White Paper

Introducing Linear Generators to the Rapidly Evolving DER Landscape

How Affordable, Fuel-Flexible, and Low Emissions Onsite Generators Fill Key Commercial and Utility Resource Gaps

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Executive Summary

Within the overall distributed energy resources (DER) market, the fuel-based distributed generation (DG) sector has been served for the past two decades by three primary technologies: engines, turbines, and fuel cells. These technologies provide the essential functions of baseload power, standby power, and combined heat and power (CHP) applications, with the latter providing both electricity and thermal energy services. As the DER market moves increasingly toward solar photovoltaics (PV) and battery energy storage, new customer use cases are emerging that require greater flexibility and dispatchability. These use cases must be achieved while still improving reliability and reducing cost and carbon emissions relative to the utility distribution grid.

A new category of clean, distributed power generation—the linear generator—can deliver onsite, fuel-flexible, and dispatchable power at a lower cost and with lower carbon emissions than competing solutions.

In addition, the increasing frequency and magnitude of extreme weather events and wildfires that result in extended grid outages have highlighted the need for dispatchable fuel-based DG to provide resiliency, especially during multiday outages. Driven by governmental and corporate initiatives to enable the net zero carbon grid of the future, new technologies are now required to optimize increased renewable energy uptake while ensuring reliable and cost-effective energy services. A new category of clean, distributed power generation—the linear generator—can deliver onsite, fuel-flexible, and dispatchable power at a lower cost and with lower carbon emissions than competing solutions.

With the prospects of tapping renewable biogas and green hydrogen in the future, linear generators can significantly reduce carbon and costs now while serving as a transition from natural gas to a permanent source of net zero carbon and reliable electricity. The extraordinary value of clean, fuel-flexible, and dispatchable onsite power generation can be uniquely delivered by linear generators. This white paper explores value propositions and use cases for such fuel-flexible technologies for three key market segments:

- Behind-the-meter (BTM) commercial and industrial (C&I) customers
- Front-of-the-meter (FTM) utility substation and wider distribution grid support
- Microgrids, which offer resiliency by extracting maximum value from DER when the larger utility grid goes down or requires load reductions

The emergence of linear generators capable of firming up renewables and serving as a gateway to more sustainable DER aggregations is a game changer. The value propositions and use cases identified in this white paper illustrate the business case for fuel-based generators in an era of reform, change, and transition to a low carbon energy future. Rather than a direct competitor to either solar PV or batteries, linear generators can be the missing complementary technology that counters many assumptions about fuel-based generation resources. The potential serviceable market for linear generators could be $38 billion annually worldwide, with a compound annual growth rate (CAGR) of 15.6% from 2020 to 2025, illustrating its potential to make a major impact on global energy markets.

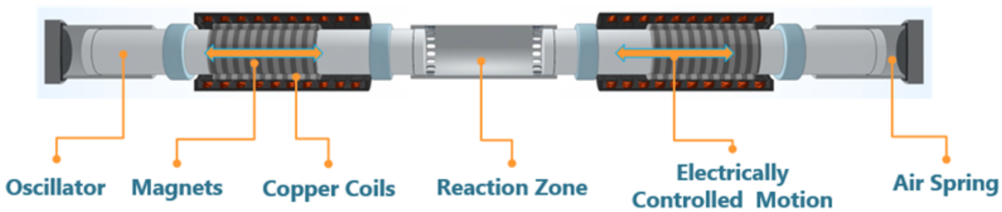
Linear Generators: Definitions and Competitive Landscape

What is a linear generator, and why does this new type of power generation make such a great fit in today's evolving distributed energy resources (DER) landscape? Let's start with a basic definition:

> *A linear generator is an electromechanical device that directly converts motion along a straight line into electricity using chemical or thermal energy. A state-of-the-art linear generator uses a low temperature reaction of air and fuel to drive magnets through copper coils to efficiently produce electricity. With incorporation of adaptive control software, a linear generator can reach high efficiency levels, near-zero nitrogen oxides (NO_x) emissions, full dispatchability, and seamless switching between fuels.*

A linear generator can achieve low capital and maintenance costs through use of standard materials and without the use of complex mechanical systems or expensive catalysts. Compared with traditional technologies, a linear generator has a substantially reduced number of moving parts, managed entirely by power electronics and controls software.

Figure 1 State-of-the-Art Linear Generator Key Components



A mixture of air and fuel are compressed in the center reaction zone until a low-temperature reaction occurs. The reaction drives the two oscillators, carrying magnets, through copper coils, directly producing electricity through linear motion. The outer springs are compressed to return the oscillators for the next cycle.

(Source: Mainspring Energy)

Because of its use of a low temperature, non-combustion reaction, state-of-the-art linear generators such as those offered by Mainspring (pictured above in Figure 1) can meet the strictest emissions standards in the US, allowing for fast, streamlined permitting. Fuel flexibility, dispatchability, and low costs are three of the primary differentiators between this new class of advanced linear generators and other DER solutions. The design leads to high efficiency and low emissions with the added ability to dynamically switch between renewable fuels such as biogas and hydrogen or non-renewable fuels such as natural gas and propane. Full dispatchability, or the ability to turn on/off and ramp up and down on command, allows linear generators to serve fluctuating energy demand profiles. This makes it easy for the technology to be paired with onsite solar PV or battery storage to firm intermittency, add resiliency, and enable rapid growth in renewable energy while accelerating adoption of renewable fuels.

Competitive Landscape Overview

The value proposition for linear generators compared with traditional fuel-based generation options (engines, microturbines, and fuel cells) is a new field of inquiry. Key metrics for comparing any fuel-based generation technologies should include items such as life cycle cost, efficiency, emissions levels, dispatchability, and fuel flexibility. Metrics such as cost are typically foremost in the minds of potential purchasers of any distributed generation (DG) option. However, life cycle cost incorporates a longer-term view than just upfront capital costs. Cost is followed closely by efficiency in terms of priority—a measure of performance in relation to kilowatt-hours harvested from fuels—which typically then affects emissions levels, another outcome growing increasingly important to regulators and end users alike.

As portfolios of DER and wholesale assets shift to intermittent renewable energy resources such as solar and wind, the ability of fuel-based generators previously evaluated as simply baseload resources must evolve to capture the inherent benefits of dispatchability. Dispatchability is defined as the ability to quickly adjust power output up or down to balance solar and wind power generation.

Another important consideration when evaluating fuel-based DG is the ability to operate on both non-renewable and renewable fuel sources without major retrofits or substantial pretreatment of the fuel. A rare attribute for fuel-based generation in the past, fuel flexibility puts linear generators at the forefront of a marketplace now recognizing the value of a DG technology adaptable to shifting regulations or availability of particular fuels in a regional market.

These metrics are applied to the primary fuel-based generation options available today in Figure 2. For front-of-the-meter (FTM) deployments, linear generators are also a good fit because of their high efficiency and low operating costs compared with centralized peaker plants. The following section is a more detailed overview of the three fuel-based generation technologies.

Figure 2 Comparing Linear Generators with Competing DER Options

	Engines	Microturbines	Fuel Cells	Linear Generators
Low Cost	◐	◐	◔	●
High Efficiency	◔	◔	●	●
Low Emissions	○	◔	●	●
Dispatchable	●	●	◔	●
Fuel Flexible	◕	◕	◔	●

(Source: Mainspring Energy)

Engines and Gensets

Reciprocating engine generation sets (gensets) are the most widely adopted class of DER in the world, providing standby power to millions of buildings and facilities globally. The technology has been commercially deployed for more than 100 years and is often the de facto choice for onsite backup power due to the low capital cost, familiarity among service people, and the ability to provide emergency power for days on end. Diesel gensets have been the most popular DER technology systems in the world. Reciprocating engines burning diesel fuel have been the standard for backup, grid-tied, uninterruptible power supply systems and early generation microgrids for decades. Yet they are also typically the most polluting. Air quality regulations will limit future applications in advanced economies.

Natural gas gensets tend to compare favorably with diesel gensets in terms of economics, emissions, and often reliability. While diesel gensets have lower capital costs, total lifetime costs can be lower for natural gas gensets. The cost savings come from the low cost of natural gas, which can be half of diesel's cost per unit output. Typical natural gas gensets have a fraction of the common air pollutants (such as nitrogen dioxide) and about 10% less greenhouse gas emissions compared with typical diesels. Additionally, in 2019, the National Renewable Energy Laboratory found that natural gas generators are less likely to fail during a power outage than diesel generators.[1]

Microturbines

Combustion turbines come in many sizes, but the most common scale of turbines relevant to C&I buildings and microgrids are microturbines. Derived from automotive and truck turbochargers, auxiliary units for airplanes, and small jet engines, microturbines generally are sized from 30 kW to 500 kW. With heat waste recovery, microturbines deployed as combined heat and power (CHP) units can achieve 80% overall efficiency. Microturbines have higher power density in size and weight than diesel or natural gas generators, but they typically have lower electrical efficiency and need greater fuel pressure than gensets. The key to future improvements lies with ceramics and thermal barrier coatings, which allow for greater heat containment, leading to higher efficiencies.

Fuel Cells

Fuel cells can scale across applications from stationary power generation to transportation to other mobile applications, offer theoretically high efficiencies, and are simple to operate since they have no moving parts. Fuel cells designed for stationary power generation are typically designed to operate on pipeline natural gas, often requiring sulfur cleanup to avoid contamination. Some commercial fuel cells can operate on very clean biogas or pure hydrogen, and some can utilize their waste heat for CHP applications. Fuel cells offer high efficiencies (ranging from 43% to 56% on a lower heating value basis) and release few criteria pollutants. Some fuel cells can also be configured to utilize their exhaust thermal energy for use in CHP applications.

The primary downside to fuel cells is their high upfront capital costs and high maintenance costs, which are primarily driven by short degradation and short stack life on the order of 5-10 years. The clear market-leading technology today— solid oxide fuel cells (SOFC)—cannot vary power output quickly and takes a long time to start up. As a result, SOFCs are not a dispatchable resource and must run as a baseload resource, perhaps displacing available solar power generation during certain times of the day. As such, SOFCs need to be paired with a relatively large battery system to balance intermittent renewable resources. Though fuel cells offer a lower emissions option compared with diesel or natural gas generators and microturbines and are seeing increased uptake by data center and C&I customers, their primary shortcomings over the longer term may be cost and the inability to firm up solar PV and other intermittent renewables.

[1] Sean Ericson and Dan Olis, *A Comparison of Fuel Choice for Backup Generators*, National Renewable Energy Laboratory, March 2019, https://www.nrel.gov/docs/fy19osti/72509.pdf.

Linear Generator Value Propositions and Use Cases

Most of the opportunities identified for engine gensets, microturbines, and fuel cells apply to linear generators. Yet they also offer more than these traditional DG options. At present, as with any new technology, market education and demonstrations validating the claims are needed. This white paper is designed to fill gaps in knowledge about how a linear generator can deliver a more sustainable energy future while presenting value propositions and use cases applicable to today's current market dynamics.

Behind-the-Meter C&I Customers

Once laggards on energy innovation due to single-minded focus on the bottom line and avoidance of risks, C&I customers are now major adopters of advanced energy technologies. Costs have come down for viable solutions such as onsite solar PV, value propositions have been clearly defined, project financing has become available for many solutions, and extreme weather and other threats to grid reliability have increased awareness about the need for moving beyond business as usual. Corporations large and small are adopting internal sustainability targets and have established environmental, social, and governance metrics. As a result, C&I customers are actively moving to deploy state-of-the-art solutions for a wide array of energy challenges, including lowering cost while maintaining premium forms of resiliency.

Value Proposition: For C&I customers seeking behind-the-meter (BTM) solutions for energy cost savings, carbon savings, and added resiliency, linear generators can offer clear advantages compared with other DER options. In terms of cost savings, linear generators can offset purchased power from the grid, often saving customers 10%-30% on their energy bills. These generators can also protect against lost revenue during power outages.

For C&I customers seeking behind-the-meter (BTM) solutions for energy cost savings, carbon savings, and added resiliency, linear generators can offer clear advantages compared with other DER options.

Beyond these direct impacts to the bottom line are additional values. Increasingly, C&I customers are setting voluntary emissions reduction targets to bolster their sustainability endeavors and attract and retain new environmentally conscious customers and top employee talent. The ability of onsite power sources to reduce emissions or even eliminate them altogether without sacrificing resiliency is a compelling value proposition not only for C&I customers but also for other potential prosumers.

Use Cases: Linear generators can operate parallel to the grid, thereby providing compelling use cases during blue sky days when the distribution grid is up and running. A significant advantage of a linear generator over a fuel cell, in addition to substantially lower cost, is full dispatchability, which allows the linear generator to more easily integrate with rooftop solar PV. It can also enable islanding of a C&I building. While natural gas fuels will be here for quite some time, the fuel flexibility feature of a linear generator offers greater long-term environmental value than most fuel-based DG. As fuel sources shift away from natural gas and diesel toward renewable hydrogen and biogas, existing backup generators, for example, will require costly upgrades or replacement altogether while the fuel-flexible linear generators will not. In addition to providing backup power when the grid is down, the grid-parallel use cases offered up by linear generators include:

- 24/7 load following or baseload operation
- Economic dispatch to reduce energy costs based on tariff or real-time pricing
- Peak load shaving for demand reduction
- Complementing and firming of onsite solar PV
- Demand response and ancillary services
- Charging for fleets of EVs of all size ranges
- Scaling power capacity with less cost and time than a utility upgrade

Grid-Side (FTM) Utility Applications

Some of the solutions being offered for BTM customers can also be deployed on the utility side of the meter at scale. As utilities seek flexibility in meeting the need for future transmission and distribution (T&D) grid upgrades or balancing intermittent renewables and power needs within constrained networks, linear generators represent a valuable new tool capable of providing value on the other side of the meter.

Unlike some other FTM options, including demand response and most energy storage technologies, linear generators are fully capable of providing 24/7 baseload power.

Value Proposition: Linear generators can be installed FTM by utilities themselves. If employed as an FTM application, similar value propositions as BTM applications emerge, with the possibility of utility rate-basing and control. Along with this around-the-clock availability, linear generators are dispatchable, responding in real time to changing market conditions.

Use Cases: Unlike some other FTM technology options including demand response and most energy storage technologies, linear generators are fully capable of providing 24/7 baseload power. This attribute and others open these utility use cases:

- Non-wires alternatives (NWAs) to defer expensive and time-consuming T&D capacity-driven upgrades
- Replacement of costly and dirty centralized gas peaker plants (which typically have very low utilization) with cleaner, more efficient distributed solutions
- Congestion relief on distribution feeders if sited strategically
- Firming of intermittent grid-side renewables such as solar and wind farms
- EV charging stations in congested areas

Microgrids

Microgrids can be deployed by C&I customers, utilities, and other customer types with a wide array of applications for critical government facilities, military bases, smart cities, university campuses, or other customers seeking premium resiliency services.

Value Proposition: The primary driver for microgrids is resiliency in the form of islanding when the larger grid goes down or requires support via demand reduction. Layered on top of this fundamental driver are the ability to generate energy cost savings and carbon reductions compared with the grid. In an islanding scenario where there is no electrical distribution grid, linear generators can provide similar advantages to the common alternative—a diesel or natural gas genset. For grid-tied microgrids, the primary advantage of linear generators over backup gensets and solar PV plus energy storage systems is their ability to offer multiday/week backup power at a lower cost. Recent trends in microgrid deployments lean heavily toward solar PV as the dominant supply choice with battery energy storage for load shifting and incremental resilience, resulting in increased demand for low carbon firming technologies that are flexible and affordable.

Use Cases: The majority of microgrids deployed today include solar PV and, increasingly, energy storage. The sizing of batteries, nevertheless, is generally limited by cost, so there is a gap to fill if microgrids are truly to provide longer-term resiliency without increasing emissions from diesel or natural gas generators. BTM microgrids incorporating linear generators increase their flexibility and ability to operate parallel to the distribution grid while safely disconnecting and operating in island mode with an aggregated portfolio of DER assets. Having the ability to support long-term islanding operations without the cost premium of large energy storage devices is an advantage. The ability to integrate with batteries and renewables to reduce emissions and fuel consumption during long outages will become increasingly important in the long run. Linear generators' fuel flexibility and low cost can make microgrids more affordable while improving resiliency through resource diversity.

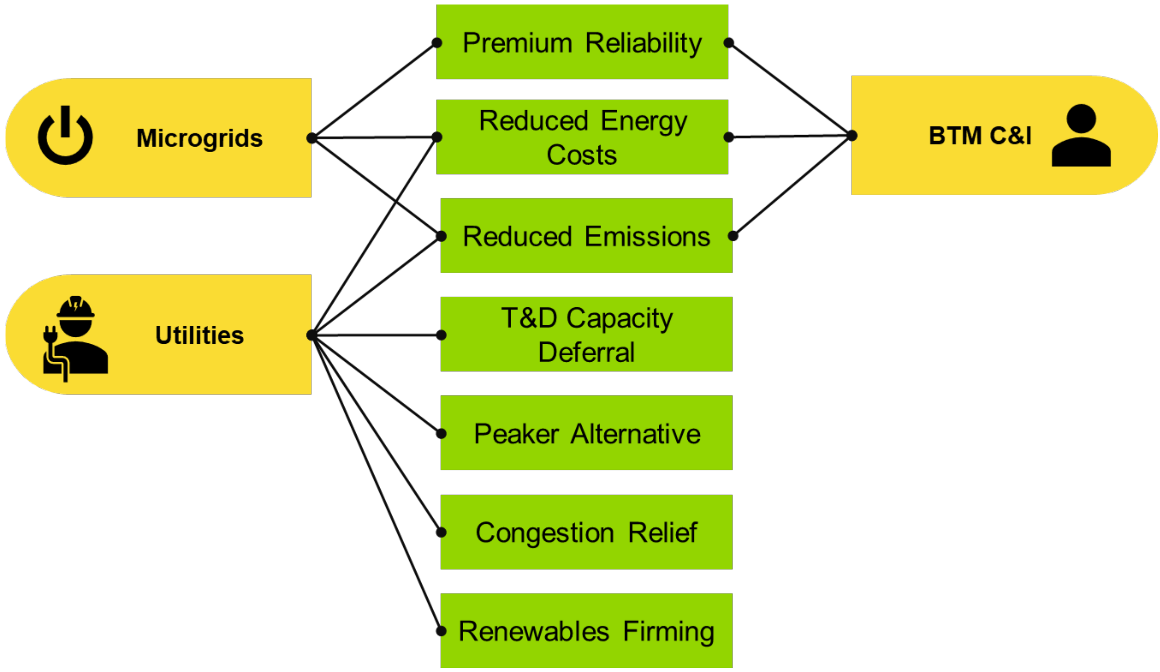
Linear generators' fuel flexibility and low cost can make microgrids more affordable while improving resiliency through resource diversity.

Linear generators are the ideal backbone for any microgrid. Some of the most compelling microgrid use cases are:

- University campuses with critical loads such as research laboratories
- Military bases that feature mission critical facilities, operations, and equipment such as sensitive radar
- Hospitals seeking to reduce their historical reliance upon diesel generators
- Data centers, logistics facilities, and retail outlets looking to reduce carbon footprints
- Community microgrids responding to residents seeking clean and resilient power
- Smart cities integrating energy generation with other urban infrastructure needs including transit and water

Figure 3 highlights customer segments and their respective value propositions.

Figure 3 Matching Customer Segments with Key Value Propositions



(Source: Guidehouse Insights)

Market Sizing for Linear Generators

Understanding the value propositions and use cases for linear generators leads to the logical follow-up question: what is the total addressable market for this new class of power generator? What is the serviceable addressable market (SAM)?

As with any new technology, market sizing is a challenge. The ability to use multiple fuels including renewable biogas and hydrogen makes future projections challenging since fuel flexibility and full dispatchability are not common characteristics among existing DG options. Totaling the set of DG assets forecast to be deployed globally over the next 10 years does, however, provides some insight into what might be possible. After sizing this global market, a serviceable market is distilled, zeroing in on the three market segments previously identified: BTM C&I, FTM utility applications, and microgrids.

Total Addressable Market Assumptions and Sizing

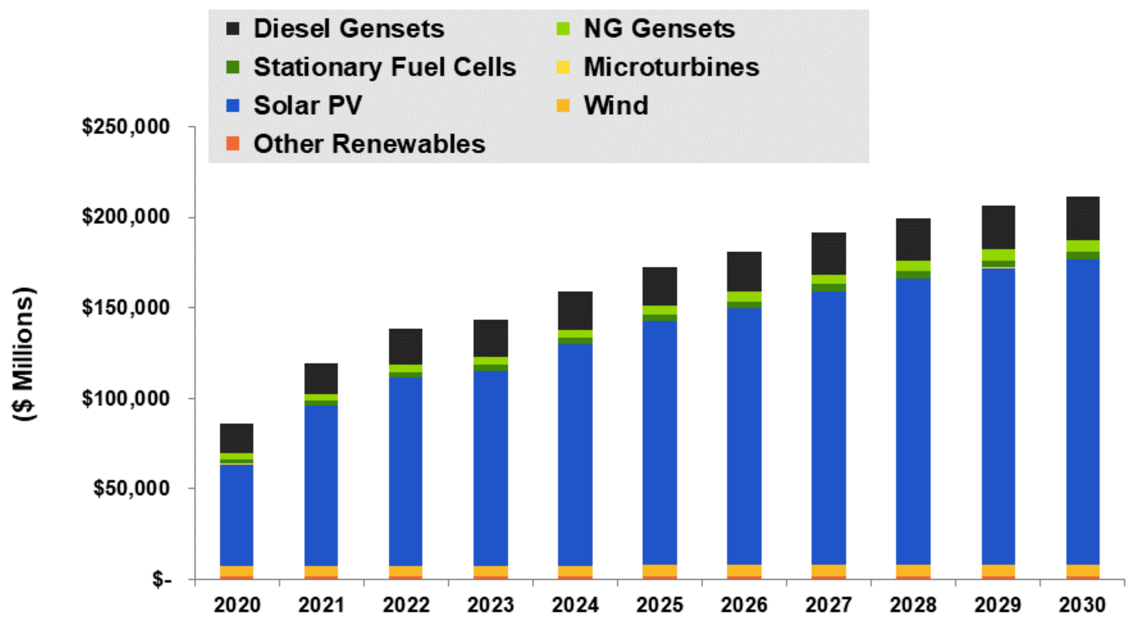
Decarbonization and clean technology initiatives across major economies supported by regulatory bodies will likely encourage a greater reliance upon the full gamut of DG and other DER. The portfolio of DG technologies tracked and forecast by Guidehouse Insights includes these technologies with the following nameplate capacity thresholds:

- Diesel gensets (less than 6 MW)
- Natural gas gensets (less than 6 MW)
- Stationary fuel cells
- Microturbines
- Distributed solar PV (less than 1 MW)
- Distributed wind turbines (less than 1 MW)
- Other renewables (distributed biomass/biogas)

Guidehouse estimates that 105.1 GW of DG capacity was deployed in 2020—an amount that will more than double to 266.7 GW in 2030, which represents a 9.8% compound annual growth rate (CAGR). Solar PV leads new installations and is projected to reach almost 176.5 GW by 2030, capturing just over 66% of the total global DG market. This DG market represents a cumulative 2 TW of addressable market over the next decade. Despite their distinct characteristics, each of these technologies usually operates BTM at customer facilities and offers market opportunities for linear generators as complementary resources.

The corresponding revenue from DG capacity worldwide paints a similar scale of immense opportunity. Based on current capital costs and forecasts of how those costs will change for each individual technology highlighted above, the total revenue in the DG market in 2020 is expected to be $86.3 billion. By 2030, that figure is expected to grow to $211.5 billion annually at a CAGR of 9.4%. Solar PV is projected to get the lion's share of the revenue: $56.1 billion in 2020, then reaching $168.1 billion annually in 2030. Over the next decade, the cumulative solar PV DG market represents a $1.3 trillion market opportunity.

Chart 1 Linear Generator Total Addressable Market Boundary Revenue, World Markets: 2020-2030

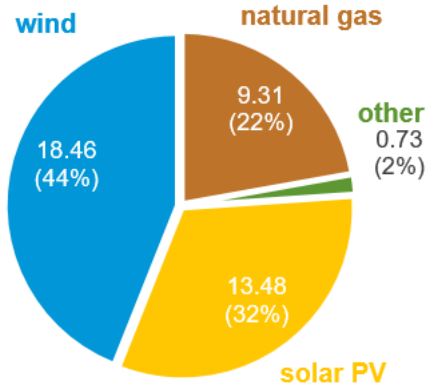


(Source: Guidehouse Insights)

A Top-Down Estimate of SAM

The need for a technology such as linear generators flows from the assumption that the world is shifting to greater reliance upon renewable resources. The US Energy Information Administration data reinforces this new reality. Leading the way in this transition are wind and solar resources, which according to Energy Information Administration data represents 76% of all new electric generating capacity in the US in 2020.[2]

Figure 4 US New Electricity Generating Capacity: 2020



(Source: US Energy Information Administration)

Virtually all new wind power capacity additions are large utility-scale projects. The story for solar PV is more diverse, with both large-scale solar PV farms being added to grids and smaller scale systems being installed directly at C&I sites and residential properties. What these two renewable technologies share is their intermittency, which exhibits itself hourly, weekly, monthly, and seasonally. The challenge from a grid management perspective and at individual customer sites is that there can be steep ramps up and down within a single day. The same dynamic is at play across longer periods of time.

Energy storage is widely seen as the solution to this dilemma. It is clearly a major part of the answer, particularly for uses cases requiring durations of 2 to 8 hours. Costs for some types of batteries, such as Lithium ion, are on a similar downward trajectory as solar PV, yet the overall cost of deploying massive batteries both BTM and FTM to support expected growth in renewable deployments may be too costly. According to one estimate by Caltech, the price tag attached to energy storage supporting a 100% solar and wind electric grid could cost as much as $23 trillion, a sum equivalent to over 60 years of current annual electricity expenditures.[3] One advantage of deploying linear generators could be to prevent the overbuilding of battery systems, thereby lowering initial capital costs for the carbon-free grid of the future while increasing system flexibility.

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[2] US Energy Information Administration, "New electric generating capacity in 2020 will come primarily from wind and solar," *TODAY IN ENERGY*, January 14, 2020, https://www.eia.gov/todayinenergy/detail.php?id=42495.

[3] Shaner et al, "Geophysical Constraints on the Reliability of Solar and Wind Power in the U.S.," *Energy and the Environment*, 2018.

> *Then consider the following startling numbers from California, which features one of the highest penetrations of renewable resources today: over 65% of curtailments are caused by local congestion constraints.*

Then consider the following startling numbers from California, which features one of the highest penetrations of renewable energy resources today: over 65% of curtailments of renewable energy are caused by local congestion constraints.[4] This is one argument on behalf of greater reliance upon DER assets, including DG, being sited closer to loads. As Guidehouse Insights forecasts show, the world is shifting to an increased reliance upon DER capacity additions that will supersede annual new centralized generation capacity in 2021. Digital platforms that can orchestrate these DER assets into microgrids for improved resiliency are relevant in both rural and urban environments. Given that the focus of the future grid is to site supply-side resources closer to the load they serve, solar PV is clearly a primary driver for market transformation. Linear generators, along with energy storage, provide a nice complement to this onsite solar PV.

With these trends and statistics in mind, one way to ascertain the SAM for linear generators deployed at a scale of between 250 kW and 10 MW is to analyze technologies in the market that linear generators would substitute or complement based on market needs or value proposition. While linear generators are direct substitutes for fuel cells, engine gensets, and microturbines, the market is much broader due to the attributes discussed previously in this white paper. When looking at the BTM DG market, onsite solar PV provides a useful comparison because its value proposition is cost and carbon savings. Since linear generators complement onsite solar PV, offer equivalent or better cost and carbon savings, and provide added resiliency, the onsite solar market can provide an indication of market potential for linear generators. The same approach can be taken for microgrids. For FTM market sizing, the key market indicators include dispatchable generation capacity and alternatives to T&D upgrades commonly referred to NWAs.

[4] Information from Mainspring Energy, based on publicly available data from California ISO in 2019.

Using data from sources such as Guidehouse Insights, the US Energy Information Administration, the Solar Energy Industries Association, and the International Energy Agency, the following capacity and revenue figures in Table 1 for SAM were calculated. These calculations were based on the need to complement growth in solar PV production with an affordable, fuel-flexible, and dispatchable technology in the US and worldwide.

- **BTM C&I Applications:** Starting with the total US market for onsite solar PV, isolating commercial installations from residential, then removing smaller commercial loads with less than 200 kW of demand leads to an SAM for linear generators of 1.4 GW/year. Using a similar methodology for SAM outside of the US, assuming natural gas availability in 65% of potential markets, yields a market of 7 GW/year.
- **FTM Grid-Side Applications:** The drivers on the FTM are more focused on displacing the following: traditional fossil fuel generation technologies such as natural gas-fired peaker plants, combined cycle facilities and engines, and other NWAs that displace the need for large-scale transmission lines. This analysis suggests an SAM of 3.4 GW/year in the US and 6.4 GW/year globally.
- **Microgrids:** Using similar assumptions noted in the BTM C&I applications example above but focusing on displacing redundant solar and natural gas generators and additive energy storage capacity nets an SAM of 0.7 GW/year in the US. Using the same assumptions globally yields an SAM of 1.6 GW/year.

Table 1 Linear Generator SAM Revenue Estimates

Segments	Total Annual SAM	BTM	FTM	Microgrids
US	$10.6 billion	$2.6 billion	$6.6 billion	$1.4 billion
Outside US	$28.7 billion	$13.4 billion	$12.2 billion	$3.1 billion

(Source: Guidehouse Insights)

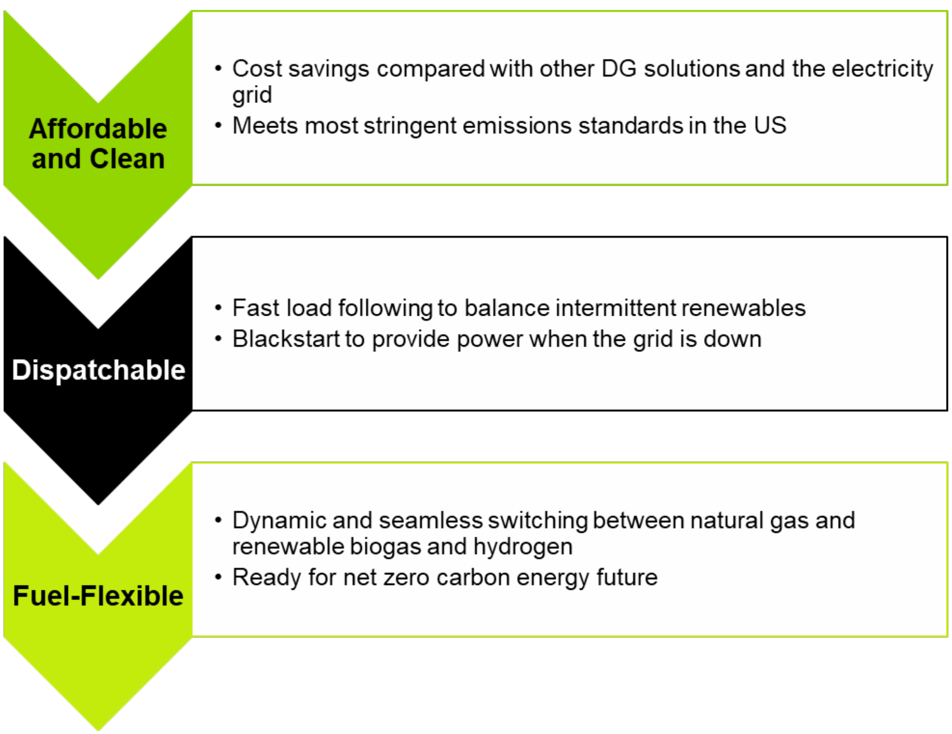
Conclusion: Building the Business Case for Linear Generators

Linear generators have the potential to transform future power generation markets. With wide applications for BTM C&I customers, FTM utility customers, and diverse microgrid applications, linear generators appear to be an ideal technology to usher in the looming transition to cleaner energy. The ability to ramp output to firm renewables and operate on renewable fuels is increasingly important as the DER landscape continues to evolve. With global DER capacity forecast to pass centralized generation on an annual basis in 2021, the need for dispatchable and fuel-flexible DG technology is abundantly clear.

It should be noted that not all linear generators are created equal. This white paper focuses on the attributes offered by Mainspring Energy's linear generator technology. This linear generator technology offers some unique attributes well aligned to the customer value propositions listed in this white paper. The linear generator technology's features illustrate the type of innovations necessary for global markets to make the transition to a low carbon, resilient, and more sustainable energy system of the future.

Within the fuel-based DG landscape, linear generators offer a unique blend of attributes that include low life cycle cost, high efficiency, low emissions, dispatchability, and fuel flexibility. Together, these attributes establish the technology as having a vital complementary role in the net zero grid of the future. The energy markets of the future cleaner grid will require resources that offer dispatchability to firm renewables over daily and seasonal durations. These markets will also value resiliency for multiday outages and fuel flexibility to transition to renewable fuels such as biogas and hydrogen.

Figure 5 Linear Generator Value Proposition Summary Matrix



(Source: Guidehouse Insights)

Acronym and Abbreviation List

BTM ... Behind-the-Meter

CAGR ... Compound Annual Growth Rate

CHP ... Combined Heat and Power

C&I ... Commercial and Industrial

DER ... Distributed Energy Resources

DG ... Distributed Generation

EV ... Electric Vehicle

FTM ... Front-of-the-Meter

kW ... Kilowatt

kWh ... Kilowatt-Hour

MW ... Megawatt

NWA ... Non-Wires Alternative

PV ... Photovoltaics

SAM ... Serviceable Addressable Market

T&D ... Transmission and Distribution

TW ... Terawatt

US ... United States

Table of Contents

Scope of Study

Guidehouse Insights has prepared this white paper, commissioned by Mainspring Energy, to provide an introduction to linear generator technology focused on its use cases and value proposition. The analysis includes a comparison with other fuel-based generator options, highlighting its key distinguishing features: fuel flexibility and dispatchability. This white paper also includes estimates of global total addressable markets and a deeper dive into potential serviceable markets for the US and global applications for behind-the-meter C&I customers, FTM utility applications, and microgrids.

Sources and Methodology

Guidehouse Insights' industry analysts use a variety of research sources in preparing research reports and white papers. The key component of Guidehouse Insights' analysis is primary research gained from phone and in-person interviews with industry leaders including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Guidehouse Insights' analysts and its staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst's industry expertise, are synthesized into the qualitative and quantitative analysis presented in Guidehouse Insights' reports. Great care is taken in making sure that all analysis is well-supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

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Notes

CAGR refers to compound average annual growth rate, using the formula:

$$CAGR = (\text{End Year Value} \div \text{Start Year Value})^{(1/\text{steps})} - 1.$$

CAGRs presented in the tables are for the entire timeframe in the title. Where data for fewer years are given, the CAGR is for the range presented. Where relevant, CAGRs for shorter timeframes may be given as well.

Figures are based on the best estimates available at the time of calculation. Annual revenue, shipments, and sales are based on end-of-year figures unless otherwise noted. All values are expressed in year 2021 US dollars unless otherwise noted. Percentages may not add up to 100 due to rounding.

Guidehouse INSIGHTS

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