IM3

INTEGRATED
MULTISECTOR
MULTISCALE
MODELING

Energy and AI

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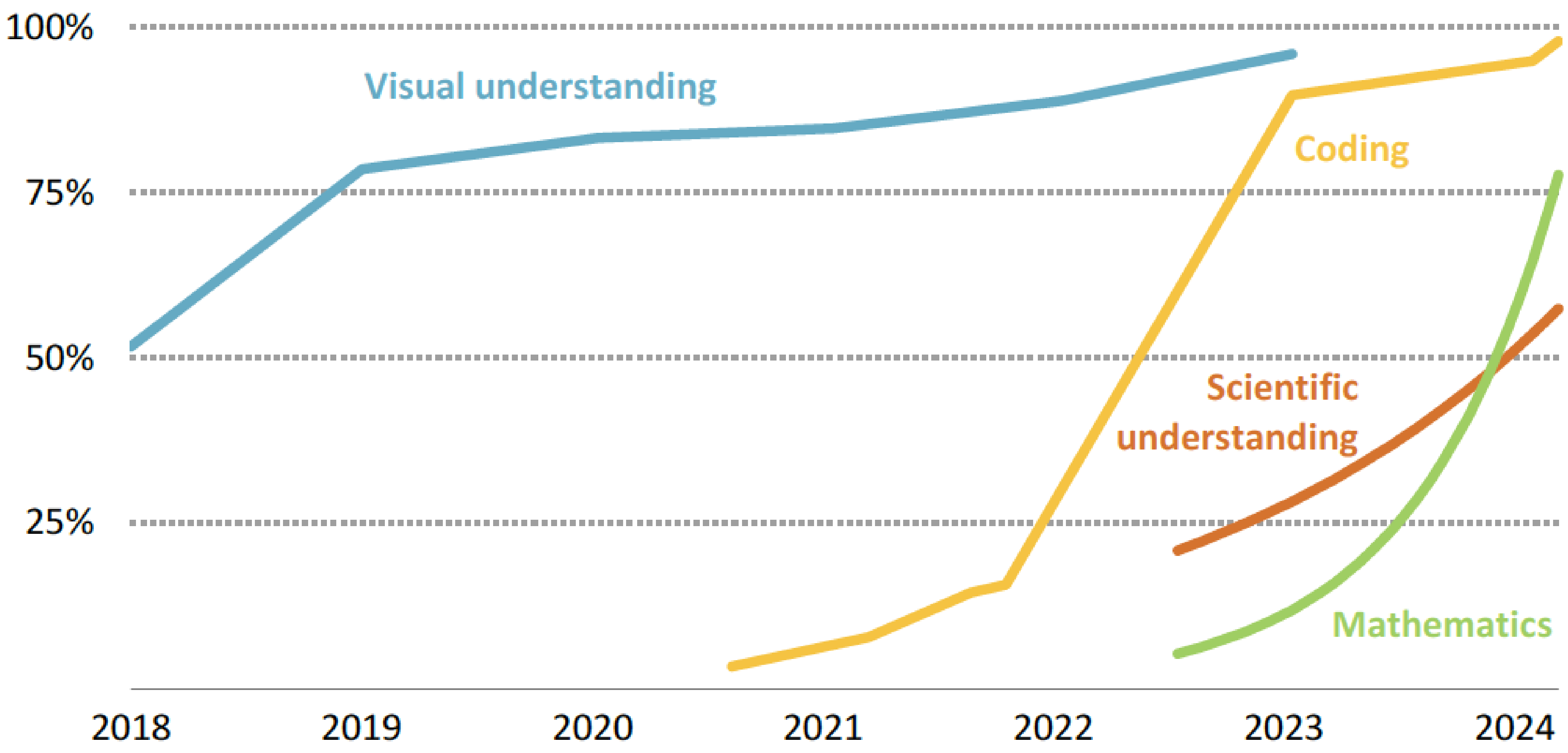
Pacific Northwest National Laboratory · Berkeley Lab · Oak Ridge National Laboratory · Sandia National Laboratories · Baylor University · Boston University · Cornell University · NC State University · The University of North Carolina at Chapel Hill · UC Davis University of California · PennState

Special report from the International Energy Agency (IEA)

- *"The development and uptake of artificial intelligence (AI) has accelerated in recent years – elevating the question of what widespread deployment of the technology will mean for the energy sector.* ***There is no AI without energy – specifically, electricity for data centers.*** *At the same time, AI could transform how the energy industry operates if it is adopted at scale."*
- Published in April 2025

The potential of AI is finally being realized

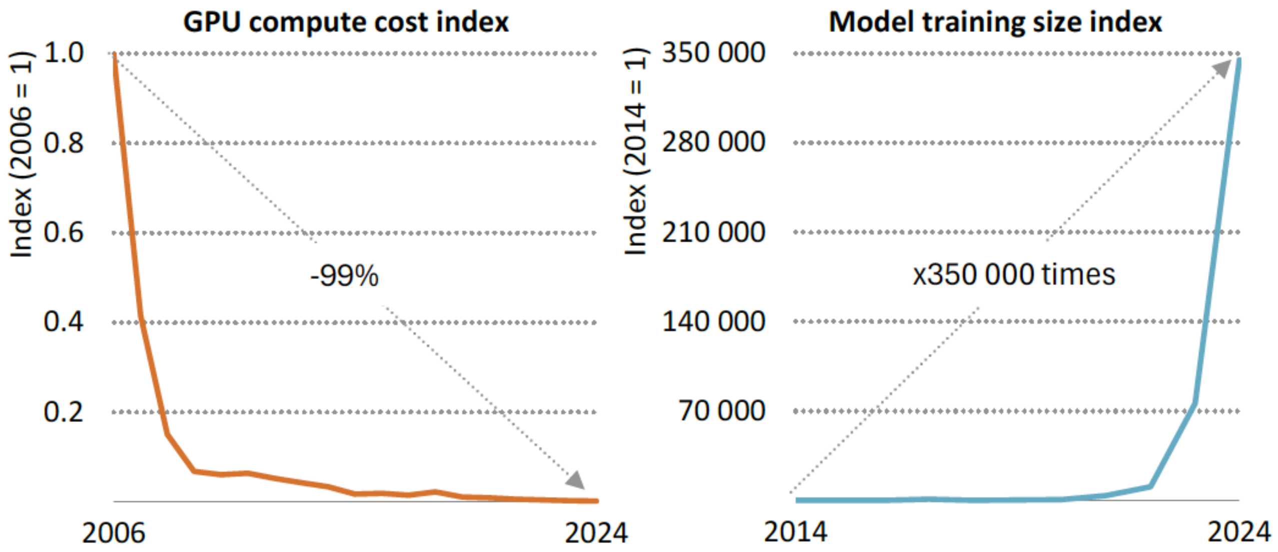
Figure 1.11 ▹ Accuracy of AI models in selected benchmarks, 2018-2024



The step change is due in large part to widely available cheap computing

- *"The exponential increase in the availability and quality of data used to train AI models due to the rise of the Internet and connectivity.* ***The amount of data used to train state of-the-art AI models has increased by nearly 30,000 times since 2008.****"*
- *"Breakthroughs in the architectures and algorithms behind AI models, notably the rise of deep neural networks, enabling the development of exponentially larger and more capable models.* ***The amount of computational power used to train state-of-the-art AI models has increased by around 350,000 times since 2014.****"*

Figure 1.1 ▹ GPU computation cost, 2006-2024, and notable AI model computational training size, 2014-2024



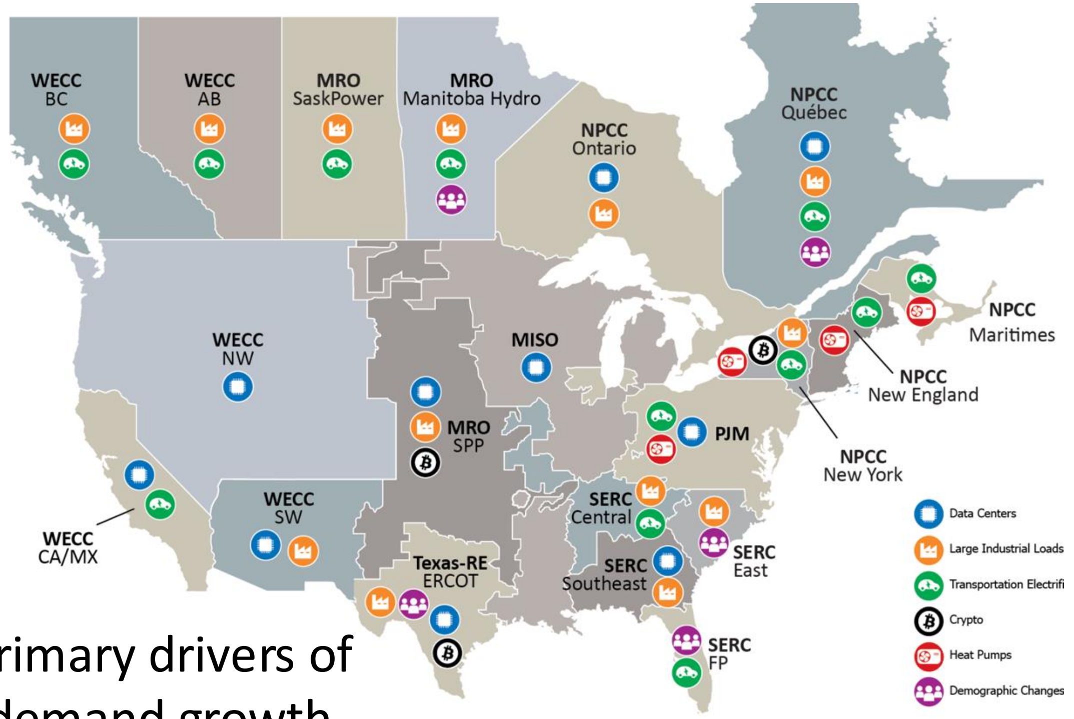
Projections of new data centers to support generative AI and cryptomining are large but highly uncertain

- Projections suggest up to a 15% annual growth in electricity demand from data centers within the next 5-10 years (EPRI 2024).
- Usage projections from more recent AI models suggest electricity demand could be much lower than ChatGPT-type models.
- Total electricity demand may grow 35-50% by 2040, driven by domestic manufacturing, data centers, and electrification (ACP 2025).
- Data centers are also potentially large consumers of fresh water, depending on the cooling technology (Siddik et al. 2021).

"Drought-stricken communities push back against data centers", 19-Jun 2021, NBC News

Rapid, uncertain growth in electricity demand poses reliability challenges for the grid

*"Electricity peak demand and energy growth forecasts over the 10-year assessment period continue to climb; **demand growth is now higher than at any point in the past two decades**. Increasing amounts of large commercial and industrial loads are connecting rapidly to the BPS. The size and speed with which data centers (including crypto and AI) can be constructed and connect to the grid presents unique challenges for demand forecasting and planning for system behavior."*



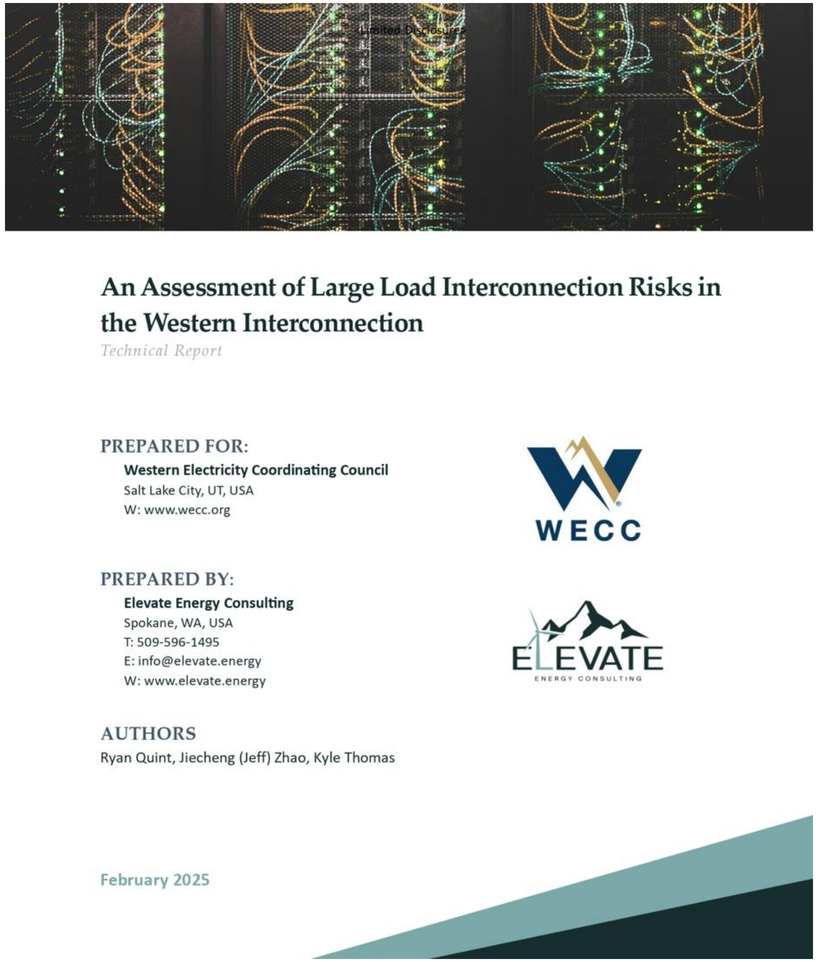
Primary drivers of demand growth

Table 12: Anticipated Reserve Margins with Announced Retirements

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
MISO	17.7%	10.3%	10.3%	13.2%	8.6%	7.1%	10.6%	8.2%	7.5%	4.2%	-2.5%
MRO-Manitoba	12.5%	21.3%	18.4%	18.0%	15.0%	9.8%	0.5%	-0.6%	-1.7%	-2.9%	-4.2%
MRO-SaskPower	28.9%	27.8%	26.6%	31.1%	29.4%	7.0%	28.8%	28.0%	26.7%	26.8%	1.2%
MRO-SPP	28.3%	26.7%	26.0%	25.0%	20.8%	19.1%	26.7%	24.9%	23.5%	22.4%	8.1%
NPCC-Maritimes	18.9%	20.6+%	25.5%	25.1%	18.6%	3.9%	23.4%	20.7%	19.1%	17.7%	-1.5%
NPCC-New England	20.4%	25.0%	25.0%	26.3%	24.9%	23.5%	22.0%	20.1%	19.7%	17.1%	14.6%
NPCC-New York	18.4%	17.1%	21.4%	22.5%	22.4%	21.6%	20.7%	18.3%	16.7%	14.9%	13.6%
NPCC-Ontario	22.5%	20.8%	23.6%	15.7%	23.0%	9.5%	5.1%	-0.2%	-1.4%	-3.9%	-5.5%
NPCC-Quebec	12.5%	12.2%	13.1%	14.2%	12.6%	11.3%	9.8%	6.2%	3.5%	0.5%	-2.2%
PJM	29.8%	34.9%	35.7%	28.1%	21.4%	18.2%	23.1%	21.6%	20.1%	18.5%	10.3%
SERC-C	28.2%	18.9%	18.9%	15.0%	16.0%	15.2%	17.3%	17.1%	18.4%	21.1%	11.8%
SERC-E	30.4%	27.3%	25.8%	24.6%	20.6%	14.4%	14.3%	10.2%	6.3%	4.6%	-2.2%
SERC-FP	27.0%	25.4%	26.0%	23.2%	22.1%	20.9%	18.4%	22.0%	20.4%	18.2%	16.0%
SERC-SE	44.9%	39.9%	35.9%	31.5%	24.5%	21.4%	27.7%	25.8%	24.7%	23.7%	13.0%
TRE-ERCOT	24.3%	30.2%	32.5%	29.7%	25.6%	25.4%	27.8%	28.0%	28.4%	28.9%	24.9%
WECC-AB	36.3%	35.8%	35.7%	38.5%	41.7%	41.9%	35.4%	41.2%	33.6%	27.8%	27.0%
WECC-BC	20.9%	25.2%	25.2%	15.8%	15.9%	22.3%	22.1%	21.6%	21.2%	13.4%	19.9%
WECC-CA/MX	38.6%	45.5%	45.2%	38.4%	43.1%	28.8%	29.6%	23.3%	25.0%	15.2%	11.1%
WECC-NW	34.5%	40.3%	38.9%	35.6%	30.7%	24.5%	18.3%	12.2%	10.2%	8.1%	5.9%
WECC-SW	28.6%	37.0%	35.6%	31.6%	24.2%	17.4%	11.3%	7.7%	0.2%	-4.7%	-9.6%

Data centers come online faster than new generation or transmission can be built to serve them

*"**Large loads are often able to plan, permit, and build within one or two years (or quicker) whereas utility scale generation can take three to ten years.** Small transmission upgrades typically take two to three years from planning to energization whereas large transmission infrastructure projects often require more than ten years…"*



An Assessment of Large Load Interconnection Risks in the Western Interconnection

Technical Report

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Utilities are scrambling to adapt

"It took SRP 120 years to develop the generation capacity we have today. ***We will need to double or triple our capacity in the next decade to be able to meet the forecasted demand growth*** *of nearly 40% while becoming more sustainable. Rapid growth and supply chain issues add complexity, but we're making significant progress, adding 1,100 MW of new capacity this past summer alone."*

Salt River Project, March 2025

AI and energy abundance are tightly coupled

"***The cost of AI will converge to the cost of energy...the abundance of it will be limited by the abundance of energy***."

Sam Altman's Senate Testimony, May 2025

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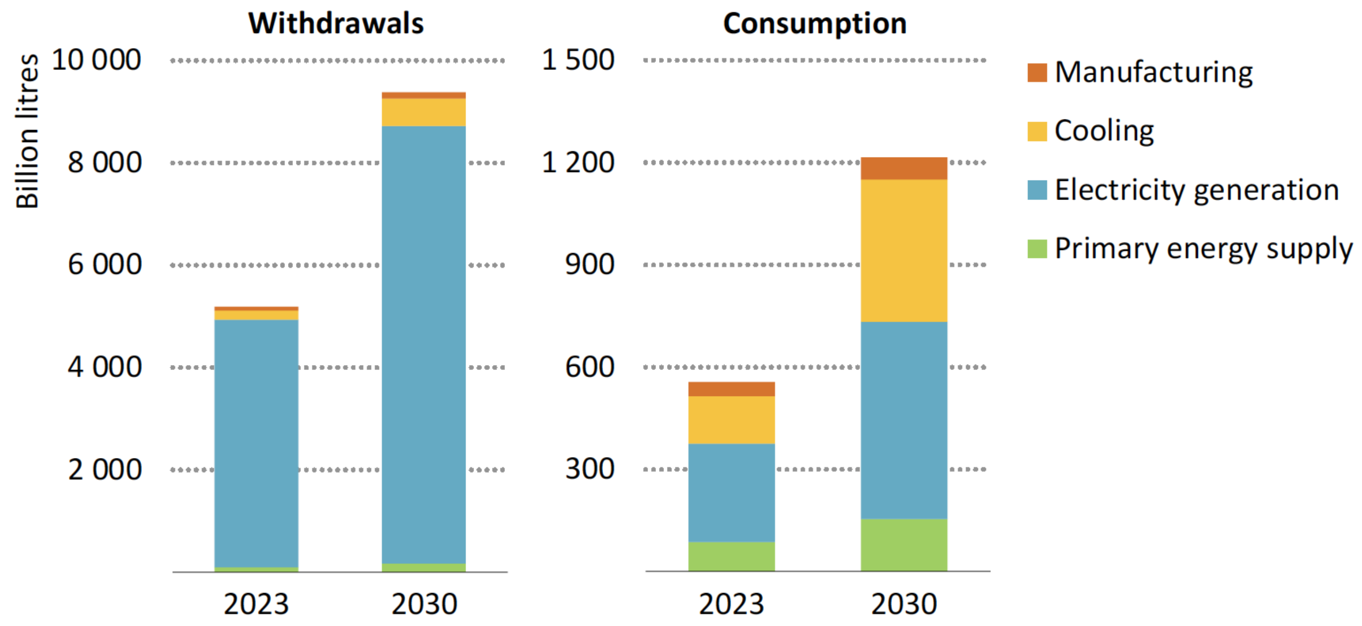
If we don’t build it, somebody else will

Figure 1.13 ▹ Global map of large data centre clusters, 2024

*“You know, in the original Manhattan Project, Nazi Germany was also trying to develop [an] atomic bomb,” Wright said. “**So, the cost of being second was just devastating. Like, that was a race not [that] you want to win. We had to win. And I think AI has similar overlay.**”* Chris Wright

The water demand to support AI is non-trivial

Figure 5.27 ▹ Water withdrawals and consumption for AI in the Base Case, 2023 and 2030



- *"In some countries, such as the United States, withdrawals for data centers today equate to less than 10% of annual municipal water withdrawals, but elsewhere, **the water demands of data centers could compete with water for agricultural irrigation and municipal uses** and even impact the supply chains that underpin microchip manufacturing."*
- *"**Operators including AWS and Google have pledged to be "water positive" by 2030**, by combining recycling and replenishment programs with reductions in the direct WUE of their operations. (Google, 2024; Amazon, 2023)."*

The interactions are not all one-way

Figure 3.5 ▹ AI applications in electricity generation and transmission

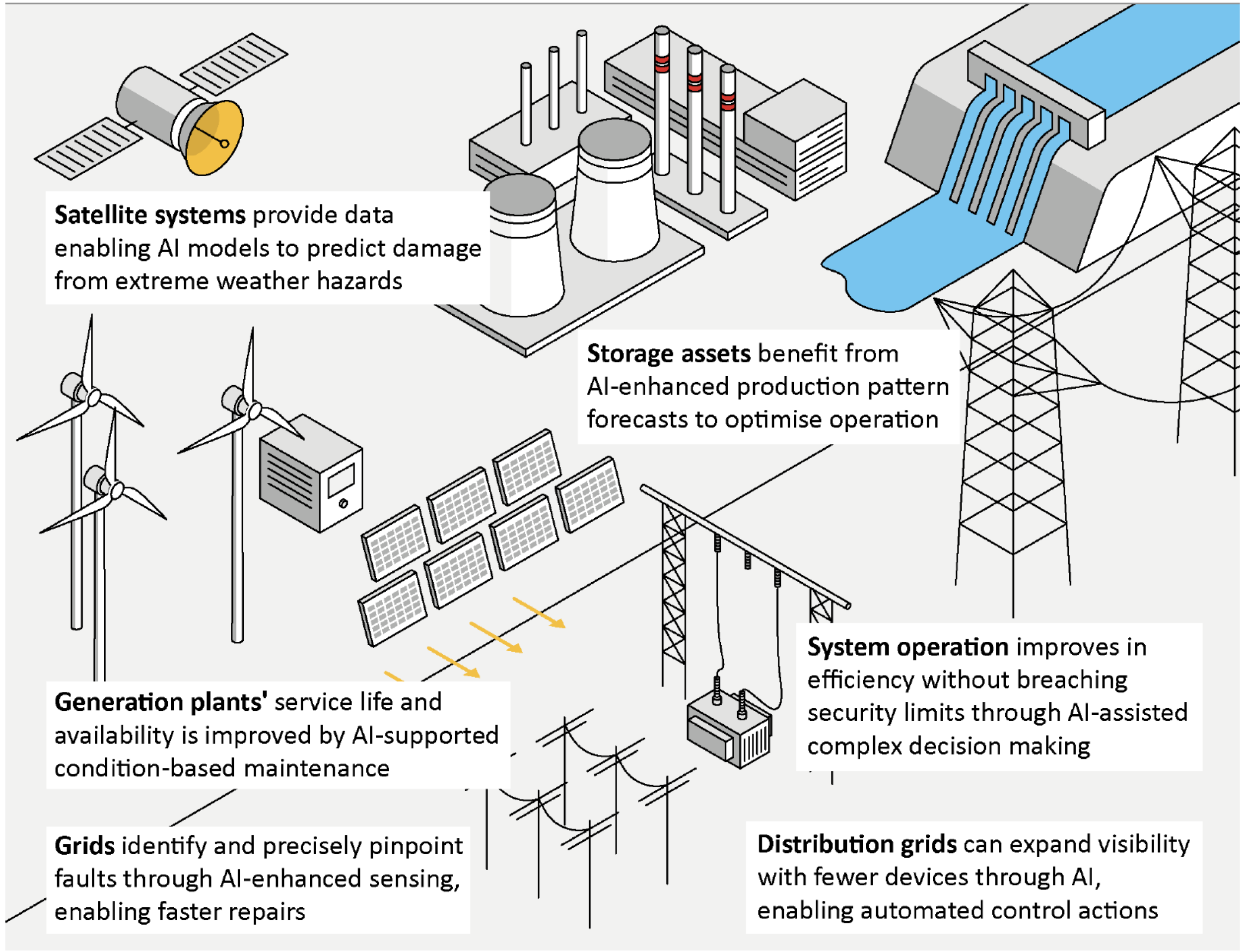
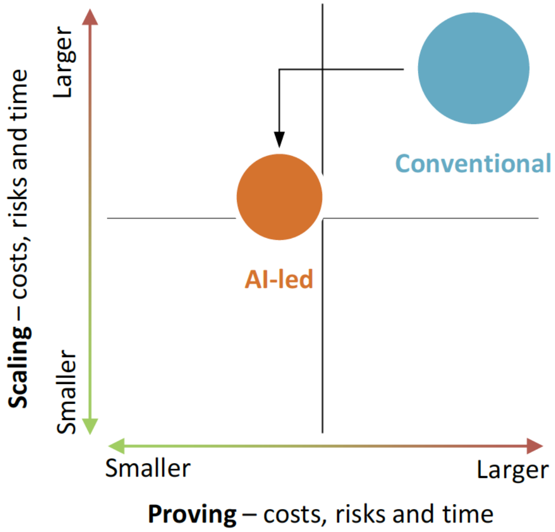


Figure 4.7 ▹ Potential to accelerate battery innovation with AI



Batteries are complex, integrated devices.

AI could substantially accelerate innovation through **materials discovery** and automated testing and analysis.

AI could slightly accelerate the **pre-commercial demonstration** phase and substantially accelerate **production efficiency** gains to reduce costs.

AI could reduce time for new battery material discovery by **as much as a factor of ten**, though many **other barriers must still be overcome** to reach commercialisation.

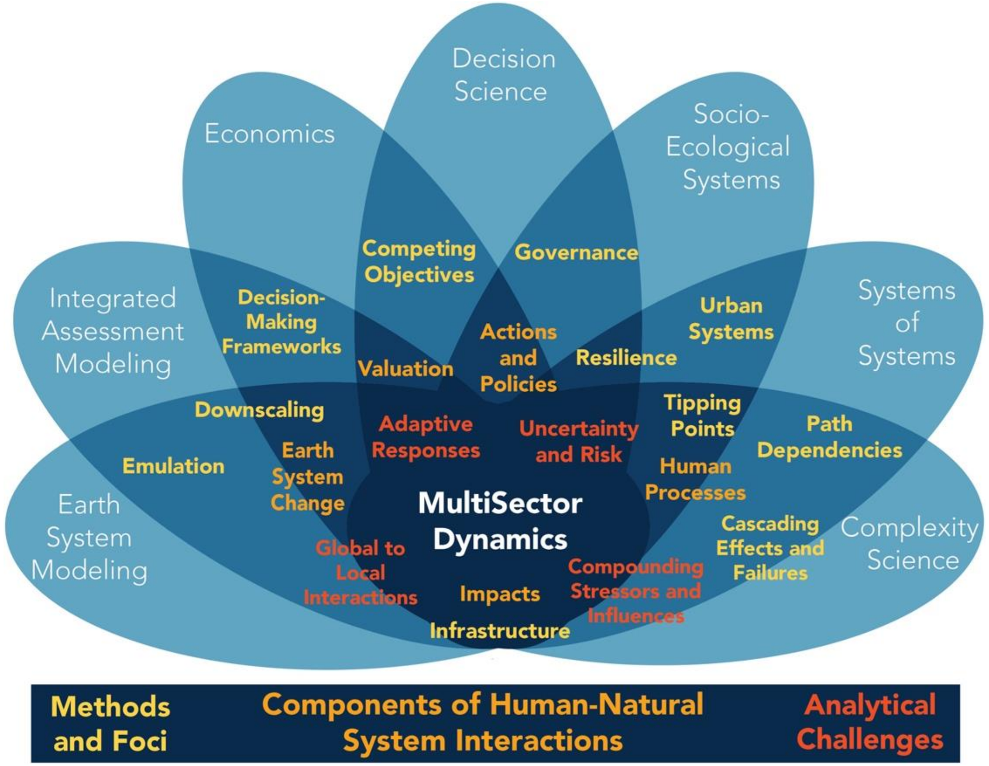
Energy sector data center risk is a classic MultiSector Dynamics problem

Connection to MSD themes:

- Systems of systems: Energy-water-economy interactions
- Economics: Supply chains and international trade
- Methods and analytical challenges:
  - Adaptive responses
  - Regulatory uncertainty and risk
  - Path dependencies

Challenges:

- Data limitations:
  - Rapid onset of highly non-linear growth rates
  - Proprietary and business-sensitive data
- Lack of models and frameworks:
  - How would one write an objective function for the growth rate of data centers?
  - How do you model their operations when their designs are constantly evolving?



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