Emerging Technology Trends in the

C&I Rooftop Solar Market in India

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Examining the Benefits and Challenges of New Technology Solutions

1. Executive Summary

India's experience with the rise in rooftop solar or onsite solar has been led by the Commercial and Industrial (C&I) segment. This segment comprises about three-quarters of the Indian rooftop solar market. Although the COVID pandemic created major disruptions and slowed the installation rate in 2020, the C&I segment is expected to bounce back and increase the pace of deployment of solar installations. This is because amidst the pandemic-induced challenges, it has become more of a necessity for the C&I sector to optimise costs. This can be achieved by adopting various new innovative technological rooftop solar solutions. In addition, rooftop solar can help corporates fulfil their RE100 (100% renewable energy) or other corporate social responsibility goals.

In the past few years, the market has witnessed a steady pace of capacity additions (hovering at about 1.5 gigawatts (GW) per annum) from this premium consumer group. As of 2020, the market size of rooftop solar was 7,920 megawatts (MW), with the C&I segment accounting for >75% of the market. Rooftop solar capacity addition in the C&I segment in calendar year (CY) 2021 is estimated to grow by 47% on a year-over-year (Y-o-Y) basis to add 1,875MW of new capacity.

The C&I segment accounted for about 75% of the rooftop solar market in 2020.

Some solutions offer considerable value-addition in terms of energy generation while others are viable only in specific scenarios, though the latter kind have high prospects in the market. Key new trends being explored in the Indian market include adoption of large format modules (400+/500+Wp series), bifacial modules depending on site-specific conditions, and battery storage for specific applications by C&I clients. With falling module and battery prices, switching to a rooftop solar or rooftop solar+storage model can help them save significantly on electricity costs. Technology prices in India are expected to fall further on account of various new

government incentives, such as the Production Linked Incentive (PLI), and new expansionary initiatives[1] being planned by domestic manufacturers.

An increase in perceived interest and overall solar market demand for lower cost and higher wattage modules, with their inherent improved technical features, is promoting adoption of larger-sized wafer-based modules. When higher-wattage modules are used for onsite solar installations in India, plant generation increases by 1% while Balance of System (BOS) costs reduce by 1%. These benefits are more profound for sites with space constraints.

Additionally, there is a growing need to optimise costs and maximise output (kWh/m2) in a given project area, especially in the C&I segment (given the limited rooftop/onsite space). Bifacial modules allow players to achieve that at a negligible additional cost. With bifacial modules, power can be produced from both sides of a panel, increasing total energy generation viz-a-viz a monofacial module-equipped project, thus reducing the levelised cost of energy (LCOE). The project case studies in this report highlight the increase in generation owing to bifacial modules of about 4-5% compared with polycrystalline modules.

Solar+battery storage rooftop projects are also likely to pick up pace in the near future. In a time span of about two years (by 2023), battery prices are estimated to fall to US$100/kWh, which would shift the market forward for integrated rooftop solar and battery storage systems from the present cusp phase. Specifically, there is a huge opportunity for rooftop solar+Battery Energy Storage System (BESS) to replace diesel gensets, which represents 90GW of aggregate capacity in behind-the-meter (BTM) applications in India.

Table 1: Details of Emerging Technology Trends In Rooftop/Onsite Solar Installations

Type of system	Specific Yield (units/ kW)	Installation cost (pre-tax) Rs. per kW	Payback period on initial Investment (CAPEX)	OPEX tariff range (Rs/ kWh)	Estimated cost savings in electricity bill	Preferred segments
Onsite Solar with poly-modules	3.6-3.8 units/ kW	Rs 32,000-34,000	3-4 years	Rs3.7-3.9/kWh	30-35%	Most common type of installations in India right now, majority of installations in <500kWp size
Onsite Solar with higher wattage modules	4.0-4.5 units/ kW	Rs 34,000-36,000	3.5-4 years	Rs3.6-3.9/kWh	35-38%	Rooftop with space constraint and high RE generation required. Advantage of this is higher capacity for the same unit area.

[1] JMK Research. 13.75 GW of new module and 6.9 GW of new cell production capacity likely to be added in India in next 18 months. June 2021.

Onsite Solar with bifacial modules	5-6 units/ kW	Rs 38,000-41000	3-3.5 years	Rs3.4-3.7/kWh	35-40%	RCC roofs, carport installations, most beneficial in ground mounted installations (within plant premises with capacity in range of 2MWp plus)
Onsite Solar+BESS	3.5-5 units/kW	Rs 70,000-80,000	7-8 years	Rs7-9/kWh	30-35%	Presently viable for consumers requiring savings on peak TOD tariff, peak load balancing and DG replacement

Source: JMK Research.
Assumptions: Industrial site with substantial size of >1MW and good solar radiation. Project costs considered are as of July 2021.

Apart from the above mentioned trends, another nascent onsite technological model that is likely to be explored by many developers in India is rooftop solar integrated with electric vehicle (EV) charging stations. This solution can potentially provide greater self-sufficiency for C&I consumers and also address the issue of EVs being fuelled by electricity generated from greenhouse gas (GHG) emitting-fossil fuels. For this reason, solar carports are already becoming a popular choice among many C&I customers. Solar carports are not only a cost saving option, they can also act as a great lever for companies to advance their sustainability performance. Captive charging is permitted in accordance with the Ministry of Power's Charging Infrastructure for Electric Vehicles - Guidelines and Standards.[2] Further, many states such as Andhra Pradesh, Bihar, Delhi, Tamil Nadu etc., through their state EV policies, promote the interlinking of a captive renewable energy system and EV charging infrastructure.

Additionally, the adoption of Building Integrated Photovoltaics (BIPV) also presents an attractive long term opportunity for corporates that are planning to set up new commercial buildings and offices in India. The outlook for this market is highly positive given the potential co-benefits it offers (i.e. providing architectural features and generating green power) and also considering that more than 50%[3] of the buildings likely to stand in India by 2030 are yet to be built. However, specific standards for BIPV are required that combine techno-electrical requirements and building codes to help streamline the process of installation.

This report also provides case studies of active, on-the-ground projects, illustrating actual benefits earned and the challenges that were encountered using some of these aforementioned emerging technological solutions.

[2] MoP. Charging Infrastructure for Electric Vehicles - Revised Guidelines and Standards. 12 January 2021.
[3] Bureau of Energy Efficiency (BEE). ECBC Commercial.

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2. C&I Market Overview

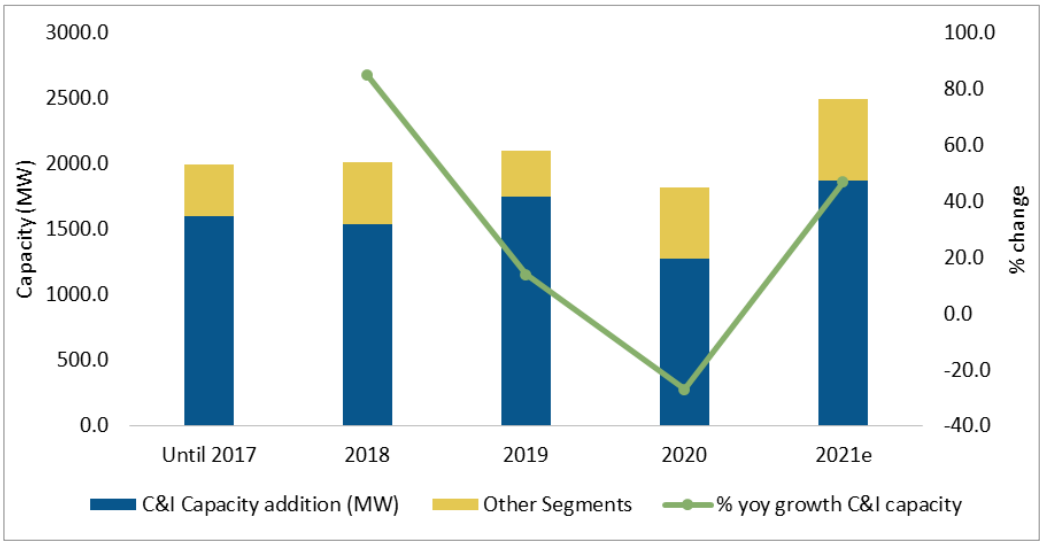
Over the last 6-7 years, the C&I segment has been the torchbearer for the development of the rooftop/onsite solar market, comprising about three-quarters of the Indian market. As of 2020, the rooftop solar market size was 7,920MW with the C&I segment covering 78% of the market.

Installation Trends

In CY2020, capacity additions in the C&I segment was 1,274MW, declining by 27% Y-o-Y. The industry managed a quick rebound in the second half of the year owing to robust consumer demand in the C&I segment. In fact, based on some of the industry interviews conducted for this report, the demand for onsite solar installation has risen substantially post India's first COVID-induced lockdown in 2020 and is expected to be sustained. Rooftop/onsite solar capacity additions in the C&I segment in CY2021 is estimated to grow by 47% Y-o-Y to 1,875MW.

So far, the majority of PV modules used by this segment have been polycrystalline with lower wattage (less than 400Wp), though the share of onsite solar systems with higher wattage mono-PERC modules has been on the rise since the modules became a commercially viable option about 1.5 years ago.

Figure 1: Rooftop Solar Capacity Addition Trend in India



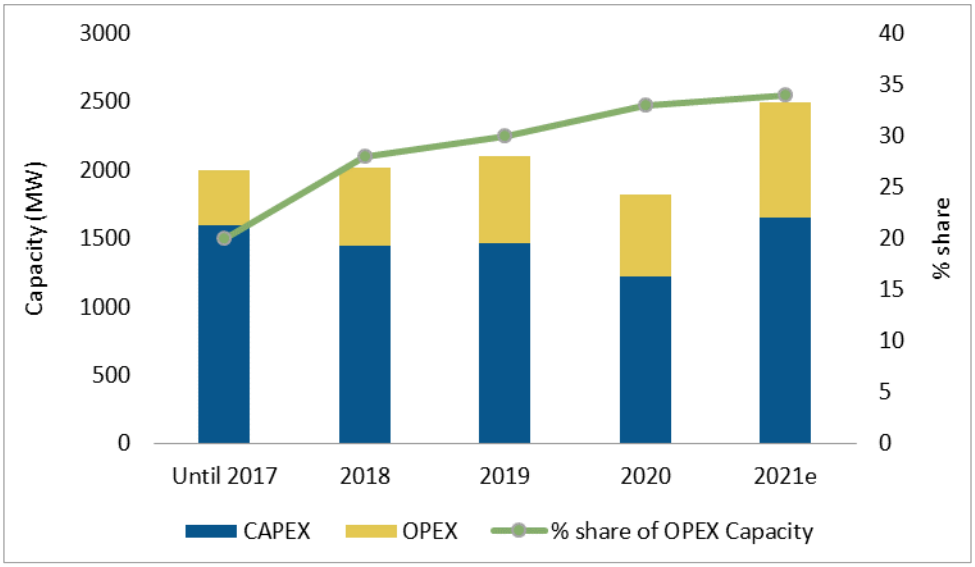
Source: JMK Research.

3. Business Models

The two most-adopted business models for rooftop solar ownership in the Indian solar industry are Capital Expenditure (CAPEX) and Operating Expenditure (OPEX). In a CAPEX model, the project is owned and financed by the consumer/rooftop owner whereas in the OPEX model, the projects are owned, financed, and developed by third-party owners or investors. Currently, in a CAPEX model, payback can be realised in a short duration (3-4 years), while for an OPEX project the tariff rate is

about Rs3.5-4/kWh (US$0.047–0.053) for 10-12 years, which is less than half the average C&I grid tariffs prevalent across most states. These OPEX projects typically realise a 14-15% return on equity for the third-party investors.

Figure 2: Rooftop Solar – OPEX vs. CAPEX Capacity Addition Trend



Source: JMK Research.

4. New Growth Drivers for Increasing Renewable Energy Adoption by the C&I Segment

Although the COVID pandemic created major disruptions and slowed down the installation rate in 2020, the C&I segment is expected to bounce back and increase the pace of deployment of solar installations. This is because amidst the pandemic-induced challenges, it has become more of a necessity for the C&I sector to optimise costs. This can be achieved by adopting the different technological rooftop solar solutions detailed in this report.

Another driving factor for this segment is the push by corporates to achieve their RE100 commitments. This, coupled with improvements in technology, falling prices of components, increasing awareness, and accessible financing options is expected to boost rooftop solar installations.

RE100+ and Net-Zero Targets by Corporates

Currently the Indian C&I sector consumes 51% of the total electricity produced, but only 3.5% of it is from renewable sources.[4] On the flip side, C&I customers accounted for >75% of total rooftop solar installations in India as of 2020. With increasing focus on sustainability, rooftop solar installation is expected to grow,

[4] WWF. Global Corporate Renewable Power Procurement Models: Lessons for India. 2019.

especially in the C&I segment as it stands out as a viable solution for organisations wanting to switch to 100% renewable energy (RE).

Many organisations are voluntarily committing to run their operations on 100% renewable energy sources. In India, big companies such as Mahindra Holidays & Resorts, Infosys, Dalmia Cement, Tata Motors, Zomato, and JSW Cement have already committed to RE100 targets. Additionally, many MNCs (multinational corporations) with a presence in India have committed to RE100 goals and are driving renewable adoption to meet sustainability targets.

A recent study[5] found that out of the total solar capacity installed by corporates globally, almost 50% has been installed in the last 3 years. The main reason behind this is the drastic fall in technology costs leading to higher savings on electricity costs, and the increase in the number of companies committing to RE100. A similar trend can also be observed in India, as shown in Figure 2.

Optimising Costs

Optimising costs is another main driver for the projected growth in the C&I segment, especially after the disruption caused by the COVID pandemic. Also, rooftop solar offers an excellent value proposition to micro, small and medium enterprises (MSMEs) by significantly bringing down the cost of electricity consumption, which is about 5-20% of their operation costs[6] depending on the nature of the industry. With falling prices of modules and batteries, switching to a rooftop solar or rooftop+storage model can help optimise costs to a great extent.

Switching to a rooftop solar or rooftop+storage model can help optimise costs.

Increasing Consumer Awareness

Insights from discussions with leading onsite solar EPC players suggest that most C&I consumers who installed rooftop solar plants at some of their facilities are now expanding and planning to adopt rooftop solar across their other industrial assets. Consumers are driven by the popularity and benefits of rooftop solar, especially the guaranteed cost savings and zero upfront capital investment under the OPEX model. C&I users have also become more socially responsible and are aware that using clean power improves goodwill among clients, staff, and industry peers.

Accessible Financing

Previously, raising debt for rooftop solar projects used to be a challenge. However, the environment has become more conducive as banks become familiar with rooftop solar technology and therefore less sceptical about lending. Along with

[5] Solar Energy Industries Association (SEIA). Solar means Business. October 2020.
[6] Deloitte and Climate Investments Funds. Scaling up of rooftop solar in the SME sector in India. April 2019.

falling interest rates, this has made financing more accessible to C&I consumers. Since 2015 bank interest rates have dived, as per industry interviews, from 11-12% to about 9.5-10% for rooftop solar projects.

5. Emerging Technology Trends

The Indian rooftop solar C&I market is constantly exploring new technological developments to increase the share of RE electricity generation with limited onsite/rooftop spaces. Some solutions offer considerable value-addition in terms of energy generation while others are viable only in specific scenarios.

Key new trends that are being explored in the Indian market include:

- Adoption of large format modules (400/500Wp series instead of 330Wp series)
- Adoption of bifacial modules depending on site-specific conditions
- Adoption of battery storage for specific applications
- RE+EV solutions for solar carports
- BIPV technology for new commercial buildings.

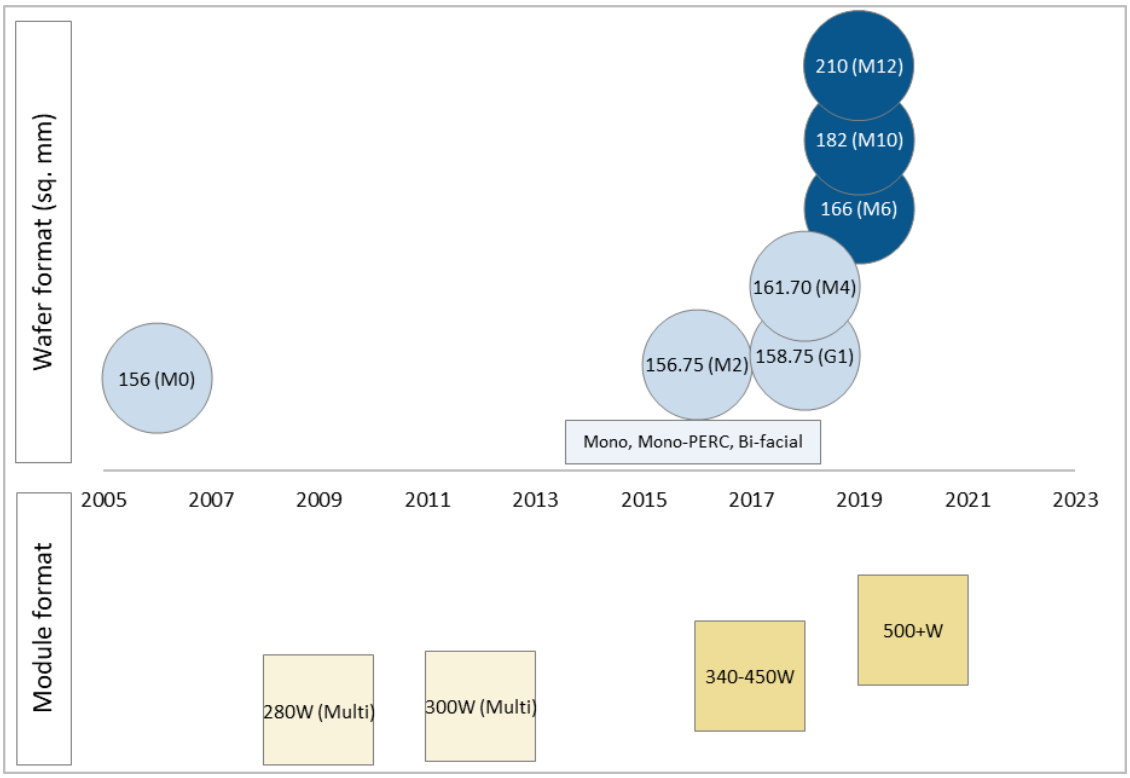
Most of these emerging technology trends are driven by falling module prices which have led to marginal price differences between poly vs. mono vs. bifacial, along with a drive to explore new technological advancements to increase green power procurement for corporate customers.

5.A: Adoption of Large-Format Modules

Key stakeholders (clients, developers, investors) in the market are pushing for further reductions in the cost of solar power. This has pushed the industry to favour growth in wafer size modules which has helped in curtailing manufacturing costs and, down the value chain, decreases cost per wattage. Thus, an increase in perceived interest and overall solar market demand for modules with lower cost and higher wattage, with their inherent improved technical features, is promoting industry adoption of M6 (166mm x 166mm), M10 (182mm x 182mm) and M12 (210mm x 210mm) wafer-based modules.

M2 (156.75mm x 156.75mm) and M2.5 (a.k.a. G1, 158.75mm x 158.75mm) wafers were the industry standard in 2018. From 2019 onwards, manufacturers started rolling out even larger wafers, with the power output of related modules breaching 500W.

Figure 3: Wafer and Module Format Evolution



Source: Industry news articles, JMK Research.

Some of the key drivers to shift to higher-wattage size modules for rooftop/onsite solar installations are:

Higher Generation and Falling Balance of System Costs

Increasing the size of wafers substantially improves the power output of the module. This brings savings at several levels within the PV system. Greater power output decreases the balance of system (BOS) costs by accommodating more watts in the same racking system. Use of larger-sized wafers means fewer modules to mount on fewer trackers or fixed-tilt racks and fewer strings to connect to achieve the same installed capacity at the power plant. These benefits are more profound for sites with space constraints, which is a significant issue in Indian metro cities in particular.

In 2022, the M6 wafer size is likely to have a 52% share of total global production.

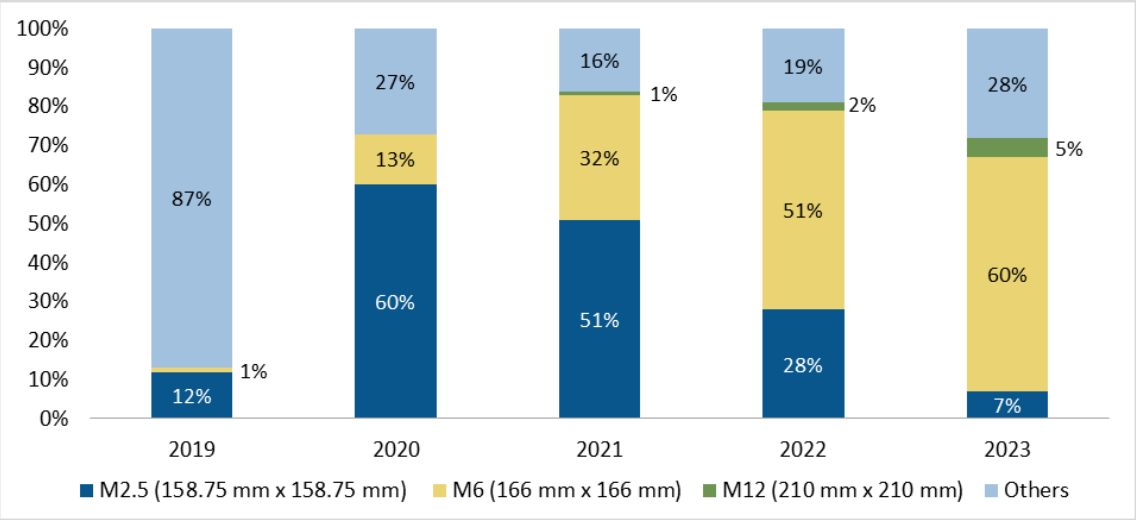
From an operations and maintenance (O&M) perspective, related expenses are trimmed in the long term by having fewer

plant components. With M6 wafers, a drop in costs at both cell and module level of 0.7cents/Wp can be achieved and the overall power output boosted by 6%.[7] For onsite solar installations in India using higher-wattage modules, the plant generation increases by 1%, while BOS costs reduce by 1%.

Global Technological Shifts

Offering the best balance between cost reductions and system compatibility, the M6 (166mm x 166mm) is expected to become the dominant wafer size in coming years. In 2022, the M6 wafer size is likely to have a 52% share of total global production, up from just 1% in 2019.

Figure 4: Forecast for Global Share of Wafer Format Production



Source: PV Infolink.

Risks and Challenges

It is necessary to find the right equation that balances module size with optimising the manufacturing process and ease of module installation. The M2 wafer and M2.5 wafer (introduced only last year) are being phased out in 2021. It is expected that the domestic rooftop solar market will shift from the M2.5 type to M6 cell-based modules in the near-term.

However, parameters such as power per unit area and per unit weight, roof utilisation rate and load-bearing capability must be carefully studied prior to selecting the module size. The larger format of higher wattage modules poses higher handling and installation risks. Although deploying modules of up to 540Wp enables a significant reduction in BOS costs compared to 400Wp modules, a similar level of BOS cost reduction becomes more difficult to achieve when moving from 540Wp to 600Wp modules due to the differing dimensions.

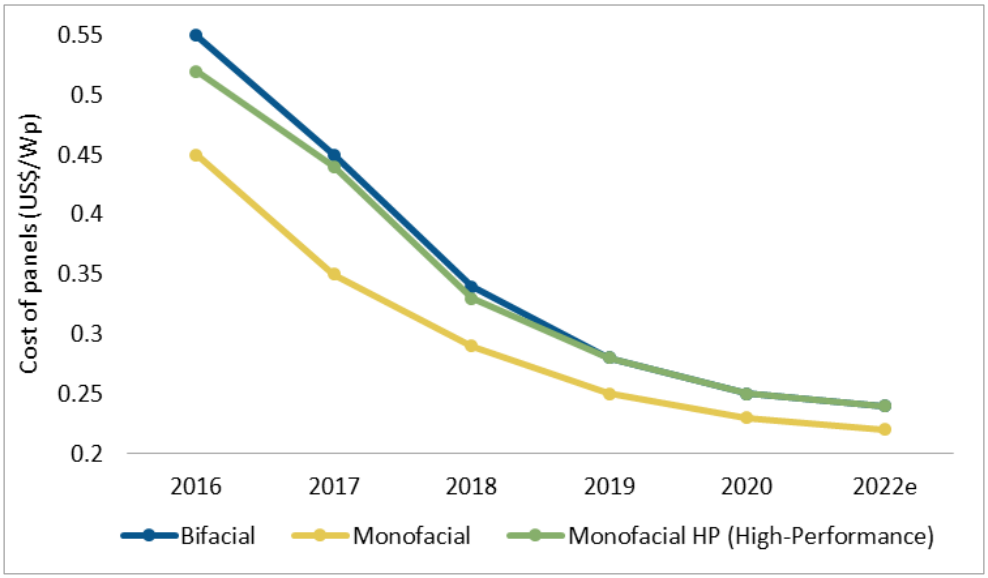
[7] Novergy solar. Significance of increasing size of mono-crystalline wafers in modules. September 2020.

5.B: Adoption of Bifacial Modules

As discussed, adoption of higher-wattage, larger-sized modules is becoming the norm. At the same time, players are also exploring other options such as bifacial panels, depending on the application, site, etc. These panels are becoming increasingly popular due to their availability at similar per watt peak prices to their monofacial equivalents[8], as illustrated in Figure 5.

Adoption of higher-wattage, larger-sized modules is becoming the norm.

Figure 5: Cost of Different Modules from 2016-2020



Source: PV Magazine, JMK Research.

Furthermore, in India there is a growing need to optimise costs and maximise output (kWh/m^2) in a given project area, especially in the C&I segment (given the limited rooftop/onsite space). Bifacial modules allow players to achieve these at negligible additional cost.

Also, with monofacial modules, the reflected light from the ground tends to increase the internal temperature of the module resulting in lower productivity. This phenomenon hampers the maximisation of output in limited spaces and therefore makes bifacial modules a necessity in the rooftop segment, provided that site conditions are suitable for bifacial installations.

Bifacial solar modules offer the following advantages over traditional monofacial

[8] Radovan Kopecek et al, Bifacial Photovoltaics 2021: Status, Opportunities and Challenges. April 2021.

solar panels:

- Power can be produced from both sides of bifacial modules, increasing total energy generation of similar sized projects, thus reducing the LCOE. A study carried out by LONGi Solar showed bifacial panel systems can increase module efficiency by 10-12%[9] compared to conventional panels. Additionally, efficiency can go as high as 27% when combined with solar trackers.

- They are more durable because both sides are UV resistant, and potential-induced degradation (PID) concerns are reduced when the bifacial module is frameless.

- They utilise glass which is 20-30% cheaper than the transparent sheets employed in monofacial panels.[10]

- BOS equipment and thus related costs are reduced as more power can be generated from bifacial modules in a smaller array footprint. This also translates to a proportional decrease in labour costs and maintenance costs.

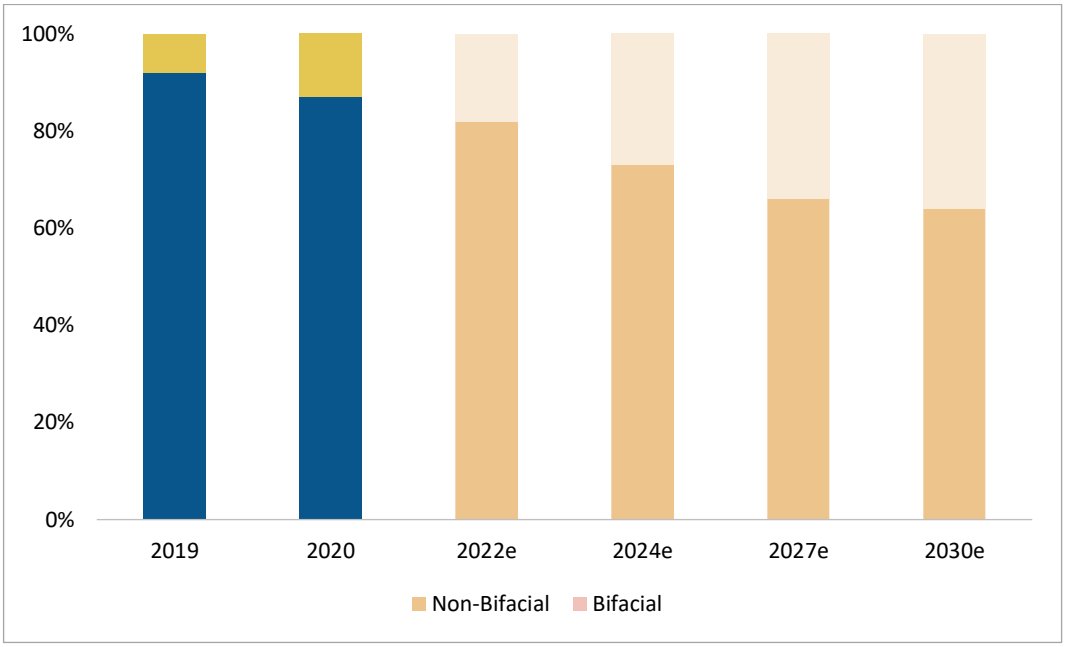
- Reduced internal temperatures in bifacial modules also results in enhanced performance.

The Kallam Textiles plant project in Andhra Pradesh, developed by Ilios Power, uses bifacial panels (see Case Study 1). Although the project does not use trackers, it uses seasonal tilt (varying the panel tilt in accordance with the season) which increases the yield by 2.5% over a fixed tilt model. Additionally, the developers have reported an efficiency gain of 1.93% due to the use of higher-wattage modules and further, a bifacial gain of 3-4%. In the Chiplun project in Maharashtra by Cleantech solar (see Case Study 2), the increase in generation due to bifacial modules is about 2.5% in comparison to monocrystalline modules, and 5.1% compared with polycrystalline modules.

The ITRPV (International Technology Roadmap for Photovoltaic) 2020 roadmap sees bifacial solar panels dominating the market in 5 years from now, as shown in Figure 6. This projection is in line with the path taken by module manufacturers to increase bifacial panel production.

[9] Greentech Media (now, Wood Mackenzie). Bifacial plus Trackers boosts Solar Energy Yield by 27%. April 2018.
[10] EPR Magazine. Bifacial Solar Panels, possessing that added advantage.

Figure 6: Forecast of Share of Bifacial Panels



Source: ITRPV

Companies such as LONGi, Jinko Solar and Trina Solar are major players in this space. Interestingly, by 2020 LONGi's global shipment of high-efficiency bifacial panels had already reached 10GW which accounted for nearly 40.8% of their total global shipments in 2020.

In relation to the Indian context, the shift to bifacial modules for onsite C&I segment installations is inevitable. However, we expect the rise to be incremental because the installation of bifacial modules depends on site-specific conditions and the potential to overcome certain challenges, which are discussed in brief below.

The shift to bifacial modules for onsite C&I segment installations is inevitable.

Risks and Challenges

Despite the advantages, the adoption of bifacial modules in rooftop systems in India has been slow in recent years. This is due to the following challenges:

→ Technical Risks and Challenges

DC design and installation can be more challenging for a PV plant using bifacial modules. Also, the use of bifacial modules is not viable in cases

where the corresponding environment has low albedo (measure of the diffuse reflection of solar radiation).

→ Site Constraints

Bifacial panels work best with flat roofs. With sharp angle or multi-directional roofs, shadowing and space constraints can hinder the output optimisation of the plant. Bifacial modules are not suitable for flush-mount systems because there is not enough room to reflect light onto the backside, even with a light-coloured roof.

→ Performance estimations

Due to a lack of installation and field estimation data on bifacial panels, the output cannot be modelled accurately, which could lead to errors in the project. Errors in installation can, in turn, result in self-shading between modules and rows which may increase module mismatch and therefore reduce energy yield.

→ Maintenance

Care must be taken to ensure moss does not grow on the roof surface. A recent study found annual energy gains, when compared to monofacial counterparts, fell from 22% on a clean, white surface to 5-7% due to the growth of moss. Therefore, managing such systems might lead to a small escalation in O&M costs.

As a result, in a price-sensitive market like India, adoption of bifacial modules is only possible where the roof is made from Reinforced Cement Concrete (RCC) and has an albedo factor of >25%. In other cases, such as installation on industrial sheds, bifacial modules are not feasible.

The Adoption of Bifacial Modules by C&I Consumers

Case Study 1: Kallam Textiles – Onsite Bifacial Modules Installation by Ilios Power

Project Description

Site Name	Kallam Textiles Ltd., onsite captive power plant
Location	Addanki, Andhra Pradesh
AC Capacity	1,000 kW
DC Capacity	1,270 kWp
Year of Commissioning	September 2020
Installation type (rooftop. Ground mounted/ carport etc.)	Ground-mounted
Module make and specifications	Longi: 425Wp dual glass Bifacial PERC with half-cut technology
No. of modules	2.988
Inverter make and specifications	Sungrow String Inverter: 100 kW, model: SG110CX with 9 MPPT
Net metering	Yes
Grid Interconnection Voltage	415 V
Construction time	60 days

Project Highlights

This project is one of the first in India to make use of Mono-PERC half-cut bifacial modules. In fact, this technology was still in its research phase in India when the project was taken up. Several design iterations were followed to derive the most optimal design including the structural design, sufficient albedo, DC sizing, number of modules and their orientation, and finding the right balance between overloading and clipping losses.

Another interesting factor is that the project employs seasonal tilt, i.e. varying the panel tilt between 5 to 24 degrees based on seasonal variations. This has enabled the developer to gain an additional 2.5% of yield as compared to a fixed-tilt layout. Using LONGi's 425Wp resulted in an efficiency gain of 1.93% followed by an additional gain of 3-4% in the form of bifacial gain.

The forecasted generation of the plant is 20 lakh units per annum, which in 2015 was equivalent to the generation from a single N-S axis tracker-equipped system with poly modules. The project has maintained an average CUF of 27.62% and an average PR (Performance Ratio) of 83.7% from January to June 2021. In the current year (2021), the plant has already generated 10.99 lakh units (as predicted by the developer using PVsyst with irradiation values varying by +/-5% month-wise in real time with respect to meteonorm data). If the irradiation value forecast is within the same range for the remainder of the year, the project will positively achieve the forecasted generation at year-end. In the past 8 months, the plant has achieved a maximum generation of 8,158 kWh i.e. 6.42 kWh/kWp, with a whopping CUF of 33.99% on 12 March 2021.

Challenges and Solutions

Design of Structure to Maximise Generation from Bifacial Modules

The structure designed for this plant is 3 landscape racking x 6 modules, maintaining a Ground Coverage Ratio (GCR) of 66.7% to facilitate maximum reflected sunlight from the ground reaching the rear side of the bifacial modules. The albedo is estimated to be 25% as the site ground is covered in weeds. The structure was designed with longer spans of 4.4m so that the structural members are not casting a constant shadow on the backside of the module during generation hours, thereby avoiding future hotspots that might affect the longevity of the module. All the structural members used are 90-120 microns and are hot dip galvanised to keep them durable in a corrosion-inducing atmosphere (the site is 60km from the sea).

Increase in Albedo

The grass or soil provides an albedo of 25%. But in this case, the aim was to increase the albedo to 40%. To achieve this, the developer added 6mm stone chips on the ground surface. The bifacial gain due to the addition of white stones above the stone chips to further enhance the albedo (as per recent data, white stones induce an albedo of 80%) is currently under research.

Completion of the Project During the Pandemic

The project was executed during the peak phase of the COVID-19 pandemic and the EPC of the project was completed within 60 days. The project development team came up with an organised plan to complete the project on time and the construction team followed a strict health and safety (HSE) plan throughout the project duration. There was no compromise on quality as proven by the amazing SCADA numbers.

Plant Performance

Annual generation capacity:	1,622.6 kWh/Year (Specific Production)
Plant CUF:	27.62%
Increase in generation due to bifacial modules:	3-4%
Estimated cost savings for Kallam Textiles:	Rs10 million/annum
Plant Performance Ratio:	83.7%

Case Study 2: Chiplun – Installation of Bifacial Modules by Cleantech Solar

Project Description

Site Name	Chiplun, India
Location	Maharashtra
DC Capacity	828.64 kWp (409.2 + 419.44) kWp
Year of Commissioning	2021
Installation type (rooftop, ground mount/carport etc.)	Rooftop + ground-mounted
Module make and specifications	Trina Solar/ Vertex (490 Wp), Canadian Solar-CS6U-P (330Wp)
No. of modules	1240 (Phase 1), 856 (Phase 2)
Inverter make and specifications	Phase 1: Sungrow SG50KTL-M (04 Nos.)/SG60KTL-M(01 No.)/SG33KTL-M (02 Nos.) Phase 2: Sungrow SG100CX (03 Nos.), SG50CX(01 No.)
Net metering	Yes
Grid Interconnection Voltage	LT – 440V
Construction time	Phase 1 (3 months), Phase 2 (3 months)

Project Highlights

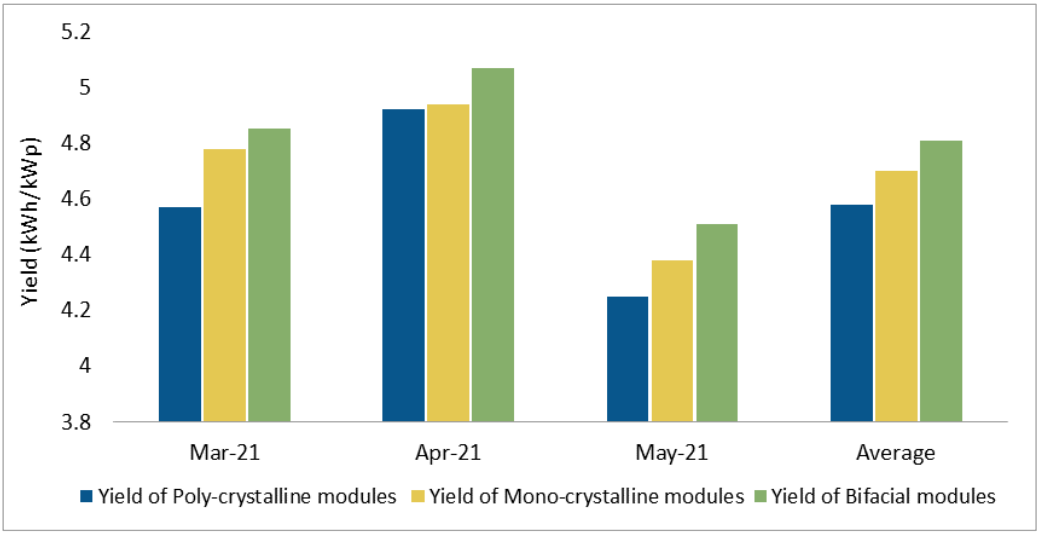
This project has set a benchmark for increased efficiency of generation. The ground-mounted installation employs bifacial modules, increasing the energy generation and overall efficiency of the project. The project consists of one inverter with bifacial modules and another with monofacial modules in the ground-mounted section for assessing the performance gain with bifacial modules under similar operating conditions.

Plant Performance

Annual generation capacity:	828.64 kWp
Plant CUF:	17.4% (based on the performance assessed from March 2021 – May 2021)
Increase in generation due to bifacial modules:	2.5% in comparison to mono-crystalline modules and 5.1% in comparison to poly-crystalline modules
Plant Performance Ratio:	80.6%

The average monthly savings generated by the solar PV installation is approximately Rs2.6 lakhs (0.26 million).

Figure 7: Specific Yield Comparison Between Bifacial, Mono and Poly-Crystalline Modules



Source: Cleantech Solar.

5.C: Adoption of Battery Storage

The market demand for Battery Energy Storage System (BESS)-integrated with onsite PV systems in India is currently limited to few scenarios. In the near future, solar+storage rooftop projects are likely to pick up in the following scenarios:

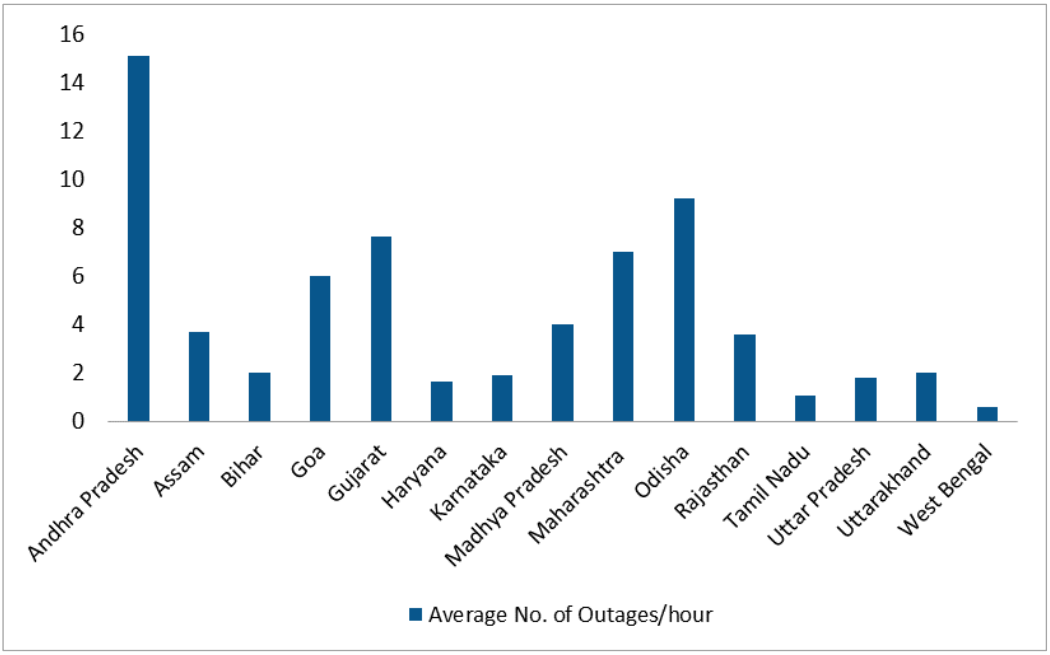
1. Projects where there are restrictions/no provisions for net metering and where commercial tariffs are high, especially if there are opportunities for significant time-of-use arbitrage or reductions in demand charges e.g. charging the storage component during non-peak hours of the day through power generated by the PV system and discharging or consuming the stored

energy during peak hours (such as the evening peak hours of 6 to 9pm), facilitating optimisation of cost of energy.

2. Projects for which the client organisation makes sustainability a priority or needs to meet RE100 targets, and an increase in electricity charges has little or zero P&L impact.

3. India has over 90GW[11] of behind-the-meter diesel generators primarily used as power backup to cope with frequent power outages (see Figure 10). These generators require regular maintenance and have high operating costs, especially with diesel prices on the rise (fuel taxes have increased around sixfold since 2013, with the retail price reaching more than Rs100 per litre). Battery storage, on the other hand, requires little to no maintenance and has no operation cost. High fuel costs coupled with free-falling battery prices (at the rate of 89% from $1,100 per kWh in 2010 to $137/kWh in 2020[12]) are set to make batteries a more viable option vis-à-vis diesel gensets. If low-cost financing options are made available, it is expected that diesel generators would be quickly replaced by solar+storage systems. Concessional credit lines from international organisations like the World Bank – which currently fund pure-play solar projects like rooftop solar in India – could be made applicable to the rooftop solar+BESS segment as well.

Figure 8: Average Number of Outages per Hour in Different States



Source: Urja Mitra, Ministry of Power, Government of India.

[11] Business Standard. Diesel generator sets' capacities witnessing an upward trend in India, June 2017.
[12] BloombergNEF. Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh. December 2020.

Outlook

Battery prices, already on a fast downward trend, are expected to fall further to US$100/kWh by 2023 and US$58 by 2030.[13] However, despite these drastic falls, lithium-based BESS is still not a commercially viable option in India. An additional 25-30% decline in battery prices is required before the cost of solar+battery systems is at parity with utility tariff rates. This fall can be achieved by filling the voids, i.e. the dearth in cell and battery manufacturing capabilities and absence of vertical integration of the current battery supply chain in India. To achieve this, the central government recently approved the Production-Linked Incentive (PLI) scheme worth Rs180 billion for battery manufacturing, which is expected to boost the capacity addition of local battery manufacturing and significantly bring down the cost of lithium batteries. According to Bloomberg New Energy Finance (BNEF), India is the lowest cost country for li-ion-based cell manufacturing. The subsidy under the PLI scheme is expected to be as low as US$27/kWh at the cell level.

The withdrawal of net-metering as well as banking provisions by multiple states for C&I customers also makes energy storage a more attractive option. In such scenarios solar+storage would be an apt proposition for C&I consumers, having the potential to insulate them from a lot of policy and regulatory hurdles. Further, solar+storage systems for new C&I loads enables offsetting of peak capacity augmentation of the grid.

All of these factors combined can aid in pushing battery prices down even further, making BESS a commercially viable option for the C&I segment. JMK Research estimates that in a time span of 2-3 years, with the increase in battery manufacturing and with battery prices estimated to reach US$100/kWh by 2023, the market for integrated rooftop solar and battery storage systems would shift forward from the present cusp phase.

Global Scenario

While coupling batteries with rooftop solar systems has become mainstream in countries such as Australia, batteries have limited application in most parts of the world. However, there have been some recent developments which make batteries a more viable option, as discussed below:

- Extensive R&D is being carried out to maximise the energy density of battery packs. One such innovation is Tesla's tabless batteries (smaller batteries that maintain their energy capacity). To put things into perspective, tabless batteries enable Tesla to go from 2,170 cells (currently used in its Powerwall) to 4,680 cells without compromising on performance or safety, thus doubling the capacity of the Powerwall.

- Players such as Tesla and LG have developed smart battery solutions that come with integrated inverters, controllers and intelligent energy monitoring solutions which ensure the battery is fully charged while keeping electricity costs at minimum. Combining these components not only

[13] IEEFA. India's Battery Storage Market is a Sleeping Giant. May 2021.

reduces the overall project size, but reduces the maintenance costs as they can be controlled and troubleshot remotely.

Risks and Challenges

→ Technical Risks

Lithium-ion batteries utilise Battery Management System (BMS) to ensure proper charging and discharging and safety. However, if the BMS is not installed properly or is of a low rating, it can cause thermal runaway due to overcharging, which can be a critical issue in India given the higher temperatures. This may also lead to batteries catching fire. However, a well-designed system with a properly rated BMS can help mitigate these risks by maintaining the system's temperature profile and state-of-charge.

→ Service Life of Battery Storage Systems

BESS generally have a service life of 10-15 years, while that of a rooftop solar system is about 25 years. Hence to assess the viability of energy storage in a project, it is critical to factor in the replacement cost for the energy storage systems.

→ Regulatory Environment

There is a need for more reform of policy support for the rooftop solar segment and specifically for solar+storage applications. Much of the existing regulatory framework does not explicitly address the interaction of power systems with storage. There is a lack of clarity about the functional classification of energy storage as it is both a generator and a consumer of electricity. As such, under the current net metering provisions, the export of power from BESS to the grid is not permitted. However in an encouraging move, the term "energy storage" is included under secondary and tertiary reserves with performance-based incentives in a recent draft of Ancillary Services Regulations from the Central Electricity Regulatory Commission (CERC). Furthermore, changes to the existing regulatory framework are required to identify what energy storage is, and to add this definition to the Electricity Act, 2003.

Adoption of Solar+BESS System

Case Study 3: Om Shanti Retreat Centre – Solar+Battery Storage by Vision Mechatronics

Project Description

Site Name	Om Shanti Retreat Centre (ORC)
Location	Bilaspur Chowk, Gurgaon, Haryana
AC Capacity	144 kW (180 kVA) (minimum)
DC Capacity	200 kWp
Battery Capacity	1.0944 MWh
Battery Technology	Hybrid (Lithium +Lead) Battery
Battery make and specifications	Vision Mechatronics, 614.4 kWh (Lithium) HBL 480kWh (Lead Acid)
Year of Commissioning	2021
Installation type	Rooftop solar + battery storage
Module make and specifications	Renewsys, 390 Wp
No. of modules	512 Nos, Monocrystalline
Inverter make and specifications	Victron Energy, 180 kVA + Fronius 135kW
Net metering	Yes
Grid Interconnection Voltage	415V
Construction time	3 months
O&M details	Annual System Check by Vision Mechatronics Pvt. Ltd.

Challenges

- Excessive use of diesel generators for facility operations resulted in increased energy costs for the Retreat Centre. This was not only environmentally detrimental but also expensive.

- The existing lead acid batteries installed needed frequent maintenance and replacement which further increased the cost as well as the downtime.

Project Highlights

- The Om Shanti Retreat Centre hosts India's first solar-based microgrid with MW-scale lithium-lead hybrid energy storage. This hybrid deployment utilises the existing old tubular gel (lead acid variant) batteries and fresh new lithium batteries, providing long duration backup, and ensuring zero blackouts and uninterrupted power supply when the grid fails. Currently, lithium batteries are observed to be commercially viable for a period of up to 4 hours of backup. Instead, this hybrid energy storage system was deployed to make a commercially-viable backup solution of 8 to 18 hours. Also, the integration of existing lead acid batteries facilitates a circular approach, adds to the life of the lead

This is India's first solar-based microgrid with MW-scale lithium-lead hybrid energy storage.

acid batteries, increases the backup duration, and enables maximum utilisation for the end user. The lithium-lead hybrid energy storage system is capable of reducing the capex investment of commercial entities on battery energy storage by 35-40%.

- The system is selected as an alternative to a diesel generator, however it also performs the function of a UPS-battery and stabiliser for voltage fluctuations. This storage solution also carries out peak shaving and frequency regulation functions. Due to the long-life expectancy of about 10 years and no need for maintenance or replacement of the lithium batteries, the system saves any additional cost involved in maintenance and replacement and also saves time. This eco-friendly solution uses solar power as the primary source to both charge the battery and simultaneously run the load. The excess energy is exported to the grid to avoid waste of solar energy.

- The system's response time is less than 10 milliseconds which ensures zero blackout while aiding in achieving maximum system efficiency.

- The "Active Balancing" BMS in the lithium battery enhances the life expectancy and performance of the battery by at least 30-40%. The "Predictive Monitoring", for monitoring hourly cell-level data, helps to predict non-functional status or repair/replacement need 15 days in advance. With the auto-on/off feature, the smart battery reports the failure reason by email, enabling the customer to take corrective actions to ensure complete system functionality and reliability, offering up to 99% uptime.

- The IoT-enabled Li-Rack ECO batteries used are non-flammable and non-explosive, making them completely safe to use.

6. Cost Analysis of Onsite/Rooftop Solar Installation Models in India

In order to extend the understanding of key factors and implications surrounding different onsite solar models, techno-commercial analyses were carried out for 4 different installation models, as shown in Table 2.

1. The first type of system consisting of polycrystalline modules (power output: 330 Wp) would have an OPEX tariff in the range of Rs3.7-3.9/kWh and lead to relatively lower savings on electricity bills (30-35%).

2. Superior 450-500 Wp mono-modules assumed in the second kind of onsite solar model would generate greater utility bill savings of 35-38%, although at a higher tariff of Rs3.6-3.9/kWh.

3. The third kind of model – onsite plant utilising bifacial modules – realise the highest specific yield (5-6 units/kW) and consequently, maximum utility bill savings (>40%) in comparison with the assumption that the site has good

albedo (>25%). With optimal conditions, this kind of model would have a tariff range almost equivalent to that of a typical system with poly-modules. The payback period for these 3 pure-play onsite solar models is in the range of 3-5 years.

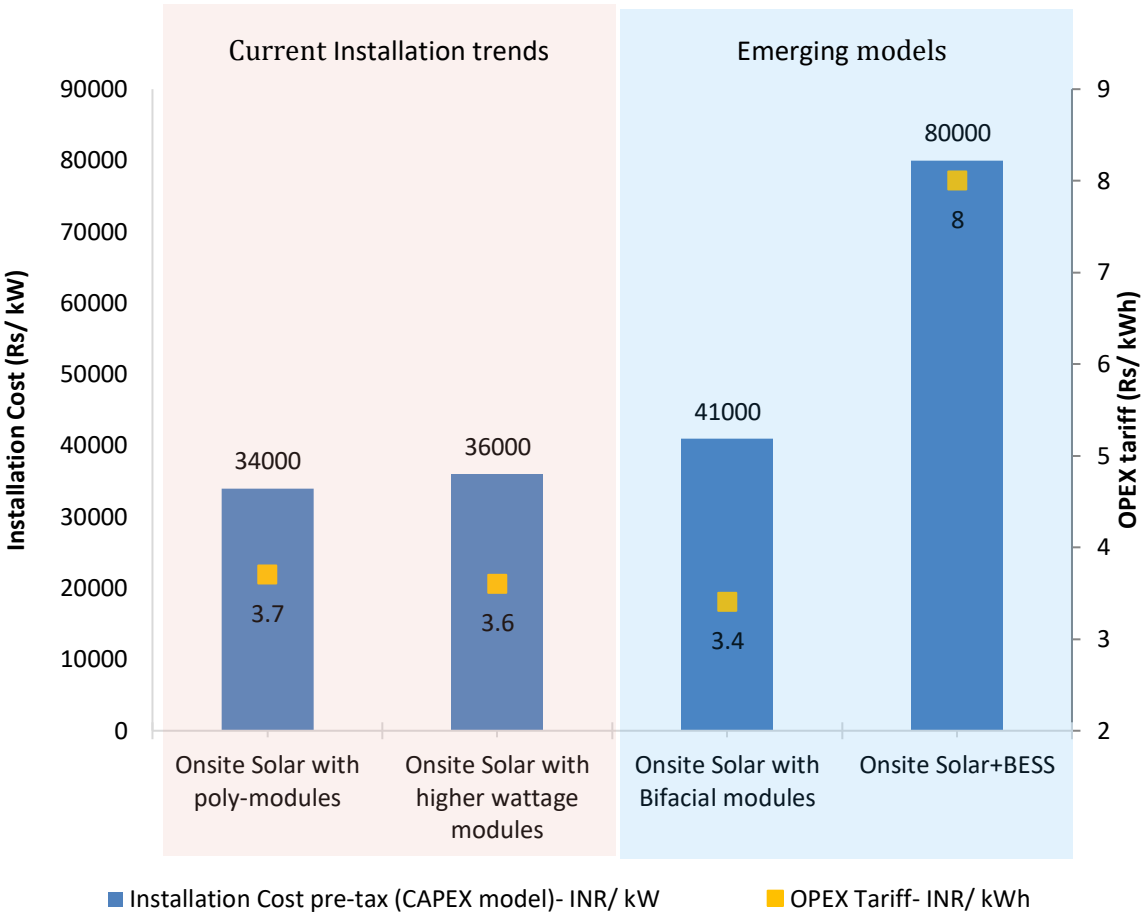
4. For the final type of system, an integrated onsite solar and BESS model plant was considered. The 'energy generation' component was assumed to be a poly-module-equipped system of same technical characteristics CUF, specific yield, etc. as that of the first type of system model. Combining li-ion BESS and the PV component increased the payback period of the model to some 7-8 years for a tariff of about Rs8/kWh.

Table 2: Details of Emerging Technology Trends in Rooftop Solar/Onsite Solar Installations

Type of system	Specific Yield (units/kW)	Installation cost (pre-tax) Rs per kW	Payback period on initial Investment (CAPEX)	OPEX tariff range (Rs/kWh)	Estimated cost savings on electricity bill	Preferred segments
Onsite solar with poly-modules	3.6-3.8 units/kW	Rs32,000-34,000	3-4 years	Rs3.7-3.9/kWh	30-35%	Most common type of installation in India right now, majority of installations in <500 KWp size
Onsite solar with higher wattage modules	4.0-4.5 units/kW	Rs34,000-36,000	3.5-4 years	Rs3.6-3.9/kWh	35-38%	Rooftops with space constraints and high RE generation required. Advantage of this is higher capacity for the same unit area.
Onsite solar with bifacial modules	5-6 units/ kW	Rs38,000-41000	3-3.5 years	Rs3.4-3.7/kWh	35-40%	RCC roofs, carport installations. Most beneficial in ground-mounted installations (within plant premises with capacity in the range of 2MWp plus).
Onsite solar+BESS	3.5-5 units/ kW	Rs70,000-80,000	7-8 years	Rs7-9/kWh	30-35%	Presently viable for consumers requiring savings on peak TOD tariff, peak load balancing, and DG replacement.

Source: JMK Research. Assumption: Industrial site with substantial size of >1MW and good solar radiation. Project costs considered are as of July 2021.

Figure 9: Cost Analysis of Various Rooftop/Onsite C&I Solar Installations in India



Source: JMK Research. Assumption: Industrial site with substantial size of >1MW and good solar radiation. Project costs considered are as of July 2021.

The analysis above shows that an onsite solar system with bifacial modules is the most economical solution if site conditions permit their use. However, shifting to higher-wattage modules also provides marginal benefits. Where space is a constraint, higher-wattage modules could be the optimal solution compared to small-sized polycrystalline module installations.

An onsite solar system with bifacial modules is the most economical solution.

BESS is currently not economically viable and despite the expectation of falling battery prices, the landed cost for the end customer is likely to remain unchanged for the next 10-12 months because of an increase in transportation and freight costs

and safety precautions in managing battery storage, etc. It is only viable for specific use cases, and end customers are still sceptical about exploring this option because of a lack of awareness, safety concerns in battery handling, and high upfront lithium-ion battery costs. While a payback period of less than 10 years is attractive in other countries (such as Australia), with relatively high interest rates this is not the case in India, provided there are no additional incentives or availability of low-cost finance.

7. Other Emerging Opportunities for Rooftop Solar Deployment

Apart from the cases discussed, there are other nascent technological models such as onsite solar integrated with EV charging stations and BIPV for new commercial buildings, both of which are elaborated upon in the following sections.

7.A: Combining Rooftop Solar with EV Charging

In a recent report[14], IEEFA argued that combining rooftop solar with storage and EVs can be a particularly valuable combination for India as it is more cost effective for private and public consumers to have distributed charging co-located with power generation and to directly charge EVs using behind-the-meter solar, especially given government support for EVs.

Combining rooftop solar and EVs offers 3 advantages over stationary storage:

1. EVs have larger battery capacities - new model EVs have 6-10 times the capacity of small-scale batteries.[15]

2. EVs are mobile and can be driven to charge from different locations.

3. If charged with renewable energy, EVs will help in rapidly decarbonising the transport sector, reducing India's enormous and growing reliance on imported oil while providing air pollution benefits.

Currently, players such as Fourth Partner, Hero Future Energies, Magenta and Tata Power Solar have installed multiple carport projects which provide the dual benefits of harnessing solar power while providing canopies for parked cars.

Solar carports are becoming a popular choice among many C&I businesses since they are not only a cost saving option, but can also be leveraged for the companies' sustainability goals and CSR obligations. In terms of business models, players can opt for the OPEX route by which customers would not have to spend on the installation. Moreover, they also end up saving on constructing canopies and other car parking structures, as the solar panels provide for the same, in addition to

[14,19,20] IEEFA. Lessons from Australia for India on Integrating Distributed Energy Resources (DER). March 2021.

allowing clients to save on power bills.

There is also potential for managed charging and discharging and vehicle-to-grid (V2G), which can provide much-needed grid flexibility and also provide ancillary services as and when needed. It is important to initiate active promotion of V2G pilot projects in India and build a conducive policy and regulatory environment in order to commercialise this novel mechanism.

Currently, there are about 15 million light vehicles on India's roads. If all of these vehicles were converted to electric and charged with renewable energy, total capacity required would be much greater than current utility-scale renewable energy generation.

Combining solar and EVs effectively has the potential to provide greater self-sufficiency for C&I consumers that adopt this combination of technologies while also addressing the issue of EVs being charged with electricity generated from greenhouse gas (GHG) emitting-fossil fuels, which defeats the purpose of EV adoption. However, IEEFA's report[20] also suggests that for such a model to be successfully implemented, discoms and policy makers need to think innovatively and develop measures that increase adoption of RE+EVs and change usage patterns to leverage low-cost solar when it is available and enhance grid stability.

7.B: Building Integrated Photovoltaics (BIPV)

While the C&I segment has so far driven rooftop solar adoption in India, for many corporates in tall buildings, it may not be a viable option. In such a situation, BIPV stands out as an innovative solution. This technology can also be used to extend current onsite/rooftop generation capacity.

The BIPV system involves integrating photovoltaic (PV) modules with the building envelope, such as the roof or the facade. BIPV modules can be a valuable part of the building such as wall material or roofing coverage; they can also be used as shades, peaks and other architectural construction elements. By simultaneously serving as an element of the building envelope and a power generator, BIPV systems provide savings on materials and electricity cost, reducing use of fossil fuels as well as adding architectural interest.

BIPV stands out as an innovative solution.

In India, U-Solar, Topsun and Atum Solar are some of the players active in deploying BIPV. India's current largest BIPV project is located on a building in Mumbai. It consists of BIPV panels that are vertically aligned on all four sides of the building. Further project details can be found in Case Study 4 of the report.

It is important to note that while one could argue that BIPV and other installations such as rooftop solar ultimately perform the same function of generating electricity,

realistically they both perform different functions and pitting one against the other is irrational and unfair. If compared in terms of output and costs, rooftop solar stands out as the superior option. However, a rooftop model is a retrofit or a building-attached construction installed solely for the purpose of energy generation, whereas BIPV takes an additional step in terms of functionality by also serving as an architectural element. In essence, BIPV ends up offering a greater ROI considering its dual functionalities. It is difficult to come to a conclusive ROI figure range for BIPV due to its context-dependent nature, as it is important to factor in the architectural element it replaces and the functions it performs.

Currently in India, green building certification codes from organisations such as Energy Conservation Building Code (ECBC) by the Bureau of Energy Efficiency (BEE), Indian Green Building Council, and Green Rating for Integrated Habitat Assessment (GRIHA) by The Energy and Resources Institute (TERI) also include solar power as a design metric. This aspect can be beneficial for organisations that wish to employ BIPV technology. Furthermore, there are no standards in place for using PV panels in lieu of building materials.

Advantages of BIPV

Using PV panels for the rooftop and facades of the building not only enables the building to generate electricity but also helps in reducing heat gain, thereby decreasing the energy demand for air-conditioning while concurrently allowing energy generation from multiple directions.

BIPV systems use existing building infrastructure (thus, no land requirement) and if combined with bifacials modules, internal lighting would also aid in power generation to some extent. If factored in and integrated during the initial stages of design, BIPV can also aid in offsetting the initial cost spent on building materials and labour used for building the parts which the panels are replacing. Another advantage of BIPV is that it supports innovative designs, making the building aesthetically pleasing.

Global Scenario

BIPV is still a new concept in most parts of the globe. However Europe is far advanced in this respect, being a thriving marketplace for BIPV. As of 2020, Europe had installed about 7GW[16] of BIPV projects, the majority of them in Italy and France. The major drivers for BIPV installations in Europe are favourable regulations that promote BIPV adoption and the need to carry out restoration work to buildings.[17] BIPV has been installed not only on facades and roofs but also on balconies, canopies, tiles, and semi-transparent windows.[14]

[16] SUPSI and Becquerel Institute. Building Integrated Photovoltaics: A Practical handbook for solar buildings' stakeholders. November 2020.
[17] Cristina S. Polo López et al, Photovoltaic BIPV Systems and Architectural Heritage: New Balance between Conservation and Transformation. An Assessment Method for Heritage Values Compatibility and Energy Benefits of Interventions. May 2021.

Outlook

BIPV is likely to become a favourable option for the construction sector because of the energy savings potential it offers[16] and it could be a key initiative under the 'net-zero' or 'green building' plan[14] likely to be widely adopted in the corporate sector in coming years. Integrating BIPV with existing buildings can be challenging yet beneficial, and the scale can be tipped further towards the 'benefits' if solar project developers and building architects collaborate from the design stage of building construction. This represents a huge opportunity, especially considering the fact that more than 50%[18] of the buildings that will stand in India by 2030 are yet to be built.

BIPV is expected to become mainstream in the mid to long term.

BIPV also offers commercial clients an excellent opportunity to optimise costs and expand their onsite power generation capabilities. With more corporates committing to RE100 and net-zero targets, BIPV is expected to become mainstream in the mid to long term. High costs and lack of customisation choices with regard to BIPV solutions are hindrances in the short term, however these are expected to be addressed as the technology upscales.

Risks and Challenges

→ Challenges with Existing Buildings

BIPV modules are different from traditional modules as they require certain customisations for optimal functioning. This is more valid especially in the case of integrating them with existing buildings. Customisations required include transparency (can vary from 0-40% depending on the application), shading, module size and design, lighting controls, etc, and it can also vary from one building to another. All of these make BIPV expensive and a less viable option for existing buildings.

→ Design Standards and Codes

Since this segment is still in its infancy, there are no standards or codes for designing buildings with BIPV. As BIPV modules serve dual functions, they must adhere to the codes and standards of two separate industries (PV and construction). Also, it is hard to follow a certain standard as different buildings might require different customisations.

In Europe, for instance, standards for BIPV have been/are being developed. The combined techno-electrical requirements and building codes have not only eased the design process but have also aided in regulators recognising

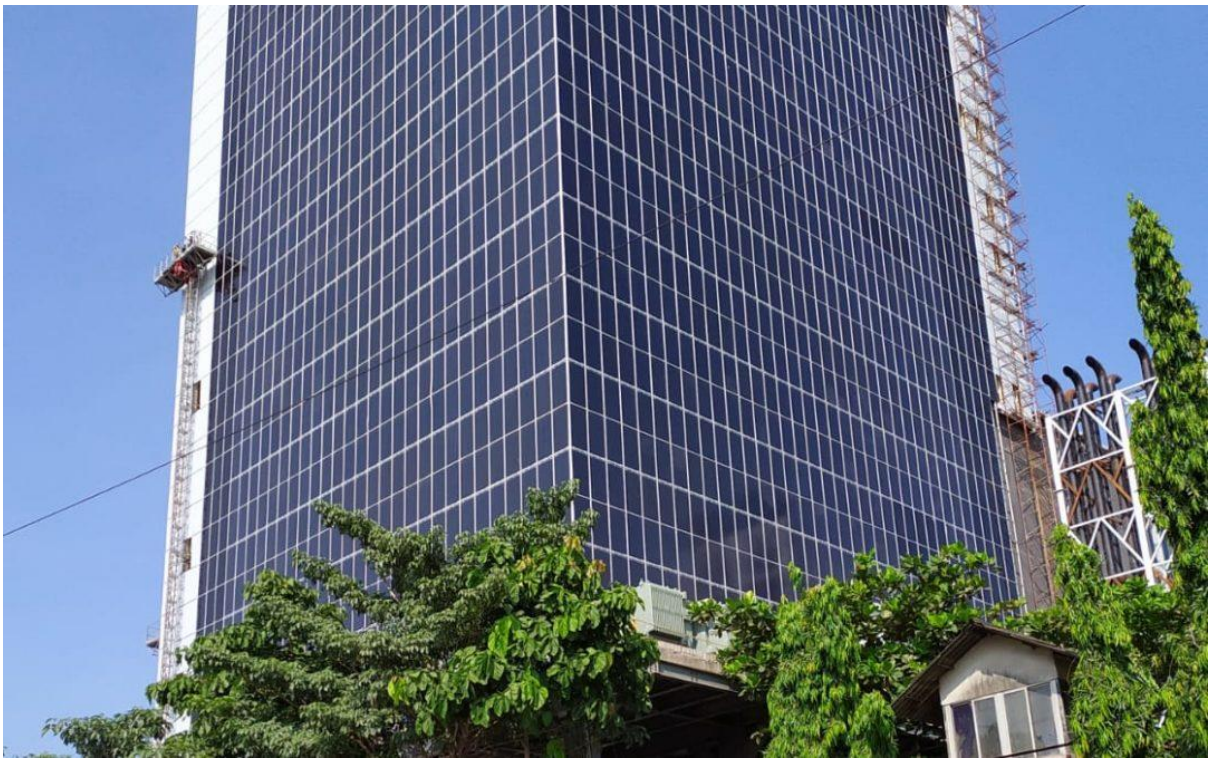
[18] Bureau of Energy Efficiency (BEE). ECBC Commercial.

BIPV as a viable option to catalyse solar uptake. India needs to create regulatory clarity for BIPV installations and must design its own codes and standards to enable developers and consumers to fully exploit the opportunities existing around this technology, while enabling regulators to recognize BIPV as a feasible onsite solution.

→ Lack of Manufacturers

Currently, there is a shortage of Indian manufacturers in BIPV, with Atum Solar and Waaree being the only players in this segment. A short term work-around is the import of the customised panels, although this would make the whole project highly expensive. However, going forward, as and when the demand from the real estate sector for BIPV technology for new commercial buildings reaches a certain desired level, existing module manufacturers could embark on developing and commercialising this niche technology.

Case Study 4: CtrlS Datacentre – Retrofit with BIPV by USolar



Project Description

Site Name	CtrlS Datacentre
Location	Mumbai
AC Capacity	719 kWp
DC Capacity	863.1 kWp
Year of Commissioning	2019
Installation type	BIPV

Module make and specifications	Mono crystalline WSM 350 Wp Waaree frameless solar panels
No. of modules	2,466
Inverter make and specifications	9 solar edge MPPT power optimisers
Net metering provision	No net metering (self-consumption)
Construction time	5 months (August to December 2019)
Project business model type	CAPEX
O&M details	O&M contract for 3 years

Project Highlight

As the building is cemented on all four sides, a glass façade was considered essential to add to its aesthetic appeal. Instead of applying regular façade-covering glass, the datacentre installed 2,466 high-efficiency mono-crystalline-Building Integrated Photovoltaic (BIPV) series 350 Wp Waaree frameless solar panels, and module-level optimisations were carried out using MPPT (Maximum Power Point Tracker) optimisers.

Challenges and Solutions

- Solar panels require specific orientation towards the sun for maximum energy yield. However, as the building was already constructed, there were constraints on the amount of energy that could be harnessed.

- Since the BIPV plant was being integrated into an existing building, custom-designed aluminium rails were used as the Module Mounting Structure (MMS).

The solution devised by U-Solar to tackle the constraints on harnessing energy was to place solar panels on all four sides of the building using glass facades, and power optimisers and a remote monitoring system were used to further improve energy generation.

Customised aluminium frames were made and mounted on the building in collaboration with façade fabricators. Modules were placed and interconnected in trays on the frame which led to an electrical room on the roof. Frameless panels were ordered to fit the MMS structure/glass façade. This helped maintain the high solar power generation without compromising the aesthetics.

Plant Performance

Annual generation capacity: 410,244.802 kWh

Plant Performance ratio: 38.74%

Plant CUF: 5.43%

Power demand met through this plant: 0.60% (The facility is a datacentre with very high loads running 24/7 – the BIPV is a part of the green building certification and sustainability mandate)

Cost Savings in last year:	Rs 6,703,660
Projected savings for next 25 years:	Rs 170,434,995
CO2 offset:	1,177 tonnes per year

8. Conclusion

Saving on electricity costs is imperative for C&I consumers in India who are levied higher discom charges, cross-subsidising the other consumer categories. Adoption of onsite solar solutions remains the "lowest-hanging fruit" for consumers that want to optimise their electricity costs or increase their procurement of renewable supply.

Post the first wave of COVID-19, the price sensitivity of C&I consumers has increased in parallel with the fast-growing relevance of sustainability metrics. Therefore, rooftop solar companies (developers and EPC players) anticipate considerable growth in capacity addition in the C&I segment in the near future, especially through OPEX models.

The adoption of large-format modules and bifacial modules in the rooftop solar market is expected to become a significant trend in the short term as benefits increase, for example, through module price reduction, greater standardisation of products under each solar plant component, and compatibility between all the components, etc.

Battery prices are estimated to reach US$100/kWh by 2023.

In contrast, BESS is still not economically viable and despite expectation of falling battery prices, the landed cost for the end customer is likely to remain unchanged at least for the next year because of an increase in transportation and freight costs and safety precautions in managing battery storage etc. Growth of BESS-integrated onsite solar systems is expected to gain substantial traction in another 2-3 years with battery prices estimated to reach US$100/kWh by 2023. These systems are only viable for specific use cases and end customers are still sceptical about exploring this option because of a lack of awareness, safety concerns, and substantially high upfront lithium-ion battery costs.

Scaling up domestic manufacturing capabilities of modules and li-ion batteries in the near future is also likely to have a strong positive influence on the adoption of various onsite solar+battery storage systems. BESS is also expected to replace many diesel genset installations over the next decade as it offers additional cost saving opportunities, along with negligible maintenance costs.

In terms of economic benefits, bifacial modules are at the moment the best possible solution out of the four types of onsite technologies considered for analysis in this

report, provided that site conditions permit their installation. Shifting to higher-wattage size modules also gives marginal benefits and where space is a constraint, these modules can be the optimal solution compared to small-sized poly-module installations.

More nascent sustainable solutions, such as solar-powered carports and BIPV, are also expected to pick up installation pace on account of their multiple benefits, with a significant share of demand potential being represented by corporate consumers looking to set up new commercial complexes.

About JMK Research & Analytics

JMK Research & Analytics provides research and advisory services to Indian and International clients across Renewables, Electric mobility, and the Battery storage market. www.jmkresearch.com

About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

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