The Future of Data Center Electrical Grid Impacts

Impacts of AI & Data Centers on Demand & Distribution Systems

Charging Ahead Webinar

28 January 2025

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Agenda and Housekeeping

Agenda

- Drivers of Data Center Growth
- Data Center Loads, Efficiency and Flexibility Options
- Data Center Siting and Sizing
- Industry Levers for Least Cost Data Center Integration
- Key Takeaways and Recommendations

Housekeeping

This webinar is being recorded and distributed to all registrants along with this presentation

Add your questions to the chat. My colleague, Sara, is monitoring the queue for the Q&A session

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Drivers of
Data Center Growth

- IT Intensive Segments
- Segment Case Studies
- Consensus Wisdom Outlooks

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IT Intensive Sectors

Key Sectors Driving Data Center Growth

Industry	Segment
Hosted IT	Cloud Compute
	Outsourced Management
	Data Management and Analytics
	Communications
AI/ML	Natural Language Processing
	Computer Vision
	Predictive Analytics
	Robotic Process Automation
	Generative AI
E-Commerce	Online Retail
	Logistics and Fulfillment
	Payment Processing
	Analytics and Data
Social Media	User Content Platforms
	Digital Advertising
	Influencer and Social Marketing
Streaming and Entertainment	Video Streaming
	Audio Streaming
	Gaming
Financial Services and FinTech	FinTech Solutions
	Blockchain Technology
Government and Public Sector	Public Sector Cloud
	Defense and Intelligence
	Municipal Services
Healthcare and Life Sciences	Health Information Systems
	Telemedicine Solutions
	Genomics and Research
	Drug Discovery
Telecommunications and 5G Infrastructure	5G Network Infrastructure
	IoT Infrastructure
	Network Operations Centers
Energy Sector	Utility Data Management
	Renewable Energy Management
	Exploration Data Analytics

Source: NAICS (2024), Energeia Research

- Energeia researched key industries and sectors contributing to demand for data centers globally
- Key sectors include, but are not limited to:
  - Generative AI
  - Cloud Compute Resources and Storage
  - Online Retail and E-Commerce
  - Social Media
  - Gaming Platforms
  - Blockchain Tech and Cryptocurrency
  - Virtual Reality
  - IoT Infrastructure
- 6-digit NAICS categories and sub-categories are shown at left
- Key questions include
  - What drives their electricity consumption?
  - How flexible is their electricity consumption?
  - How close to users do they need to be?
- The following slides dive deeper into a selection of key sector case studies, including indicators of growth and potential

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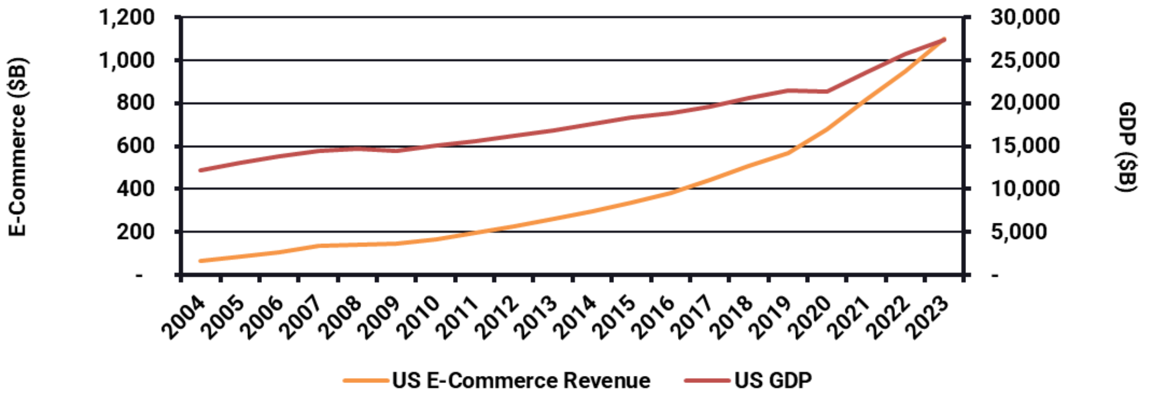
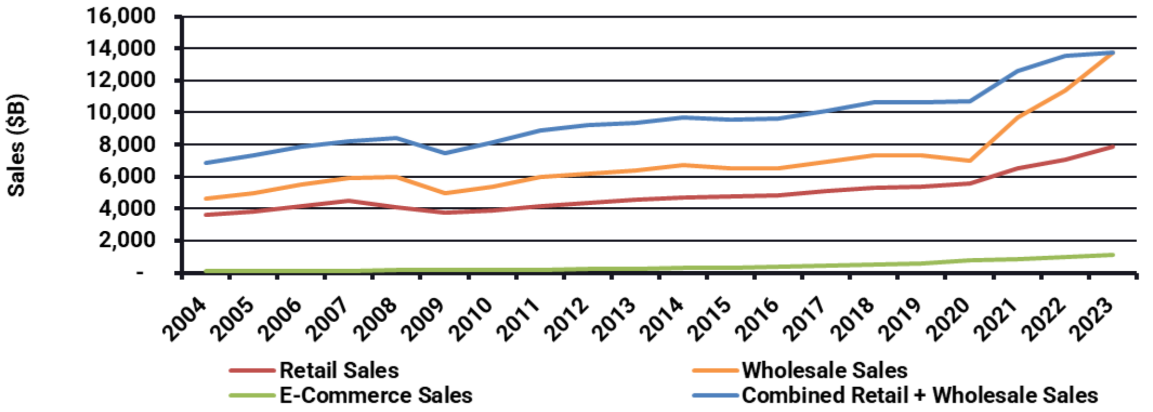
E-Commerce

US E-Commerce Revenues vs. US GDP



Source: US Bureau of Economic Analysis (2024)

US Retail + Wholesale vs. E-Commerce Sales



Source: US Bureau of Economic Analysis (2024)

- E-Commerce one of the oldest IT applications
- It is the basis for cloud computing like AWS
- It was growing in parallel to the US economy until 2010, and then it has grown much more rapidly
- Significant flexibility in the load, due to inventory, etc. – perhaps a reason AWS made a lot of sense to Amazon

- In terms of its potential, it is relatively small to retail or wholesale markets, and much smaller than both combined
- As more buying and transactions become digitized, this sector's electricity consumption will continue to grow
- A simple analysis suggests E-Commerce electricity demand could easily grow 7X over next 10-20 years
  - Assumes saturation at 80% of total sales

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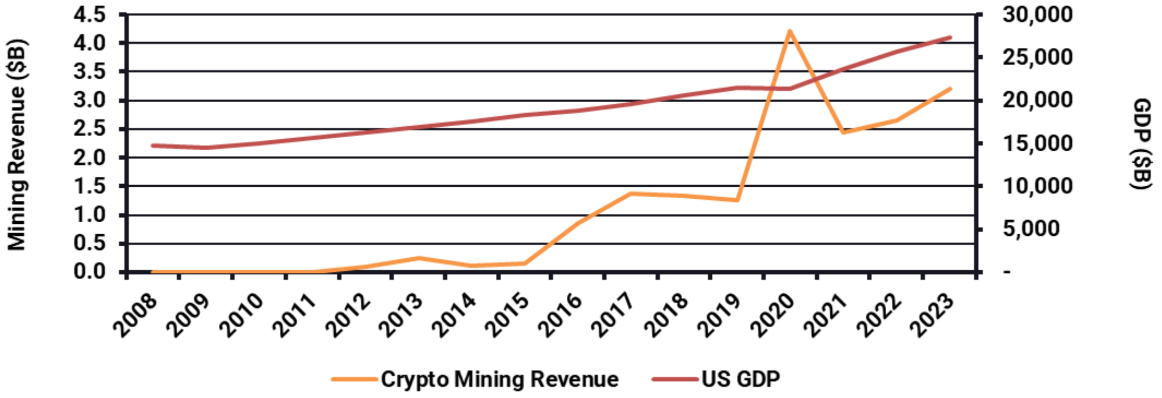
Cryptocurrency Mining

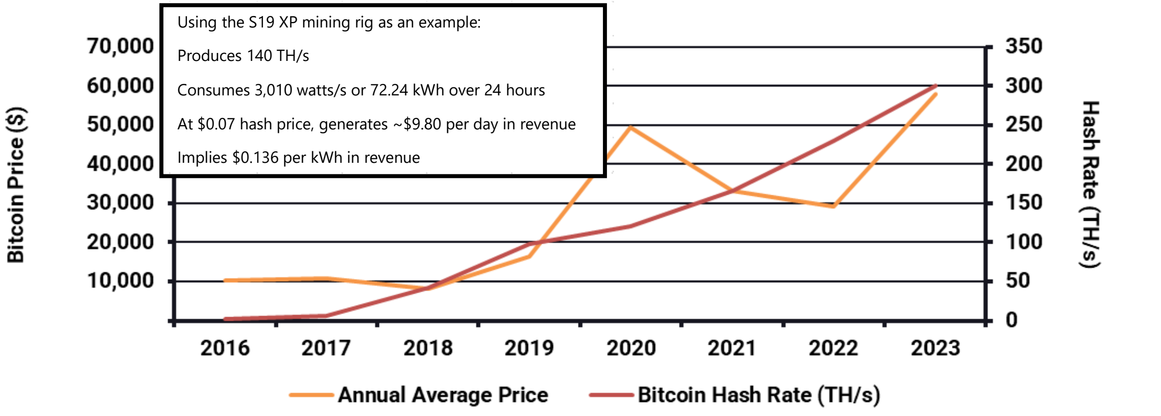
Mining Revenue vs US GDP



Source: Blockchain (2024), Federal Bureau of Economic Analysis (2024)

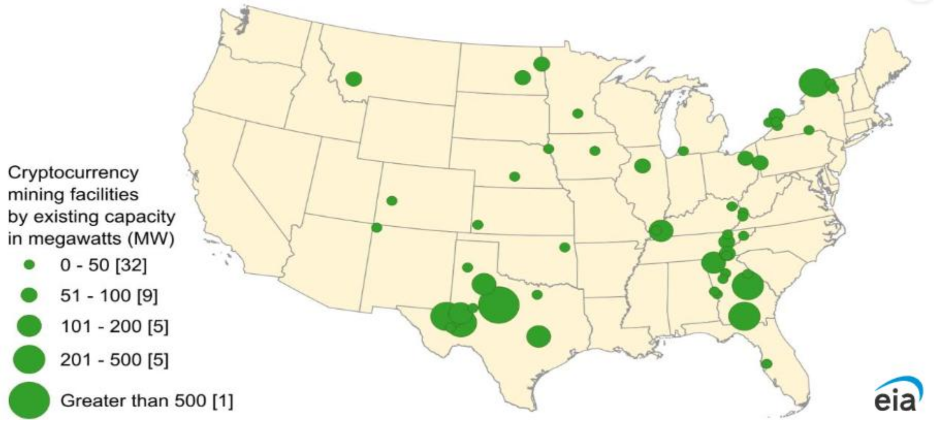
- Crypto currency is interesting because it is subject to economic factors; if prices are higher than costs, more mining will occur
  - Relationship between prices and hashing, or mining, is shown bottom left – the relationship is imperfect
  - The largest locations are not necessarily the lowest cost real-estate or electricity prices, which is interesting – maybe special deals?
- In the case of Bitcoin, it has been growing in total value at about twice the rate of the economy overall
- Upper limit as currency and investment could be bank savings and money market accounts – significant room to grow

Bitcoin Price vs. Hash Rate



Source: Forbes (2024), CoinWarz (2024), Energeia Analysis

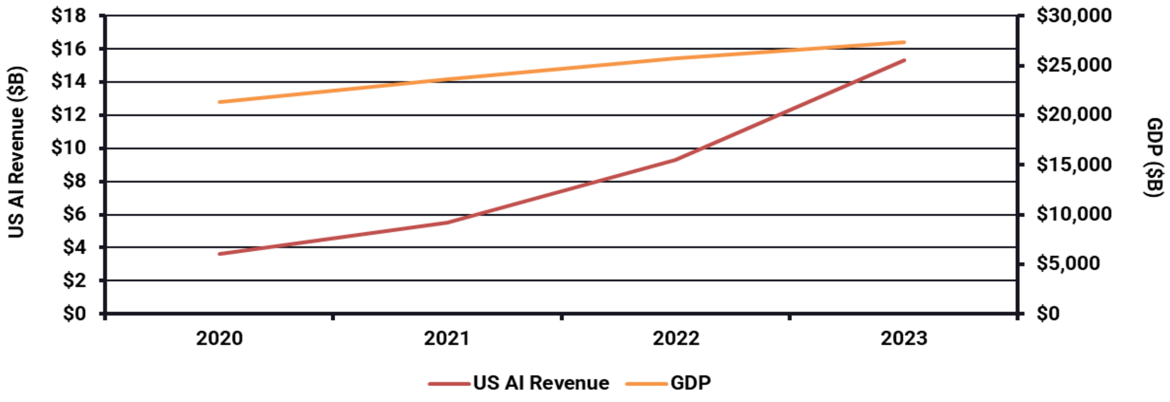
Current US Crypto Mining Hot Spots



Source: US EIA (2024)

Generative AI

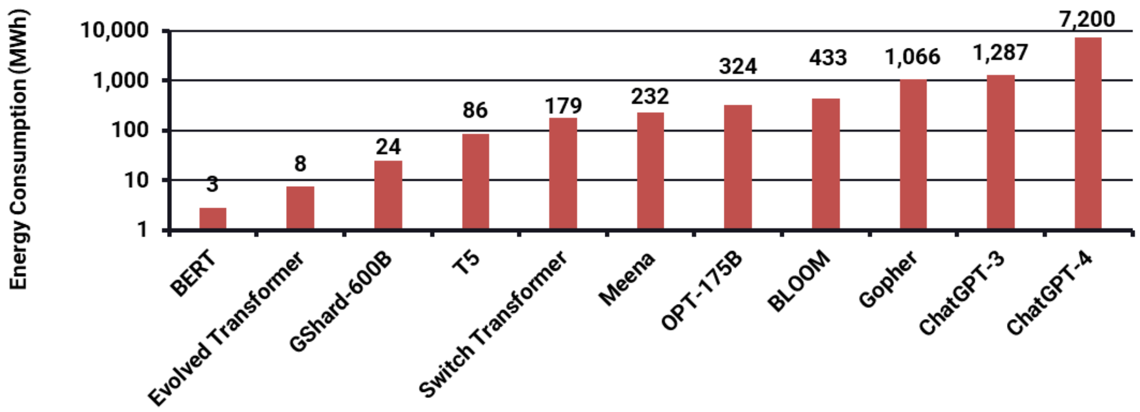
US AI Revenues vs US GDP



Source: Bloomberg (2023), World Bank (2024), Precedence Research (2024), Energeia Analysis

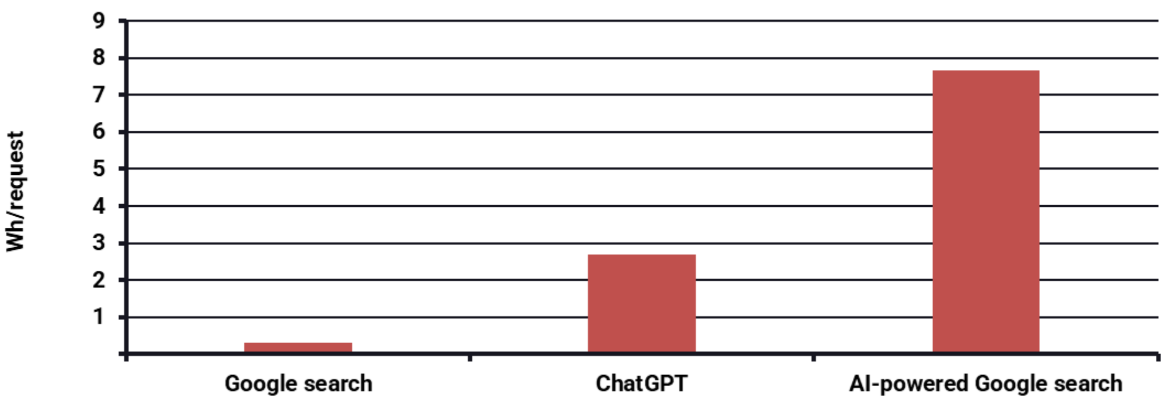
- US AI industry poised to double in market size over the next decade if current trajectory is maintained
  - Trends in AI model training show a large increase in training energy consumption (note it is log-scale!)
  - ChatGPT queries use more than 10x the energy consumption of a typical Google search, and AI-powered Google searches 2.5x more
- How much more training will be needed?
- How many AIs (instances) will be needed?
- How many applications will there be (other than search)?

AI Training Energy Consumption by Model



Source: EPRI (2024), TRG Data Centers (2024), Energeia Analysis

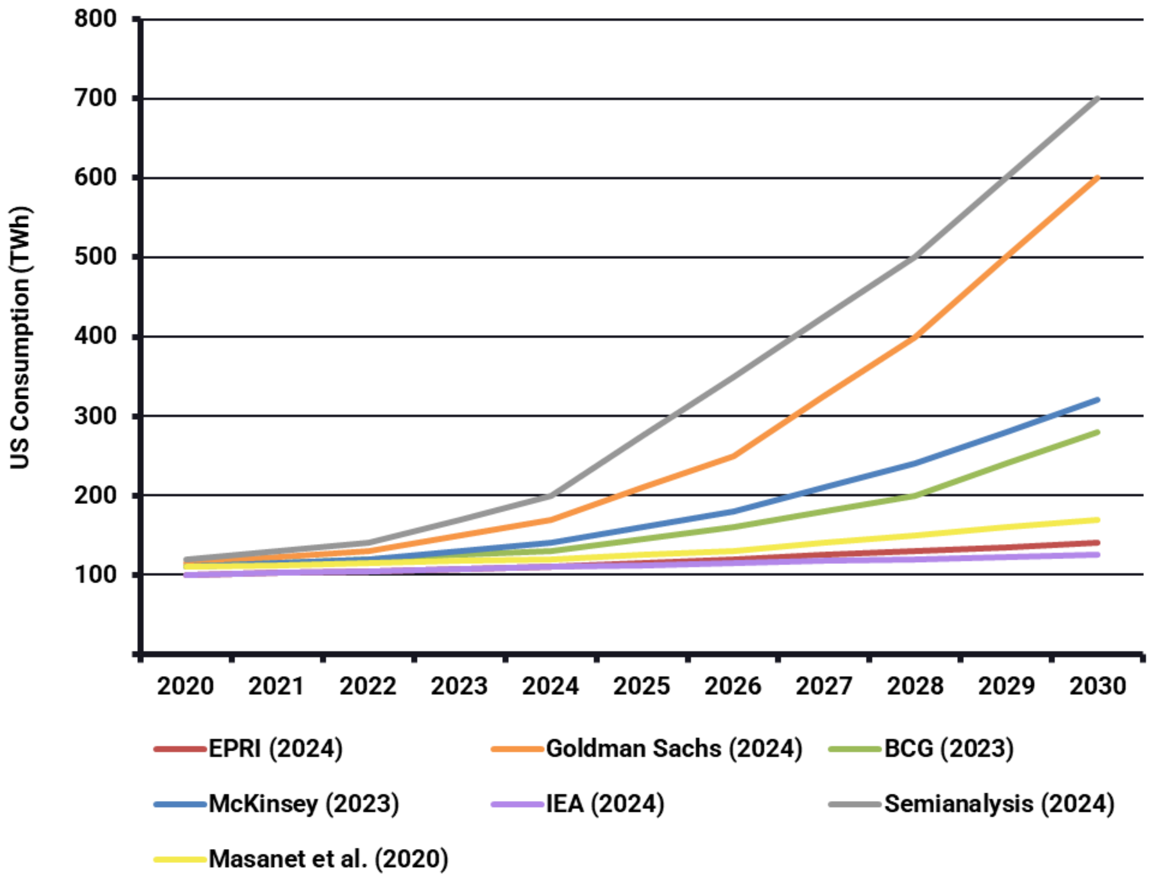
Energy Consumption by Query/Search Type



Source: Stanford (2024), EPRI (2024)

No Industry Consensus Outlook

US Data Center Consumption Forecast Comparison



Source: IEA (2024), Energeia Research

- Key industry authorities have forecasted data center growth in the US and international contexts, with no consensus on what the future holds
- Estimates for 2030 US data center energy consumption range from 120 TWh to more than 600 TWh
  - Current and historical consumption is not exact as some large-scale enterprise data centers not required to release consumption metrics
- Forecasting methodologies largely fall into two categories:
  - **Top-Down:** Compound annual growth rates based on recent history – does not factor in saturation or assumes perpetual growth
  - **Bottom-Up:** Driven by key industry segment growth metrics like processor sales, typical processor power requirements, and infrastructure efficiency assumptions
- Load serving entities face significant risk in getting this right:
  - What will drive connection sizing, build out and operating load?
  - How many sites do we plan for and over what timeline?
  - How can we best integrate this load at least cost?
    - Load flexibility
    - BTM resources
    - Rate design
    - Connection policy

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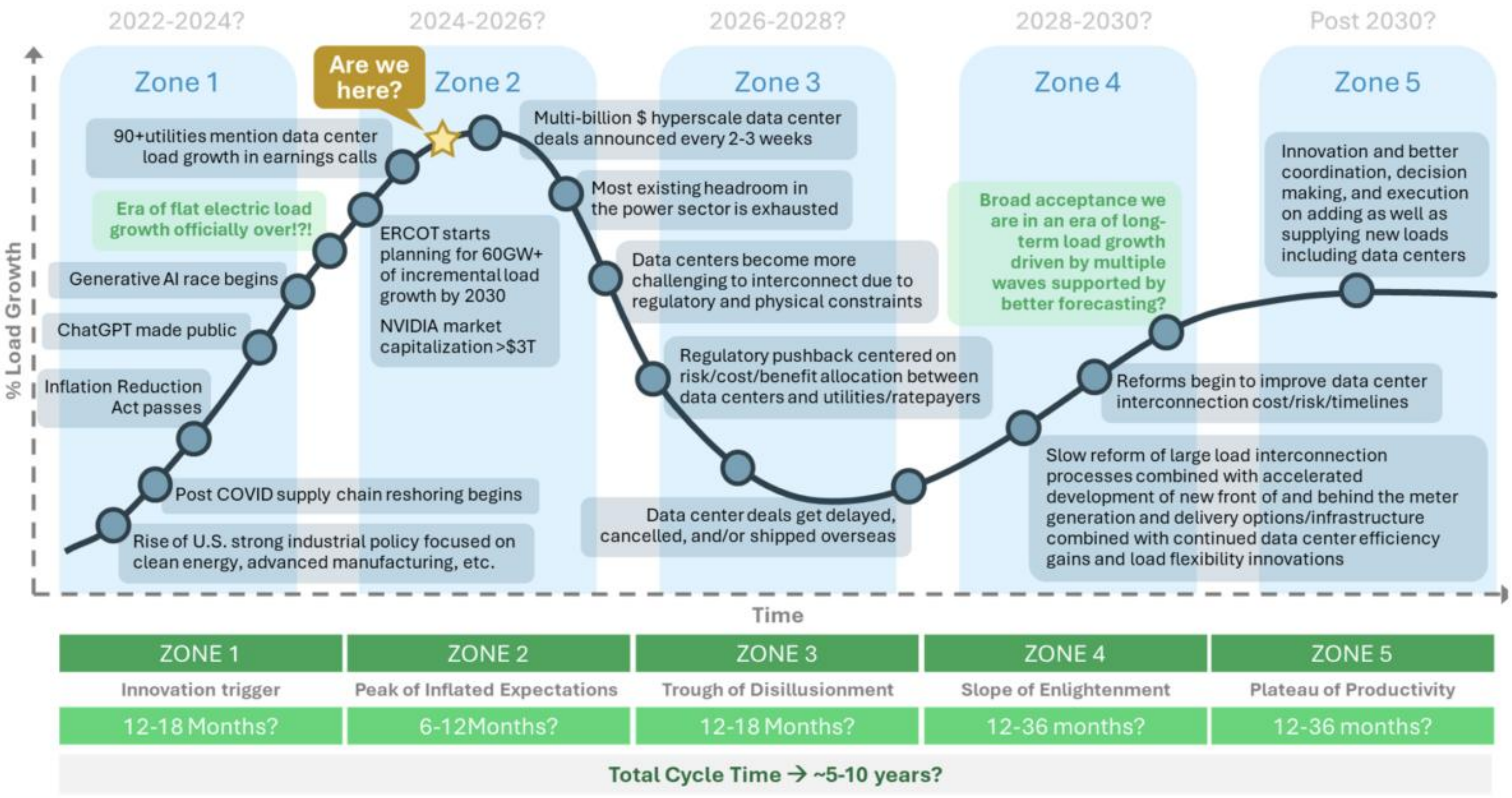
E3's Outlook on Data Center Load



Source: E3 (2024)

- Agree that we are likely to see resistance growing due to impact on headroom, supply chain costs, etc.
- Also agree that political will grow in time to ensure economic growth is supported
- A key question is what a sustainable level of higher growth looks like
- It will be uneven, as speed likely to drive metro regional sites

Data Center Loads, and Efficiency and Flexibility Options

- Consumption
- Energy Efficiency
- Load Profiles
- Flexibility

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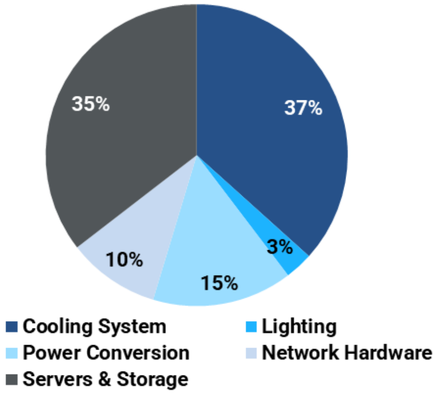
Data Center Consumption and Energy Efficiency Potential

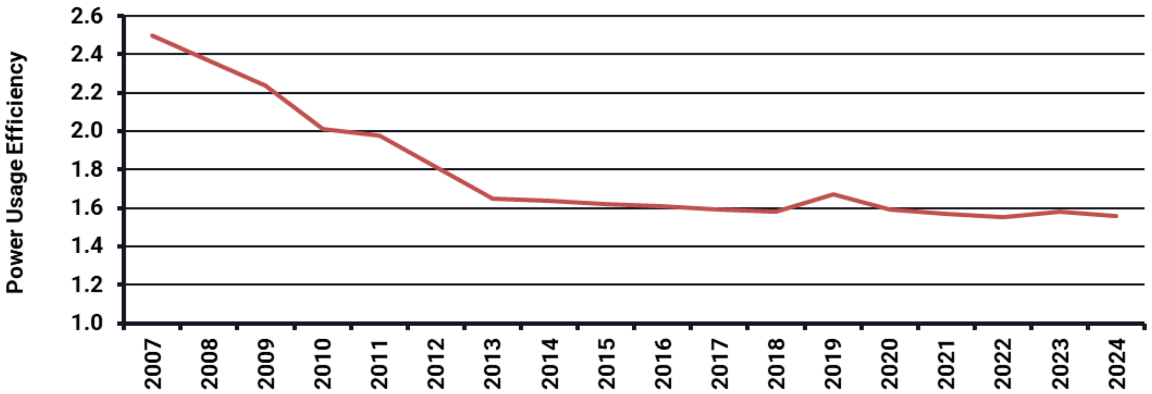
Typical Data Center Consumption Mix (PUE: 1.56)



Source: US Federal Energy Management Bureau (2024), Semianalysis (2024), Energeia Analysis

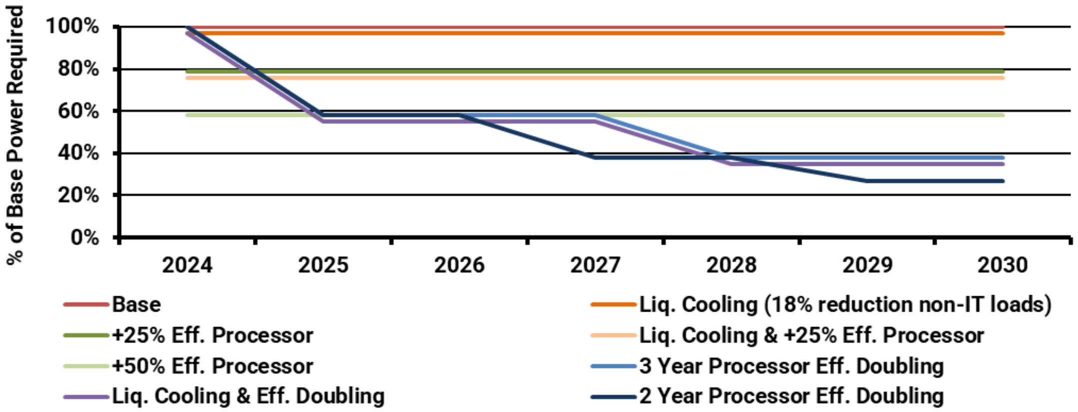
- Majority of data center energy consumed by cooling system, servers, and storage
  - Power conversion and network hardware in the second tier of consumption culprits, while lighting load is typically less than 3%
- Power Usage Efficiency (PUE) is a key metric for non-IT load efficiency of data centers
  - Ratio of total data center power requirement to critical IT power requirement
  - Critical IT power includes servers, storage, network hardware, and power conversion
  - Average data center PUE fell substantially to 2013, but has flatlined since
- Industry leaders such as NREL, Google, and Meta have deployed high-efficiency data centers with PUEs as low as 1.03 via deployment of liquid cooling, but industry-wide PUE has yet to catch up with leading tech giants

Historical US Average Data Center PUE



Source: Semianalysis (2024), NVIDIA (2024)

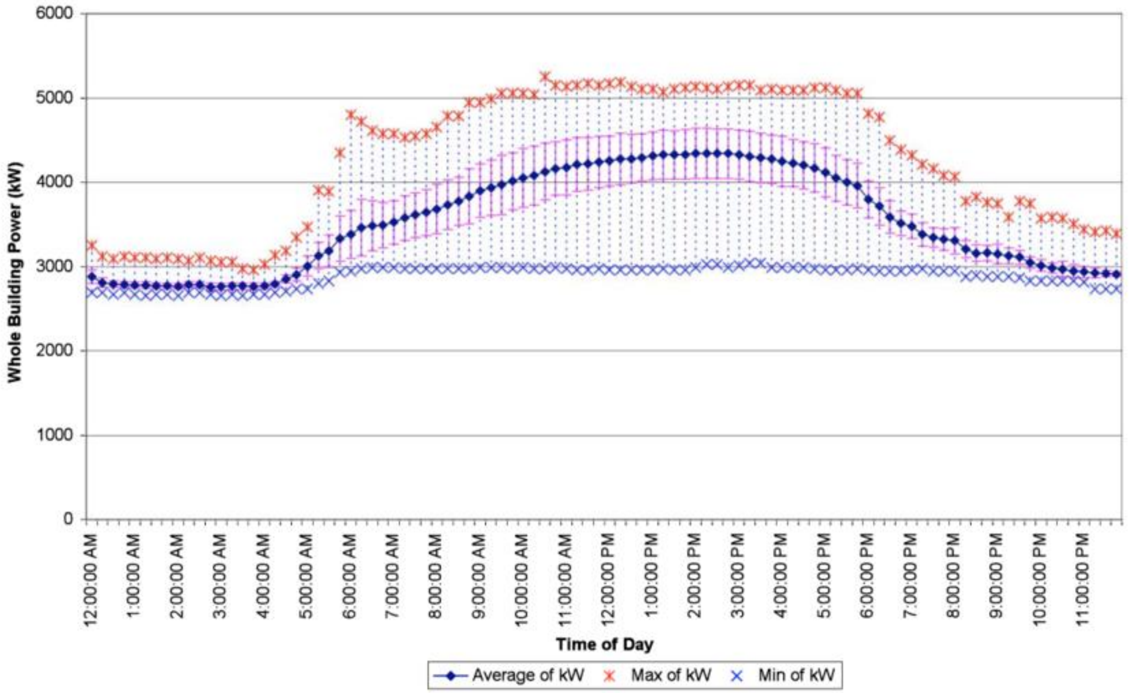
Data Center Energy Efficiency Scenarios



Source: E3 (2024), Energeia Analysis

Data Center Load Profiles

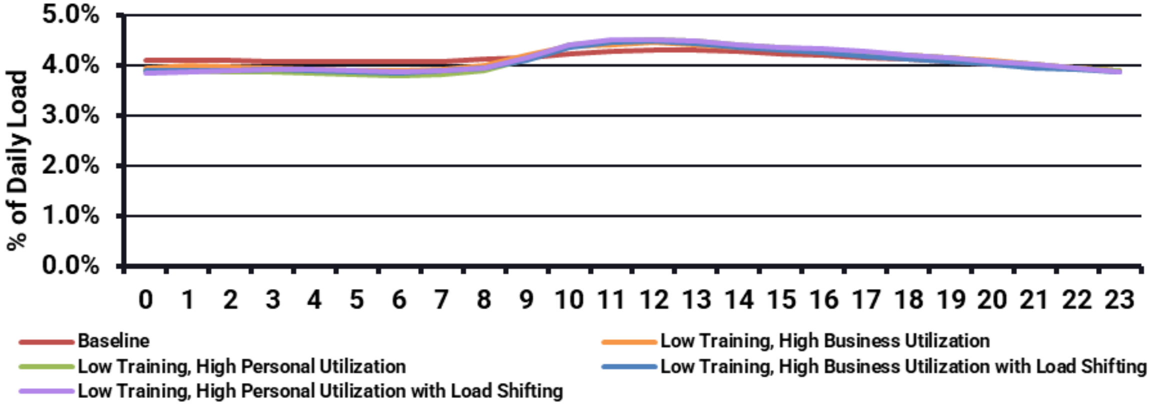
Actual Data Center Average Daily Load



Source: Ghatikar et. al (2010)

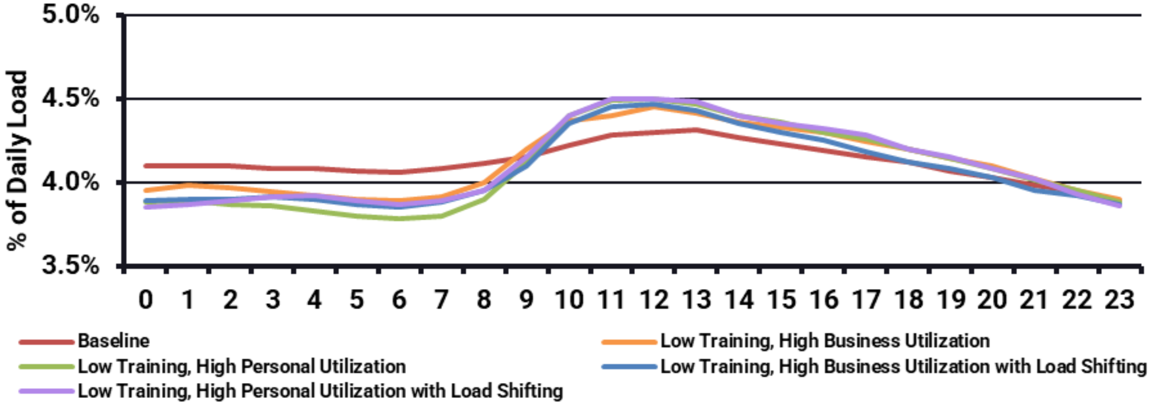
- Real-time processing requirements drive shape
- Asynchronous processing potential represents flexibility
- IT must forecast load much like electricity to avoid service outage

Estimated AI Data Center Average Daily Load



Source: E3 (2024)

Estimated AI Data Center Average Daily Load (Focused)



Source: E3 (2024)

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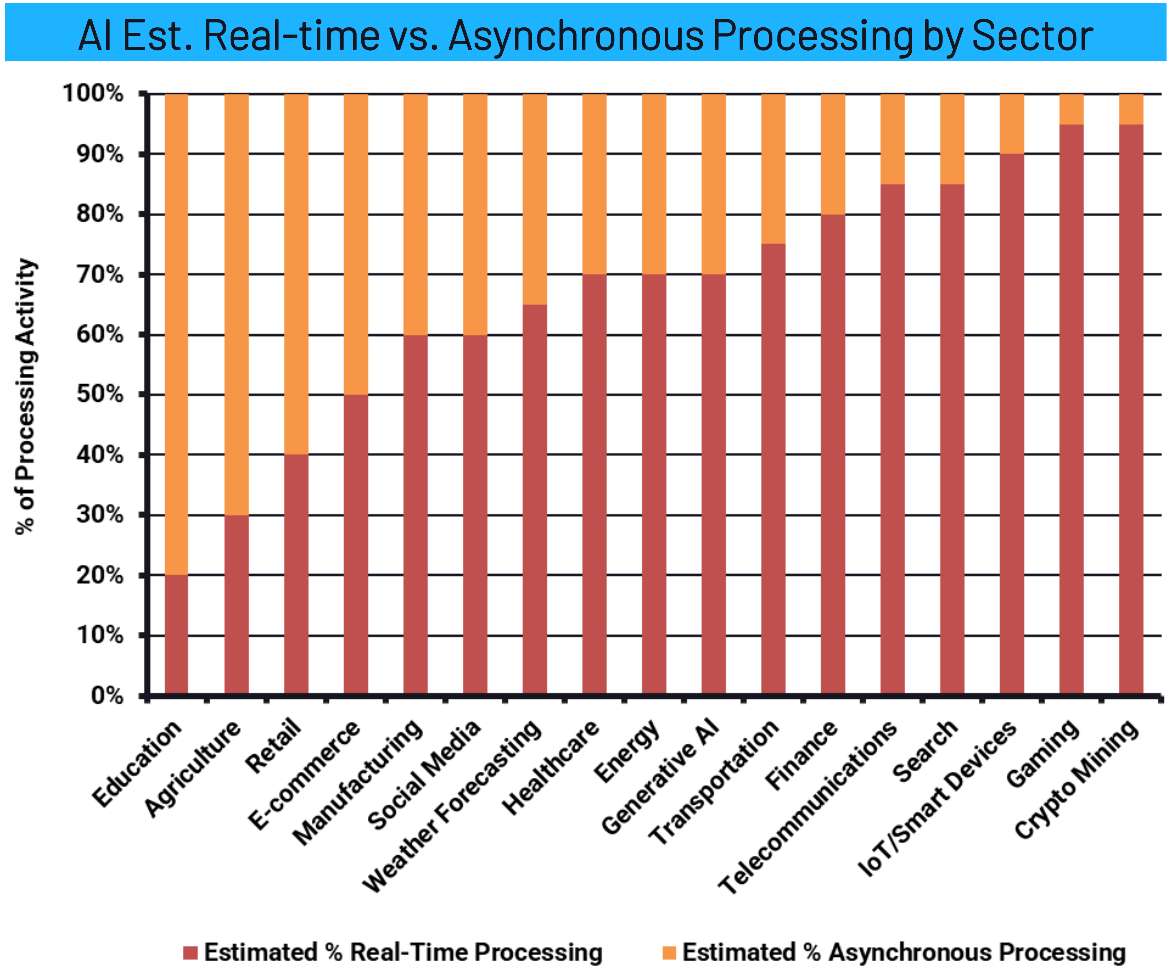
Data Center Flexibility – Illustrative



Source: Perplexity AI

- Data on the actual amount of synchronous vs. asynchronous processing by IT intensive sector not widely available
- Graphic to the left is AI's best estimate at the current time, backed by well reasoned explanations (but no real-world data)
- Future research plans are to review the IT load forecasting literature to see if more insights can be gained
- Meter data could also provide insights here
- Asynchronous processing can be moved around, in space and time, in response to price or emissions signals
- Real-time processing likely to need to be located close to users
- Together, these factors drive the electricity load profile, as well as the likely siting watershed

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Data Center Siting and Sizing

- Data Center Types
- Siting Data Centers

Types of Data Centers

Overview of Data Center Types and Sizes

Type	Definition / Overview	Typical Size Range (MW)	Approximate Count of Data Centers (US)
Hyperscale Data Center	Large-scale facilities that offer extensive space, power, cooling, and infrastructure to support massive data and cloud computing operations	100-300	510
Enterprise Data Center	A data center that is owned and operated by a single organization to support their IT needs	1-300	Unknown
Colocation Data Center	Space within a building, owned or leased by a company, that is rented out to third parties for their networking equipment or server storage	5-100	1,400
Edge Data Center	Smaller facilities located close to the populations they serve that deliver cloud computing resources and cached content to end users	1-5	1,000

Source: Energeia Research

- There are a wide range of types of datacenters, but there are four main categories, which are shown at left
- The largest ones have been typically built by the largest companies, e.g., Google and Meta
- While total size is upwards of 300 MW, they are typically developed in blocks of around 25 MW, over time
- This is not dissimilar to any industrial estate

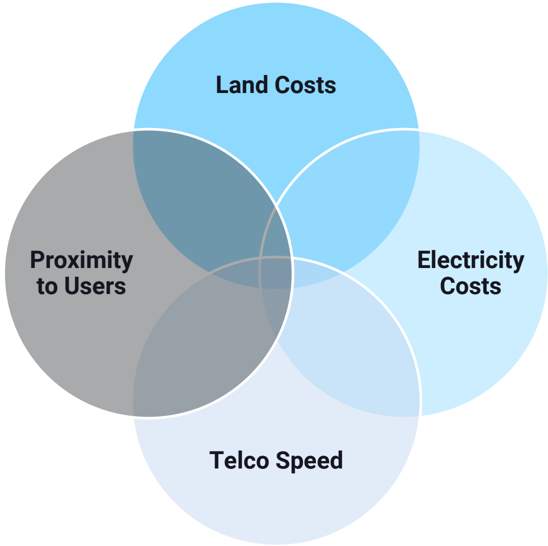
Data Center Siting and Sizing

Current US Data Center Hot Spots

Rank	Location	Data Centers	MW	MW/Data Center
1	Northern Virginia	300	3,945	13.2
2	Phoenix	100	1,380	13.8
3	Dallas	150	1,125	7.5
4	Atlanta	80	1,065	13.3
5	Chicago	110	805	7.3
6	Northern California (Silicon Valley)	160	790	4.9
7	Portland (including Hillsboro)	50	540	10.8
8	New York & New Jersey	145	450	3.1
9	Seattle (including Quincy)	70	395	5.6
10	Los Angeles	65	220	3.4
Total		**1,230**	**10,715**	**8.7**

Source: DGTL Infrastructure (2024), Energeia Analysis

Drivers of Data Center Siting



Source: Energeia Research

Current and Forecast Data Centers by ISO/RTO

Source: BCG (2023)

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Industry Levers for Least Cost Data Center Integration

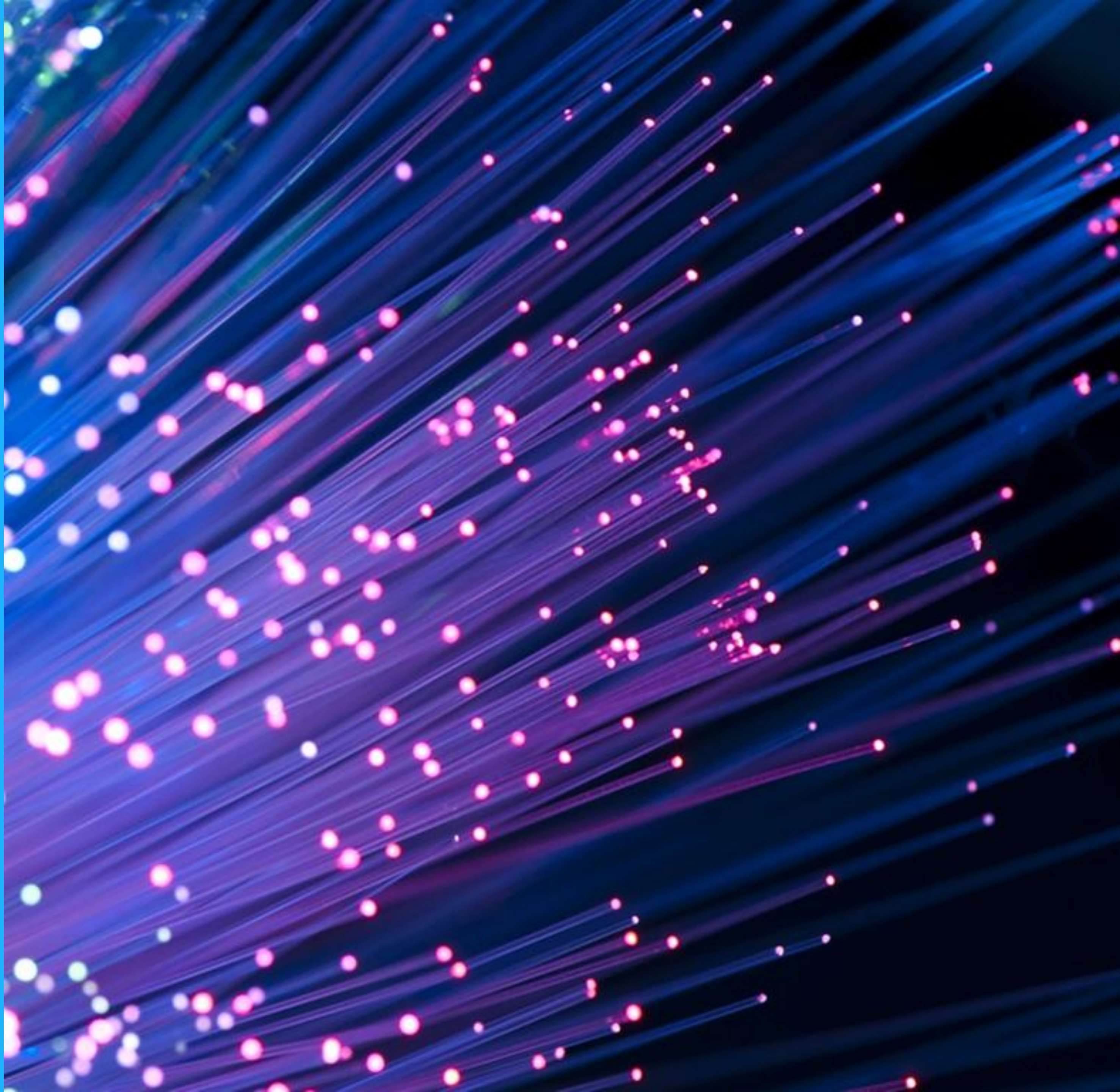
- Customer Classification
- Connection Policy
- Rates
- Energy Efficiency and DR Programs
- BTM / Co-located Resources

Key Industry Levers for Integrated Data Centers at Least Cost

Lever	Issues	Strategies
Customer Classification	• Are these loads materially different in shape, flexibility, i.e. cost to serve, to justify their own rate class? • Significant flexibility potential indicated for some server intensive sectors	• FERC recently found this not to be the case, at least in the specific case • Further evidence will be required before a new class is allowed, e.g., agriculture, etc.
Connection Policy	• First come basis leads to strategic queuing, eating up spare capacity that may not be realized • Potential for some sectors, e.g., crypto, to close down if forecast prices decline	• A strategic approach, e.g., Renewable Energy Zones, may make sense for similar reasons • Important that cost recovery policies carefully balance future revenues against this risk is offset considerations
Rates	• Some sectors may have significant flexibility • May be possible to arbitrage franchise areas, if lower cost area close enough to avoid latency threshold	• Demand response programs probably of interest • Drying up of spare capacity may push to higher cost grids
Energy Efficiency and DR Programs	• AC is the second largest source of demand; other energy efficiency opportunities very technical • Significant demand flexibility seems possible	• Programs to help optimize AC loads could be valuable • Programs to monetize load flexibility could be valuable
Renewable Energy / BTM Resources	• Tier-1 IT companies all have strong sustainability targets • Potential for load to follow zero carbon generation periods	• Renewable energy solutions that align to load profile • Consider in load forecasting models

Source: Energeia

Takeaways and Recommendations



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Key Takeaways and Recommendations

- **Key Takeaways**
  - Growth in server intensive industries is uncertain, but the fundamentals suggest it has legs for next 10 years at least
  - Growth will be uneven, focused on areas near to major populations, fiber links, low real estate and electricity costs
  - New connections will vary in size, with the largest connections likely near to population centers (synchronous) or major fiber links with low-cost land and electricity (asynchronous) – the latter is for overflow only after load sharing
  - A significant portion of the load seems likely to reflect underlying economic and demographic patterns
  - There is still significant potential for energy efficiency to reduce consumption per compute/storge activity, with AC and standby power opportunities well understood
- **Key Recommendations**
  - Determine the nature of your utility’s likely share of IT intensive industry load, to allocate appropriate levels of effort:
    - How close are you to population or business centers?
    - How good is your fiber connectivity?
    - How low are your land and electricity prices?
  - How much spare capacity do you have the in MV and sub-transmission networks in areas of low land prices, connected to the fiber optic backbone?
  - Consider opportunities for strategic planning and connection policies, e.g. like for renewable energy
  - Be proactive with cost reflective rates and associated demand response programs, best practice here does not yet exist
  - Be proactive with renewable energy solutions, as this customer segment is generally ahead of government mandates

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Q & A

Next Power Session Topic

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Energeia's Charging Ahead Series

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  - Add your questions in the chat
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  - Industrial Decarbonization: Hard-to-Abate Sectors
  - Heavy/Medium Transportation Electrification
  - Best Practice Approaches to Climate and Weather Impacts
  - Electrification Workforce Analysis and Planning
  - Virtual Power Plants: Best Practices

Reserve your place at the next **Charging Ahead** discussion

Industrial Decarbonization: Hard-to-Abate Sectors

Mar 18, 2025
9:30 AM – 10:00 (PST)

Where to find Energeia and Ezra Beeman

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Watch for a follow-up email with recording and presentation links to share

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