Cleantech That Will Thrive in 2025

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The 2025 cleantech environment

- Frontier technology strategies: Finesses and Game-Changers
  Robert A. James, *Finesses and Game-Changers in Frontier Project Development*
  (Stanford Program on Energy and Sustainable Development Working Paper No. 87 (2009))
- Can't *depend* on federal policy and incentives to turn **red** to **green**
- Can *benefit* from removal of obstacles in permitting and access to resources
- Can look to broader geographic and application reach, and sources of support (private, states, foreign)
- Renewed focus on monetization opportunities
- Energy investments have a time horizon > 48 months

Cleantech to thrive in 2025

On my February virtual desk:

- **Carbon capture, use and sequestration**
- **Methane emission reduction**
- **Advanced geothermal**
- **Modular nuclear reactors**
- **Critical minerals**

Carbon Capture: Why It Thrives

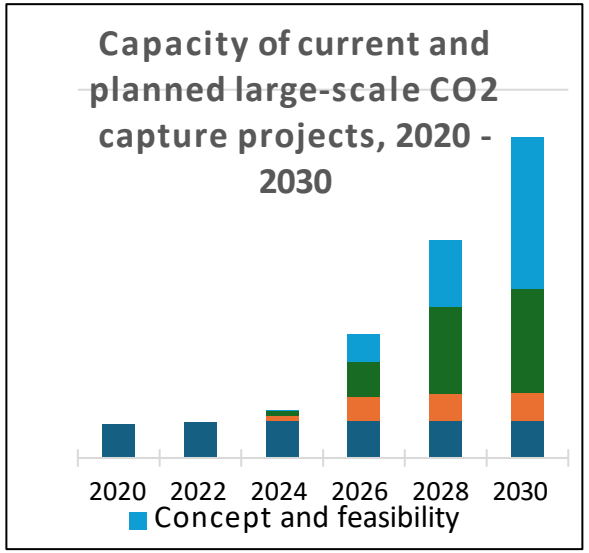
Projects Grounded Beyond Federal Incentives
- 45Q tax credits not sufficient to turn red to green
- Built instead primarily on enhanced oil recovery, salable products, and zero-emission power buyers

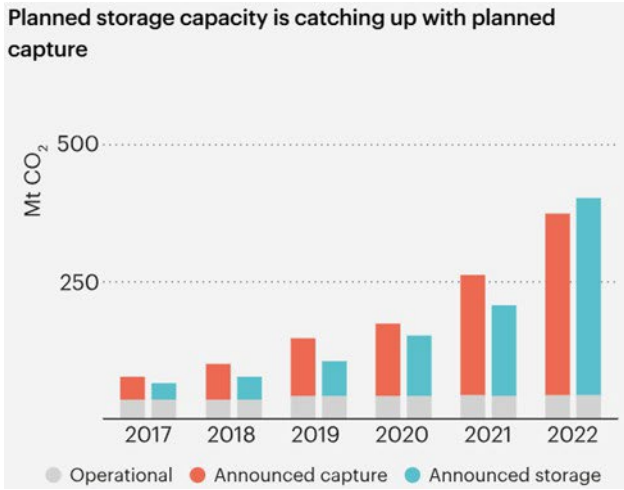
Aligns with Administration Goals
- Sustains fossil industries, domestic production
- Streamlined permitting and greater property access

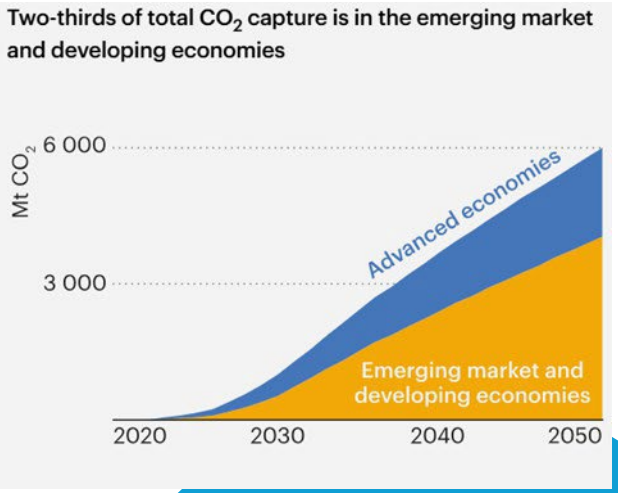
Global Capacity Growth (70% developing world)
- 45 operational facilities capture 50+ Mt CO_2/year
- Announced 2030 capacity: 435 Mt CO_2 capture, 615 Mt CO_2 storage

Technological Innovation
- Hybrid and modular system capture rates exceed 98%

U.S. Leadership Momentum?
- $1.7B allocated for CC demonstration projects; $1.2B for DAC hubs under 2021 Infrastructure Act







Methane Emission Reduction: Why It Thrives

Economic Potential

- Methane leaks cost the U.S. oil and gas industry $2 billion/year; globally, losses reach $30 billion/year
- Reducing leaks will enhance competitiveness of U.S. oil and gas industry

Industry and State Support

- Some states and companies are implementing or exploring methane reduction efforts independent of federal action
- Industry venture funds at work here (Climate Investment UK)

Enhanced Technological Ability

- **Frequency Comb Laser:** Pinpoints leaks to a 5 m^2 area, monitors continuously for weeks/months
- **Drones:** Detect leaks as small as 10 g/hr, open-source designs for global adoption
- **LiDAR Systems:** High-resolution aerial mapping for large-scale leak detection

Advanced Geothermal: Why It Thrives

Supports Administration Goals

- Aligns with using oil and gas assets, technology, workforce
- Provides baseload power for enhanced grid reliability and energy security

New Technology Expands Deployability

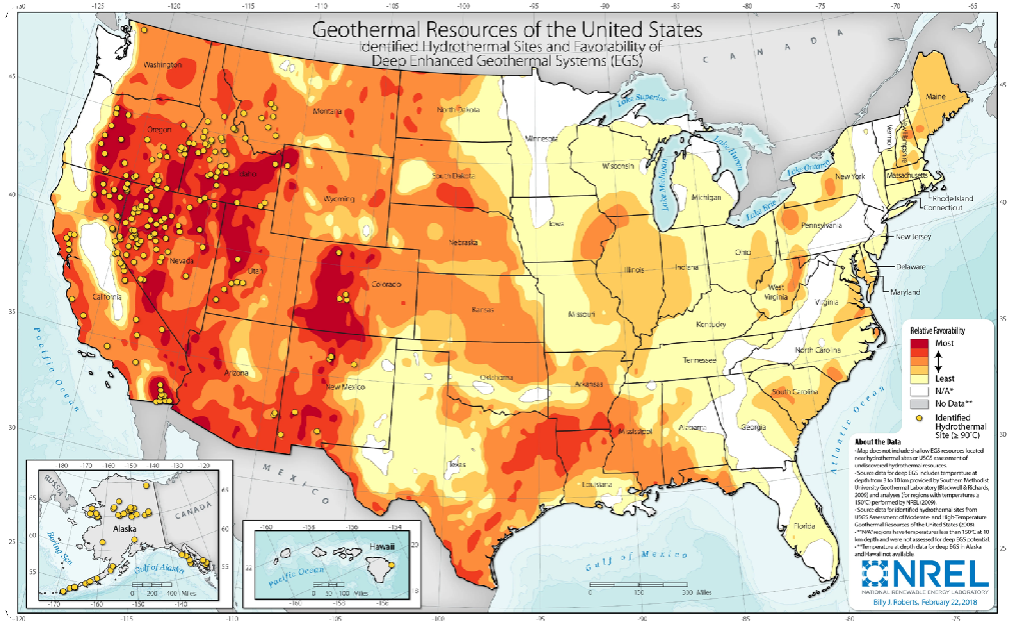
- *Not just the Mountain West and Iceland!*
- **EGS** : horizontal drilling, extreme heat tools; drill deeper, inject fluids, extract heat from dry, less permeable rock
- Broader scalability and regional deployment potential

Massive Untapped Resource

- U.S. geothermal reserves hold **5 TW of geothermal heat**, enough to meet global electricity demand

Additional Applications

- Geothermal brine: lithium extraction for many applications
- Energy storage innovations using the Earth's heat



Advanced Geothermal

Key Projects:

- **DOE:** $60M for Chevron, Fervo Energy, Mazama Energy pilot programs to power 65M homes
- **Fervo Energy, UT**: world's largest plant by 2026; **e**xploring HT geothermal + horizontal drilling in TX
- **Controlled Thermal Resources, California's Salton Sea:** to produce 25,000 MT of Li/year plus power
- **Eavor, DOE, U.S. Air Force:** geothermal energy solutions for Joint Base San Antonio
- **Sage Geosystems, Earthstore** – $14M, 3MW (potentially scalable to 50+ MW) facility in TX, stores electricity using Earth's heat to efficiently move water to and from underground fractures

Image: Sage Geosystems

Image: NREL

Modular Reactors: Why They Thrive

- Modularity, factory construction
- Improved safety features
- Emission-free generation rewarded locally and globally
- Baseload capability
- Repower existing fossil fuel sites
- Beyond juice: industrial heat, desalination, H_2 production

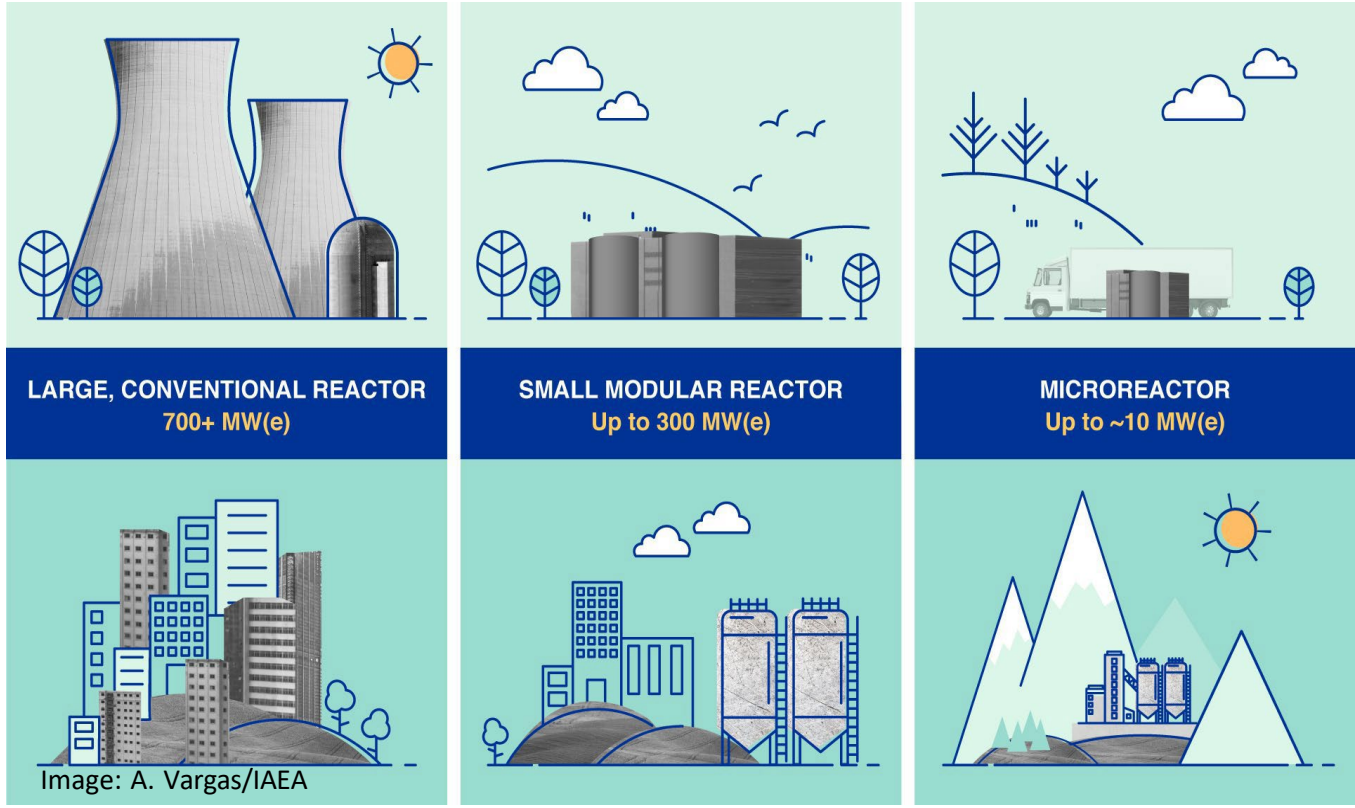


Image: A. Vargas/IAEA

Modular Reactor *Racing Form*

Classification	Design	Nameplate Capacity	Details & Status
Pressurized Water Reactor (PWR)	NuScale Reactor	77 MWe	NRC Certified 50 MWe design in 2022.
	Holtec SMR 300	300 MWe	Two units to be deployed at Palisades site in Michigan.
	Westinghouse AP300	300 MWe	Smaller version of AP1000. Early discussions with USNRC.
	Westinghouse AP1000	1100 MWe	Full size AP1000 PWR. NRC design certified and successfully constructed at Vogtle Units 3 & 4.
Boiling Water Reactor (BWR)	GE-BWRX-300	300 MWe	Selected for deployment by Ontario Power Generation (OPG) and potentially TVA.
High-Temperature Gas Reactor (HTGR)	BWXT HTGR	15-20 MWe	Contract with Wyoming Energy Authority to evaluate placement at mining/industrial sites.
	X-Energy XE-100	80 MWe	Selected for DOE ARDP – Two units at Dow Texas site. Four units at Amazon/ EnergyNorthwest.
Molten Salt Reactor (MSR)	Natura Resources MSR	Non-power research 100 MWe commercial	Initial prototype research reactor received construction license for deployment at Abilene Christian University.
	Kairos Power Fluoride Salt-Cooled HT Reactor	150 MWe	Selected for $30 million risk reduction award by DOE. First non power units at Oak Ridge. 500 MWe deal with Google.
	Terrestrial Energy Integral Molten Salt Reactor	195 MWe	Selected for NRC pre-application & CNSC review.
Liquid Metal-Cooled Reactor (LMR)	TerraPower Natrium Sodium Fast Reactor	345 MWe 500 MWe (5.5 hrs)	Selected for DOE ARDP - construct near former coal plant in Wyoming.
	Oklo Aurora Sodium Fast Reactor	1.5 MWe 15 MWe	1.5 MWe design review by USNRC. 2 – 15 MWe units to be deployed in Ohio.

Critical Minerals

- "**Critical**" to the Nation's economy or national security ***and*** have supply chains that are vulnerable to disruption
  - Disruptions: foreign political risk, abrupt demand growth or price collapse, military conflict, violent unrest, anti-competitive or protectionist behavior, other risks
  - "Critical" either directly or vis-à-vis a product they're used to manufacture (energy, defense, communications, …)

Critical Minerals: Why They Thrive

They are in everything we need

- **Rare earth elements** used in semiconductors, EV motors
- **Lithium, cobalt, and high-purity nickel** used in energy storage technologies
- **Platinum group metals** used in catalysts for automotive, chemical, fuel cell, and green hydrogen products
- **Gallium and germanium** used in semiconductors, transmission lines

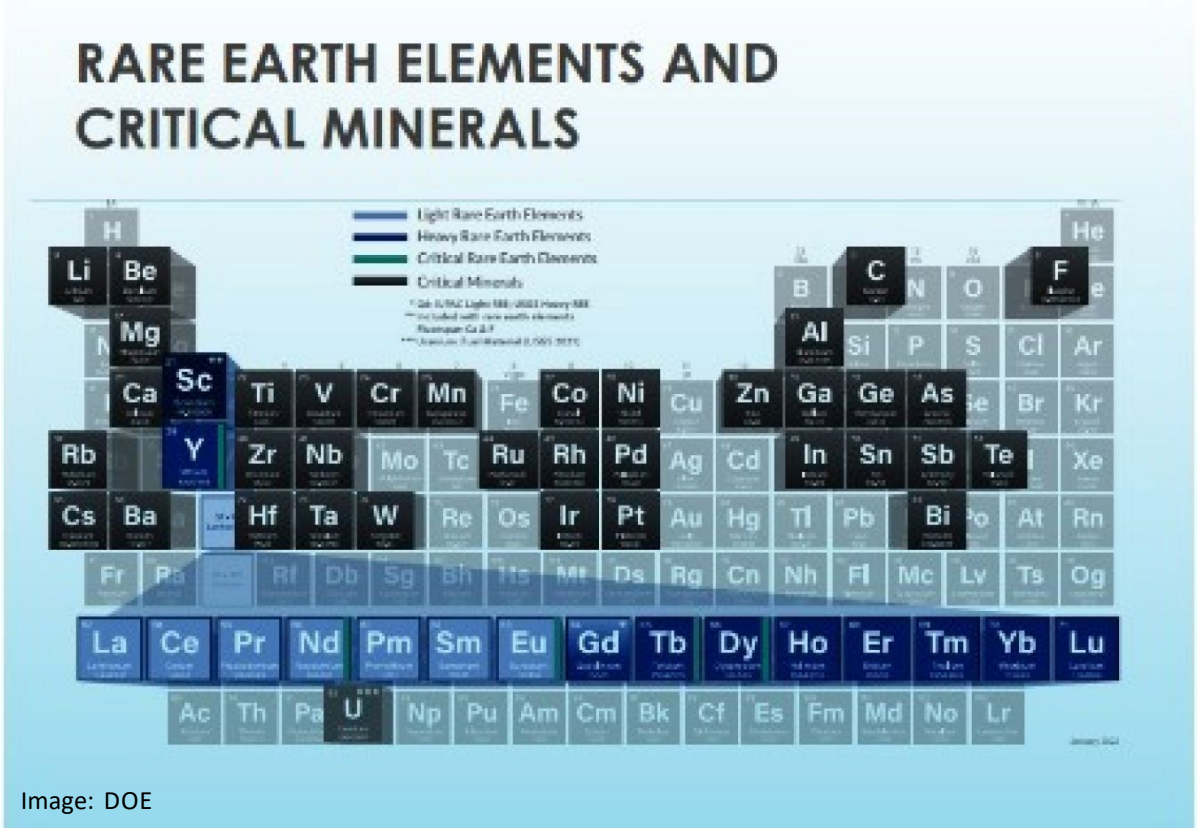


Image: DOE

Energy policy déjà vu

LBJ quoting KJV, "Let us reason together" (Isaiah 1:18)

- Energy Secretary Chris Wright's DOE speech and first order
- Liberty Energy (Secretary Wright's company): company's annual report
- Bjorn Lomborg, *The Skeptical Environmentalist* (2001) and
  Alex Epstein, *The Moral Case for Fossil Fuels* (2014)

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- Jody Freeman, *A Critical Look At "The Moral Case for Fossil Fuels,"* 36 ENERGY L.J. 337 (2014)
  2014 article
- Lisa Friedman, *Trump's Choice to Run Energy Says Fossil Fuels Are Virtuous,* N.Y. Times, Dec. 12, 2024
  recent NYT article
- Robert A. James, *Candor, Climate, and the Energy Transition*, 8 J. LEGAL METRICS 11 (2023)
  advocating candor about transition goals

All are worthy of your respect and consideration!

Read and communicate beyond your tribe on all aspects of energy innovation

Consider all human and environmental consequences of energy policy

Thanks!

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