Data Centers and Artificial (General) Intelligence Energy Consumption in the Next Decade

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Energy Transition and Climate Adaptation

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AGENDA: Mega Trends

1. AI and Power Infrastructure

2. Electrification and Decarbonizing

3. Climate Change and Adaptation/Resilience

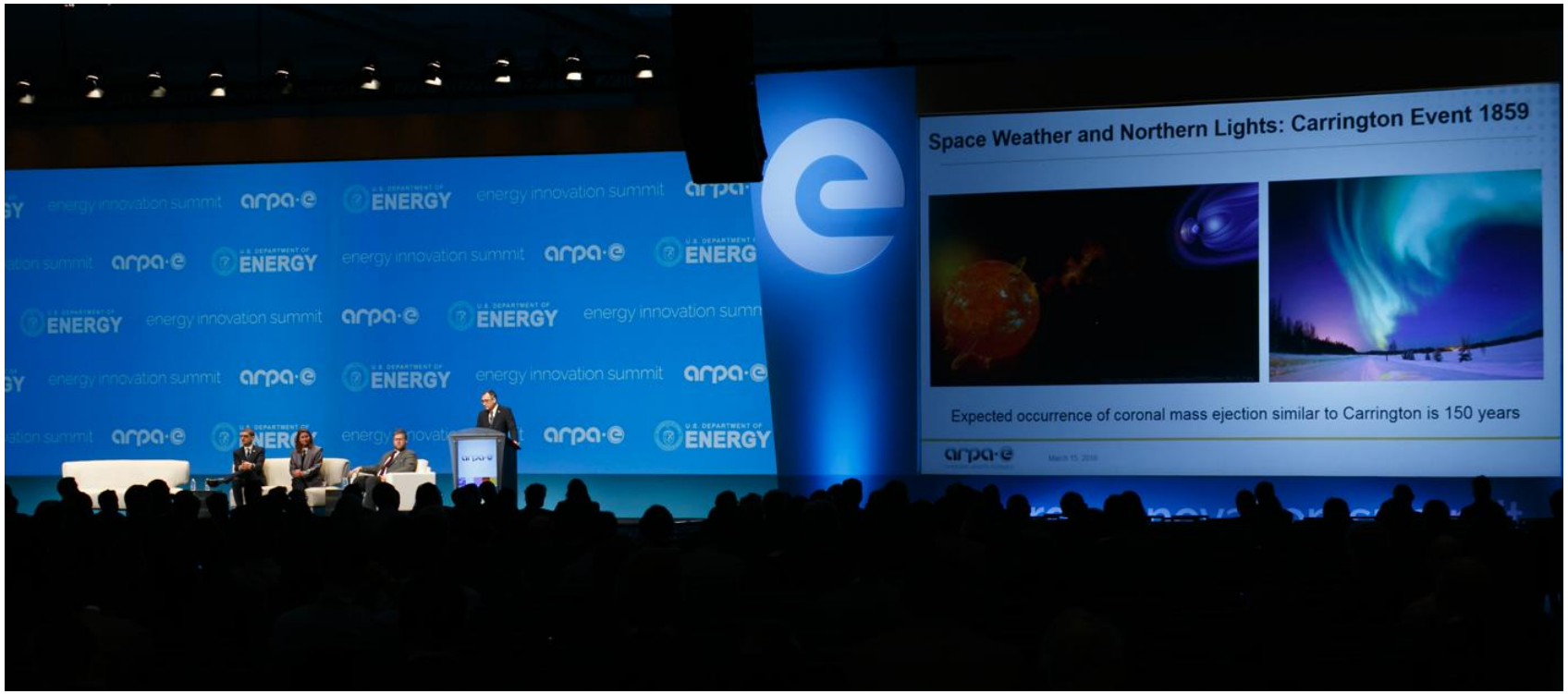
You can see the future first in San Francisco.

Over the past year, the talk of the town has shifted from $10 billion compute clusters to $100 billion clusters to trillion-dollar clusters. Every six months another zero is added to the boardroom plans. Behind the scenes, there's a fierce scramble to secure every power contract still available for the rest of the decade, every voltage transformer that can possibly be procured. American big business is gearing up to pour trillions of dollars into a long-unseen mobilization of American industrial might. By the end of the decade, American electricity production will have grown tens of percent; from the shale fields of Pennsylvania to the solar farms of Nevada, hundreds of millions of GPUs will hum.

L. Aschenbrenner*, Situational Awareness - *The Decade Ahead*, June 2024

***Based on publicly available information, general field-knowledge, or SF-gossip.**

Grid Resiliency
~~Transformers, MV DC Distribution, SF_6 Free Switchgear~~

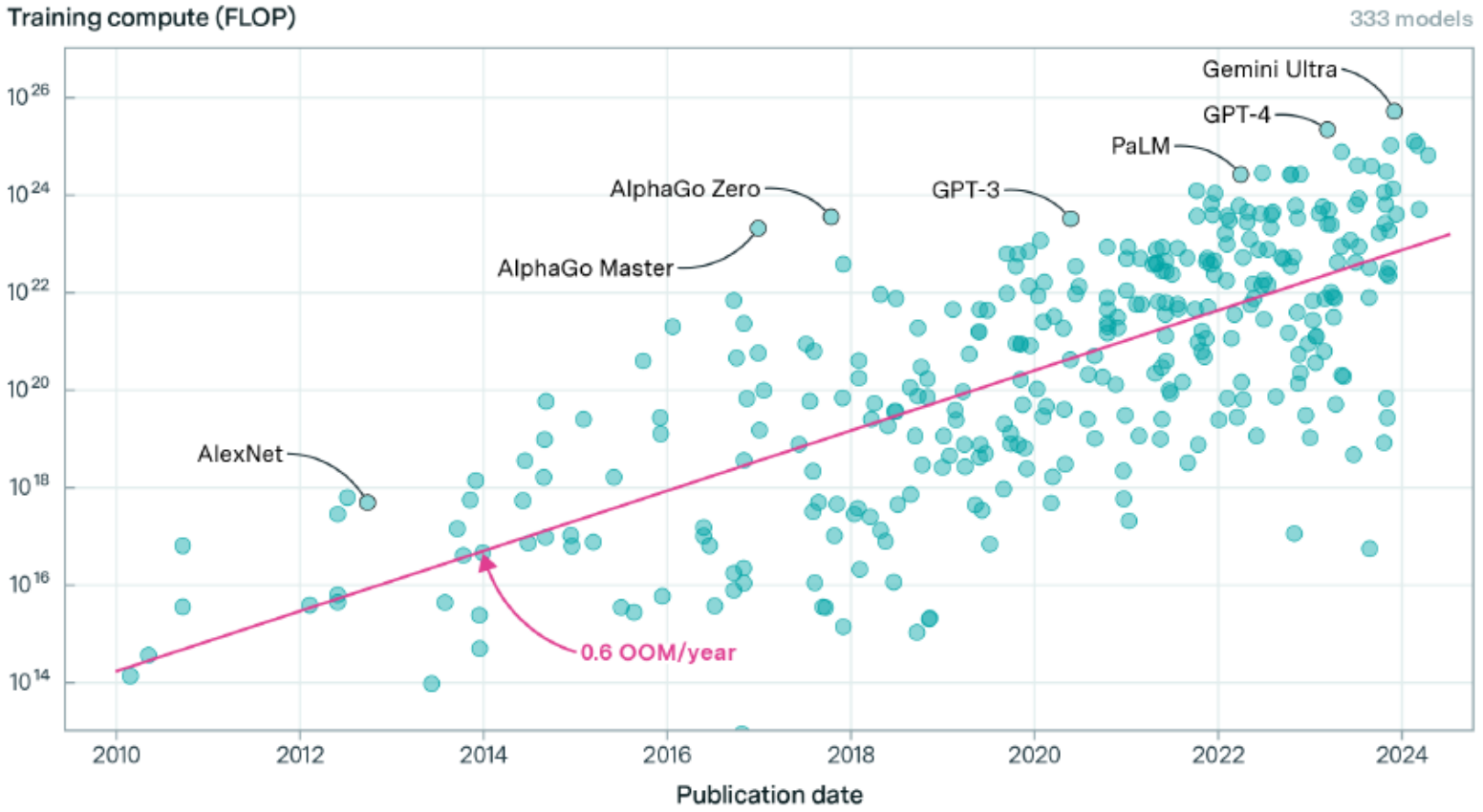


ARPA-E Energy Technology Summit 2018

Training Compute of Notable Models – Epoch AI

Performance on common exams
(percentile compared to human test-takers)

	GPT-4 (2023)	GPT-3.5 (2022)
Uniform Bar Exam	90th	10th
LSAT	88th	40th
SAT	97th	87th
GRE (Verbal)	99th	63rd
GRE (Quantitative)	80th	25th
US Biology Olympiad	99th	32nd
AP Calculus BC	51st	3rd
AP Chemistry	80th	34th
AP Macroeconomics	92nd	40th
AP Statistics	92nd	51st



EPOCH AI

https://epochai.org/

Scaling the Largest Training Clusters

Year	OOMs	H100s-equivalent	Cost	Power	Power reference class
2022	~GPT-4 cluster	~10k	~$500M	~10 MW	~10,000 average homes
~2024	+1 OOM	~100k	$billions	~100MW	~100,000 homes
~2026	+2 OOMs	~1M	$10s of billions	~1 GW	The Hoover Dam, or a large nuclear reactor
~2028	+3 OOMs	~10M	$100s of billions	~10 GW	A small/medium US state
~2030	+4 OOMs	~100M	$1T+	~100GW	>20% of US electricity production

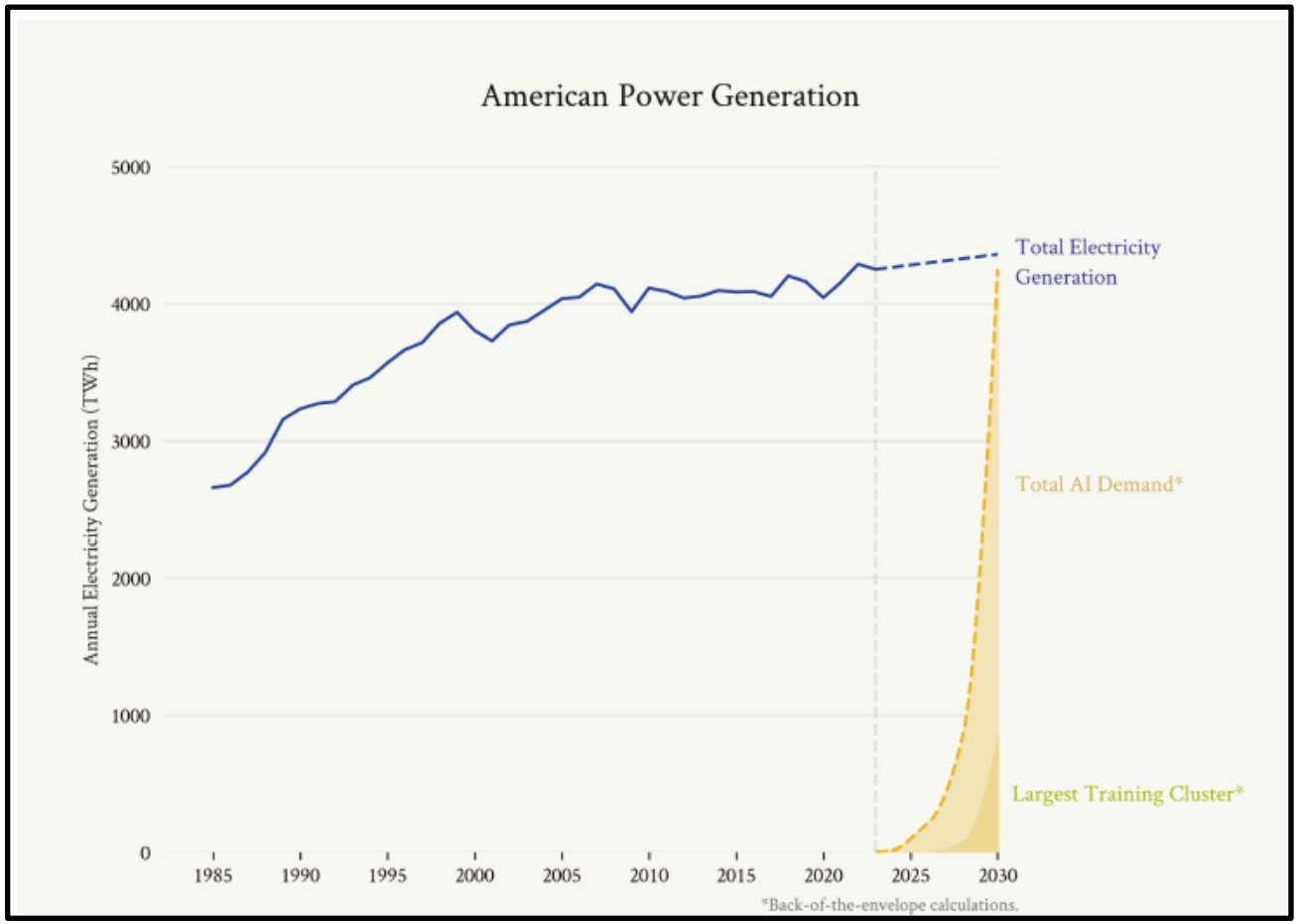
AI Accelerator Shipments and IC Production

Year	Annual investment	AI accelerator shipments (in H100s-equivalent)	Power as % of US electricity production	Chips as % of current leading-edge TSMC wafer production
2024	~$150B	~5-10M	1-2%	5-10%
~2026	~$500B	~10s of millions	5%	~25%
~2028	~$2T	~100M	20%	~100%
~2030	~$8T	~100s of millions	100%	4x current capacity

Racing to the Trillion-Dollar Compute Cluster

Utility Scale and Unsustainable Electricity Demand – Generation Behind the Meter or Not

Power appears to be the Single Biggest Constraint on the Supply Side



- Limited Spare Capacity
- NG(45% 550/1280GW)
- Power Contracts
  - Long Term
  - Locked-In
- Build GW Scale Reactor?
  - SMR 3-5 years
  - Large Scale 6 years

Wildest Part – Willingness-to-Spend is not the Limitation for Training Clusters

McKinsey Quarterly

The cost of compute: A $7 trillion race to scale data centers

April 28, 2025 | Article

The Economist

Weekly edition | The world in brief | World Ahead 2026 | War in Ukraine | United States | Middle East | The world economy | Business

Graphic detail | Moving target

For the first time, climate models show the 1.5°C goal is dead

Governments have failed to limit global warming. What comes next?

Save | Share

Nov 4th 2025 | 3 min read

Impact of 3°C Global Warming and “Climate Adaptation”

- **Extreme weather**: More frequent and severe heat waves, droughts, floods, and tornadoes
- **Rising sea levels**: The collapse of ice caps could lead to cities like Shanghai, Rio, Miami, and The Hague being submerged
- **Ecosystem loss**: The Amazon, Congo Basin rainforests could be endangered, Australia's ecosystems unrecognizable
- **Biodiversity loss**: Widespread loss of biodiversity, and some species may struggle to keep up with the rate of warming
- **Displacement of people**: Over a billion people could be displaced
- **Food and water shortages**: Food prices could spike, and food and water shortages could occur
- **Broken supply chains**: Supply chains could break
- **Contaminated drinking water**: Drinking water could be contaminated
- **Interference with irrigation systems**: Irrigation systems could be interfered with
- **Erosion, flooding, and soil contamination**: Erosion, flooding, and soil contamination could occur
- **Insect-borne diseases**: The risk of insect-borne diseases could increase
- **Energy demand**: Energy demand for air conditioning could skyrocket

Is nuclear energy the zero-carbon answer to powering AI?

After decades of stagnation, the world's biggest tech groups and banks are considering an alternative energy option

There has been a rush of demand for nuclear plants from the so-called hyperscale tech companies © FT montage/Getty Images

Financial Times, Oct. 3, 2024

Meta's Mark Zuckerberg says energy constraints are holding back AI data center buildout

"We would probably build out bigger clusters than we currently can if we could get the energy to do it"

April 19, 2024 By: Sebastian Moss Have your say

- **Microsoft**
  - **Three Mile Island – Constellation**
- **Google**
  - **Kairos Power (SMR) 1st in 2030**
  - ***Fervo Energy (Geothermal)***
- **Amazon**
  - **Dominion Energy (>300MW SMR)**
  - **Talen Energy's Cumulus Data**
- **Meta/Facebook**
  - **Sage Geosystems (150MW)**

Accelerating the Deployment of Nuclear Power

Competitive Operating Costs

$27M

GEMINA™

Competitive Construction Costs

$30M

MEITNER™

Reactor

Used Nuclear Fuel

NEWTON
$40 M

arpa·e NEWTON PROGRAM

New Fuel

Advanced Reactor (AR) Fuel Feedstock

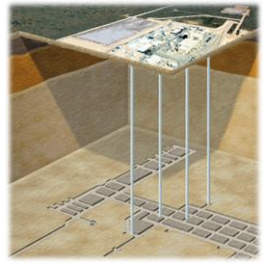
Fuel recycling

Waste

ONWARDS $36M

CURIE™ $38M

10X Reduction in repository waste volumes



ONWARDS

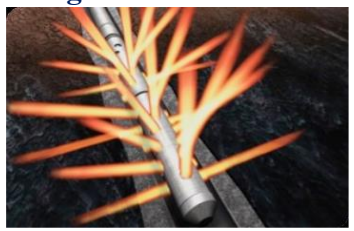
Waste Disposition

From Dr. R. Ledoux, Annual Technical Review, 9/18-9/19/2024

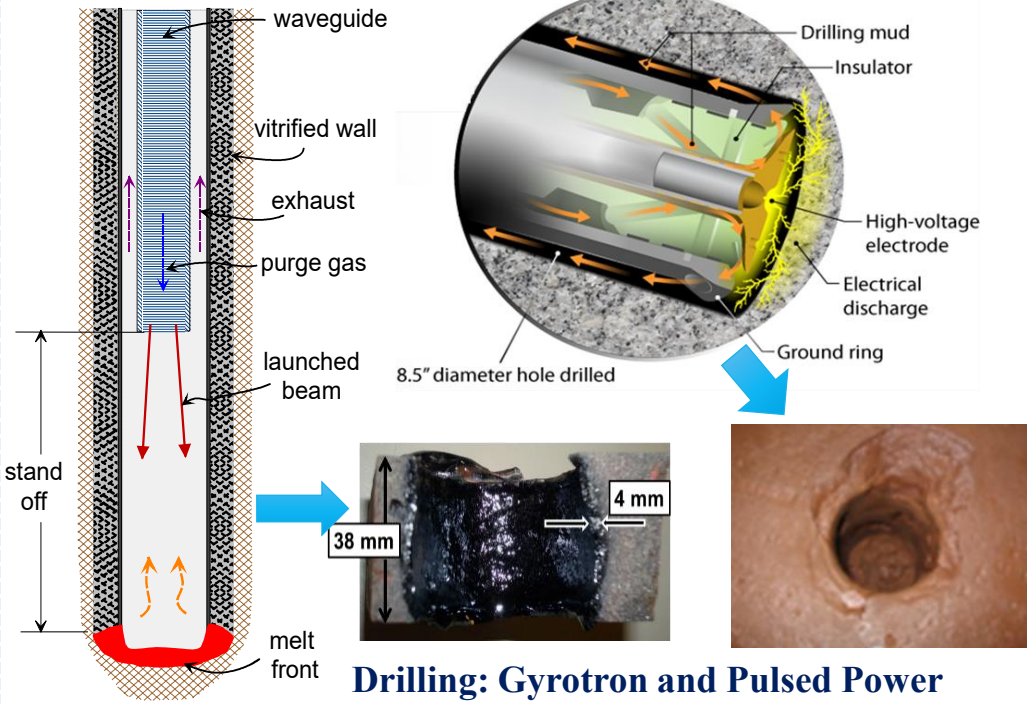
PLUTO: Subsurface and Subsea Instrumentation and Drilling

Decommissioning Subsea Assets using Laser Cutting

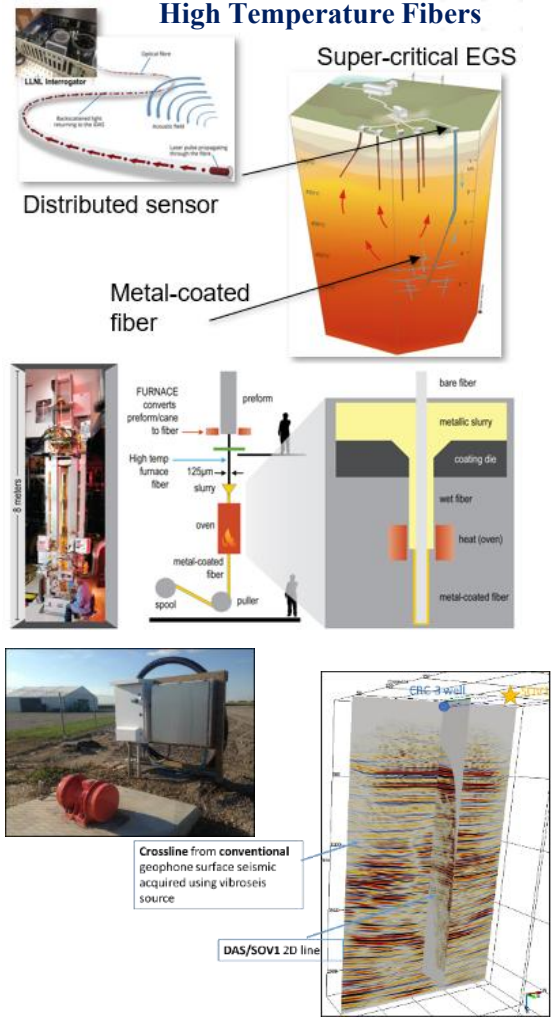




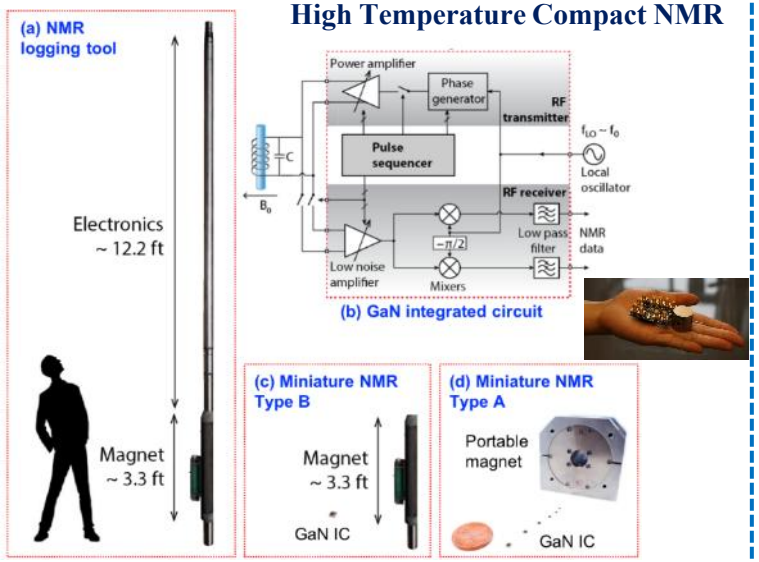
Drilling: Gyrotron and Pulsed Power



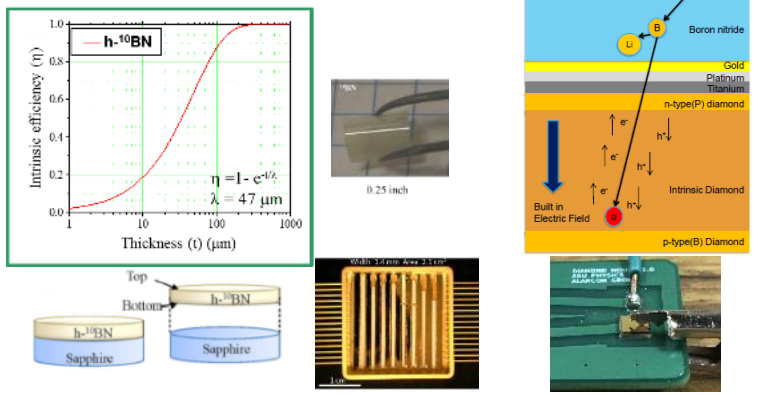
Distributed Acoustic Sensing High Temperature Fibers



High Temperature Compact NMR



Solid State Neutron Detectors

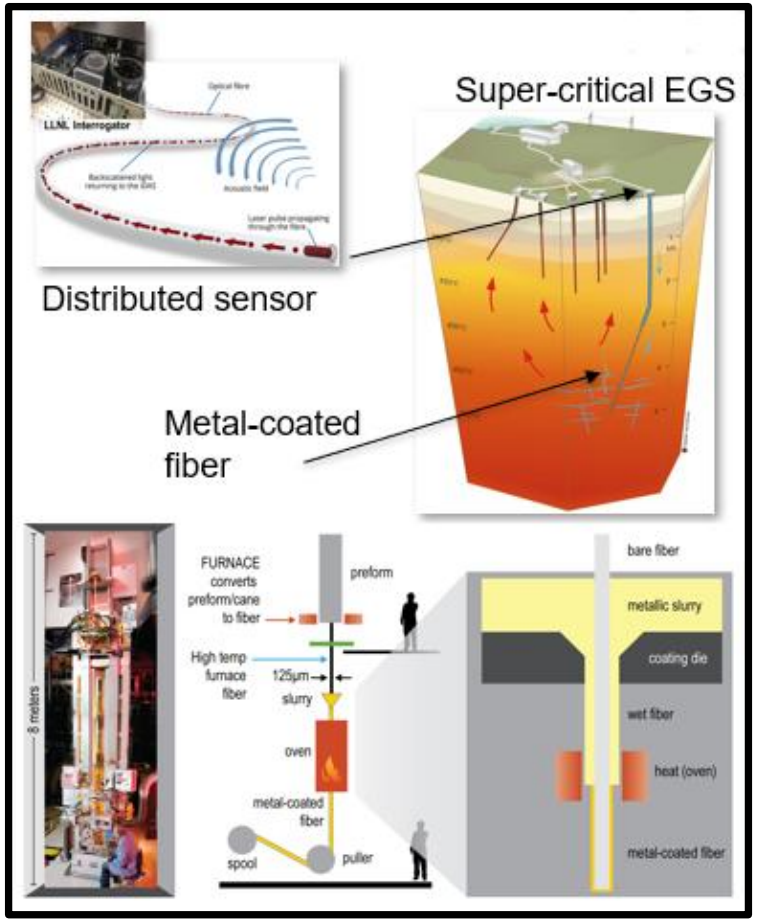


Original 8 +6 Projects = $41M Investment

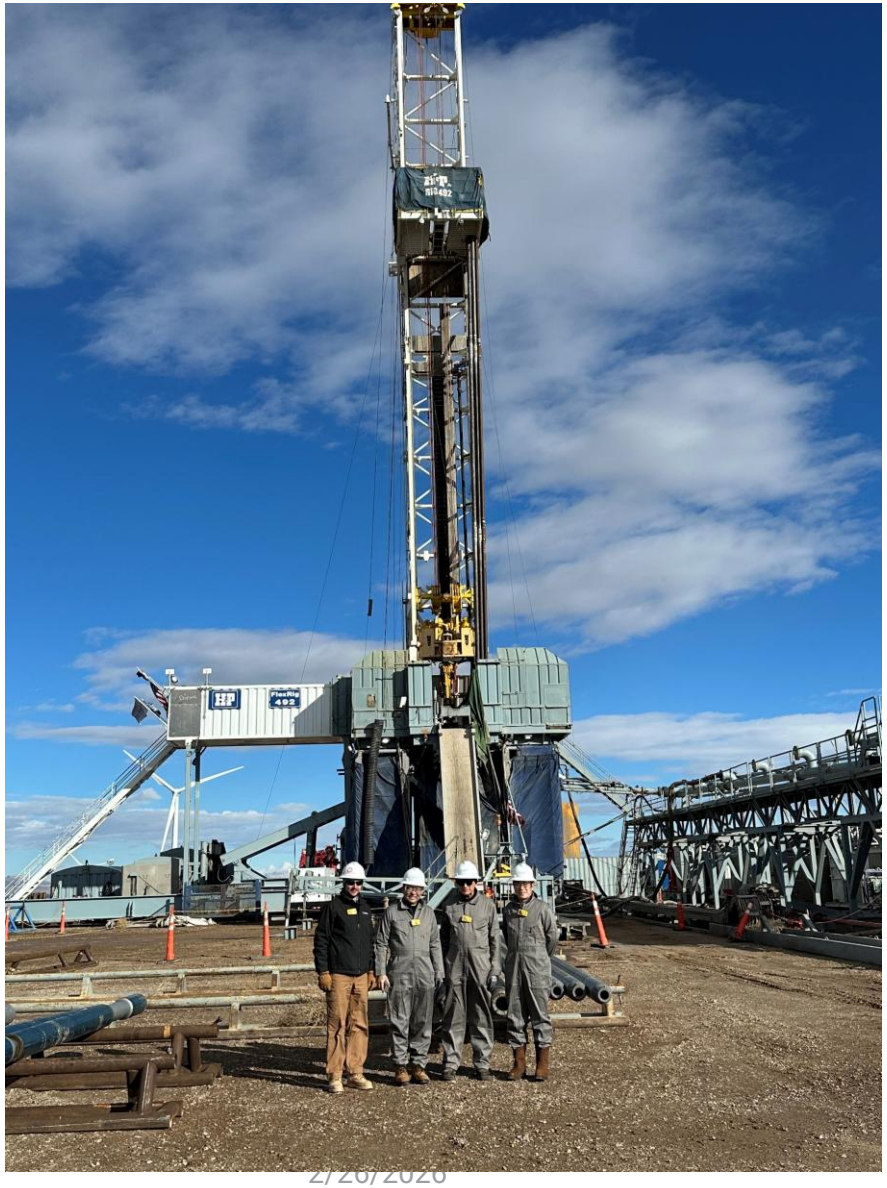
Worlds 1st Horizontal Doublet EGS Well – 4MW

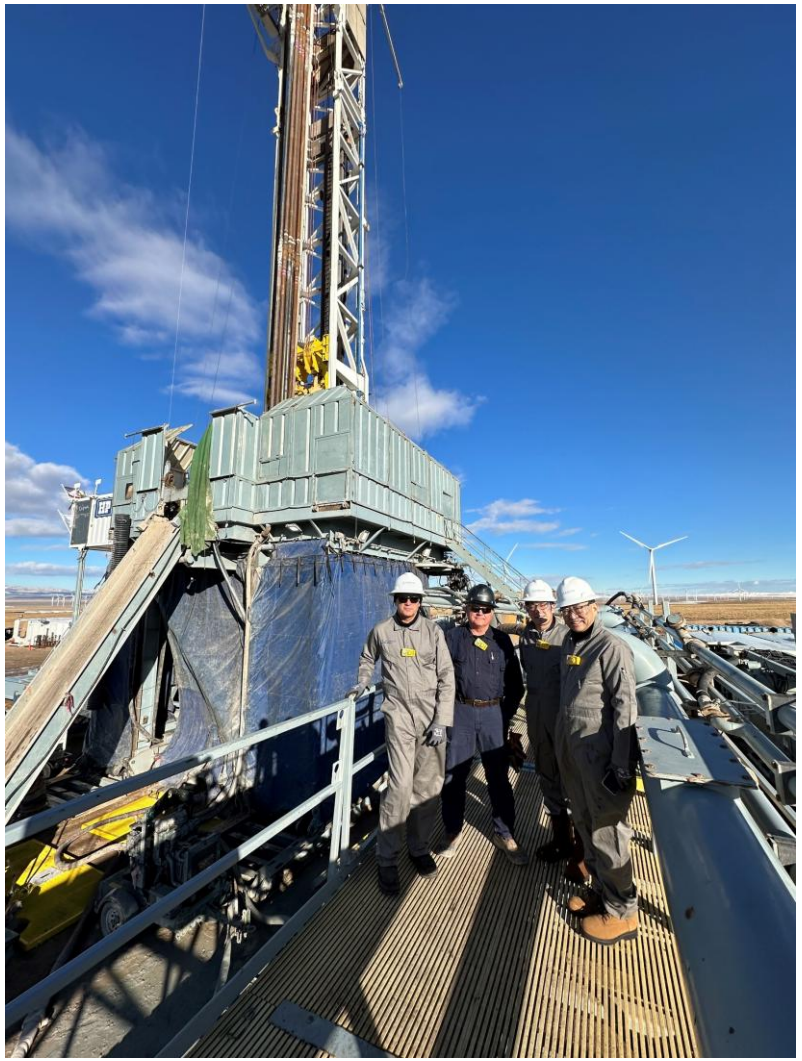
Fervo Energy – Blue Mountain, NV Geothermal Site (2023)

Distributed Acoustic Sensing High Temperature Fibers



Fervo Utah Site (site visit with NEDO, January 2024)





The Washington Post
Democracy Dies in Darkness

CLIMATE SOLUTIONS

U.S. approves mega geothermal energy project in Utah

The Interior Department gave the green light to Fervo Energy's Cape Geothermal Power Project in Beaver County, Utah, the White House confirmed to The Washington Post.

A rig operator walks through a Fervo Energy geothermal drilling site near Milford, Utah, in 2023. (Ellen Schmidt/AP)

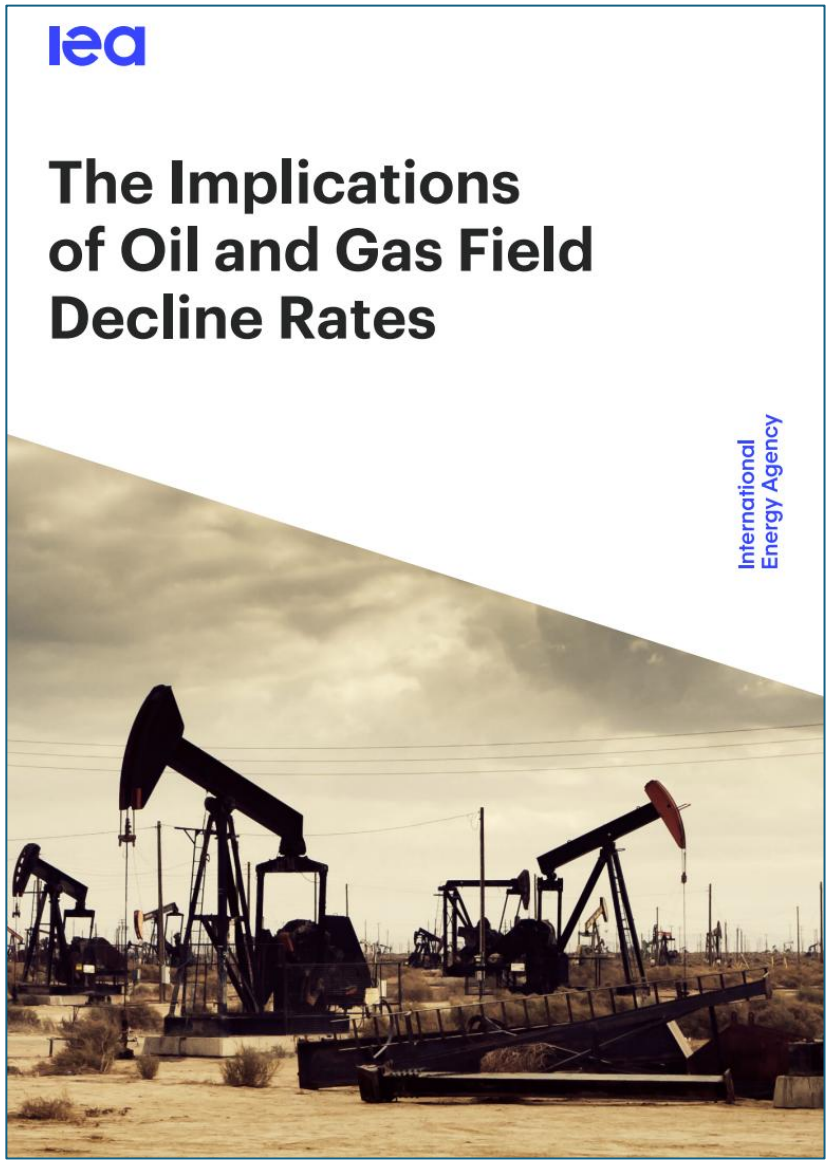
By Maxine Joselow

October 17, 2024 at 2:09 p.m. EDT

The Interior Department's Bureau of Land Management gave final approval to Fervo Energy's Cape Geothermal Power Project in Beaver County, Utah, the White House said. Once fully operational, the project could generate up to 2 gigawatts of electricity — enough to power more than 2 million homes.

In addition, the BLM proposed Thursday to speed up the permitting process for geothermal projects on public lands across the country. Earlier this month, the agency also hosted the biggest lease sale for geothermal developers in more than 15 years.

Easily Accessible Oil and Gas Mapped and Developed



September 2025

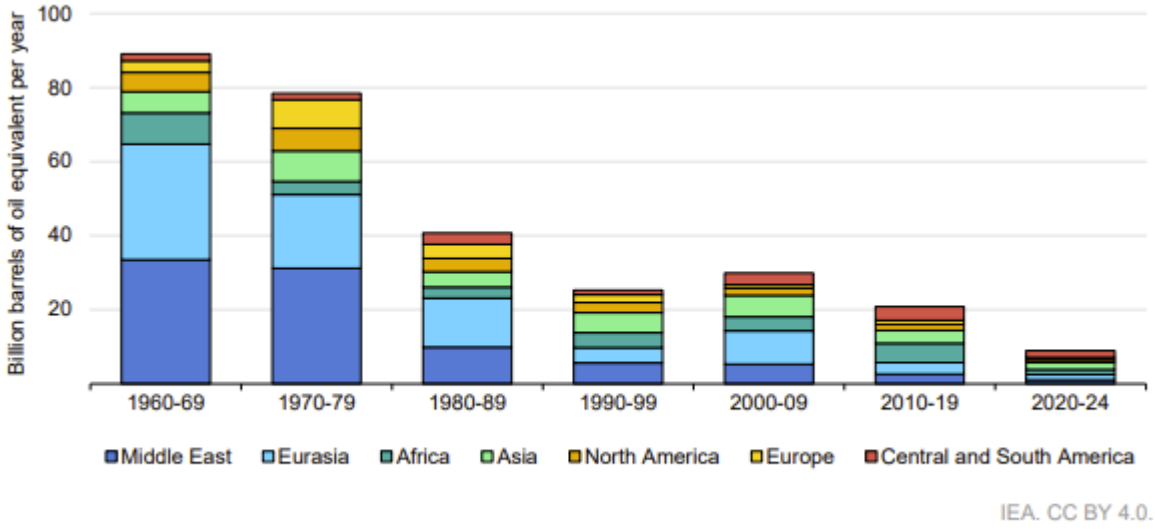
Most of the large, easily accessible conventional fields have been thoroughly mapped and developed.

The oil and gas industry needs to run fast to stand still.

Since 2019, 90% of annual upstream O&G investment has been to offset production declines rather than meet demand growth ($560B in 2025)

Leaves smaller, deeper, and technically challenging fields.

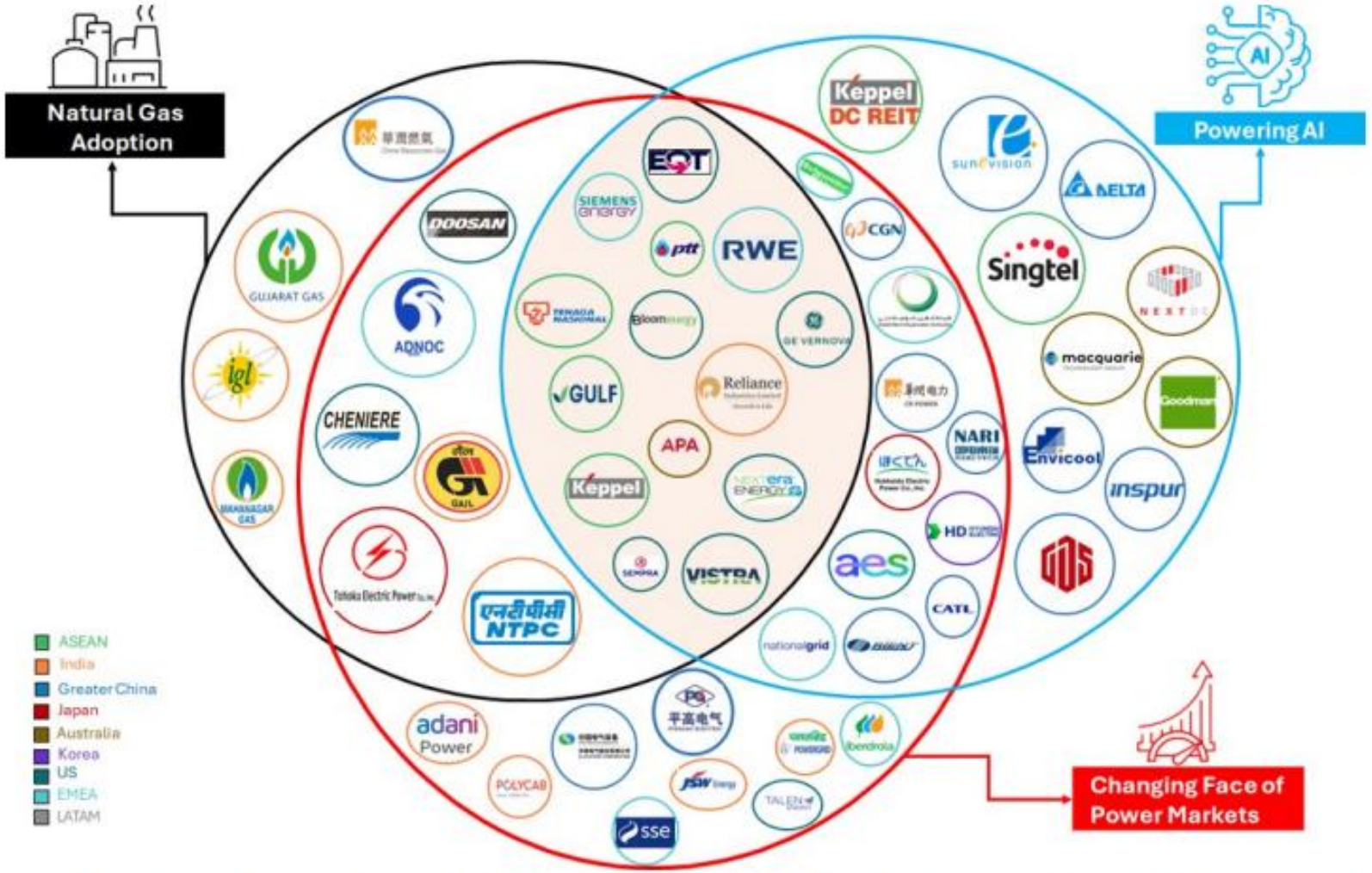
Average annual conventional oil and gas *discoveries*, 1960-2024



Source: IEA analysis based on data from Rystad Energy (2025).

Gas Pipeline and Power Producers Benefit the Most

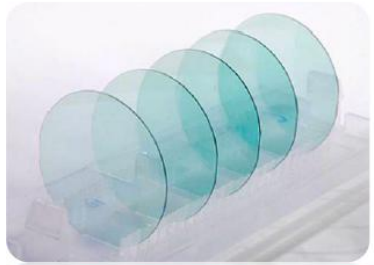
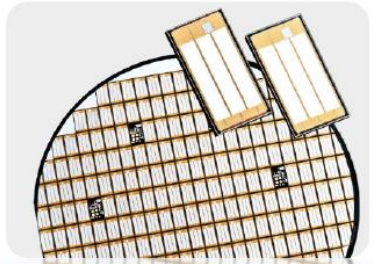
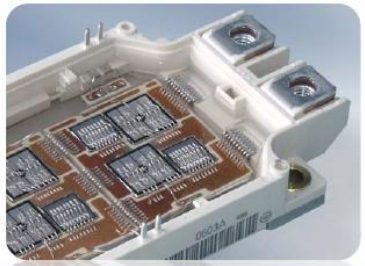
Exhibit 1: Looking at our global Morgan Stanley Research coverage across multiple sectors, we see three thematics intersecting. Gas pipeline and power producers stand to benefit the most



Source: Morgan Stanley Research. *We see our previous global thematic notes of Natural Gas Adoption and Powering AI intersecting with the Changing Face of Power Markets which we highlight below. For the full list of preferred ways to play Natural Gas Adoption and Powering AI, please refer to the appendix.

Power Electronics Programs

>$350M investment


Materials | **Devices** | **Modules** | **Power Cells** | **Converters** | **System**

2023 - , $45M
ULTRAFAST

2024 - $38M
DC-GRIDS

Power Grid
⋮
Microgrids
⋮
Electrified Transportation

2014-2019, $35M, 14 projects
SWITCHES

2017-2023, $38M, 21 projects
CIRCUITS

2017-2022, $18M, 10 projects
PNDIODES

2019 - , $23M, 7 projects
BREAKERS

2009 - , ~$95M
2009,2012, 2018, 2021
OPEN
SPARKS
IDEAS, CREATE, SEED, SPARKS

+ Relevant Cohort Programs:

SF_6-FREE
2021 -, $10M

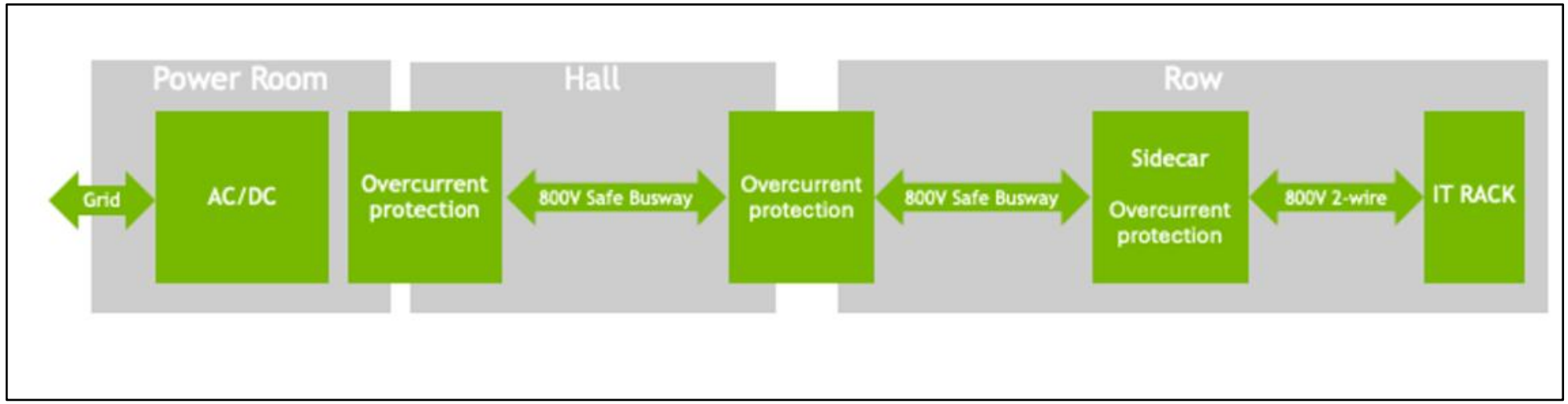
INSULATE
2021 -, $3.5M

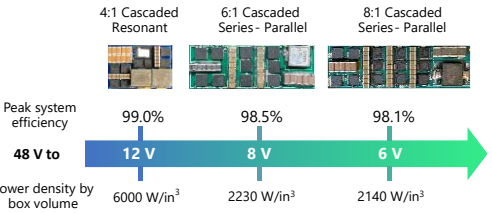
SUBSURFACE
2021 -, $16M

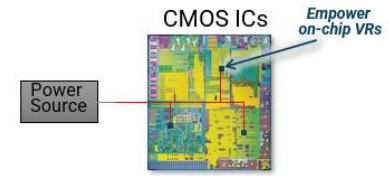
CABLES
2021 -, $10.5M

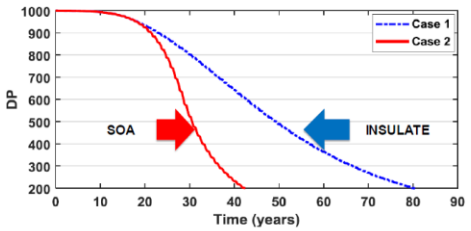
GENI
2012-2017, $43M, 15 projects

NVIDIA 800 VDC Architecture Will Power the Next Generation of AI Factories?



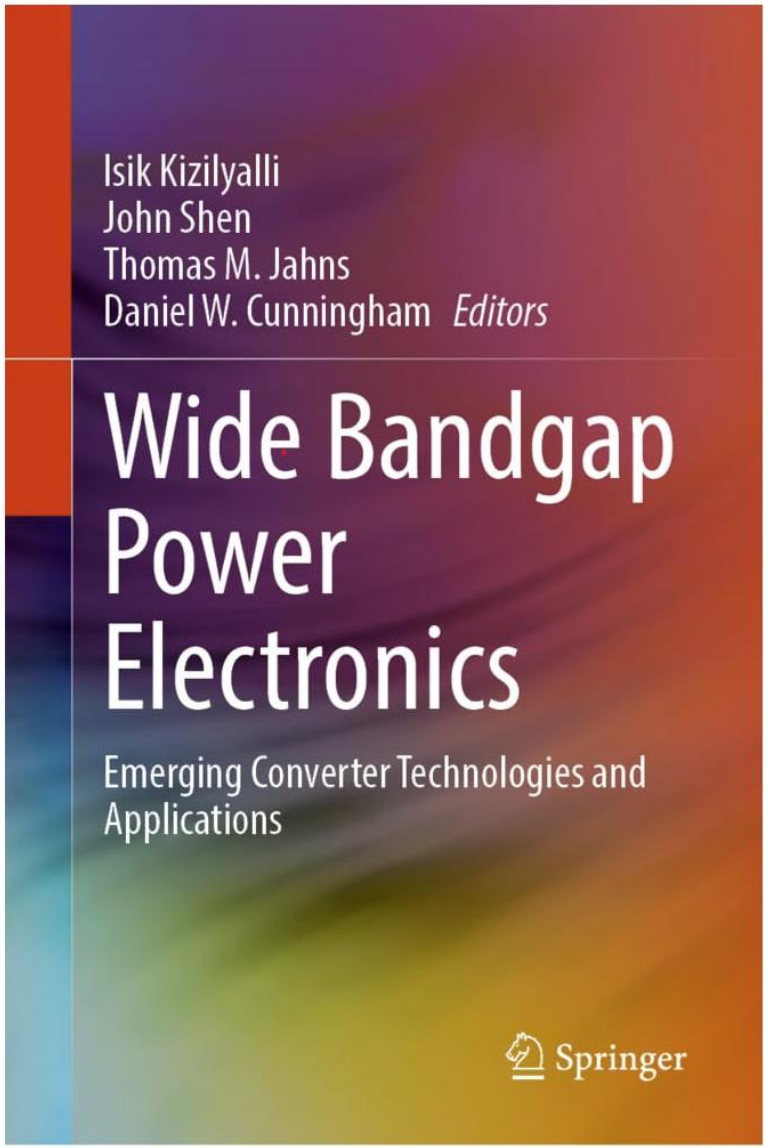




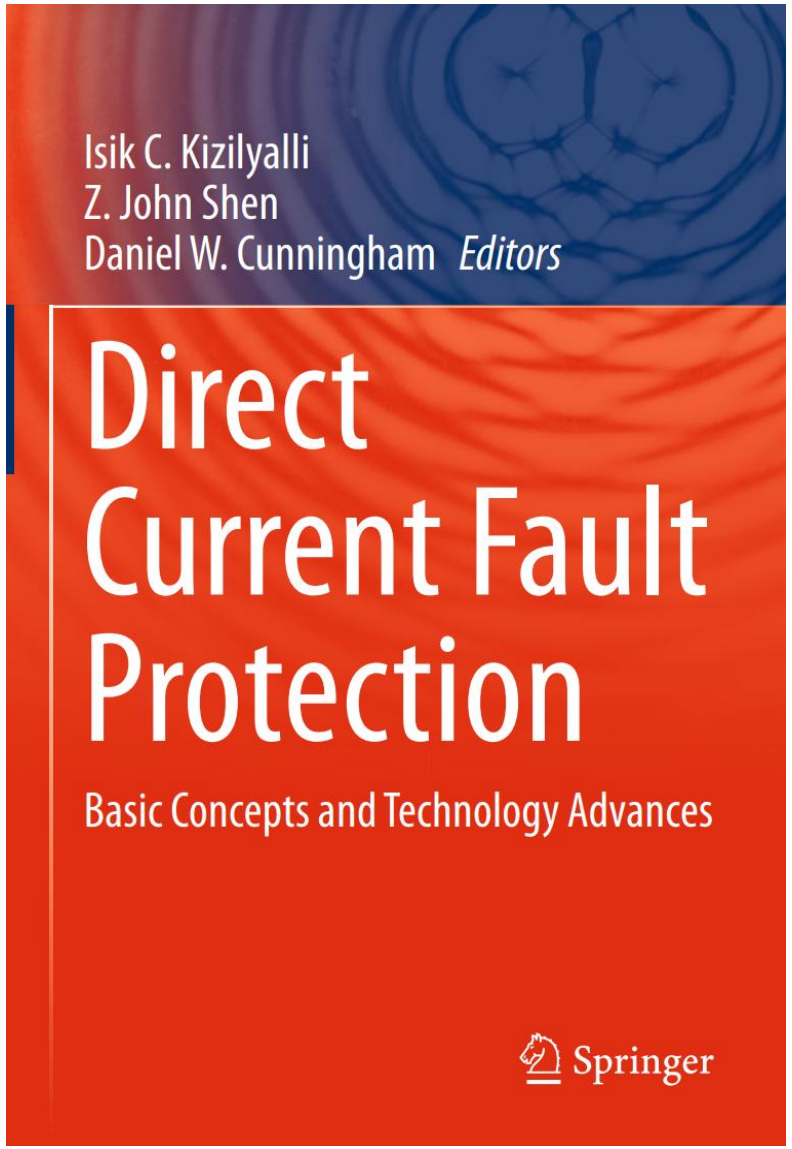


Solid-State Transformer Landscape

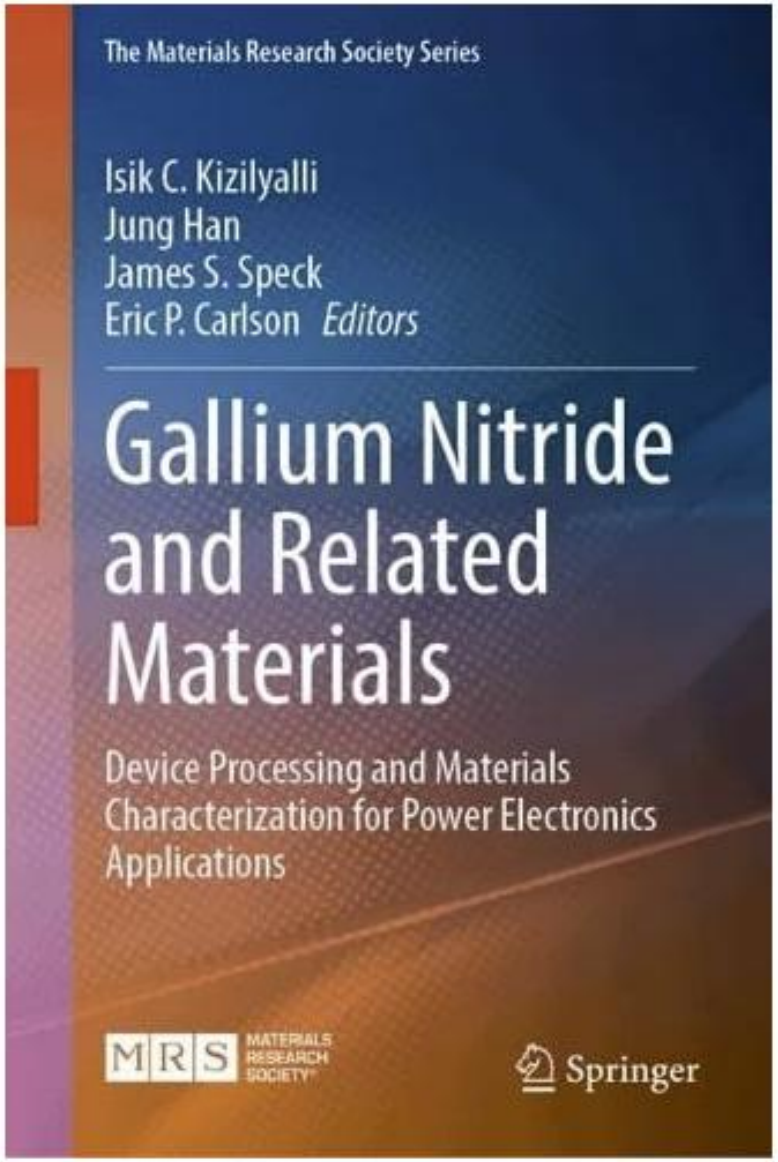
SST	VOLTAGES [AC:DC KV]	POWER [MW]	EFFICIENCY [%]	TOPOLOGY	SEMI	SWITCH/CAP COUNT
Heron Power	34.5 : 800	4-5	98.5	Modular (3 stage)	GaN, SiC	100 %
Solar Edge	13.8-34.5 : 0.8-1.5	2-5	99	Modular (3 stage)	SiC	~100 %
DG Matrix	13.8	0.2-2.5	96-98	Modular (200 kW)	SiC	~100 %
WattEV	12-15	1.2-3.8	98	Modular	SiC/GaN	—
Amperesand	12-15 : 0.8	2-6	98	Modular (3 stage)	SiC	100 %
Eaton	13.2-15 : 0.8-1.5	1-5	98	Modular (3 stage)	SiC	100 %
GE Vernova	13.8 : 480 V ac	1	98	Modular (4 stage)	SiC	~100 %
Delta Electronics	13.8 : 0.8	0.4-1	98	Modular (3 stage)	SiC	~100 %
SEL	15 : 0.75-1	1	97	Modular (3 stage)	SiC	~100 %



September 2025
CIRCUITS Program



2023
BREAKERS Program



April 2025
SWITCHES and PNDIODES Program

Thank You

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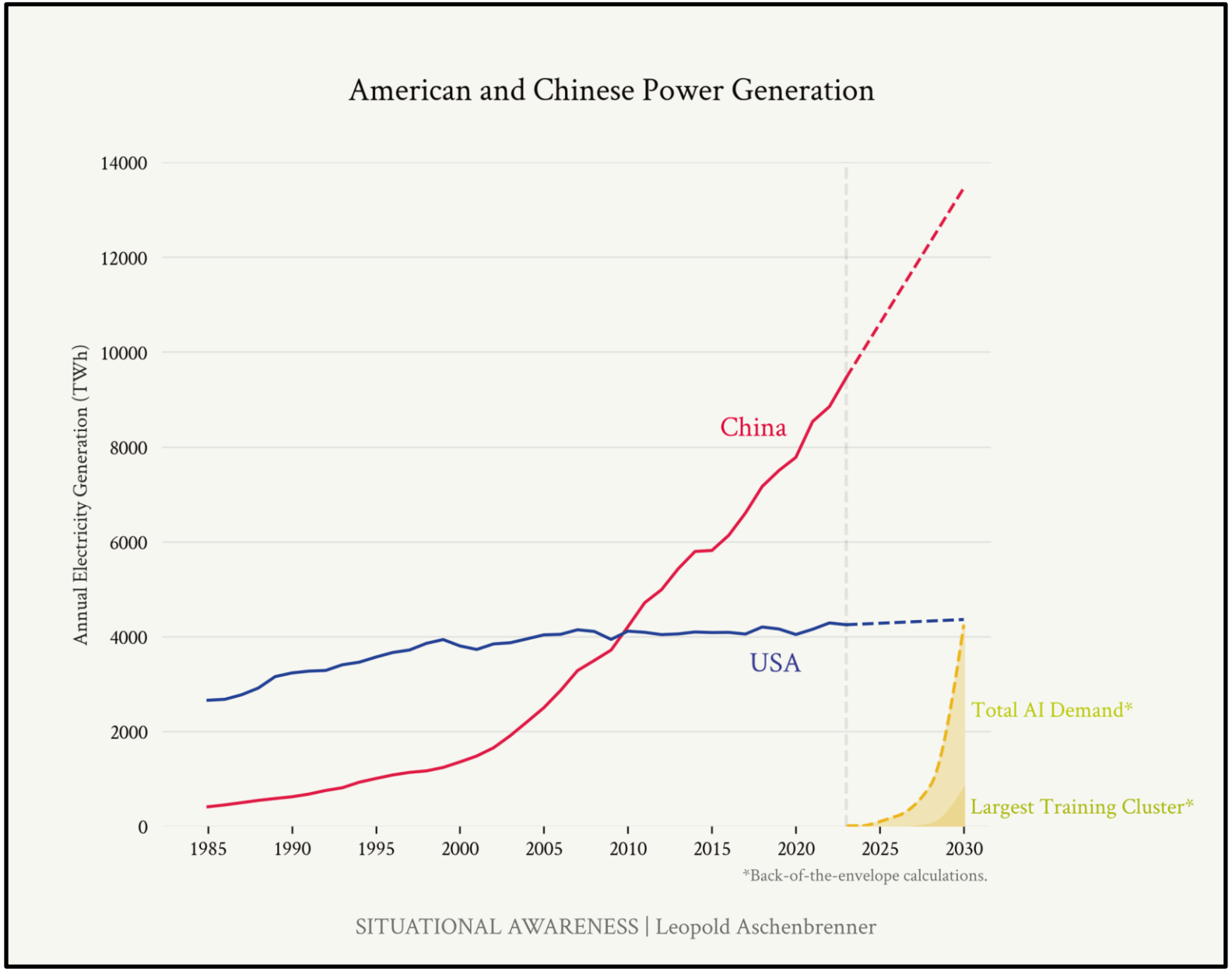
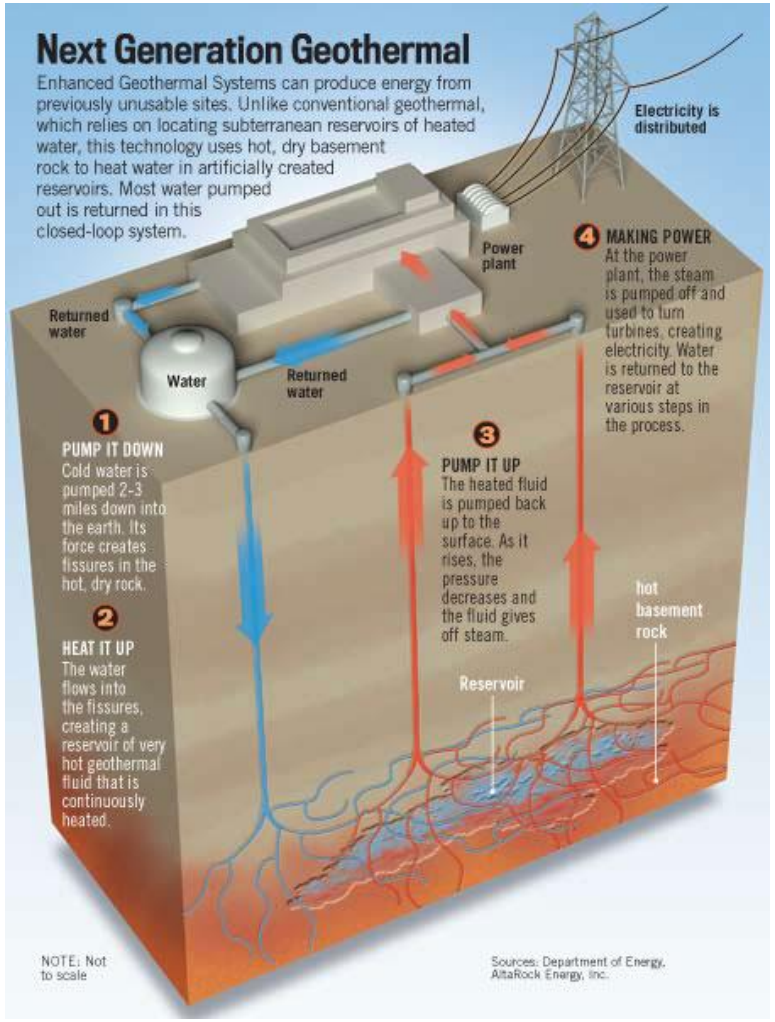
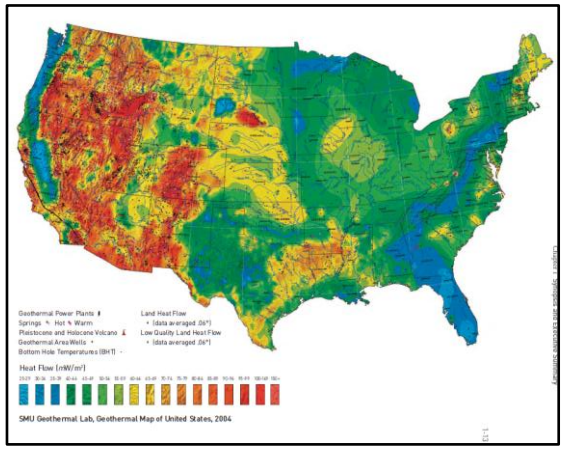

American and Chinese Power Generation
Annual Electricity Generation (TWh)
14000
12000
10000
8000
6000
4000
2000
0
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
China
USA
Total AI Demand*
Largest Training Cluster*
*Back-of-the-envelope calculations.
SITUATIONAL AWARENESS | Leopold Aschenbrenner

Earth as a Battery: Enhanced Geothermal Systems (EGS)



- Identify Resource (Hot Rock)
- Create Fracture Network
- Convert Hot Fluid to Electricity



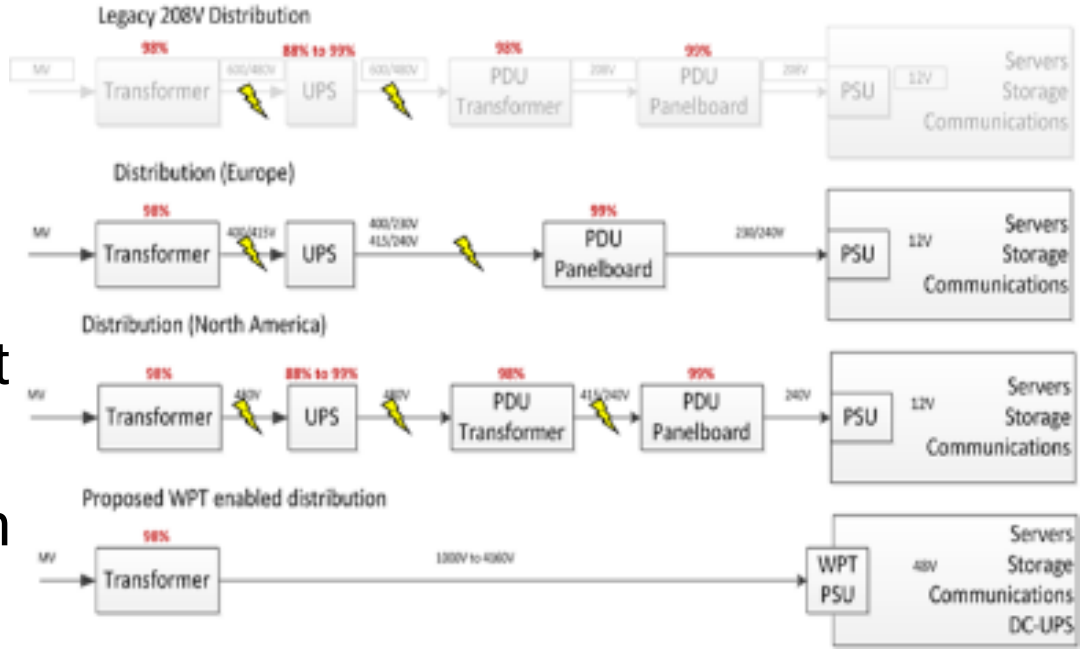
- 3-10-X km
- > 200°C
- **500GW-15,000 GW_e**

$100GW_e$ Powers 100M Homes by 2050

ARPA-E CIRCUITS: Enabling MV distribution

SiC-Based Wireless Power Transformation for Data Centers & Medium Voltage Applications

- Medium voltage distribution inside data centera to Point-of-use
- Physical galvanic isolation barrier between MV distribution and low voltage application side
- WPT transformer with high turns ratio as efficient as server supply
- 20kW 1kV-to-48V supply enabling MV distribution
- Elimination of arc-flash hazard



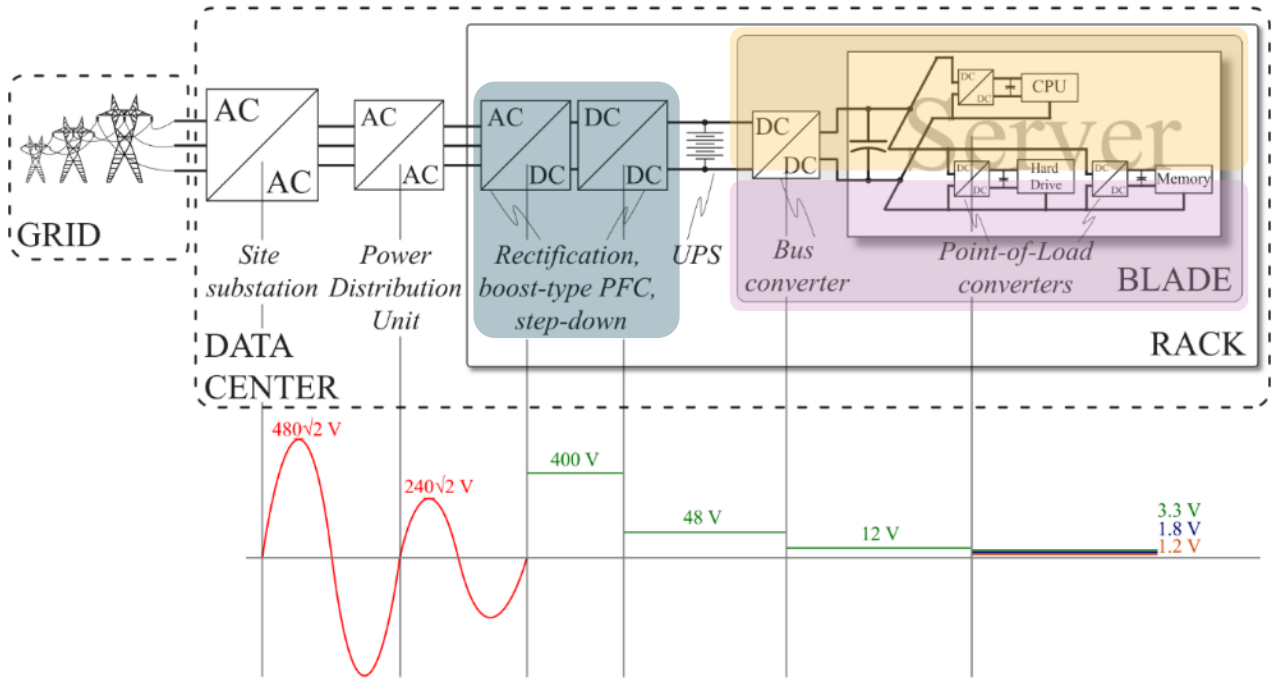
Metric	State of the Art	Proposed
Application Voltage	*Multiple conversion stages to 240V*	*Single conversion to 1kV*
Overall Data Center Efficiency	81% to 91%	95%
Safety	PPE required	PPE not required

Safe Medium Voltage Distribution to Point-of-Use

Efficiency Targets	**95% @ 50% load** **91% @ 100% load** **90% @ 20% load**

Data Center Power Conversion

Traditional data center architecture



Single-phase ac-dc converter (240 Vac to 48 Vdc)

- Direct single-stage step-down
- Power factor correction (PFC) capability

Multi-port dc-dc converter (48 Vdc to 5 Vdc HDD)

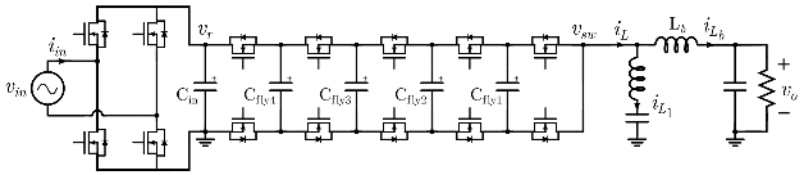
- Series-stacked architecture
- Differential power processing (DPP) for extreme efficiency
- Multi-port ac-coupled (MAC) converter

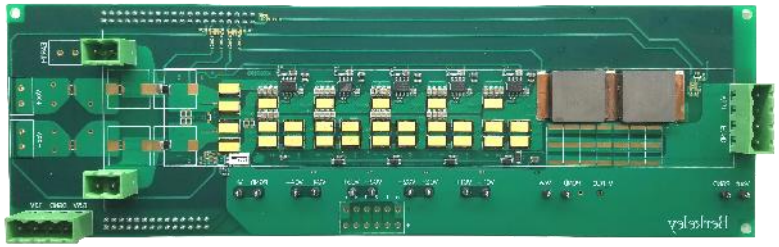
Dc-dc converter (48 Vdc to POL)

- Work with conventional datacenter systems
- Hybrid switched capacitor converter

Key Project Prototypes and Circuit Topologies

Single-stage FCML PFC

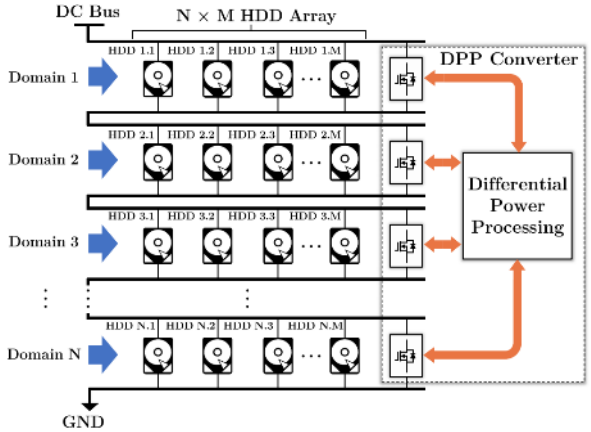




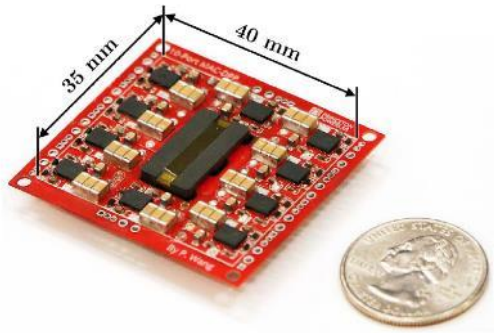
Buck PFC FCML
(120-240Vac to 48 Vdc)

- Peak system efficiency: 97%
- Power rating: 750 W
- Power density: 277 W/in^3
- Power factor: 0.98

Multi-Port Dc-Dc Converter



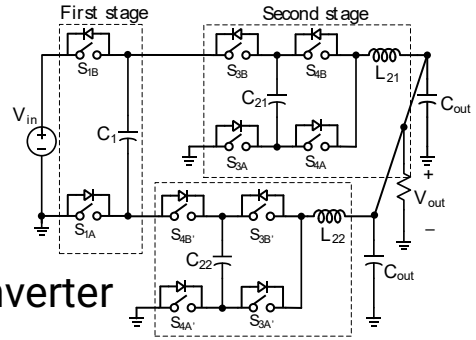
Series-Stacked Power Architecture with DPP



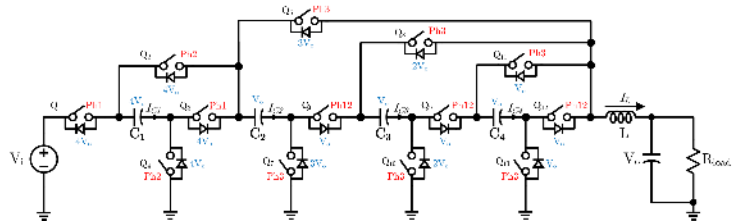
MAC-DPP Prototype

- 99.77% peak system efficiency
- 700W/in^3 power density

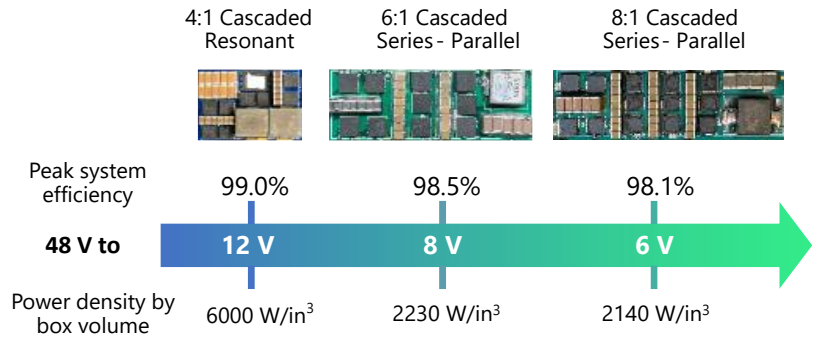
48 V Point-of-Load Converter



48-12 V cascaded multi-resonant converter



48-6 V cascaded series-parallel converter



Selected Examples: VEIR

OPEN 2021

High temperature superconductor (HTS) cables

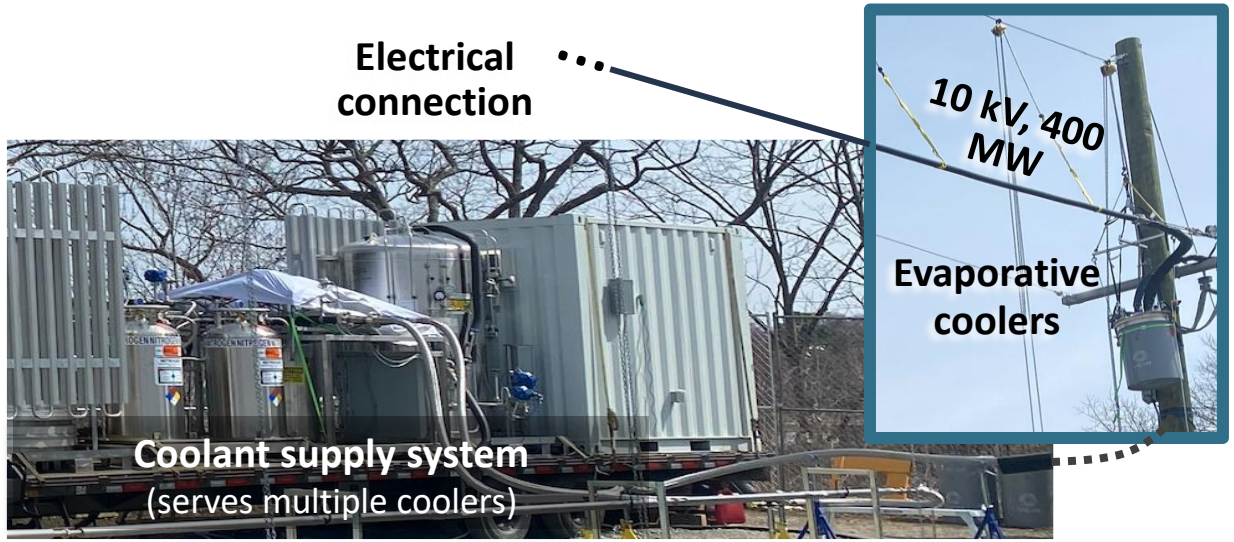
Enables transformative acceleration of transmission capacity

Solves the HTS cooling challenge

20x cooling power increase
via passive evaporative cryogenic cooling

10x current vs. conventional cable
while maintaining superconductivity

Lower line voltages, smaller rights-of-way
for affordable long-distance, high-power transmission



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CHANGING WHAT'S POSSIBLE