



IERE TECHNOLOGY FORESIGHT 2025

Executive Summary

100 Disruptive Technologies in the 2030s
(Update from TF2023)

June 2026

EXECUTIVE SUMMARY

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SYNOPSIS

This report (TF2025) revisits the 100 technologies identified in TF2023 by reassessing their relevance in light of recent technological advancements and evolving socio-economic and industrial conditions, with a focus on the power sector in the 2030s.

In this study, the original 100 technologies (effectively 99, as two of them were merged this time) were expanded by adding 54 newly identified candidates, resulting in a total of 153 technologies. Each technology was evaluated using three indicators—Technology Readiness Level (TRL), Human Readiness Level (HRL), and Business Readiness Level (BRL)—and technologies with weighted scores within the intermediate range (5–8) were selected in Step 1.

In Step 2, a qualitative review incorporating recent technology trends and market developments was conducted. Based on this, some technologies outside the threshold were reselected, while others within the threshold were excluded. As a result, a final set of 100 technologies was identified as having high relevance for the 2030s.

The review excluded technologies that are already commercialized or expected to reach commercialization before 2030, while newly including technologies with strong forward momentum, such as reconfigurable intelligent surfaces (RIS), causal AI, monolithic 3D ICs, and neuro-symbolic AI.

The selected technologies are categorized into six domains: Power Generation, Transmission & Distribution, Retail Customers, Strategic Management, Common Technologies, and Cutting Edge Technologies. Compared to TF2023, the share of Cutting Edge Technologies has increased.

Each of the 100 selected technologies is presented as a “file card,” summarizing its overview, impacts on the economy, regions, power business, and society, future outlook, and key companies and projects involved.

Future work will include scenario analysis on regional differences and market potential, incorporating four additional perspectives: artificial intelligence applications, geopolitics, supply chains, and long-duration energy storage (LDES), to be compiled in the TF2026 report.

BACKGROUND AND OBJECTIVE

Background

In the TF2023 report, 100 technologies with the potential to emerge as disruptive forces in the power industry in the 2030s were identified, with the aim of supporting IERE members in developing their technology strategies. Two years have passed since this selection, and amid rapid technological advancements and significant changes in the global landscape, reviewing and reselecting these technologies has become increasingly important for reassessing and refining members' technology strategies.

Objective

The objective of this study is to revisit the 100 technologies identified in the TF2023 report by adding 54 newly identified candidates, thereby forming a total pool of 153 technologies, and to reselect 100 technologies expected to emerge in the 2030s. The results are compiled as the TF2025 report.

KEY FINDINGS 1/3

Two-Step Approach

As a first step in the review process, all technologies were evaluated using three indicators—TRL (Technology Readiness Level), HRL (Human Readiness Level), and BRL (Business Readiness Level)—each scored on a scale of 1 to 9. Technologies with weighted scores falling within the intermediate range of 5 to 8 were extracted in Step 1.

In Step 2, a further review incorporating recent major technology trends was conducted. Based on this, technologies outside the threshold were reselected where appropriate, while some within the threshold were excluded, resulting in the final selection of 100 technologies.

Long List of Technologies

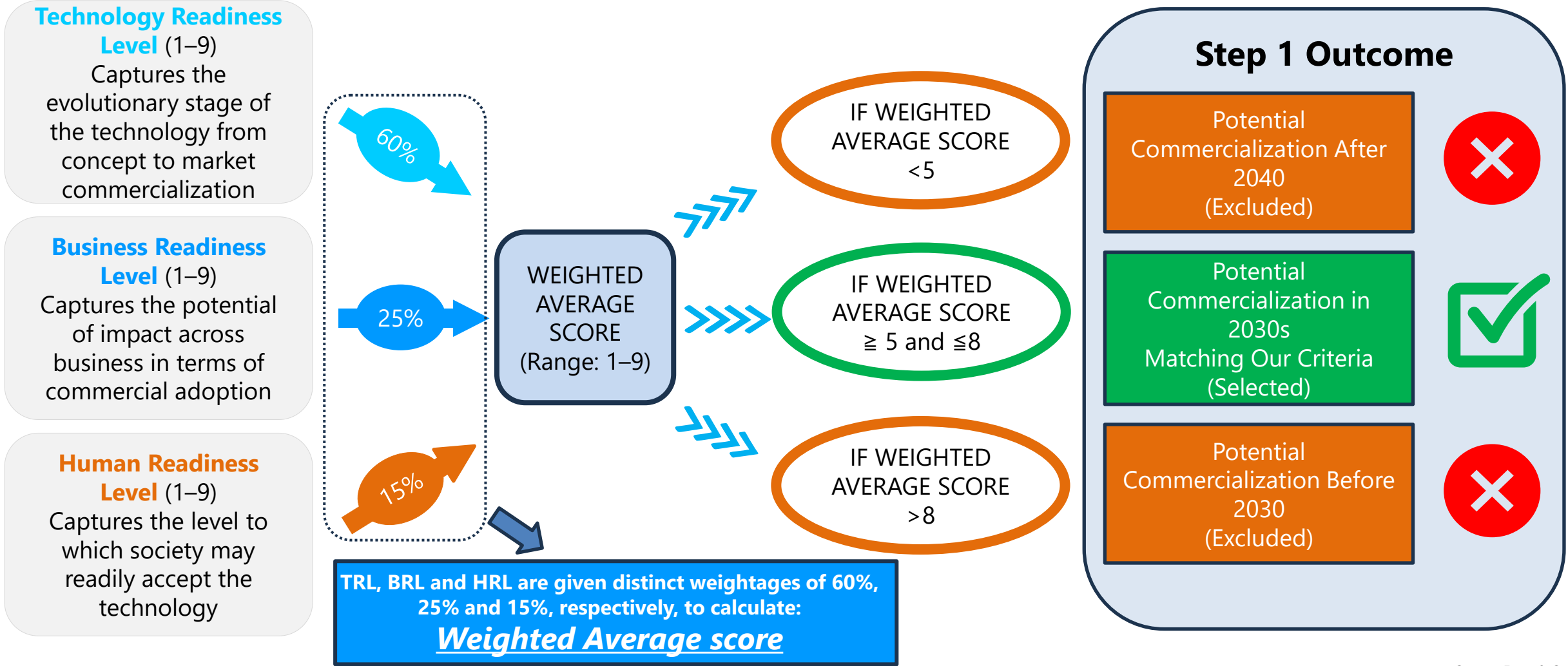
- IERE and Frost & Sullivan (F&S) developed a long list of emerging and innovative technologies impacting the electric power sector. The long list of technologies was compiled based on inputs from industry experts and IERE as well as a reassessment of technologies identified in the TF2023 report. In terms of numbers, it consists of 153 technologies in total, adding 54 newly identified candidates to the 100 technologies from TF2023 (actually 99 technologies since two technologies were integrated this time).

Selection of 100 Technologies for the Electric Power Sector

- Through further consultation with IERE with two analysis steps, the list was narrowed down to 100 technologies with high impact and strong feasibility for application in the electric power sector.
- The selected technologies are grouped into six categories: 1. Power Generation, 2. Transmission & Distribution, 3. Retail Customers, 4. Strategic Management, 5. Common Technologies, and 6. Cutting Edge Technologies.

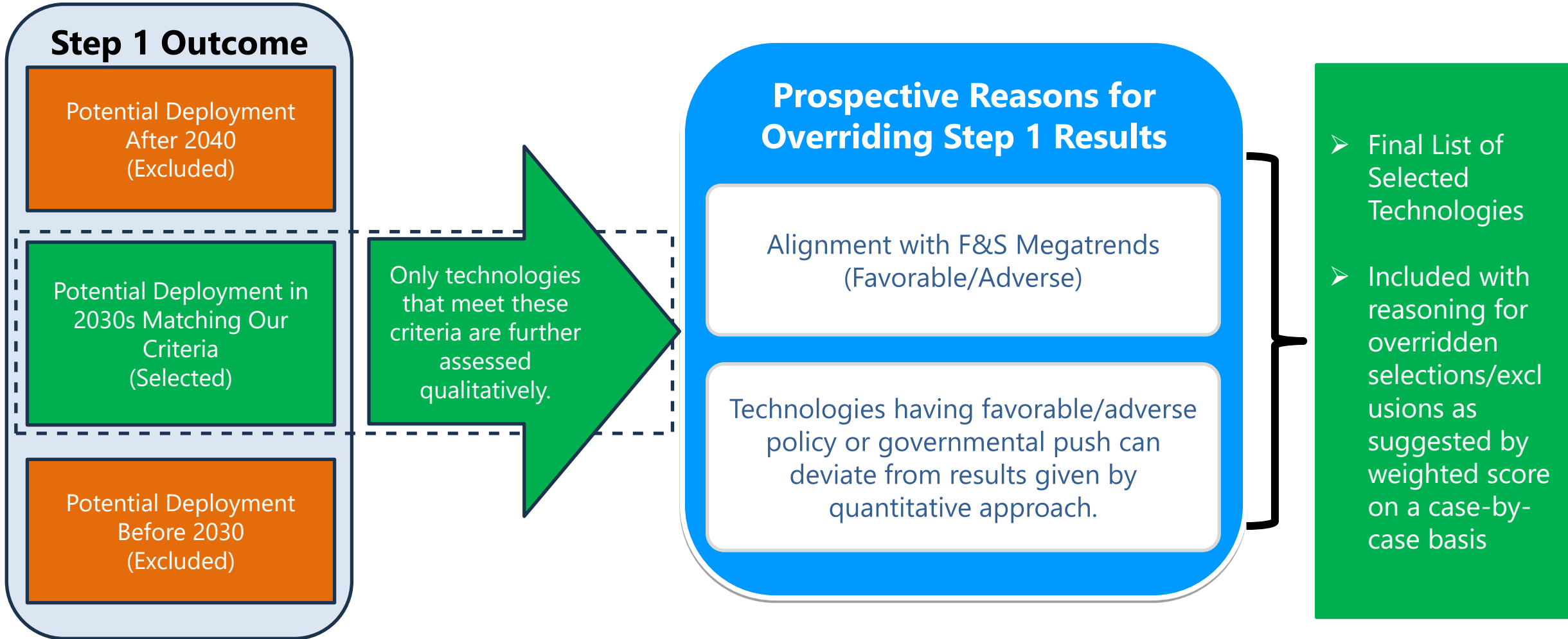
STEP 1: QUANTITATIVE ASSESSMENT BASED ON WEIGHTED AVERAGE SCORE OF TRL, BRL AND HRL GIVES INITIAL LIST OF SHORTLISTED TECHNOLOGIES

A key feature of Step 1 in the technology selection process is that each evaluation element for the technologies was first quantified using individual scores, which were then combined into a weighted score to enable a structured and quantitative assessment.



STEP 2: APPLYING QUALITATIVE ASSESSMENT TO FINALIZE THE TOP 100

A key feature of Step 2 in the technology selection process is that each technology was re-evaluated in light of broader technological trends, and decisions were made to re-select or exclude technologies as necessary, with clear, technology-specific justifications provided for each decision.



KEY FINDINGS 2/3

Evaluation of 153 Technologies

Out of the total 153 technologies, 94 fell within the threshold range in Step 1, while 59 fell outside it, including 27 with weighted scores above 8 and 32 below 5. In Step 2, 11 technologies that had initially fallen within the threshold were excluded, as they were assessed to have already been commercialized or likely to be commercialized before the 2030s due to recent technological progress. Conversely, among the technologies below the threshold (weighted score <5), 17 were reselected. These were identified as technologies benefiting from favorable momentum toward the 2030s, such as reconfigurable intelligent surfaces (RIS), causal AI, monolithic 3D ICs, and neuro-symbolic AI. Technologies that were not reselected can be broadly characterized as follows: those with weighted scores above 8 were all assessed as likely to be commercialized before 2030, while those with scores below 5 were not reselected due to insufficient maturity, limited business viability, or limited or undefined applicability.

Narrowed Down to 100 Technologies

Among the 99 technologies originally selected in TF2023*, 60 were reselected and 39 were excluded. The excluded technologies were assessed to have already been commercialized or expected to be commercialized before 2030. These include not only technologies that exceeded the upper threshold (weighted score >8) in Step 1—such as heat pumps, PEM/alkaline low-temperature electrolysis, satellite utilization, and weather forecasting—but also technologies that fell within the threshold yet were excluded in Step 2 upon further review, such as PEM, floating solar PV, and smart contracts.

* Note: During the reselection process, two of the original 100 technologies (Thin Film Solar Cells and Printable Solar Cells) were consolidated into a single category (Flexible Solar Cells), resulting in a total of 99 technologies.

LIST OF 100 TECHNOLOGIES 1–49

Power Generation

1. Vertical Axis Wind Turbines
2. Floating Wind Farms
3. Organic Solar Cells
4. Tidal Energy
5. Wave Energy
6. Small Modular Reactors
7. Advanced Geothermal—Closed-Loop Heat Harvesting
8. Wind Turbine Blade Circulation/Recycling
9. Bladeless Wind Turbines
10. Flexible Solar Cells
11. Airborne Wind Energy Generation
12. Perovskite Solar Cells
13. Hydrogen-Fueled Turbines
14. Floating Ocean Thermal Energy Conversion
15. Ammonia-Fueled Combustion Turbines
16. Dye-Sensitized Solar Cells (DSSCs)

Transmission & Distribution

17. Molten Salt Storage Systems
18. Grid Forming Inverters
19. Ultra-High Voltage DC
20. CO₂ Batteries
21. Sensible Heat Energy Storage
22. Sand Thermal Storage
23. Metal Air Battery
24. Dynamic Line Rating
25. Intelligent Universal Transformers

26. High Temperature Superconductors
27. Superconducting Magnetic Energy Storage (SMES)

Retail Customers

28. Bi-Directional Chargers
29. Virtual Power Plants
30. Multiple-Device Smart Meters
31. Internet of Energy
32. Net Zero Homes
33. Electric Vehicle—Battery Energy Storage
34. Autonomous Vehicles
35. DC Grids

Strategic Management

36. Sustainable Aviation Fuel
37. Lithium Manganese Iron/Ferrous Phosphate (LMFP) Batteries
38. Carbon Recycling
39. Green Hydrogen
40. Atmospheric Water Generation
41. SOEC High Temperature Electrolyzers
42. Bioenergy Carbon Capture and Sequestration
43. Offshore Hydrogen Production
44. Biohydrogen
45. Solar PV Module Recycling
46. E-Fuels
47. Carbon Emissions to Fuel
48. Liquid Organic Hydrogen Carriers
49. Hydrogen Blending in Natural Gas Pipelines

LIST OF 100 TECHNOLOGIES 50–100

Strategic Management (cnt'd)

50. Liquid Hydrogen Storage Systems on Ships
51. Direct Air Capture
52. Mixed-Salt Process (MSP) for CO₂ Capture
53. Wave-Powered Desalination Systems
54. Carbon Emissions into Minerals
55. Repurposing Existing Pipelines for CO₂ and Hydrogen
56. Membrane-Less Electrolyzers
57. Pink Hydrogen
58. Lithium-Sulfur Batteries
59. CO₂ Recycling for Geothermal Power
60. Causal AI

Common Technologies

61. Short-Wave Infrared (SWIR) Sensors
62. 3D/4D Imaging Sensors
63. Frequency Modulated Continuous Wave (FMCW) / 4D LiDAR
64. Single-Photon Avalanche Diode (SPAD) LiDAR
65. Advanced Li-Ion Batteries
66. Tokenization of Renewable Energy Certificates
67. Sodium-Ion Batteries
68. Adaptive Sensor Networks
69. Solid-State Batteries
70. Neuro-Symbolic AI

Cutting Edge Technologies

71. Multimodal Generation

72. Post-Quantum Cryptography (PQC)
73. Edge-AI-Enabled Sensors
74. Event-Based Vision Sensors
75. Interoperable Blockchain
76. Agentic AI
77. Cognitive Radio Networks
78. Cold Spray Additive Manufacturing (CSAM) 2.0
79. Gallium Oxide Electronics
80. Self-Healing Components
81. Zero Touch Automated Networks
82. Generative AI-Driven Manufacturing
83. Fully Homomorphic Encryption (FHE) Accelerators
84. Energy Harvesting Wearables—Smart Textiles
85. Additive Friction Stir Deposition (AFSD)
86. Metacognitive AI
87. Quantum AI
88. Friction Stir Additive Manufacturing (FSAM)
89. Reconfigurable Intelligent Surfaces (RIS)
90. Monolithic 3D ICs
91. Neuromorphic Sensors
92. Quantum Sensors
93. Cross Domain Federated Learning
94. Quantum Dot Solar Cells
95. Zero-Gravity Manufacturing
96. Laser Fusion
97. Volumetric Additive Manufacturing (VAM)
98. Magneto-Inertial Fusion
99. 5D Optical Storage
100. 4D Printing

SELECTED TECHNOLOGIES—REASON AND ANALYSIS

Of the 99 technologies selected in TF2023, 60 were re-selected. In addition, 54 new candidate technologies were considered, of which 40 were ultimately selected for inclusion in the final list of 100 technologies and are presented as file cards in this report. Some of these selected technologies had relatively low weighted scores; however, they were reinstated following a review based on alignment with the megatrends identified by F&S. The rationale for each such decision is provided individually in this report.

A comparison of the final set of 100 technologies by category shows a relative decrease in the number of technologies in the fields of power generation, retail customers, and common technologies, while only the cutting-edge technologies category saw an increase. The key characteristics of selected technology groups are outlined below.

Enabling technologies with cross-sector spillover

- Sensors (LiDAR, SWIR, event-based, quantum), adaptive sensor networks, edge-AI sensors, and neuromorphic systems act as foundational enablers across mobility, energy, defense, and manufacturing.
- AI stack (agentic, causal, neuro-symbolic, quantum AI, multimodal) accelerates autonomy, optimization, and decision intelligence.
- New generation electrolyzers such as SOEC, membrane-less, as well as other hydrogen economy enabling technologies like hydrogen carriers, hydrogen turbines, etc. have a potential commercialization window in 2030s.
- Emerging battery chemistries such as LMFP batteries, Lithium-sulfur batteries, as well as technologies in grid management like Dynamic Line Rating and SMES are also becoming important with the increased penetration of RE in grids.

EXCLUDED TECHNOLOGIES—REASON AND ANALYSIS

In TF2025, 100 technologies were selected out of the total 153 technologies assessed, while 53 technologies were excluded. The primary reasons for exclusion are summarized below. Among the 99 technologies originally selected in TF2023, 39 were excluded in this revision. Detailed explanations for the exclusion of each individual technology, including these cases, are provided in this report.

Already mature or commoditized: limited differentiation (Commercial before 2030)

- Technologies such as machine learning, digital twins, sensor fusion, smart contracts, zero-trust architecture, teleoperated robots, AR/VR, smart glasses are widely deployed today.
- Technologies such as PEM Electrolyzers, flow batteries, heat pumps, etc. are already commercial and in mainstream use today.

Crowded solution space with weak relative advantage (Limited business viability)

- Metal 3D printing, laser cladding, solid-state LiDAR face intense competition and cost pressure.

Long-term or research-heavy with limited near-term impact (Insufficient maturity)

- Quantum computing, fault-tolerant quantum computing, quantum cryptography, quantum manufacturing, remain predominantly R&D-led.
- Multi-valent batteries, nuclear fusion, radioisotope batteries, etc. are some technologies which need a lot of R&D work to materialize in coming years.

KEY FINDINGS 3/3

File Cards of Selected Technologies

The technologies were classified into six categories: Power Generation, Transmission & Distribution, Retail Customers, Strategic Management, Common Technologies, and Cutting-Edge Technologies. Compared to TF2023, the composition of the final 100 technologies shows an increase only in the Cutting-Edge Technologies category.

The final 100 technologies were compiled into “file cards,” each summarizing the technology overview, impacts on the economy, regions, power business, and society, future outlook, and key companies and projects involved in development.



- For the 100 technologies across six categories, F&S studied each technology in detail and developed file cards using the following parameters:
 - Technology Readiness Level: Capturing the technology's progress toward commercialization.
 - Human Readiness Level: Capturing the technology's ability to operate safely among humans and its acceptance.
 - Business Readiness Level: Assessing the extent to which technologies at that stage are adopted by industries.
 - Economics or Economic Impact: Capturing the economic feasibility of the technology compared with current costs.
 - Regional Aspect or Regional Impact: Capturing the technology's relevance or acceptance in various geographies.
 - Impact on Electric Power Business: Capturing how the technology would influence the future of the electric power business.
 - Impact on Society: Capturing the technology's influence on end consumers and the environment.
 - Development Entities: Identifying prominent entities working on the technology.
 - Projects: Identifying major projects led by some of the leading development entities.
 - Other reference material: Providing readers with additional technical and economic analysis on the technology.

MORE CONTENTS IN MAIN VOLUME ½

—Partial List of 153 Technologies Based on Weighted Scores with Include/Exclude Reasons

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153 TECHNOLOGIES RANKED BY WEIGHTED SCORE 3/10

No. (WS Rank)	No. (100 Techs)	TECHNOLOGY (Newly Added in BLUE)	TRL (60%)	HRL (15%)	BRL (25%)	Weighted Score (WS)	Related Megatrends*										Assessment Notes ● Selected, ● Selected via Override, ● Excluded, ● Excluded via Override
							1	2	3	4	5	6	7	8	9	10	
32	37	LITHIUM MANGANESE IRON/FERROUS PHOSPHATE (LMFP) BATTERIES	8	7	8	7.85	✓								✓		● Selected: Meets criteria
33	71	MULTIMODAL GENERATION	8	7	8	7.85		✓				✓	✓				● Selected: Meets criteria
34	38	CARBON RECYCLING	9	6	6	7.80									✓		● Selected: Meets criteria
35		FLOATING SOLAR PANELS	8	8	7	7.75											● Excluded via Override: Commercial before 2030 Floating solar is widely deployed globally, with companies such as Ciel & Terre, Sungrow , ENGIE, and Ocean Sun leading large-scale projects. https://ciel-et-terre.net/ https://oceansun.no/our-projects/ https://www.eqmagpro.com/in-india-engie-secures-100-mw-solar-project-with-seci-expands-clean-energy-portfolio-eq/
36	1	VERTICAL AXIS WIND TURBINE	8	8	7	7.75									✓		● Selected: Meets criteria
37		SOLID-STATE LIDAR	8	8	7	7.75											● Excluded via Override: Commercial before 2030 Solid-state LiDAR is already entering large-scale commercial use and is expected to become a standard sensing component.
38	62	3D/4D IMAGING SENSORS	8	8	7	7.75		✓				✓	✓				● Selected: Meets criteria
39	72	POST-QUANTUM CRYPTOGRAPHY (PQC)	8	8	7	7.75	✓	✓				✓					● Selected: Meets criteria
40	17	MOLTEN SALT STORAGE SYSTEMS	8	7	7	7.60					✓			✓			● Selected: Meets criteria
41	29	VIRTUAL POWER PLANT	8	7	7	7.60					✓			✓			● Selected: Meets criteria
42	30	SMART METERS FOR MULTIPLE DEVICES	8	7	7	7.60					✓			✓			● Selected: Meets criteria
43	31	INTERNET OF ENERGY	8	7	7	7.60					✓			✓			● Selected: Meets criteria
44	39	GREEN HYDROGEN	8	7	7	7.60	✓							✓			● Selected: Meets criteria
45	40	ATMOSPHERIC WATER GENERATION	8	7	7	7.60								✓			● Selected: Meets criteria
46	32	NET ZERO HOMES	7	8	8	7.40					✓			✓			● Selected: Meets criteria
47	41	SOEC HIGH-TEMPERATURE ELECTROLYZERS	7	8	8	7.40	✓							✓			● Selected: Meets criteria
48	42	BIOENERGY CARBON CAPTURE & SEQUESTRATION	8	7	6	7.35								✓			● Selected: Meets criteria

MORE CONTENTS IN MAIN VOLUME 2/2

—Excerpt from a File Card of Selected 100 Technologies

Re Reselected

Within Threshold

Back to 100 List

13. HYDROGEN-FUELED TURBINES

Hydrogen Power || Gas Turbines

Technology Overview

A hydrogen-fueled gas turbine is a modified combustion turbine that uses hydrogen as its primary fuel instead of natural gas – upon which commercial gas turbines depend. Hydrogen gas turbines fueled by a mixture of hydrogen and natural gas have already been demonstrated commercially for power generation. However, developing a purely hydrogen-based gas turbine is constrained by the differences in the properties of hydrogen and natural gas. For utilizing 100% hydrogen as a fuel, the premixing, fuel delivery, control systems as well as the power plant safety systems need to be modified to handle hydrogen's high flame speed, low density, etc.

Power Generation



Current Technology Opportunity Stage

Nascent



Technology Disruptiveness

Step Change

Potential to turn existing gas-fired power infrastructure into near-zero-carbon, fast-ramping firm power providing solution

Relevance to F&S Megatrends

2 Megatrends

- Rise of a Multi-Polar World Order
- Energy Sovereignty and Decarbonization

Weighted Score
5.25

Economics

[Impact Score: 4/5]

Hydrogen turbines are expensive to build, and the fuel cost (green H₂) is still not yet competitive with natural gas. Without subsidies and public policy efforts, the economics might not be favorable for most global regions. However, as demand for hydrogen increases, economies of scale is expected to reduce the price of hydrogen further. These developments might make the gas turbine driven by hydrogen economically viable in the coming years.

Technology Readiness Level



TRL 5 – Prototype tested in relevant field environments

Regional Aspect

[Impact Score: 2/5]

The global impact is expected to be uneven and region dependent. Countries that have abundant renewable energy resources, strong policy incentives, and existing industrial hydrogen use (e.g., EU, Japan, North America) are likely to see early deployment. Developing regions typically lack hydrogen infrastructure as well as strong decarbonization policies. Moreover, hydrogen turbines are expected to

AND MORE

Future Work

Future work will involve scenario analysis on regional differences and market potential, using four additional analytical dimensions: applications of artificial intelligence, geopolitics, supply chains, and long-duration energy storage (LDES). The results will be compiled in the TF2026 report.