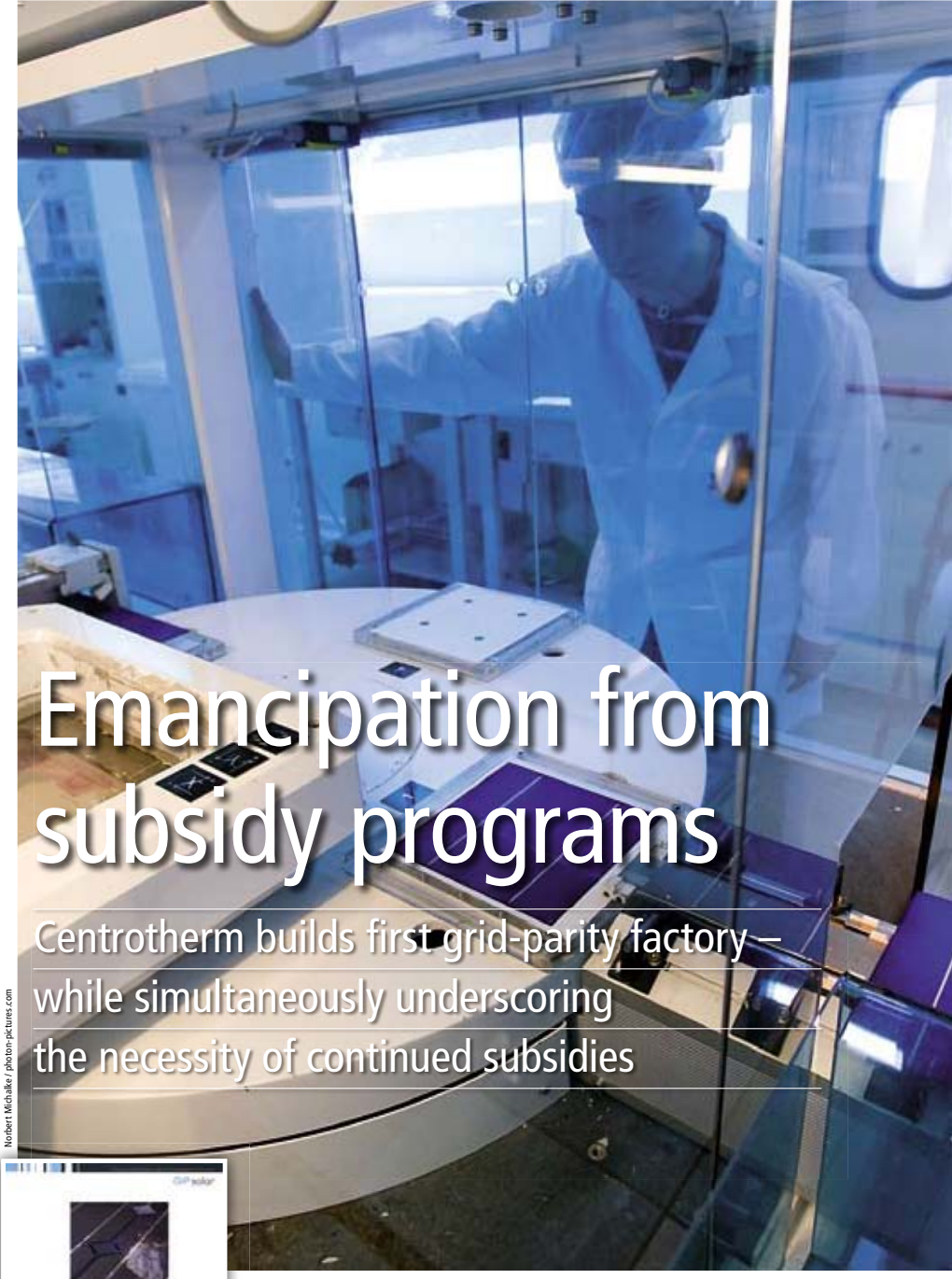
Emancipation from subsidy programs

Centrotherm builds first grid-parity factory – while simultaneously underscoring the necessity of continued subsidies



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Centrotherm builds factories that allow operators to produce solar modules so inexpensively that PV systems using them would no longer require additional subsidies to be profitable. Still, there was a heated discussion inside the company about whether it should give PHOTON International its 14-page paper documenting production costs – after all, politicians shouldn't get any bright ideas about axing PV subsidies.

For manufacturers planning to build a new module factory today, it's more than likely that some of their products will be sold in markets without subsidy programs. And why have subsidy programs at all, when new thin-film factories can produce modules at around €1 ($1.27) per W and crystalline module factories are producing modules for a little over €1 ($1.27) per W. In many countries, when using these modules, system operators are able to produce solar electricity at prices competitive with grid electricity. This article presents such a crystalline silicon-based grid-parity factory in detail.

It's a touchy subject. Which is why PHOTON International needed approval from Centrotherm's board of directors before printing the figures that follow in this article, under the headline: Centrotherm builds first grid-parity factory. That's not because the individual figures would reveal some great company secret – the company prudently avoided providing a detailed breakdown of costs. Rather, it's the conclusions that can be drawn from these figures that are potentially political dynamite. Grid parity is the term used to represent the competitiveness of solar electricity with conventional electricity from the grid – and therefore the end of PV's dependence on subsidies. And thus, at the start of our research, Centrotherm made an unambiguous statement: »At the end of the article, you'd better not say ›Now, we no longer need subsidies,‹« said Peter Fath, CTO at the stock-listed company. And, that's certainly not the conclusion we draw at the end.

The Centrotherm factory described in this article can produce modules at costs so low they can be sold on the world market without the help of any subsidy program – and it's not just a theoretical plan, it's going to be built. Negotiations with a Norwegian investor are already fairly advanced, but apparently there are other interested parties in India and the Ukraine, too. For just €718.1 million ($915 million), a Centrotherm customer gets a fully integrated c-Si-based PV factory with an annual output of 347 MW of solar modules (see graph/table, p. 91).

It's actually more accurate to describe the factory as five separate sub-factories, which handle everything from polysilicon production to complete solar modules. The different factories do not need to be constructed at the same location. For instance, silicon production is very energy intensive, so finding a location with the lowest possible electricity costs would be advantageous. This is also true for crystallization of the ingots. The cell and modules, on the other hand, can then be manufactured closer to the target market to minimize transport costs. In this respect, in Europe, the northern country Norway would be a good choice: cheap electricity, thanks to hydropower, and it's not too far a journey to the most attractive markets in Southern Europe. However, as supply is increasingly coming from Asia and demand is spreading beyond Germany, with more solar electricity generated at grid-parity prices, and with the US considered the next super solar power market, Centrotherm has assumed three case studies for us in different locations for the calculations presented in this article: one scenario combines Canada and Germany. The factories for the production of polysilicon and multicrystalline ingots would be located in Canada near a large hydropower plant, while the ingots would be cut into wafers, processed into solar cells

TCS & polysilicon production

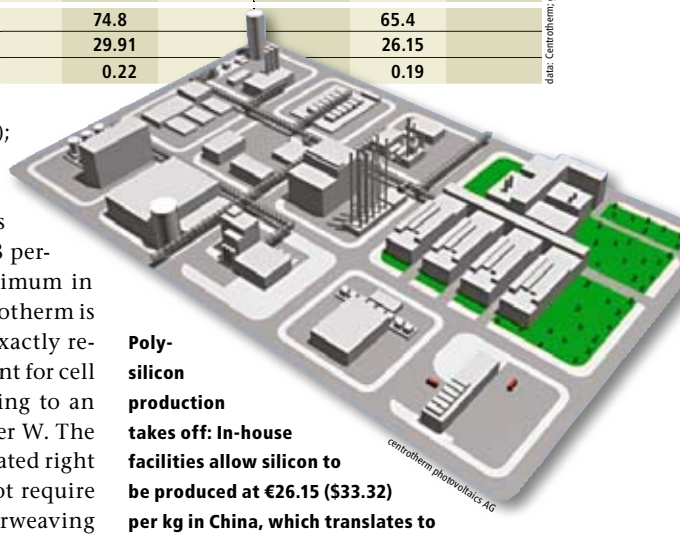
		Canada / Germany			USA			China		
	Quantity	€ mn	€ mn/year	%	€ mn	€ mn/year	%	€ mn	€ mn/year	%
Equipment (Depreciation 10 years)										
Metallurgical silicon mills	2									
TCS synthesis reactors	2									
Distillation & purification	1									
Tank storage	1									
Siemens type deposition reactors	18									
STC - TCS converters	9									
Poly rod crashing	1									
Etching	2									
Seed crystal production	6									
Vent gas recovery unit	1									
Waste treatment	2									
Physical characterization laboratory	1									
Auxiliary equipment	1									
Project management & process know-how										
Total		**227.0**	**22.7**	**32%**	**227.0**	**22.7**	**30%**	**227.0**	**22.7**	**35%**
Building & facility (Depreciation 15 years)										
Building	80,000 m²									
Facility & infrastructure										
Project management										
Total		**85.0**	**5.7**	**8%**	**85.0**	**5.7**	**8%**	**85.0**	**5.7**	**9%**
Production goods										
MG silicon	1.60 t/t polySi									
HCL	0.48 t/t polySi									
Hydrogen	0.08 t/t polySi									
Total			**8.6**	**12%**		**8.6**	**12%**		**8.6**	**13%**
Running costs										
Electricity	165 kWh/kg									
Utilities	€1.61/kg									
Maintenance equipment	3% of invest									
Maintenance building	3% of invest									
Total			**22.9**	**32%**		**25.8**	**35%**		**25.8**	**39%**
Workforce										
Management	15									
Engineers / technicians	60									
Operators	164									
Total	**239**		**12.0**	**17%**		**12.0**	**16%**		**2.6**	**4%**
Total costs per year			**71.9**			**74.8**			**65.4**	
PolySi costs per kg (€)			**28.75**			**29.91**			**26.15**	
PolySi costs per W (€)			**0.21**			**0.22**			**0.19**	

data: Centrotherm; graphic: PHOTON International

and manufactured into complete modules at a location in Germany. This distribution of labor makes sense, since the silicon bricks can be easily transported. In addition, the scenario was calculated for the US, which offers both cheap electricity – there's a reason why Hemlock, the world's biggest silicon manufacturer is based in Michigan and SolarWorld is dramatically increasing its ingot/wafer capacities in the Northwest – and soon also a gigantic market. Finally, the figures have also been calculated for China to account for a low labor-cost country that has recently turned into the world's biggest wafer, cell and module producer.

Achieving grid parity only requires standard c-Si technology

As an advanced warning: the next few paragraphs contain little new information for PV experts. That's because the grid-parity factory exclusively uses well-established technology. The equipment is based on Centrotherm's standard, tried and true equipment used by many big producers around the world (including its silicon equipment currently being set up at the first companies); the wafer thickness is 180 µm, a value easily achieved with today's wire saws; efficiencies are moderately ambitious (15.8 percent) but guaranteed as a minimum in the turnkey cell factories Centrotherm is selling today; and yield isn't exactly record breaking (around 96 percent for cell and module production), leading to an average silicon usage of 7.2 g per W. The individual sub-factories are located right next to one another and do not require any particularly complex interweaving of production processes. Centrotherm is currently working on a Smart Integrated Factory concept in which the processes are combined to produce a truly integrated production facility with average multicrystalline efficiencies of 16.5 percent. »That could reduce investment costs, the number of required employees, the amount of breakage and increase efficiency,« explains Franz-Josef Feilmeier, module technology project manager at Centrotherm's subsidiary GP Solar GmbH. However, based on Centrotherm's calculations the conclusion is: achieving grid parity doesn't require anything more than building upon established standard technologies.



Polysilicon production takes off: In-house facilities allow silicon to be produced at €26.15 ($33.32) per kg in China, which translates to a cost of 19 euro cents (24.2¢) per W of module power. Manufacturers buying silicon on the spot market can pay 10 times that amount, or twice as much with long-term contracts.

Polysilicon and ingot production

The essential component in this equation is owning in-house silicon production, which frees factory operators from the effect of price fluctuations on the

Ingot production

		Canada / Germany			USA			China		
	Quantity	€ mn	€ mn/year	%	€ mn	€ mn/year	%	€ mn	€ mn/year	%
Equipment (Depreciation 5 years)										
Crucible preparation stations	6									
Drying furnaces	6									
Crystal growth units	53									
Saws/bricking	10									
Saws/cropping	10									
Grinding machines	16									
Physical characterization lab	1									
Auxiliary equipment	1									
Project management & process know-how										
Total		**80.5**	**11.5**	**24%**	**80.5**	**11.5**	**24%**	**80.5**	**11.5**	**34%**
Building & facility (Depreciation 15 years)										
Building	28,000 m²									
Facility & infrastructure										
Project management										
Total		**16.0**	**1.1**	**2%**	**16.0**	**1.1**	**2%**	**16.0**	**1.1**	**3%**
Production goods										
Crucibles	2.2 pcs/t									
Total			**8.1**	**17%**	**8.1**	**17%**			**8.1**	**24%**
Running costs										
Electricity	25.9 kWh/kg									
Utilities	€1.10/kg									
Maintenance equipment	5% of invest									
Maintenance building	3% of invest									
Total			**9.8**	**21%**		**10.2**	**21%**		**10.2**	**30%**
Workforce										
Management	14									
Engineers / technicians	64									
Operators	280									
Total	**358**		**16.6**	**35%**		**16.6**	**35%**		**2.9**	**9%**
Total costs per year			**47.1**			**47.5**			**33.8**	
Production costs per kg (€)			**20.71**			**20.88**			**14.86**	
Production costs per W (€)			**0.14**			**0.14**			**0.10**	

data: Centrotherm; graphic: PHOTON International

silicon market. A suggested size would be a production capacity of 2,500 tons of polysilicon annually – smaller units would be disproportionately expensive. This explains the factory's uneven figure for module capacity at 347 MW, since the amount of available silicon determines module capacity. However, Centrotherm points out that all calculations have a tolerance of +/- 10 percent.

The production of polysilicon begins with metallurgic silicon (MG-Si), which must be purchased on the world market. By adding hydrochloric acid (HCl), one obtains trichlorosilane (TCS), which is distilled and purified in this process. Then, highly purified silicon is deposited in a total of 18 Siemens reactors, the waste product left over is silicon tetrachloride ($SiCl_4$), which is then transformed once again into TCS in nine conversion reactors and fed back into the original production process. The conversion reactors are expensive, but reduce the amount of MG-Si required per kg of polysilicon significantly, which is why they should be included in every new silicon production facility going forward. The same holds true for the complicated system for treating the waste gasses, which ensures that no dangerous fumes are released into the environment. At the end of the production process, the silicon rods obtained in the Siemens reactors are broken and etched. The factory's total surface area of 80,000 m² is dimensioned for a subsequent 100 percent increase in capacity.

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Right next to the silicon factory is the ingot production facility. Here, the polysilicon is melted and crystallized, and the ingots are cut into bricks. In China, the production costs for these silicon bricks (not including the raw silicon) can be as low as €14.86 ($18.93) per kg – that's 10 euro cents (12.7¢) per W of module power and much cheaper than production in North America.

At a cost of €227 million ($289.2 million), the machinery required for the polysilicon production component is the largest cost factor in a grid-parity factory (see table, p. 85). »If the factory continues to produce after its depreciation in 10 years, then production costs will decrease accordingly,« adds Feilmeier. The investment cost – at least when

contracting Centrotherm to supply the product – is the same for the three locations, as well as the price for production goods, mainly consisting of MG-Si, HCl and hydrogen at €8.6 million ($11 million), which account for 12 percent of the costs in North America and 13 percent in China – which, relatively speaking, is quite negligible. But it is somewhat of a surprise that project management and facility costs in the eastern country are also level with the silicon locations in the West. »Since the costs vary so strongly even in the different markets and depending on which construction and project management companies you work with, we assumed one price level for the model for the reason of simplification,« says Fath.

One big differentiator is electricity prices, which play a very important role for selecting a location. The calculations here assume an industry price of 2.8 euro cents (3.6¢) per kWh for Canada, and for the USA and China is was assumed to average out at 3.5 euro cents (4.5¢), although this can strongly vary in the last two cases. In China, for example, there is a silicon producer with its own mine and coal power plant that can probably produce electricity at below 2 euro cents (2.6¢) per kWh.

However, while it is obvious that cheap solar modules require cheap electricity for manufacturing, a grid-parity factory could even operate with German average industrial electricity prices of 8 euro cents (10.2¢), at least according to an additional calculation Centrotherm did upon our request (which seems odd at first glance, but then Wacker, the world's second biggest silicon manufacturer, has been expanding solely in Germany for both its silicon and solar ingot/wafer production so far). China's biggest advantage comes into play with labor costs, which require only a fifth of the spending required in North America. In consequence altogether, production costs in China are only €26.15 ($33.32) per kg of highly pure silicon. That corresponds to a cost of 19 euro cents (24.2¢) per W for a complete module, which is 2 euro cents (2.6¢) cheaper than the Canadian plant and 3 euro cents (3.8¢) cheaper than the US-based plant, where silicon can be produced at €28.75 ($36.63) and €29.91 ($50.85) per kg, respectively.

In Centrotherm's scenario, the ingot factory is also located in Canada for the first example (see table, p. 86). That's where the polysilicon pieces are melted together with a dopant in crystallization furnaces. In these directional solidification furnaces, 53 of them to be exact, the silicon crystallizes into multicrystalline ingots. These are then cut into bricks that have the same length and width of the subsequent wafers. The entire process produces a certain amount of waste – that means 1.1 tons of silicon is required to produce 1 ton of ingots. Or, the other way around: 2,500 tons of silicon can produce 2,273 tons of multicrystalline silicon ingots, which are then packed after grinding and shipped to Germany for further processing into modules, or in the cases for China and the US, remain in these countries.

In addition to the main raw material for the ingot factory – that being polysilicon from the neighboring site, the cost of which resurfaces in the final total – the production equipment represents a considerable share of production costs: €80.5 million ($102.6 million). Centrotherm assumes that the machines can be depreciated in seven years, but when taking into consideration that similar systems have already been operating for several decades in eastern Europe and Asia, continued use of such equipment remains profitable. Another significant cost is the crucibles in which the ingots are crystallized. They must be made of highly pure quartz to avoid contaminating the silicon

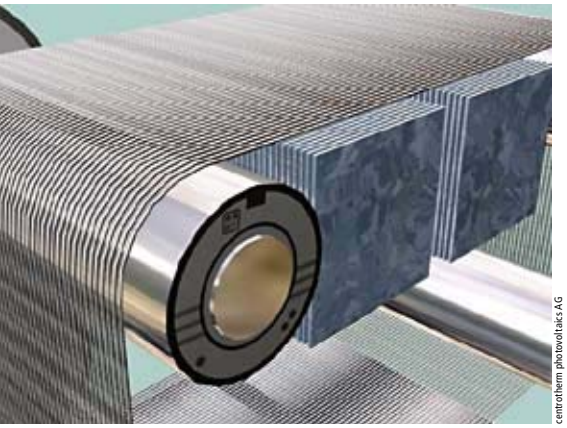
Wafer Production

		Canada / Germany			USA			China		
	Quantity	€ mn	€ mn/year	%	€ mn	€ mn/year	%	€ mn	€ mn/year	%
Equipment (Depreciation 5 years)										
Wire saws	55									
Slurry supply wafering	5									
Gluing	5									
Wafer cleaning & drying	6									
Quality control	1									
Auxiliary equipment	1									
Project management & process know-how										
Total		**76.8**	**15.4**	**25%**	**76.8**	**15.4**	**27%**	**76.8**	**15.4**	**31%**
Building & facility (Depreciation 15 years)										
Building	18,500 m²									
Facility & infrastructure										
Project management										
Total		**13.0**	**0.9**	**1%**	**13.0**	**0.9**	**2%**	**13.0**	**0.9**	**2%**
Production goods										
Slurry										
Wire										
Total			**16.8**	**27%**		**16.8**	**30%**		**16.8**	**34%**
Running costs										
Transportation & insurance of bricks	€0.005/W									
Electricity	0.20 kWh/W									
Utilities	€0.023/W									
Maintenance equipment	5% of invest									
Maintenance building	3% of invest									
Total			**18.9**	**31%**		**14.1**	**25%**		**14.1**	**29%**
Workforce										
Management	10									
Engineers / technicians	32									
Operators	156									
Total	**198**		**9.3**	**15%**		**9.3**	**16%**		**1.8**	**4%**
Total costs per year			**61.2**			**56.4**			**48.9**	
Production costs per W (€)			**0.18**			**0.16**			**0.14**	

data: Centrotherm; graphic: PHOTON International

and can only be used once. Companies are developing the first reusable crucibles – for instance, France's Apollon Solar SAS – but Centrotherm's grid-parity factory doesn't need them, it works just as well with single-use crucibles.

As in the case of silicon production, the price of electricity has a major influence in ingot production: that's because a great deal of energy is needed to produce the very high temperatures required for smelting silicon. In fact, the running costs of electricity make up almost one-fifth of the total cost of ingot production in Canada and the USA; in China it is almost a third. The largest cost factor in this part of integrated module production is personnel costs, at €16.6 million ($21.2 million), or 35 percent, in both Canada and the USA. This rather labor-intensive job can be accomplished for only €2.9 million ($3.7 million), or 9 percent of total ingot production costs, in China. While Centrotherm estimated personnel cost for a German-Canadian grid parity factory at around €50,000 ($63,700) per employee annually, the assumption for China was about a fifth of that.



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At the wafer production facility, silicon ingots are sawn into wafers with a wire saw. Including purification, the costs for this process can be as low as 14 euro cents (17.8¢) per W of module power. Again China heads up the pack.

The manufacturing cost for multicrystalline ingots come to a total of only €14.86 ($18.93) in China, which corresponds to a mere share of 10 euro cents (12.7¢) per W of total module power compared to €20.71 ($26.39) and 14 euro cents (17.8¢) in Canada. In conclusion, China has a clear cost advantage when it comes to the first stage – silicon and ingot crystallization – of a grid factory. »Besides electricity, the main reason is the low labor cost in China,« says Peter Fath. In its model, Centrotherm used the same technology for all locations, but if much higher automation is used for Western countries, this will somewhat offset the imbalance, he adds.

Wafer, cell and module manufacturing

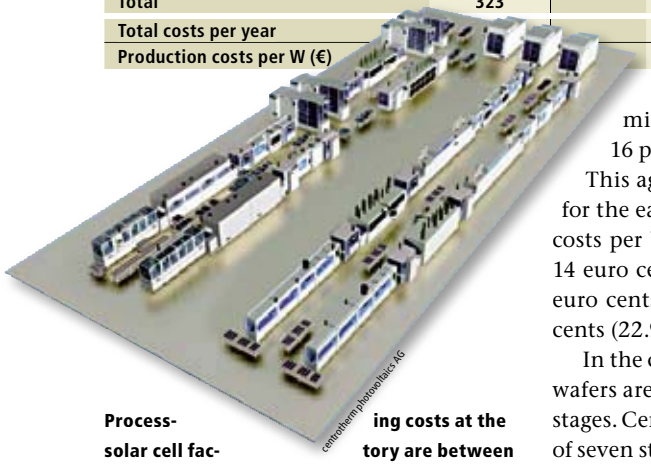
In the first scenario, wafer, cell and module manufacturing would take place in Germany, while the other two case studies remain in the US and China. At the wafer factory, the annual production of 2,273 tons of multicrystalline ingots is cut into 97.2 million wafers, which will eventually become 93.8 million solar cells (a little waste is unavoidable), and finally 1.6 million solar modules. Thus, 347 MW of total module power leave the factory every year.

In the case of the wafer sub-factory (see table, p. 88), the investment costs for equipment total €76.8 million ($97.9 million) – that makes up one-fourth of production costs in Germany, a little more in the US and represents the highest share in China (31 percent). The financial depreciation period is – as in the case of the cell and module factory – rather short at just five years. »Less conservative assumptions would result in even lower costs,« underscores Feilmeier. Another important cost factor are the saws and slurry (the costs for the ingots, the wafer pre-product made in-house, are again assigned to the preceding sub-factory). The running costs, which in addition to electricity also include transportation of the blocks cut from the ingots, as well as transportation insurance and maintenance, are lower in both the US and China, each at €14.1 million ($18 million), than in Germany with €18.9 million ($24.1 million). Again, China beats its competitors in regard to labor – €1.8 million ($2.3 million) per year, or 4 percent of the total, versus €9.3

Cell production

		Canada / Germany			USA			China		
	Quantity	€ mn	€ mn/year	%	€ mn	€ mn/year	%	€ mn	€ mn/year	%
Equipment (Depreciation 5 years)										
Wet bench for texturing	7									
$POCl_3$ diffusion	14									
Wet bench PSG removal	7									
SiN PECVD	14									
Metallization line	7									
Firing furnace	7									
Classification & sorting	7									
Inspection systems inline toolset	7									
Offline measurement toolset	1									
Auxiliary equipment	1									
Project management & process know-how										
Total		**110.0**	**22.0**	**23%**	**110.0**	**22.0**	**24%**	**110.0**	**22.0**	**28%**
Building & facility (Depreciation 15 years)										
Building	18,000 m²									
Facility & infrastructure										
Project management										
Total		**16.3**	**1.1**	**1%**	**16.3**	**1.1**	**1%**	**16.3**	**1.1**	**1%**
Production goods										
Paste frontside	0.047 g/W									
Paste rear contact	0.042 g/W									
Paste rear area	0.416 g/W									
Chemicals & gasses										
Total			**39.3**	**41%**		**39.3**	**43%**		**39.3**	**50%**
Running costs										
Electricity	0.34 kWh/W									
Utilities	€0.024/W									
Maintenance equipment	5% of invest									
Maintenance building	3% of invest									
Total			**17.5**	**18%**		**13.2**	**14%**		**13.2**	**17%**
Workforce										
Management	11									
Engineers / technicians	64									
Operators	248									
Total	**323**		**16.2**	**17%**		**16.2**	**18%**		**3.7**	**5%**
Total costs per year			**96.1**			**91.8**			**79.3**	
Production costs per W (€)			**0.28**			**0.26**			**0.23**	

data: Centrotherm; graphic: PHOTON International



Processing costs at the solar cell factory are between 23 euro cents (29.9¢) per W in China and 28 euro cents (35.7¢) in Germany – the assumption being a cell efficiency of 15.8 percent. But Centrotherm predicts that efficiency will be 16.5 percent by the time the factory is actually opened – which would further decrease costs.

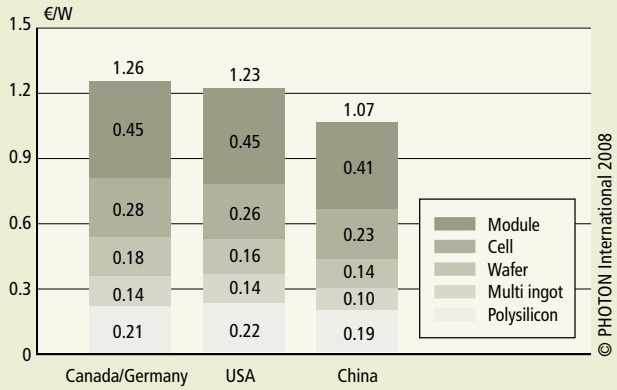
million ($11.9 million), or 15 and 16 percent in Germany and the US. This again results in a cost advantage for the eastern country: in China, wafer costs per W in module power add up to 14 euro cents (17.8¢) – in the US, it is 16 euro cents (20.4¢); in Germany, 18 euro cents (22.9¢).

In the cell factory (see table, p. 90), the wafers are put through a series of process stages. Centrotherm's cell factory consists of seven standard lines with a production capacity of 50 MW each. At an investment cost of €110 million ($140.2 million) for equipment, the depreciation of the machinery makes up between 23 percent of the processing costs in Germany and 28 percent in China. A particularly large chunk of the cost in cell manufacturing is the paste that is applied to the front and back of the wafers to form the contacts. This paste, together with the wet chemical material and the various process gasses, constitute 41 percent of production costs in the Germany-based cell factory, 43 percent in the US and 50 percent in China. The factory's 323 employees account for 17 percent of manufacturing costs in Germany, 18 percent in the US and only 5 percent in China. However, in today's cell factories many more people work in China at lines with the same capacity as in Western countries; the reason is a generally much lower degree of automation, although this is currently changing. It's also worth noting at this

juncture that the costs for the pre-products manufactured in-house (in this case wafers) isn't included in the calculations for this particular configuration, so these figures could not be applied to a stand-alone cell factory.

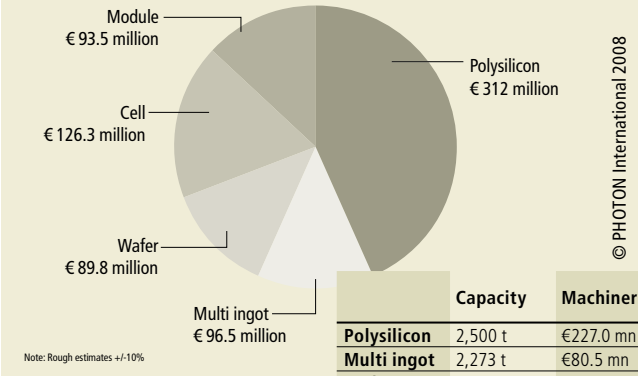
At Centrotherm's grid-parity module factory every module made consists of 60 cells and therefore has 217 W of power (see table, p. 92). The investment costs for this final step in the production chain are relatively low, just €73.5 million ($93.7 million) for the equipment. Without a doubt, the largest share of production costs is made up by consumables like glass, foil, frames and junction boxes. The costs are estimated at €112.4 million ($143.2 million) annually at any of the locations, whereby Centrotherm based its calculations on available list prices for »considerably smaller factories,« Feilmeier emphasizes. While running costs are the lowest in China, the difference in Germany and the US is very small. Again, with regard to labor, costs in China outshine Germany and the US – €2.7 million ($3.4 million) in expenses, or 2 percent of total module production costs, is much less than the €14.6 million ($18.6 million) or 9 percent needed in the two Western countries. As the costs for all other items

Production cost



An integrated PV factory of this kind, would allow module production for €1.07 ($1.36) per W in China and €1.26 ($1.61) in Canada/Germany. But even the most expensive of the three case studies would allow electricity generation below residential grid prices in sunny locations today.

Investment summary



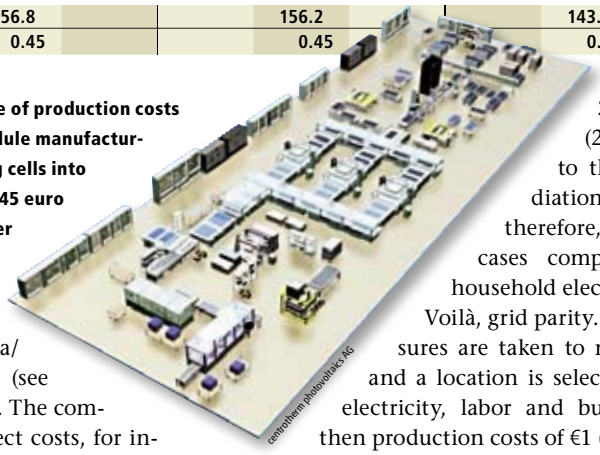
	Capacity	Machinery	Buildings & infrastructure
Polysilicon	2,500 t	€227.0 mn	€85.0 mn
Multi ingot	2,273 t	€80.5 mn	€16.0 mn
Wafer	374 MW	€76.8 mn	€13.0 mn
Cell	361 MW	€110.0 mn	€16.3 mn
Module	347 MW	€73.5 mn	€20.0 mn

One solar factory please!: That'll be €718.1 million ($915 million) plus taxes – perhaps it will be a little less than the prices Centrotherm used for its calculations on which this article is based, as these reflect list prices prior to any negotiations.

Module production

		Canada / Germany			USA			China		
	Quantity	€ mn	€ mn/year	%	€ mn	€ mn/year	%	€ mn	€ mn/year	%
Equipment (Depreciation 5 years)										
Glass washing & 1st EVA	5									
Double stringer & layup units	10									
Interconnection & 2nd EVA & backsheet	5									
Lamination lines	20									
Back-end lines	4									
Module tester	4									
Packaging and sorting unit	1									
Auxiliary equipment	1									
Project management & process know-how										
Total		**73.5**	**14.7**	**9%**	**73.5**	**14.7**	**9%**	**73.5**	**14.7**	**10%**
Building & facility (Depreciation 15 years)										
Building	20,000 m²									
Facility & infrastructure										
Project management										
Total		**20.0**	**1.3**	**1%**	**20.0**	**1.3**	**1%**	**20.0**	**1.3**	**1%**
Production goods										
Glass	1.6 m²/module									
EVA	3.2 m²/module									
Backsheet	1.6 m²/module									
Frame	5.2 m/module									
Junction box	1 pcs/module									
Total			**112.4**	**72%**		**112.4**	**72%**		**112.4**	**78%**
Running costs										
Electricity	0.05 kWh/W									
Utilities	€0.025/W									
Maintenance equipment	5% of invest									
Maintenance building	3% of invest									
Total			**13.8**	**9%**		**13.2**	**8%**		**12.5**	**9%**
Workforce										
Management		10								
Engineers / technicians		64								
Operators		231								
Total		**305**	**14.6**	**9%**		**14.6**	**9%**		**2.7**	**2%**
Total costs per year			**156.8**			**156.2**			**143.6**	
Production costs per W (€)			**0.45**			**0.45**			**0.41**	

data: Centrotherm; graphic: PHOTON International



The lion's share of production costs stem from module manufacturing: Processing cells into modules costs 45 euro cents (57.3¢) per W in the US/ Germany.

are basically the same, this leads to a total pure module production cost of 41 euro cents (52.2¢) in China versus 45 euro cents (57.3¢) in the US and Germany.

So it seems that China is the most attractive location for producing grid parity modules for each step of the value chain. However, there's a few things investors always take into consideration when analyzing potential locations for new factories. Stable investment conditions are needed, such as taxation or legal security. Not only cheap but also stable electricity supply is required, especially in regard to poly and ingot production. Moreover, enough highly qualified engineers are needed, in particular for cell production to make sure continued cost reduction can be achieved to remain competitive. »And with regard to module production, in the long run, it will be essential that Asia is able to create its own markets – to be close to customers and create excitement about the technology they are producing,« emphasizes Peter Fath.

C-Si modules for €1.07 ($1.36) per W

All in all, the production costs of Centrotherm's grid-parity factory range from €1.07 ($1.36) per W in China, €1.23 ($1.57) per W in the US to around €1.26 ($1.61) per W in Canada/ Germany (see graph, p. 91). The company's indirect costs, for instance for purchases, distribution and finances, are not included in the pure manufacturing costs. One can make a rough estimate for a factory of this size of about 10 percent on top of the production costs, which increases the total cost to between €1.17 and €1.37 ($1.49 and $1.75) per W. With a return on sales of 25 percent, that results in between €1.46 and €1.71 ($1.86 and $2.18) per W. With multicrystalline solar modules at this level, a system could be installed roughly between €2,250 and €2,500 ($3,200 and $3,200) per kW in Germany, for example. And at that price, solar electricity in Germany could be generated between 27 and 30 euro cents (34.4¢ and 38.2¢) per kWh. In sunnier countries like Italy, Greece or Spain, the solar electricity production costs would be just around 20 euro cents (25.5¢) thanks to the high irradiation levels – and therefore, in many cases competitive with household electricity prices. Voilà, grid parity. If a few measures are taken to make savings and a location is selected that cuts electricity, labor and building costs, then production costs of €1 ($1.27) per W are feasible, says Feilmeier. Although that wouldn't be a new record: thin-film manufacturer First Solar Inc. is already producing modules at $1.08 per W. Even vendors of turnkey production facilities for thin-film modules advertise production costs of €1 ($1.27) per W – that would make it possible to buy a PV system for around €2,000 ($2,550) in Germany – that means even grid parity in the world's largest market despite its rather poor irradiation.

And the subsidy programs? »Even after this integrated factory is completed, it will only account for a small portion of the production volume of the existing production facilities worldwide,« says Centrotherm. And, in any case, it takes three years to build this kind of factory.

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