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Catching Up or Leaping Ahead? How Energy Innovation Can Secure U.S. Industrial Stature in a Net-Zero World—Abbreviated Version

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U.S. clean energy and industrial strategy should accelerate "leapfrog" technologies that circumvent supply chain vulnerabilities, capitalize on existing labor force, and offer cost-competitive alternatives in less saturated sectors. China's lead across net-zero technologies poses a geostrategic challenge to the United States, which needs an "innovation-first" agenda to propel advanced technologies to market and develop a low-carbon domestic industry.

Key Findings

The analysis highlights where U.S. next-generation technologies have attracted institutional investment, measured by low-carbon market opportunity, commercial proximity, and impact on incumbent technologies and their supply-chain risks (see figure 1).

- Batteries and magnetic motors are crucial for macroeconomic and national security. The United States could compete on next-generation batteries with lower supply risks that use silicon, lithium metal, and lithium-metal sulfur technology. Advanced magnet technology that does not require rare earth minerals is less well developed.

- Critical minerals production has potential, especially for advanced lithium extraction, mineral processing, and material production. Battery recycling is at a later stage of commercialization but will not abate the need for more extraction.

- Next-generation geothermal is the decisive sector where U.S. technology and industry could drive low-carbon growth and prove internationally competitive.

- Advanced grid and storage are areas of industrial opportunity; relevant technologies are close to commercialization but have varying levels of resilience potential.

- Advanced power generation like next-generation solar, offshore wind, and nuclear energy is a sector where leapfrog potential is less clear and it remains difficult to compete against Chinese industry, albeit beneficial for domestic decarbonization.

- Low-carbon heavy industry and fuels are areas where U.S. technology could be at an advantage, with high proximity to commercialization. Some advanced hydrogen processes are at earlier stages but have leapfrog potential.

These key findings are drawn from Milo McBride's paper "Catching Up or Leaping Ahead? How Energy Innovation Can Secure U.S. Industrial Stature in a Net-Zero World," Carnegie Endowment for International Peace, September 19, 2024..

Domestic Policy Considerations

Macroeconomic conditions have muted growth-funding markets, which exacerbates the need to support startup technology to commercialization through the following mechanisms:

- Tax extender provisions to the Inflation Reduction Act could include bonus tax credits for next-generation power and storage technologies to pull them to market and help them compete with incumbents; other tax credits could be leveraged for advanced grid and low-carbon industry (these incentives should expire eventually to prevent subsidy reliance).
- Treasury rulings could favor high-impact next-generation technology over incumbents; for example, more restrictions on Chinese minerals for electric vehicle battery subsidies would benefit next-generation tech that replaces graphite with lithium metal or silicon.
- Government procurement should target leapfrog technologies that boast long-term resilience benefits. Federal vehicle fleets with lithium-metal (sulfur) batteries or non–rare earth magnets could start the phaseout of Chinese incumbent technology and minerals.
- Coordination with state governments and electricity regulators could further demand-pull mechanisms for clean firm power generation and storage like advanced geothermal, nuclear, and long-duration batteries.
- Regional innovation and testing hubs should continue to be pursued, with new opportunities like lithium metal batteries in Georgia and lithium extraction in Arkansas; expanding the geothermal hub in Utah might include other drilling techniques.
- The Energy Act could authorize the Department of Energy's (DOE) Office of Manufacturing Energy Supply Chains as a center for supply chain security with a focus on next-generation batteries and mineral processing. The DOE's Office of Clean Energy Demonstrations could offer funding for geothermal hubs as it did in the hydrogen and direct air capture sectors.
- To further incubate new technologies, the Energy Act could direct greater funding to the Advanced Research Projects Agency – Energy; tax extender provisions could streamline the amortization of R&D expenditures to help startups and impose R&D minimums for larger firms.

International Policy Considerations

- Diplomacy for science could target areas where U.S. know-how is less advanced, like mineral processing with Finland or Canada, or areas where the United States and other countries share mutual interest in discovery, like geologic hydrogen with France or Australia, or super-hot rock geothermal with Kenya or Iceland.
- R&D and commercial collaboration should be prioritized in nonpartisan, multilateral fora like the Quadrilateral Security Dialogue, where next-generation solar and advanced battery metal processing offer opportunities for international alignment.
- For dual-use technologies like batteries and magnets, the United States should consider exporting the manufacturing of next-generation systems that do not require Chinese minerals (especially to allies facing analogous supply risks).
- The United States could develop export market potential in advanced grid and battery storage systems, especially in regions with high renewable penetration, weak power grids, and concerns about the increasing prevalence of Chinese critical infrastructure.
- Low-carbon heavy industrial processes could be prioritized for diffusion into emerging and developing markets for manufacturing.
- Next-generation geothermal could be targeted toward countries with existing geothermal industries like Indonesia, Kenya, Türkiye, and the Philippines, as well as countries with state-owned oil and gas companies.

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Figure 1. U.S. Next-Generation Energy and Industrial Technologies Have Varying Potential

● Power ● Mobility ● Defense ● Industry ● Heating ● Agriculture ● Consumer Electronics

Sector	Gap to Net-Zero	Sectors Impacted	Next-Generation Technology	Catalytic Impact on Resilience	Commercial Proximity
Critical Minerals	Medium	Power, Mobility, Defense, Consumer Electronics	Direct lithium extraction	High	Medium-High
			Battery recycling	Medium	High
			Advanced processing and materials	High	Medium-High
Permanent Magnet	Medium	Power, Mobility, Defense, Consumer Electronics	Iron nitride magnets	High	Medium
Battery	Low	Mobility, Defense, Consumer Electronics	Lithium-sulfur batteries	High	Medium
			Lithium-metal batteries	Medium	Medium
			Silicon anode batteries	Low-Medium	Medium-High
Stationary Storage	Low	Power	Sodium-ion batteries	High	Medium-High
			Iron-air flow batteries	High	High
			Nickel hydrogen batteries	High	High
			Zinc bromine batteries	High	High
			Geopressured geothermal system	High	Low-Medium
Power Grid	Medium	Power	Advanced conductors	Low	High
			Dynamic grid management	Low	High
			Distributed energy integration	Low	High
Solar	Low	Power	Perovskite solar cell	Medium	Low-Medium
Wind	Low	Power	Floating offshore wind turbines	Low	Low-Medium
Geothermal	Medium	Power, Industry	Enhanced geothermal systems	High	High
			Advanced geothermal systems	High	Medium
			Super hot rock geothermal systems	High	Low-Medium
Nuclear	Medium	Power	Fusion	High	Low
			Generation IV fission	Medium	Low-Medium
Clean Hydrogen Fuels	Medium	Mobility, Industry, Agriculture	Photocatalytic	High	Low-Medium
			Pyrolytic	Medim	High
			Geologic	High	Low-Medium
Clean Heat	High	Industry	Molten salt batteries	Low	High
			Thermal batteries	Low	High
			High-temperature heat pumps	Low	Medium
Cement	High	Industry	Electrochemical	Low	High
			Material substitution	Low	Medium-High
			Biomimetic	Low	Medium
Steel	High	Industry	Molten oxide electrolysis	Low	Medium-High
			Electrochemical	Low	Medium
			Laser diode	Low	Low
			Hydrogen-direct reduced iron	Low	Medium-High
Sustainable Aviation Fuels	High	Mobility	Fischer-Tropsch	Low	Medium-High
			Carbon re-utilization	Low	Medium
			Alcohol-to-jet	Low	Medium-High

Notes: The gap to net-zero emissions refers to different ranges including low (0–249%), medium (250–999%), and high (1,000%+). In the case of catalytic impact on resilience, low means reduced emissions or enhanced legacy technology with no resilience impacts, medium means new technology that enhances sector growth and displaces some supply chain risks, and high means new technology that displaces incumbent technology and reduces all supply risks. In the context of commercial proximity, low means that a technology is in early stage R&D, medium means that a technology is at the pilot stage, and high means that a technology has begun deployment or scheduled to start commercial-scale demonstration or factory production (a low-medium score could imply firms are beginning to develop a pilot facility or that multiple firms developing the same technology are observed between the low and medium stages). All technologies are in reference to U.S. domiciled companies.

Source: Author's analysis, "Gap to Net Zero" based on Allen et Goldman, Johns Hopkins Net-Zero Industrial Policy Lab via data from BloombergNEF, International Energy Agency, WoodMackenzie.