



White Paper

MODULAR NATURAL GAS POWER PLANT SOLUTIONS FOR AN EVOLVING GRID.



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A Rolls-Royce
solution

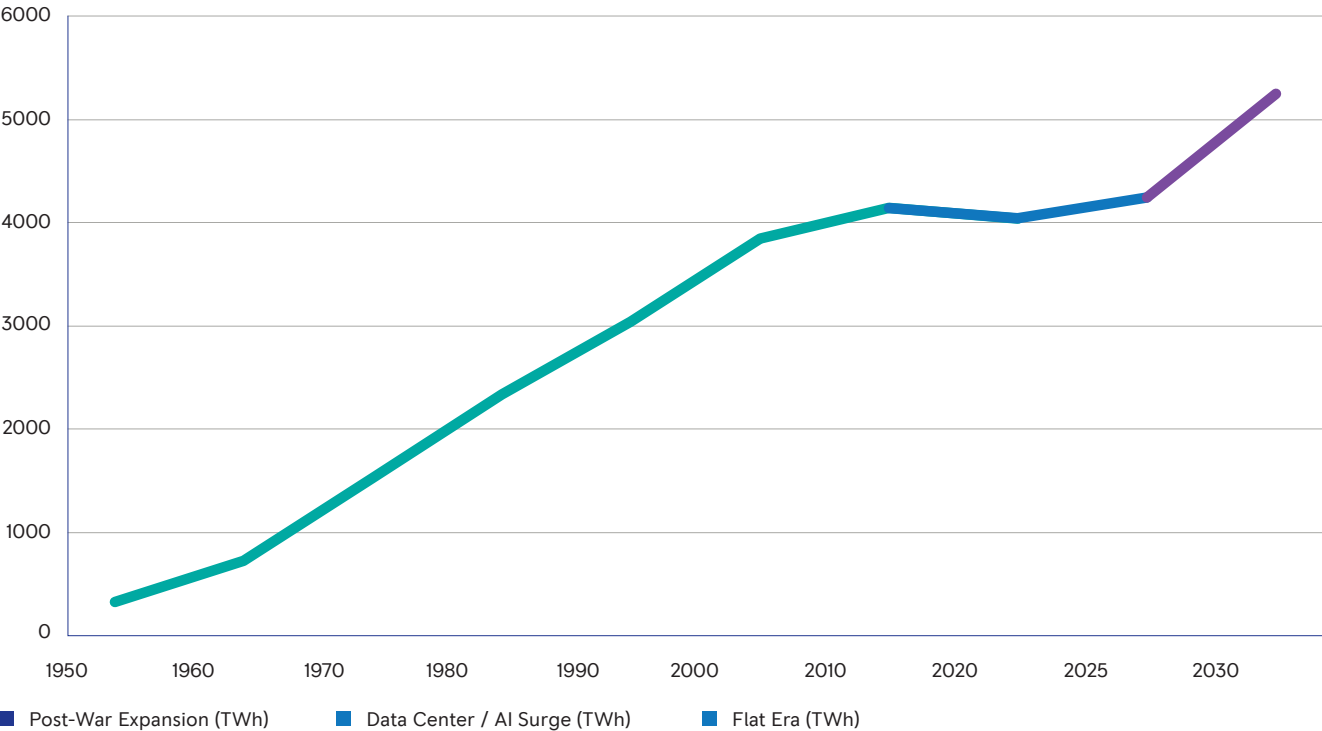
Rapid data center expansion and a surge in renewable energy installations are creating new challenges for the aging U.S. power grid. The high power demands from data centers and the intermittent power provided by renewable generation are driving a need to rethink the way utilities approach power plant design and placement.

In the past, large-scale, centralized coal and natural gas turbine power plants served a stable base load with some excess capacity for peak demand. This design ensured reliability and resilience, and was based on the following assumptions:

- The demand was highly predictable, and based on well established load profiles
- Growth was well understood, and peaks could be managed under those conditions
- Big distribution systems could reliably service customers with minimum downtime

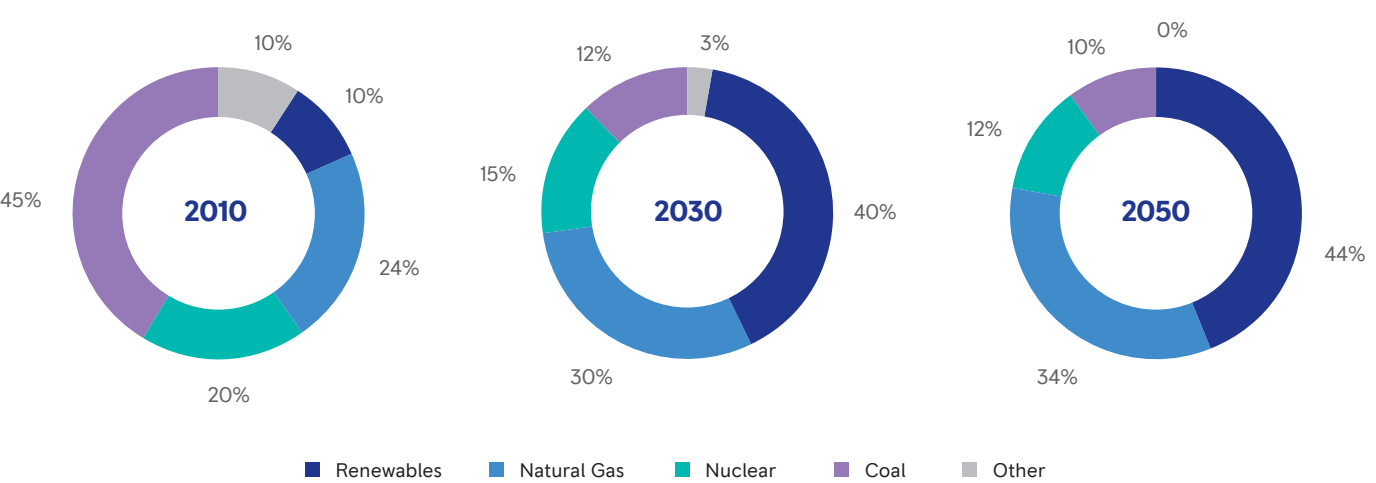
The days of slow and steady are over: The growth of data centers and integration of renewable energy resources are changing the game. The United States is entering a new era of demand growth after years of stagnation. This growth is primarily driven by data centers, making them a critical factor when planning load capacity (**U.S. Electricity Demand Evolution Chart¹**). Data centers, especially AI data centers, present a unique challenge in their size and load profile. A single hyperscale AI data center can present a 100 MW load to the grid, equivalent to the needs of roughly 80,000 U.S. households [1], or double the capacity of the typical power plant in the United States [2]. And while power plant planners would typically plan for a capacity swing of 5-25% [3], AI data centers can experience swings of 50-100% in seconds [4].

U.S. Electricity Demand Evolution¹



At the same time, renewables are set to become the most prominent source of energy by 2050 in the United States with PV installations being the primary driver [5] (**2010 and 2050 Renewable Share Pie Chart²**). Solar’s popularity in the renewable energy sector is due to its low cost of entry, and its feasibility at almost any scale. Both the public and private sectors are finding ways to adopt solar, and this trend will continue.

Share of Electricity Source 2010-2050²



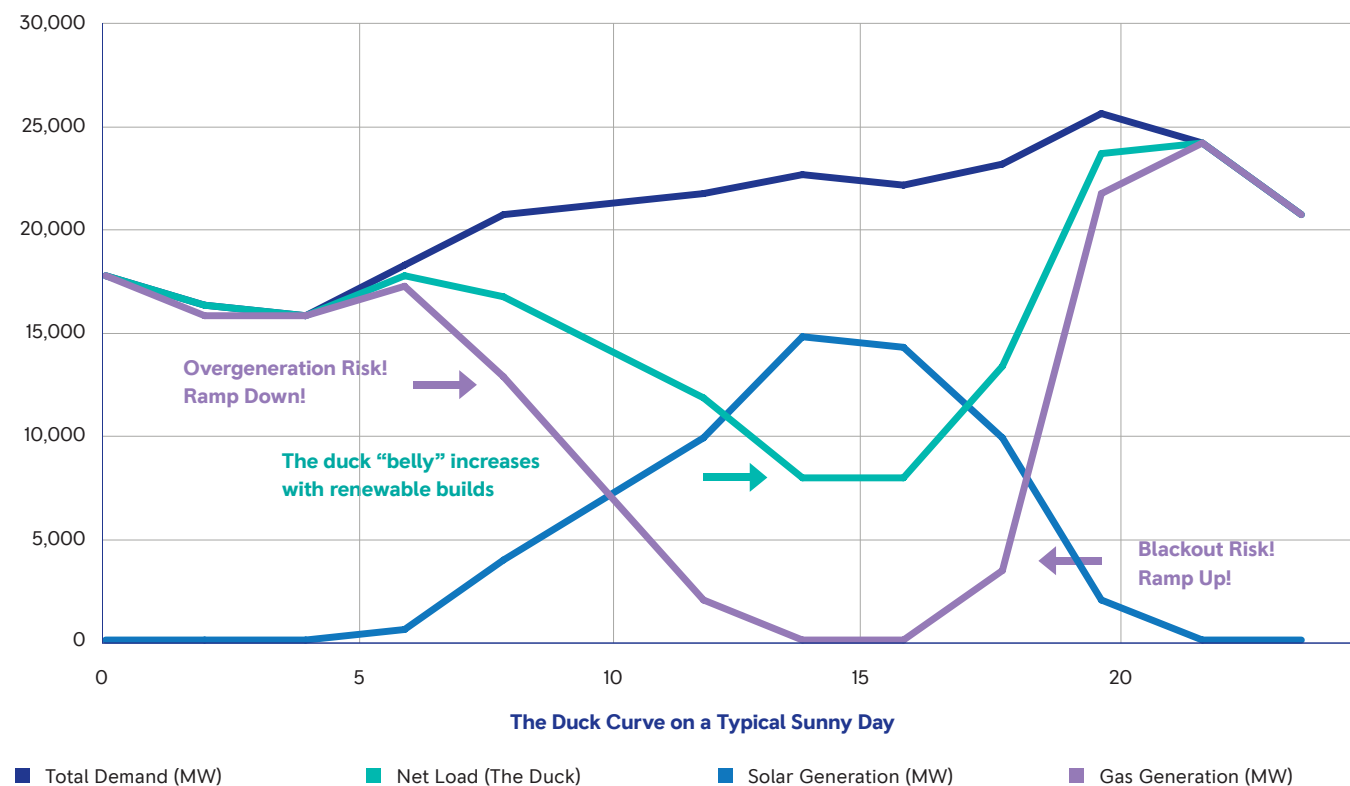
One challenge that emerges from this proliferation of renewable energy is a load profile commonly referred to as the “duck chart” [6] (**Typical Sunny Day Chart³**). This is a phenomenon that occurs when peak generation of renewable energy is outside the peak demand for energy. Demand on the grid tends to decrease as renewable production is at peak (mid day sun), leading to excess power production. Operators need to throttle down their non-renewable power plants to keep the grid stable. As luck would have it, demand on the grid tends to increase at the same time renewable energy production ramps down. This means operators must ramp up their non-renewable power plants to keep up with demand. As more renewable energy comes online, this phenomenon will be exaggerated.



References

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Typical Sunny Day³



A solution for today's grid: Gas power plants can close the gap between volatility and increasing demand.

The United States has undergone a significant transition away from coal powered plants in the last two decades. Several factors have caused this:

- The proliferation of fracking and the “shale revolution” that significantly lowered the cost of natural gas, making coal uncompetitive [7].
- Efficiencies in natural gas power plants exceeding that of coal power plants [8].
- Tightening environmental regulations that have forced coal plants to either shut down or become expensive to run [9].
- Coal power plants are less flexible than natural gas powered plants when facing load variance [10].

Reliability and stability are hallmarks of the U.S. grid: Operators must adapt to a changing demand base to keep this reputation. As noted in this white paper, the growth of data centers and proliferation of renewables present a new challenge to the grid. Adaptability to large load swings is becoming part of the design conversation.

As a result, the United States is building grid capacity using two methodologies: via renewables and natural gas-powered plants. Because renewable energy production is variable depending on weather, natural gas sourced electricity is an essential choice for power in the United States. Two types of gas power generation technologies are considered in this white paper: Turbines and Reciprocating Internal Combustion Engines (RICE) in a Modular Engine Power Plant (MEPP) configuration. Turbine power plants have been the technology of choice for traditional large power generation. Large power plants with high running hours at full load and only a few starts per year result in low Total Cost of Ownership (TCO) and Levelized Cost of Energy (LCOE) using turbines. However, the proliferation of high-density data centers and renewables is fundamentally shifting power plant requirements. Variable loads, fast response, fast startup and fast deployment are now the primary driving forces when planning. The reliance on traditional, slow-ramping turbines is diminishing in favor of the MEPP that can provide highly responsive, flexible and quickly deployed power.

Smaller building blocks for versatility and reliability: How a modular approach can win in today's applications.

Turbine power plants exhibit high efficiency under full-load operations. However, most turbine power plants consist of large turbines in small quantities, their efficiency drops significantly for partial load operations/load increments. In the case of a power plant composed of many small reciprocating engines, partial load operation strategies can differ. To run on load increments, a Modular Engine Power Plant (MEPP) can simply disable several units, leaving the rest to run at peak efficiency.

When comparing technologies themselves, reciprocating engines can respond faster to load changes and do not have significant costs related to a start-up compared to turbines. Reciprocating engines also maintain their efficiency over a wider load range. This is especially important given the load swings AI data centers and renewables introduce. Fast response and high efficiency along with flexibility are critical success factors and enablers of the energy transition.



The MEPP is a scalability, servability and speed champion

While the MEPP can outperform turbine systems given current and emerging load challenges; it's modular architecture also allows planners to scale capacity alongside the evolving needs of the consumer. One can consider each genset (Power Unit) as a building block with maximum versatility.

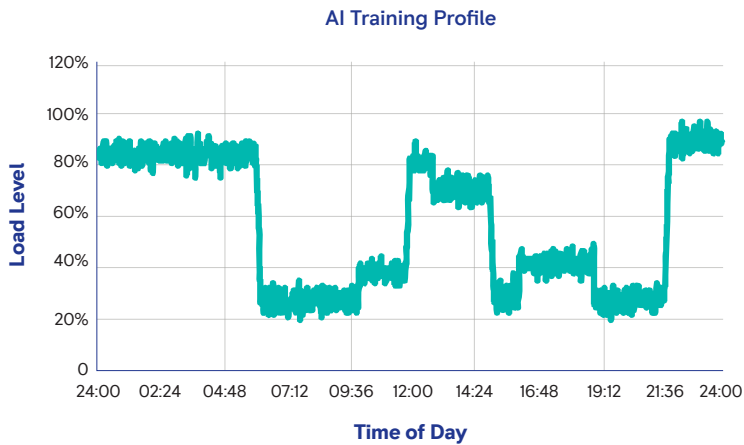
- Can be installed in generator halls or containerized for fast deployment.
- “Drop-and-go” containerized systems can be deployed quickly with minimal site preparation.
- Can be double stacked for increased power density.
- Can be placed near the load due to their compact footprint.
- The entire MEPP does not need to be finished before generating power; capacity can be added incrementally as demand grows.
- Units can be re-allocated as the needs of the project changes.
- Units can be converted to standby duty if the project gets utility power.

In addition to deployment flexibility, MEPP systems offer a significant advantage in serviceability and long-term operational support. Because the system is composed of multiple generator sets rather than large scale turbine assets, maintenance can often be performed by on-site staff or local distributors. Service familiarity improves parts availability, reduces dependence on specialized field crews, and shortens maintenance/repair response times. This results in a solution that is scalable, resilient, and practical.

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Managing the swing: A cost comparison of gas technologies applied to today’s load challenges

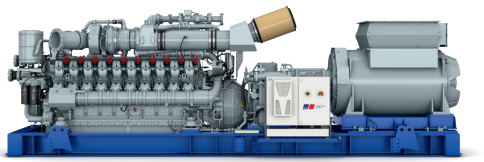
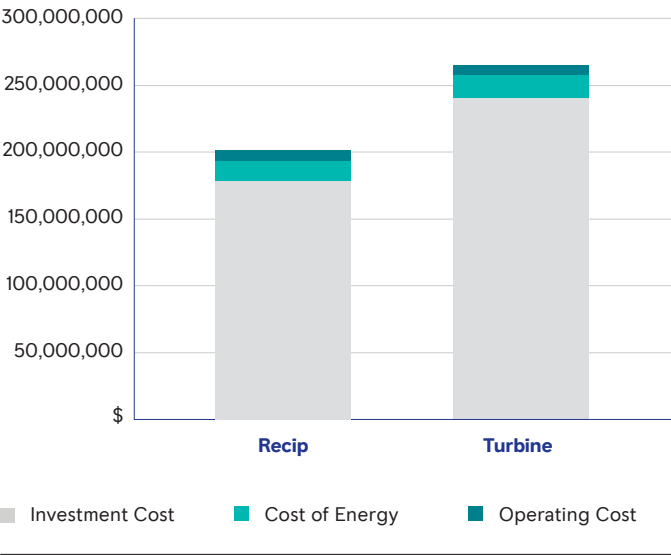


Shown is a figure of a typical AI training load profile. These profiles are running continuously at AI training data centers. Loads can swing over 50% in seconds. The large load swings and steep ramps present a challenge most operators are not used to.

A simplified 15-year TCO calculation using the shown load profile was done using open cycle turbines versus high speed reciprocating engines via TOP-Energy® (Total Cost of Ownership Chart⁴). The planned peak demand was set at 100 MW. The number of units was sized to maintain reliability while compensating for loss of efficiency and start/ramp times during load swings. Reciprocating natural gas fired engines offer the flexibility required to augment today’s grid and support data center growth.

Total Cost Ownership⁴

Scenario		
Load profile	AI Training	
Peak load	100 MW	
Natural gas price	12 (\$/MWh)	
Annual cost increase	4 %	
PPA price	90 (\$/MWh)	
Run time	15 years	
Technologies	Recip	Turbine
Unit size (MWe)	2,5	30
Amount of units	4+6 (115 MW)	4+1 (140 MW)
Efficiency @ 100% load	43%	39%
Efficiency @ 50% load	41%	27%
Investment cost (\$/MW)	1,550,000	1,600,000
Fixed O&M (\$/MW/year)	25,000	30,000
Variable O&M (\$/MWh)	10	4
Start-up time / cold start (min)	5	20
Results		
	Recip	Turbine
Investment cost (USD)	178,250,000	240,000,000
Cost of energy (USD)	14,788,780	17,497,140
Operating cost (USD)	8,174,313	6,619,725
TCO	201,213,093	264,116,865



20V 4000 L64 FNER used in simulation

Modular Engine Power Plants: Strength in numbers

In a study conducted by Collicut Energy, the same AI load profile was applied to a 250 MW installation that required 99.90% reliability. A standard turbine plant was compared with a MEPP. When analyzed as a system, the MEPP was able to achieve the desired system reliability with a lower overall system cost and better performance.

This was due to multiple factors:

- The larger size of each turbine drives a power overbuild when designing for reliability requirements.
- Turbines have a hard time responding to fast ramp rates and take more time to come online.
- The MEPP can quickly respond to changing loads with a better turndown rate, which correlates to a plant’s ability to reduce load efficiently.

Scenario		
Load profile	AI training	
Peak load	250 MW	
Natural gas price	12 (\$/MWh)	
Reliability of plant	99.90%	
Technologies	Recip	Turbine
Unit size (MWe)	2,5	30
Units needed base load	100	5
Additional units to achieve reliability	15	2
Plant size (MWe)	287.5	350
Financials		
Investment cost (USD)	460,000,000	560,000,000
Cost of energy (USD)	8 years	13 years
Performance		
	Recip	Turbine
Average turn down rate	89%	60%
Load step exceedences	96	102

Modular Engine Power Plants: The reliable, scalable, and cost-effective choice for the modern grid

The power grid is changing rapidly.

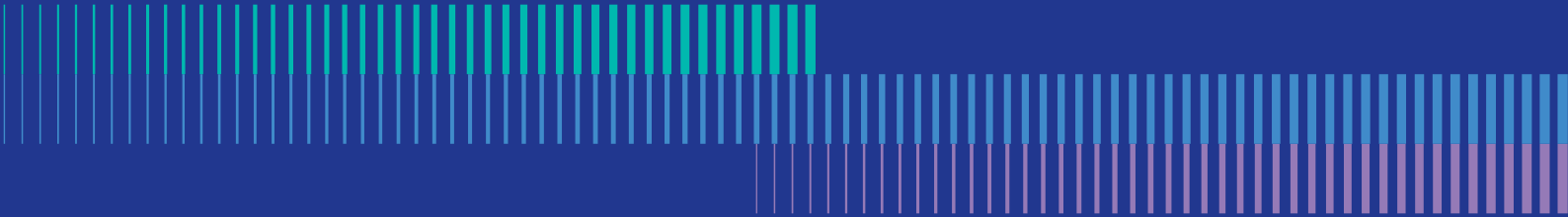
- Load swings and sizes that were never part of the discussion are now essential to system design.
- Load growth is outpacing power plant build schedules and lead times.
- Renewables are part of the solution but also part of the problem.
- Natural gas in the United States is plentiful and inexpensive, making it a key in ensuring a stable grid.

When building the power plant of the future, the traditional turbine is no longer the default choice for an evolving grid. The MEPP, driven by high-speed reciprocating natural gas engines such as the ones from *mtu*, is a superior choice. By transitioning to a modular framework, operators gain flexibility, scalability, and resilience that can handle modern load volatility. The power density and self-contained design of the MEPP allow for rapid and flexible deployment.

Furthermore, unlike large-scale turbines that suffer efficiency penalties at partial loads, the MEPP maintains optimal efficiency when facing these highly variable demand cycles. When paired with simplified maintenance protocols that utilize local technician skillsets rather than specialized crews, the MEPP delivers a lower operational expenditure.

Comparison factor		Scoring – Turbine Power Plant	Scoring – ICE Power Plant
Footprint		+	-
Hydrogen-readiness		+	0
CAPEX		0	+
OPEX	conventional	+	-
	variable	0	+
	future	-	+
TCO	conventional	+	-
	variable	0	-
	future	-	+
Start-up costs		2,5	30
Load increments		100	5
Partial load operations		100	5
Construction time/ Pre-fabrication ability		15	2
Mobility/modularity		287.5	350
+ superior 0- no difference - inferior			

Qualitative comparison between turbine and ICE power plants along a multitude of different criteria. Important criteria for future power plants are highlighted in blue.



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