The Changing Mission of Colombia's Thermal Fleet:

Oportunidades tecnológicas de las plantas térmicas para la mitigación de emisiones de CO2

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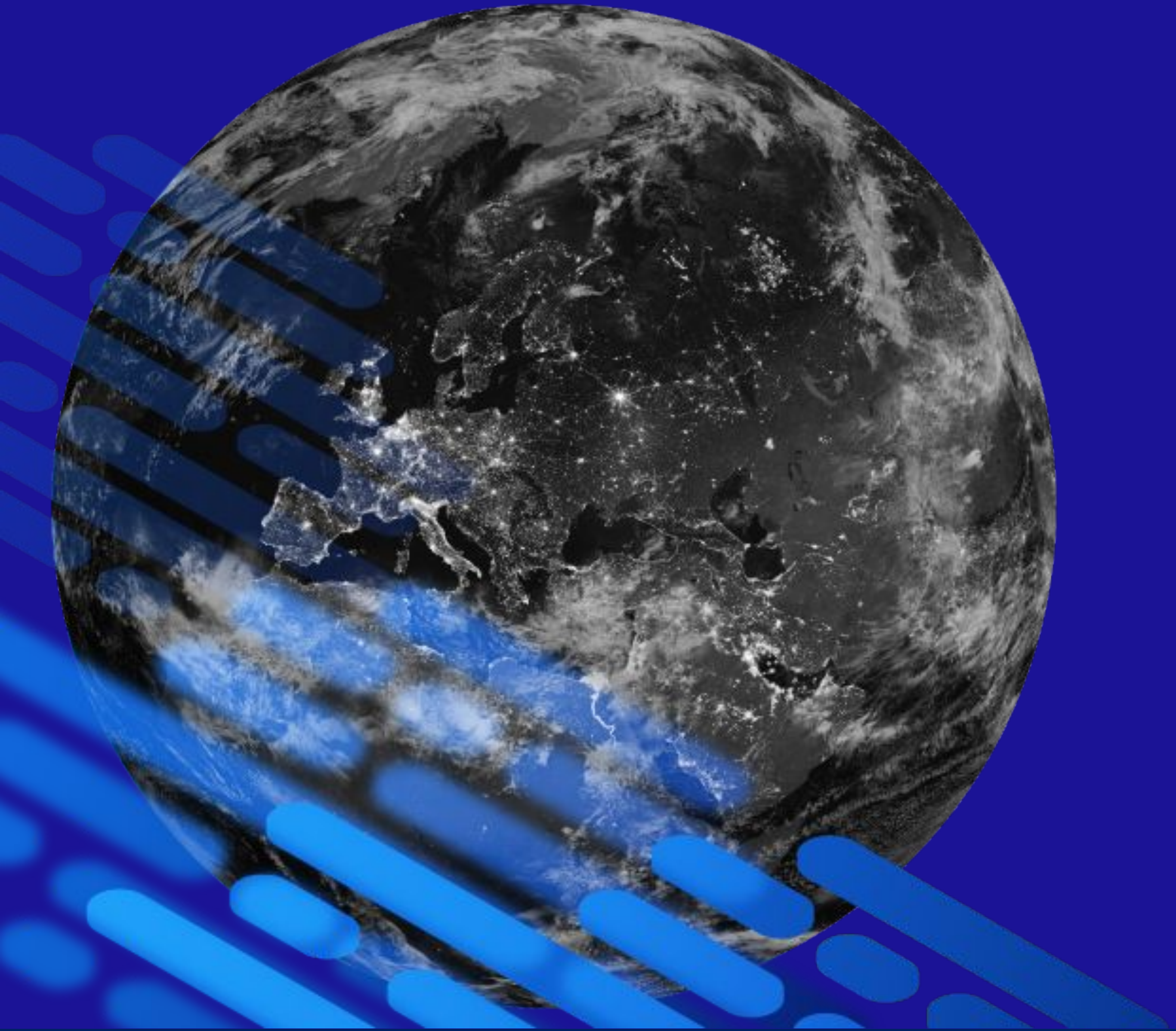
Agenda



- EPRI Overview
- A review of EPRI's last presentation at ANDEG
- Next Steps for a Reliable, Flexible, Lower Emissions Thermal Fleet
  - Operational Excellence and Organizational Alignment
  - Asset Management Best Practice
  - Controls Maturity
  - Fuel Flexibility
  - Preserving Future Optionality
- Summary

2026 Generation Portfolio

ARP Program *(all same price!)*
Supplemental Program
Strategic Supplemental Project

Thermal Fleet

214: Boilers
215: 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

Renewable Fleet

206: Wind Generation
*Environmental Aspects of Wind (**SP250**)*
*Offshore Wind (**SP249**)*
207: Solar Generation
*Environmental Aspects of Solar (**SP252**)*
Hydropower Generation *(**SP212**)*
Geothermal Interest Group

Next-Generation Fleet

221: Bulk Energy Storage
222: Advanced Generation and Carbon Capture and Storage
Low-Carbon Resources Initiative
*Generation Transitions (**SP248**)*
Gen. & Emerging Fuels Cross-cutting Topics
*Generation Climate Resilience (**SP263**)*

Thermal Optimization & Emissions Controls

223: Heat Rate and Flexibility: Generation Fleet Optimization
232: SCR Performance Issues
233: Continuous Emissions Monitoring and Measurements
Integrated Combustion & Emissions Controls for Conventional Power Plants *(**SP253**)*

Water, Land, & Ecosystem Management

195: Endangered & At-risk Species
238: Water Treatment Technologies
239: Aquatic Resource Protection
240: Water Quality and Effluent Guidelines
241: Byproducts Management and Market Development
242: Groundwater and Land Management
Ecosystem Risk & Resilience *(**SP258**)*

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**)*

Materials

229: Materials
Advanced Manufacturing

Air Quality & Health

235: Air Quality Assessments and Multimedia Characterization
236: Air Quality, Health, and Communities

Digitalization

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

2026 Emerging Fuels & Technologies

Emerging Fuels Production & Sourcing

264: Renewable Fuel Supply Chains
265: Electrolyzers and System Integration
266: Natural Gas Conversion and Markets

Customer Applications of Emerging Fuels & Technologies

267: Resiliency Applications with Emerging Fuels
268: Next Generation Industrial Energy Systems
269: Hydrogen-fueled Mobility

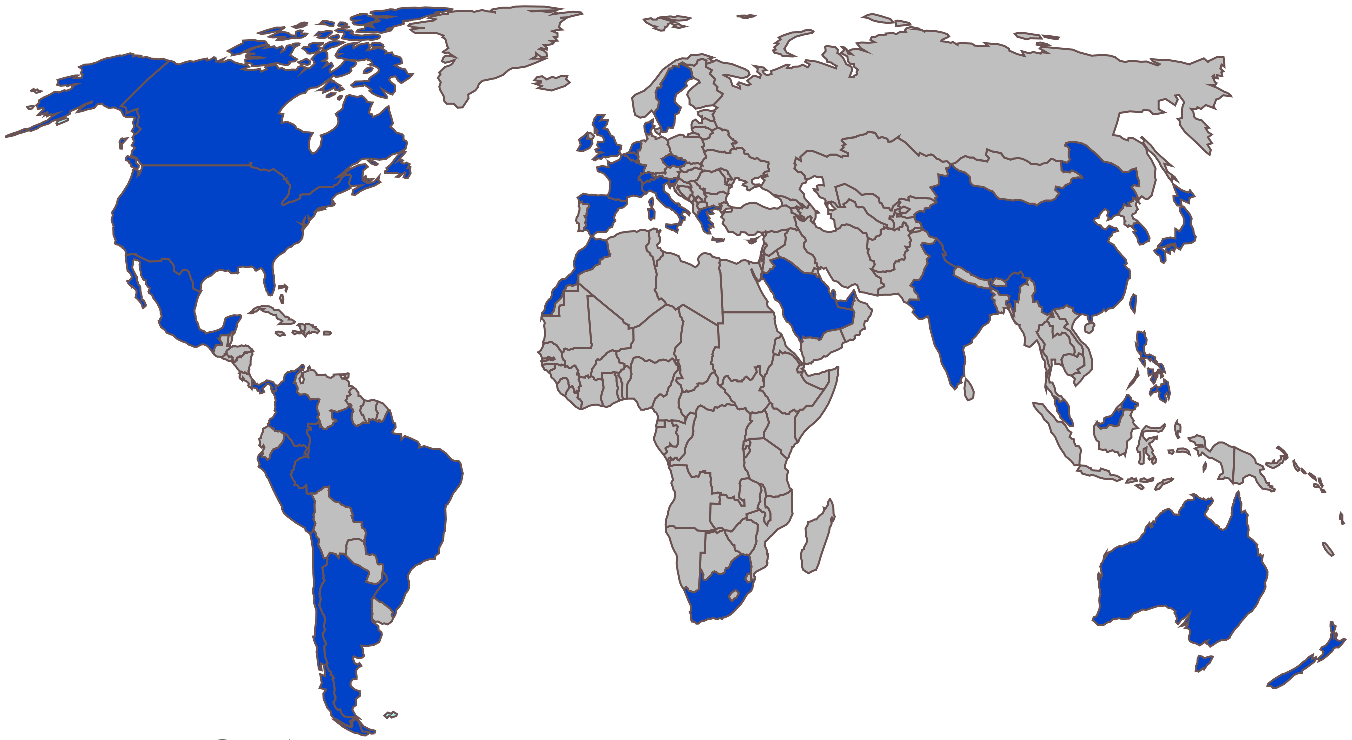
Emerging Fuels for Power Generation & Carbon Management

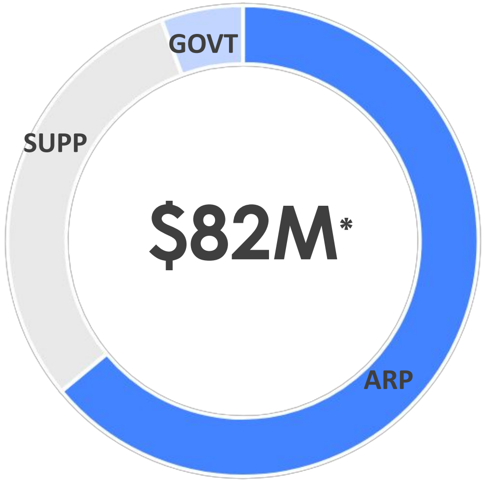
270: Emerging Fuels for Power Generation
271: Transport and Storage Infrastructure

Energy System Economics, Environment, & Stakeholders

272: Economics of Energy Sector Coupling
273: Environment, Health, and Safety
274: Workforce and Stakeholder Engagement

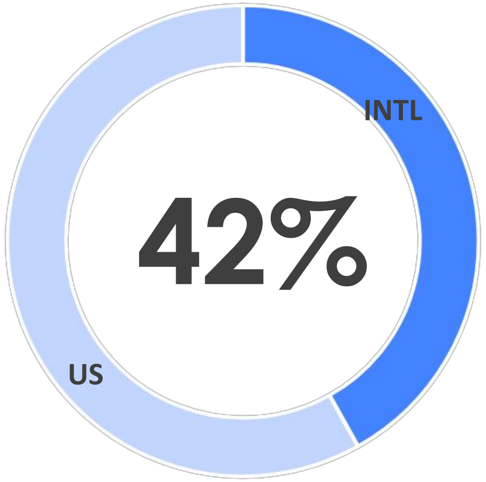
EPRI Generation R&D at a Glance





GENERATION & LCRI RESEARCH PORTFOLIO SCOPE

*2025 Funding



INTERNATIONAL OVERALL PARTICIPATION

36 COUNTRIES REPRESENTED

108 ORGANIZATIONS ACROSS THE SUPPLY CHAIN
(NON-TRADITIONALLY INTEGRATED COMPANIES)

98 INTERNATIONAL PARTICIPANTS

233 TOTAL US AND INTERNATIONAL PARTICIPANTS

OUR TEAM

~150 TECHNICAL STAFF

2,000+ YEARS OF INDUSTRY EXPERIENCE

Power Companies – OEMS – Suppliers
Engineering Firms – Academia – Government

Thermal Plants Become More Strategic

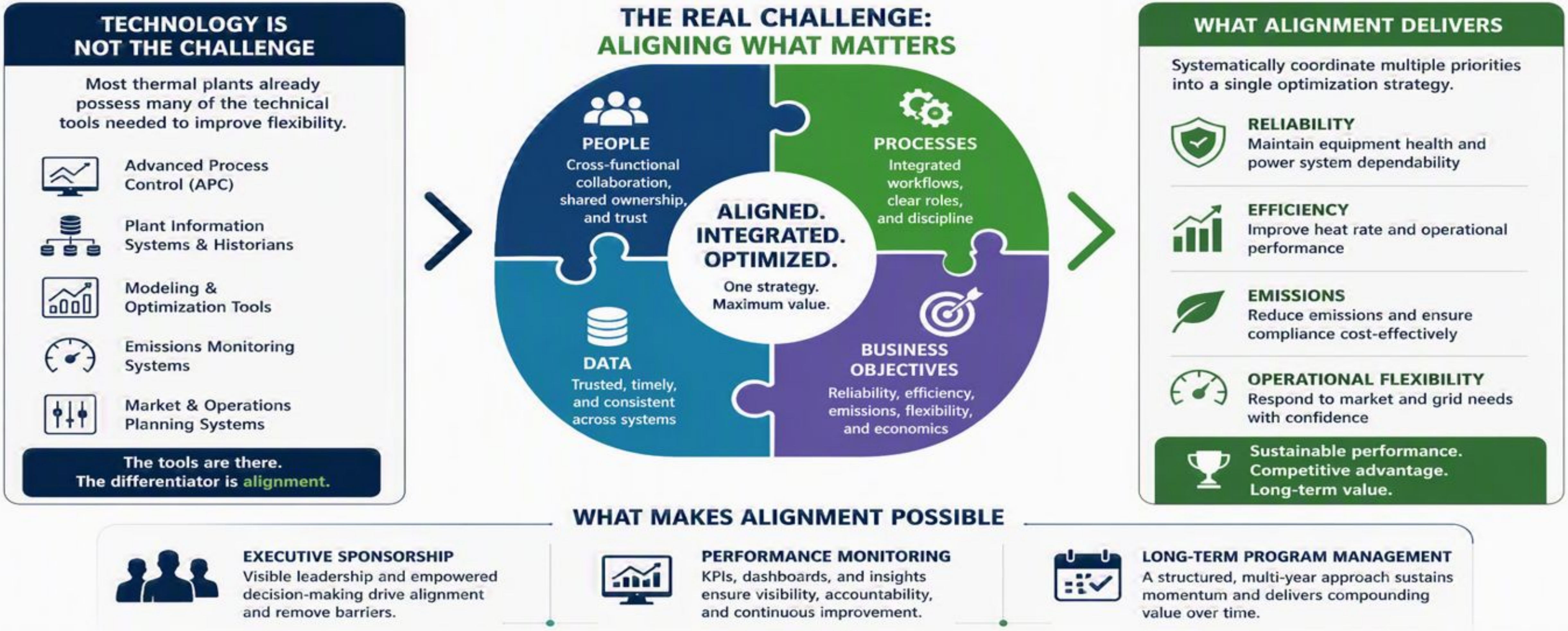
Key takeaways from Michael Caravaggio's 2025 ANDEG Presentation (mcaravaggio@epri.com)

LOWER UTILIZATION DOES NOT MEAN LOWER IMPORTANCE • Flexible thermal assets become increasingly critical for reliability as hydro variability and renewable penetration grow.

__Keynote__: Colombia's energy transition will succeed by preserving a highly __reliable__ and __flexible__ thermal fleet

- ***Asset Management Must Be Risk Based***
- ***Better Control System Utilization***
- ***Fuel Flexibility / Optionality***
- ***Future Carbon Optionality***

Integrated & Optimized Asset Management Requires Aligning People, Processes, Data, and Objectives



Critical Building Blocks for Digital Asset Management

Our engagements with utilities show that success starts with getting the fundamentals right.
These building blocks are **the foundation** of any enduring digitalisation initiative.

1. **Data Foundation** — Trusted, complete and consistent asset data
2. **Asset Hierarchy** — Logical structure that reflects how assets operate
3. **Asset Criticality Ranking** — Risk-based view of what matters most
4. **Maintenance Strategy** — Right strategy for the right asset at the right time
5. **Work Management** — Plan, schedule and execute with discipline
6. **Performance Analytics** — Measure what matters and drive improvement
7. **People & Capabilities** — Right skills, roles and ways of working
8. **Governance & Enablement** — Policies, standards and controls that sustain

Integrated and optimized asset management improves reliability without requiring new generation investment

The Solution: Asset Criticality Ranking (ACR)

A structured, risk-based approach that turns complexity into clarity and **drives action.**

HOW ACR WORKS

1. **Define** — Establish consistent criteria and priorities
2. **Assess** — Evaluate systems, equipment and failure modes
3. **Rank** — Calculate risk (probability and consequence) and rank criticality
4. **Prioritize** — Identify what matters most and where to focus resources
5. **Act** — Inform maintenance, investments and operational decisions

- Risk-based and consistent
- Flexible to your business priorities
- Repeatable across sites and fleets
- Full audit trail and transparency
- Aligned with stakeholder goals

ACR creates a common language for risk — and a clear path to better decisions.

Risk Must Be Assessed at Multiple Levels

ACR evaluates risk at system, asset and failure mode level across **8 key business impact areas.**

WHERE WE ASSESS RISK

SYSTEM LEVEL
Broader impact on plant availability and output

EQUIPMENT LEVEL
Importance of equipment within the system

FAILURE MODE LEVEL
Specific ways equipment can fail and their likelihood

HOW WE MEASURE IMPACT

Each failure is evaluated across **8 key business impact areas**

- SAFETY
- ENVIRONMENT
- AVAILABILITY
- COST
- RELIABILITY
- REGULATORY
- REPUTATION
- STRATEGIC

Risk exists at multiple levels.

What Defines Asset Criticality

ACR evaluates impact across **8 key business impact areas** to determine criticality.

Safety
What is the most probable safety impact if the system or equipment loses its functionality?

Environment
What is the most probable impact on the environment if the system or equipment loses its functionality?

Availability
What is the most probable impact on unit availability if the system or equipment loses its functionality?

Cost
What is the most probable cost impact if the system or equipment loses its functionality?

Efficiency
What is the most probable impact on efficiency if the system or equipment loses its functionality?

Flexible Operations
What is the most probable impact on flexible operations if the system or equipment loses its functionality?

Cyber Risk
What is the most probable cyber risk impact if the system or equipment loses its functionality?

Climate Resilience
What is the most probable impact on climate resilience if the system or equipment loses its functionality?

Criticality is defined by impact – not opinion and the business consequences of system/equipment failure.

Can a Generating Unit Be More Flexible Without Increasing Emissions?

Optimize startup execution through better utilization of the existing control system

CURRENT STATE

Frequent Starts & Load Changes

- Startup Variability
- Higher Fuel Use
- Higher Emissions

BETTER CONTROL SYSTEM UTILIZATION

Optimize and Automate Startup Execution

Automated sequencing • Constraint management • Reduced operator burden

Reliability | **Flexibility** | **Emissions**

OPTIMIZED GENERATING UNIT

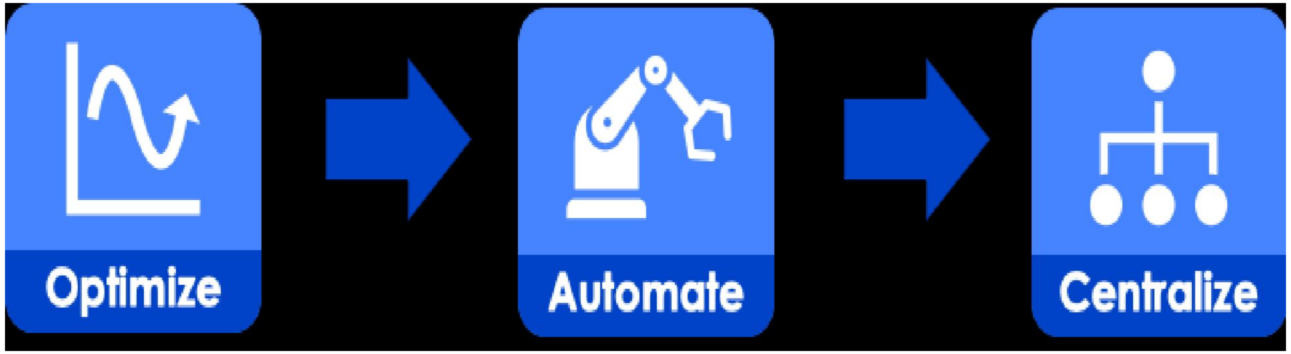
✓ Consistent Startups

✓ Faster Response

✓ Lower Emissions

✓ Lower Cost

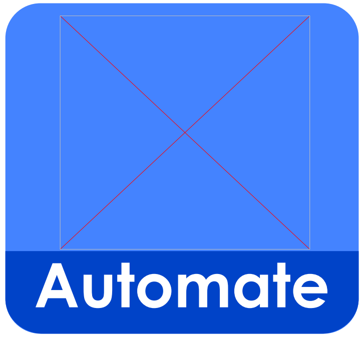
Importance of I&C Maturity



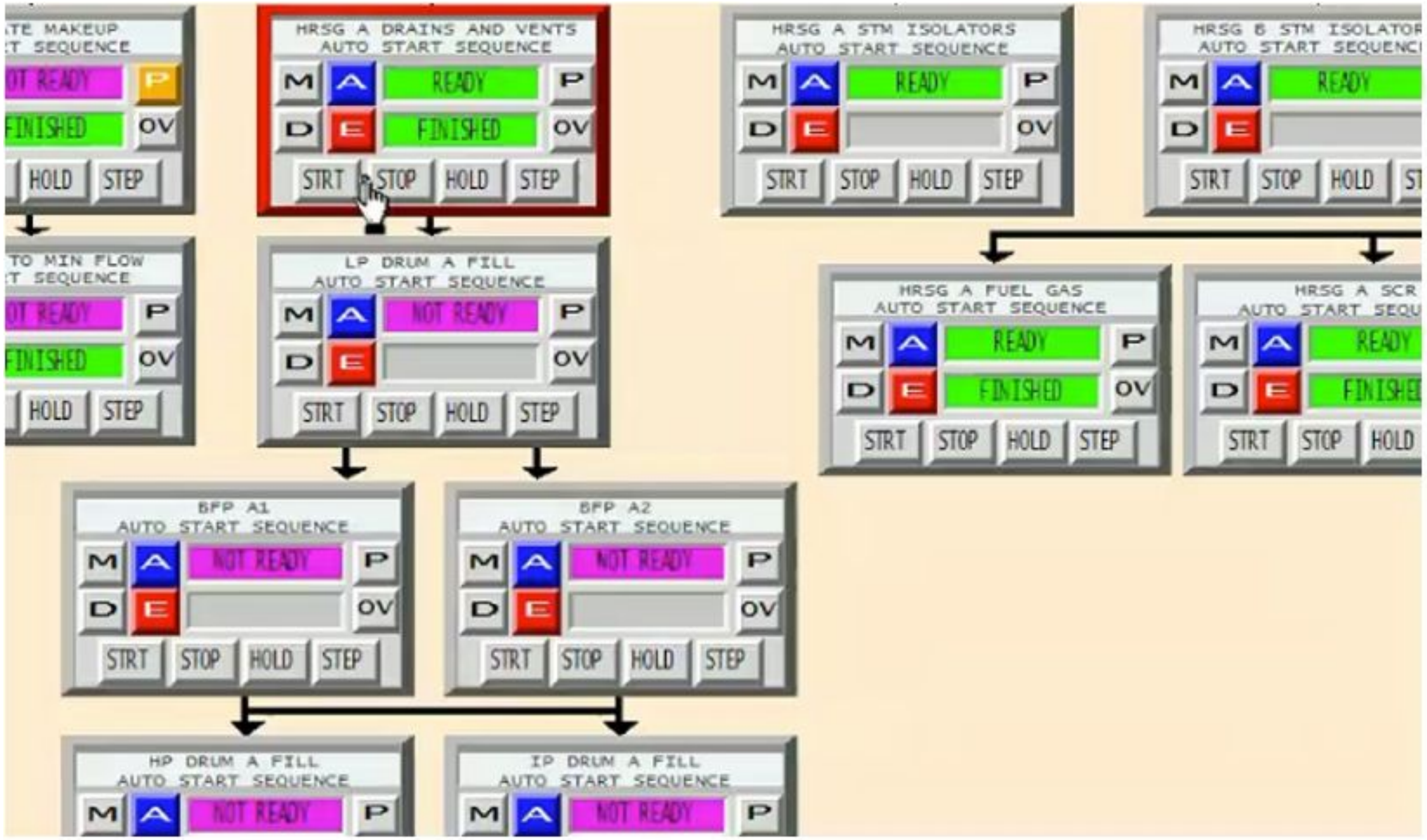
- **Enhances Operational Efficiency**
  - Mature I&C systems improve process control and reduce downtime
- **Reduces Risk**
  - Advanced I&C systems mitigate operational risks and enhance safety
- **Supports Flexibility**
  - Mature systems adapt to changing operational demands and regulatory requirements
- **Optimizes Performance**
  - Ensures optimal performance and reliability of power generation units

White Paper - Control System Maturity Trajectory for Cost-Effective Flexible Operation of Power Generating Plants

Automation Solutions



- **Goals**
  - Consistent operation
  - Reduced operator burden
- **Guidance**
  - Automation Benefits
  - Implementation Process
    - Goal setting
    - System identification
    - Readiness assessment
    - Function implementation
- **Case Study**
  - Cold Start Automation for Combined Cycle (CC) Unit
  - 52 sequences, saving over 400 operator actions
- **Benefits**
  - Improved predictability of unit starts
  - **Reduced start-up fuel costs**
  - Enhanced operator training
  - Reduced start-up failures



Fuel Flexibility Strengthens Reliability and Preserves Future Strategic Options

RELIABILITY TODAY → OPERATIONAL AGILITY → FUTURE READINESS

SUPPLY SECURITY

GAS SUPPLY CONSTRAINT

↓

DUAL-FUEL CAPABILITY

↓

RELIABLE GENERATION

- **Reduced Fuel Supply Risk**
- **Greater System Resilience**

OPERATIONAL FLEXIBILITY

FUEL A↔FUEL B

↓

REAL-TIME SELECTION

↓

OPTIMIZATION

- **Expanded Fuel Optionality**
- **Improved Operating Agility**

DECARBONIZATION PATHWAY

NATURAL GAS + H_2

↓

CO-FIRING

↓

LOWER CARBON FUTURE

- **Hydrogen-Ready Assets**
- **Supports Emissions Strategy**

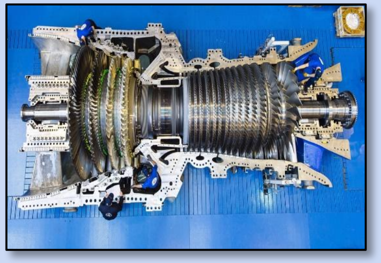
KEY TAKEAWAY: Fuel flexibility improves reliability today while preserving optionality for future decarbonization and market adaptability.

Emerging Fuels[1] are Advancing at Different Rates

High

Mid

Low



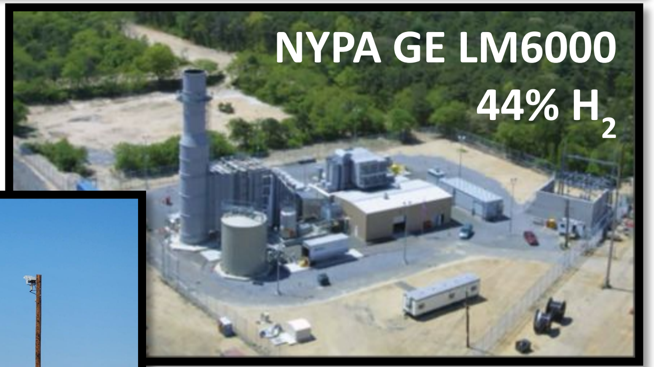


	Gas Turbines	HRSGs	Boilers	RICE[2]	Fuel Cells
Natural Gas & RNG					Including Reformer
Hydrogen	Diffusion DLN	Industrial Scale	Industrial Scale EPRI Demo		
Hydrogen & Natural Gas Blends (H_2<30% vol)	EPRI Demos	Industrial Scale	Industrial Scale	EPRI Demo	Including Reformer
Renewable Diesel	EPRI Demo			EPRI Demo	Including Reformer
Ethanol	EPRI Lab Studies		EPRI Lab Studies		Including Reformer
Methanol	EPRI Lab Studies		EPRI Lab Studies	Marine	Including Reformer
Ammonia	EPRI Lab Studies			Marine	
Ammonia Co-firing			Asia Coal Plant Demos	Marine	

[1] *Includes fuels produced via biofuel and electric pathways;* [2] *Status varies depending on stationary, marine, spark ignited, and dual fuel models*

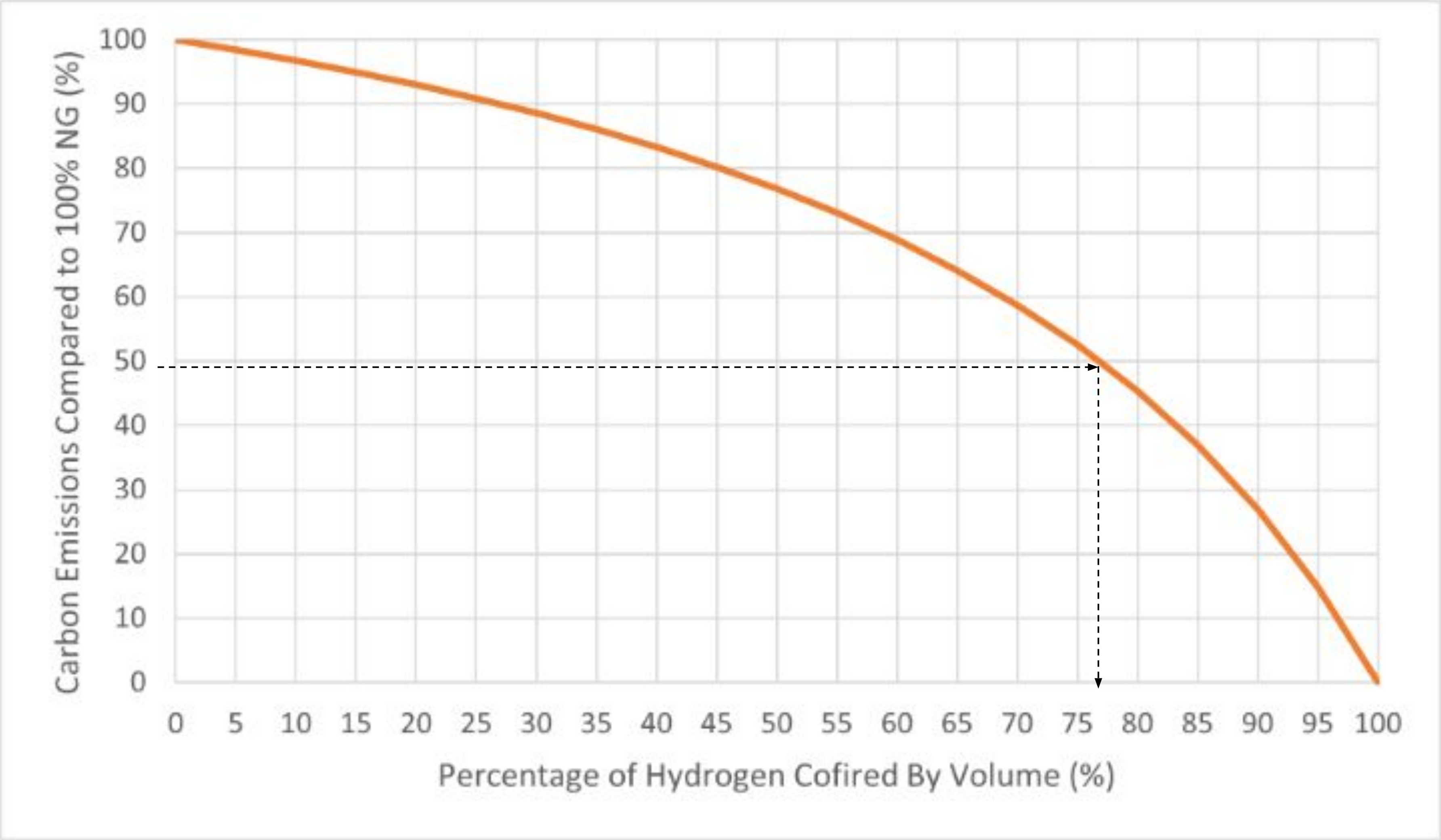
EPRI Gas Turbine Hydrogen Blending Demonstrations

- New learning and validation in safety procedures, emissions, operability, output, heat rate, part life, operational flexibility/turndown with hydrogen blending
- Record breaking results at each hydrogen blend test
- Collaboration with 4 GT OEMs
- Vetted hydrogen infrastructure suppliers
- No reliability or safety issues
- Validated multiple design methodologies for hydrogen delivery



EPRI demonstrations have shown hydrogen blending can be accomplished safely and reliably with proper engineering controls

Myth Busting: H_2 Volume ≠ Carbon Reduction Volume



Carbon Capture and Storage Readiness

- CCS remains a potential long-term decarbonization pathway
- Capture technology continues to mature
- Transport and storage infrastructure will largely determine feasibility
- Major commercial projects over the next decade will provide important lessons
- Near-term focus should be maintaining CCS readiness and preserving future options

Other Carbon Capture Considerations

- Storage appears more important than capture
- Regional geology matters for storage options
- Expect significant energy penalties
  - Lower plant efficiency by 11% for NGCC and 22% for coal along with higher operating costs
- Costs remain substantial - Reported capture costs for new-build applications were approximately \$87/tCO_2 for NGCC and \$55/tCO_2 for coal cases
- Transport scale drives economics (pipelines needed)
- Commercial experience is growing but limited

The value of CCS in Colombia may depend more on transport and storage availability than capture technology itself.

A prudent strategy is to preserve CCS optionality through CCS-ready planning and storage/transport evaluations today, while deferring major capital commitments until commercial deployment experience, infrastructure availability, and project economics become clearer over the next 5-10 years

Summary

Colombia's thermal fleet remains strategically important because it must:

- Start when needed
- Ramp when needed
- Support hydro variability
- Enable reliability during the energy transition

To accomplish this:

- Apply risk-based asset management
- Improve control system maturity
- Preserve fuel flexibility
- Maintain future CCS optionality

A reliable, flexible, and emissions-conscious thermal fleet is not a bridge to the future. ***It is part of the future.***

Actúa

Esta presentación refleja específicamente las contribuciones y la experiencia del sector de Generación de Investigación y Desarrollo de EPRI:

Operational Flexibility and Efficiency:
- Stephen Storm, Program Area Manager

Asset Management
- Jeong Kim, Program Area Manager
- Ricky Swanepoel, Technical Executive

Instrumentation and Controls
- Stephen Seachman, Program Leader

Fuel Flexibility
- Bobby Noble, Program Area Manager
- Tom Martz, Senior Principal Team Leader

Carbon Capture, Storage, and Transport
- Abhoyjit Bhown, Program Area Manager
- Joe Swisher, Principal Technical Leader

- **El principal punto de contacto para interactuar con EPRI es el Servicio Miembro y Técnico:**

Ricardo Mejia, Senior Regional Manager Latin America

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EPRI colabora con >30 organizaciones en América Latina:

Argentina - **PAMPA**
Brasil – **ENEVA / PETROBRAS / BRASKEM**
Chile - **COLBUN**
Colombia - **TERMOTASAJERO**
Costa Rica - **ICE**
Ecuador
México - **CFE**
Perú - **ORYGEN**
Puerto Rico

Other stakeholders: WEC, CIER, WB/IFC, USTDA, G-PST, NREL, ITA, COLOMBIA INTELIGENTE

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