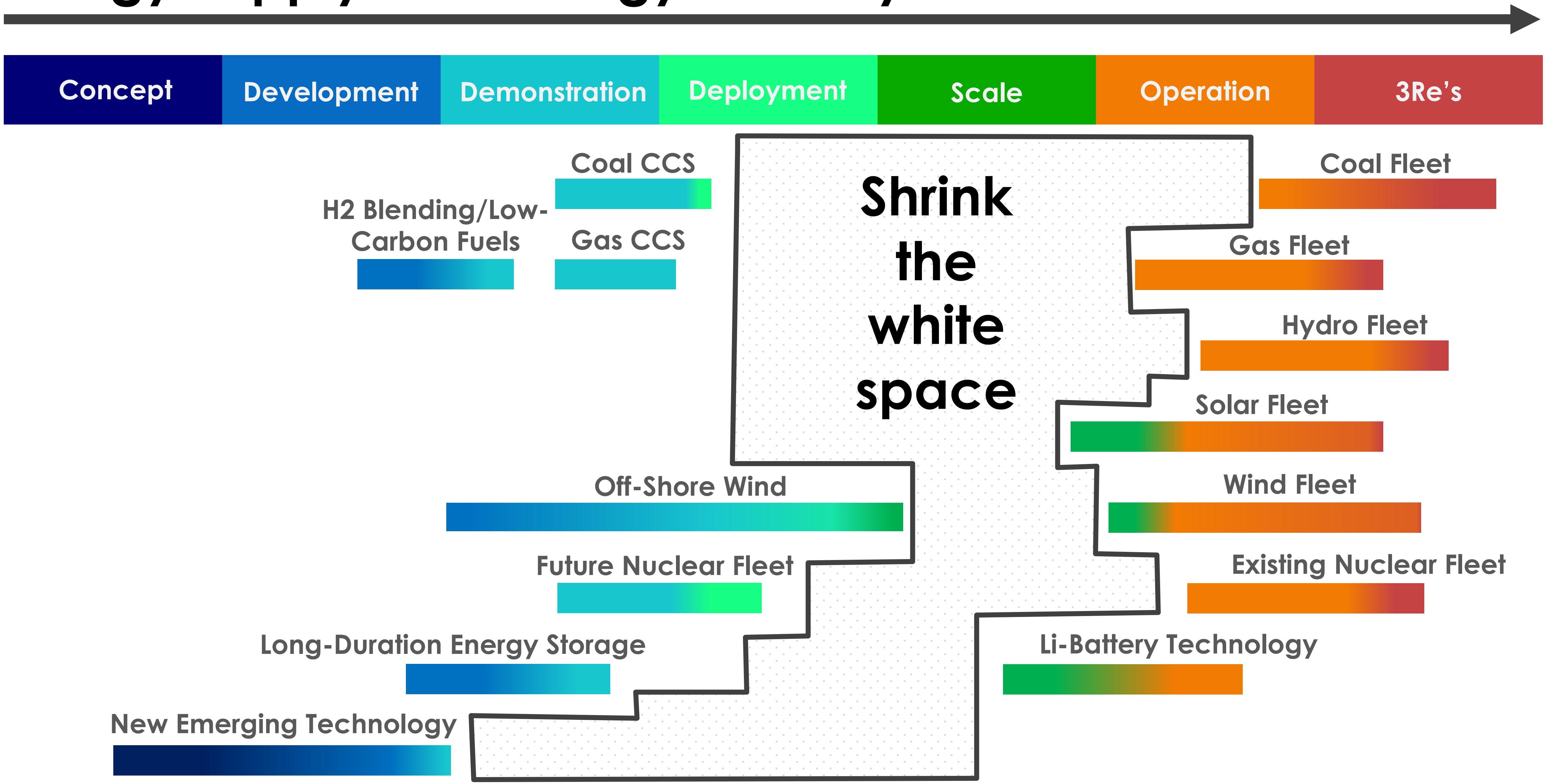
U.S. 2050 Net-Zero Limited Options



U.S. 2050 Net-Zero All Options



Energy Supply Technology Maturity



Concept

Development

Demonstration

Deployment

Scale

Operation

3Re's

Coal CCS

H2 Blending/Low-Carbon Fuels

Gas CCS

Off-Shore Wind

Future Nuclear Fleet

Long-Duration Energy Storage

New Emerging Technology

Shrink the white space

Coal Fleet

Gas Fleet

Hydro Fleet

Solar Fleet

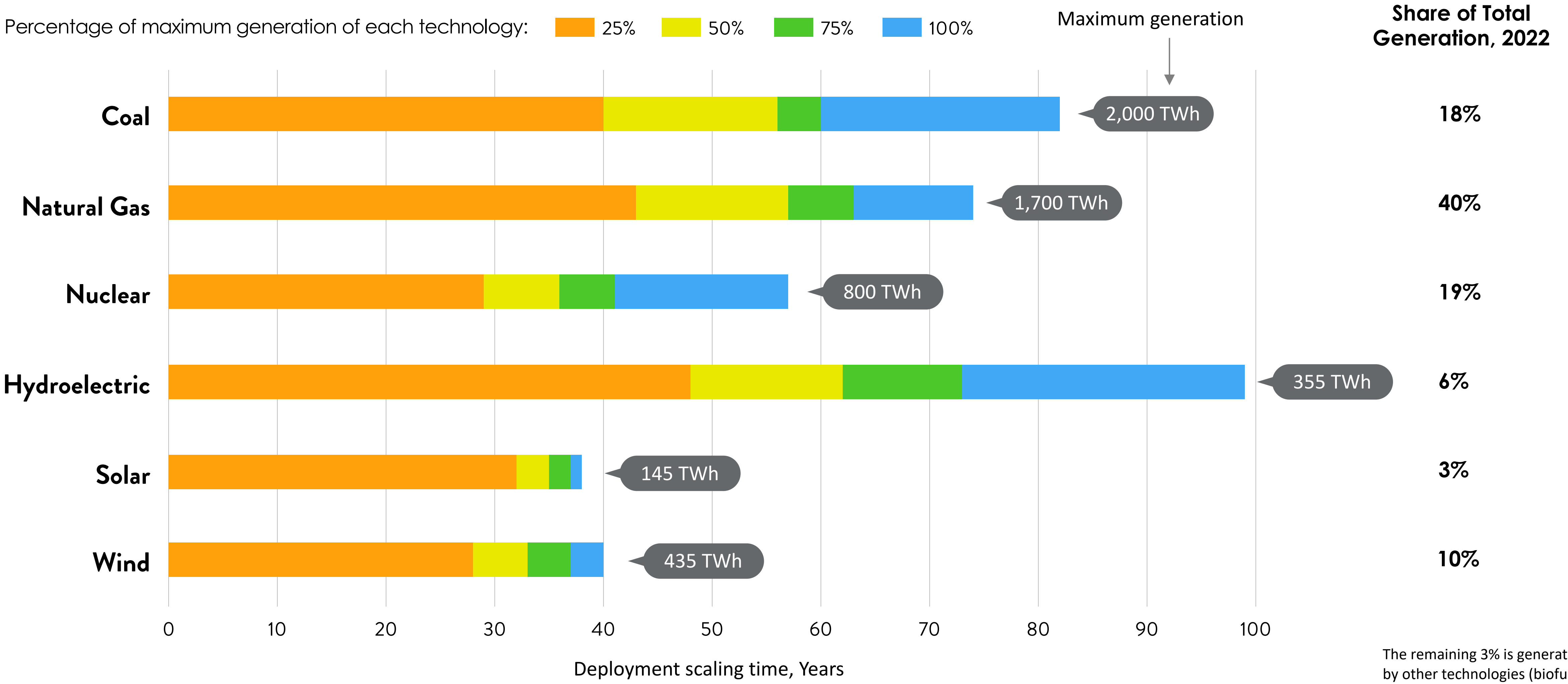
Wind Fleet

Existing Nuclear Fleet

Li-Battery Technology

Deploying Commercial Technologies at Scale

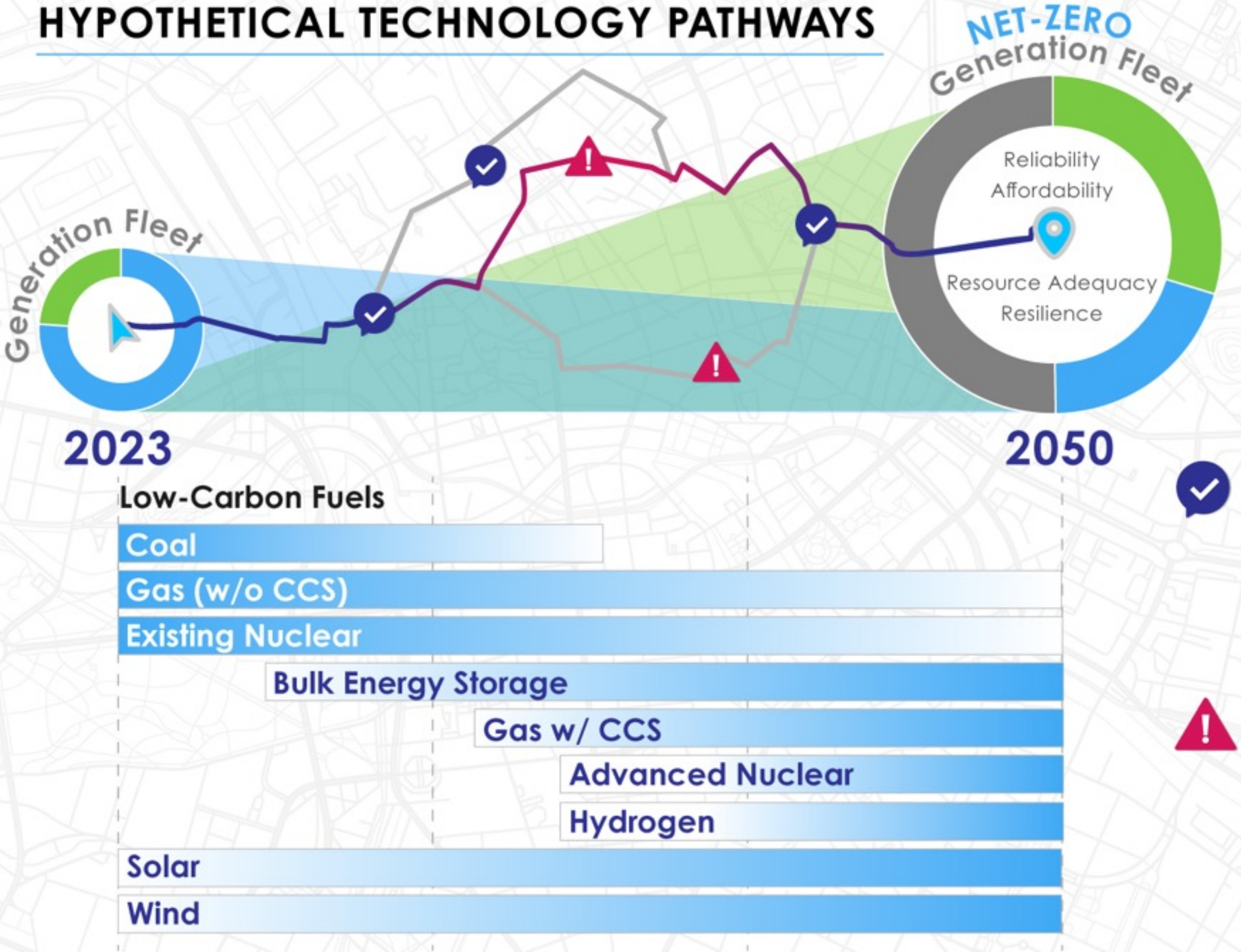
Realistic Timeline



The remaining 3% is generated by other technologies (biofuel, waste, etc.)

Data Source: U.S. Energy Information Administration

HYPOTHETICAL TECHNOLOGY PATHWAYS



🟦 **Dispatchable**

🟩 **Variable**

⬛ **Additional Resources**

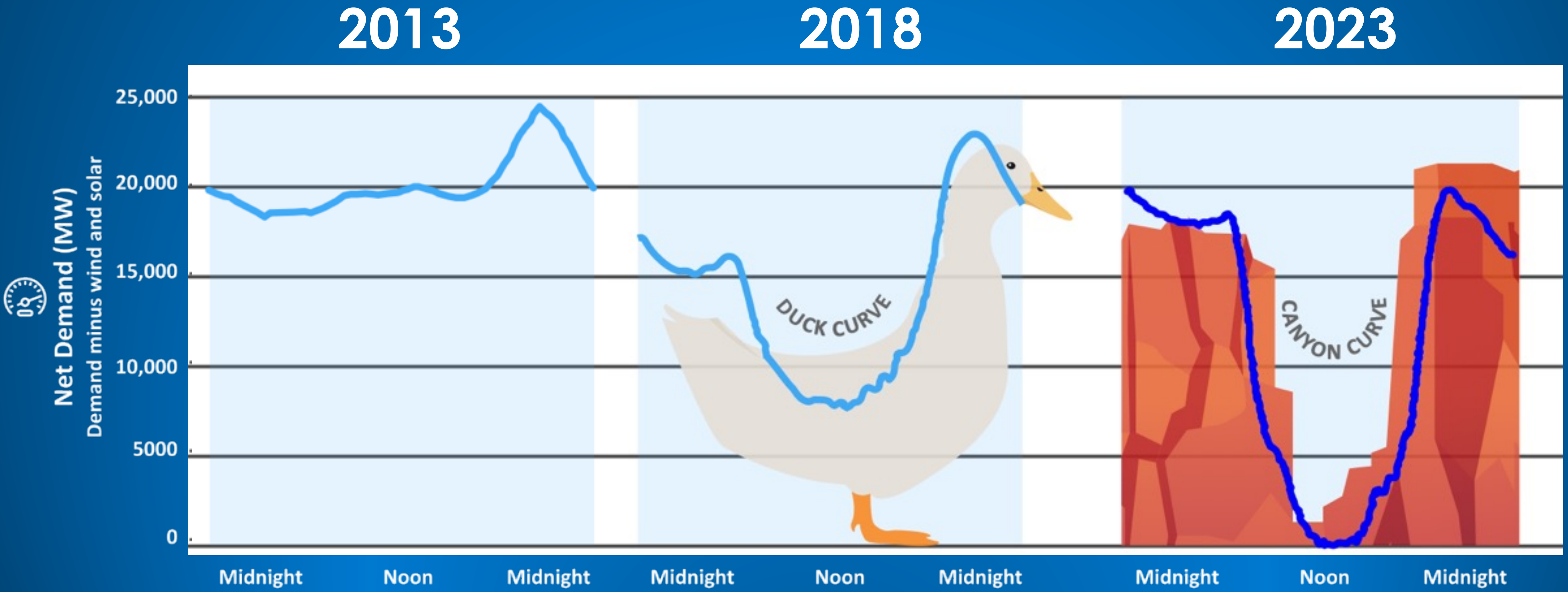
✓ **Advancements**
- Long-duration energy storage
- Dispatchable renewables
- Small modular reactors
- CCS
- Hydrogen

⚠ **Challenges**
- Supply chain limitations
- Technology setback
- Regulatory change

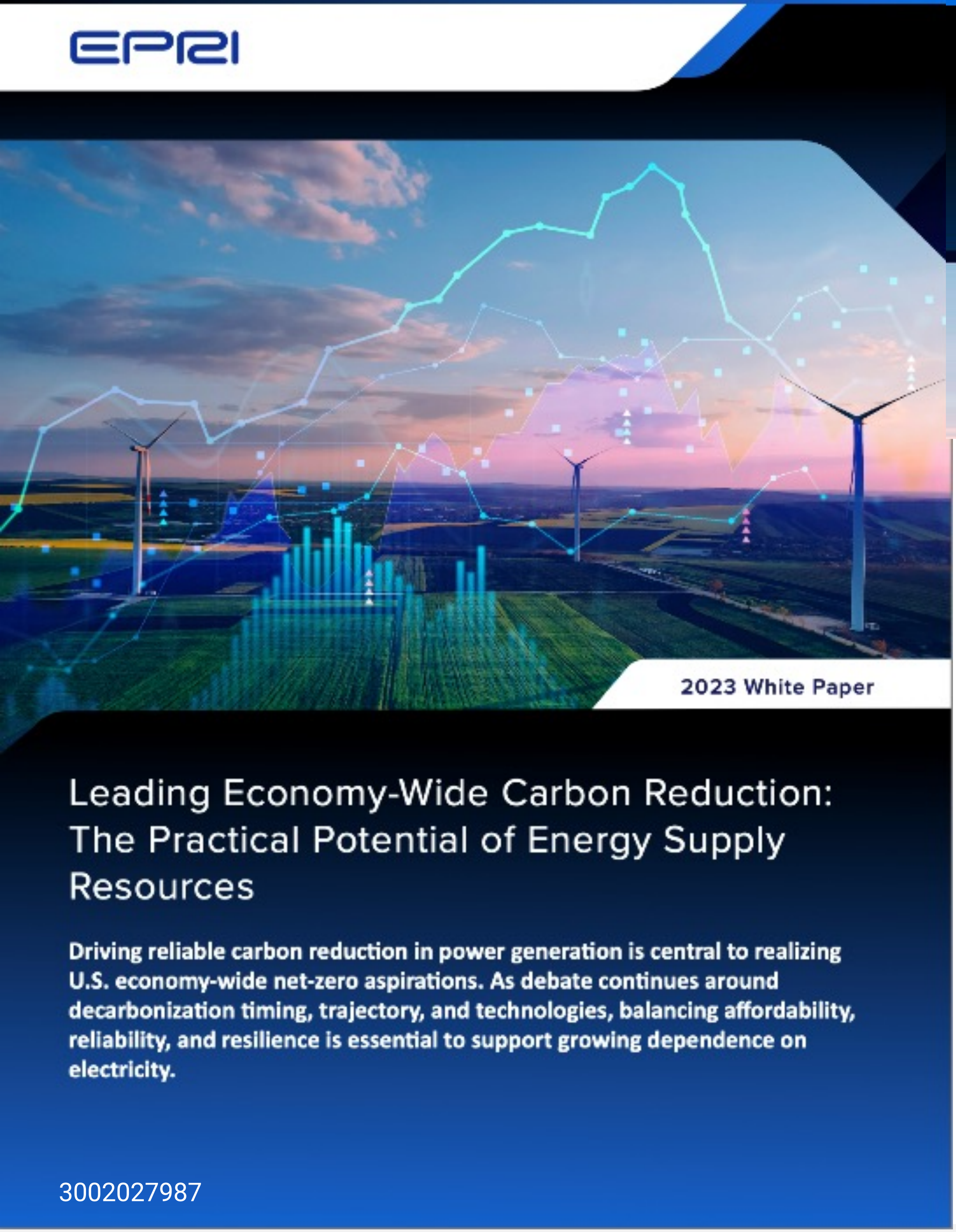
The Operation of the Electric System is Changing

CALIFORNIA SPRING DAY NET LOAD

Dispatchable Power Demand



Practical Realities of the Energy Transition



2023 White Paper

Leading Economy-Wide Carbon Reduction: The Practical Potential of Energy Supply Resources

Driving reliable carbon reduction in power generation is central to realizing U.S. economy-wide net-zero aspirations. As debate continues around decarbonization timing, trajectory, and technologies, balancing affordability, reliability, and resilience is essential to support growing dependence on electricity.

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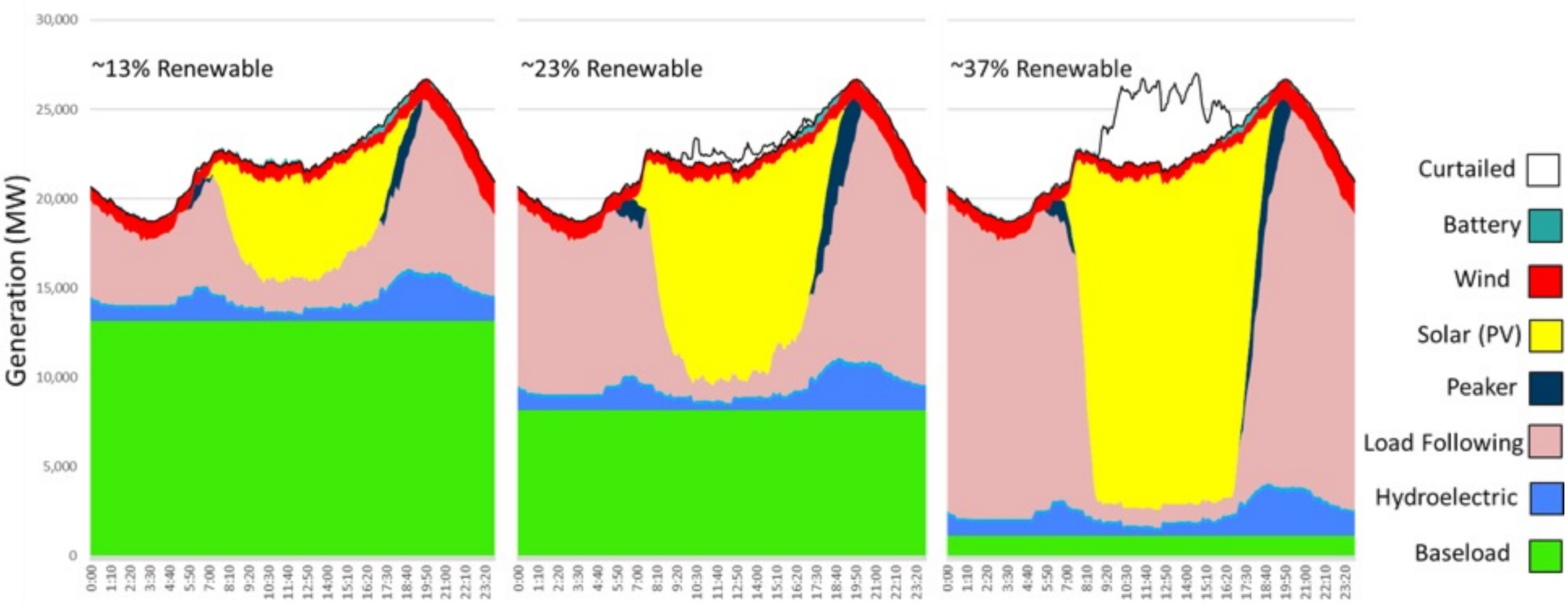
https://www.epri.com/research/products/000000003002027987

Increased Variable Renewable Energy impact on Dispatchable Generation

Dispatchable thermal energy is required to meet peak net load demand hours. These are the marginal hours when renewable energy output is low, and demand is high. Meeting the demand in those hours is increasingly difficult as dispatchable generation continues to retire and remaining dispatchable generation sees reductions in capacity factors.



Flexibility Demands with the Transition

GENERATION FLEXIBILITY

FASTER RAMP RATES

LOWER MINIMUM LOADS

FASTER STARTUP TIMES

SHORTER MINIMUM UPTIME AND RUN TIMES

Increased variable renewable energy (VRE) puts more stress on dispatchable generation flexibility to support net load peak days or net load minimum days to avoid VRE curtailment.

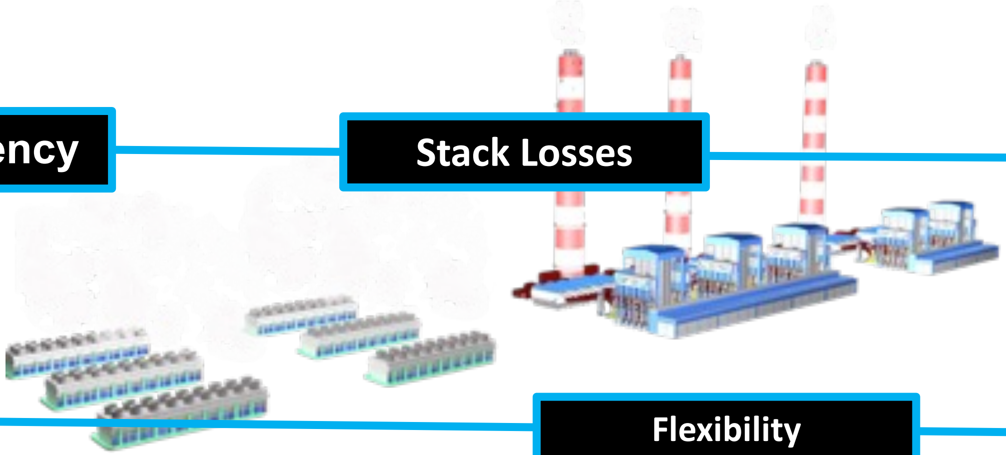
Net Load Peak Days

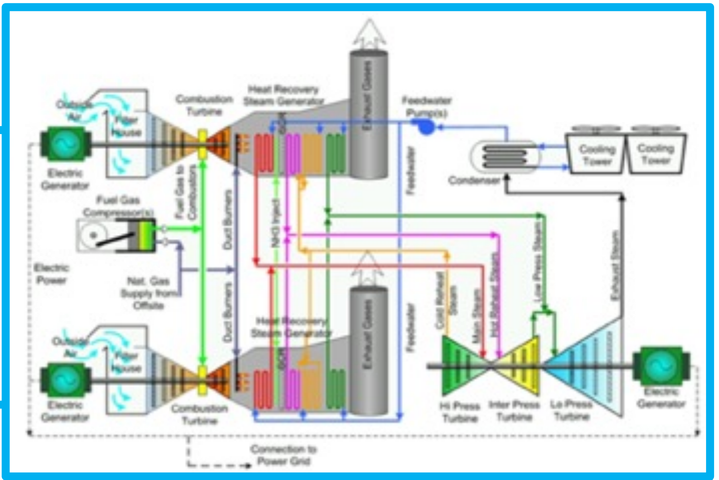
- All units required to meet peak
- Often hottest or coldest days
  - Use of VRE limits output and efficiency

Net Load Minimum Days

- Units must turn down or shut down but be prepared to respond
  - Can be offline for days before being required

Emerging Challenges with the Energy Transition





Overall Thermal efficiency

Stack Losses

Power Cycle Losses

Flexibility

- Minimum Load
- Ramp Rate
- Start-up Time

Component Evaluations

- Cycle Component Efficiency
  - Cooling Tower Losses
- Cycle Isolation
  - Auxiliary Power
  - Pre-Outage Inspections

Balance of Plant

Turbine Reliability

- Chemistry
- Corrosion
- Creep

Boiler/HRSG Reliability

Emissions Control

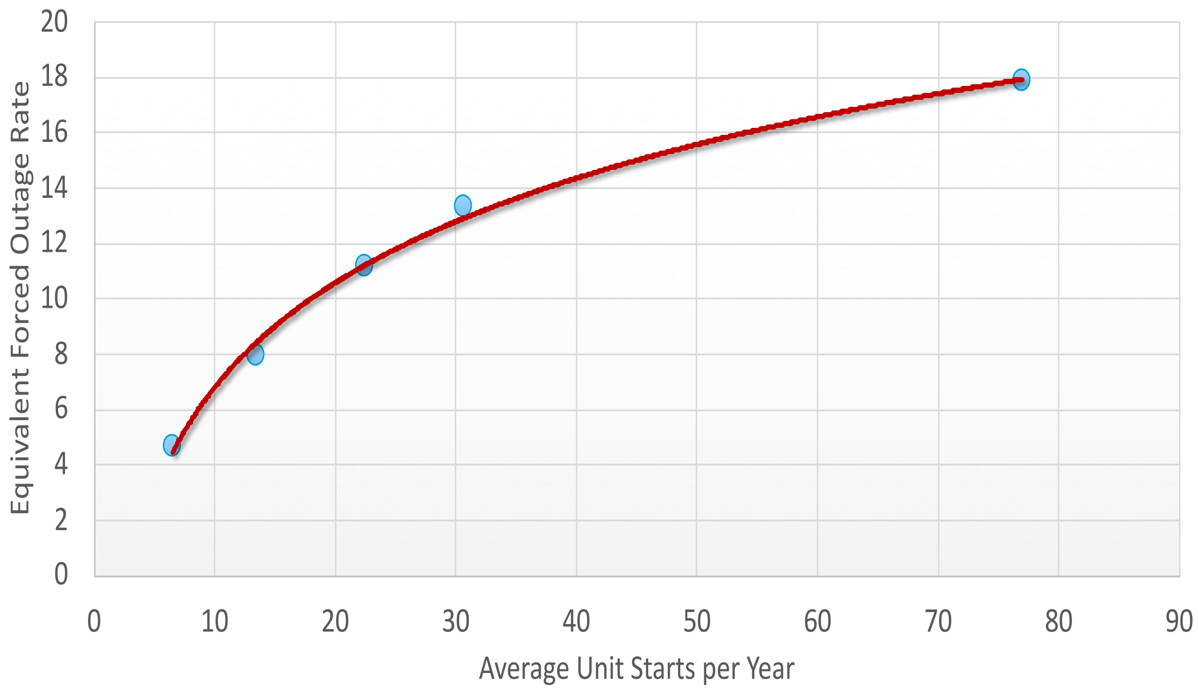
EFFICIENCY FLEXIBILITY RELIABILITY EMISSIONS

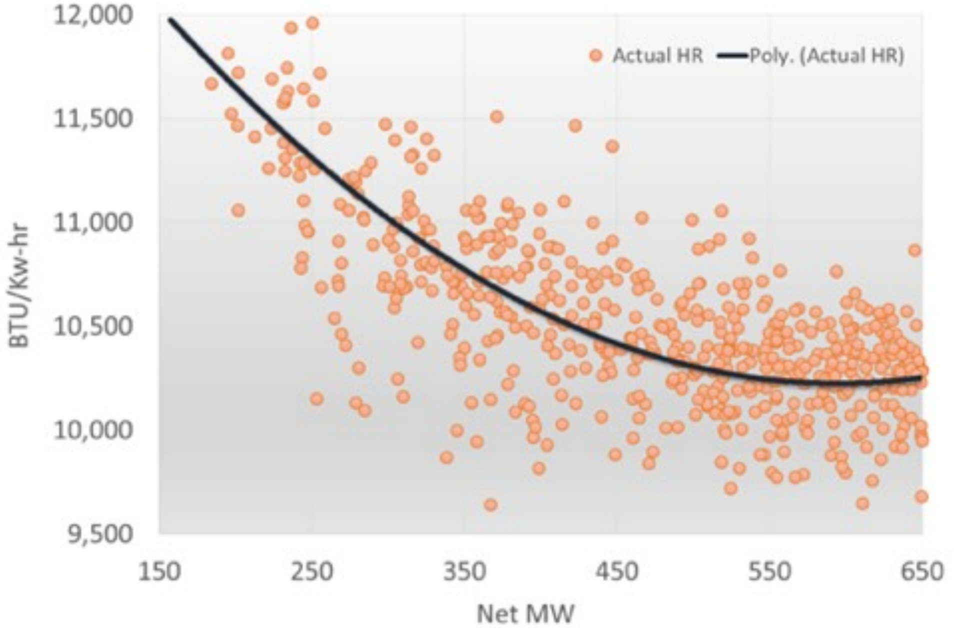
Flexibility and Heat Rate

Cycling is the least desirable. It consumes component life at the greatest rate*

- Poses the greatest risk for a plant damaging accident. (Operator error or equipment malfunction)
- Requires the longest period of time for the unit to be available for changing load demand
- Incurs the greatest fuel costs per MW generated

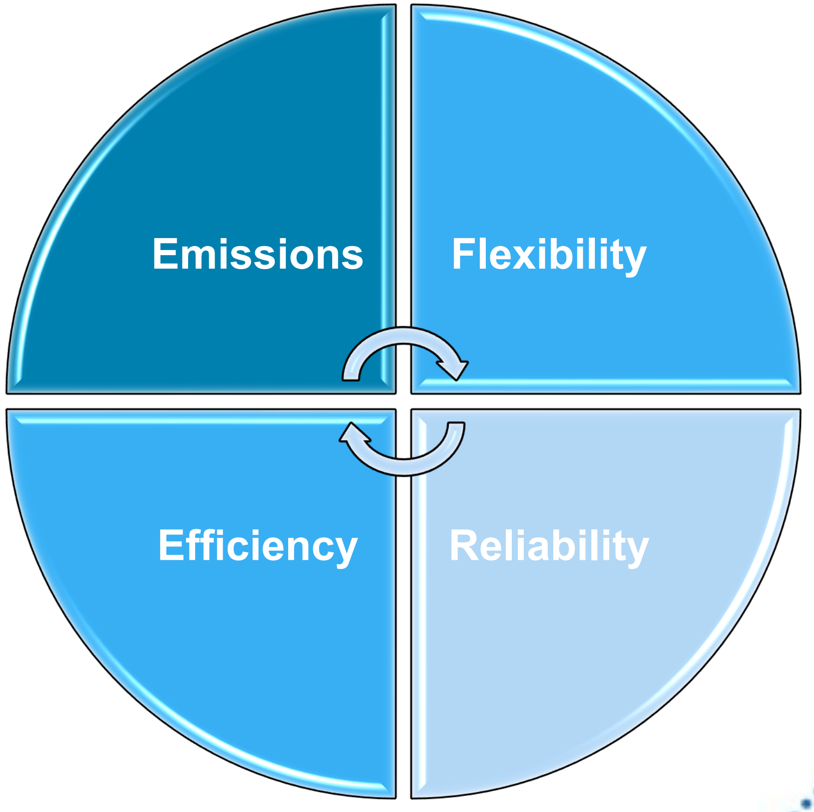
* *Highly dependent on unit configuration and operator observance of guidelines and operating limits.*

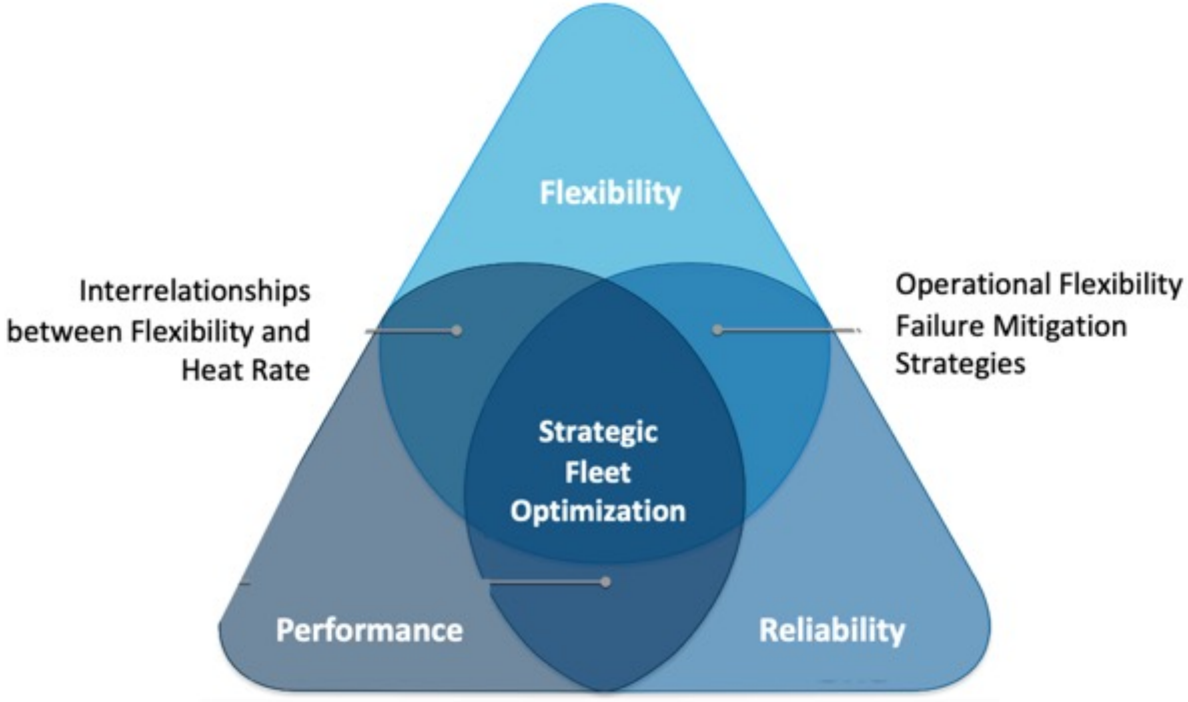




Subcritical Coal Unit Example

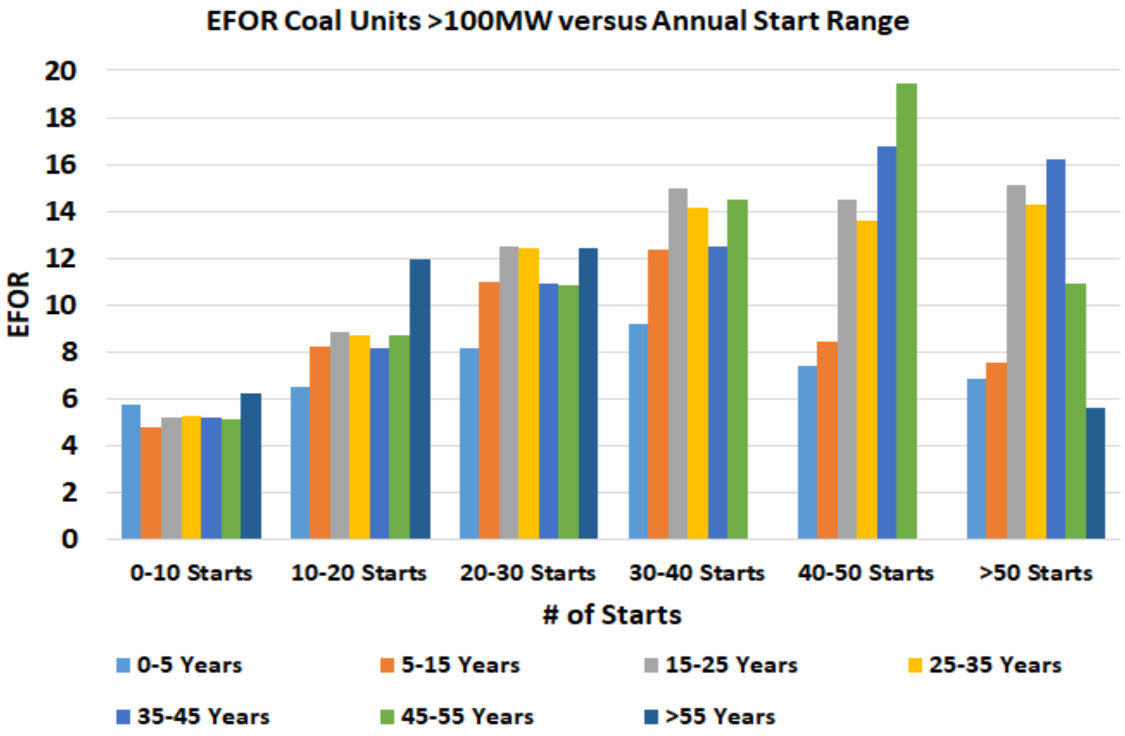
Fleet Optimization Strategy



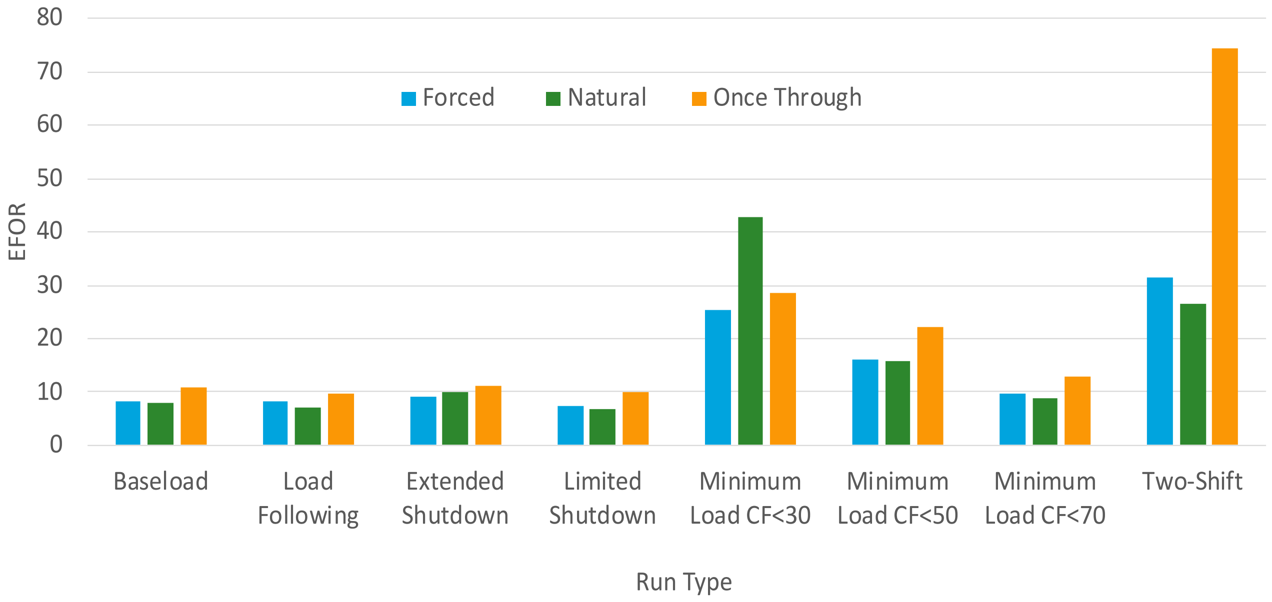


NERC GADS Data Assessment:

Coal-Fired Units by Starts and Age 1980-2020



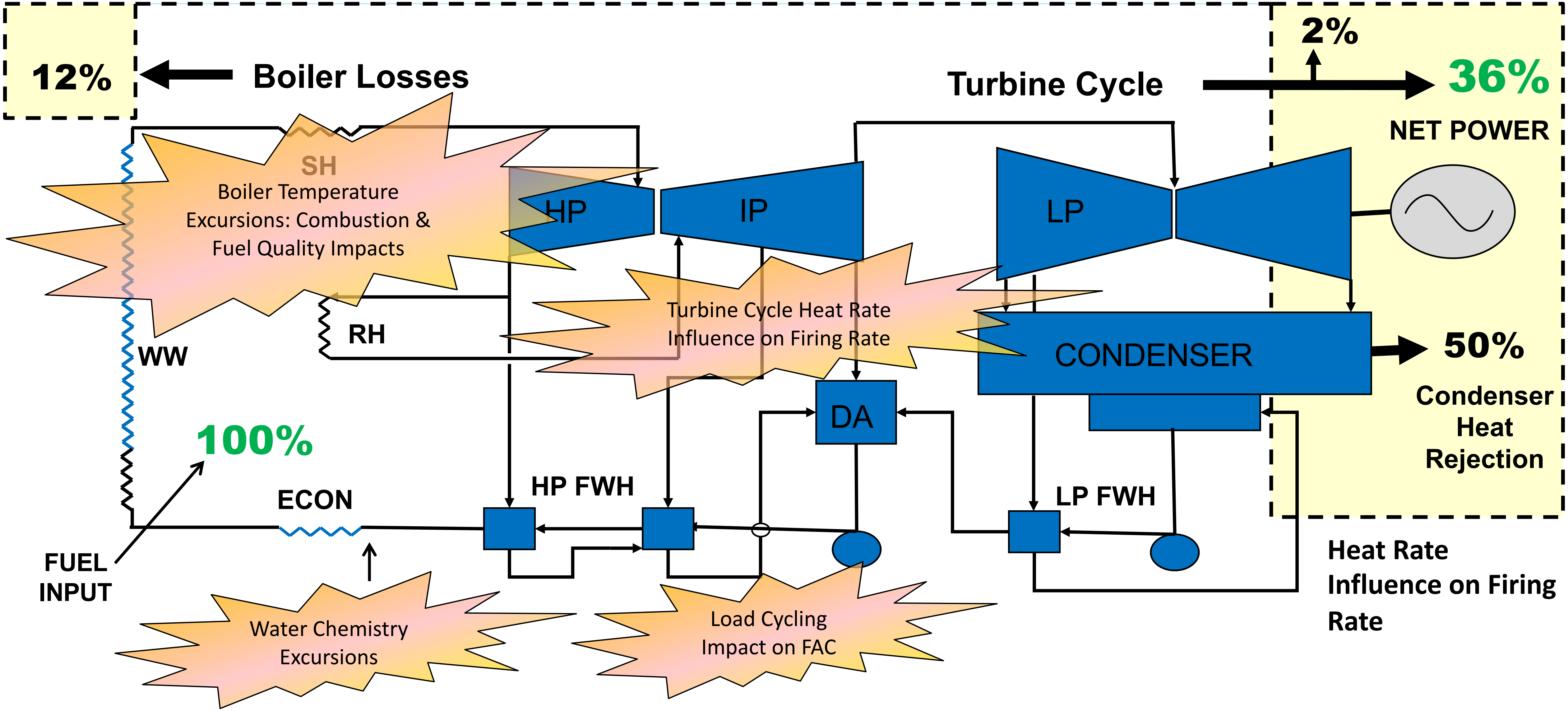
- Criteria:
  - Primary Fuel (Design) Type: Coal
  - MW Rating: 100-1500
  - Actual Number of Starts: Range of Starts
  - Age of Unit: Range of Ages



Conventional coal units are negatively affected by cycling and transient operating conditions. A GADS data study of the US fleet that spans four decades revealed that the aging boiler's reliability is most impacted with reduced minimum load and 2-shift operations.

Interrelationships of Heat Rate and Flexibility: NERC GADS--Assessment of 40 Years 3002023069

Plant Performance Considerations



Boiler Temperature Excursions: Combustion & Fuel Quality Impacts

Turbine Cycle Heat Rate Influence on Firing Rate

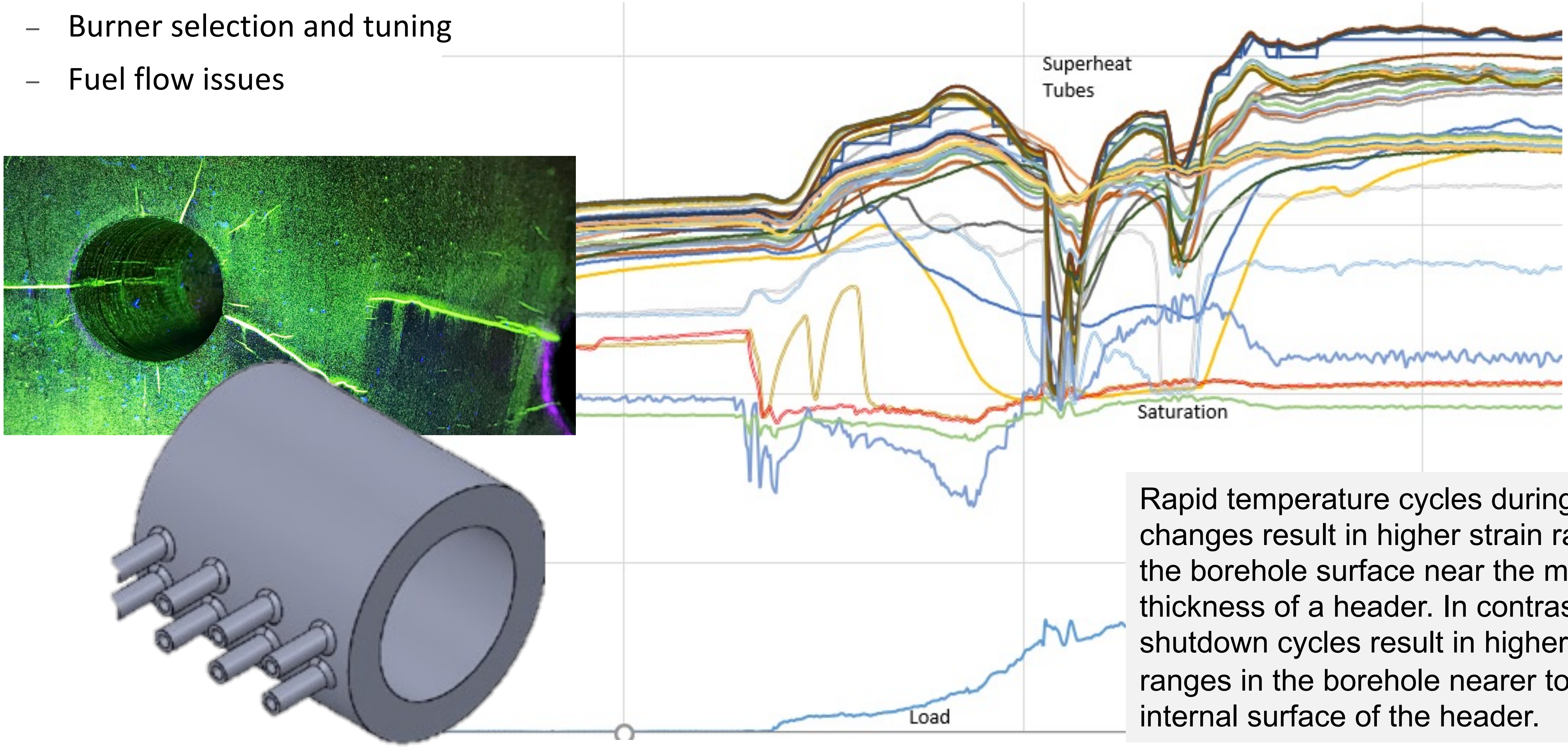
Water Chemistry Excursions

Load Cycling Impact on FAC

Heat Rate Influence on Firing Rate

Damage from Flexible Operations

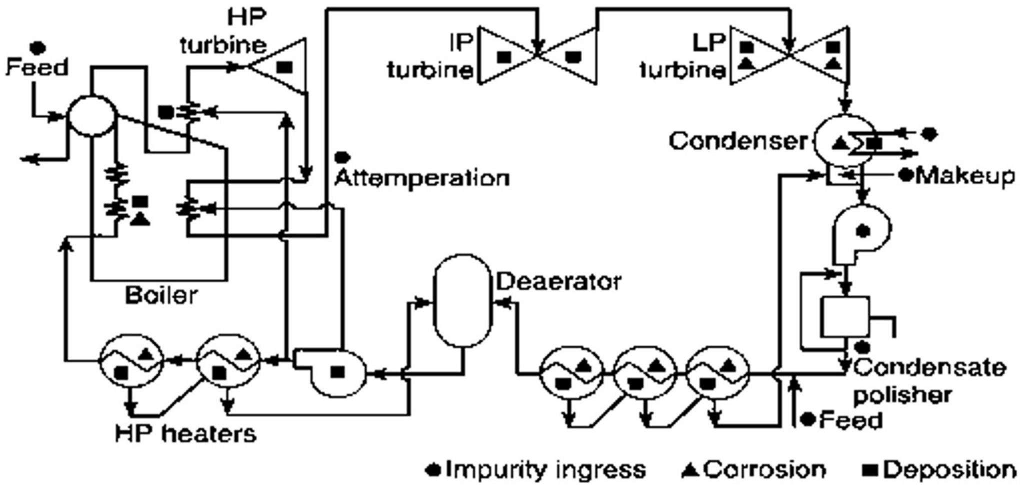
- **Temperature imbalance on startup due to**
  - Water migration
  - Burner selection and tuning
  - Fuel flow issues



Rapid temperature cycles during load changes result in higher strain ranges at the borehole surface near the mid-wall thickness of a header. In contrast, startup-shutdown cycles result in higher strain ranges in the borehole nearer to the internal surface of the header.

Cycle Chemistry Considerations

Sampling and On-line Analyzer Systems	Timely and accurate analysis during startup is key to successful control
Condensers and feedwater heater tubes	FAC, corrosion, deposition, and stress corrosion cracking
Feedwater piping	Corrosion / FAC
Feedwater heater shells and drains	Corrosion / FAC
Boiler Tubes	Corrosion fatigue, under-deposit corrosion, FAC (econ inlet), pitting
Economizers	pH control, two-phase FAC



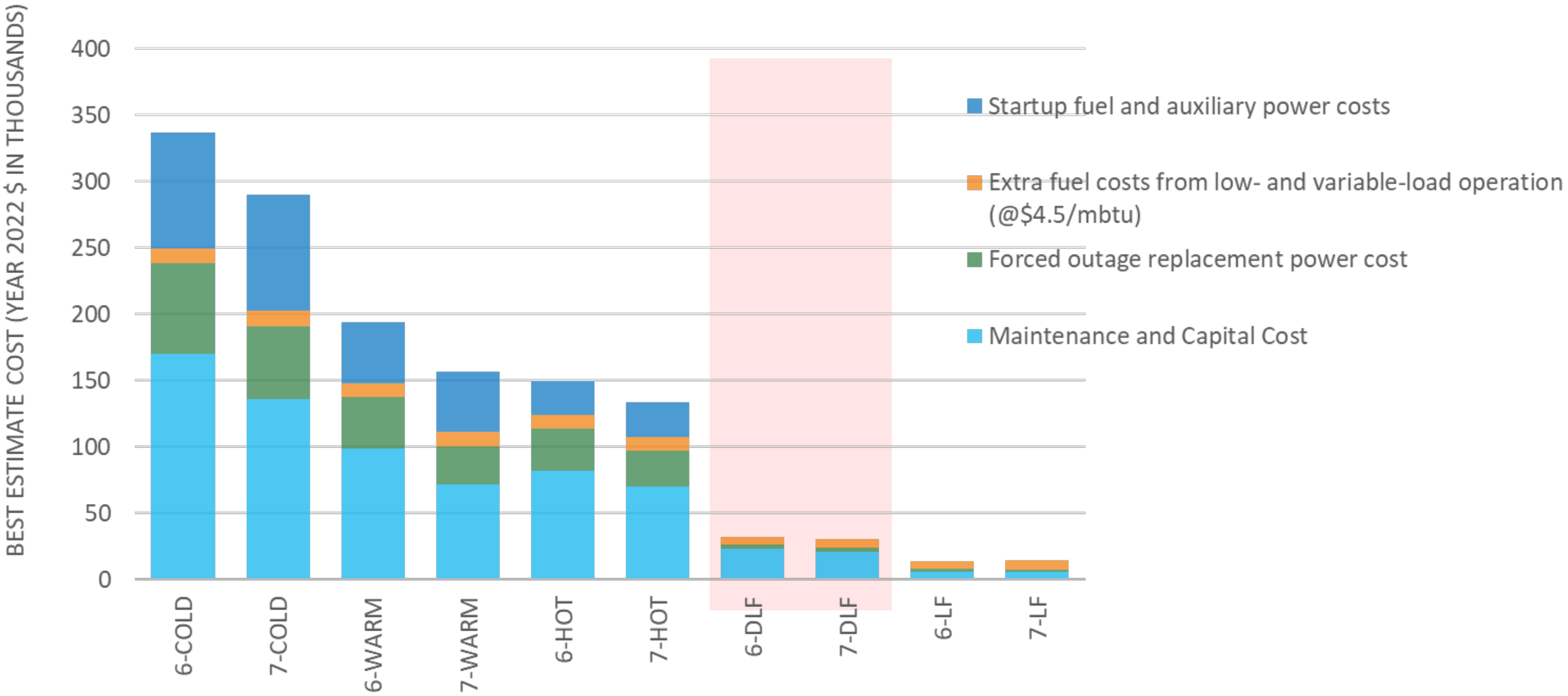
Lay-up

- Preservation & Proper Storage vs. Availability
- Sudden Need for Flexible Operation - Time Required to Implement Necessary Layup Practices
- Return to service requirements
- Make –up water

Startup / Shutdown

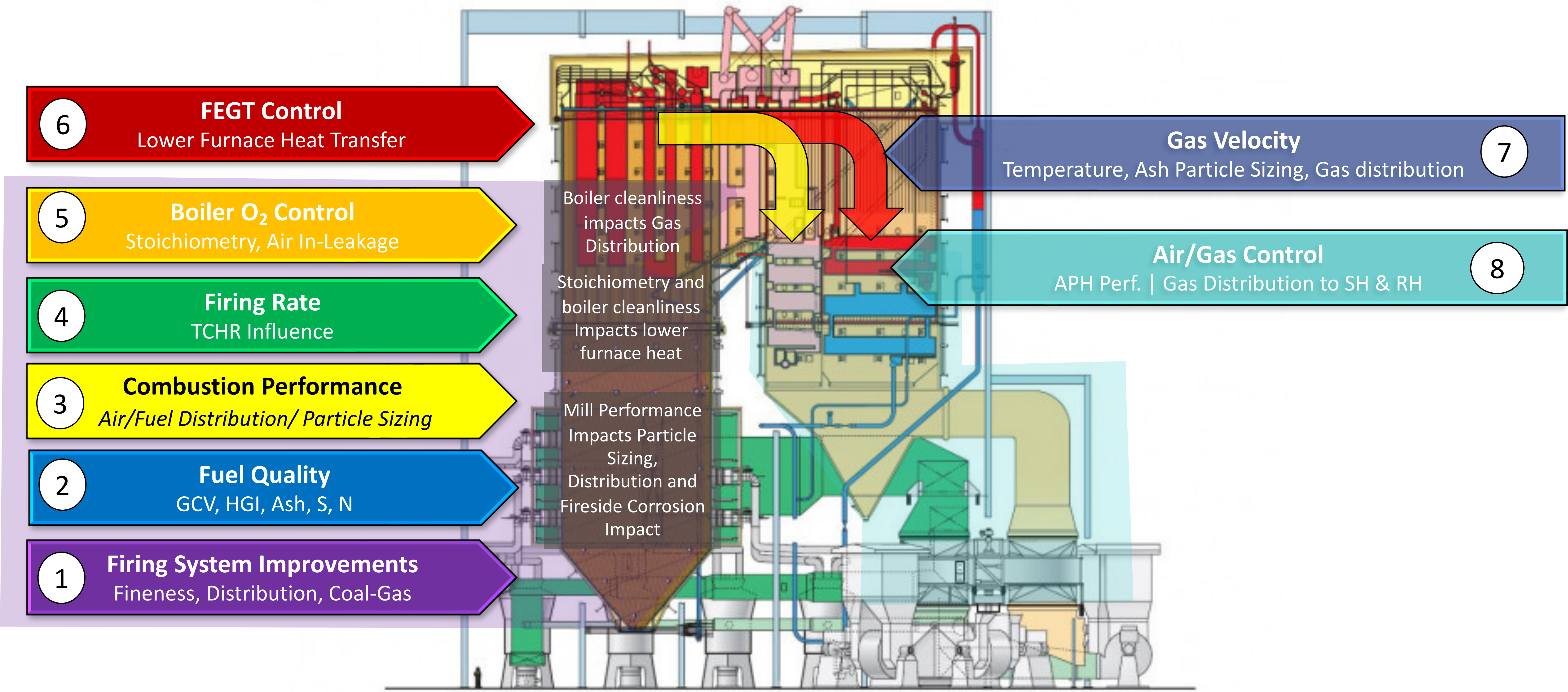
- Oxygen Concentration
- pH Control
- Startup Holds
- Increased Corrosion Product Transport and Subsequent Deposition in Boilers/Evaporators
- Increased Risk of Under Deposit Corrosion

Flexible Operations Cost Impact



Cost from 1 load follow is small, but numerous such cycles may contribute towards overall impact.

Performance and Reliability Impacts



6 **FEGT Control**
Lower Furnace Heat Transfer

5 **Boiler O_2 Control**
Stoichiometry, Air In-Leakage

4 **Firing Rate**
TCHR Influence

3 **Combustion Performance**
Air/Fuel Distribution/ Particle Sizing

2 **Fuel Quality**
GCV, HGI, Ash, S, N

1 **Firing System Improvements**
Fineness, Distribution, Coal-Gas

Boiler cleanliness impacts Gas Distribution

Stoichiometry and boiler cleanliness Impacts lower furnace heat

Mill Performance Impacts Particle Sizing, Distribution and Fireside Corrosion Impact

Gas Velocity 7
Temperature, Ash Particle Sizing, Gas distribution

Air/Gas Control 8
APH Perf. | Gas Distribution to SH & RH

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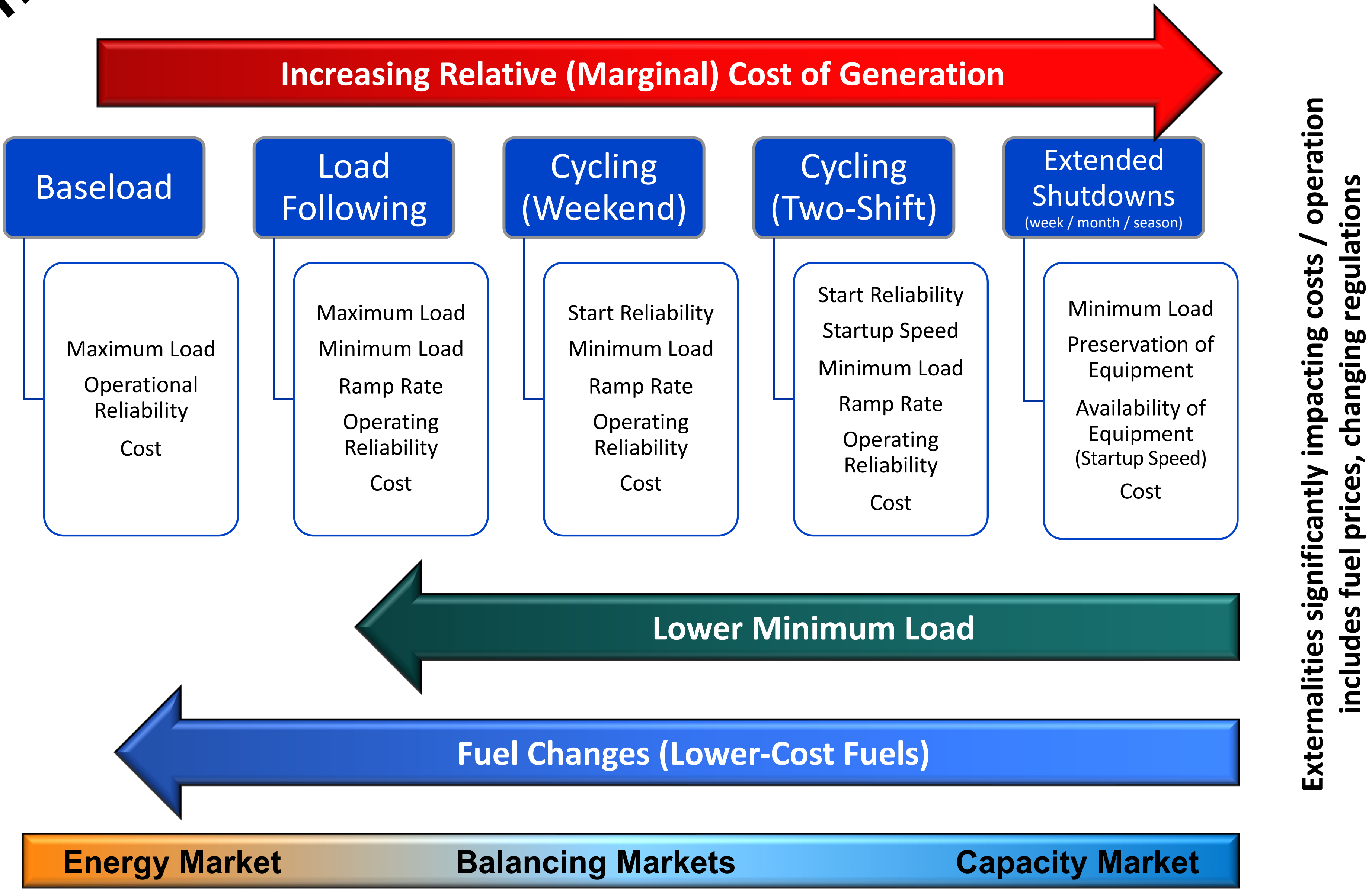
Spectrum of Flexible Operation

Operating Mode

Defining Characteristics



Increasing Relative (Marginal) Cost of Generation

Baseload	Load Following	Cycling (Weekend)	Cycling (Two-Shift)	Extended Shutdowns (week / month / season)
Maximum Load Operational Reliability Cost	Maximum Load Minimum Load Ramp Rate Operating Reliability Cost	Start Reliability Minimum Load Ramp Rate Operating Reliability Cost	Start Reliability Startup Speed Minimum Load Ramp Rate Operating Reliability Cost	Minimum Load Preservation of Equipment Availability of Equipment (Startup Speed) Cost

Lower Minimum Load

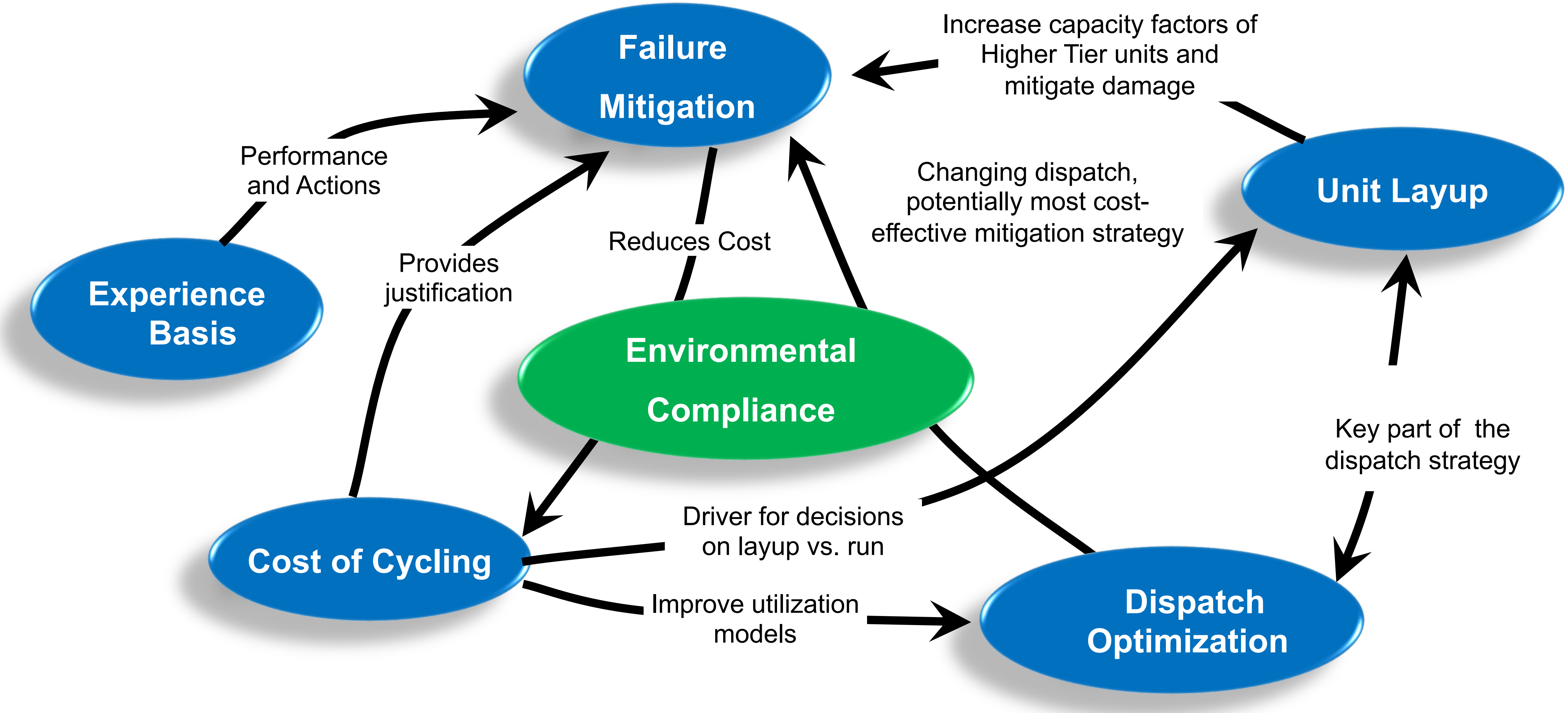
Fuel Changes (Lower-Cost Fuels)

Energy Market **Balancing Markets** **Capacity Market**

Externalities significantly impacting costs / operation includes fuel prices, changing regulation

Economic Viability

Fleet Generation Optimization



Failure Mitigation

Experience Basis

Environmental Compliance

Unit Layup

Cost of Cycling

Dispatch Optimization

Performance and Actions

Provides justification

Reduces Cost

Increase capacity factors of Higher Tier units and mitigate damage

Changing dispatch, potentially most cost-effective mitigation strategy

Key part of the dispatch strategy

Driver for decisions on layup vs. run

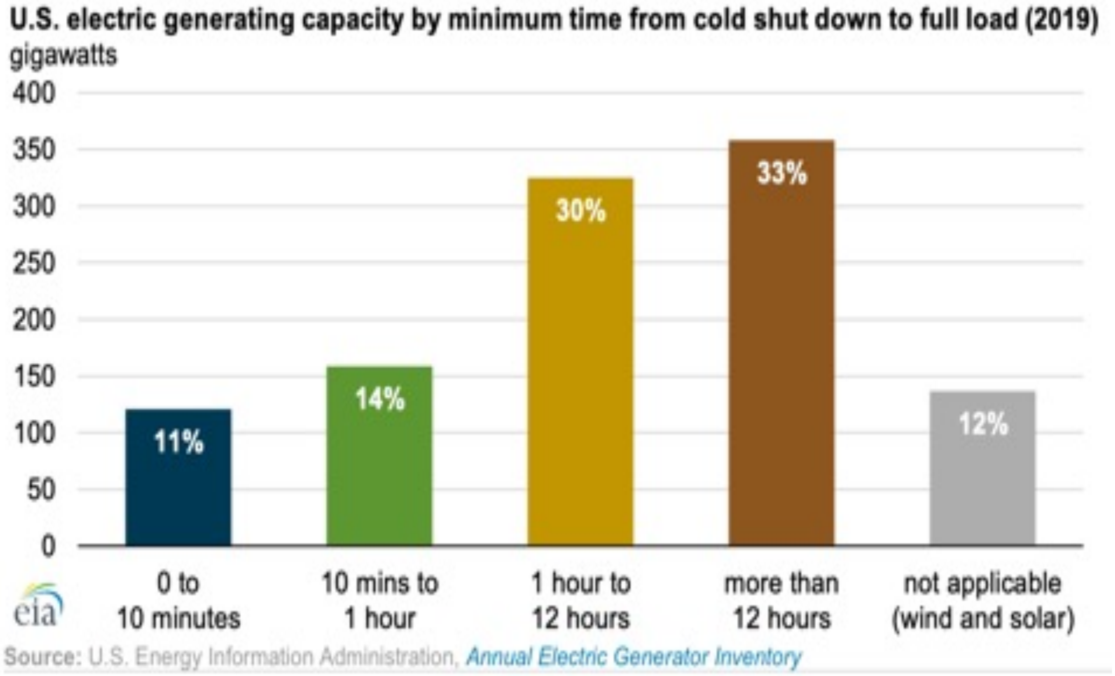
Improve utilization models

Benchmarking Generating Asset Capabilities

	On/Off	Ramp Rate	Minimum Load
Coal (Subcritical)	Possible 2-5h lead time (Not typically done)	0.6-4%/minute (avg. 1%)	20-55% (avg. 38%)
Coal (Supercritical) Constant Pressure	Not done	0.6-4%/minute (avg. 1%)	40-70% (avg. 52%)
Coal (Supercritical) Sliding Pressure	Possible 2-5h lead time (Not typically done)	1-8%/minute	20-40%
Combined Cycle	**Possible 1-4h lead time**	**0.8-15%/minute (avg. 3%)**	10-70% (1x1 ~65%, 2x1 ~55%, 3x1 ~45%)
Simple Cycle	**Possible 0.1-1h lead time**	**7-30%/minute (avg. 14%)**	35-60%
Hydroelectric	**Possible,<0.1h lead time**	**15-25%/minute**	5-6%
Reciprocating Engines	**Routinely done 0.1h lead time**	**25%/minute**	Modular

Asset Mix

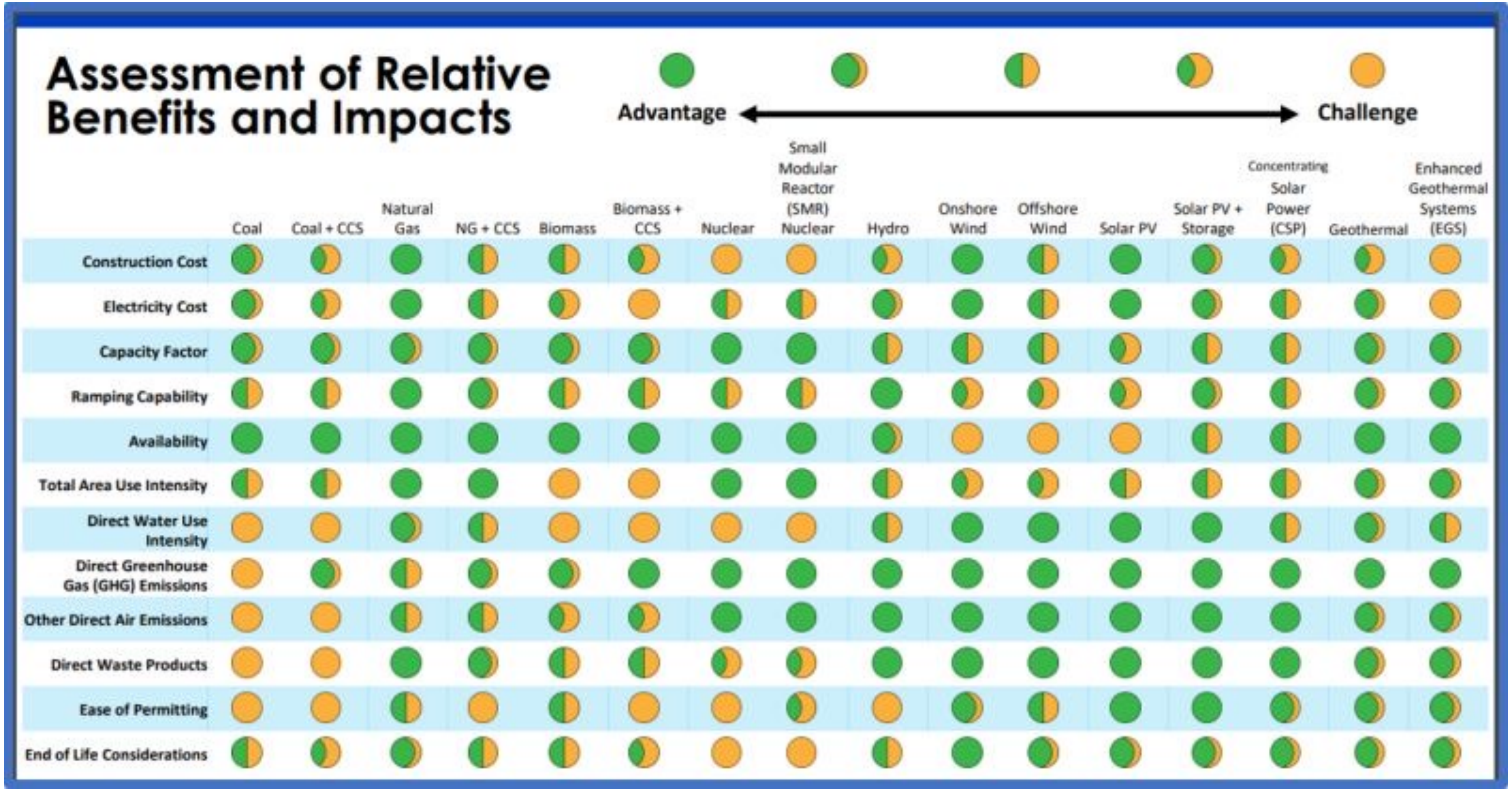
Flexibility Demand



U.S. electric generating capacity by minimum time from cold shut down to full load (2019)

Source: U.S. Energy Information Administration, *Annual Electric Generator Inventory*

Energy Supply Reference Card



Assessment of Relative Benefits and Impacts

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Advantage ←→ Challenge

	Coal	Coal + CCS	Natural Gas	NG + CCS	Biomass	Biomass + CCS	Nuclear	Small Modular Reactor (SMR) Nuclear	Hydro	Onshore Wind	Offshore Wind	Solar PV	Solar PV + Storage	Concentrating Solar Power (CSP)	Geothermal	Enhanced Geothermal Systems (EGS)
Construction Cost	◕	◔	🟢	◑	◑	◔	🟠	🟠	◔	🟢	◑	🟢	◕	◔	◔	🟠
Electricity Cost	◕	◔	🟢	◑	◔	🟠	◑	◑	◕	🟢	◑	🟢	◕	◑	◕	🟠
Capacity Factor	◕	◕	◕	◕	◕	◕	🟢	🟢	◑	◑	◑	◔	◑	◑	◕	◕
Ramping Capability	◑	◑	🟢	◕	◑	◑	◑	◑	🟢	◔	◔	◔	◕	◑	◕	◕
Availability	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	◕	🟠	🟠	🟠	◑	◑	🟢	🟢
Total Area Use Intensity	◑	◑	🟢	🟢	🟠	🟠	🟢	🟢	◑	◔	◔	◑	◑	◑	◕	◕
Direct Water Use Intensity	🟠	🟠	◕	◑	🟠	🟠	🟠	🟠	◑	🟢	🟢	🟢	🟢	◑	◕	◑
Direct Greenhouse Gas (GHG) Emissions	🟠	◕	◑	◕	◕	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Other Direct Air Emissions	🟠	🟠	◑	◑	◔	◔	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	◕	◕
Direct Waste Products	🟠	🟠	🟢	◕	◑	◑	◔	◔	🟢	🟢	🟢	🟢	🟢	🟢	◕	◕
Ease of Permitting	🟠	🟠	◑	🟠	◑	🟠	🟠	◔	🟠	◕	◑	🟢	🟢	◕	◕	◕
End of Life Considerations	◑	◔	◕	◑	◑	◔	🟠	🟠	◑	🟢	◕	◕	◕	◕	◕	◕

[Source: https://lnkd.in/gxjuJpmg](https://lnkd.in/gxjuJpmg)

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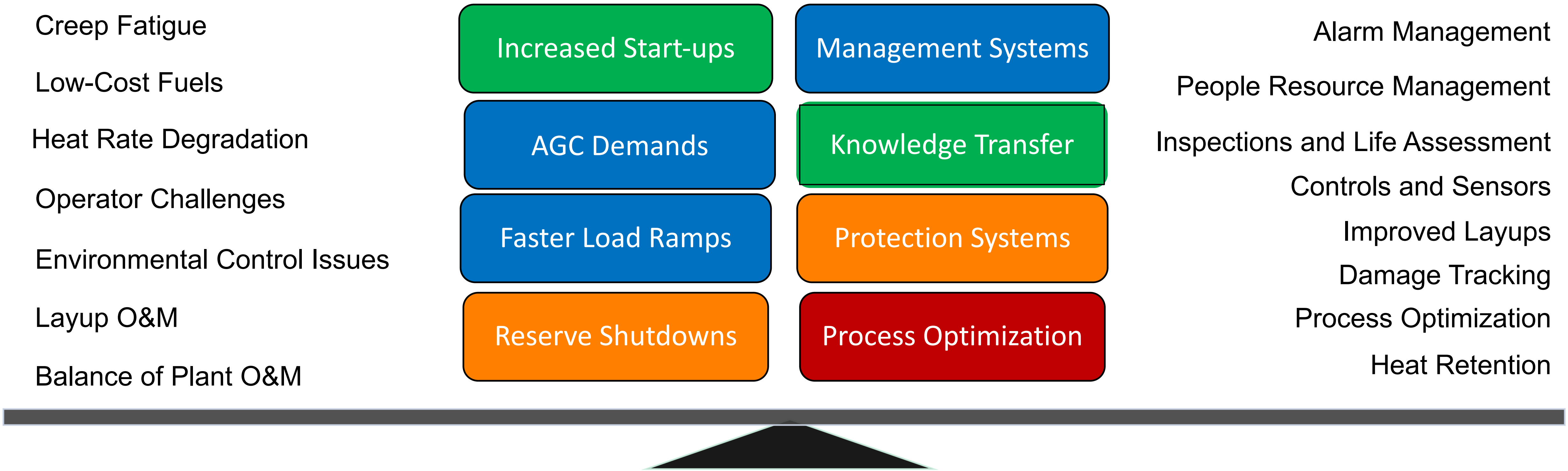
Balancing Market Implications with O&M Best Practices



Thermal Fatigue
Layup Corrosion
Corrosion Fatigue
Creep Fatigue
Low-Cost Fuels
Heat Rate Degradation
Operator Challenges
Environmental Control Issues
Layup O&M
Balance of Plant O&M

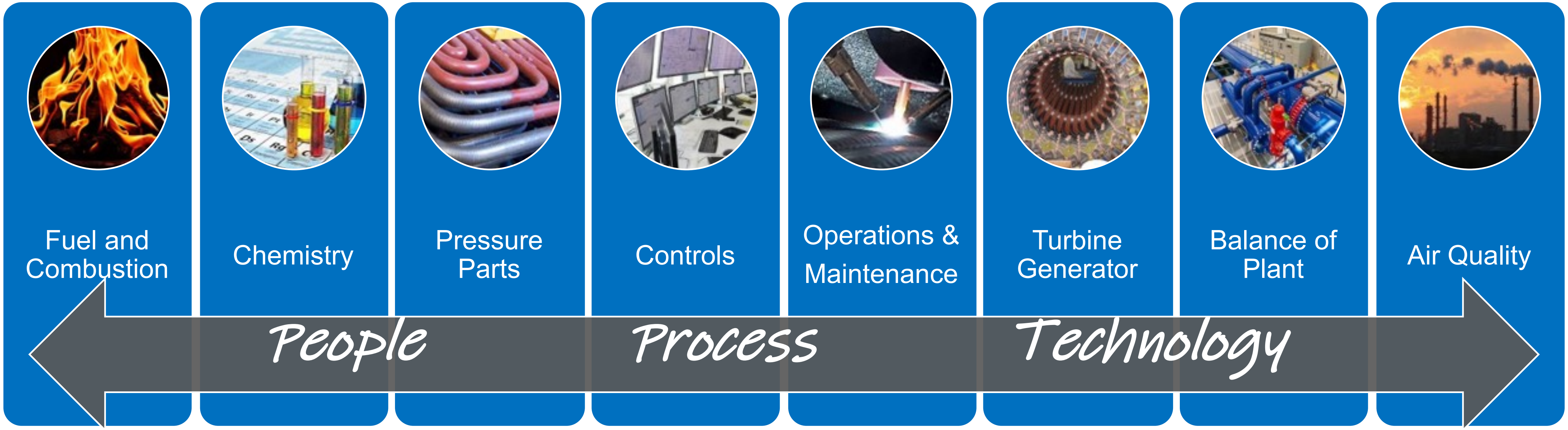
Increased Start-ups
AGC Demands
Faster Load Ramps
Reserve Shutdowns

Management Systems
Knowledge Transfer
Protection Systems
Process Optimization

Training and Awareness
Fuels Flexibility Strategy
Diagnostic and Digital Strategy
Alarm Management
People Resource Management
Inspections and Life Assessment
Controls and Sensors
Improved Layups
Damage Tracking
Process Optimization
Heat Retention

Aligning People, Process and Technology

The reliability and flexibility of dispatchable thermal generation stations is interrelated with performance of various subsets of equipment, operational and maintenance actions. Those actions are driven by people, process and the application of technologies that assist with a complex interplay which is required to ensure performance sustainability and market availability.



Fuel and Combustion

Chemistry

Pressure Parts

Controls

Operations & Maintenance

Turbine Generator

Balance of Plant

Air Quality

People *Process* *Technology*

Operational Procedure
Training, Monitoring
Inspections, Programs

Water Chemistry (core instrumentation, alarms)
Condensate Polishing, Corrosion Mitigation
Protection Systems, Lay-up Program, Asset
Integrity and Predictive Maintenance

Sensors
Diagnostics
Automation
Dynamic Optimization

Program Management

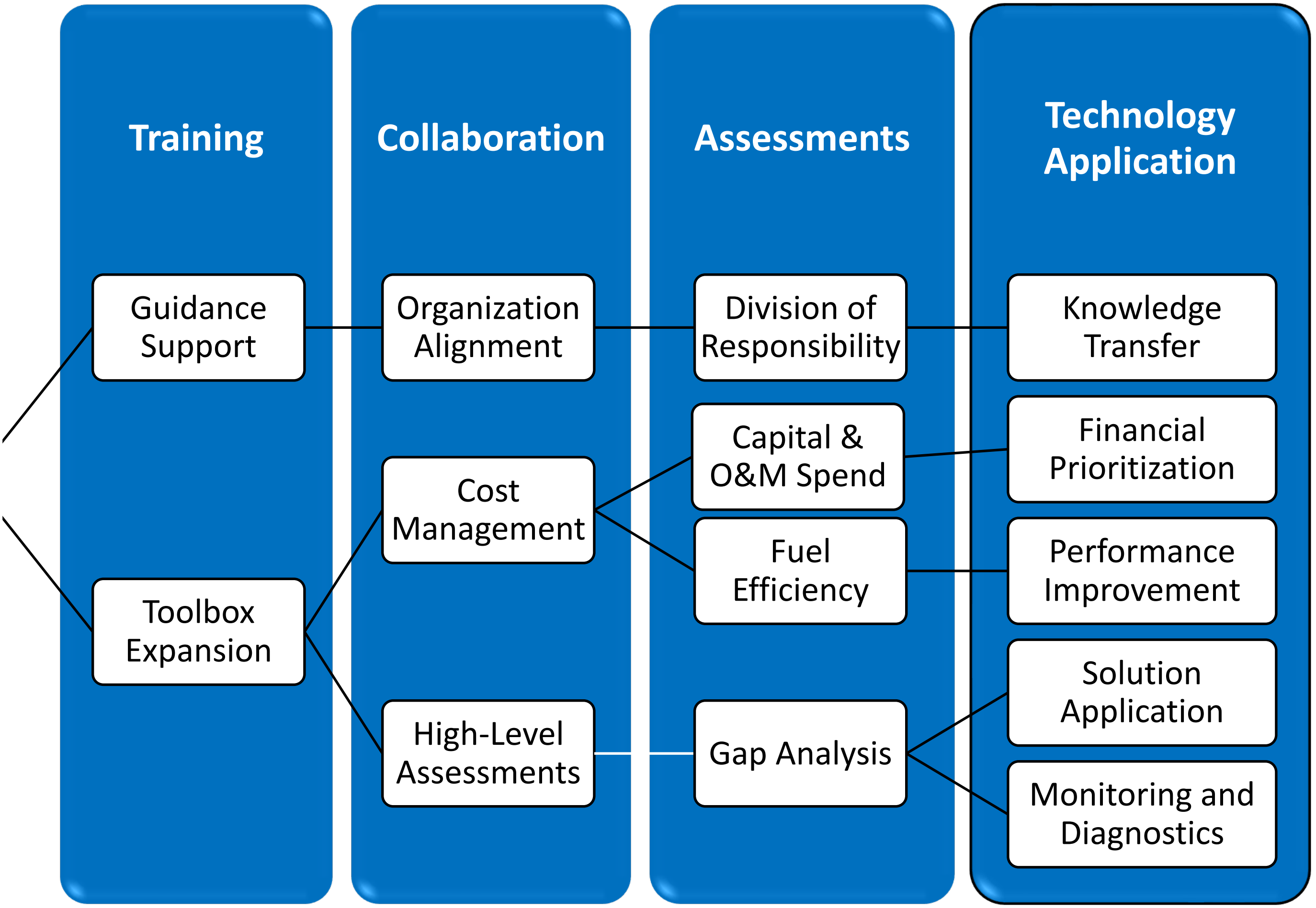
TRAINING & AWARENESS

O&M BEST PRACTICES

Fleet Optimization

SYSTEMATIC PROGRAM MANAGEMENT

DEFENSE STRATEGIES



Training
- Guidance Support
- Toolbox Expansion

Collaboration
- Organization Alignment
- Cost Management
- High-Level Assessments

Assessments
- Division of Responsibility
- Capital & O&M Spend
- Fuel Efficiency
- Gap Analysis

Technology Application
- Knowledge Transfer
- Financial Prioritization
- Performance Improvement
- Solution Application
- Monitoring and Diagnostics

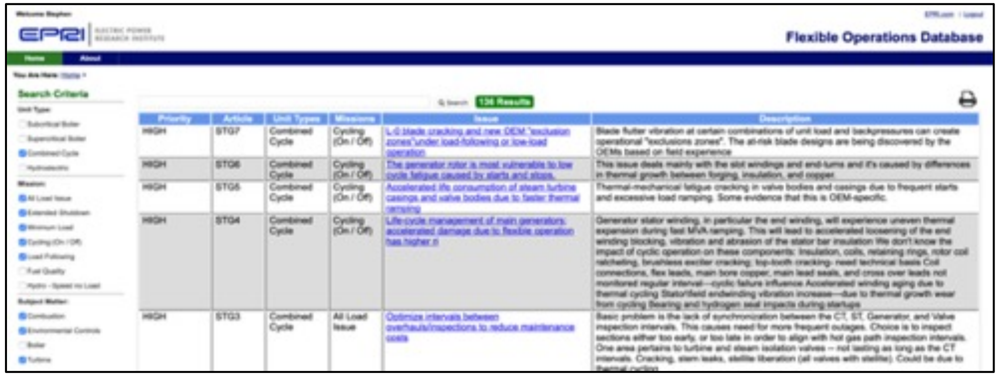
Flexibility Issues and Solutions Database

FLEXOPS.EPRI.COM

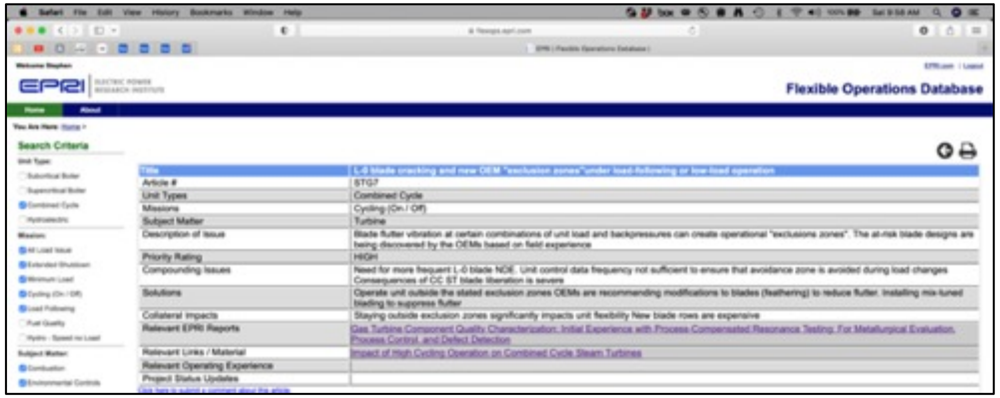
Project Objective and Scope

Tools for Managing Flexible Operation of Power Plants

SPN 3002016820



Priority	Article	Unit Types	Missions	Issue	Description
HIGH	STG7	Combined Cycle	Cycling (On / Off)	L-0 blade cracking and new OEM "exclusion zones"under load-following or low-load operation	Blade flutter vibration at certain combinations of unit load and backpressures can create operational "exclusions zones". The at-risk blade designs are being discovered by the OEMs based on field experience
HIGH	STG6	Combined Cycle	Cycling (On / Off)	The generator rotor is most vulnerable to low cycle fatigue caused by starts and stops.	This issue deals mainly with the slot windings and end-turns and it's caused by differences in thermal growth between forging, insulation, and copper
HIGH	STG5	Combined Cycle	Cycling (On / Off)	Accelerated life consumption of steam turbine casings and valve bodies due to faster thermal ramping	Thermal-mechanical fatigue cracking in valve bodies and casings due to frequent starts and excessive load ramping. Some evidence that this is OEM-specific.
HIGH	STG4	Combined Cycle	Cycling (On / Off)	Life-cycle management of main generators; accelerated damage due to flexible operation has higher n	Generator stator winding, in particular the end winding, will experience uneven thermal expansion during fast MVA ramping. This will lead to accelerated loosening of the end winding blocking, vibration and abrasion of the stator bar insulation We don't know the impact of cyclic operation on these components: Insulation, coils, retaining rings, rotor coil ratcheting, brushless exciter cracking, top-tooth cracking- need technical basis Coil connections, flex leads, main bore copper, main lead seals, and cross over leads not monitored regular interval—cyclic failure influence Accelerated winding aging due to thermal cycling Stator/field endwinding vibration increase—due to thermal growth wear from cycling Bearing and hydrogen seal impacts during startups
HIGH	STG3	Combined Cycle	All Load Issue	Optimize intervals between overhauls/inspections to reduce maintenance costs	Basic problem is the lack of synchronization between the CT, ST, Generator, and Valve inspection intervals. This causes need for more frequent outages. Choice is to inspect sections either too early, or too late in order to align with hot gas path inspection intervals. One area pertains to turbine and steam isolation valves -- not lasting as long as the CT intervals. Cracking, stem leaks, stellite liberation (all valves with stellite). Could be due to thermal cycling



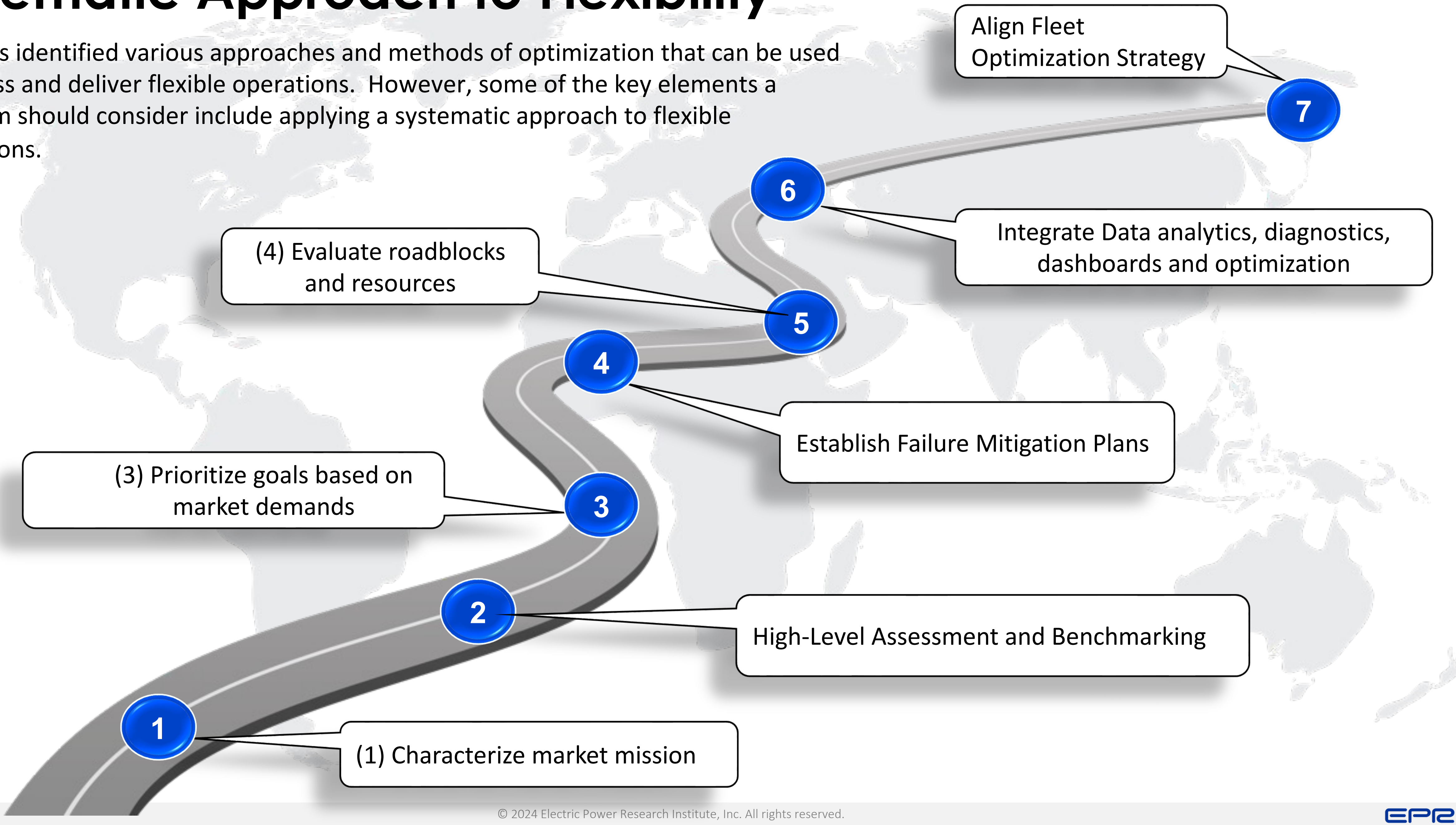
Title	L-0 blade cracking and new OEM "exclusion zones"under load-following or low-load operation
Article #	STG7
Unit Types	Combined Cycle
Missions	Cycling (On / Off)
Subject Matter	Turbine
Description of Issue	Blade flutter vibration at certain combinations of unit load and backpressures can create operational "exclusions zones". The at-risk blade designs are being discovered by the OEMs based on field experience
Priority Rating	HIGH
Compounding Issues	Need for more frequent L-0 blade NDE. Unit control data frequency not sufficient to ensure that avoidance zone is avoided during load changes Consequences of CC ST blade liberation is severe
Solutions	Operate unit outside the stated exclusion zones OEMs are recommending modifications to blades (feathering) to reduce flutter. Installing mis-tuned blading to suppress flutter
Collateral Impacts	Staying outside exclusion zones significantly impacts unit flexibility New blade rows are expensive
Relevant EPRI Reports	Gas Turbine Component Quality Characterization: Initial Experience with Process Compensated Resonance Testing: For Metallurgical Evaluation, Process Control, and Defect Detection
Relevant Links / Material	Impact of High Cycling Operation on Combined Cycle Steam Turbines
Relevant Operating Experience	
Project Status Updates	

Click here to submit a comment about the article

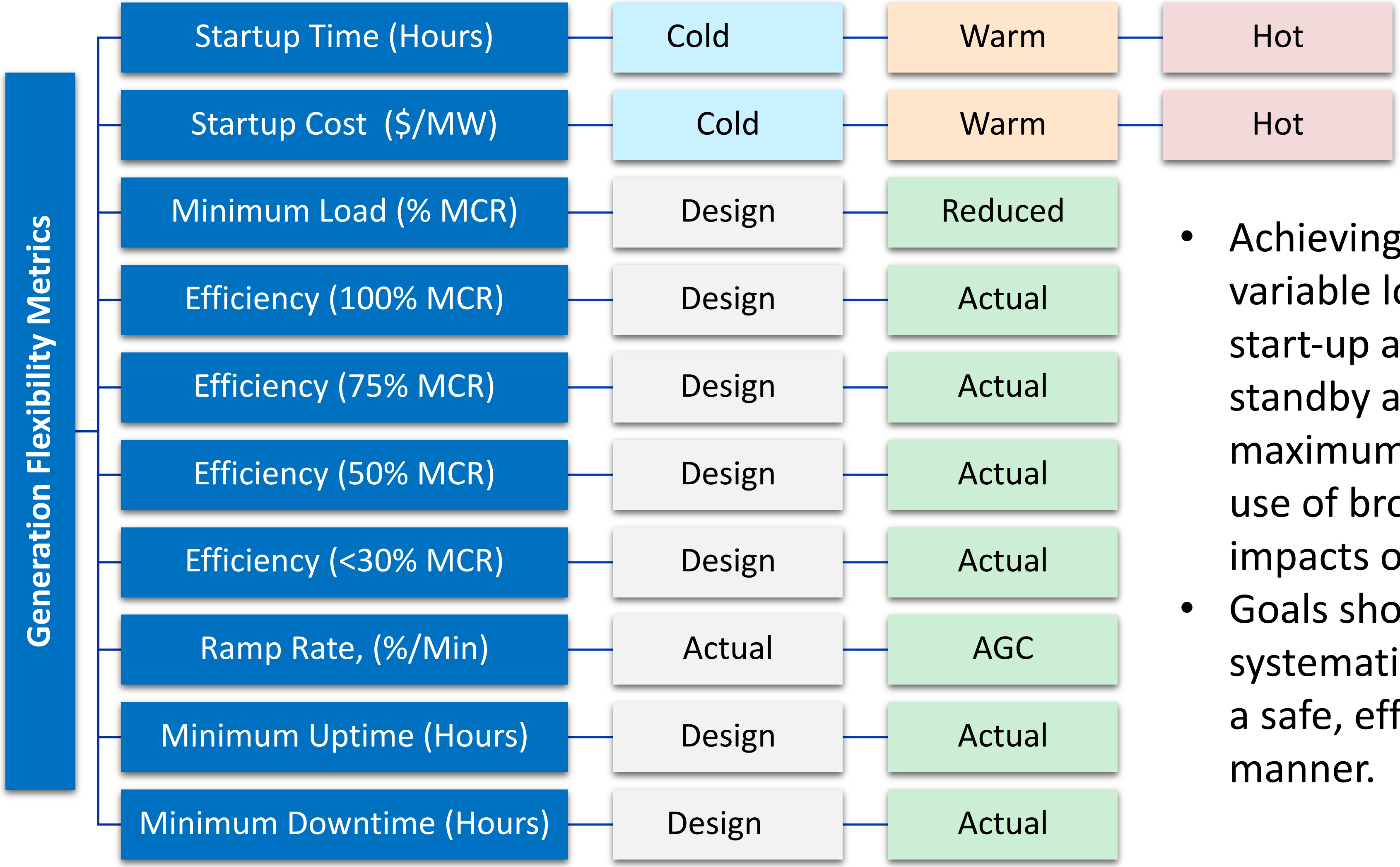
3002016820

Systematic Approach to Flexibility

EPRI has identified various approaches and methods of optimization that can be used to assess and deliver flexible operations. However, some of the key elements a program should consider include applying a systematic approach to flexible operations.



Prioritize Goals Based on Market Demands



Generation Flexibility Metrics

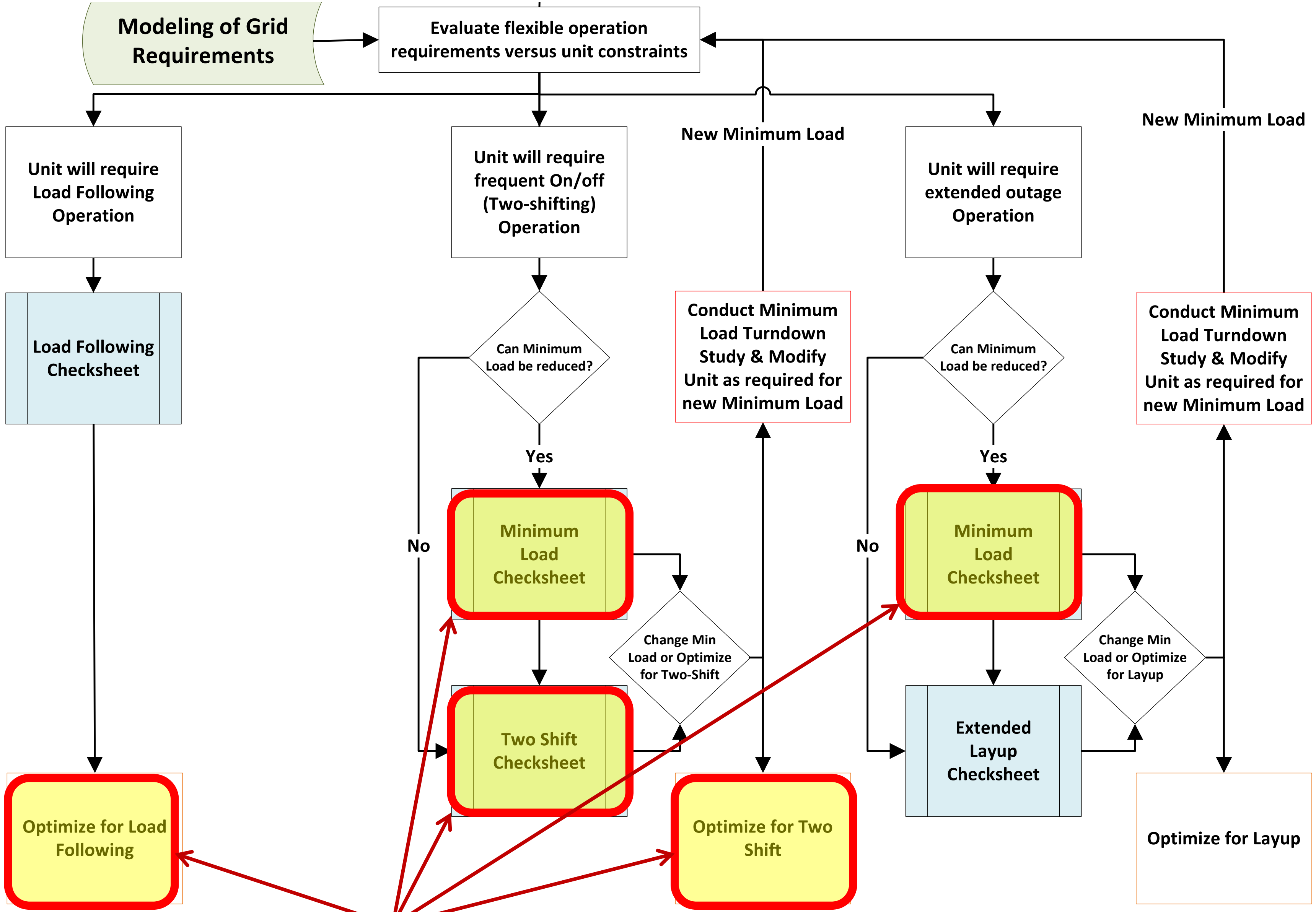
Startup Time (Hours)	Cold	Warm	Hot
Startup Cost ($/MW)	Cold	Warm	Hot
Minimum Load (% MCR)	Design	Reduced	
Efficiency (100% MCR)	Design	Actual	
Efficiency (75% MCR)	Design	Actual	
Efficiency (50% MCR)	Design	Actual	
Efficiency (<30% MCR)	Design	Actual	
Ramp Rate, (%/Min)	Actual	AGC	
Minimum Uptime (Hours)	Design	Actual	
Minimum Downtime (Hours)	Design	Actual	

- Achieving flexible operations such as variable load following, faster ramp rates, start-up and shutdown cycling, longer standby and offload periods, extension of maximum and minimum load limits, or even use of broader fuel mix criteria has complex impacts on the plant.
- Goals should be established using a systematic approach to improve flexibility in a safe, efficient, environmentally friendly manner.

Optimization

Once unit goals are established plant system performance reviews are often required to identify roadblocks, challenges, and solutions. These often require operational trials, system improvements, and then retests to validate unit capability.

Mode of Operation
Load Following
Minimum Load
Two Shifting



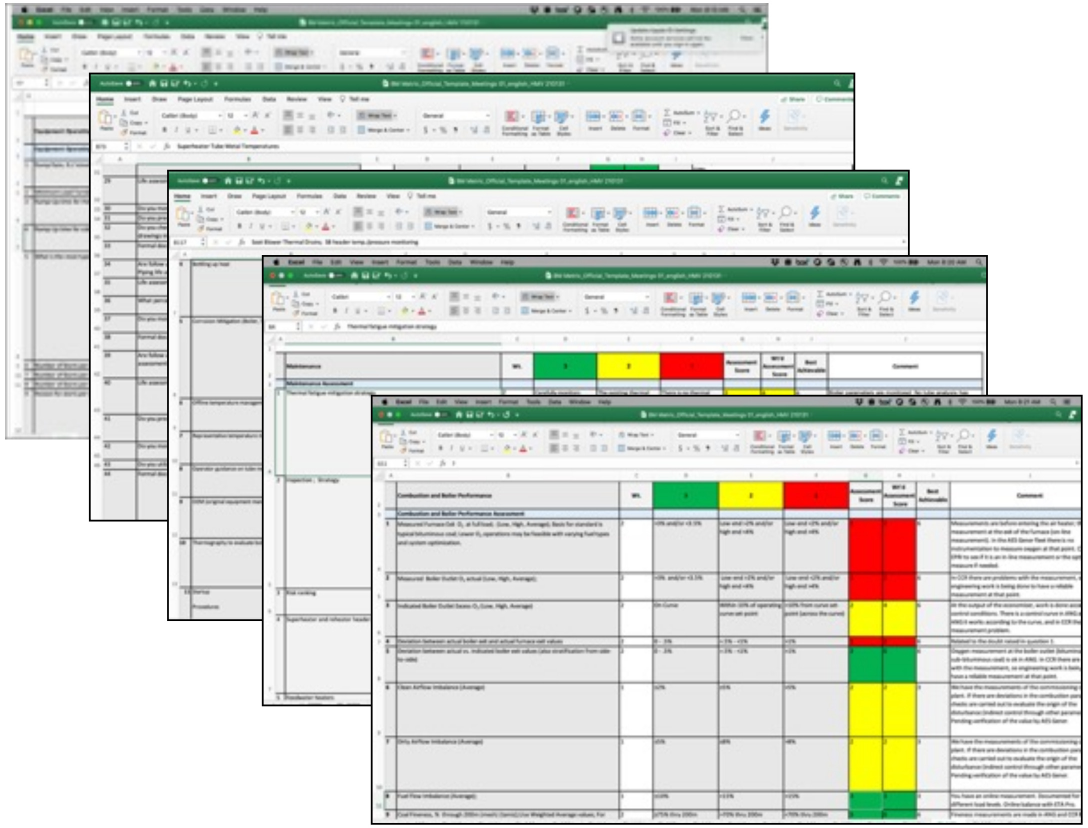
Performance Plays a Key Role in Optimization

Flexibility Assessments

A comprehensive assessment of flexibility should be carried out.

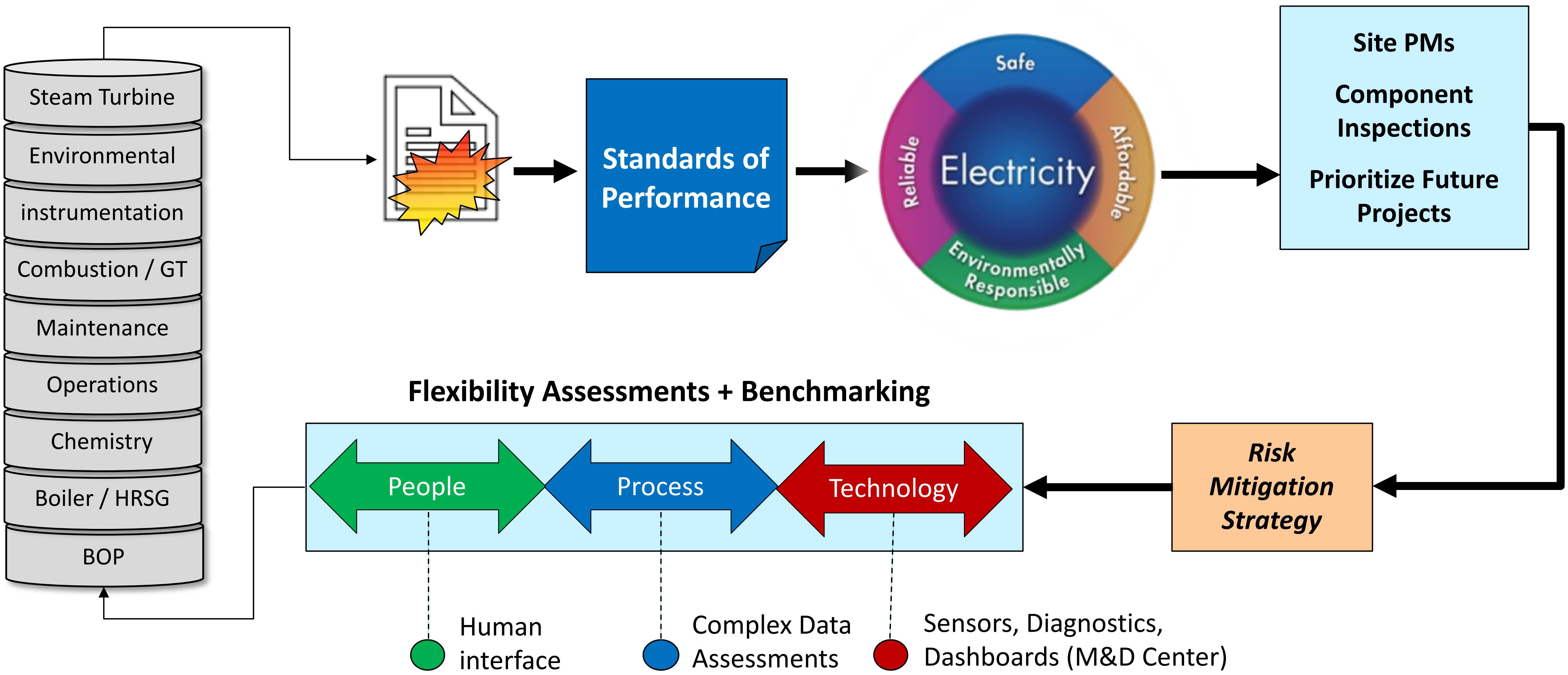
Assessments should cover - major plant systems to identify the gaps and the vulnerable areas for prioritization of the interventions.

The prioritization of interventions should be based on the operating strategies of the plant – reduction in minimum loads with/without fuel quality variability, reduction of start-up time or reduction of online hours (requiring layup).



High-Level Assessment Tools:	
High-Level Flexibility Assessment Tool: Conventional Steam Generators	300201990
High Level Flexibility Assessment Tool: Combined Cycle Units	3002024227

Establish Failure Mitigation Plans



- Steam Turbine
- Environmental
- instrumentation
- Combustion / GT
- Maintenance
- Operations
- Chemistry
- Boiler / HRSG
- BOP

Standards of Performance

Site PMs

Component Inspections

Prioritize Future Projects

Risk Mitigation Strategy

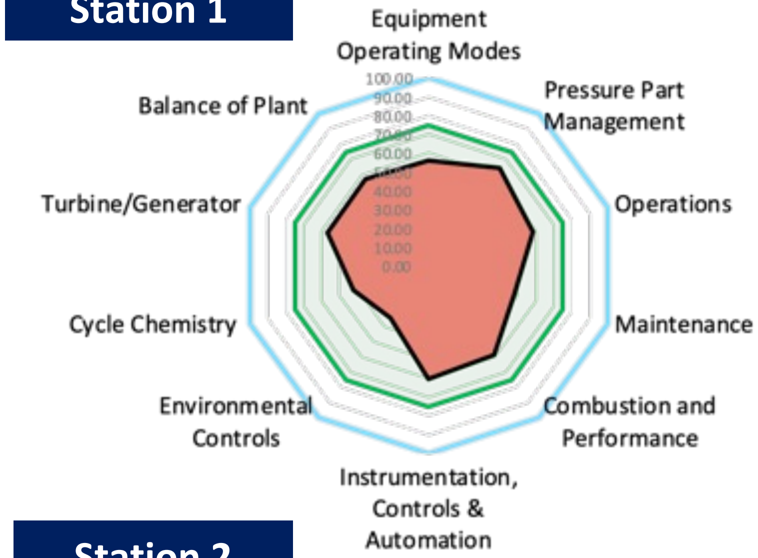
Flexibility Assessments + Benchmarking

People | Process | Technology

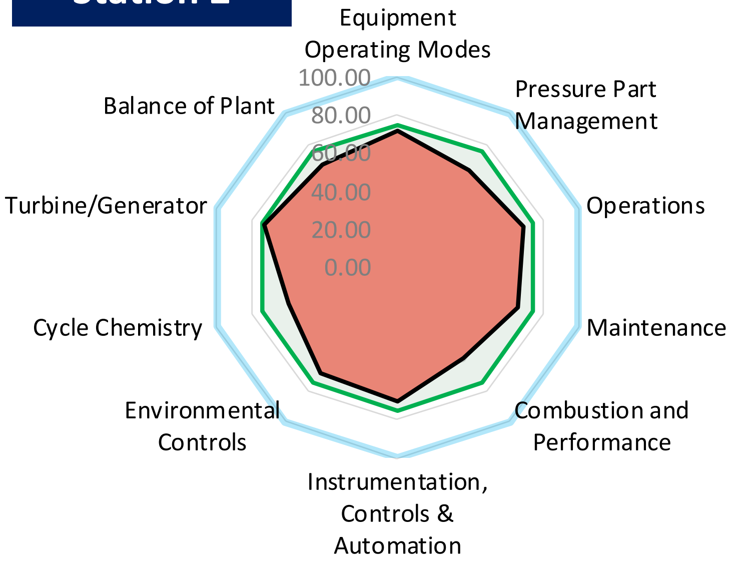
- 🟢 Human interface
- 🔵 Complex Data Assessments
- 🔴 Sensors, Diagnostics, Dashboards (M&D Center)

High-Level Fleet Flexibility Assessments

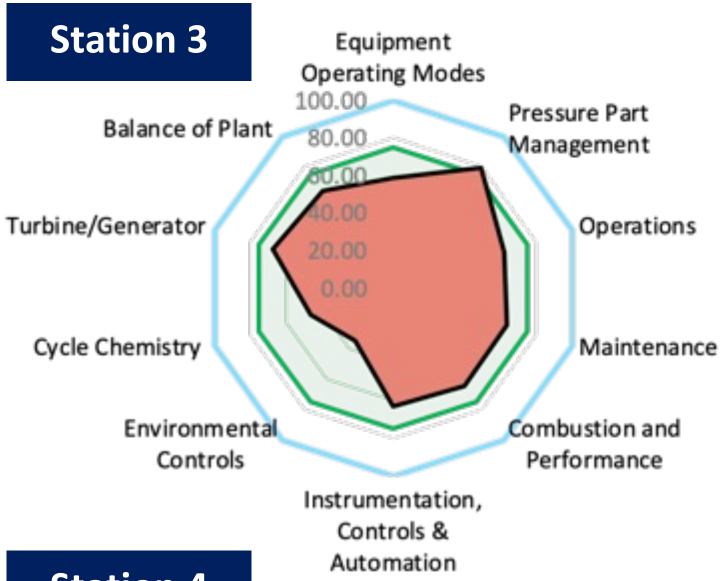
Station 1



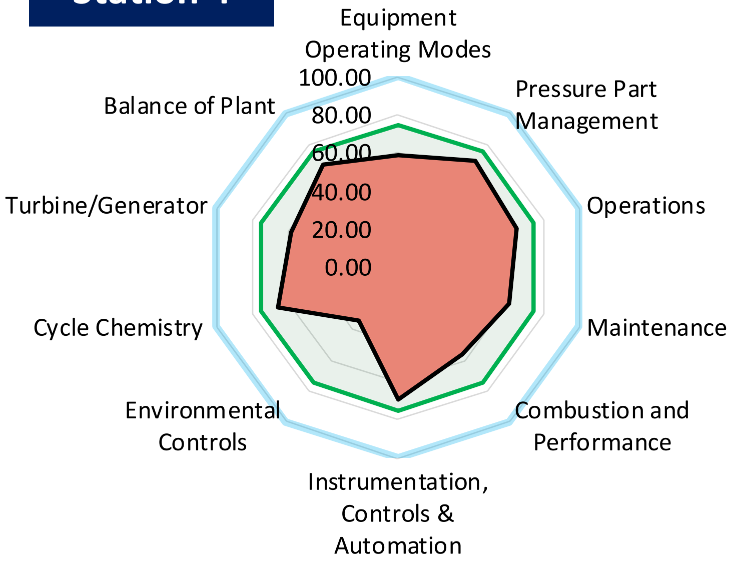
Station 2



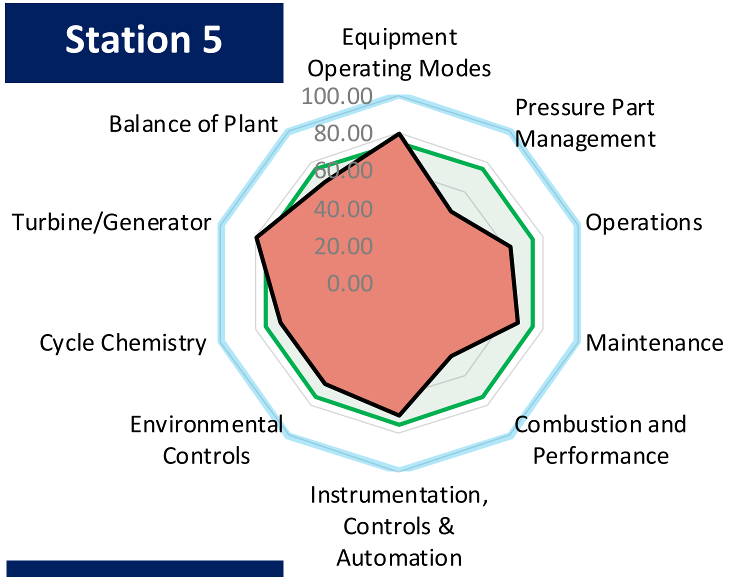
Station 3



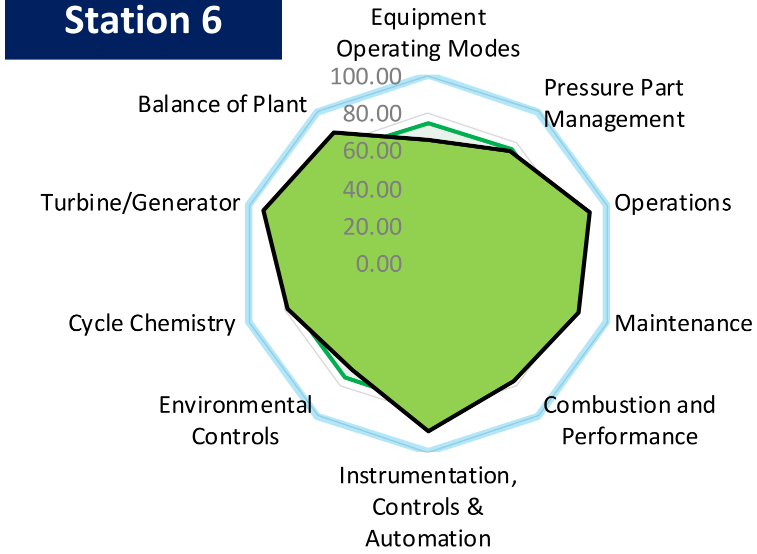
Station 4



Station 5

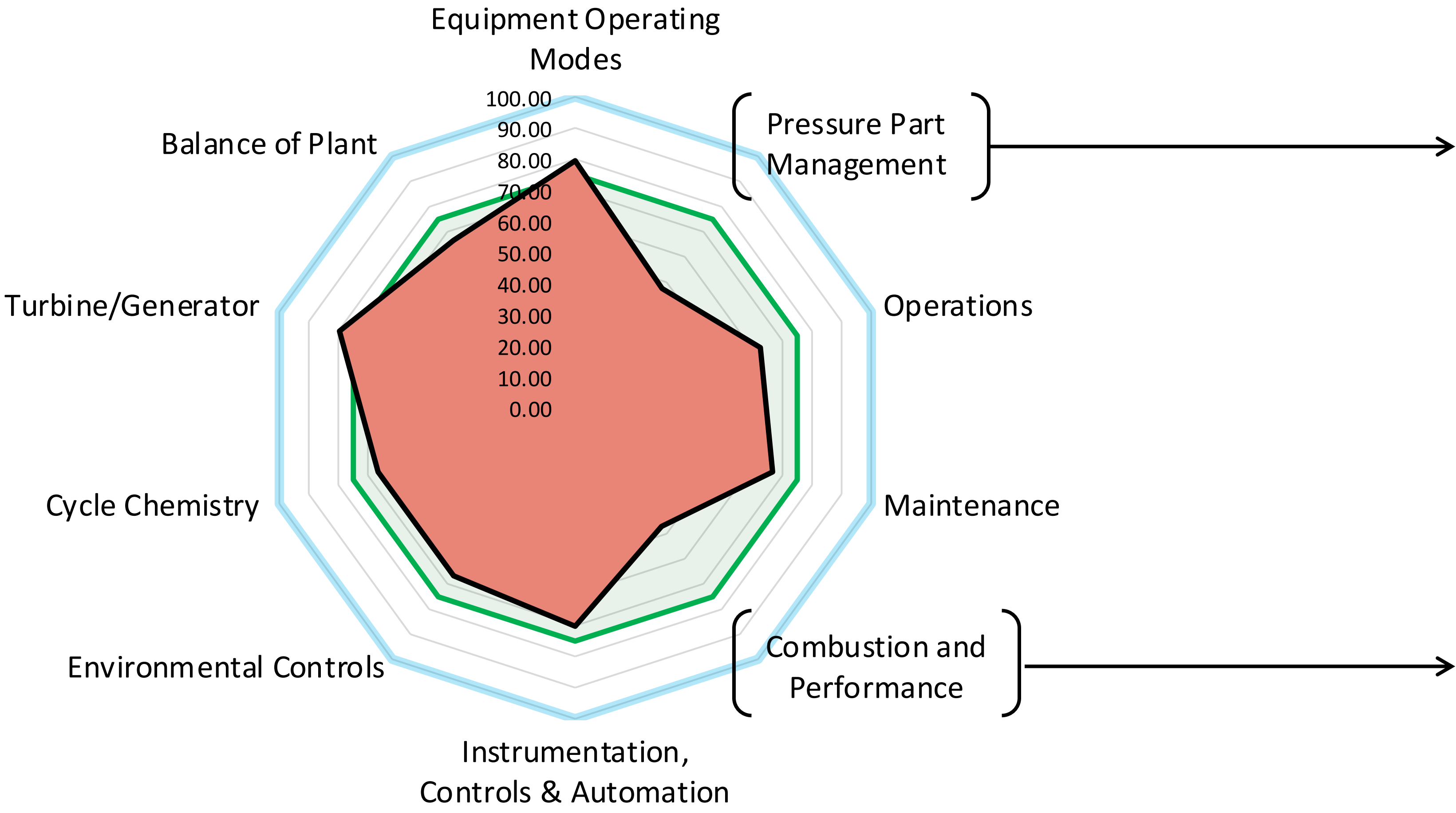


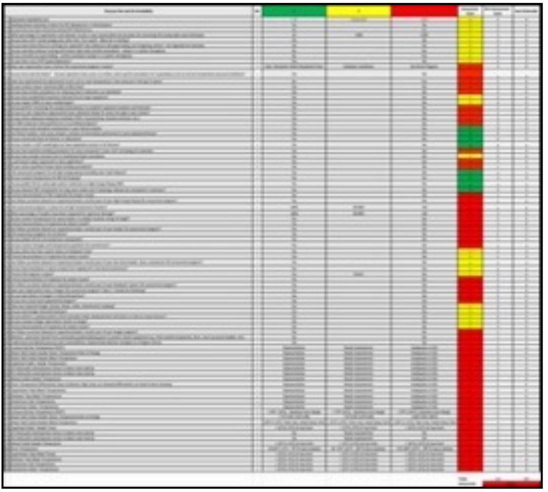
Station 6



High Level Flexibility Assessments

Once the risks and issues are identified, the next step is to prioritize projects and goals:





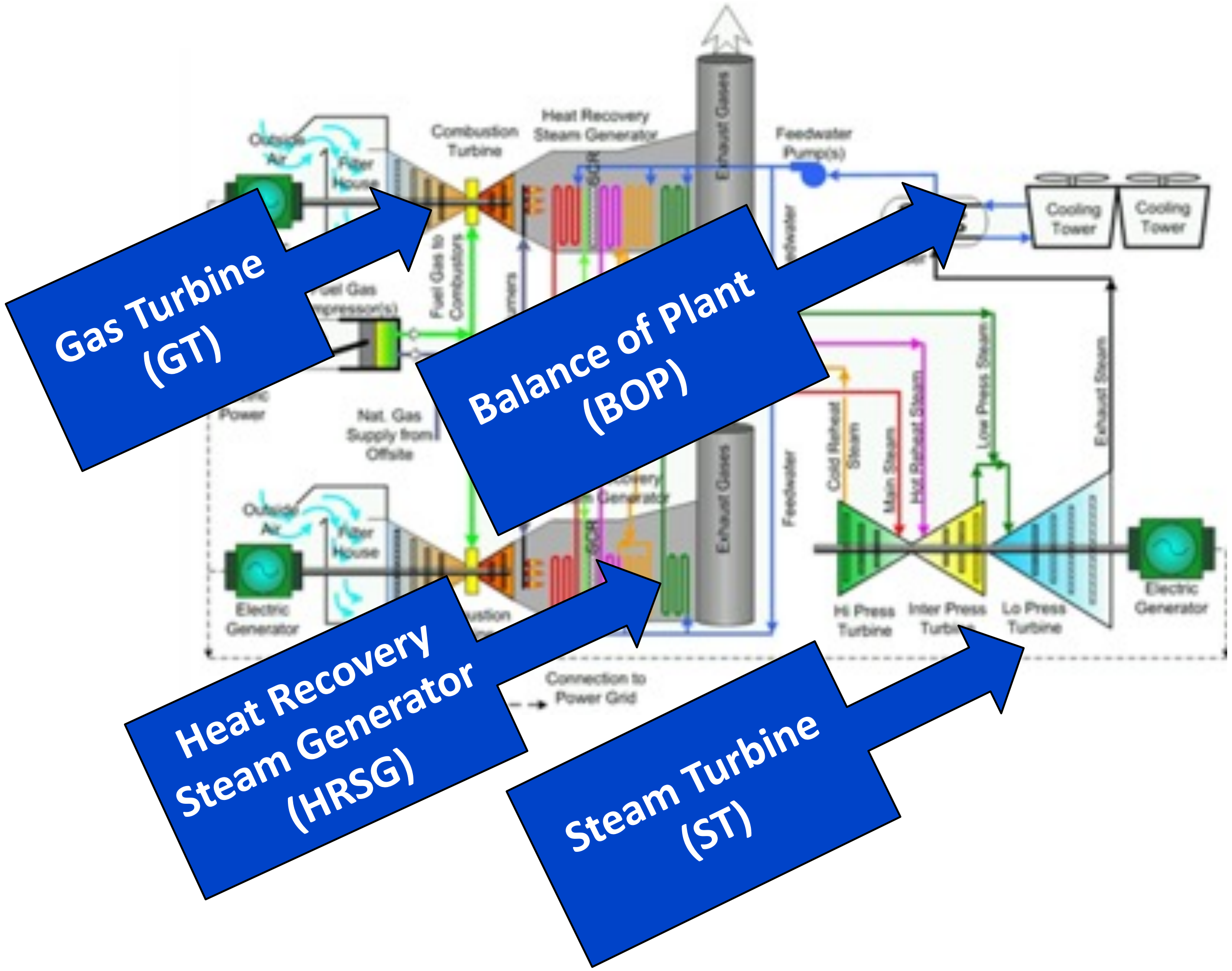
Leverage Assessments, Roadblocks, and Key Issues Needing Resources for Improvement to Achieve Goals

TEMPLATE	ROADBLOCKS	DESCRIPTION	PRIORITY	DEPT.	ACTION PLAN
(6) INSTRUMENTATION, CONTROLS AND AUTOMATION					
(7) ENVIRONMENTAL CONTROLS					
(8) CYCLE CHEMISTRY					
(9) TURBINE -GENERATOR					
(10) BALANCE OF PLANT					

TEMPLATE	ROADBLOCKS	DESCRIPTION	PRIORITY	DEPT.	ACTION PLAN
(1) EQUIPMENT OPERATING MODES					
(2) HRSG PRESSURE PARTS AND LIFE AVAILABILITY					
(3) OPERATIONS					
(4) MAINTENANCE					
(5) GAS TURBINE PERFORMANCE AND O&M					

Applying the Systematic Approach

Aligning Gaps

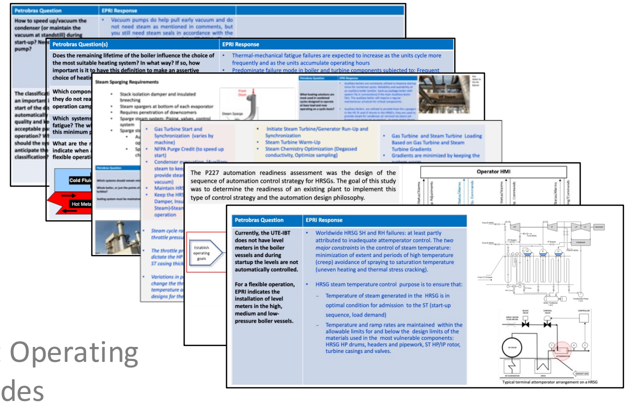


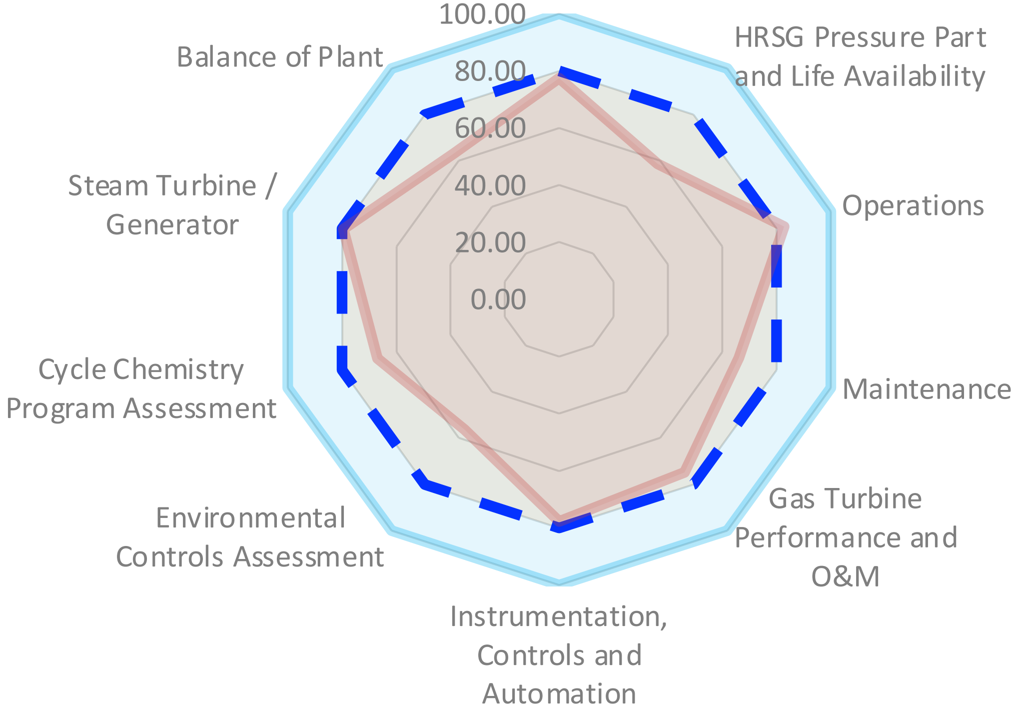
Gas Turbine (GT)

Balance of Plant (BOP)

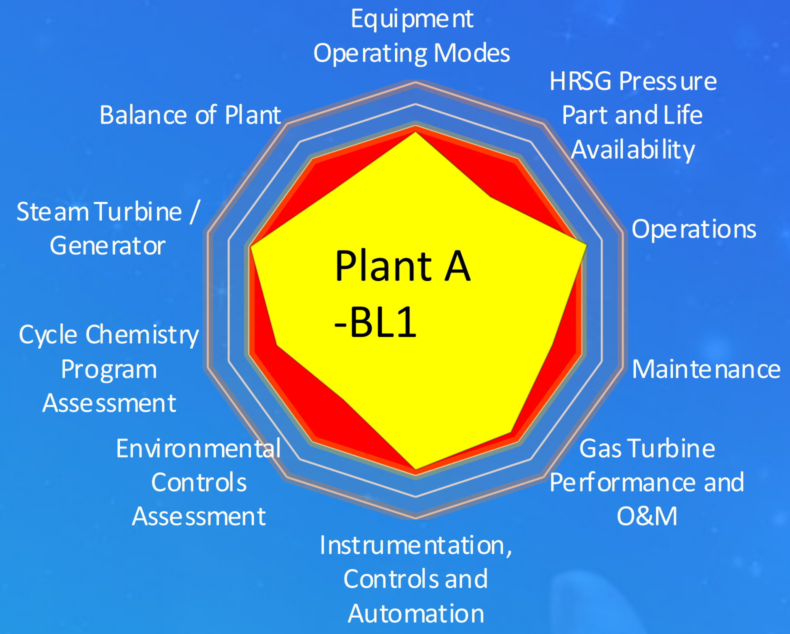
Heat Recovery Steam Generator (HRSG)

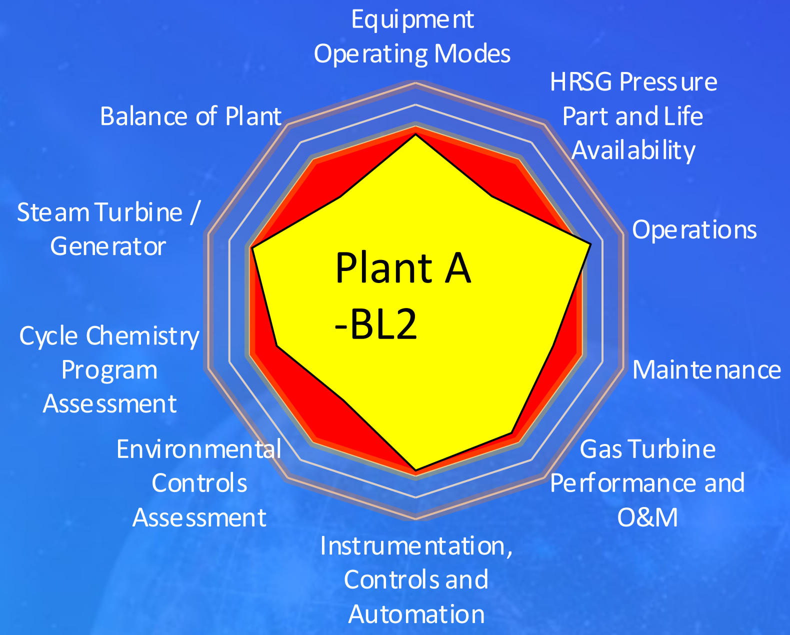
Steam Turbine (ST)

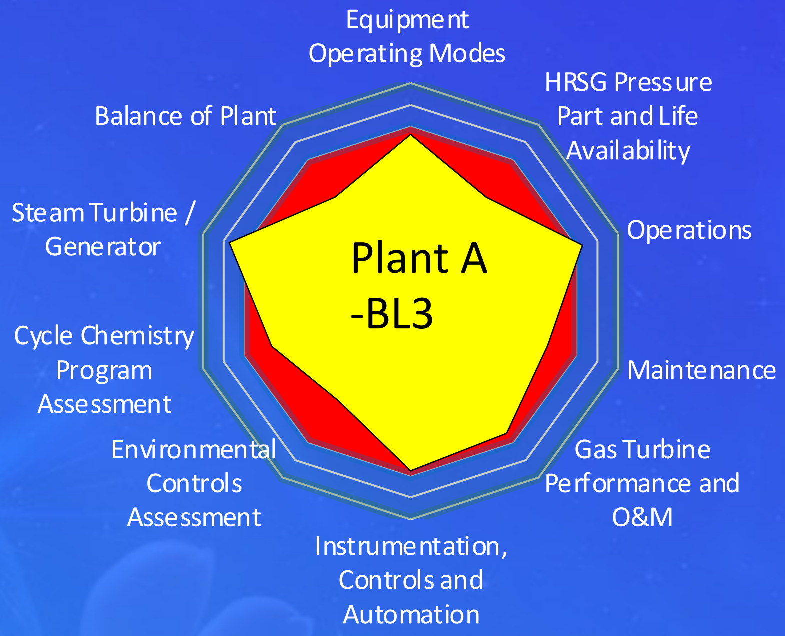




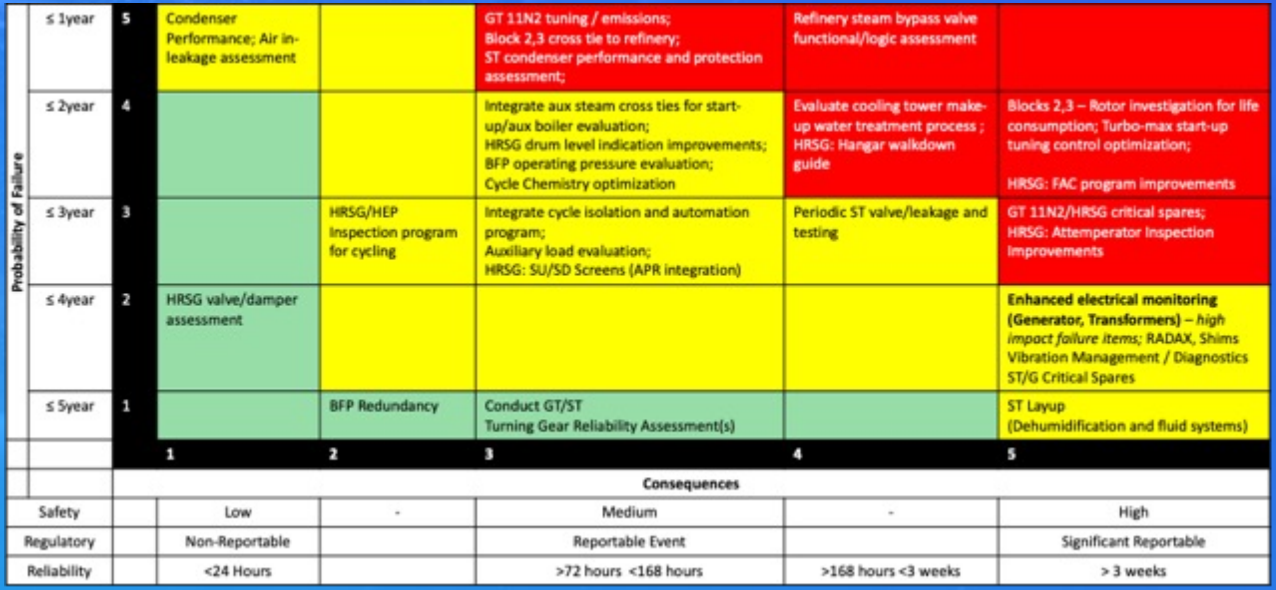
Managing Risk







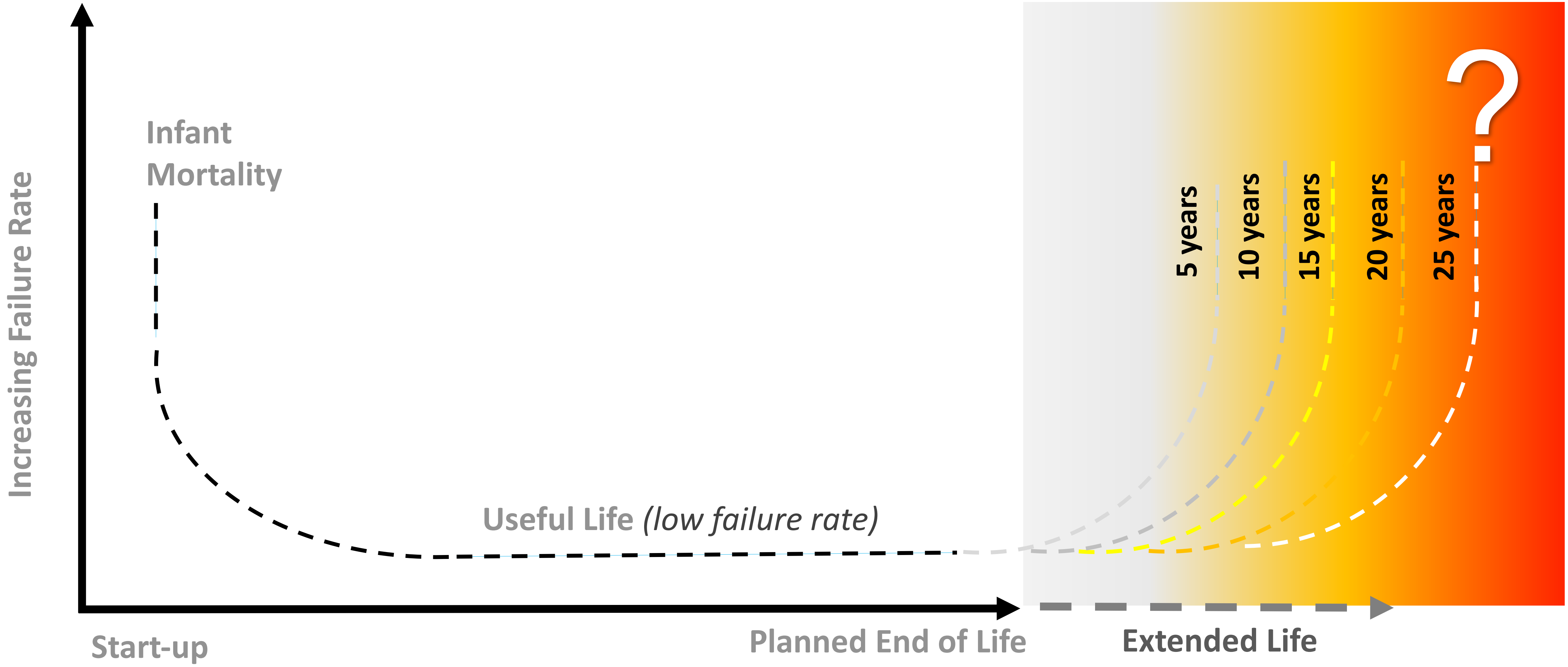
	Flexibility Benchmarking Metric	**BL1**	**BL2**	**BL3**
1	Equipment Operating Modes	76.47	76.47	76.47
2	HRSG Pressure Part and Life Availability	59.39	59.39	59.05
3	Operations	84.33	84.33	82.81
4	Maintenance	66.13	66.13	66.13
5	Gas Turbine Performance and O&M	74.73	74.73	74.73
6	Instrumentation, Controls and Automation	77.73	77.73	77.73
7	Environmental Controls Assessment	56.32	56.32	56.32
8	Cycle Chemistry Program Assessment	66.97	66.97	66.97
9	Steam Turbine / Generator	78.95	78.95	87.41
10	Balance of Plant	59.06	59.06	59.06
	Overall Score	**70.01**	**70.01**	**70.67**



Probability of Failure							
≤ 1year	5	Condenser Performance; Air in-leakage assessment		GT 11N2 tuning / emissions; Block 2,3 cross tie to refinery; ST condenser performance and protection assessment;	Refinery steam bypass valve functional/logic assessment	
≤ 2year	4			Integrate aux steam cross ties for start-up/aux boiler evaluation; HRSG drum level indication improvements; BFP operating pressure evaluation; Cycle Chemistry optimization	Evaluate cooling tower make-up water treatment process ; HRSG: Hangar walkdown guide	Blocks 2,3 – Rotor investigation for life consumption; Turbo-max start-up tuning control optimization; HRSG: FAC program improvements
≤ 3year	3		HRSG/HEP Inspection program for cycling	Integrate cycle isolation and automation program; Auxiliary load evaluation; HRSG: SU/SD Screens (APR integration)	Periodic ST valve/leakage and testing	GT 11N2/HRSG critical spares; HRSG: Attemperator Inspection Improvements
≤ 4year	2	HRSG valve/damper assessment				**Enhanced electrical monitoring (Generator, Transformers)** – *high impact failure items;* RADAX, Shims Vibration Management / Diagnostics ST/G Critical Spares
≤ 5year	1		BFP Redundancy	Conduct GT/ST Turning Gear Reliability Assessment(s)		ST Layup (Dehumidification and fluid systems)
		1	2	3	4	5
		Consequences				
Safety		Low	-	Medium	-	High
Regulatory		Non-Reportable		Reportable Event		Significant Reportable
Reliability		<24 Hours		>72 hours <168 hours	>168 hours <3 weeks	> 3 weeks

Managing Uncertainty

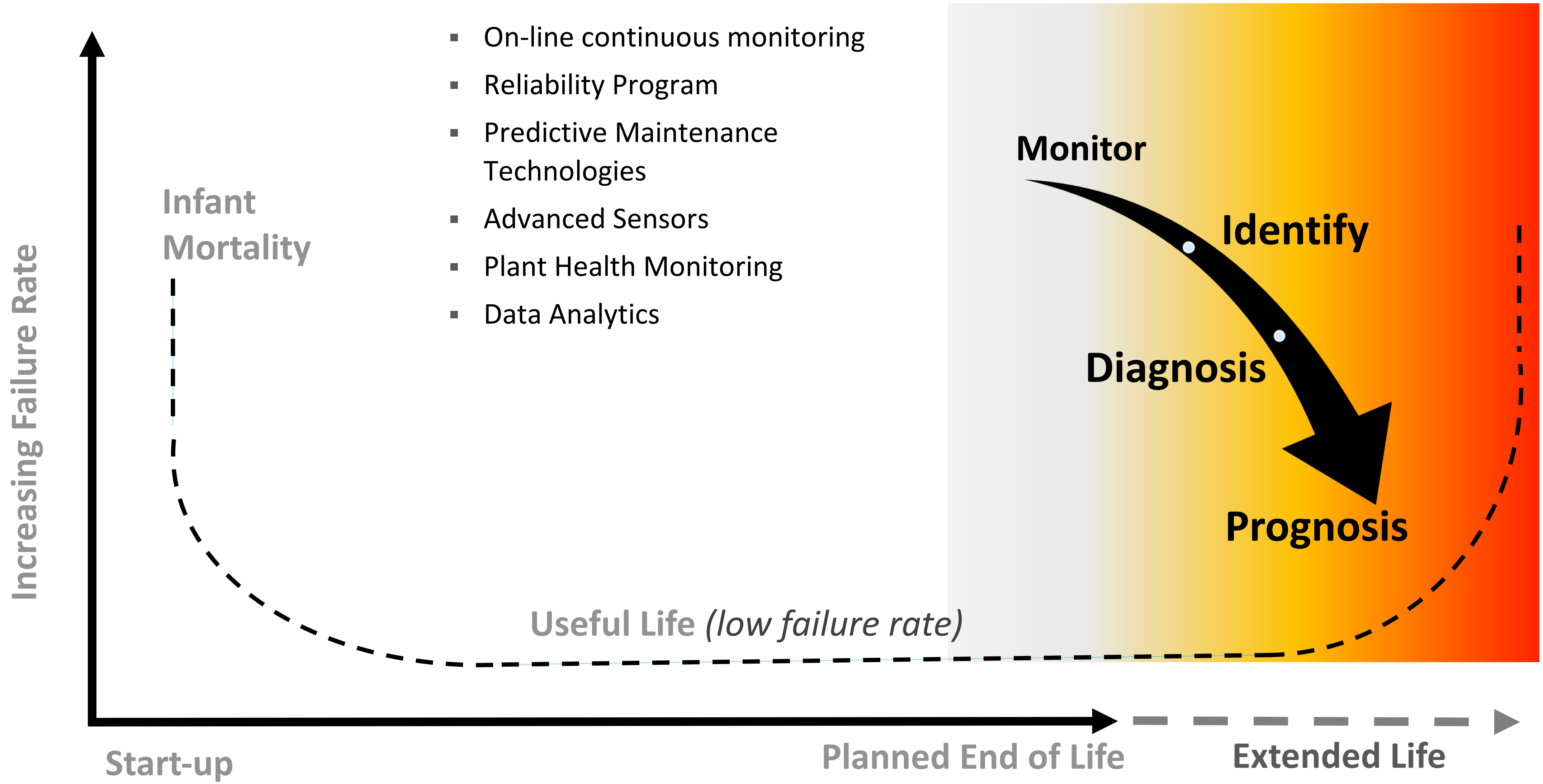
High level “gap” identification to drive various program research to help minimize uncertainty and identify best strategies for the remaining useful life of generating assets



Operational Flexibility: Failure Mitigation Strategies Handbook 3002024255

Leveraging Advanced Maintenance Strategies

- On-line continuous monitoring
- Reliability Program
- Predictive Maintenance Technologies
- Advanced Sensors
- Plant Health Monitoring
- Data Analytics



Increasing Failure Rate

Infant Mortality

Monitor

Identify

Diagnosis

Prognosis

Useful Life *(low failure rate)*

Start-up

Planned End of Life

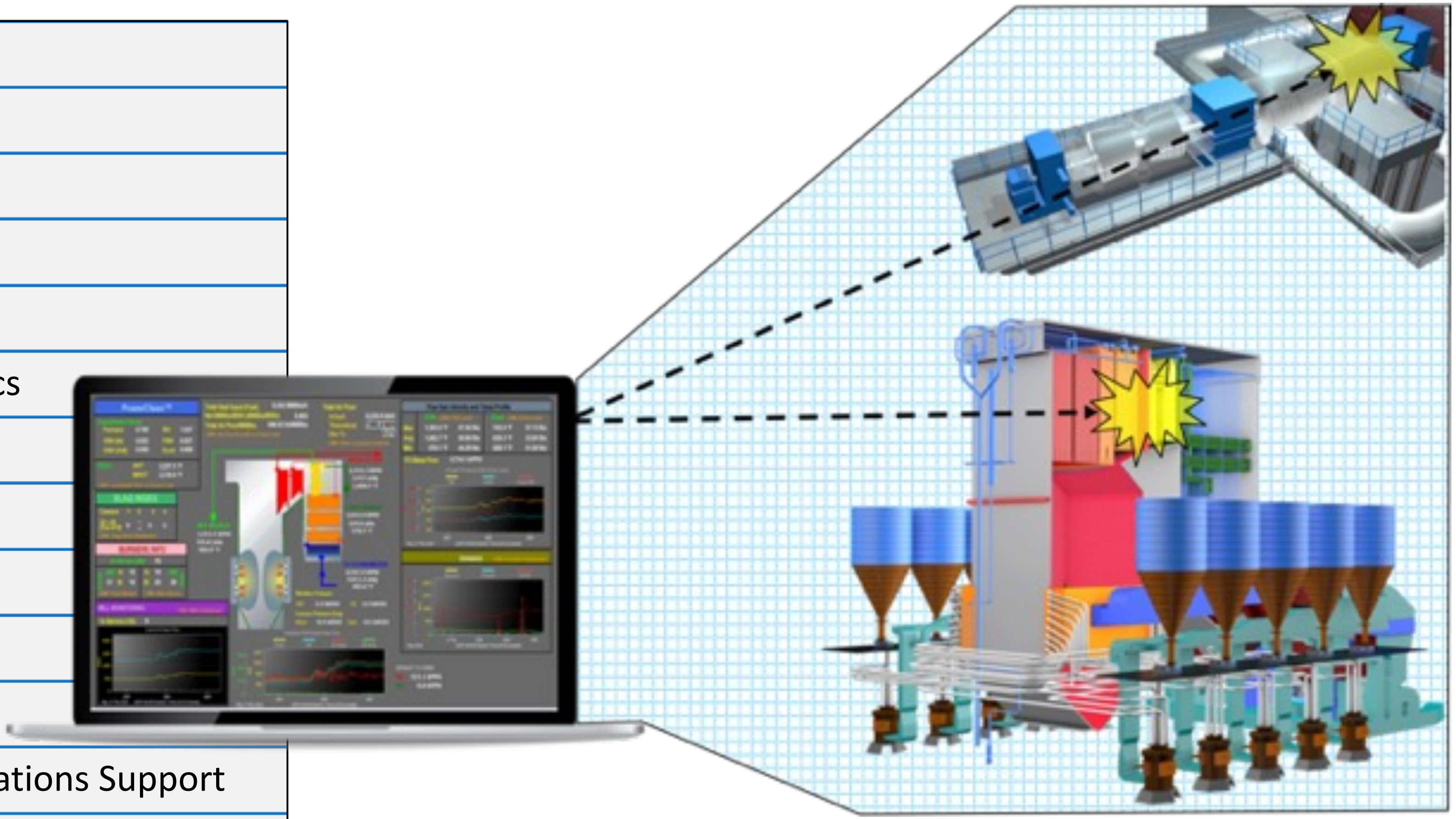
Extended Life

Operational Flexibility: Failure Mitigation Strategies Handbook

3002024255

Integrating Data Analytics, Dashboards, and System Optimization

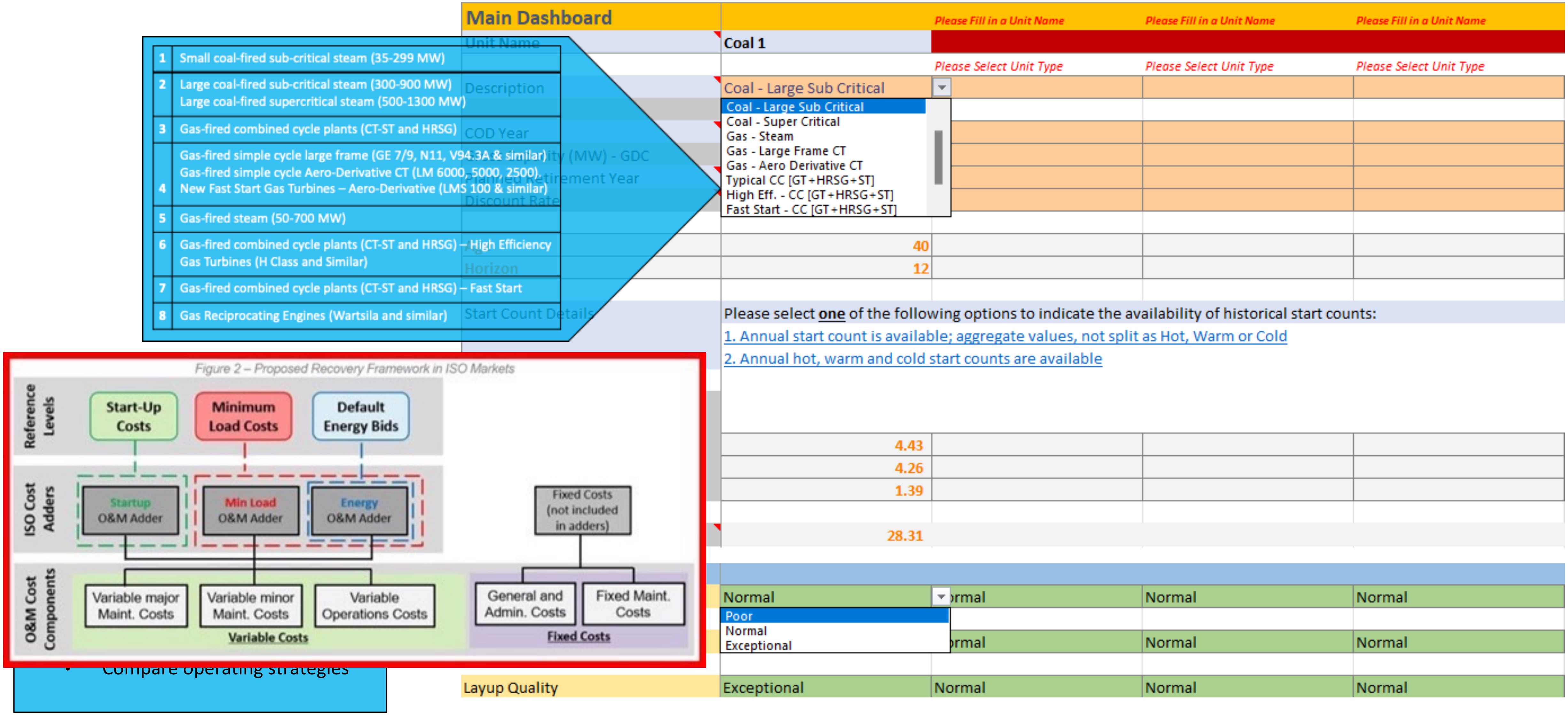
- Risk Assessments
- Thermal Performance Models
- System Health Monitoring
- Diagnostic Causal Asset Networks
- Electromagnetic Signature Analysis
- Advanced Vibration Monitoring/Diagnostics
- Thermal Fatigue Modeling/Monitoring
- Neural Networks
- Prognostics
- APR
- Digital Twins
- Remote Monitoring, Diagnostics and Operations Support
- Adaptive Predictive Controls



Methods to Understand the Effect of Heat Rate and Flexibility in Real Time: Conventional and Combined-Cycle Units

3002020703

Flexible Operations Cost Management



1	Small coal-fired sub-critical steam (35-299 MW)
2	Large coal-fired sub-critical steam (300-900 MW) Large coal-fired supercritical steam (500-1300 MW)
3	Gas-fired combined cycle plants (CT-ST and HRSG)
4	Gas-fired simple cycle large frame (GE 7/9, N11, V94.3A & similar) Gas-fired simple cycle Aero-Derivative CT (LM 6000, 5000, 2500) New Fast Start Gas Turbines – Aero-Derivative (LMS 100 & similar)
5	Gas-fired steam (50-700 MW)
6	Gas-fired combined cycle plants (CT-ST and HRSG) – High Efficiency Gas Turbines (H Class and Similar)
7	Gas-fired combined cycle plants (CT-ST and HRSG) – Fast Start
8	Gas Reciprocating Engines (Wartsila and similar)

Main Dashboard

Please Fill in a Unit Name *Please Fill in a Unit Name* *Please Fill in a Unit Name*

Unit Name: Coal 1

Please Select Unit Type *Please Select Unit Type* *Please Select Unit Type*

Description: Coal - Large Sub Critical

- Coal - Large Sub Critical
- Coal - Super Critical
- Gas - Steam
- Gas - Large Frame CT
- Gas - Aero Derivative CT
- Typical CC [GT+HRSG+ST]
- High Eff. - CC [GT+HRSG+ST]
- Fast Start - CC [GT+HRSG+ST]

COD Year

…ity (MW) - GDC

Planned Retirement Year

Discount Rate

40

Horizon: 12

Start Count Details: Please select one of the following options to indicate the availability of historical start counts:

1. Annual start count is available; aggregate values, not split as Hot, Warm or Cold
2. Annual hot, warm and cold start counts are available

4.43

4.26

1.39

28.31

Normal	…rmal	Normal	Normal
	…rmal	Normal	Normal

- Poor
- Normal
- Exceptional

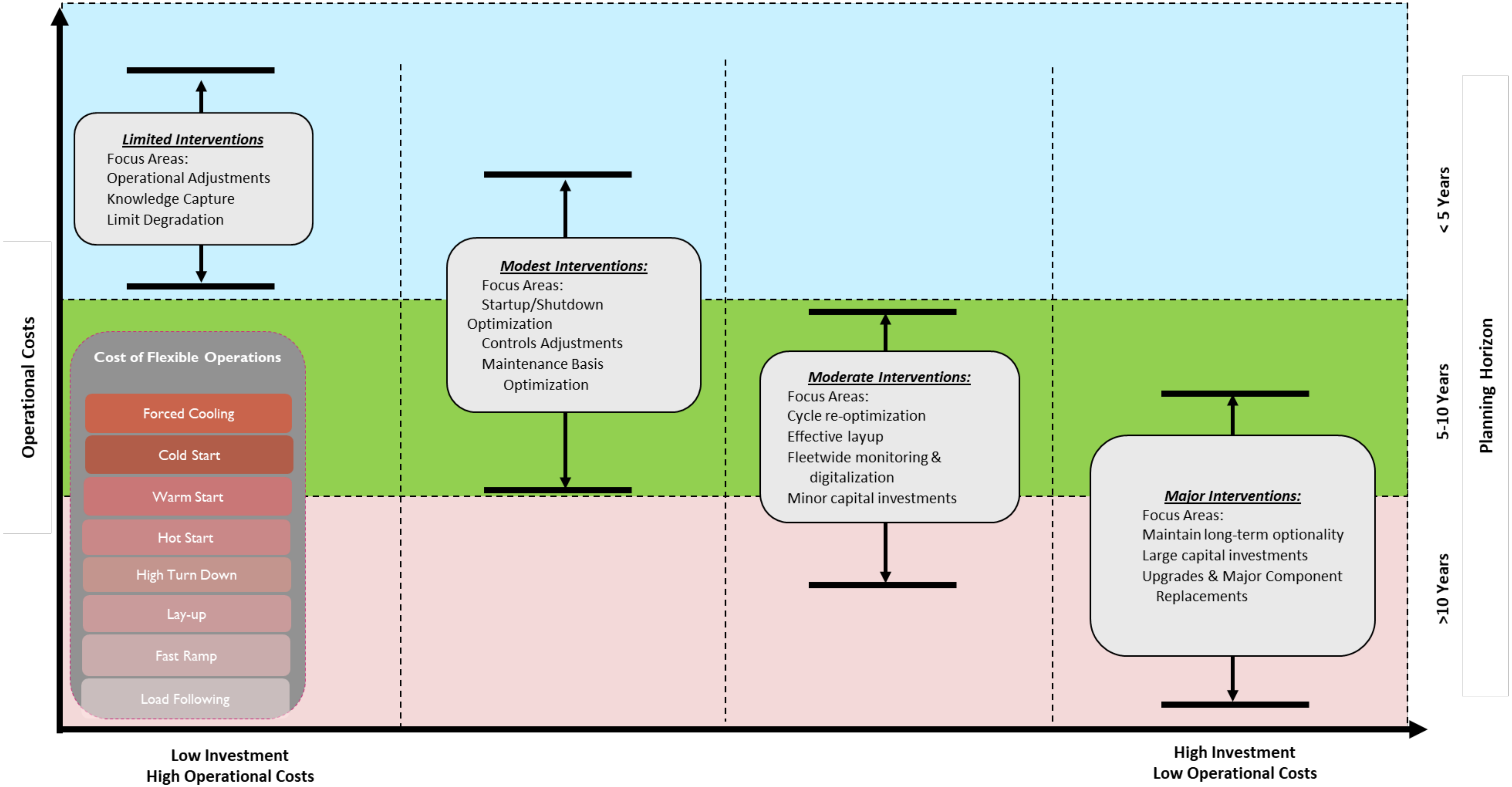
Layup Quality	Exceptional	Normal	Normal	Normal

Figure 2 – Proposed Recovery Framework in ISO Markets

- Compare operating strategies

FLEXIBLE OPERATIONS COST MANAGEMENT TOOL: CONVENTIONAL AND COMBINED CYCLE UNITS 3002020714

Performance and Flexibility: Glidepath to Retirement



Limited Interventions
Focus Areas:
Operational Adjustments
Knowledge Capture
Limit Degradation

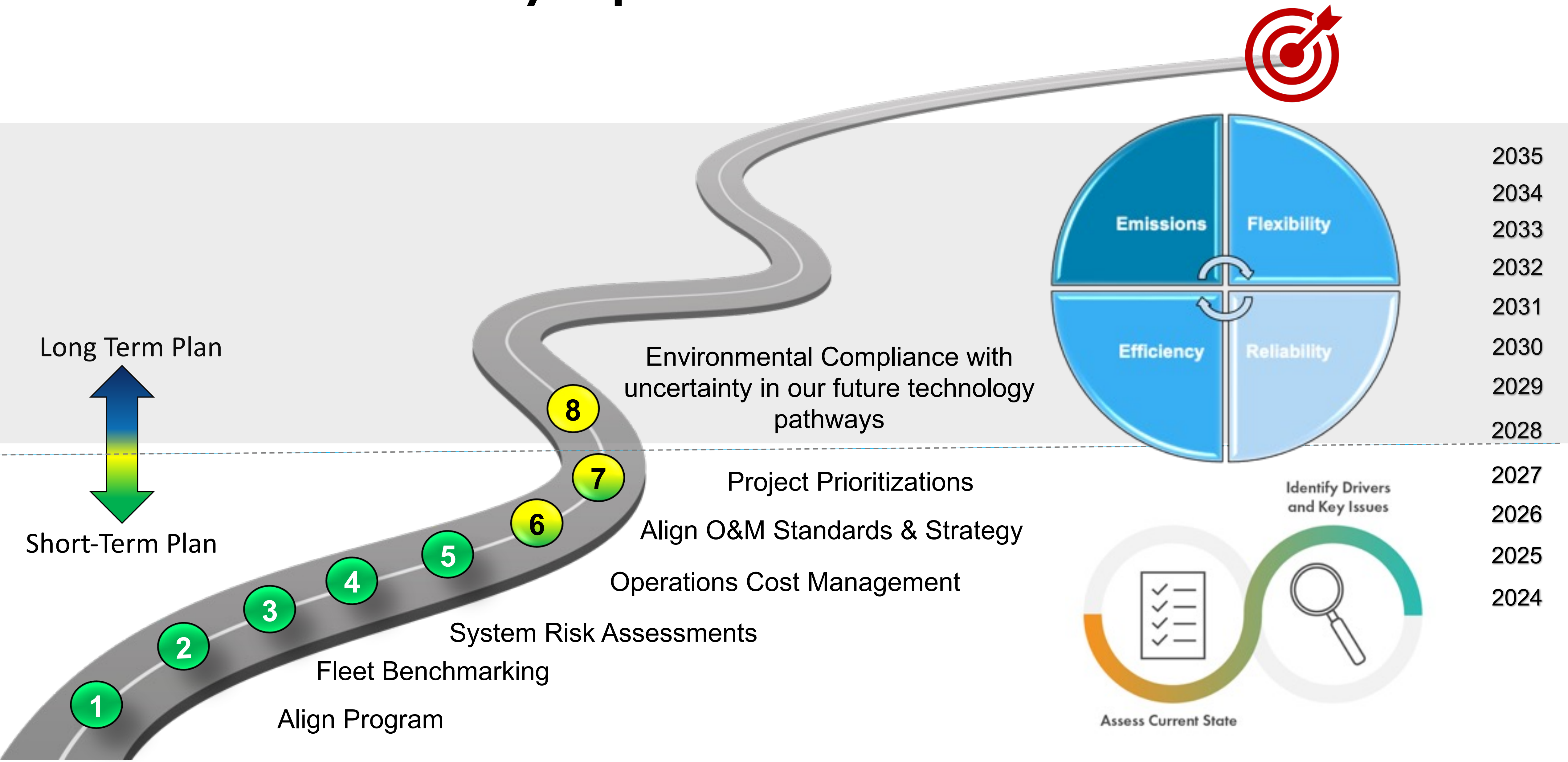
Modest Interventions:
Focus Areas:
Startup/Shutdown Optimization
Controls Adjustments
Maintenance Basis Optimization

Moderate Interventions:
Focus Areas:
Cycle re-optimization
Effective layup
Fleetwide monitoring & digitalization
Minor capital investments

Major Interventions:
Focus Areas:
Maintain long-term optionality
Large capital investments
Upgrades & Major Component Replacements

3002027382

Generation Flexibility Optimization



Long Term Plan

Short-Term Plan

Environmental Compliance with uncertainty in our future technology pathways

Project Prioritizations

Align O&M Standards & Strategy

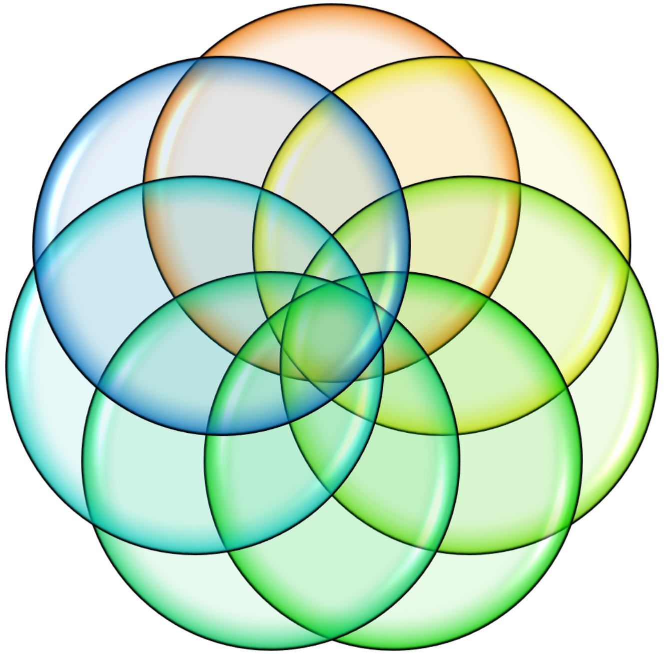
Operations Cost Management

System Risk Assessments

Fleet Benchmarking

Align Program

Managing Generation Asset Reliability and Risk Management



Generation Stability and Weatherization

Resource Planning and Unit Commitment (growth and data centers; critical equipment shortages)

Fuel Supply, Storage, Dual Fuel Capability, Transportation, diversity, Onsite Storage

Plant Operations and Maintenance

Supply chain disruptions

Emerging Technologies

Environmental Compliance

THE ENERGY TRANSFORMATION

Accelerating towards clean, affordable, reliable, and resilient energy for everyone.

OPTIONALITY

Leveraging the full portfolio of existing and emerging energy resources while accounting for regional differences

INNOVATION

Developing and deploying innovative solutions across the clean energy economy

COLLABORATION

Reaching across industry and government to align technology development and deployment with customer needs

TOGETHER…SHAPING THE FUTURE OF ENERGY®

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