

Comparative Assessment of Technologies: Crystalline PV vs. Thin Film Solar

Overview

This comparative assessment of the two technologies: crystalline PV and thin film solar is neutral with respect to technologies, companies, lenders, institutions and societal interests. Presently, all stakeholders in this sector are on a learning curve. While carrying out this comparative assessment exercise, many organizations, individuals, scientists, government officers, promoters, manufacturers and financiers have been contacted. Their views along with supporting documents provided by them, while subject to confidentiality, have been very helpful in enriching the study. Therefore, the names of individuals have not been included. Only references already available in the public domain have been incorporated for the sake of transparency and independent evaluation. The objective of this study is to help all the stakeholders, so as to result in the healthy growth of the solar power sector in India.

This comparative assessment looks at the two technologies from four different perspectives: the perspectives of equity investors, the perspectives of debt investors (lenders), the perspectives of various institutional entities including central and state govt bodies, and also the societal perspective towards environmental externalities. Hence the two technologies are judged from these differing perspectives in arriving at a balanced conclusion with respect to the technologies.

Comparison of Investment Costs: The Equity Investors perspective

This section of the study has been carried out for comparing the investment costs of crystalline and thin film PV technologies. This comparison is important from the equity investors' perspective. It also has relevance in the debt investors' perspective. A sample case of 1 MW each power project has been considered.

A cost break-up has been prepared considering the present module cost as of 11th April 2012 (www.pvinsights.com) and latest forex conversion rate of RBI. The project cost break-up accordingly for both the technologies is given below:

Table 4.1 Comparative Project cost of crystalline & thin film SPV power project (1 MW)		
	Crystalline	Thin film
Cost Component	Rs in lakhs	
Land (3.2 Lakh/ acre) ⁽¹⁾	14.4	28.8
PV module ⁽²⁾	447	383
Civil and General Work ⁽³⁾	90	135

Mounting Structures ⁽⁴⁾	100	150
Power conditioning unit ⁽⁵⁾	98	98
Preliminary and pre-operative expenses including IDC and contingency ⁽⁶⁾	80	80
Additional cost towards degradation & auxiliary (ref CERC guidelines) ^(7,8,9,10)	66	66
Evacuation Cost up to Inter-connection Point (Cables and Transformers) ⁽¹¹⁾	100	120
Total capital cost	995.8	1060.9
Please refer the following subsections (1-11) for the basis of cost estimation		

(1) Land required for power generation

Land requirement for crystalline technology is assumed to be 4.5 acres/MW and for thin film technology is 9.0 acres/MW, considering the difference in their efficiencies. Due to low efficiency, the thin film technology needs almost double the area required by crystalline technology for the same capacity of power plant. A comparative statement given below is self-explanatory. This will have a detrimental effect on the economics of projects in the areas where land is a scarce commodity. Recent trend has shown that even waste land costs have skyrocketed in the case of wind power projects and in some cases in solar power projects. In near future, with the rush of the green investors, there will be severe shortage of land and this factor deserves serious attention.

Type of module	Area requirement (per kW _p)
Single crystal silicon	~ 7m ²
Polycrystalline silicon	~ 8m ²
Amorphous silicon	~15m ²
Cadmium telluride	~11m ²
Copper indium diselenide	~10m ²

(2) Cost of Modules

Cost of Crystalline module \$ 0.87/W_p (Rs. 44.74)

Cost of Thin Film module \$ 0.745 /W_p (Rs.38.31)

Source: (www.pvinsights.com), USD 1 = Rs. 51.42 (*Reserve Bank of India*)

(3) Civil and General Work

In case of thin film, additional provision of 50% in civil and general works compared to

crystalline has been considered, due to the larger area of works.

(4) Mounting Structures

For mounting structure and cabling an additional cost of 50% and 20% respectively compared to crystalline has been considered, due to larger area.

(5) Power Conditioning Unit

This cost is assumed equal for both technologies

(6) Pre-Operative Expenses

This cost is assumed equal for both technologies

(7) Module degradation

As stated in the technical chapters, module degradation on exposure to sunlight is the inherent property of solar modules of all types whether crystalline or thin film. Thin films are by nature such that there is initial drop in power output due to light soaking up to 1000 hours of exposure to radiation and thereafter it stabilizes for long term. No such effect is observed in crystalline solar cells. Therefore in the case of thin film one must ask about the “stabilised output” rather than “initial output”. Although, different manufacturers claim their own performance indicators, actual measurements at the sites after 10-20 years of installation is the only way to get the true picture. Some of the observations of WISE research team in this regard are as follows:

- NREL study of various kinds of 10 years old SPV modules installed at Solar Energy Centre, New Delhi has shown that the degradation in thin film modules is 2% or more per year. Moisture seepage through edges has been observed. Many of the thin film modules had “bar graph corrosion”.
- Mono-crystalline solar modules used for off-grid applications at the Solar Energy Centre have shown amazing results. These modules are referred to as champion modules wherein only 10% degradation has been observed in more than 20 years old mono-crystalline solar modules. (A Sinha et al. “Performance of champion’s module of PV lighting systems in India”, Oral presentation).
- A close study of percentage-degradation of various kinds of modules has shown maximum degradation in thin film modules and the losses in power were observed primarily due to material degradation. While, mono and multi crystalline modules have shown power reduction from the rated output of 1-10%, amorphous silicon recorded 16-30%. The same value for CdTe module was 19% and that for CIS module 36%. None of the modules had any visual defects (as seen with naked eyes) and appeared normal. However, electroluminescence and thermal imaging have shown the degradation spots very clearly. Amorphous silicon modules have shown electrochemical degradation of SnO₂ layers. (O S Sastry et al. “Degradation in performance ratio and yield of exposed modules under arid

conditions”, 26th European photovoltaic solar energy conference and exhibition).



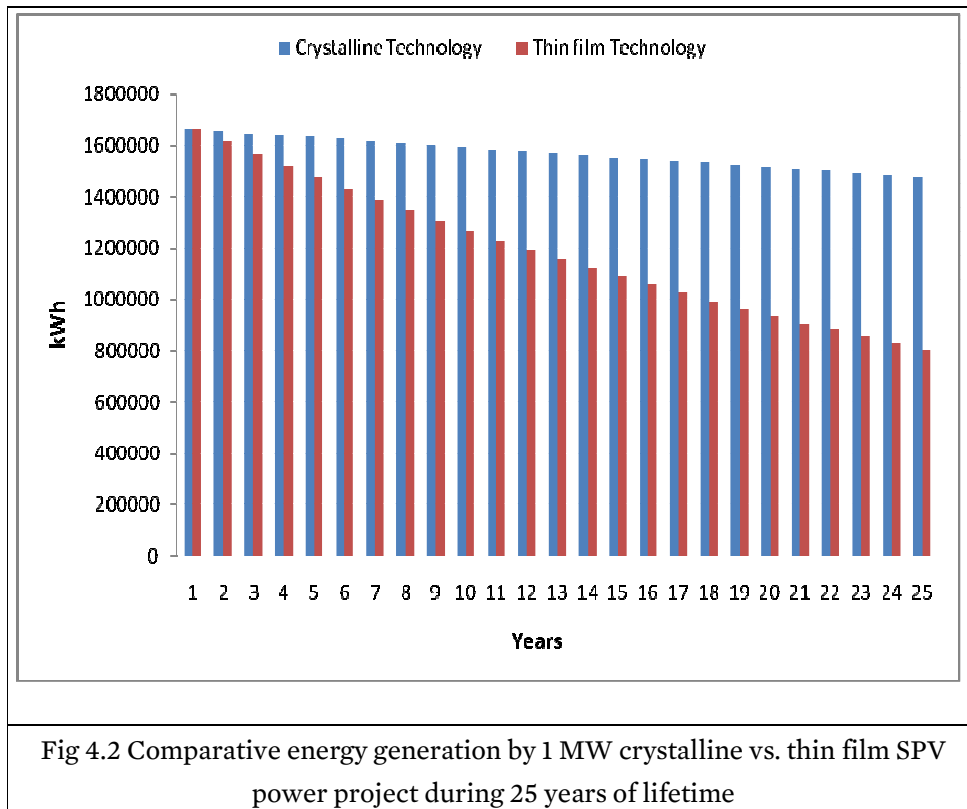
Figure 4.1 CIS modules under field condition

- A performance ratio comparison has shown that thin film modules have better performance ratio in general. Further, amorphous silicon performance was 16% higher in the months of April and May and 12% less during December as compared to multi-crystalline modules.
- Even IEC certified mono-crystalline modules have degradation in certain cases. However, these were mainly due to degradation of encapsulant materials rather than the basic cell degradation. Therefore, certification of only sample modules is not sufficient and occasional testing of sample field modules is also recommended for larger power projects.
- Out of a series of different modules studied at the ambient temperature of 40 °C, a failure of 70% of thin film modules and 25% of crystalline silicon modules were observed. The extent of degradation has not been reported. Govindasamy Tamizh Mani, TÜV Rheinland PTL & Arizona State University, Tempe, Arizona, USA, which appeared in the eighth print edition of Photovoltaics International journal, on “Testing the reliability and safety of photovoltaic modules: failure rates and temperature effects”,
- A study by European Commission, DG JRC, Institute for Energy, Ispra, Italy has shown that mono-crystalline silicon modules are still working perfectly with very low degradation rate of maximum 0.8% per year. This is one of the best performances for mono-crystalline modules till date. According to them they have found no statistically significant difference in poly and single crystalline modules.
- In 1990, the Schatz Energy Research Center (SERC) installed a nominal 9.2 kWp photovoltaic (PV) array at Humboldt State University in Trinidad. A degradation study has shown that mono-crystalline SPV modules have shown only 4%

degradation in 11 years even under the corrosive environment of seashore.

All the above studies indicate that thin film module degradation is much faster than crystalline modules. Mono-crystalline and probably poly-crystalline silicon modules have shown very good stability with time.

A sensitivity analysis regarding generation of energy using a sample case of 1 MW for crystalline and thin film each has been carried out CUF 19% for 1st year as per CERC norm and degradation factors of 0.5% and 3.0% for crystalline and thin film technologies respectively. A comparative picture is shown in **figure 4.2**, which indicates that if 1 MW crystalline PV project is replaced by same capacity thin film project, there will be loss of 9,634,282 units over a period of 25 years.



(8) Life of the modules

While all the modules manufacturers claim 25 years of life whether it is crystalline or thin film, the main question is what would be the balance capacity after 25 years considering the degradation rate. A good quality and state-of-art hermetically sealed crystalline module has been reported to be working with little degradation even after 25 years which is a bonus for the power plant owner. The experience at the Solar Energy Centre, New Delhi shows upto 40% degradation in 10 years in the case of thin films. Under such situation, the life of thin film modules is questionable and poses technology risk to the project.

(9) Breakage and replacement

The thin film modules have a double glass structure. Thin film of absorber materials are deposited either on “substrate” or on “superstrate” depending upon the side exposed to sun. Under both the situations, the thin film is sandwiched between two glass sheets.

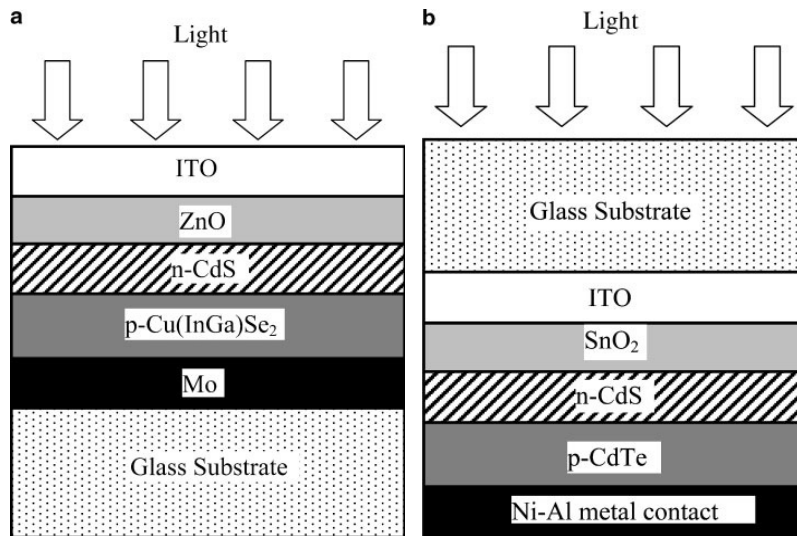


Figure 4.3 Typical Thin Film Solar Cell structures for single-junction: (a) substrate Cu(InGa)Se₂; (b) superstrate CdTe;

It is well known that due to inherent losses, the actual cell temperature is higher than the ambient temperature and many times it goes up to 25-30 deg C above the ambient temperature. This causes thermal stress not only to solar cells but to encapsulant also e.g. EVA material and glass.

In the case of thin film solar cells, the thin layer of absorber material is fixed between two glass layers of around 3mm thickness each. In the event of rise in temperature, the two rigid layers of glass face severe stress due to temperature difference between top and bottom layers. This causes micro-cracks in the top glass layer. Such a case is more prominent when the thin film modules are washed with a spray of water at around 6:00 p.m. while the whole system is yet to be stabilized to normal temperature. It has been observed that modules are generally cleaned in the evenings due to availability of labour. Eventually, the micro-cracks keep increasing resulting into complete deterioration of the solar module due to ingress of moisture.

Therefore, the thin film power plants have to compulsorily replace 1% of modules per year that leads to additional cost. However, this factor is not incorporated while calculating the

financials of thin film power projects.



Figure 4.4 Micro-cracks resulting into major cracks in thin film modules

However, in case of crystalline PV modules, no such replacement of modules are reported anywhere. The crystalline PV cells are fixed between encapsulant (usually ethylene vinyl acetate; EVA) and back sheet (polyvinyl fluoride films). The top layer is toughened glass above the EVA layer. In the case of heating of cells, the top layer has higher temperature compared to bottom layer due to natural cooling on the lower side and cell heating at top layer. The thermal stress faced between the layers, as radiation increases, is managed due to flexible back sheet that avoids any crack on the top glass layer.

(10) Warranty Periods

For, crystalline modules, confidence among manufacturers has increased over time as shown by the following table.

Table 4.2 Increase in warranty of SPV modules over a period of years	
Period	Warranty
Before 1987	5 years
1987 to 1993	10 years
1993 to 1999	20 years
Since 1999	25 years

The crystalline module manufacturers are now offering warranty for 10% degradation in output in 12 years and 20% in 25 years which indicates higher confidence level.

Interestingly, thin film module manufacturers are also now providing warrantee for 10% degradation in output in 10 years and 20% in 25 years. The reason that the warranties have been increased is that the manufactures had to compete with crystalline silicon modules. However, they provide the basis of IEC 61646 certification which carries out accelerated

degradation test under simulated situation. There are doubts whether thin film will actually show this trend in actual field conditions.

Many technical experts and financial experts have suggested that additional bank guarantee needs to be taken from the manufacturer of thin film modules to cover the field condition risks. This becomes more important when manufacturers use the term “limited warranty”. Further, the asterisk of “conditions apply” indicates that “manufacturer reserves the right to modify the specification and warranties without notice”. Moreover, the limited warranty certificates made public by the company especially for thin film solar modules are both vague and ambiguous. While limited warranty may be a comfortable position for the crystalline modules reported with minimum degradation, the same for thin film puts it into an uncomfortable position due to reported faster degradation of thin films.

As stated earlier, the thin film modules suffer from initial decay. Some manufacturers do not mention whether the rated values are post initial decay or the initial one and what is the initial decay percentage. (Recently, a news report in the 5 March 2012 issue of “The Hindu” has reported that First Solar has admitted that one of the reasons for its 4th quarter operating loss of \$485.3 million was higher warranty payments.) Therefore, one needs to be careful while reading the warranty clauses and module rating under stabilised condition.

Despite the technological differences outlined in (7), (8), (9) and (10), we have assumed the same cost component for both technologies, based on current CERC guidelines which do not differentiate between the two technologies. However, these technological differences result in lower net generation from thin film technologies as compared to crystalline PV technologies. This difference shows up in the financial performance comparison of the two technologies, which is shown in section on “Comparison of financial returns” below.

(11) Evacuation Cost up to Interconnection Point

Due to the larger spread area of thin film arrays, the cabling cost consisting of both material costs of cable and labour cost of installation will be higher for thin film PV as compared to crystalline PV as shown in table 4.1.

Comparison of financial returns: Equity Investors perspective

Table 4.3 Financial viability analysis output		
Parameter	Crystalline	Thin film
Project IRR (Pre Tax)	17.30%	13.43%
Project IRR (Post Tax)	15.59%	12.18%
Average Debt Service Coverage Ratio (DSCR)	1.67	1.37
Equity IRR	19.58%	12.80%

As regards financial viability analysis, major parameters have been considered as per latest CERC RE tariff order dated 27th March 2012. By keeping the above project cost, the analysis has been carried out with only variation of de-rating factor. In the case of thin film, the de-rating factor of 2% as reported in the field is considered initially. In addition, 1% de-rating in power generation has been considered to compensate the 1% modules replacement in thin film power projects. Thus, total 3% of de-rating in the case of thin film is considered for the practical purpose. The de-rating of 0.5% is considered for crystalline SPV modules based on practically observed degradation as explained in the preceding chapters. Incorporation of these parameters results in the above output in calculation of financial viability.

Temperature coefficients of the two technologies

Power output from any kind of solar cell decreases with increase in temperature. It is reported that temperature coefficient of thin film modules is lower (-0.3%/°C) as compared to crystalline (-0.4%/°C). Hence, it is claimed that they are more suitable for hot climate and hence will give more generation for the equivalent capacities of power projects. However, the most potential areas of Gujarat and Rajasthan also have winter which is favourable for creating less NOCT. Therefore, low output in summer will be compensated by higher output in winter which can be seen in the **figure 4.5** below.

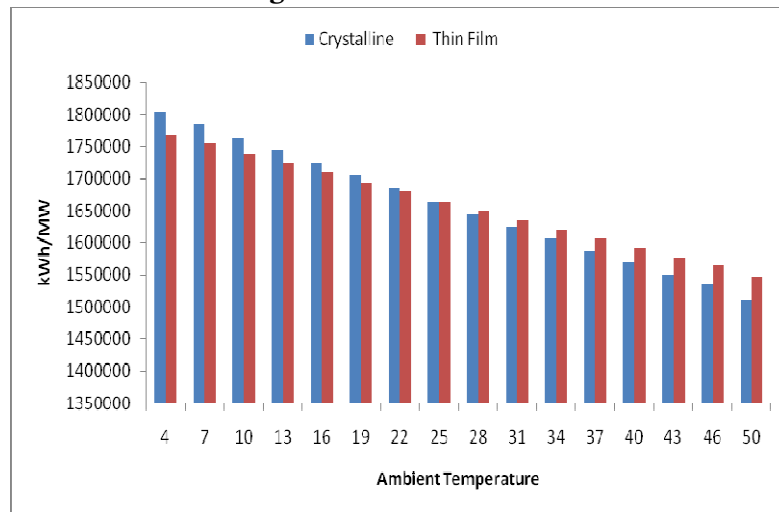


Fig. 4.5 Energy generation against ambient temperature for 1 MW crystalline and thin film PV power project

Naturally, there will be a minor effect of this difference of temperature coefficient. The higher output in hot climate by thin film based power project is yet to be ascertained in actual field conditions. (Recently, a news item in “The Hindu” dated 5 March 2012 reports “First Solar admits to unsuitability of its products to hot climate”. According to them, “the company’s warranty rates for hot climate are slightly higher than for temperate climates”. The company is reported to keep a provision of 1% additional amount against warranty in hotter climates). Therefore, the claimed advantage of lower temperature coefficient is not valid.

Acceptance by Financial Institutions: Lenders perspective

The Financial Institutions in India are yet to show confidence in thin film technology. Majority of proposed thin film power projects in India are backed by huge soft international loans for long term (16.5 years) provided by US Exim Bank, which is the main reason for promotion of thin film in the country. This constitutes a form of technology risk coverage or hidden international subsidy to the thin film technology. Thin film technology is presently less preferred by Indian Financial Institutions. As regards power projects based on crystalline modules, many of the projects are already installed in India and have been financed by banks. As Table 4.2 indicates, both Internal Rate of Return (IRR) and Debt Service Coverage Ratio (DSCR) are higher for crystalline PV. This performance, coupled with lower technology risk and longer life, makes it more acceptable from Lenders perspective. While Lenders have a preference for higher returns, it is coupled with a preference for lower risks in the projects that they finance.

Policy and regulatory aspects: The Institutional perspective

Government of India and different state governments have been very proactive in promoting solar sector in line with the enabling instruments provided by the Electricity Act 2003, NAPCC and JNNSM. Similarly, regulatory bodies i.e. CERC and SERCs have also supported the solar sector through FiTs and other regulatory provisions. The pragmatic approach on policy front by the respective governments and regulatory front by the respective regulatory bodies has resulted in installation of around 800 MW of solar power projects in the country today, which is higher than envisaged 5 years ago.

The PV sector got a push initially in crystalline PV technology. Recently, thin films have also attracted attention under JNNSM scheme due to allowance of import for thin film while crystalline technology has domestic component and are not allowed to import under the scheme. As a result, large quantities of thin film modules with poor efficiency at the pretext of so called low cost are being dumped in India from all over the world. More than 60% of the approved power projects will be using thin film technology. Ultimately the nation will be the loser.

As stated above, crystalline and thin film technologies are primarily different from each other considering the technical parameters and application methodologies. They need different treatments. However, the policy and regulation in the country does not differentiate between the two technologies. It is again emphasized based on the analysis in preceding sections that the nation will be loser by 9,634,282 units/MW in 25 years life of the project if only thin film PV power project are installed in the country. That translates into 4,817 MUs loss in 25 years for the present scenario in the country with 1000 MW installed capacity having 50% share of thin film. Things will further worsen with yearly capacity addition of solar power projects dominated by thin film technology. This will pose a setback to the en-

ergy policy makers who have projected energy security by achieving solar power of 20,000 MW by 2022 assuming 19% CUF.

Both the technologies need entirely different treatment on policy and regulatory front mainly because the government and regulatory bodies are responsible to the society for;

- Efficient utilization of land resource
- Assuring long-term power availability
- Quality assurance and reliability of power
- Avoiding large scale dumping of lower efficiency technologies
- Dissemination of correct information to investors
- Health hazard of the technologies
- Declaration of PV as e-waste and efficient management of waste from power projects after useful life

Use of thin film technology is exempted from domestic content guidelines applicable to crystalline technology. As a result, majority of the projects under JNNSM are expected to prefer thin film technology considering their lower cost and without taking care of other implications. The decisions are purely based on financial considerations and no care is taken for efficient land utilization, environmental concerns and long-term profitability. In fact, many of the promoters are not aware of the technicalities and their implication on their future revenues resulting in large-scale dumping of low quality thin film modules in India which will have a wider ramification in the coming years. The short-term view of investing and exiting as soon as the investment is recovered, is detrimental to the national interest.

It is the government's responsibility to maintain a level playing field in the competing PV technologies. At the same time, it is the responsibility of regulators to vet the technical and financial parameters for thin film and crystalline technologies and to accord differential regulatory treatment, if necessary. Presently, the policies and regulations are both completely silent about the type of PV cells and their future impact on state and national power scenario.

Environmental externalities: The societal perspective

CdTe raises environmental concerns because Cadmium is highly toxic. The maximum permissible value for workers (according to German law) is 15 micro gram per litre. No such law exists in India. Once absorbed, Cd is efficiently retained in the human body, in which it accumulates throughout life. Cd is primarily toxic to the kidney, especially to the proximal tubular cells, the main site of accumulation. Cd can also cause bone demineralization, either through direct bone damage or indirectly as a result of renal dysfunction. (A. Bernard, "Cadmium & its adverse effects on human health", Indian J Med Res 128, October 2008, pp 557-564).

Under Indian conditions, it is observed that minimum 1% of modules need to be replaced every year due to breakage of modules caused by thermal stress and micro cracks. These rejected modules can pose severe environmental hazards.

The main manufacturer of CdTe “First Solar” has a policy of EPR (Extended Producer Responsibility) wherein anyone in possession of First Solar module can request collection and recycling at any time at no additional cost. However, responsibility of dismantling and packaging of the modules lies with the owner. This is a dicey situation. First, it is not known whether there is a guarantee that these modules will be taken back by the company. Second, the rejected modules coming out every year from the power plant and their environmental impact if kept in the open as prevalent in India with consequent leakage of Cadmium to the environment through rain water has not been duly considered. Third, the additional cost of dismantling and packing after their useful life is not currently factored in, nor its effect on the economics of the project.

Further, solar modules are officially regarded as e-waste and are going to be considered by the European Union to be regulated under WEEE. This will impose further restrictions.

Scrap generation

Solar power projects based on crystalline modules will generate scrap of 100 tonnes per MW, after their useful life. Since the mounting structures for thin film are almost double that of crystalline PV, the scrap generation will also be double in the case of thin film. Moreover, thin films are expected to have shorter life and hence earlier scrap generation. None of these life-cycle related costs are internalized into the current cost calculus.

Considering the projected target as given in section on “National Status” in chapter-2, the comparative projected scrap generation by the two technologies after expiry of the project i.e. 25 years are presented in **figure 4.6** below.

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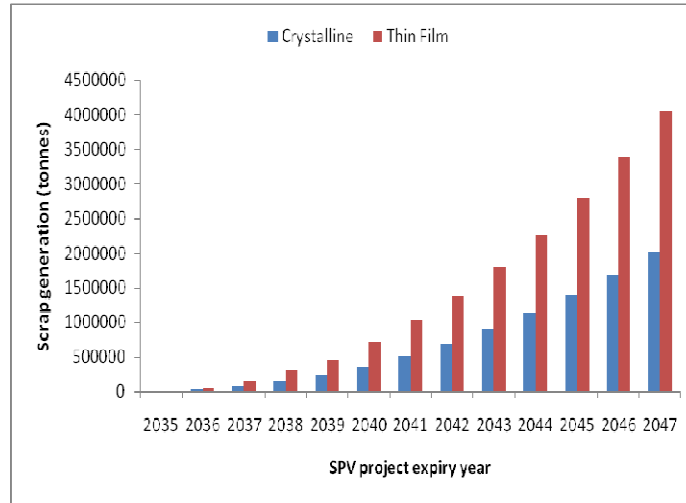


Fig. 4.6 Comparative projected scrap generation by the two technologies after expiry of the project i.e. 25 years

Thin film business risk: Sample case

An interesting sample case of the business leader in thin film solar cells is of First Solar, USA. The annual report 2011 of the company has declared following risk factors relevant to the present study (Reproduce as it is) which are self explanatory.

- Environmental obligations and liabilities could have a substantial negative impact on our financial condition, cash flows, and profitability.
- Thin-film technology has a short history, and our thin-film technology and solar modules and systems may perform below expectations; problems with product quality or performance may cause us to incur significant and/or unexpected warranty and related expenses, damage our market reputation, and prevent us from maintaining or increasing our market share.
- If our estimates regarding the future cost of collecting and recycling our solar modules are incorrect, we could be required to accrue additional expenses at and from the time we realize our estimates are incorrect and face a significant unplanned cash burden.

Conclusions

- Thin films do not have the cost advantage in terms of initial investment costs over the crystalline solar cells – important from both equity and debt perspectives.
- The return on equity is higher for crystalline PV as compared to thin film technology - important from both equity and debt perspectives.
- The Debt Service Coverage Ratio (DSCR) is higher for crystalline PV as compared to thin film technology. Projects based on crystalline technology will have lower technology risk as compared to thin film technology. Both these are important from

debt perspectives.

- Evaluated over the entire project lifetime of 25 years, i.e. in longer term, crystalline technology scores significantly higher than thin film technology. Moreover, projects based on crystalline technologies can probably continue generating beyond 25 years, making them more attractive.
- Apart from other factors, crystalline technologies require less land per MW compared to thin film technologies. This is important from policy perspective of both central and state governments.
- At the project / technology level, thin film technology has higher environmental externalities due to presence of heavy metals as compared to crystalline PV technologies. This is important from the societal perspective.

Based on the above considerations, it is concluded that crystalline PV technologies perform significantly better than thin film technologies in our assessment. This conclusion derives from the due diligence approach adopted in this study.
