# India's crystallizing manufacturing hub

**Valerie Thompson examines ingot and wafer manufacturing capacity trends as India's PV production industry expands and goes vertical in a bid for self reliance.**

Indian solar manufacturing is going further upstream, from modules and cells to wafers and ingots. New entrants and established manufacturers are diversifying the PV supply chain in a trend supported by legislation such as the production-linked incentive (PLI) program.

Adani Solar was first to begin making large monocrystalline silicon ingots and wafers, offering M10 (182 mm x 182 mm) and G12 (210 mm x 210 mm) formats.

Such integrated manufacturing sites in India typically have 2 GW to 3 GW of annual capacity, and can have up to 5 GW, according to Sukumar Madugula, director of RCT Solutions India, a German factory engineering, consulting, and installation services company active in India.

Indosol has announced an ingot-to-module manufacturing strategy, plus solar glass, while Grew Energy, part of India's Chiripal Group, has announced 2.8 GW of ingot, wafer, and cell capacity, as part of an

Photo: Adani Solar

*Adani Solar has integrated ingot and wafer production in Gujarat, India.*

eventual 6 GW module output. Reliance Industries has plans for 10 GW of integrated module, cell, glass, wafer, ingot, and polysilicon production, as **pv magazine India** has reported.

"There are plans for meaningful volumes of ingot and wafer manufacturing to come online in India," said Alex Barrows of manufacturing advisory Exawatt, now part of the UK-based CRU Group. "We track over 60 GW planned over the next four years [to 2028]."

Barrows said most production capacity concerns companies moving upstream from module and cell manufacturing.

"Several of these plans have already been delayed, compared to their original timelines, and some will probably be delayed further," he added. "Several manufacturers seem to be pausing and waiting for the current market issues, with prices below production cost, to play out a little more before pushing ahead."

RCT's Madugula confirmed that the choice between making ingots and wafers in-house or buying from Chinese suppliers is influenced by low prices in the market.

## Pure play

US-Indian company Renaissance Solar and Electronic Materials (RSOLEC) is focusing solely on Recharge Czochralski (RCZ)-based crystal growing and wafer production, without downstream integration plans.

"RSOLEC is the only pure-play merchant wafer producer developing a 5 GW capacity in India to address the silicon wafer shortage outside China," said CEO Milind Kulkarni. "We were among the first to realize the wafer shortfall but it is very well accepted today. We expect less than 50 GW of wafer capacity by 2028 in the US and India, in the most optimistic scenario. In fact, if one considers all announcements, there should be close to 150 GW of cell capacity in the US and India, collectively, in 2028. Even if it turns out to be only 90 GW or 100 GW of cell capacity, the opportunity remains."

Kulkarni said RSOLEC will be competitive on quality and cost with the "best players in China" from the start, with a prospective capital intensity of less than $30 million per gigawatt of output. He claimed that costs may fall by "more than 30%" after initial operations as productivity improves "by nearly 100%" through the company's plans. RSOLEC's production plan includes performance, quality, and productivity-enhancing strategies based on advanced design, process, and control improvements. Those will be driven by the industrial experience of RSOLEC's management and the company's experts, according to Kulkarni.

"Many other cost drivers, such as power, labor, and consumables depend on productivity," said the CEO. "Labor is cheaper in India than in China. The cost of power in certain Indian states is also competitive. This means the key to achieving a lower cost of production is realizing a very high productivity while maintaining the required quality."

Regarding the variable cost of PV raw material polysilicon, Kulkarni said that "there is abundant supply from China and for the US manufacturers who are unwilling to accept Chinese polysilicon, there is more than sufficient polysilicon supply available in Malaysia, Germany, and the US."

## Competitive factors

"The Indian government is actively promoting the expansion of ingot and wafer production facilities by offering attractive incentives to encourage investments. In addition to monetary support, other favorable conditions are required for this industry's sustenance and growth," said Grew Energy Director and CEO Vinay Thadani. He noted that pricing and good quality, uninterrupted power are also influential. "This will not only give India an edge in ingot and wafer manufacturing but also help reduce imports for the solar sector."

The nation's domestic PV module assembly capacity is increasingly satisfying domestic demand, according to Niclas Weimar, chief technology officer of Sinovoltaics, a Hong Kong-based technical compliance and quality assurance company.

"The Approved List of Models and Manufacturers was put on hold for 12 months due to insufficient domestic manufacturing capacity but was recently reimposed when the government felt more confident about local capacity meeting demand," Weimar told *pv magazine*.

That trend has enabled India to export some of its module output, with most shipments going to the United States, according to Weimar. RCT Solutions' Madugula said that exporting is a "bright light" for many Indian manufacturers.

Photo: Linton Crystal Technologies

*US-based Linton Crystal Technologies has been working with the Indian market since 2019.*

Photo: Adani Solar

*Adani Solar was the first of India's PV manufacturers to add large-sized monocrystalline silicon ingot and wafer capacity.*

> *"Compared with Southeast Asia, plans for ingot and wafer facilities in India are dominated by local companies"*

When asked about the Indian manufacturing hub's ability to compete with other emerging production centers outside of China, Exawatt's Barrows said that one key difference, compared to Southeast Asia, is that in India, the plans for ingot and wafer facilities are dominated by local companies. "This is differentiated from hubs in Southeast Asia, where Chinese companies are transferring their mass production processes to a new location," said Barrows. That key difference could mean Indian manufacturers will be relying "quite heavily" on their equipment suppliers to provide the expertise, he added.

One of those equipment suppliers, active in India, is Linton Crystal Technologies, a US-based provider of solar-silicon crystal-growing Czochralski furnaces and process controls, wafering equipment, and technical and process engineering services. "Linton has been working closely on India as the next big market for the last five years [since 2019] and we have talked to, or are talking with, all the major players that have applied for the PLI," said Todd Barnum, Linton's president and chief operating officer. "We feel that India has the potential to eclipse the investments from the United States or Europe. With the PLI government incentive, combined with a lower cost of labor, proximity to the current manufacturing areas, and close ties with the US market, India looks to have the tools to succeed in the industry."

Madugula said RCT Solutions is working with both Chinese and Western solar production equipment suppliers, selecting the "best, most suitable, and optimal" solutions based on client requirements and market conditions. "The choice is for flexible equipment," said Madugula. "We are guiding clients to also consider operating expenditure and flexibility as decision drivers."

Balachander Krishnan, chief operating officer of Indosol Solar, said, "There are one or two equipment companies that have backed out, however, there are still a handful of companies in China to support the Indian manufacturing companies by supplying state-of-the-art equipment for international customers."

## Wafer size

Popular wafer dimensions include typical square formats as well as newer rectangular formats. RCT's Madugula said his company's customers are building capacity to support n-type PV technology such as tunnel oxide passivated contact (TOPCon) solar cells in an M10 (182 mm) wafer format.

"At Indosol, we intend to start with 182 mm or 210 mm during the ramp-up stage, until we complete the site acceptance test," said Krishnan, referring to square wafers. He added that optimizing logistics costs and industry trends might involve producing rectangular formats like 182.2 mm x 191.6 mm or 182 mm x 210 mm.

RSOLEC plans a range of products from M10 size to G12 (210 mm) and G16 (230 mm) dimensions, and is flexible to meet customer demand. "We can make full wafers as well as half wafers," said Kulkarni. "We can make n-type as well as p-type wafers. We can also tune the wafer thickness."

Grew Energy's Thadani said the company is focusing on meeting local demand, which is currently centered around G-12R (182 mm x 210 mm), M10, and G12. "However, the size preference is determined based on the needs of end-users and EPC [engineering, procurement, and construction services] installers."

## Sustainable practices

Building new manufacturing capacity means developing sustainable practices and recycling concepts for items such as PV modules. There are several Indian startups investing to make recycling possible, alongside initiatives by some EPC companies, according to RCT Solutions' Madugula, who said that there might be a breakthrough by early 2025.

The recycling of end-of-life PV panels still has to overcome cost and chemical sustainability challenges. "Current methods use environmentally unfriendly chemicals and a lot of energy and that makes the process too expensive for practical recycling," said Indosol's Krishnan. "However, in the coming years, this is likely to change." pv

*Valerie Thompson*

***India plans***

**60GW**

***of ingot and wafer capacity by 2028***