

EFFICIENCY FIRST: U.S. ENERGY EFFICIENCY POLICY LESSONS FOR AI FACTORIES

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Abstract

For nearly two decades, U.S. energy consumption remained relatively flat despite growth in population and economic output, reflecting substantial efficiency gains. Today, electrification, domestic manufacturing and AI-driven data centers are driving the first significant increase in electricity demand in more than twenty years. Using U.S. Energy Information Administration (EIA) data, this paper examines national and state-level energy-efficiency trends, policies, and the challenges of sustaining future improvements. AI factories represent a particularly important emerging load, requiring massive electricity consumption, cooling infrastructure and careful peak-demand management. While leading facilities achieve Power Usage Effectiveness (PUE) values near 1.1-1.2, high-density AI facilities, especially retrofits and less optimised designs, can operate at significantly higher levels, highlighting new efficiency challenges. California serves as a policy case study. The policy analysis examines how regulatory measures ("sticks"), incentive programmes ("carrots") and information tools have contributed to efficiency improvements. Drawing lessons from this experience, the paper proposes a policy framework for AI factories that combines performance standards, transparent reporting, advanced cooling incentives, demand flexibility and metrics beyond PUE. The findings suggest that a balanced mix of regulation and incentives can provide a roadmap for improving AI-era energy efficiency while supporting economic growth.

1 Introduction

Energy efficiency is the central link between U.S. decarbonisation, affordability and industrial competitiveness. Over the last two decades, total U.S. primary energy use has remained within a narrow band, while energy per capita and energy per real dollar of gross domestic product (GDP) have declined. The U.S. economy has become less energy intensive even before full electrification [1, 2].

But the next phase is harder. The previous U.S. long-term strategy for net-zero emissions relied on electrifying end uses and decarbonising electricity supply [3]. That strategy remains technically attractive because motors, heat pumps and batteries can deliver the same services with less final energy than combustion technologies. However, data centers, electrification, and manufacturing reshoring are now increasing expected electricity demand.

The paper therefore makes a policy argument. Historical efficiency gains were not produced by technology alone. Federal standards, voluntary labels, utility programmes, state codes and financial incentives changed both the minimum efficiency floor and the speed of market adoption. This view is consistent with energy-efficiency literature that emphasises market failures, information barriers, capital constraints and the importance of measurable efficiency indicators [24-26]. As AI factories become a new class of industrial electricity load, similar policy design will be needed to convert energy

efficiency from a voluntary best practice into a core condition for growth.

2 U.S. Energy Efficiency Trends by Sector

The paper uses EIA data for national energy consumption, sector energy use, electricity sales, state energy intensity and electricity prices [1, 2]. Efficiency is reported through intensity metrics because total energy consumption alone does not distinguish structural growth from energy productivity. National metrics include energy per capita and energy per unit of real GDP. California sector metrics are expressed per capita, while electricity is reported as kWh per capita.

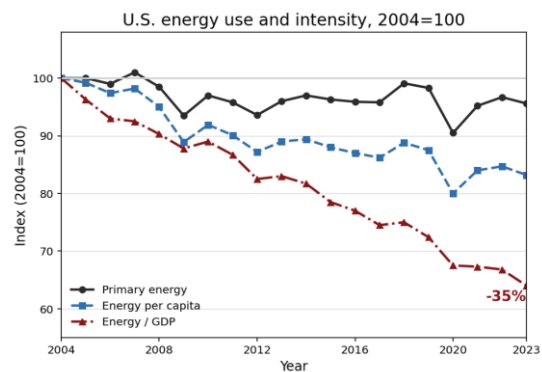


Fig. 1 U.S. total primary energy, energy per capita and energy per real dollar of GDP, indexed to 2004. Source: EIA SEDS and national energy series [1, 2].

The policy analysis is descriptive rather than causal. California policy coverage is represented by a cumulative event count across the sectors most relevant to efficiency. Pearson correlations compare that policy stack with sector intensity indices, excluding 2020 to reduce the pandemic outlier. The results support a policy-efficiency relationship, but they should be interpreted alongside economic structure, technology cost declines, weather, prices and federal standards.

2.1 Electricity

Electricity is the clearest decoupling story. Sales increased modestly over 2004-2023, but power sector CO₂ emissions fell sharply because the generation mix changed and efficiency limited demand growth. This is why clean electricity is the enabling platform for transportation, buildings, industry and AI data centers.

2.2 Transportation and industry

Transportation and industrial energy use are more persistent. Transportation depends on vehicle miles travelled, freight activity and fleet turnover. Industrial energy depends on process heat, feedstocks, output mix and utilization. Efficiency therefore must be sector-specific: vehicle standards and clean fuels in transportation; motors, pumps, boilers, process optimisation and electrified heat in industry.

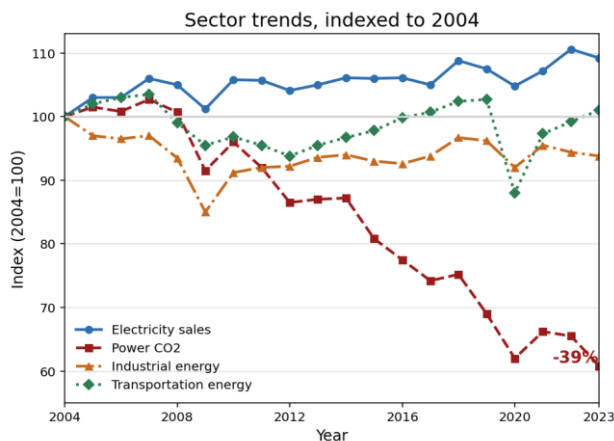


Fig. 2 U.S. electricity sales, power-sector CO₂ emissions and sector energy-use indices. Source: EIA [1, 2].

3 AI factories change the load growth problem

The most important new efficiency challenge is AI data center load growth. Berkeley Lab estimates that U.S. data center electricity use was roughly 60 TWh in 2014-2016, rose to 76 TWh in 2018 and reached about 176 TWh in 2023. The same report projects 325-580 TWh by 2028, depending on deployment, utilization and efficiency assumptions [4]. This scale is large enough to affect utility planning, transmission needs, local reliability and capacity procurement. Because many AI clusters operate near full power for long training runs, their contribution to peak demand can be close to their

nameplate load unless operators shift work, use storage or participate in demand response [4, 8, 27].

PUE provides the standard facility-level metric. It is defined as total facility energy divided by IT equipment energy; a theoretical PUE of 1.0 means all energy reaches IT equipment. A PUE of 1.2 means that every 1.0 unit of IT energy requires about 0.2 units of additional overhead for cooling, power distribution and other facility systems. Cove notes that older or less efficient facilities can exceed 2.0, modern designs often fall around 1.2-1.5 and leading hyperscale facilities target approximately 1.1-1.2 [5]. Google reported fleet-average PUE near 1.09, while the broader industry average remains materially higher [6, 7].

For AI factories, the efficiency challenge is sharper than in traditional cloud facilities. Dense GPU clusters concentrate heat and require advanced heat rejection, pumps, manifolds and power distribution. Purpose-built liquid-cooled AI facilities can reduce cooling overhead, but retrofit and air-cooled high-density facilities may operate at significantly higher PUE. More importantly, PUE does not measure computational efficiency: a facility can have excellent PUE but still waste energy through low GPU utilization, inefficient models, idle accelerators or unnecessary inference. The same distinction matters for peak demand: an efficient facility can still impose a large system peak if training and inference loads coincide with regional heat waves, evening ramps or constrained transmission hours.

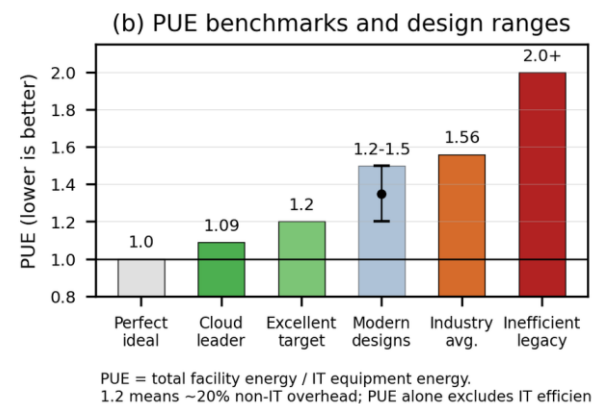
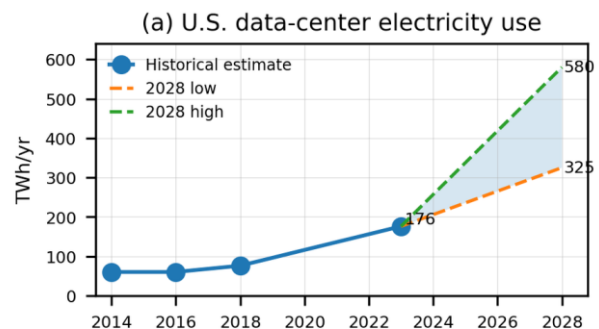


Fig. 3 Data center electricity demand and PUE benchmarks. PUE is useful but incomplete for AI factories because it excludes IT utilization, computational output and peak-load flexibility [4-8].

4 National policy drivers: carrots, sticks and market information

National policy has been a major driver of U.S. energy efficiency. Federal standards and rules generally act as sticks: they remove the least efficient technologies from the market and create a mandatory floor. Incentives act as carrots: they reduce upfront cost and accelerate adoption. Information programmes sit between the two: they create transparent comparisons that allow consumers, firms and utilities to reward efficient choices. The combined use of standards, incentives and information is consistent with the economics literature on efficiency adoption barriers [25, 26].

DOE appliance and equipment standards are the clearest national stick. The programme covers broad residential, commercial and industrial product classes, and DOE reports that standards implemented since 1987 reduced utility bills for households and businesses by \$105 billion in 2024 alone [9]. ENERGY STAR is the best-known information carrot. Since 1992, ENERGY STAR and its partners have helped save about 5 trillion kWh, avoid more than \$500 billion in energy costs and reduce greenhouse-gas emissions by about 4 billion metric tons [10].

Table 1 National energy-efficiency drivers by policy type

Driver	Policy type and impact
DOE standards	Stick: minimum performance floors for appliances and equipment; large recurring bill savings [9].
ENERGY STAR	Information/carrot: trusted label and benchmarking; 5 trillion kWh and \$500 billion saved since 1992 [10].
EISA 2007	Stick/enabler: vehicle, lighting, appliance, federal building and smart grid provisions [11].
CAFE	Stick: fuel economy requirements; projected gasoline and CO2 savings through 2050 [12].
EERS/utility EE	Hybrid: utility savings targets plus rebates and programmes; over 80% of utility savings in EERS states [13].
IRA rebates	Carrot: household efficiency and electrification incentives; \$8.8 billion authorised [14].

The Energy Independence and Security Act of 2007 (EISA) strengthened the national framework by addressing vehicle fuel economy, appliance and lighting efficiency, federal energy management and grid modernisation [11]. CAFE standards then provided a transportation-sector stick by

requiring higher fleet fuel economy; NHTSA estimated that updated standards for model years 2027-2031 and heavy-duty pickup/vans for 2030-2035 would save almost 70 billion gallons of gasoline and prevent more than 710 million metric tons of CO2 through 2050 [12].

Utility energy-efficiency resource standards (EERS) provide a hybrid model. They are usually state-level requirements, but they operate through utility-administered programmes and shape national practice. ACEEE reports that 26 states plus the District of Columbia had EERS policies, accounting for more than 80% of utility efficiency programme savings in 2023 [13]. The Inflation Reduction Act (IRA) adds a large carrot by providing \$8.8 billion for Home Energy Rebates and related efficiency and electrification upgrades; DOE estimated these rebates could save households up to \$1 billion annually while supporting residential construction and manufacturing jobs [14].

5 California case study: stacking carrots and sticks

California illustrates how national policy floors can be reinforced by state policy stacking. EIA reports California energy intensity at 2.10 thousand Btu per chained 2017 dollar of GDP in 2023, roughly half the U.S. average of 4.13 [1]. This does not mean one policy caused the result; California also has a different economic structure and climate. But the state provides a useful test case for how regulations, incentives and disclosure can be aligned over time.

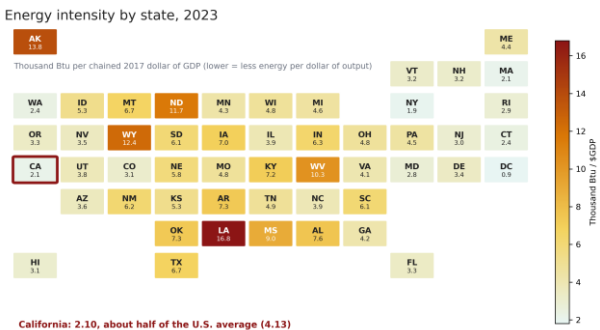


Fig. 4 State energy intensity in 2023. California is highlighted as a low-intensity large economy. Source: EIA SEDS [1].

5.1 California sticks: codes, standards and mandates

Title 24 Part 6 is the central building-code stick. It applies to residential, multifamily and nonresidential buildings, including new construction, additions and alterations. Its impact is especially visible in the commercial sector because lighting, HVAC, envelope requirements and controls are central drivers of commercial building energy use. CALGreen, Title 24 Part 11, adds green-building provisions that reinforce the code pathway [15].

Title 20 appliance and equipment standards complement Title 24 by regulating products rather than whole buildings. This matters for residential and commercial equipment, and for some industrial and commercial equipment categories. AB

802 benchmarking is another stick with an information function: owners of large commercial and multifamily buildings must report energy use to the CEC annually, creating transparency and management attention [16].

In electricity, RPS and SB 100 do not directly reduce kWh consumption. They reduce emissions per kWh by shifting electricity procurement toward renewable and zero-carbon resources, which makes electrified end uses a cleaner

5.2 California carrots: financing, rebates and market transformation

California also used carrots to reduce adoption barriers. AB 758 directed the CEC to develop an existing-buildings efficiency strategy. The resulting Energy Efficiency Action Plans created a long-term roadmap for benchmarking, financing, workforce development, retrofit delivery and market transformation across residential, commercial and public buildings [22]. SB 350 is best described as a stick/carrot hybrid. It created a statewide requirement to double energy efficiency savings in electricity and natural-gas end uses by 2030, implemented through utility programmes and integrated planning [23].

Financing programmes translate policy goals into adoption. AB 811 authorised property-assessed clean energy financing for energy efficiency and renewable improvements. CHEEF reduces upfront costs for retrofits by using credit enhancement lower rates, and longer terms to support broader borrower access. This decreases the upfront costs of retrofit, instead allowing them to be financed and repaid over time. SB 1477 created BUILD and TECH pilots for building decarbonisation and heat-pump market transformation. These carrots matter most where efficient technologies have higher upfront cost but lower operating cost.

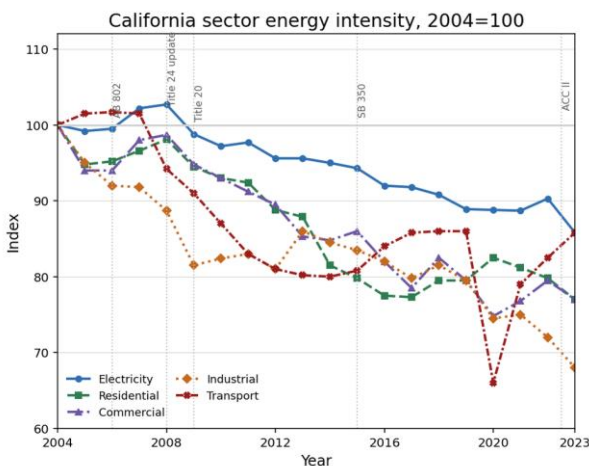


Fig. 5 California sector energy-intensity indices and cumulative policy stack.

5.3 Correlating policy with sector improvement

The descriptive results show sector improvement where policy coverage is deepest. From 2004 to 2023, California intensity declined by about 14% for electricity, 23% for residential, 23% for commercial, 15% for transportation and 32% for industry.

efficiency strategy and reduces the carbon impact of each incremental AI-factory kilowatt-hour [17, 18]. In transportation, LCFS, Advanced Clean Cars and SB 375 apply a standards-based approach to fuels, vehicle technology and land-use/transportation planning [19-21]. These policies correlate with improved transportation energy intensity, although vehicle miles travelled and economic activity still matter.

Sticks set the minimum; carrots accelerate replacement, retrofits and market transformation. Buildings benefit from both: Title 24 and Title 20 set the floor, while AB 758, CHEEF and utility programmes help retrofit the existing stock. Transportation needs standards to shift vehicles and fuels but also charging incentives and infrastructure. Electricity decarbonisation needs clean energy mandates plus interconnection, transmission, storage and demand flexibility.

Table 2 California policy lessons by carrots and sticks

Policy type	Sector lessons
Sticks	Title 24 and Title 20 reduce building and equipment waste; LCFS and Advanced Clean Cars shift transport fuels and vehicles; RPS/SB 100 clean each kWh.
Carrots	AB 758, AB 811, CHEEF, utility programs and SB 1477 lower retrofit costs and accelerate building and equipment turnover.
Information	AB 802 benchmarking and ENERGY STAR Portfolio Manager create visibility for large commercial and multifamily buildings.
Observed pattern	Residential and commercial intensity declines are most aligned with policy stacking; transport and industry improve more slowly because assets turn over slowly.

6 Policy Recommendations for AI Factories

AI factories should be treated as a new industrial load class. Their scale can be comparable to large industrial plants, but their efficiency depends on a different combination of factors: cooling and power delivery systems, GPU utilization, model design, workload scheduling and the flexibility of training and inference operations. Peak demand makes this an electricity system issue rather than only a facility efficiency issue: a few hundred megawatts of coincident AI load can determine local substation capacity, transmission upgrades, and the need for peaking generation. The national and California lessons suggest a balanced carrots-and-sticks framework.

The stick side should begin with measurement. Large AI loads should report total energy, IT energy, PUE, water use, carbon intensity, hourly load profile, peak demand, demand

flexibility and IT utilization. Minimum performance requirements can then be phased in for new facilities, with climate-adjusted PUE/WUE thresholds, commissioning requirements and peak-demand management. Interconnection approval can require evidence of grid-impact mitigation, flexible operation, demand response capability, storage backed peak shaving or clean capacity procurement.

The carrot side should reward verified efficiency improvements. Incentives should support direct-to-chip liquid cooling, efficient power conversion, high-efficiency UPS systems, waste-heat reuse, water-efficient cooling, on-site or contracted clean electricity, storage and load flexibility. A national ENERGY STAR-like label for AI factories could benchmark PUE, WUE, CUE, GPU utilization, peak-load flexibility and computational efficiency, helping customers choose efficient AI services in the same way that ENERGY STAR helped consumers choose efficient appliances.

Table 3 Applying lessons to AI factory policy

Tool	AI factory application
Stick	Report total, IT and peak energy; apply climate-adjusted PUE/WUE/CUE thresholds; require commissioning, flexible demand and grid-impact mitigation for interconnection.
Carrot	Provide tax credits, utility rebates and accelerated depreciation for liquid cooling, efficient power systems, heat reuse, storage and load flexibility.
Information	Create ENERGY STAR-like benchmarking with public PUE, WUE, CUE, utilization, peak-flexibility and compute-efficiency metrics.
Hybrid	Tie faster interconnection and incentives to verified reporting, efficiency, flexibility and clean-capacity performance.

7 Conclusion

The U.S. energy-efficiency record shows that growth and lower energy intensity can coexist when technology improvement is reinforced by policy. National standards, ENERGY STAR, utility programmes and IRA rebates changed both the market floor and adoption speed; California shows how state codes, benchmarking, clean energy mandates and financing can be stacked. These tools did not eliminate the hard sectors, but they helped explain why energy per capita and energy per unit of GDP declined while the economy expanded.

AI factories now make the next stage more difficult. PUE remains necessary, but it is incomplete without water, carbon, peak-demand, load flexibility and computational efficiency metrics. The central policy lesson is therefore to pair reporting and performance standards with incentives for advanced cooling, efficient power systems, storage, heat reuse and flexible operation. Such a package can support AI growth

while preserving the efficiency gains that have defined the last twenty years.

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