KICP Strategic Studies

Saudi Arabia Solar Energy Study

manufacturing and technology assessment

2009

CONFIDENTIAL

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Executive Summary

Solar energy can provide a very attractive way of tackling the energy-related and economic challenges the Kingdom of Saudi Arabia is facing.

Motivated by the need to diversify the Kingdom's economy, as well as by the various perspectives being offered by the establishment of the King Abdullah University of Science and Technology (KAUST), this study aims to provide a comprehensive understanding of the opportunities solar energy offers to the Kingdom, especially regarding solar manufacturing and research activities.

This study may lay the foundation for making the Kingdom a leading location for solar manufacturing as well as a leading solar research location globally. The study is the result of a six-month collaboration by a project team formed by the following parties:

- National Industrial Clusters Development Program (NICDP), Consumer Goods Cluster
    - Focus on solar manufacturing activities
- King Abdullah University of Science and Technology (KAUST), Economic Development
    - Focus on solar research activities
- Apricum – The Cleantech Advisory (a Germany-based consultancy exclusively dedicated to the Cleantech industry)
    - Advice and project management

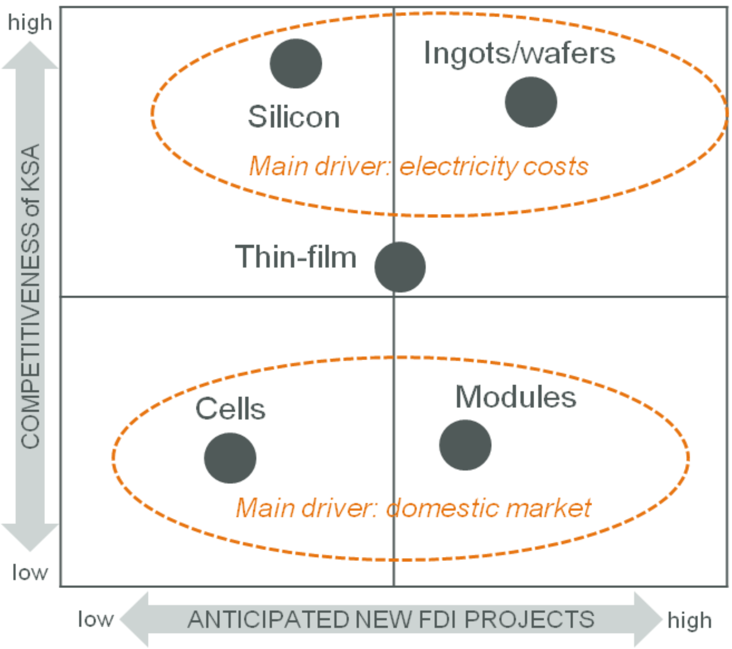
A key result of the study shows that the Kingdom offers very attractive conditions for the attraction of solar manufacturing activities from abroad. Key assets include the very low energy cost being a top argument in attracting photovoltaics companies that are active in energy-intensive manufacturing steps, such as silicon and ingot/wafer production. In addition, solar thermal companies will find very attractive business conditions in the Kingdom, but require a domestic market to set up operations. Thus, the establishment of a domestic solar market is essential. Considering the very competitive global FDI (Foreign Direct Investment) environment to attract solar investment, only those countries and regions with comprehensive and targeted investment and policy strategies will benefit from the profitable growth and job creation prospects in solar. CO_2 emissions reduction, as well as utilization of CO_2 reduction certificates, is important for the attraction of solar manufacturers to the Kingdom. Their involvement would work towards decreasing the dependency on oil for the local economy in the Kingdom and help develop a viable, as well as environmentally responsible, solar-based economy in the Kingdom of Saudi Arabia.

Saudi Arabia is best positioned to attract silicon and ingot/wafer projects. At this upstream part of the value chain, electricity costs and equipment depreciation are the main cost drivers. At the same time, the still virtually non-existent regional market for PV final products, which is of essential importance for projects further downstream, is not a decisive factor for silicon and ingot/wafer operations. The ingot/wafer step of the PV value chain is potentially a strategic one for Saudi Arabia. On the one hand, it can benefit from, and draw on, an expected domestic silicon production. At the same time, it is the link to the downstream development of PV manufacturing in the Kingdom. While a domestic/regional market in the Kingdom and other Gulf countries will be developed, ideally, within the next 3-5 years, solar wafers are products that can easily be shipped and exported overseas in large quantities in anticipation of the foreseeable emergence of a domestic demand.

Cell manufacturing, as well as thin-film operations, requires a relatively sophisticated site infrastructure, especially with regard to electricity and other utilities as well as specialty gases. Nonetheless, while the Kingdom’s current global competitive positioning is better for silicon and ingot/wafer production, there are several factors that potentially favor the country as a location for thin-film manufacturing. Aside from inexpensive electricity, which can become a considerable operating expense in absolute terms for large thin-film facilities, other favorable factors include spacious and flexible production plots and, particularly, local (in the case of Yanbu, even on-site) glass production. This last point is a potential ‘big winner’ because glass sourcing is a key issue in the thin-film supply chain.

CSP (Concentrated Solar Power) can provide many opportunities for the existing local industry base in Saudi Arabia, as glass, aluminum, steel, and cement are some of the main inputs for CSP installations. The number of components required for a typical 50 MW parabolic trough plant (for example: in Puertollano, Spain) demonstrates nicely why CSP is a local business. The solar field requires 352 collectors, each measuring approximately 150 meters in length. Each collector contains 12 modules that are 12 meters in length, comprising 28 mirrors and 3 absorber tubes. This totals 120,000 mirrors and 12,700 absorber tubes, equating to about 50 km of absorber tubing.

The figure below shows PV segment assessment based on location competitiveness and investment potential



PV segment assessment based on location competitiveness and investment potential

Saudi industrial sites can attest to having good – and for some segments even leading – performance across the board concerning cost factors. Performance with regard to environmental factors has been less favorable. The main areas, in which industrial sites in the Kingdom currently underperform, but which can be improved in the short-term, are:

- The timeline of land preparation for a potential investor and the administrative processes that are required are not transparent.
- Currently available electricity supplies are insufficient for most PV projects and the reliability of supplies is questionable.
- Availability and capacities of other utility supplies, such as water, wastewater, and solid waste management, proved to be somewhat unclear.
- There is a complete lack of general upfront provision information on the Internet.
- No rail access exists at any of the sites under evaluation.

Three priority arguments have been singled out as 'unique sales propositions' for the country in the context of the solar manufacturing investment attraction: financing/incentives, local engineering talent pool and scientific/technical support, electricity costs, and the Kingdom's track record of foreign direct investment (FDI) attraction to-date.

A potential scenario for the future development of the solar industry in the Kingdom could look as follows:

Short-term potential

In the short-term, defined here as two years, it is realistic to expect the recruitment of two to three PV manufacturing projects (silicon, ingots/wafers, possibly thin-film) to the country, involving $200-500 million capex each and >1,000 jobs total.

It is also feasible to attract one CSP production project (>50 MW), provided one or more solar power plants will be commissioned in the Kingdom.

Medium-term potential

Over the next three to five years, further downstream development of the PV value chain in the Kingdom can be achieved if the market is developed in parallel. This could mean at least one cell and one module manufacturing project.

In this timeframe, it is also realistic to expect the evolution of a true solar industry 'cluster' in the country, involving two to three leading R&D institutes, two to three industrial parks and several manufacturers and installers.

Several CSP pilot scale projects can be commissioned that cover different technologies that are applicable to Saudi Arabia such as: Trough, Fresnel, Tower and hybrids thereof, with outputs that vary from power generation, process steam, water desalination to Solar cooling as well.

Long-term potential

Five years and more from now, solar has the potential to become one of the main industrial pillars of Saudi Arabia with approximately 50,000 jobs, US$10 billion in sales and an export share of more than 50%. Thereby, the industry can act as a pioneer for the downstream industrial development of the country more generally.

As for the Research and Technology attraction side, the Kingdom can well attract research-driven solar companies based on the very attractive *research* environment being established at KAUST. An important enabler would be the provision of funding opportunities to innovative solar companies. Such funding opportunities can be seen in the creation of a solar VC fund and in matchmaking with Saudi financial investors.

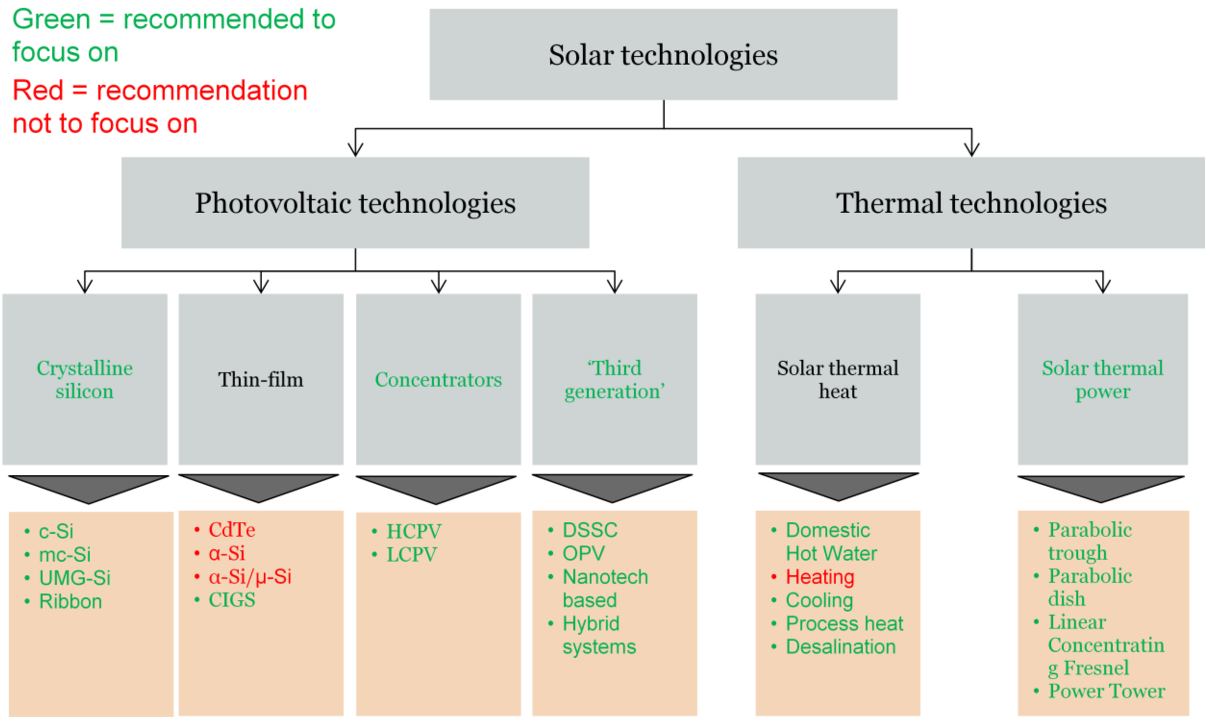
As another result of this study, the establishment of a center for testing, demonstration and certification of solar products is recommended, thereby paving the way for commercialization of solar technologies in the Kingdom.

The most attractive solar technologies and research fields for the Kingdom/for KAUST have been identified in a two-step approach covering both market potential and synergies to Saudi Arabia/KAUST.

In the selection process, five solar technologies prevailed:

- Crystalline silicon PV – The most mature PV technology with high cell efficiency still bearing significant potential for cost reduction.
- CIGS thin-film PV – The thin-film technology with the biggest potential for efficiency improvement and, with regard to building-integrated photovoltaics (BIPV), offers very attractive fields for future application.
- Concentrated PV (HCPV) – The PV technology with the highest efficiency today and in the future the highest potential for the lowest levelized cost of energy in areas with high sun irradiation, such as in the Kingdom.
- 'Third generation' PV – Covering an array of solar technologies that are being widely regarded as the 'most exciting' ones for the more distant future due to its potential for achieving very low production costs.
- Solar thermal heat and solar thermal power (CSP) – Due to their similar characteristics being lumped together, these solar technologies have a very high potential for domestic application in the Kingdom.

The following figure illustrates the results of the selection of solar technologies:



Selected solar technologies for R&D activities in Saudi Arabia / at KAUST

A national Saudi solar energy strategy needs to be developed to function as a framework for all solar-related activities in the Kingdom. Furthermore, it is recommended that a national solar energy authority be established as a steering body for solar-related activities, thereby leveraging and coordinating the work of the different entities in Saudi Arabia.

The opportunities for the Kingdom presented by solar are vast. The time is **now** to establish solar as a key industry and benefit from the enormous potential solar offers the Kingdom in terms of job creation and energy generation.

1. Preface

"Saudi Arabia Solar Energy Study: manufacturing and technology assessment" is the first study of what will be a series of techno-economic studies to be published by King Abdullah University of Science and Technology (KAUST). These studies are in fulfillment of a core mission of the university: translating scientific research into economic opportunity. It has been the result of collaboration between the Economic Development group at KAUST and the National Industrial Clusters Development Program (NICDP).

In order to establish appropriate mechanisms and strategies for the market introduction of solar technology in the Kingdom, credible information on demand and resources, technologies and applications is essential. The present study provides such information as a database for strategic development in the Kingdom with the goal of achieving a sustainable solar energy sector contributing to the Kingdom's economy in the long term.

This study began with a review of state-of-the-art solar energy technology available in 2009, and then attempted to identify those technologies with the greatest potential for manufacturing and use in the Kingdom, as well as for competitive export. In assessing the potential for solar manufacturing in the Kingdom, it has become clear that the Kingdom possesses significant advantages for the mass production of silicon crystalline-based photovoltaics (PV), thin-film, and solar thermal technologies. Those advantages are mainly due to the availability of raw materials and low energy costs. On the other hand, a number of factors negatively impact that potential, as highlighted by the study. They are what are called "environmental" factors: industrial land availability, legal frameworks, transparency and others which hamper not just the establishment of a solar manufacturing industry, but any industry.

To transform the potential into reality, however, requires a major effort on the part of leaders and decision makers at all levels, to overcome those negative environmental factors. This includes the lack of incentives, which are a necessity for any early-stage technology. Finally, as we look forward to the creation of a sustainable solar energy sector in the Kingdom, we must emphasize the role of research and innovation without which a competitive advantage cannot be maintained.

In recent years it has become quite common to read headlines such as “Arizona – the Saudi Arabia of Solar Power.” It is my hope that 2010 will be the year of the *real* “Saudi Arabia of Solar Power.”

Ahmad O Khowaiter, former Interim VP of Economic Development at KAUST

2. Introduction

2.1. Status / History

Solar energy has seen a number of boom-and-bust cycles over the last century. The OPEC oil shock in the 1970s triggered a renewed, but short-lived interest in solar electricity generation. After the crisis subsided, solar electricity generation quickly faded from public awareness and went back to the Ivory Tower, where researchers on meager R&D budgets continued to work on improving solar technologies.

Increasing environmental concerns, close to non-existing local energy resources, and supportive government policy frameworks in some industrialized countries, especially Japan and Germany, led to a resurrection of solar energy in the 1990s. Figure 1 shows a forecast of the global energy supply until year 2100.

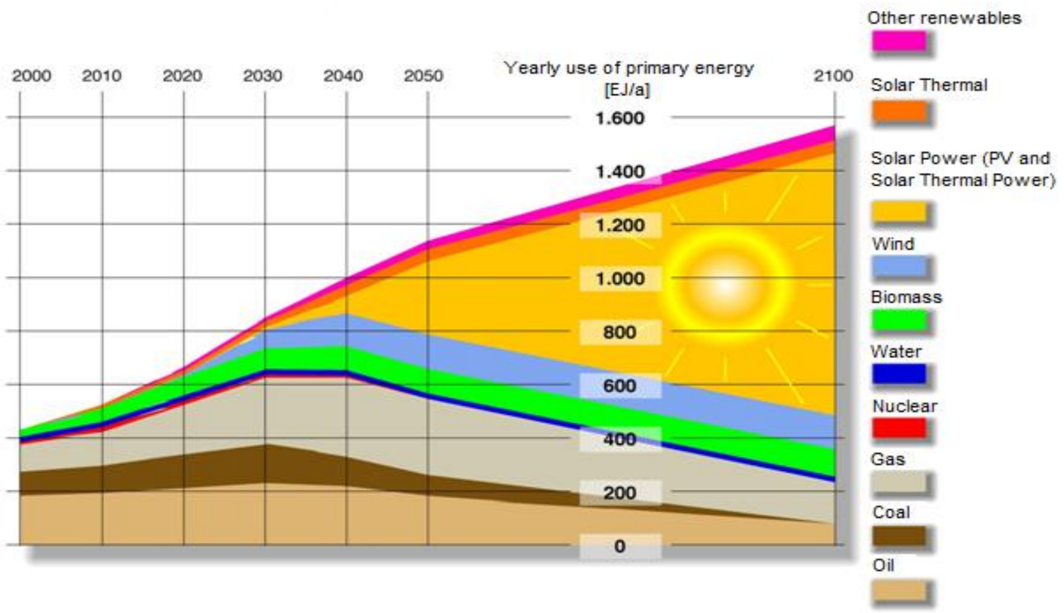


Figure 1: Global Energy Supply until 2100 - Forecast of the German Scientific Advisory Board

World electricity demand is projected to grow at an annual rate of 2.5 % to 2030. According to estimates[1] of the International energy Agency (IEA) cumulative investments of USD 26 trillion are required through to 2030 – on average USD 1.1 trillion per year – to provide new power generating capacities totaling 4,800 GW by

[1] IEA – World Energy Outlook 2009, Executive Summary

2030. With the power sector being the source of one- third of the global greenhouse-gas (GHG) emissions, it will be crucial to shift these necessary investments away from GHG-intensive technologies to renewable energy sources.

By the mid 2000s, with increasing consensus in many countries between government, industry and consumers about the reality of climate change (due to greenhouse gas emissions), oil prices passing $100/barrel, and per capita oil consumption in China growing by 400%, the pressing need to accelerate the development of advanced clean energy technologies was acknowledged, Figure 2.

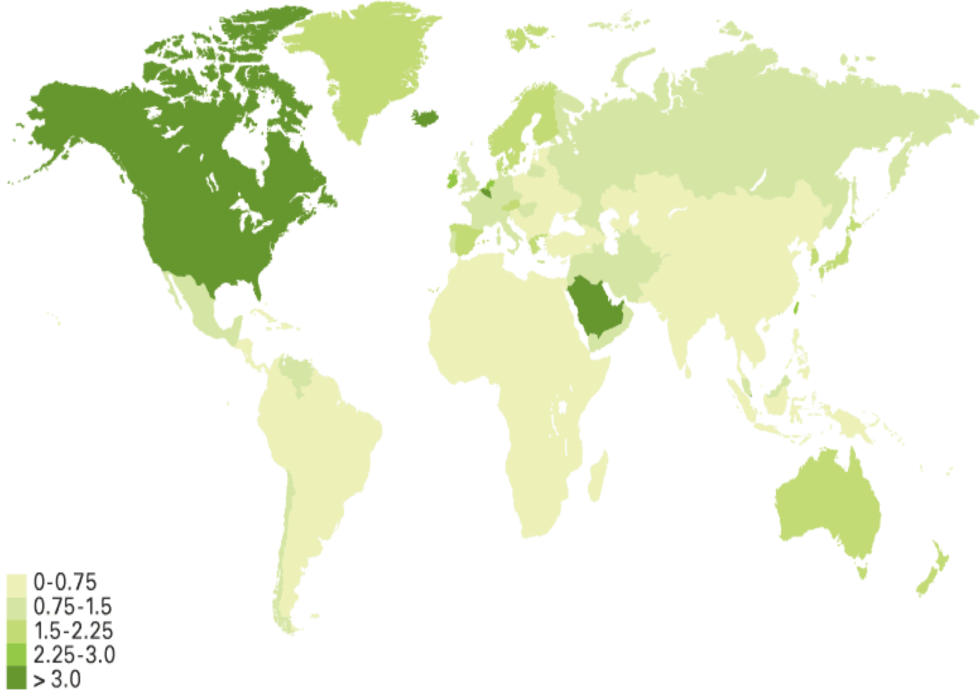


Figure 2: Per capita oil consumption, 2007 [tons] (Source: BP, IEA).

Political commitment in the form of renewable energy targets, and government support in the form of incentives became major market drivers for solar and led to the explosive growth of solar energy in some markets. Between 2001 and 2008, PV markets enjoyed a compound annual growth rate (CAGR) of 47% - exceeding most forecasts as shown in Figure 3 and 4.

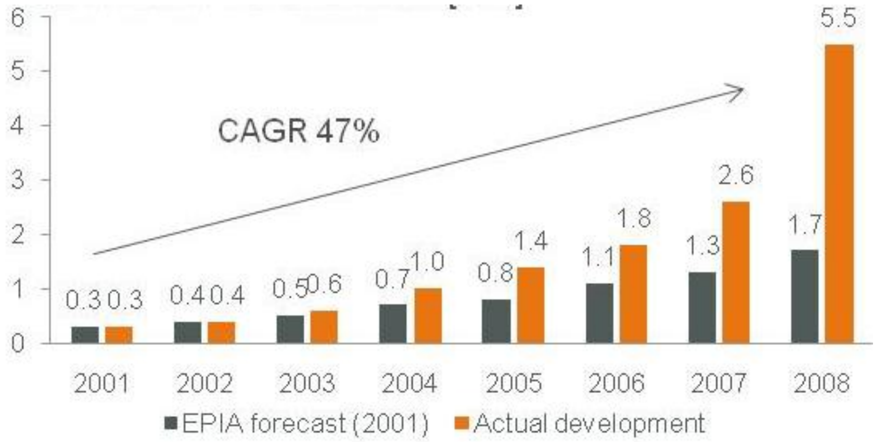


Figure 3: Global annual PV installations for 2001 – 2008 in GW

For the period 2002 to 2008, worldwide cumulative PV installations had a CAGR of 35%.

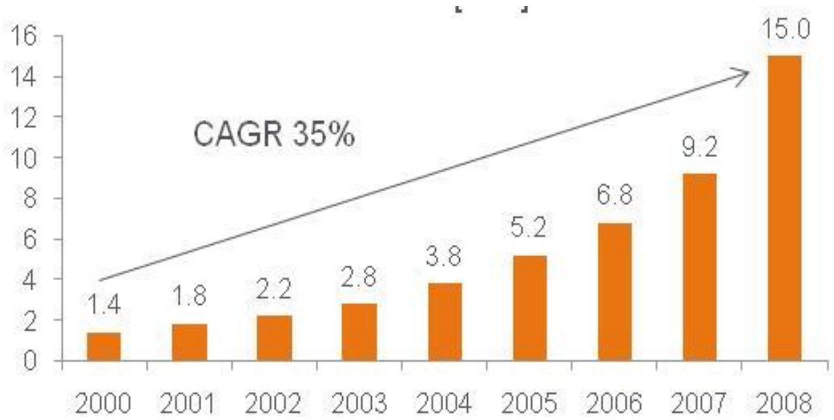


Figure 4: Global cumulative PV installations

From 2005 to 2007 the solar energy sector saw some impressive IPOs and attracted $1.8 billion in venture capital investments[2]; press attention was far outweighing the 0.04% contribution it had made to the world energy supply in 2007.[3] In 2008 the PV market grew to more than twice its 2007 size, driven by feed-in-tariffs in Spain and Germany. In 2008 global annual PV installations reached approximately 5.6 GW, with Spain and Germany accounting for over 70% of the new installations.

[2] Greentech Media
[3] IEA

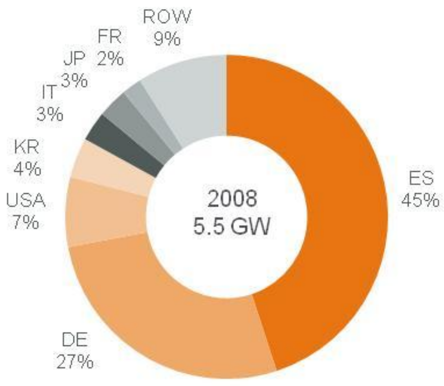


Figure 5: 2008 annual solar markets by region

As of 2008 global cumulative PV installations have reached approximately 15 GW, with Germany and Spain accounting for over 50% of the cumulative installed PV capacity, Figure 5 and 6.

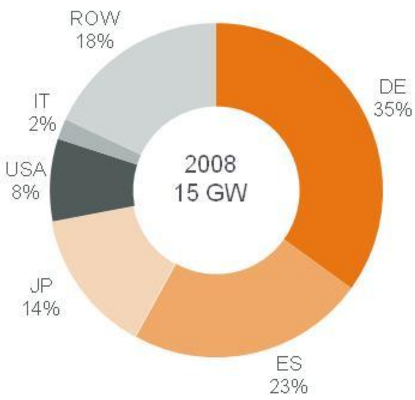


Figure 6: Global cumulative installed PV capacity by region

The financial crisis and following recession caused a slowdown and, most likely, consolidation of the solar industry, but the global market for solar power is forecast to stay strong and see continued growth over the next decade. While analysts' forecasts cover a wide range of data, with CAGR between 24% and 68%, they unanimously expect medium- and long-term growth as shown in Figure 7.

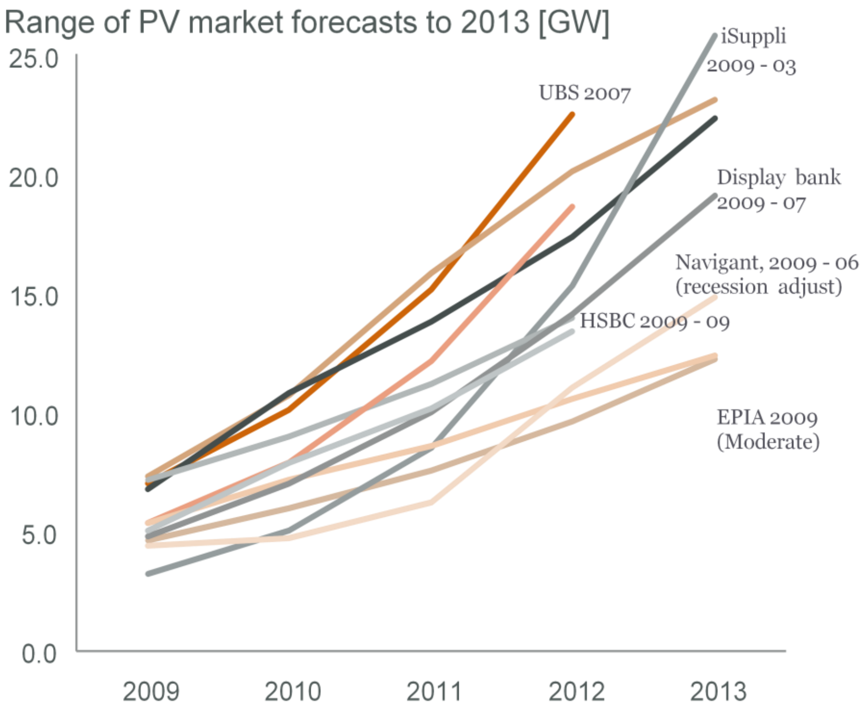


Figure 7: New global annual PV installation – Range of forecasts for 2009 – 2013 [in GW]

Building on analysts' market forecasts and its own industry knowledge, Apricum estimates that new annual PV installations will continue to grow at a CAGR of about 40% between 2009 and 2015 as shown below in Figure 8.

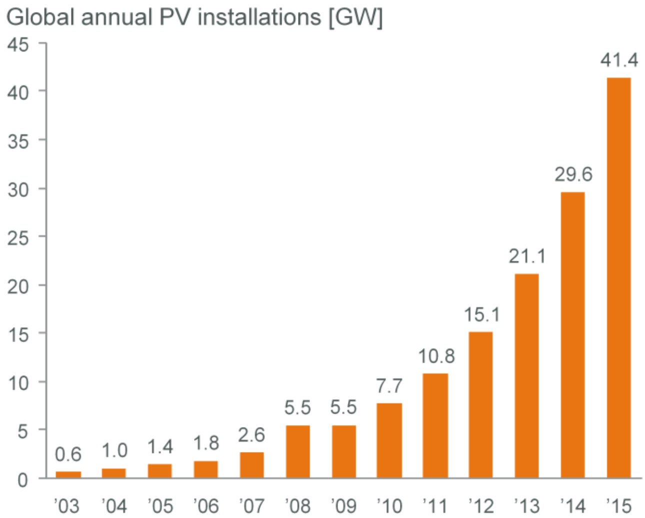


Figure 8: New global annual PV installation (2009-2015 are forecasts) [in GW]

In addition to the current primary markets, new PV markets with annual volumes of 500 MW will emerge in the next two years, and non-European markets are expected to achieve higher than average growth rates. By 2020 the cumulative PV market is estimated to be over 200 GW. Germany, the largest solar market today, will continue to grow, but the U.S., China and the Middle East are expected to become the next hot markets, as shown in Figure 9.

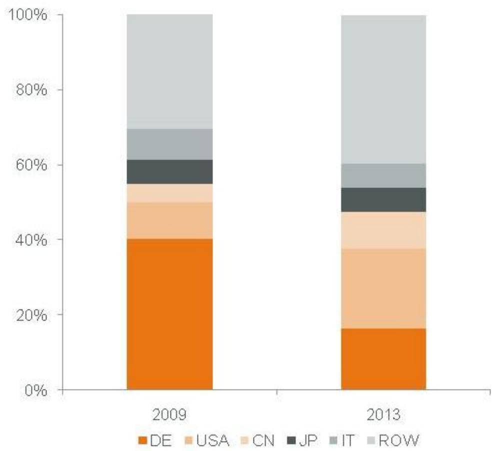


Figure 9: New annual PV installations by region [in %][4]

During 2009, in response to the financial crisis and the worldwide recession, many countries such as the U.S.A, China, South Korea, Japan, Germany, and France have announced significant stimulus packages which have a strong component for supporting renewable energy programs and infrastructure (for example "smart grid") improvements. In the American Recovery and Reinvestment Act (ARRA), $94 billion are earmarked for renewables, energy efficiency, the grid ("smart grid"), green transportation and water as shown in Figure 10.

[4] Sources: EPIA, Gartner Research

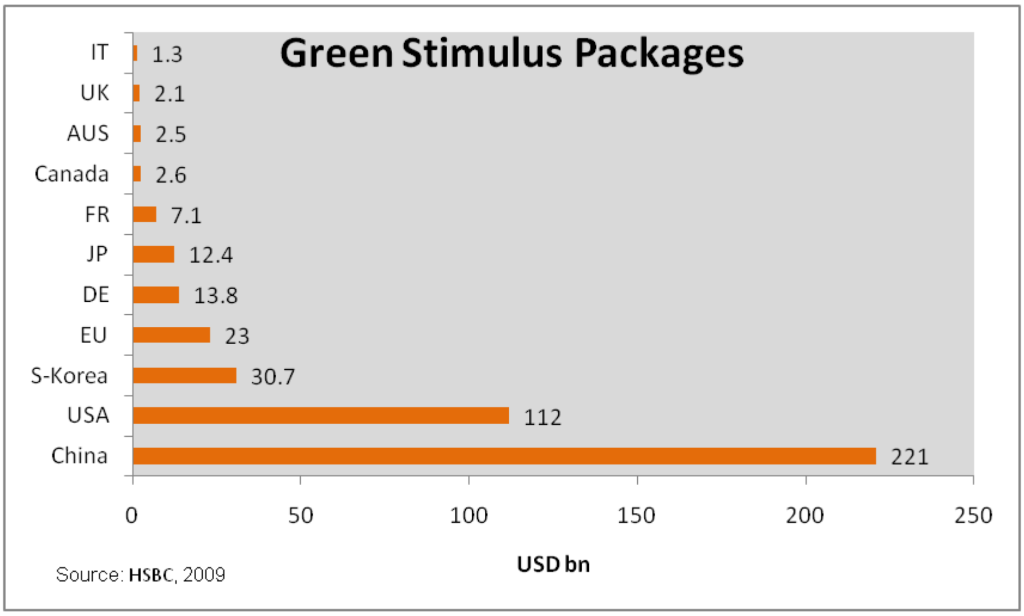


Figure 10: Green stimulus packages by region

Even though solar produced electricity is or will be cost competitive ("grid-parity") soon in some limited markets where electricity prices are high at certain times, continuing government support will be needed to allow for sustained market growth, optimal technology progress, cost reduction, large-scale industrial manufacturing and mass deployment in order to reach grid parity conditions in many more markets.

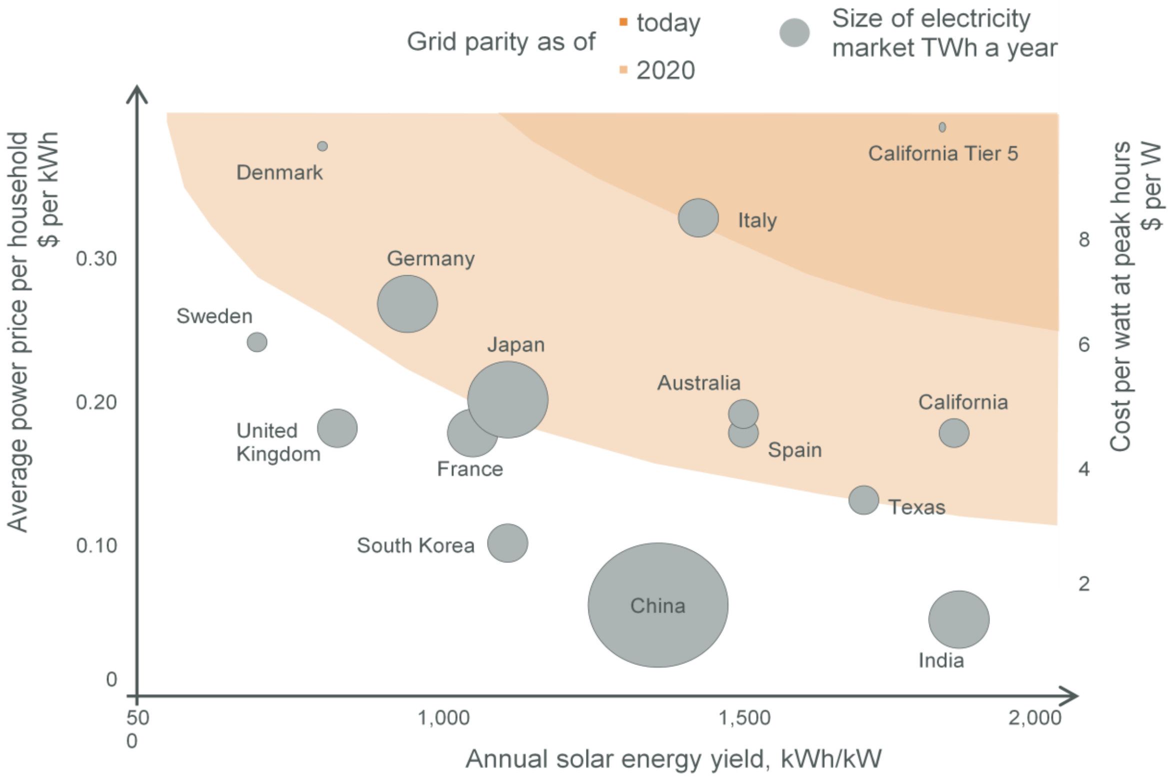


Figure 11: The growing competitiveness of solar power

Figure 11 shows the move to grid parity; today and projected for 2020.

2.2. Market and Technologies

The solar market today is a hodgepodge of diverse technologies, material and equipment supply constraints, and a mess of different government subsidies. As a result of this, the economic viability of solar power varies widely by geography, application and technology. It is expected that a broad variety of technologies will continue to characterize the solar technology portfolio, but – hopefully – in the future, a specific application and geographic conditions will determine the most suitable technology of choice, as shown in Figure 12.

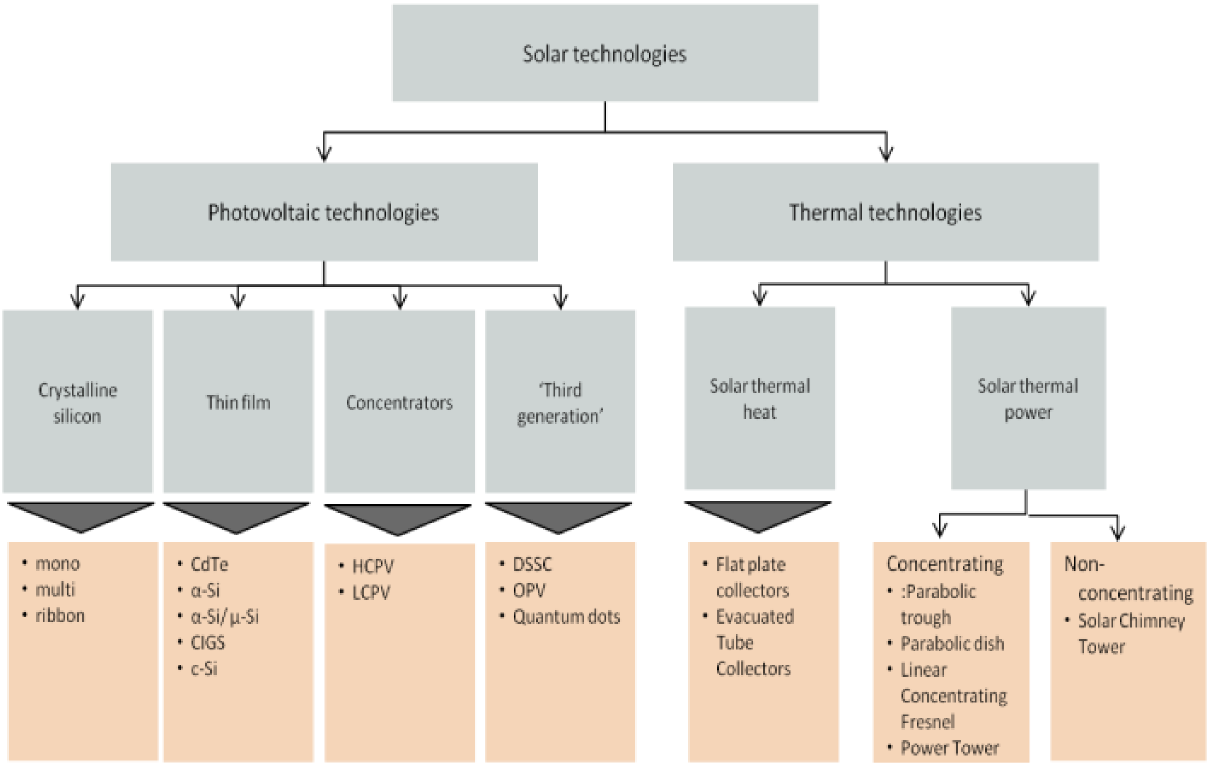


Figure 12: Solar energy technologies

2.2.1. Supply constraints

The large-scale deployment of solar technologies has considerable effects on energy, material and equipment requirements in manufacturing. Possible bottlenecks in the supply of critical materials – as experienced with respect to silicon – can have dramatic effects. Silicon is made from the abundant material quartz (SiO_2) but, due to the exponential growth of the solar market, established silicon manufacturing companies could not keep up with the demand from the solar industry. The result: the bottleneck in silicon manufacturing drove up spot-market prices for silicon, paved the way for silicon thin-film technologies and encouraged the development of other, non-silicon-based solar cell technologies. The National Renewable Energy Laboratory (NREL), in a report[5] published in December of 2003, had come to the conclusion that most commodity materials such as glass, steel, plastic, concrete and copper would require little growth in production to offset growing demand for PV sys-

[5] The National Renewable Energy Laboratory, "Will we have enough materials for significant PV production?", DOE/GO-102003-1834, December 2003

tems. Based on NREL's assessment, glass production would have to grow the most, but still only at about 0.13% per year. With respect to some of the specialty metals used in PV, NREL concluded that current production growth in zinc extraction (indium is a byproduct of zinc) and copper mining (tellurium and selenium are byproducts of copper) would be enough to keep up with the PV demand. Only if PV production levels passed 100 GW/year could the availability of indium and tellurium limit growth. Other potential bottlenecks can be on the equipment side. Wafer-saw factories are capacity constrained. If wafer manufacturers do not communicate their expansion plans ahead of time with the wire-saw manufacturers, they might be facing equipment lead-times of 18-24 months, as experienced in 2007. In an aggressive CSP deployment scenario, steam turbine and storage media (molten salt) supplies could become the bottlenecks. Prior to the economic downturn in 2009, delivery time for steam turbines already exceeded three years.[6]

2.2.2. Government subsidies

Subsidies have helped create markets for solar power in many countries. Japan and Germany, neither blessed with high solar irradiation, have developed thriving solar industries as a result of the subsidies. Government subsidies come in two types – incentives and mandates ("carrot and stick" approach). Mandates, like renewable portfolio standards (RPS) or carbon cap-and-trade schemes, are negative incentives ("stick") as they penalize those not using renewable energy sources. Positive incentives ("carrot") like the feed-in-tariff, tax credits or installer subsidies offer financial motivation to use renewable energy sources. Feed-in-tariffs (FITs) have been shown to be the most effective tool, albeit at a significant cost. The main advantage of FITs is that they provide long-term planning security and promote good system performance – both major advantages for local market development and fostering the establishment of local manufacturing. The United States, up until now, has relied on a combination of different incentives, none of them promoting system performance or providing a long-term planning horizon. More recently, several states or municipalities in the U.S. have started to explore / implement feed-in-tariffs. On a cautious note, as the example of Spain has illustrated very clearly, it is critical to put the right incentive framework in place in order to promote a sustain-able solar market and industry growth.

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[6] http://www.powermag.com/coal/CERAWeek-2009-Floundering-Economy-Eclipses-Renewable-Carbon-Plans_1795_p2.html (accessed 2009-11-24)

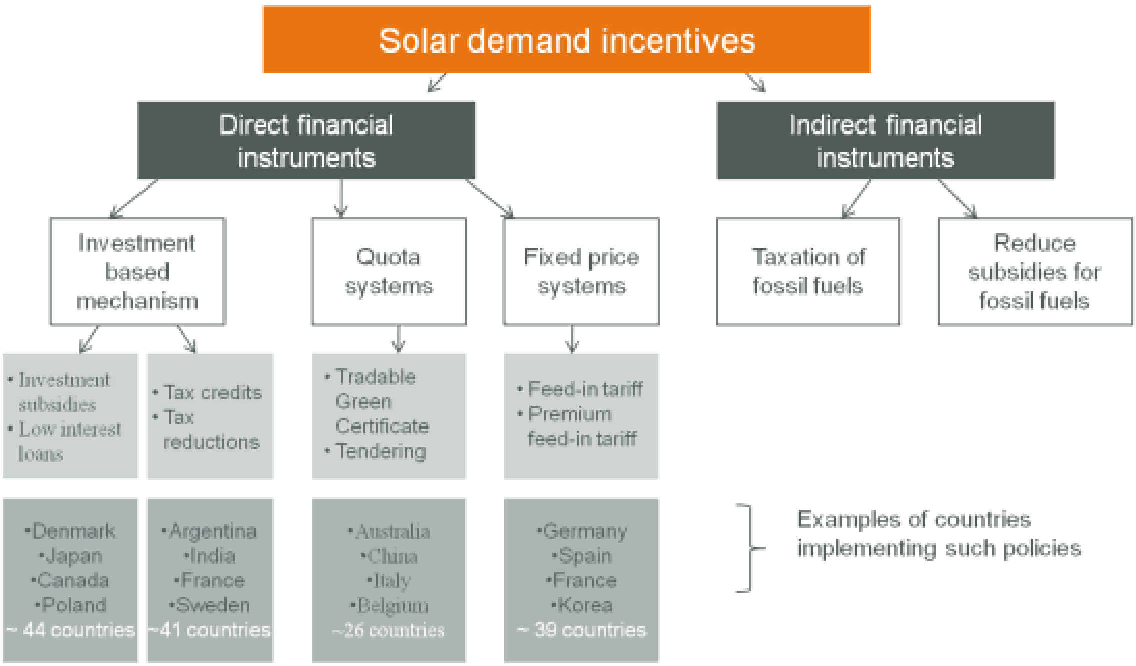


Figure 13: Primary solar incentive schemes

Figure 13 shows a breakdown of adopted Solar demand incentives in different countries around the world.

2.2.3. Technologies

Two main solar technology branches exist: photovoltaic (PV) technologies use the sun's light to generate electricity, while solar thermal technologies use the sun's heat to generate electricity or provide hot water or steam for various applications/processes. Solar thermal, so far, has been a much undervalued energy source, even though the current global installations far outpace PV as shown in Figure 14.

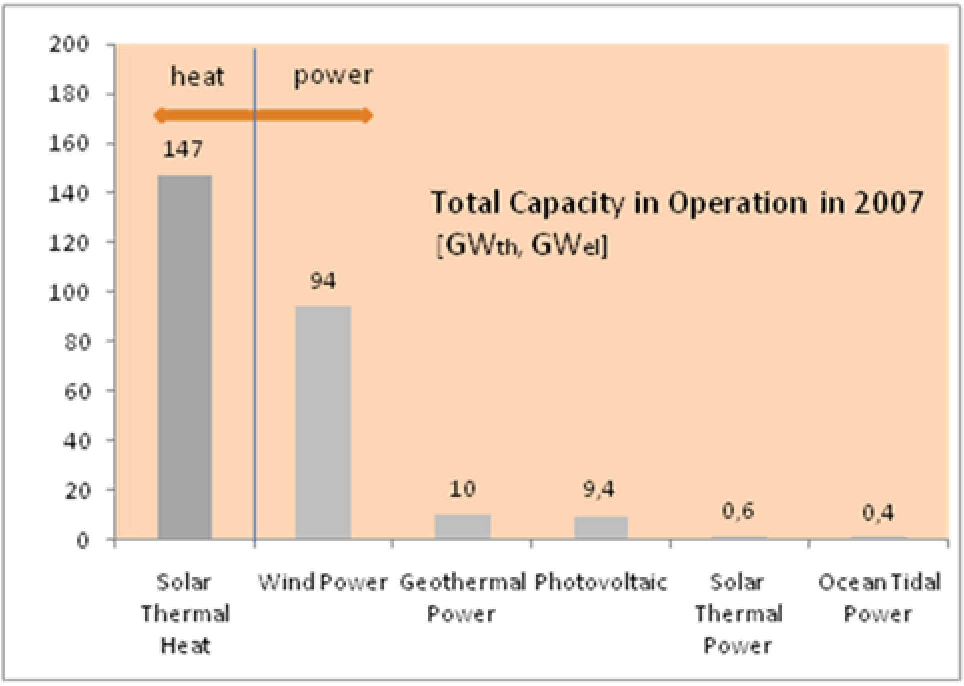


Figure 14: Solar thermal heat – an undervalued energy source (Source: IEA, 2009)

Compared to the low and medium temperature solar thermal market for water heating, concentrated solar power (CSP) is still a very small market, even though it offers the lowest electricity production cost of all solar technologies today: between USD 0.15 - 0.40/kWh. As of 2008 less than 0.5 GW of CSP have been installed worldwide, compared to over 150 GW_{th} of solar thermal capacity or more than 14 GW of PV. But CSP gained significant momentum in 2008, with over 1GW under construction as of April 2009, and at least ten times as much being planned globally as shown in Figure 15.

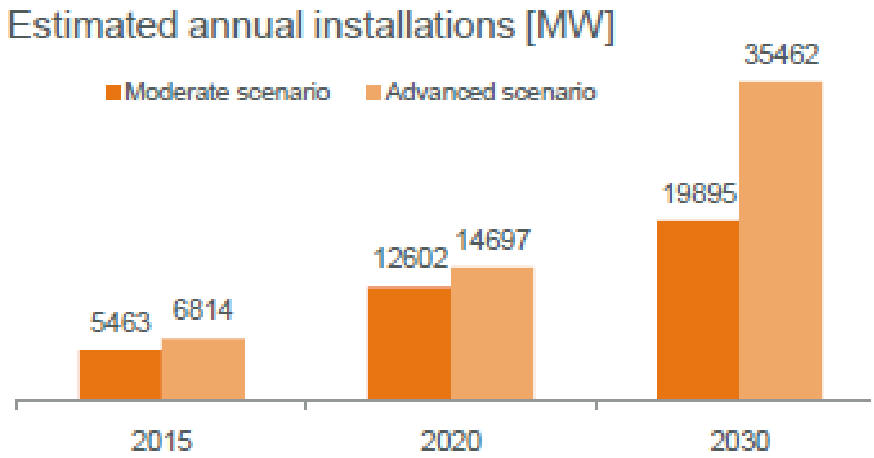
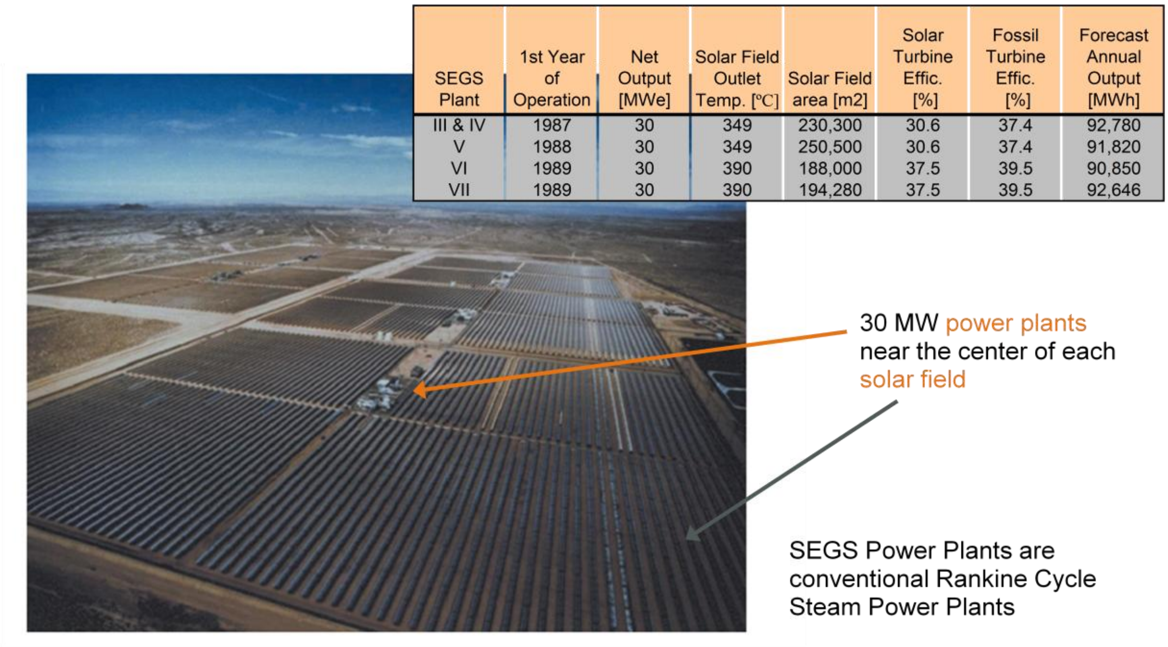


Figure 15: Estimated annual CSP installations [in MW] (Source: Greenpeace International, Solar PACES ESTELA Report, 2009)

Nine parabolic trough-type solar thermal energy generating systems (SEGS) with a total capacity of 345 MW in the Mojave Desert in California, installed between 1985 and 1991, are the longest operating CSP plants, providing excellent references for new parabolic trough CSP projects, Figure 16.



SEGS Plant	1st Year of Operation	Net Output [MWe]	Solar Field Outlet Temp. [°C]	Solar Field area [m2]	Solar Turbine Effic. [%]	Fossil Turbine Effic. [%]	Forecast Annual Output [MWh]
III & IV	1987	30	349	230,300	30.6	37.4	92,780
V	1988	30	349	250,500	30.6	37.4	91,820
VI	1989	30	390	188,000	37.5	39.5	90,850
VII	1989	30	390	194,280	37.5	39.5	92,646

Figure 16: SEGS plants at Kramer Junction, CA, USA

For commercial use, CSP needs to be deployed in regions with direct normal irradiation (DNI) in excess of 5-6 kWh/m2/day (or > 2,000 kWh/m2/year) – the "Sun Belt" between 35° latitude south and north. Currently, the CSP market is led primarily by the U.S. and Spain, but North Africa and the Middle East (MENA) are excellent candidates for large-scale CSP projects as shown in Figure 17.

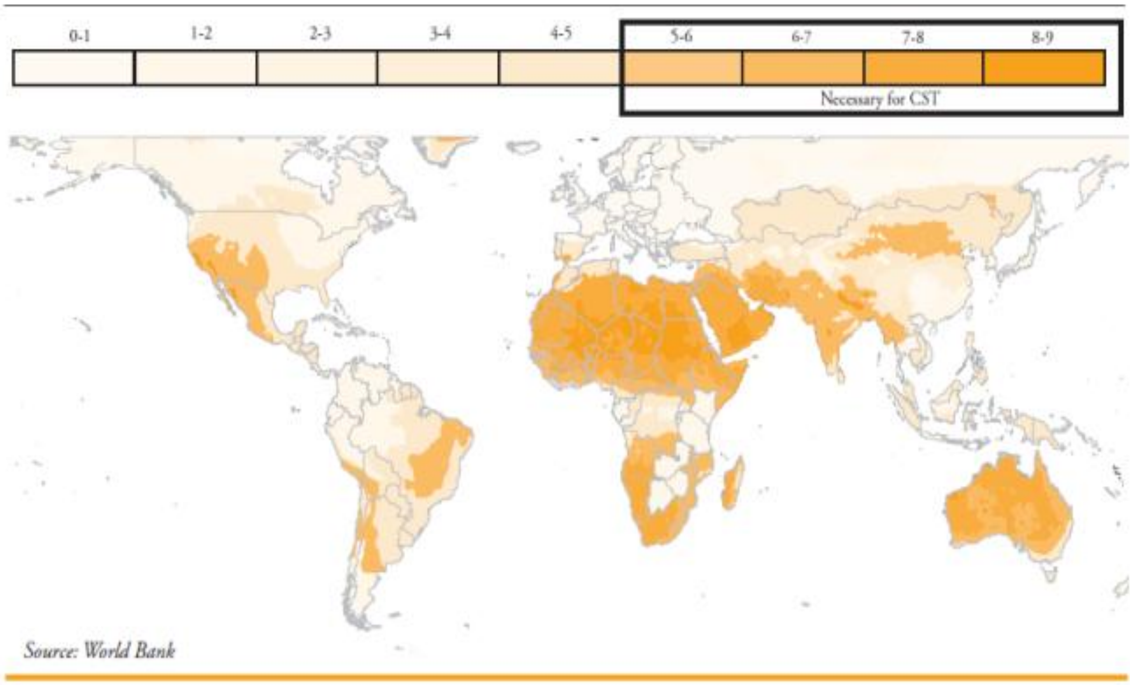


Figure 17: Global average insolation [kWh/m2/day] (Source: World Bank)

Algeria already promotes electricity generation by Integrated Solar Combined Cycle (ISCC) plants through special feed-in-tariffs in its Renewable Energy Law of 2004. ISCC projects with a total capacity of 60 MW are under construction in Egypt, Algeria, and Morocco, and further projects are in development in Abu Dhabi and Oman. Forecasts by various institutions call for a total of over 9 GW of CSP installations in the Middle East by 2020, Figure 18.

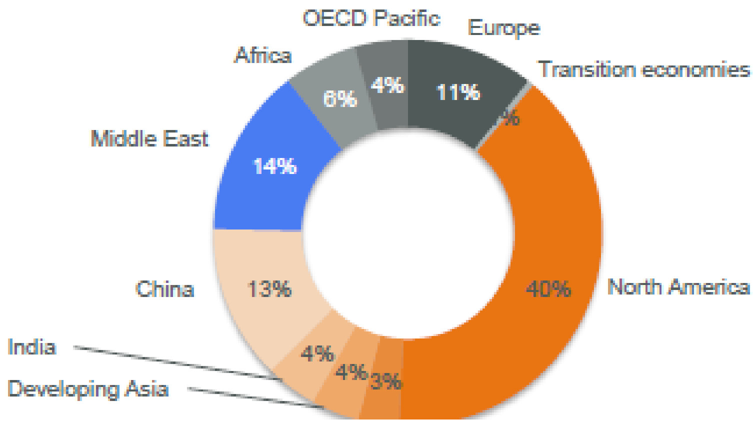


Figure 18: Estimated geographic breakdown of total CSP installations by 2020 – moderate scenario (Source: Greenpeace International, SolarPACES ESTELA Report, 2009)

Theoretically, CSP plants, covering less than 3% of the total area of the Sahara desert, would be sufficient to meet the world's total electricity demand.

The Trans-Mediterranean Renewable Energy Cooperation (TREC) and the Club of Rome have for years promoted a concept – the DESERTEC concept – that would feed electricity from various renewable energy sources into a high voltage DC power transmission super grid to supply electricity to Europe, while at the same time providing energy for seawater desalination plants in MENA. The envisioned DESERTEC grid is depicted below. The DESERTEC idea, Figure 19, recently gained momentum when 12 companies such as Siemens, Deutsche Bank, E.On, Munich RE, ABB and the DESERTEC Foundation signed a Memorandum of Understanding (MOU) to establish a DESERTEC Industrial Initiative, with the objective to analyze and develop the framework for carbon-free power generation in the MENA deserts.

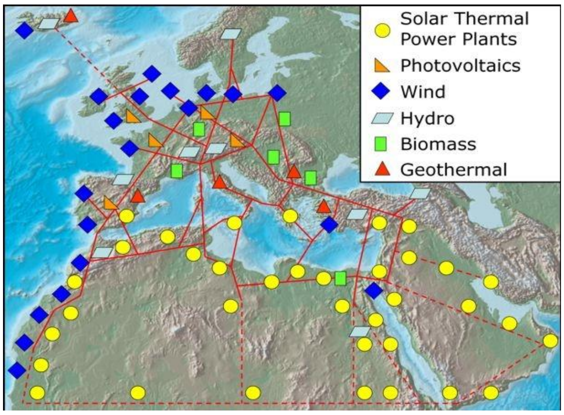


Figure 19: The DESERTEC concept

Among the various PV technologies installed today, crystalline silicon (c-Si) wafer-based solar cells and modules account for over 80% of the PV market, and therefore set the benchmark with respect to efficiency, cost, and manufacturing scale and throughput. The best, monocrystalline silicon-based solar cells, have achieved conversion efficiencies of 24.75%[7] in the lab, and SunPower just achieved the highest efficiency rating (20.4%) for a full-sized monocrystalline silicon solar panel, as confirmed by the National Renewable Energy Lab (NREL)[8]. Most run-of-the-mill commercial modules are much less efficient, typically hovering around 14% efficiency for either mono- or multi-crystalline modules.

Crystalline silicon solar cells are made from ultrapure[9] polysilicon. The tremendous growth rate of the solar industry left polysilicon manufacturers unable to keep up with the demand in 2007. The silicon supply bottleneck, together with the resulting high costs, had constrained the industry, but it also invigorated the search for alternatives, like less expensive, less pure silicon (UMG-Si) or technologies using less or no silicon (e.g., thin-film technologies, concentrated PV). Many new companies and technologies entered the market much faster than expected before the polysilicon shortage.

[7] University of New South Wales, Australia
[8] SunPower corporate website, press release on Oct 26, 2009 (http://investors.sunpowercorp.com/releasedetail.cfm?ReleaseID=417965)
[9] Typically 9N or 99.9999999% pure

The entry of turnkey equipment providers like Applied Materials or Oerlikon further accelerated the growth potential for thin-film PV technologies, and the market saw an explosion of new entrants in 2007, Figure 20. Today, the various thin-film technologies, such as amorphous or micromorph silicon (a-Si / µ-Si), cadmium telluride (CdTe), and copper indium (gallium) diselenide (CI(G)S), account for less than 20% of the total PV market.

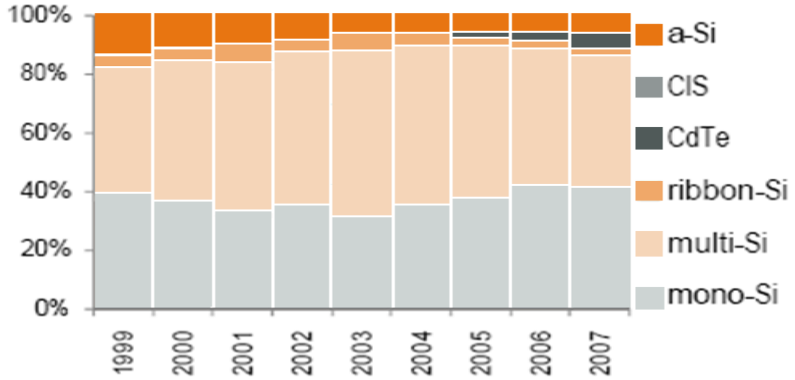


Figure 20: Technology Market Share in [%] (Source: PHOTON International, March 2008)

With many established PV players invested in thin-film technologies (e.g., Q-cells, Sanyo, Schott, Sharp), and many of the new entrants getting ready to ramp production, thin-film will gain a significant market share over the next few years. It is expected that by 2013 thin-film technologies will account for over 6 GW of new PV installations.[10]

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[10] Sources: Apricum research; EuPD Research; Displaybank; Navigant

Figure 21: Thin-film technologies will gain a significant market share in the future

In the short-and medium-term Europe and the U.S. will see the strongest growth of thin-film PV, especially because the U.S. is home to a larger-than-average number of CdTe and CIGS start-up companies, Figure 21.

All three major thin-film technologies – a-Si, CdTe, and CIGS – have been under development since the 1970s, but until recently only amorphous silicon could be manufactured repeatably enough for it to gain any market share. As amorphous silicon has the lowest conversion efficiency of the three technologies, 13% in the lab compared to 16.5 % for CdTe and 19.9% for CIGS, development efforts have continued for the more promising thin-film technologies. During 2007 many start-up companies invested in turnkey thin-film silicon lines, but thin-film PV has increased its market share primarily due to the phenomenal growth of one company, First Solar (CdTe), which in 2009 surpassed the 1GW mark in annual production capacity for CdTe modules, achieving a module efficiency of about 11%. The other thin-film technology, CIGS, today accounts for less than 2% of the overall PV market, with only a few companies at manufacturing scale. But CIGS, having demonstrated the highest conversion efficiencies of all thin-film technologies in the laboratory, has the biggest potential for further improvements in solar module efficiency[11] (see

[11] NREL, company data sheets, PV Expo 2008 – Würth Solar

Figure 22), as well as significant cost advantages in the future[12] (see Figure 23). Therefore, if only a few of the many CIGS companies currently in transition from pilot- to large-scale manufacturing are successful, module efficiencies increase from the current 9-11% range, and good, relatively inexpensive barrier layers[13] enable flexible CIGS modules, CIGS will reach its full market potential and surpass CdTe, Figure 24.

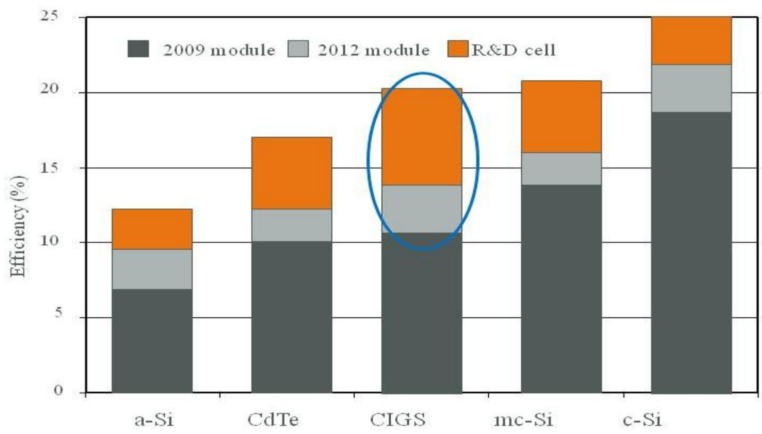

Figure 22: CIGS has greatest potential for improving module efficiency

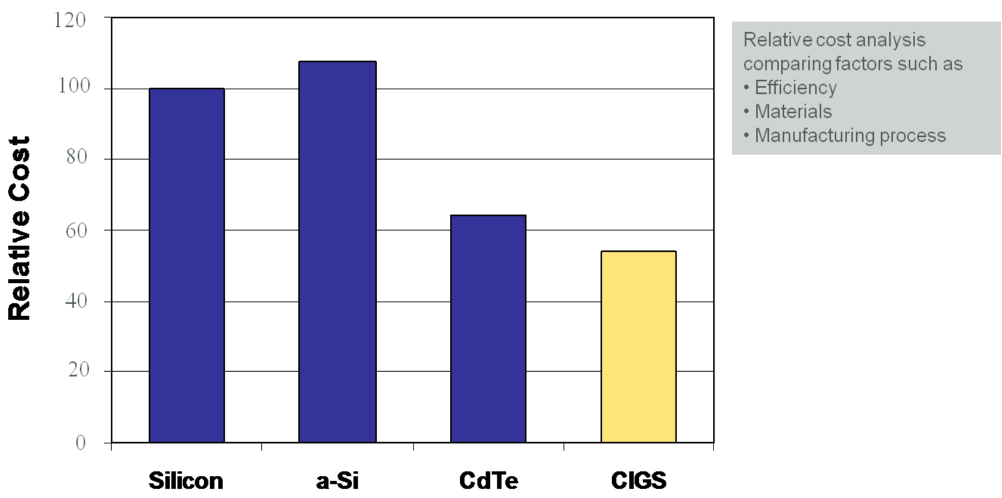

Figure 23: Anticipated future relative cost in %

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[12] NREL, presented at 33rd IEEE Photovoltaic Specialist Conference, San Diego, CA, May 11-16, 2008

[13] Barrier layers with water vapor transmission rates of 10^{-5} g/m^2/day at cost of USD 30/m^2 or less are needed

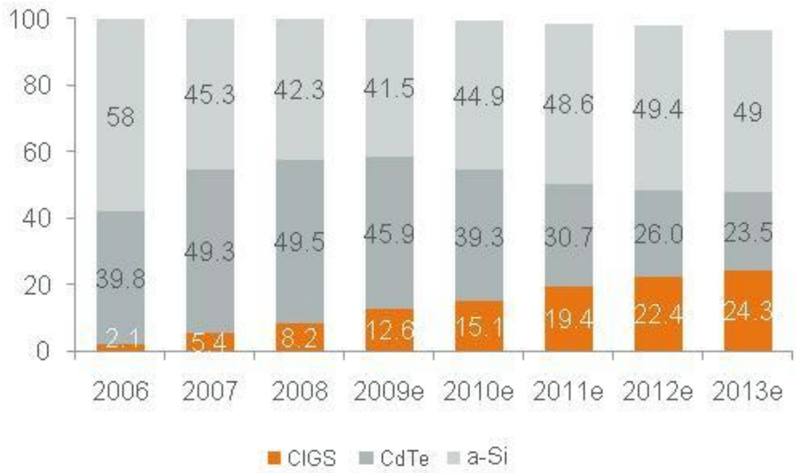

Figure 24: Contribution of each thin-film technology to the total thin-film market share [in %]

CIGS is estimated to increase its market share relative to other thin-film technologies as well as with regard to the total market - from currently less than 2% of the overall PV market to about 9% by 2015, Figure 25.

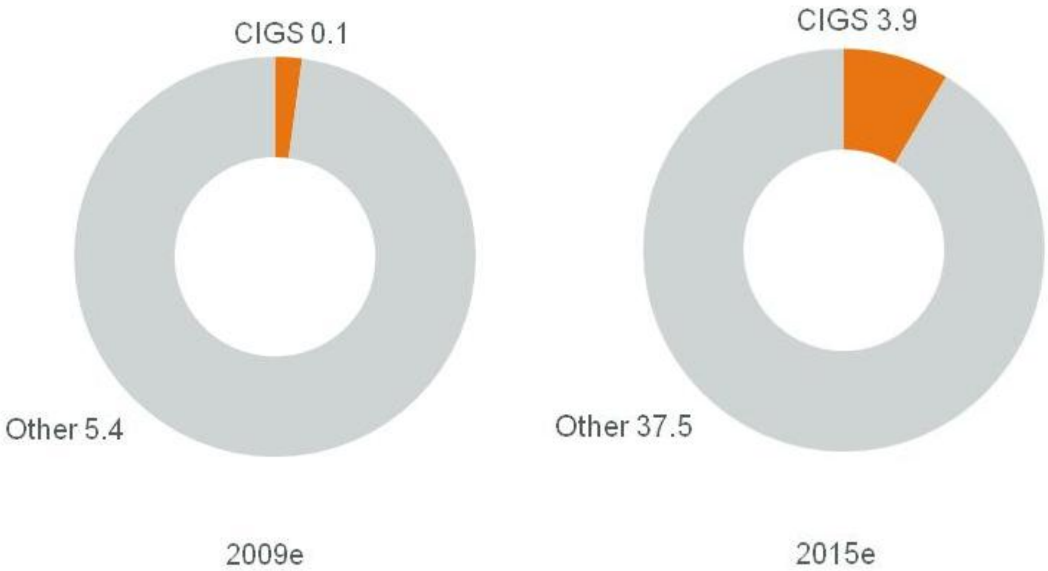

Figure 25: CIGS market share in 2009 and 2015 [in GW]

Concentrated photovoltaics (CPV) is still an emerging market, with less than 20 MW cumulative installed capacity as of the end of 2008.[14] High concentrated PV (HCPV), just like concentrated solar power (CSP), requires high direct normal irradiation (DNI), and is therefore best deployed in medium-sized installations in the "Sun Belt" region of the world, where it has the potential for the lowest LCOE of all PV technologies. Although both are best deployed in high DNI areas, CPV and CSP are not necessarily exclusive of one another. A high-level comparison of some of the technologies' parameters (see Figure 26) provides a first guidance at their unique positioning and best-suited applications.

Parameter	HCPV	CSP
Location	High direct normal solar irradiation (DNI), no dust or smog	High direct normal solar radiation (DNI), no dust or smog
Surface requirements	More flexible in land layout;	Large, level sites, slope <1% most economic to develop
Area requirements	Min. Lot size: 3 ha	20,000 m² (5 acres = 2 ha) per 1 MW in good solar location, 11 m² per 1 MWh/y; min lot size: 30 ha
Cost to install solar field providing MWs of electricity	USD 4 mill / 1MW (Amonix, 2002) USD 3 mill / 1MW (Isofoton, 2005)	USD 4 million / 1MW (Nevada Solar 1, 64 MW) USD 3 million / 1MW (Ausra Kimberlia, 5MW) EUR 6.4 million / 1MW (Andasol-1, 50MW) USD 5.5 million / 1MW (Shams-1, 100 mW)
Financing	Construction in phases possible -> financing in phases possible	All at once; high upfront cost
Optimal size	100 kW – 10 MW; greater flexibility in size of installations; optimal: ≥ 1 MW	About 50 - 250 MW; optimal: > 100 MW
Storage	Batteries	Thermal storage (molten salt; steam,..)
Water requirements	Water for cleaning; lower water usage than CSP; 0.02 m³/MWh	Water for cleaning & cooling; 4,500 - 5,500 liters per MWh (4.4 m³/MWh) air-cooling possible - reduces efficiency
Response time	Responds more quickly when sun returns on a cloudy day	Slower response
Cost of electricity	USD 0.20 / kWh (Isofoton, 2005)	USD 0.17 / kWh (Nevada Solar 1)

Figure 26: High-level comparison of HCPV and CSP

An increasing number of companies are pursuing various HCPV approaches, but financing for commercial installations is still hampered by the lack of a track record and experience in the field. Recognizing this issue, Spain's Institute of Concentration Photovoltaic Systems (ISFOC) provided a test site and research personnel for data collection, and chose six CPV manufacturers to deploy and test their systems in a commercial environment to collect data to prove the reliability, productivity and cost capabilities of CPV.

[14] JRC European Commission, PV Status Report 2009

Solar power has many merits – the most pressing drawback: it is still 5-10x more expensive than electricity from fossil fuels; solar thermal is closest to achieving grid parity with fossil fuel electricity costs.

Therefore, the focus is on cost reduction – all along the solar value chain. Cost reduction can be achieved in many different ways – economies-of-scale in manufacturing, continuous improvement of existing solar technologies, exploration of alternatives, lower cost materials, a search for radically new technological approaches, just to name a few as shown in Figure 27 below.

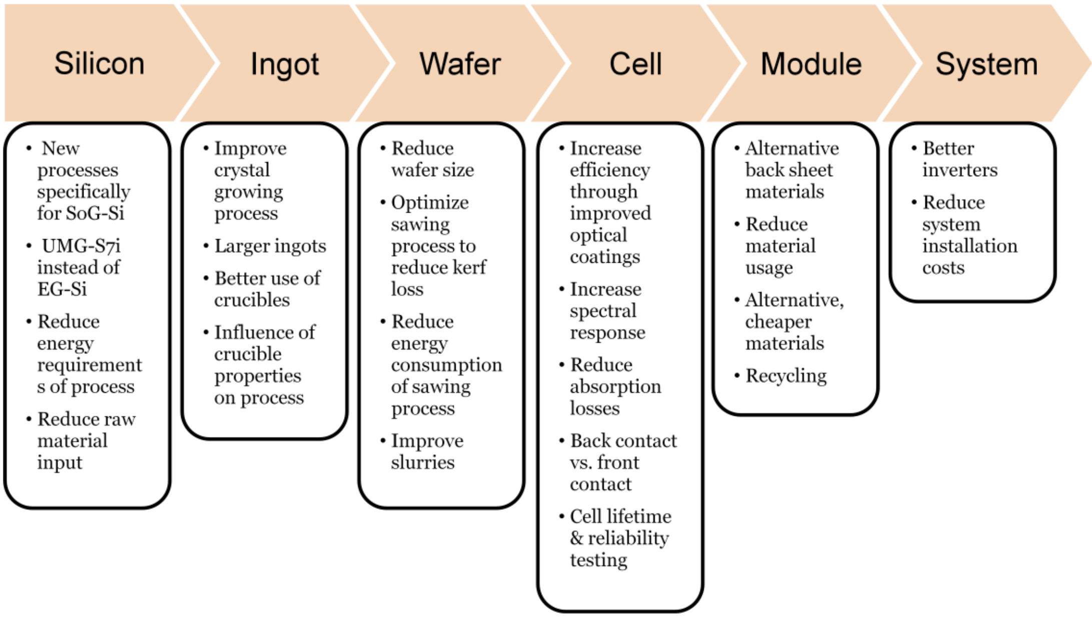

Figure 27: PV value chain and main cost reduction approaches

On the silicon manufacturing end, silicon ribbon technology or upgraded metallurgical silicon (UMG-Si) are attempts at reducing cost.

In the wafer step, reducing wafer thickness and reducing losses during sawing are major attempts at reducing cost.

On the cell level, the approaches for reducing cost range from increasing efficiency, replacing part of the cells with concentrated optics (LCPV approach) using high concentrating mirrors to focus on tiny, high-efficiency cells (HCPV) or replacing c-Si cells with various thin-film technologies or cheaper materials (organic PV).

2.3. Solar energy in the Middle East

The Middle East and North Africa are in a perfect location to play an important role in the solar power industry, and solar power has the potential to contribute to a sustainable development in the MENA region. But, due to reliance on the region's ample reserves of fossil fuels and lack of government support for renewable energy, the Middle East so far has only seen limited solar power projects, and none of the countries can point towards a significant solar industry cluster, in spite of excellent solar conditions (see map below in Figure 28).

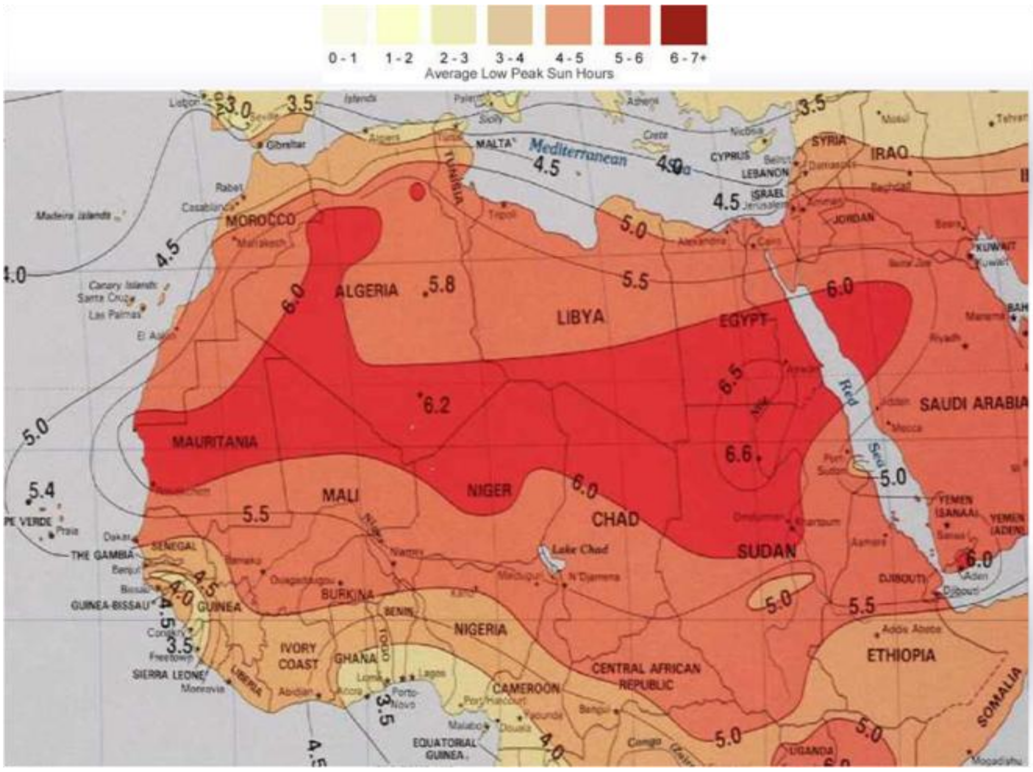

Figure 28: Solar power map: North Africa & Middle East

The tides are changing, however, and especially the United Arab Emirates (UAE) has taken a leading role. In 2008 UAE committed itself to taking 7% of its energy needs from renewable sources by 2020[15]. Abu Dhabi has made worldwide headlines with Masdar City – a city planned from scratch to be the first carbon neutral, zero waste city powered entirely by renewable energy. The first solar power plant in Abu

[15] Drummond, James, "Solar power's prospects rise in the east", Financial Times online, www.ft.com, 2009-11-09

Dhabi's Masdar City, a 10 MW PV plant, was already inaugurated in 2009, and many more announcements about solar companies signing contracts with Masdar to install their technologies were hitting the news wire on a regular basis in 2009. Masdar is also in the planning stages for a 100 MW CSP plant (Shams 1), to be completed in 2011. The capacity of Shams 1 will be increased to 2,000 MW in the future.[16] Recognizing that the geographic conditions of the MENA region might pose new challenges to the performance and materials of solar systems, Masdar has partnered with Spain's ISFOC to study the effects of dust, salt, ambient temperature and haze on the energy output and reliability of CPV technologies from a variety of manufacturers. A key goal of the project will be to determine whether any of the CPV technologies can be a competitive and reliable renewable energy technology for Abu Dhabi and the surrounding region. Figure 29 shows projects that are at various stages of development in locations around the Kingdom of Saudi Arabia.

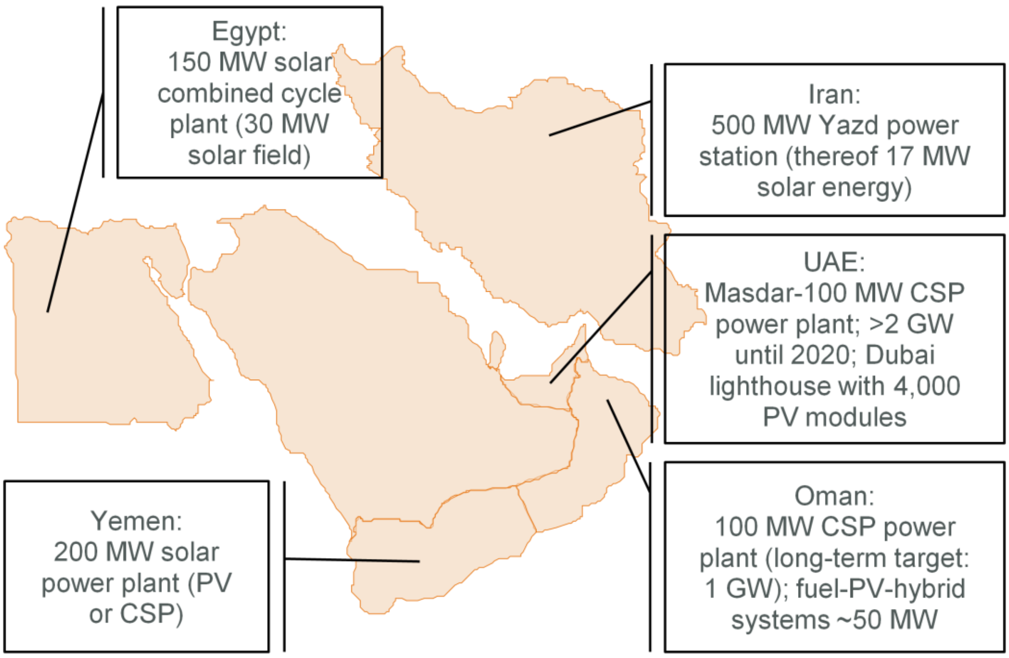

Figure 29: Current active and planned solar activities in the Middle East

[16] Masdar - Shams 1 Concentrated solar power (CSP) Plant, www.zawya.com (a website covering major construction projects in the Middle east)

2.3.1. Solar energy as an opportunity for Saudi Arabia

Saudi Arabia has toyed with small-scale solar power projects since the 1970s. The Solar Village Project in the 1980s, a 350 kW concentrated PV project, had the goal of providing power for remote villages. Under the SOLERAS program, a solar-powered seawater desalination pilot plant was completed in 1984 near Yanbu, but was eventually shut down for economic and technical reasons.[17] But Saudi Arabia's growing energy demand – from 35 GW in 2008 to an estimated 70 GW in 2023 – as well as power shortages during peak hours and environmental concerns, like the need to cut CO_2 emissions, all contribute to the Kingdom taking another look at solar power. In March of 2009, Saudi Arabia's petroleum and mineral resources minister, Ali al-Nuaimi, said, "For a country like Saudi Arabia... one of the most important sources of energy to look at and to develop is solar energy," and the country hopes to become an expert with solar energy as it has with oil.

A rather simple comparison (see Figure 30) between Saudi Arabia and some of today's leading solar markets highlights the great opportunity for solar power in Saudi Arabia.

Country	Surface area [thousand km²]	Yield [annual kWh/installed kWp]	Generation costs [€ per kWh]	Installed capacity by 2007 [MW]
Saudi Arabia	2,240	1,400-2,100	<0.20	<5
France	672	850-1,450	0.39	75
Spain	504	1,000-1,550	0.28	632
California	424	1,400-1,800	0.22	280
Germany	357	825-1,100	0.44	3,800

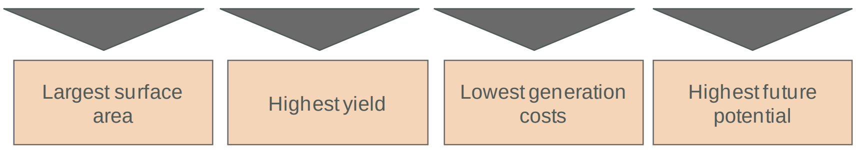

Figure 30: Saudi Arabia holds great potential for the extensive use of solar power [18]

[17] Alawaji, Saleh H., "Evaluation of solar energy research and its applications in Saudi Arabia – 20 years of experience," Renewable and Sustainable Energy Review 5 (2001), 59-77
[18] Sources: European Commission; EPIA

Saudi Arabia, due to its high direct solar radiation, is a preferred location for the deployment of any concentrated solar technology.

Large-scale CSP projects can be very interesting for Saudi Arabia. Not only will they free up oil for higher value-added uses, they also have the potential for Saudi Arabia to become a solar energy electricity exporter in the long term. The waste heat of a CSP plant can further be used for the desalination of seawater, providing Saudi Arabia, already the world's top volume producer of desalinated water, with a very economic solution for meeting its human water needs. Due to its already lower electricity generation costs compared to PV, CSP is less incentive-driven than PV[19]. But until fossil fuels are much more expensive than they are today, there is no "natural" market for CSP in Saudi Arabia, as the cost for conventional power generation is at USD 0.032/kWh. To create a market, some sort of incentive scheme will be needed, and Saudi Arabia has the financial strength to afford an incentive scheme. But more importantly, CSP is a local business. The establishment of attractive market conditions for CSP will lead to job creation in construction as well as local manufacturing opportunities, which can contribute to further economies-of-scale for CSP costs. A local solar industry would also help to alleviate Saudi Arabia's economic concerns, such as the high unemployment rate for young Saudis, the limited number of available high-tech jobs, and one-sided dependence on the oil, chemical and petrochemical industries.

Approximately 10% of Saudi Arabia's population does not have access to the national power grid. Providing them access could require up to 20,000 miles of new transmission lines. Medium-size HCPV projects might be the ideal solution for providing remote villages with electricity. HCPV, due to its modular nature, is also well-suited to support high electricity use complexes like hospitals or universities. Due to the high DNI in Saudi Arabia, HCPV will most likely also compare very favorably against dual-axis tracking silicon in solar farm installations.

Recognizing that the geographic conditions of Saudi Arabia might pose new challenges to the performance and materials of CSP and HCPV systems provides Saudi Arabia with the opportunity to establish itself as the hub for testing and certifying these systems under local conditions and for conducting research specifically tar-

[19] CSP: USD 0.17/kWh (Nevada Solar One)
PV: on average > USD 0.30/kWh

geted at making concentrated solar systems better suited for conditions in the MENA region.

Crystalline silicon, as well as thin-film technologies, can also contribute significantly to Saudi Arabia's future energy mix. Crystalline silicon, being the most widely used and most versatile solar technology, can be used in off-grid installations in remote villages, providing power to individual homes, and in huge ground-mounted solar installations, feeding electricity into the national grid. Crystalline silicon loses some of its efficiency at high temperatures, which will impair its performance under Saudi Arabia's conditions. By taking a new approach, like combining photovoltaic and solar thermal (PV/T), this disadvantage of silicon solar panels can easily be turned into a new market opportunity. Providing active water cooling for the silicon panels will keep the efficiency of the panel up, while at the same time providing hot water for domestic or commercial use.

Unlike crystalline silicon panels, thin-film solar modules do not suffer from efficiency loss at high temperatures and are, therefore, well-suited for applications in the MENA region. Thin-film technologies also hold great potential for building-integrated photovoltaics (BIPV). Glass facades doubling as electricity generating solar panels and solar-controlled window tinting can have great potential for new construction in Saudi Arabia.

2.4. Cluster development approach

Developing industry clusters thus represents exceptional opportunities on many dimensions. Above all, it provides opportunities to promote economic development, to increase a country's competitive position and, ultimately, to create high-level jobs. Focusing on the solar industry, a cluster will also allow support of the country's efforts in mitigating climate change and represents an investment in promising key future technologies.

2.4.1. Drivers for Cleantech cluster development

A cluster defines the geographical pooling of companies and also comprises associated institutions in a particular field. It not only includes companies along the entire value chain, but also suppliers and service providers, production sites, distribution channels, research organizations, universities and other educational entities from the same industry sector.

There are nine major drivers for Cleantech industry cluster development, which are dependent on political will and commitment:

- Strong domestic market driven by an attractive and reliable market incentive scheme
- Highly competitive investment incentives for manufacturing projects
- Existing industrial base conducive to Cleantech manufacturing
- Highly developed infrastructure allowing demanding production and logistics processes
- Relative cost advantage versus many competing regions
- High density of R&D institutions and universities facilitating knowledge transfer and specialist recruiting
- Public awareness for environmental and climate issues and strong support for renewables
- Cleantech-specific investment promotion and project management by industry experts
- Policy creation and institutional development

Only if all drivers are taken into consideration can ideal preconditions for the development of a sustainable cluster be established that will grow and further develop on its own in the mid- to long-term. Based on Apricum's work – particularly in site selection and in working with economic development agencies – and in order to generate optimal results for countries or regions, it has already developed and continues to suggest an integrated approach to Cleantech cluster development comprising the three pillars of *supply* (local manufacturing), *demand* (local market) and *R&D* as shown in Figure 31.

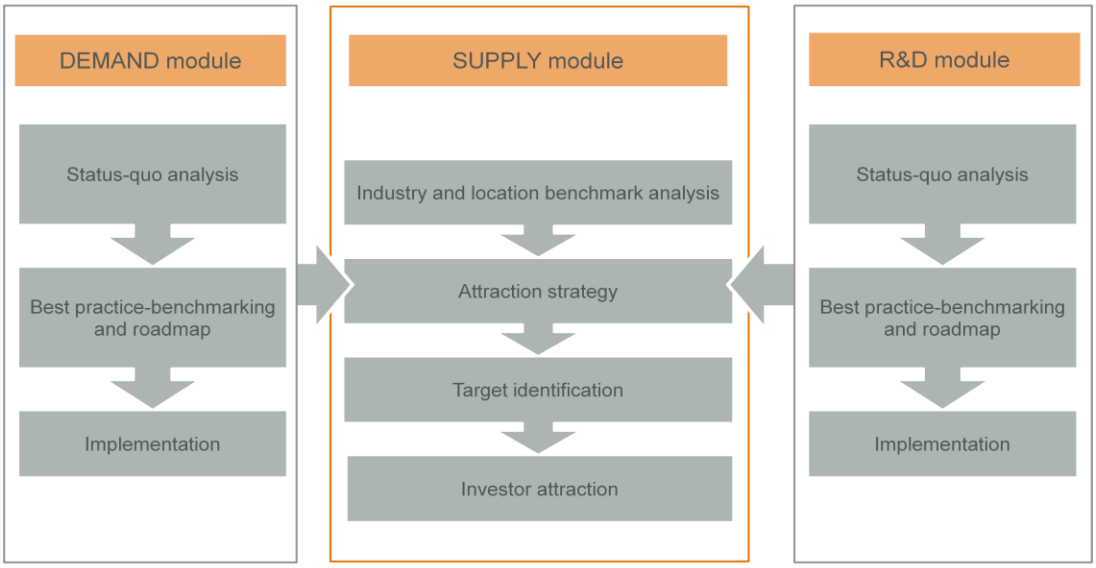

Figure 31: Integrated approach to cluster development

In conclusion, given the highly competitive environment worldwide to attract solar investment, only those countries and regions with comprehensive and targeted investment and policy strategies will benefit from the profitable growth and job creation prospects in solar.

3. Main part 1 – Solar manufacturing

The Saudi Arabia Solar Energy Study consists of the manufacturing and R&D pillars of Apricum's integrated cluster development approach. While the R&D pillar is described in detail in the subsequent section of this report, this part will focus on manufacturing.

The ultimate objective of this module is to attract international solar companies to locate manufacturing facilities in Saudi Arabia for three main reasons: creation of high value-added jobs in the Kingdom, knowledge transfer to the Kingdom, and diversification of the Kingdom's main export products. These reasons correspond directly with the strategic development goals set by the Ministry of Commerce and Industry. It is important to note that the results obtained here are valid at the time the study was compiled in the Summer of 2009, and is based on weight factors and assumptions made by Apricum for the purpose of quantifying and benchmarking different locations in the Kingdom.

3.1. Global benchmarking analysis

In order to be well-positioned for the recruitment of foreign direct investment in the solar environment, the first step for critical analysis was determining the location conditions of the leading industrial parks within the Kingdom and determining a benchmark for these sites versus other top locations for solar manufacturing worldwide. Additionally, it was necessary to identify potential shortcomings and, thereby, recommendations for improvement. The main advantages and unique selling points of Saudi sites in global competition were also determined.

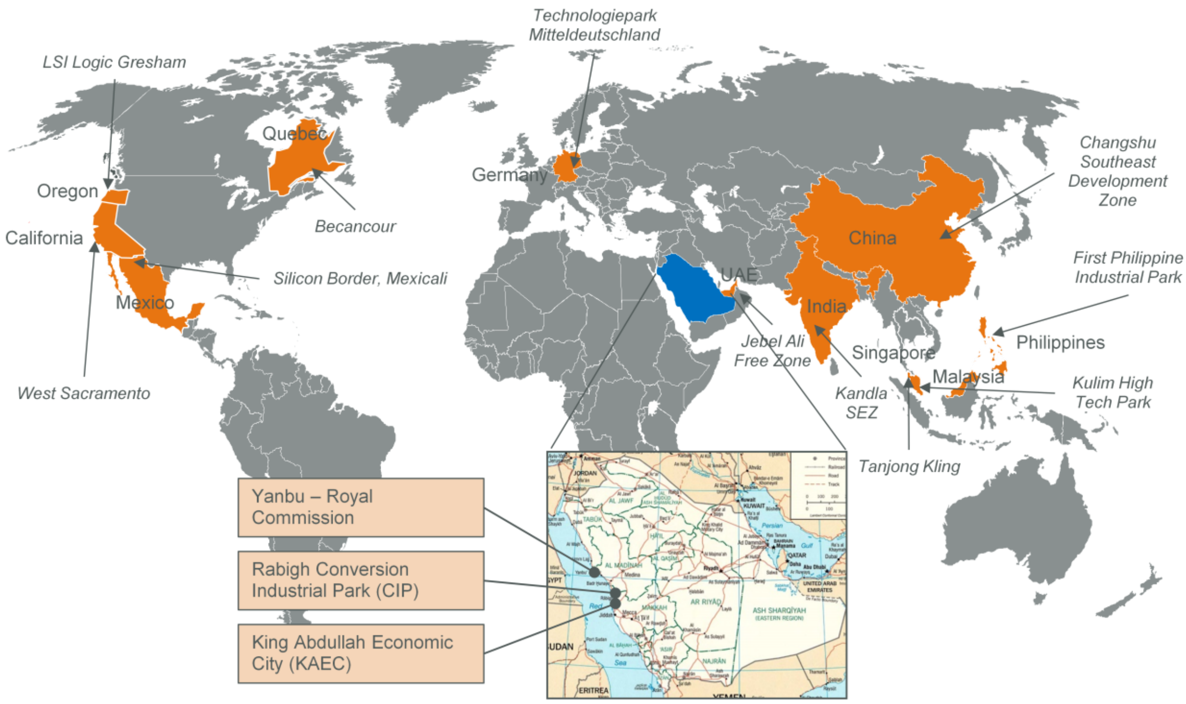

Figure 32: Location of global benchmark sites

Figure 32 shows the locations considered in the global benchmarking against sites in the Kingdom of Saudi Arabia.

The following three sites in Saudi Arabia have been evaluated:

<u>Royal Commission Yanbu</u>

The park is located close to the town of Yanbu, approximately 350 km northwest of Jeddah on the Red Sea coast. It has a total surface area of 158 km². Potential expansion plots for solar manufacturing lie adjacent to the main petrochemical site, which at the time of investigation was still under development. Yanbu currently hosts approximately 20 heavy hydrocarbon, petrochemical, and mineral facilities plus 37 light-manufacturing and support operations, which include glass manufacturing. The park also offers commercial and residential facilities and is accessible either via a six-lane main highway, the Yanbu national airport, or via an on-site container seaport.

King Abdullah Economic City (KAEC)

KAEC is located north of the Jeddah metropolitan area, directly on the Red Sea coast and in close proximity to King Abdullah University of Science and Technology (KAUST). It is a major development project with six districts including industrial, commercial and residential zones covering a total area of 168 km^2. It is currently under development and due to be finished by 2013. In early 2009, a few companies chose to locate themselves in the light industrial area (which has an industrial focus on plastics). The park is accessible via several multilane main highways, a future seaport within city boundaries, and the Jeddah International Airport.

Petrorabigh Conversion Industrial Park (CIP)

Petrorabigh Conversion Industrial Park is located approximately 120 km north of Jeddah on the Red Sea coast, adjacent to a large petrochemical site with more than 1,500 employees. The industrial area expands over 240 hectares. It is a recent development by Saudi Aramco and Sumitomo Chemical whose intended focus was on plastics conversion. Rabigh CIP is accessible via a six-lane main highway, through the Jeddah airport and seaport, as well as through the future KAEC container port.

The selection of Saudi sites for the benchmark analysis was made on the basis of short-term land availability and site readiness. The evaluation revealed that RC Yanbu and KAEC are, in principle, suitable for production facilities along the entire PV value chain. By contrast, due to park regulations, space availability and existing power capacity, as well as site management priorities, Petrorabigh is only suitable for PV module assembly. In the following benchmark, Petrorabigh was therefore only considered for that part of the value chain.

A typical site selection decision model for a solar manufacturing facility formed the basis of the benchmarking to ensure practical applicability of the analysis, see Figure 33. This model consisted of 30 criteria which were typically taken into account in the context of a location decision, grouped into the three blocked economic factors (quantifiable criteria), site-related factors (qualitative site issues) and environmental factors (general business and investment environment).

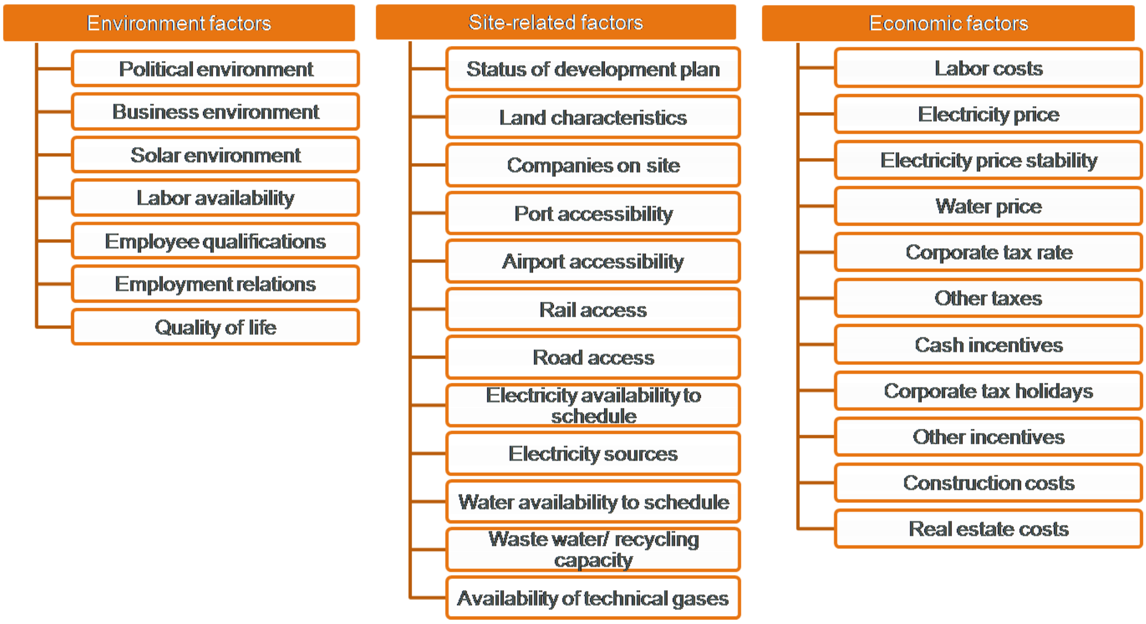

Figure 33: Criteria within the global benchmarking analysis

Data and information for the benchmarking was obtained from secondary sources as well as through first-hand experience during on-site visits in March 2009. The facts and figures gathered were verified in expert interviews carried out at various phases of the project. The full 'plus' incentives package, which is geared toward 'first-mover' investments and which was still under discussion at the time of writing, was assumed to be available for potential investors.

The benchmarking was done for every step in the crystalline PV value chain from silicon to module as well as for thin-film. While the criteria remained the same all along, their respective weightings were altered in order to reflect the differing requirements and priorities for production facilities as diverse as silicon, wafers, ingots, cells, modules and thin-film.

The outcome of this rigorous analysis was the competitive positioning of Saudi sites for hypothetical investment projects at every step in the PV value chain. This not only allowed the identification of 'best-fit' PV projects for the country but also for a detailed assessment of the performance of Saudi sites in a global comparison for every criterion under evaluation.

In essence, Saudi Arabia is best positioned to attract silicon and ingot/wafer projects. At this upstream part of the value chain, electricity costs and equipment depreciation are the main cost drivers, both of which can be addressed satisfactorily in the Kingdom by low electricity prices and "potentially" generous cash incentives. At the same time, the still virtually non-existent regional market for PV final products, which is of essential importance for projects further downstream, is not a decisive factor for silicon and ingot/wafer operations.

In terms of Saudi location performance, the main action items identified at all sites included the timely provision of sufficient and reliable electricity supplies and the transparency and speed of land allocation and plot readiness.

3.1.1. Outcomes in detail

A. Silicon

Silicon is the raw material for crystalline (wafer-based) photovoltaics and is essentially manufactured in a two-step process by refining suitable quartz sand first to low-purity metallurgic-grade silicon and then to high-purity solar-grade or polysilicon. Within the benchmark analysis, we focused on a typical polysilicon project as this is generally considered the first step in the PV value chain.

Top location criteria for silicon manufacturing:

- Electricity availability to schedule
- Electricity price
- Corporate tax rate
- Cash incentives
- Waste water/recycling capacity

The Kingdom's relative global competitive positioning is best for silicon manufacturing as compared to the remaining steps in the PV value chain. In the analysis, Saudi sites turned out to be cost leaders in comparison to the other locations, while simultaneously revealing lower ratings in site-related factors and in business environment factors.

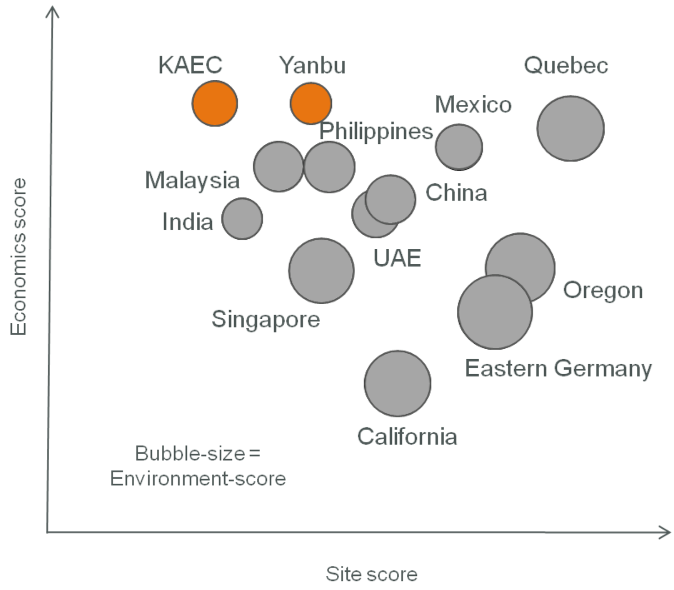

Figure 34: Cost-quality matrix for silicon manufacturing

Given the energy intensive manufacturing process, silicon production is heavily driven by electricity costs and availability. The reliability of a power supply (dual feed) is also key, as even short interruptions lead to costly downtimes in the production process. Saudi sites are among the world leaders with respect to electricity costs, although availability and reliability of supplies are issues of concern for the potential development of a silicon business in the country.

Moderate labor costs, in a global comparison, are a further advantage that potential silicon projects stand to benefit from in the Kingdom. Combined with low electricity costs and potential cash grants to lower costly equipment depreciation expenses, this package offers Saudi Arabia the realistic possibility to become one of the cost leaders for this industry worldwide, Figure 34.

The existing strong base of (petro)chemical manufacturing in the country, particularly in Yanbu, is a further asset to attracting upstream solar manufacturers since – unlike the downstream steps in the value chain – a silicon plant is essentially a chemical facility. This plays out not only with regard to an obvious readiness of domestic sites for such facilities (size, regulations and restrictions concerning noise, materials handling, waste management, etc.), but also in terms of permitting experience of authorities, supplier and services infrastructure, labor skills, exemplary ‘success stories’, and public acceptance.

Further facilitating Saudi competitiveness for silicon manufacturing is the fact that silicon projects have the longest lead times within the PV value chain: approximately 2-3 years until the start of production. This offers an ample timeframe to set up necessary administrative procedures and to bring the utility situation up to standard in parallel with the construction process.

While the existence of a local/regional sales market is of increasing importance for cells and especially module manufacturers, the polysilicon market is global because there are relatively few large-scale facilities worldwide and transportation costs relative to product price for silicon are particularly low. The lack of a substantial current market for PV products in Saudi Arabia and the MENA region thus favor the Kingdom for the upstream part of the value chain.

B. Ingots/wafers

Depending on the process used, ingots are either cast or pulled from molten polysilicon, have either a square or cylindrical shape, and weigh several hundred kilograms. The ingots are then put through a sawing process and sliced into wafers. These two steps are typically performed at the same facility, although they can be done separately; ingoting can alternatively take place as the final step at a silicon plant, or even in a stand-alone facility, which is, however, relatively rare.

Top location criteria for ingot/wafer production:

- Electricity availability to schedule
- Electricity price
- Labor costs
- Corporate tax rate
- Cash incentives
- Employee qualifications

Saudi Arabia's relative competitive positioning for ingot/wafer production is second best after silicon manufacturing. The benchmark analysis proved the potential to be featured among the global cost leaders for this segment. As argued in the previous section, qualitative site factors should be optimized to achieve best-in-class.

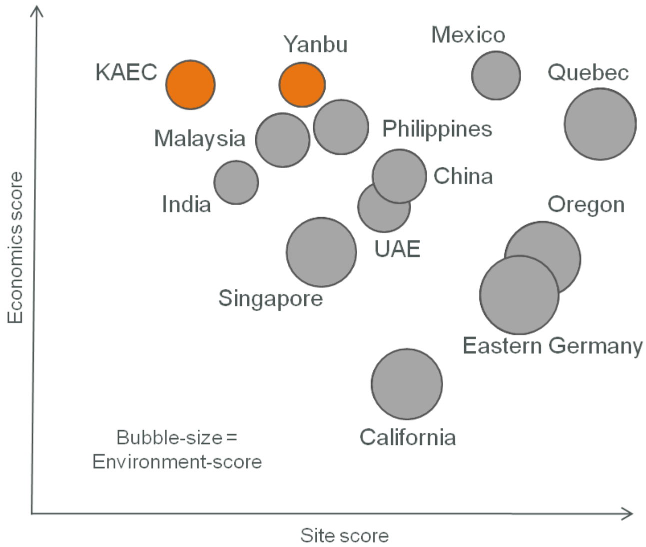

Figure 35: Cost-quality matrix for ingot production

It will become apparent that the factors favoring Saudi Arabia for ingot/wafer manufacturing are, to a considerable measure, similar to those for silicon manufacturing (as seen in Figure 34). This is due to an overlap of various decision drivers for projects at both parts of the value chain. From an inside-out perspective, however, ingot/wafer operations are more desirable for the Kingdom as they tend to have a greater employment effect per unit of output and allow for an increased downstream industrial development of the country. This is a strategic goal which has been formed by a variety of entities throughout the project.

As with silicon manufacturing, ingot/wafer production is a highly energy intensive process. Therefore, affordable electricity prices are among the prime concerns of companies making a site decision for ingot/wafer plants. As pointed out above, the Kingdom's highly competitive power rates on a global scale are a clear advantage over competing locations and of high relevance for projects at this step of the value chain, this is shown in Figure 35.

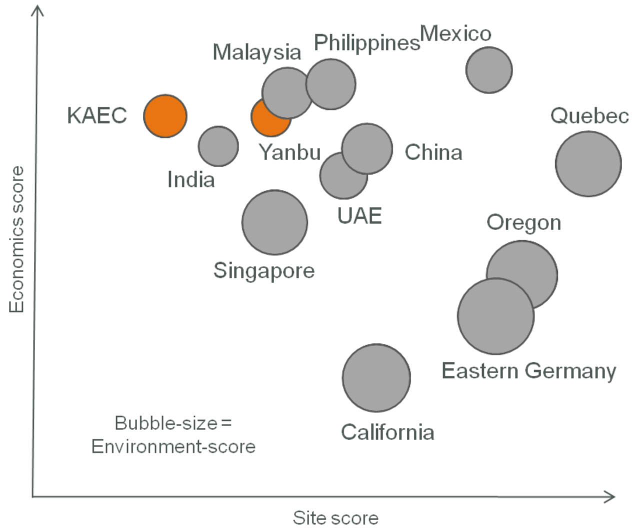

Figure 36: Cost-quality matrix for wafer production

Also similar to silicon production is the high capital expenditure for an ingot/wafer operation a shown in Figure 36. This gives cash grants, as available in Saudi Arabia, an edge over tax holidays, as offered at most competing locations as an investment incentive, given that the former has a direct effect on equipment depreciation expenses.

Moreover, ingot/wafer projects have relatively low demands on local supplier infrastructure compared to cell, module or thin-film production, making them easier to implement. Aside from silicon as the raw material, production inputs are largely limited to quartz crucibles, wire saws and slurry, while downstream steps require a variety of specialty gases, chemicals and production materials that cannot be easily or economically stored on site in large quantities.

The ingot/wafer step of the PV value chain is potentially a strategic one for Saudi Arabia. On the one hand, it can potentially benefit from, and draw on, an expected domestic silicon production. (At the time of writing, a number of projects were in planning.) At the same time, it is the link to the downstream development of PV manufacturing in the Kingdom. While a domestic/regional market in the Kingdom and other Gulf countries will ideally be developed within the next 3-5 years, solar wafers are products that can easily be shipped and exported overseas in large quantities in anticipation of the foreseeable emergence of a domestic demand.

Ingoting and wafering are also considered to be the most IP intensive parts of PV manufacturing. These two steps have a decisive effect on module performance and, on average, require a higher share of engineers in the production process, thus contributing strongly to technology transfer to the Kingdom.

C. Cells

In the next step of the production process, wafers are turned into cells. This involves various phases of surface treatment of the wafers such as texturization, diffusion, coating, the screen printing of contacts, passivation, sintering, testing and sorting, typically in an in-line process.

Although still in a relatively good cost position, sites in Saudi Arabia perform below-average in both site-related and environmental factors, and its economic position also deteriorates as compared to silicon, ingot and wafer production. This is largely due to the higher site-specific demands of cell production and the lower importance of electricity costs as a share of the total costs in comparison to the front-end of the value chain, Figure 37.

Top location criteria for cell production:

- Electricity availability to schedule
- Employee qualifications
- Status of development plan
- Labor availability
- Corporate tax rate
- Availability of technical gases

In order to maximize economies-of-scale, new cell plants are typically planned for several hundred megawatts of production capacity. At these volumes, on-site storage of input materials, essential chemicals and process gases becomes costly and complex, and manufacturers opt for a regular flow of supplies or even just-in-time service. This is often a challenge for locations without a strong industrial base given the lack of an existing local demand for such products which then have to be sourced from overseas; this is particularly pronounced for specialty gases, such as argon, ammonia and dopant mixtures.

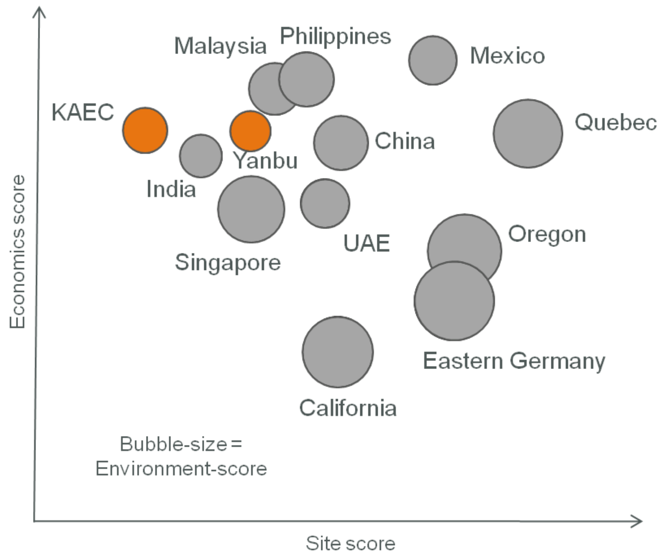

Figure 37: Cost-quality matrix for cell manufacturing

PV cell production also requires a large number of highly qualified blue collar workers with backgrounds in electronics, mechanics, and advanced chemicals manufacturing, which was found in the Kingdom to be limited.

While a local/regional end-user market is not essential for cell manufacturing, because cells are not final products and can be shipped relatively easily and economically, a sizable cell production facility that is entirely dependent on imports for raw materials (i.e., wafers), largely dependent on imports for production materials (as described above), and entirely dependent on exports for sales is a hard sell in the current environment of global over-capacities.

Finally, time-to-market has been an important consideration in the location decision for new PV cell plants, which has shown project lead times of less than one year from decision to the start of production. However, this is only possible in locations that require little or no further (infrastructure) development such as land preparation, utility upgrades, supply chain solutions, local service availability, etc. While this can and will happen in the Kingdom, there is a higher degree of uncertainty here than in some competing locations which have better pre-existing conditions and can, as a result, confirm a more feasible time plan.

D. Modules

The final step in the wafer-based PV value chain is module assembly. At this stage, cells are strung together, front- and back-foils as well as a glass cover are applied and laminated, and a frame and junction box are added. Finally, modules are tested and sorted according to their performance. Module assembly is thus essentially a mechanical process.

Top location criteria for module assembly:

- Labor costs
- Status of development plan
- Labor availability
- Solar environment
- Port accessibility
- Corporate tax rate

Although module assembly can be designed as a fully automated in-line process, a manufacturing approach with a considerable manual labor input is often opted for, given the relatively trivial and uncritical processes and in order to avoid high capital equipment costs. Coupled with relatively low labor skill demands, limited economies-of-scale and the products' bulky nature, module lines tend to be set up in, or in close proximity to, end-user markets. This is clearly not the case for Saudi Arabia and the surrounding region; this is shown in Figure 38 below.

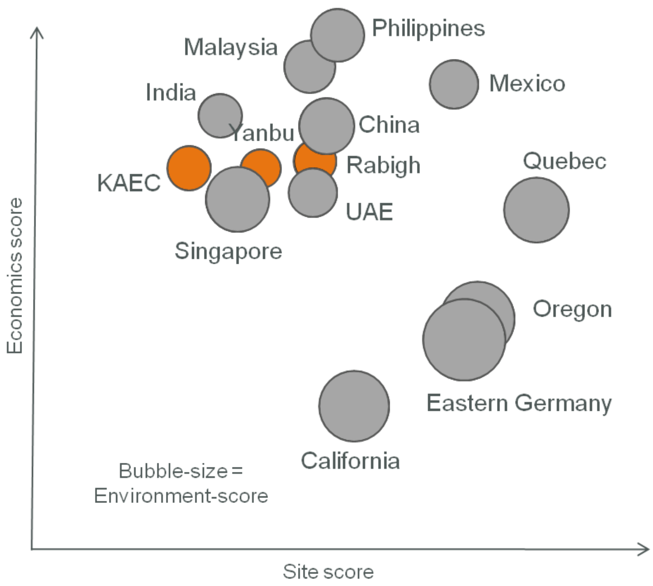

Figure 38: Cost-quality matrix for module assembly

Another reason for suboptimal performance of the KSA locations for module assembly is the relatively low capital expenditure for this type of operation and thus the low importance of equipment depreciation on operating costs. As a consequence, while potential cash incentive programs available in the Kingdom are highly attractive by international standards, they do not have a comparable impact on a module project as they do on projects at other segments of the value chain.

On a positive note, the three sites that were evaluated in Saudi Arabia are all well-prepared for module manufacturing, especially at Petrorabigh. This has to do partly with the low site demands for such a facility in terms of permitting, utilities and labor, but also with their favorable accessibility and 'shovel-readiness' for a module operation.

Another 'plus' is the potential local sourcing of glass from within the Kingdom, which is the heaviest and most costly input for module assembly.

E. Thin film

Aside from the wafer-based value chain, various thin-film PV technologies exist for standard glass modules and are being manufactured at an industrial level. Given their similarities to the production process and the location requirements, they were analyzed jointly in the context of the benchmark analysis.

In contrast to crystalline silicon modules, which – as outlined above – are produced in various steps that are often geographically separate from each other, the value chain for thin-film modules (practically) involves only a two-step process: the first one is the production of the glass, which becomes the substrate itself, and the second step is the coating of the glass with a semiconductor material followed by the finishing of the module. Rather than a back sheet, front glass and aluminum frame, as in the case of crystalline modules, thin-film modules have a front and a

Top location criteria for thin-film manufacturing:

- Labor availability
- Status of development plan
- Utilities availability to schedule
- Solar environment
- Port and road accessibility
- Corporate tax rate
- Availability of technical gases

back glass (and therefore require roughly double the amount of glass for the same module surface area as wafer-based modules) and can be frameless.

A thin-film operation thus results in a final product. Although economies-of-scale are considerably larger in thin-film production than in crystalline module assembly (which could be an argument for centralized production not necessarily close to end-user markets), thin-film modules tend to be even larger (currently up to 5.7m²) and therefore heavier and bulkier. At the same time, their production is far more automated, so facilities are typically located in or near important markets.

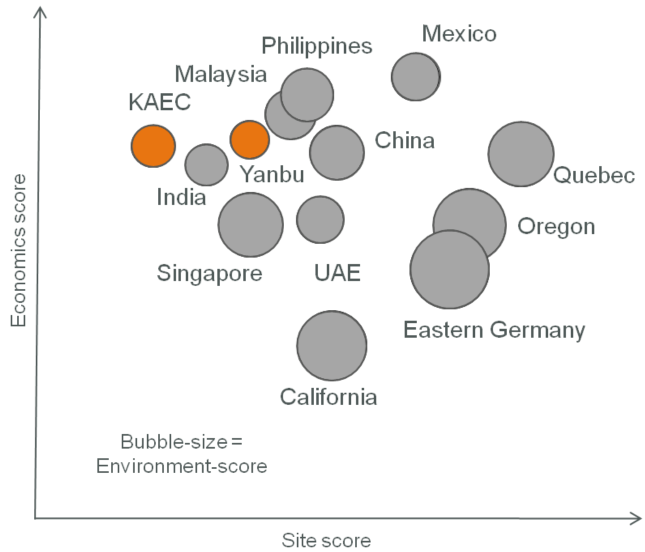

Figure 39: Cost-quality matrix for thin-film production

Similar to cell manufacturing, thin-film operations require a relatively sophisticated site infrastructure, especially with regard to electricity and other utilities as well as specialty gases. Silane gas, for example, is currently needed for the most common thin-film technology and is produced only at a handful of locations around the world. For this reason, most thin-film manufacturing facilities have thus far been set up in established higher-cost locations, as well as in Asian regions with existing microelectronics and flat panel display activities, sharing a number of location requirements with thin-film PV, this is reflected in Figure 39.

Nonetheless, while the Kingdom's current global competitive positioning is better for silicon and ingot/wafer production, there are several factors that potentially favor the country as a location for thin-film manufacturing. Aside from inexpensive electricity, which can become a considerable operating expense in absolute terms for large thin-film facilities, other favorable factors are the potentially attractive cash grants for this capital intensive segment, spacious and flexible production plots and, particularly, local (in the case of Yanbu, even on-site) glass production. This last point is a potential 'big winner' because glass sourcing is a key issue in the thin-film supply chain.

F. CSP

Top location criteria for CSP manufacturing:

- Solar environment
- Road accessibility
- Labor availability
- Corporate tax rate
- Availability of technical gases

Aside from PV, which was the focus of global benchmarking, discussions in the context of the project have pointed to the fact that conditions for concentrated solar power (CSP) and manufacturing of related parts are also potentially favorable in the Kingdom. This is due first to CSP production being heavily driven by local/regional markets. Following this logic and given their potential for solar power plants, Saudi Arabia and the Gulf region clearly provide interesting destinations for CSP manufacturing plants. Secondly, there is a good fit with existing domestic manufacturing capabilities, especially related to glass, aluminum and cement.

For commercial use, concentrated solar thermal power (CSP) needs to be deployed in regions with direct normal irradiation (DNI) in excess of 5-6 kWh/m2/day (or > 2,000 kWh/m2/year) – the "Sun Belt" between 35° latitude south and north – can potentially be very interesting for Saudi Arabia. Much more than any of the PV technologies, CSP is a local business. Typically, CSP installations of at least 50 MW per year are the threshold for companies to establish local assembly and manufacturing concerns. The establishment of attractive market conditions for CSP is therefore a prerequisite for job creation in the construction area as well as in the areas of local assembly and manufacturing.

CSP can provide many opportunities for the existing local industry base in Saudi Arabia, as glass, aluminum, steel, and cement are some of the main inputs for CSP installations.

A CSP plant can be broken down in the solar field and the power block. Especially the components of the solar field lend themselves to local manufacturing, whereas the components of the power block, such as the steam turbines, will most likely be imported.

Major components of the solar field are the collectors, the system components and the support structure. The collector contains the reflector (mirror) and the receiver.

Typically, the reflector is comprised of a substrate (glass, aluminum, steel) with a reflective and a protective coating, and is bent into shape. Both coatings can be applied by sputtering and would primarily require certain gases and the sputter targets as material input.

The receiver or absorber is typically stainless steel tubing with an absorptive coating and protective glass tubing with anti-reflective coating. Receiver manufacturing will be done locally, as is exemplified by the fact that both major receiver manufacturers (Schott and Siemens-Solel) have established receiver manufacturing plants close to today's primary CSP markets: Spain and the southwest area of the United States.

The number of components required for a typical 50 MW parabolic trough plant (example: Puertollano, Spain) demonstrates nicely why CSP is a local business. The solar field requires 352 collectors, each measuring approximately 150 meters in length. Each collector contains 12 modules 12 meters in length, comprising 28 mirrors and 3 absorber tubes. This totals 120,000 mirrors and 12,700 absorber tubes, equating to about 50 km of absorber tubing.

3.2. Target segment prioritization

The benchmarking thus clearly demonstrates a relative advantage of the Kingdom as a manufacturing location for the upstream part of the PV value chain (silicon, ingots, wafers). Adding to the picture of the current solar industry situation and its anticipated development over the coming months and years, the following prioritization of target segments for solar investment attraction has been developed. This is summarized in Figure 40.

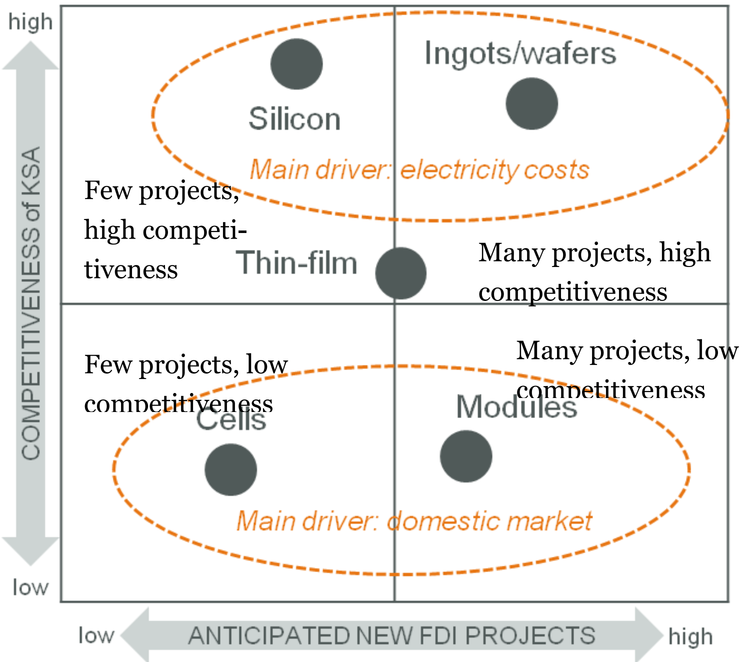

Figure 40: PV segment assessment based on location competitiveness and investment potential

Priority 1: Ingot/wafer facilities

Saudi Arabia's relatively competitive positioning for ingoting and wafering operations is favorable and only slightly behind that for silicon. Nonetheless, this segment should be the prime focus of a short-term investment attraction. Aside from positive location factors, this is first due to the excellent fit with the desired downstream industrial development in the Kingdom in terms of value added manufacturing as well as technology transfer and local IP development.

It is also, however, more promising to consider the likelihood of success given that there will be a higher number of potential new projects in the upcoming months in ingots and wafers than in silicon as the PV market continues to grow with the recent announcement that silicon capacities will be coming online. While downstream cell and module capacity utilization are currently relatively low and a considerable share of the expected demand growth will be covered by existing facilities, the need for more capacity is most acute at the ingot and wafer level. Coupled with favorable conditions for this type of manufacturing in the Kingdom, as described in detail above, this situation offers a window of opportunity for Saudi Arabia to lay the foundation for a domestic solar industry.

Priority 2: Silicon plants

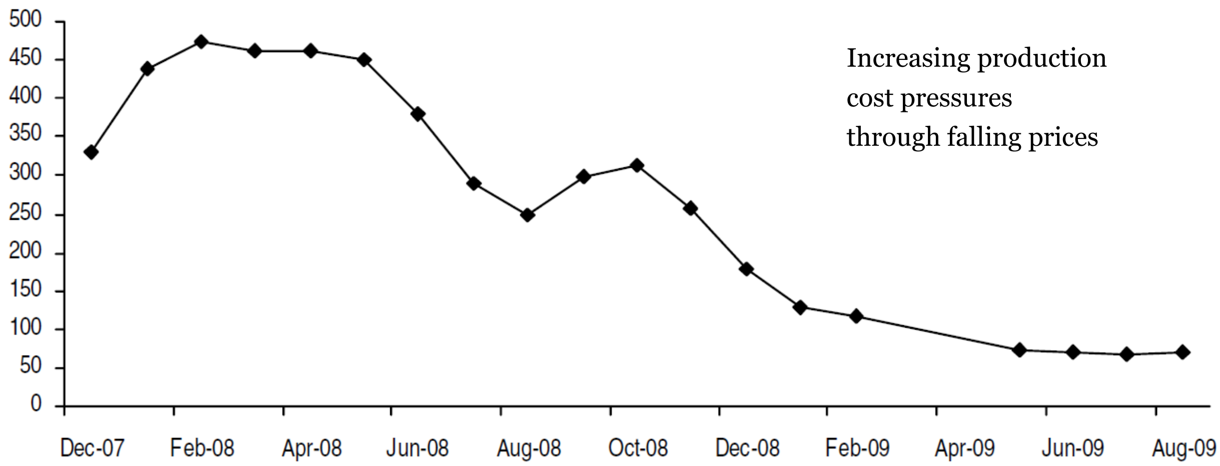

Figure 41: Average polysilicon spot prices [US$/kg] (Source: HSBC)

As apparent from the benchmark analysis, silicon production offers the best fit with existing location conditions in Saudi Arabia. However, given the demand boom in the PV industry in the last two to three years, and the long project lead times for silicon operations, a large number of investment and location decisions have already been made in this segment, both by established players in the market as well as by newcomers. While in all likelihood not all of the announced projects will be realized because of a recent sharp drop in polysilicon pricing, Figure 41, and a lack of expertise by those companies that have not previously been active in the field, high capacities will be coming online worldwide in next few years. The likelihood of new silicon projects in addition to those already being planned is thus limited. On the other hand, increasing cost pressures for silicon manufacturers due to rapidly falling spot prices throughout 2009 could support the Kingdom as one of the potential cost leaders globally for silicon production, particularly as the site selection of some of the announced projects could be revisited in the light of recent market developments.

Priority 3: Thin-film and CSP manufacturing

While not a strong short-term priority given current market conditions in the Middle East region, thin-film and CSP manufacturing could become high potential segments as soon as concrete steps toward solar market development are taken either within Saudi Arabia or by surrounding nations. This is particularly true if, by that time, some of the qualitative location deficiencies will have been resolved (see next section). For thin-film, this was demonstrated recently by First Solar's announcement of a new manufacturing facility in France following a long-term module off-take agreement with a local utility company.

In contrast to wafer-based modules, both thin-film and CSP applications are particularly relevant for large, centralized solar power plants in sunny and warm conditions without surface area limitations. Hence, this is exactly what Saudi Arabia could potentially offer and develop rapidly.

Priority 4: Cells and modules

PV cell and module manufacturing are not short-term priorities for the Kingdom. As pointed out above, these downstream steps of the value chain are strongly driven by market access, and location factors are relatively worse in Saudi Arabia than for silicon and ingot/wafer production. At the same time, module manufacturing is largely about lower-tech assembly work. It is therefore not highly desirable for the country as far as industrial development is concerned. It is also not very capital intensive and therefore is the most 'mobile' segment of the value chain in terms of location, which limits its appeal for the Kingdom with regards to sustainable job creation.

From a market and project perspective, these two downstream segments have also been recently characterized by low capacity utilization. Although visibility in the industry is currently rather limited, and cell projects have short lead times and capacities can adapt to market conditions quickly, it is unlikely that many cell manufacturing projects will be seen in the foreseeable future. While on the other hand several smaller module assembly projects are anticipated in the nearer future, these will be motivated predominantly by the emergence of new global markets (themselves often triggered by support programs), some of which will have soft or hard local content requirements.

3.3. Site improvements

The benchmark analysis not only delivered Saudi Arabia's competitive positioning for manufacturing projects at the different steps of the PV value chain but also revealed several points for improvement regarding Saudi industrial parks through the evaluation of site-related factors. While concrete recommendations were made for Yanbu and KAEC, many of the items identified can be applied to other locations as well, under the presumption that these two parks are among the most advanced industrial sites in the Kingdom.

Saudi sites can attest to having good – and for some segments even leading – performance across the board concerning cost factors. Performance with regard to environmental factors was less favorable.

However, these are more general and macro-level considerations and are typically difficult to change, at least in the short- and medium-terms. A few issues that can be actively approached in this context are outlined at the end of the chapter. The main dimension, in which the Kingdom currently underperforms but which can – and should be – improved in the short-term, are site-related factors.

3.3.1. Site-related factors

Looking at site-related factors one by one, some main action items were identified:

- The timeline of land preparation for a potential investor and the administrative processes that are required are not transparent.

Apricum suggests providing straightforward information on the zoning of potential plots as well as on potential red lines for production activities (times, noise, building height, chemical storage, etc.). There needs to be a clear indication of necessary administrative steps for land allocation, including timing, costs and required information from the investor. It is also worth considering offering 'guaranteed fast-track permitting' and executing all pre-zoning and investor-independent administrative steps in order to speed up the process and not have such procedures negatively affect the planned project timeline. A soil analysis is another typical item that can be done relatively easily in advance.

- Currently available electricity supplies are insufficient for most PV projects and the reliability of supplies is questionable.

Reliable electricity supplies are a critical item in the evaluation of any site for PV manufacturing, with the exception of module assembly. Apricum recommends the clear determination of existing excess capacities of substations at the sites and the working out of an indicative timeline and cost estimate for necessary infrastructure upgrades to supply at least 20-40MW (dual feed) within one to two years. It is also helpful to be prepared to make commitments with regard to power supply as well as long-term pricing, and to be able to answer questions on approximate expected costs of upgrades to the investor.

- Availability and capacities of other utility supplies, such as water, wastewater, and solid waste management, proved to be somewhat unclear.

Ample and reliable utility supplies are essential to ensure a smooth production process without costly interruptions. Apricum suggests including utility supply connections (except electricity) to the investor's specifications in the land price at all Saudi sites and a commitment to quantities and timelines vis-à-vis investors.

- There is a complete lack of general upfront provision information on the Internet.

The likelihood of the inclusion of Saudi sites in potential site-selection projects in solar and other industries increases with the amount and quality of information that is made freely available online and with the grade of transparency of existing site conditions. Apricum thus recommends a considerably enhanced Internet presence for the main industrial sites with detailed information about site-related factors (especially utilities and plot availability) and business costs, as well as more comprehensive and up-to-date information on the general investment environment in the Kingdom.

Industrial parks under development should specify work that is being carried out and provide details on the timeframe for further work and planned completion state.

- No rail access exists at any of the sites under evaluation.

While rail access is not typically a decisive criterion in PV site selection, and road access is well-developed and uncongested to the sites under review, a duplication of supply and delivery routes by another means of transport will be considered advantageous. Potential rail access to the main industrial parks should thus be assessed.

A timely tackling of the factors outlined above is feasible and will lead to a decisive improvement of the Kingdom's performance in a solar manufacturing site selection. Some further criteria within site-related qualitative issues are more difficult and/or less urgent to change, such as existing companies on site, international (air) access from overseas, sources of electricity generation, and availability of specialty gases. Still another set of criteria does not require immediate attention because Saudi sites are already fulfilling them satisfactorily, such as accessibility by road and seaport access.

3.3.2. Environmental factors

As mentioned earlier, environmental factors are mostly outside the direct influence of individual entities and decision makers and changes in this area are more long term. This does not mean that nothing can be done; however, we have generated several ideas on how a negative judgment of some environmental factors in a solar site selection can be counteracted, many of which boil down to demonstrating a 'micro environment' different from – and more favorable to – the general investment environment. This is due to the fact that many of the environmental factors (especially employment related) are at least partly revisited and reassessed on a micro level during and after initial site visits.

The solar environment offers the highest potential short-term leverage of all environmental factors given the incentive-driven nature of the industry – provided there is political will. In principle, this would entail the introduction of a subsidy or support mechanism for the deployment of solar installations in the Kingdom. It is referred to as the 'demand' pillar in the cluster approach (described in more detail in the introduction).

During site visits, labor availability is assessed on a more micro level as compared to the desk research phase in a site-selection project. At this stage, the outcome for potential sites in Saudi Arabia can be positively influenced by demonstrating (in a convincing manner) the existence of oblique labor pools, such as commuters and foreign workers – not only qualitatively but backed by facts. This can act to mitigate a potential negative judgment of these issues in the initial data collection phase.

In terms of employee qualifications, the demonstration of credible capabilities and readiness to introduce tailor-made training programs at local education institutions will lead to an improved assessment of this factor in the detailed site evaluation. Providing up-to-date input on the latest developments within the country, such as the inception of KAUST, which is not yet reflected in statistics or secondary sources, will add a further positive spin.

The scope of action may be limited on the quality-of-life assessments. Nonetheless, 'micro-environments' with a higher-than-average quality of life can be created to offset a purely national-level assessment. This could be the case for large-scale industrial parks with on-site housing and commercial offerings, such as RC Yanbu, and even more so for new 'microcosms' such as King Abdullah Economic City and KAUST.

3.4. The Kingdom's value proposition

Based on insights from the evaluation of Saudi sites and the global benchmarking, as well as on our in-depth understanding of the solar industry and site-selection projects in that business, three priority arguments have been singled out as 'unique sales propositions' for the country in the context of solar manufacturing investment attraction: financing/incentives, electricity costs, and the Kingdom's track record of foreign direct investment (FDI) attraction to-date.

Argument 1 – Financing/incentives

Incentive and financing options provide top arguments for Saudi Arabia as a location for PV manufacturing and should therefore feature prominently in investment attraction efforts. In the current economic environment of difficult debt financing and the solar industry context of tight cash, access to financing is among the dominant concerns for solar manufacturers. Local financing options in Saudi Arabia through low-interest loans and strong potential local equity partners are a clear competitive location advantage and can act as an 'attention-catcher' for the Kingdom among solar companies – not only, but particularly, in the current landscape.

Argument 2 – Local engineering talent pool and scientific/technical support

The inception of KAUST has pushed this point to a higher scale in the Kingdom. Any major investment in manufacturing needs to have, not only the proper pull (demand), but also the ability to feed this investment with high caliber engineers from the local market. Also, KAUST provides applied research, problem solving oriented capability (Core labs, etc.), which are important in supporting existing or new industry in the Kingdom.

Argument 3 – Electricity costs

Electricity costs should be the second priority selling proposition since they contribute considerably to an outstanding cost position and provide a clear-cut and easy-to-communicate advantage for Saudi Arabia, as shown in Figure 42.

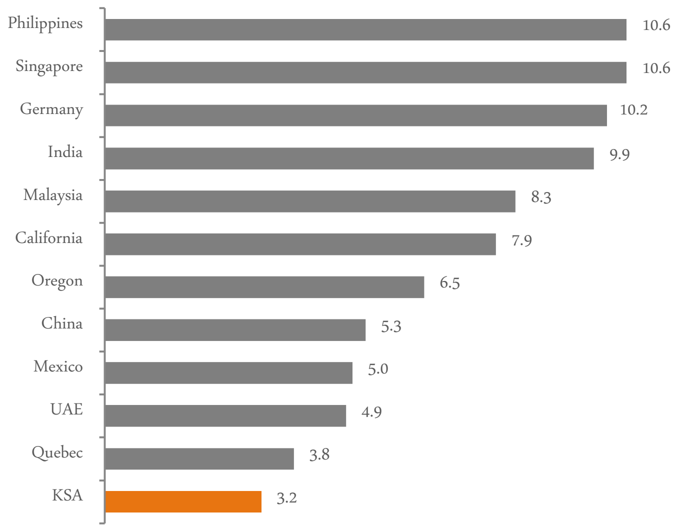

Figure 42: Electricity price for large industrial users [US$ct/kWh, 2008]

It has already been mentioned that Saudi Arabia's electricity costs for industrial consumers are among the lowest in the world. At the same time, electricity is one of the main cost factors in solar manufacturing, particularly in the upstream part of the PV value chain. It is thus straightforward to promote electricity rates as an argument for the country as a manufacturing location. Additionally, a relatively high degree of stability can be expected concerning future electricity price development in the Kingdom as a consequence of the domestic nature of fossil fuel reserves and energy generation, and non-dependence on imports.

Argument 4 – Track record of FDI attraction

Verifiable success stories of foreign companies in Saudi Arabia are the third cornerstone of the Kingdom's value proposition for solar investors. They underscore the credibility of the arguments for Saudi Arabia and facilitate trust building in local conditions.

References to other foreign investors are important indicators for the validity of Saudi Arabia's value proposition, especially with regard to labor issues and experiences with local partners. This effect is especially pronounced if the company that is being showcased is from the same or a similar cultural background and from a similar industry as the potential new investor.

Foreign investors have so far mainly been active in the Kingdom due to available raw material supplies (especially oil and gas). Nonetheless, their declared presence in the country, which should be communicated in the first phases of a project, and their positive experiences, which should be tapped at a later project stage (e.g., during a site visit), are valuable inputs for new potential clients given the exceptionally low familiarity of international solar companies with investment and location conditions in Saudi Arabia. Such an information exchange can beneficially influence both potential investors as well as previous FDI success stories. References of success stories should thus be proactively presented and interviews with trusted individuals at these companies should be offered.

3.5. Outlook

The four points outlined in the previous section are currently the main differentiators of Saudi Arabia as a location for the solar industry. They should, therefore, be the top arguments in investor attraction efforts in this industry. Nevertheless, site-related factors should be worked on in parallel, along with the indicators mentioned above. Once first results and improvements become apparent, the Kingdom's value proposition can be revisited and potentially reformulated to match the new conditions.

In the context of the study, the entire project methodology and procedure, as well as the outcomes and conclusions, were repeatedly put to practice tests in interviews and meetings with solar companies from around the world. For the most part, their feedback validated and confirmed the insights and results obtained during the course of the project. Inasmuch as they differed, this feedback is already contained in the outline above.

Discussions were held with a total of 17 companies of different sizes and origins and from all parts of the solar value chain. Besides receiving valuable input from them, a number of concrete leads for potential solar manufacturing investment projects in Saudi Arabia were generated as a result of these efforts, thereby, in principle, confirming the attractiveness of the country as a location for solar manufacturing.

3.6. Roadmap

Saudi Arabia has the potential to become a major solar player in the medium and long term if the efforts that have been started will be pursued consistently and intensified. The improvement of site-related factors and the conception of a domestic demand support program to ignite a local market for solar deployment are the two most important cornerstones in this respect and at the same time the main action items for the next one to two years.

Opportunities for the Kingdom to thrive as a solar location look all the more favorable as the solar industry is currently in a turnaround phase from a new boom business characterized by exponentially growing, relatively small and young companies, many of which have been completely driven by entrepreneurialism and idealism, to a more mature and established industry with fewer but bigger players, proven products and slower – but still highly attractive double-digit – growth rates. The consolidation process, which has only just started, will likely give way to a phase of more sustainable growth of the surviving companies.

This provides new opportunities also for locations that have so far not been in the limelight of the industry, where those regions which are seen to provide a major future market, will have higher chances to be among the winners. The Gulf Region, in general, and Saudi Arabia in particular, have the potential to put themselves into this spot if the right decisions are made in the coming months and years.

A potential scenario for the future development of the solar industry in the Kingdom could look as follows:

3.6.1. Short-term potential

In the short-term, defined here as two years, it is realistic to expect the recruitment of two to three PV manufacturing projects (silicon, ingots/wafers, possibly thin-film) to the country, involving $200-500 million capex each and >1,000 jobs total.

It is also feasible to attract one CSP production project (>50 MW), provided one or more solar power plants will be commissioned in the Kingdom.

3.6.2. Medium-term potential

Over the next three to five years, further downstream development of the PV value chain in the Kingdom can be achieved if the market is developed in parallel. This could mean at least one cell and one module manufacturing project.

In this timeframe, it is also realistic to expect the evolution of a true solar industry ‘cluster’ in the country, involving two to three leading R&D institutes, two to three industrial parks and several manufacturers and installers.

3.6.3. Long-term potential

Five years and more from now, solar has the potential to become one of the main industrial pillars of Saudi Arabia with approximately 50,000 jobs, US$10 billion in sales and an export share of more than 50%. Thereby, the industry can act as a pioneer for the downstream industrial development of the country more generally. By that time, 2/3 of local demand could be covered by domestic production. Further into the future there is potential for Saudi Arabia to become a solar energy exporter through large-scale installations and initiatives such as DESERTEC.

4. Main part 2 – Solar R&D

4.1. Relevance of solar R&D

Although the sun has been utilized by mankind for several purposes since the Stone Age, electric power generation by solar is a comparably young technology. Hence, solar technology still bears significant potential for improved research, development and demonstration activities..

Of course, R&D activities are not of value inherently, but due to the fact that they are inevitable for the manufacture of useful applications, thus the augmentation of welfare.

In the solar context, R&D activities mainly aim at enhancing the performance of solar products (referred to as efficiency) and driving down costs. From the background of the harsh environmental conditions for solar applications in Saudi Arabia, solar R&D and development activities shall additionally help make solar products resistant to these conditions.

Precisely, solar R&D activities in the Kingdom are necessary for two major reason: first, to help make the country a preferred solar manufacturing location leading not merely in terms of cost, but mainly in terms of quality aspects, such as proficiency of staff and know-how in manufacturing processes; secondly, to develop solar applications operating smoothly under specific climate conditions by meeting the requirements to enhance the welfare of the Saudi society.

4.2. Selection of solar technologies and research fields

There is a variety of solar technologies in both the photovoltaic and thermal technologies, this is shown in Figure 43.

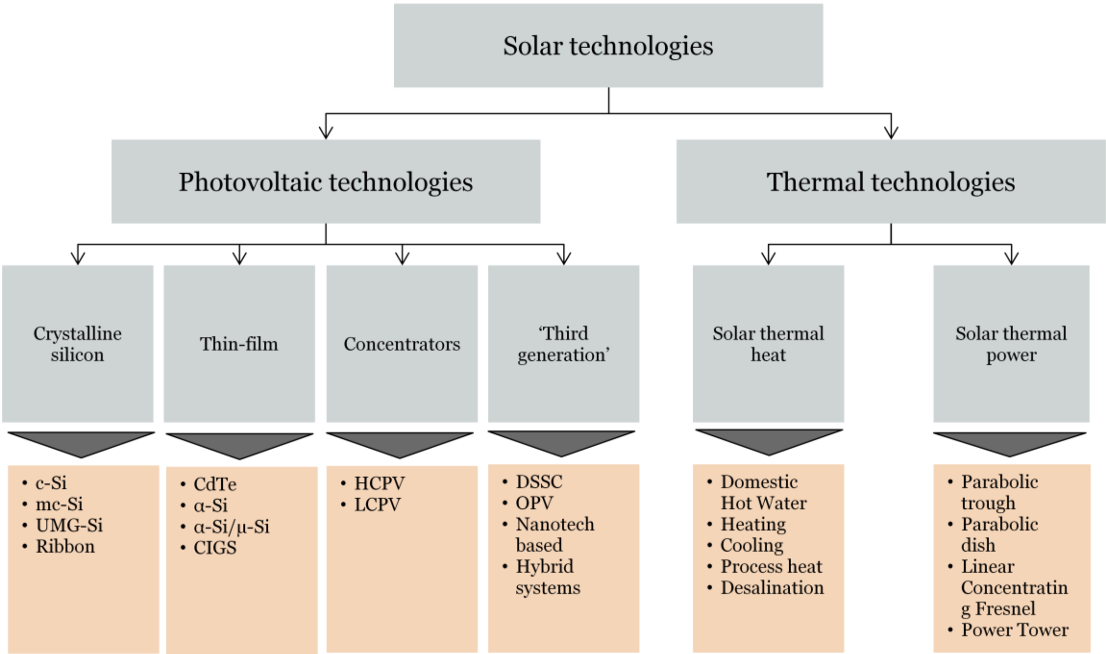

Figure 43: Overview of solar technologies

Certainly, research activities need to be focused, which makes a selection of solar technologies and subordinate research fields necessary.

4.2.1. Methodology of selection

The most attractive solar technologies and research fields for the Kingdom/for KAUST have been identified in a two-step approach covering both market potential and synergies to Saudi Arabia/KAUST. It is important to emphasize that the selection of solar technologies is exclusively aimed at giving a recommendation to the Kingdom – and KAUST in particular – to answer the question about which solar technologies to focus on with R&D activities. A prejudice towards which solar technologies to focus on for the establishment of solar manufacturing projects is not implied in this selection.

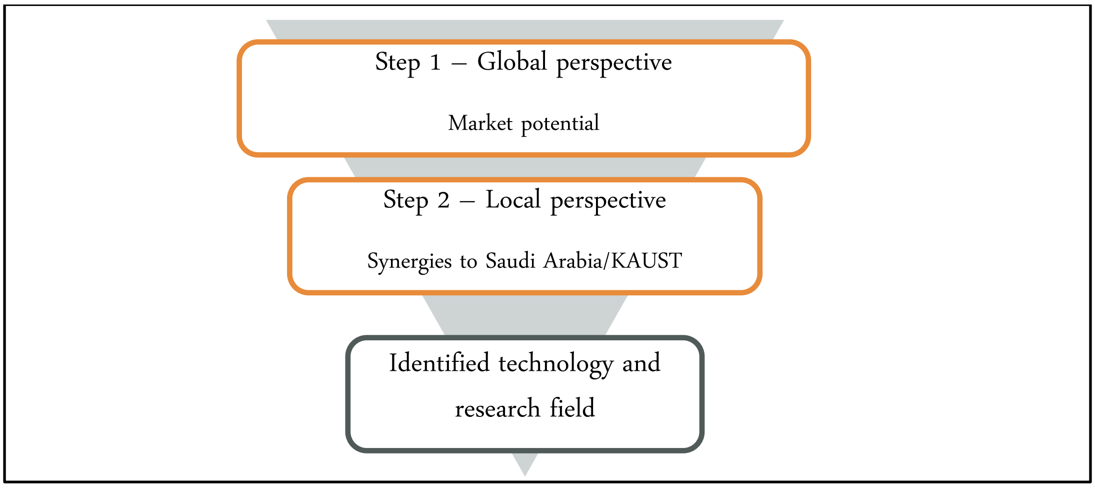

Figure 44: Two-step approach for the identification of solar technologies and research fields

In step 1 in Figure 44, the market potential of solar technologies has been assessed by the following criteria:

- Cost: cost advantage compared to alternative solar technologies
- Efficiency: superior performance compared to alternative solar technologies
- Time to market: commercial roll-out earlier than alternative solar technologies
- Market size: (future) market's size needs to have significant size with an increasing tendency

In step 2, potential synergies to Saudi Arabia and KAUST have been assessed.

Regarding potential synergies to the Kingdom, the following criteria have been considered for the selection of solar technologies:

- Synergies with existing industries in the Kingdom (e.g., mining/raw materials, petrochemicals, utilities)
- Favorite location conditions for manufacturing activities (e.g., low-cost energy, infrastructure, labor, investment incentives)
- Potential for domestic application (household, commercial, industrial)

Regarding potential synergies to KAUST, the following criteria have been considered for the selection of solar technologies:

- Fit into KAUST's strategy, especially the strategy of KAUST's Solar and Alternative Energy Research Center (overall vision, mission of the two working groups, Center Director Professor Jabbour's spheres of action)
- Synergies to KAUST's facilities and other research fields (Research Centers, e.g., Nanomaterials and Water Desalination; academic divisions, e.g., physical and chemical sciences and engineering; Research Core Facilities, e.g., Advanced Nano Fabrication, Glass Shop, Supercomputing)

4.2.2. Selected solar technologies

By applying the developed two-step selection process, the broad bands of solar technologies presented in Figure 43 have been thoroughly assessed. The table on the on the next page summarizes this assessment, Figure 45.

Selection step	Criterion	Photovoltaic technologies						Thermal technologies	
		Crystalline silicon	Thin-film			Concentrators	‚Third generation'	Solar thermal heat	Solar thermal power (CSP)
			a-Si/μ-Si	CdTe	CIGS	HCPV			
1. Market potential	1. Cost: Module manufacturing cost ($/W, 2007)	2.40 – 3.15	1.50 – 1.80	1.15 – 1.30	1.80 – 2.00	N/A	N/A	N/A	N/A
	2. Cost: Installed cost ($/W, 2007)	5.70-8.58	6.55-7.37	5.00-6.00	5.00-10.00	5.85-10	20.00	N/A	3.00-4.00
	3. Cost: Levelized cost of energy ($/kWh, 2007)	0.275 – 0.30	0.30	0.18 – 0.24	0.30	0.31 – 0.38	N/A	N/A	0.12 – 0.17
	4. Efficiency: Cell (lab,2008)	18 – 24%	11.7%	16%	21%	41%	5-8%	N/A	N/A
	5. Efficiency Module (real, 2008)	12 – 20%	6 – 10%	7 – 10%	7 – 13%	20 – 30% (system)	3-4%	N/A	11 – 24% (system)
	6. Time to market	Today	Today	Today	0-3 years	0-3 years	5-10 years	• Low temp hot water: today • Process heat: 0-3 years • Cooling, desalination: 3-6 years	• Parabolic trough: today • Power tower, Fresnel: 2-4 years • Dish, storage: 4-7 years
	7. Market size (2007)	8,540 MW	430 MW	250 MW	20 MW	16 MW	<< 1 MW	154,000 MWth	430 MW
2. Synergies	1. Saudi Arabia: Industrial environment (existing industry, manufacturing conditions)	High: Local manufacturing of silicon, wafers and ingots mainly due to low-cost energy	High: Saudi's chemical and glass industry	High: Saudi's chemical and glass industry	High: Saudi's chemical and glass industry	High: Saudi's steel/ aluminum and glass industry; plastic molding	Medium: Future opportunity for petrochemical industry	High: Saudi's steel/aluminum and glass industry	High: Saudi's steel/aluminum and glass industry

	2. Saudi Arabia: Domestic application	Medium: Wide range of applications, but loss of efficiency at high temp	High: Large potential in BIPV	Medium: No loss of efficiency at high temp, but no BIPV	High: Large potential in BIPV	High: Great fit due to high solar irradiation	High: Efficiency of organic PV increases with temp	High: Today huge for potential for hot water; in the future huge potential for cooling, desalination and process heat	High: Great potential to contribute to energy supply in larger scale
	3. KAUST (strategy, facilities, research fields)	High: Materials engineering, glass shop, supercomputing	Medium: Little potential for efficiency improvement	Medium: Little potential for efficiency improvement	High: Nanomaterials science, supercomputing	High: Materials engineering, optical science, glass shop	High: Solar Center Director Professor Jabbour's research focus; scientific partners from research network	High: Materials engineering, optical science, glass shop, water desalination	High: Materials engineering, optical science, glass shop

Figure 45: Assessment of solar technologies20

[20] Sources: All numbers reflect ranges and are based on multiple sources - US Department of Energy; Greentech Media; Deutsche Bank; Lux Research; Displaybank; CPV Today; Zentrum für Sonnenergie- und Wasserstoffforschung; company information (Applied Materials; First Solar; Oerlikon; Sopogy; Sol3g; Sulfurcell; Würth)

In the selection process, five solar technologies prevailed:

- Crystalline silicon PV – The most mature PV technology with high cell efficiency still bearing significant potential for cost reduction.
- CIGS thin-film PV – The thin-film technology with the biggest potential for efficiency improvement and, with regard to building-integrated photovoltaics (BIPV), offers very attractive fields of future application.
- Concentrated PV (HCPV) – The PV technology with the highest efficiency today and in the future the highest potential for the lowest levelized cost of energy in areas with high sun irradiation, such as in the Kingdom.
- 'Third generation' PV – Covering an array of solar technologies that are being widely regarded as the 'most exciting' ones for the more distant future due to its potential for very low cost.
- Solar thermal heat and solar thermal power (CSP) – Due to their similar characteristics being lumped together, these solar technologies have a very high potential for domestic application in the Kingdom.

The following Figure 46 illustrates the results of the selection of solar technologies:

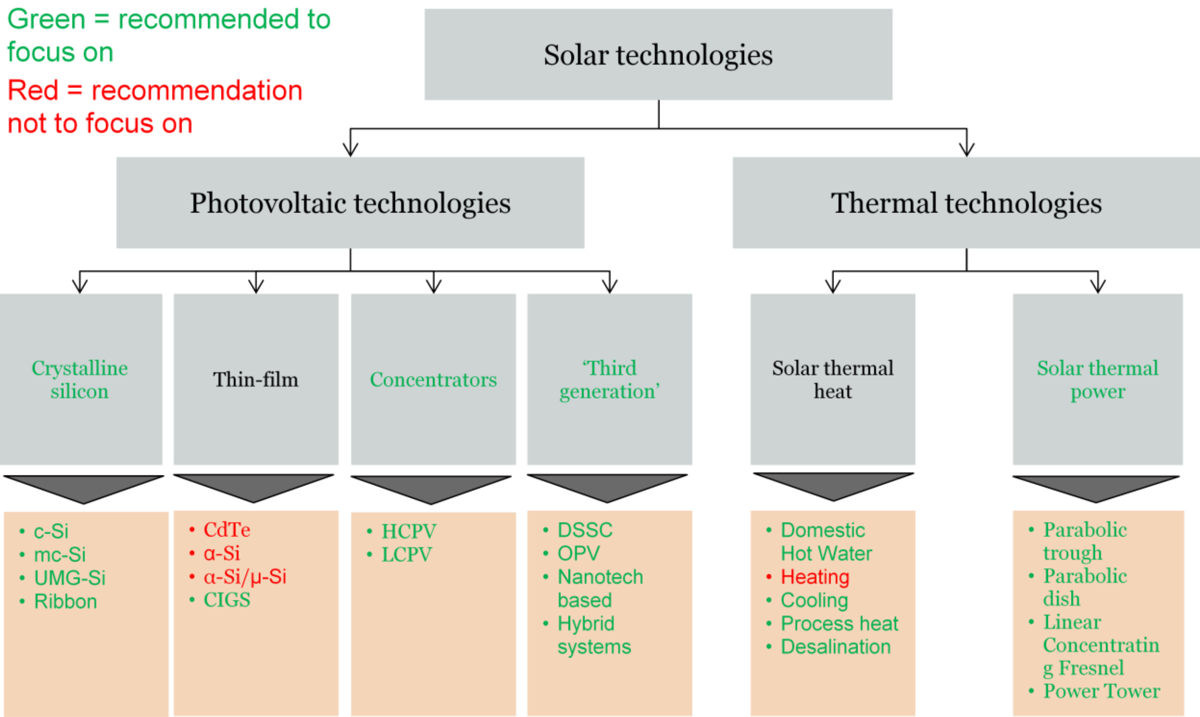

Figure 46: Selected solar technologies for R&D activities in Saudi Arabia / at KAUST

Those technologies marked in red are recommended as technologies which R&D activities shall NOT focus on mainly for the following reasons:

- CdTe thin-film PV – Cadmium and its compounds can be harmful to the environment if not applied cautiously. Thus, its use is very much restricted in several countries. For instance, Japan bans the import of CdTe solar cells and modules. On the medium run, CdTe is likely to be replaced by alternative thin-film technologies. First Solar being the most important manufacturer of CdTe-based cells has already started to investigate alternative PV technologies. Although the manufacturing process is easier than with the CIGS thin-film technology, CdTe has the significant disadvantage of having a lower efficiency both in the lab and under real-life conditions compared to CIGS.

- a-Si/µ-Si thin-film PV – A number of companies producing a-Si/µ-Si based solar cells and modules have increased substantially over the past months. This is mainly because the manufacturing IP for this technology is largely held by equipment manufacturers offering expensive turnkey lines to designated cell manufacturers. From an R&D perspective, the a-Si/µ-Si thin-film technology is less attractive than the CIGS technology as efficiency even today is the lowest among thin-film technologies and offers the most limited room for improvement among thin-film technologies.

- Logically, solar thermal technology for heating has not been named an R&D focus area because demand for this application is limited in the Kingdom.

4.2.3. Research fields

Selecting the most attractive solar technologies has been the first step. Identifying solar research topics, per selected technology, and designating the most relevant ones for R&D activities in the Kingdom, particularly at KAUST, marks the second step.

A. Crystalline silicon PV

Although it is the most widespread and most mature PV technology, crystalline silicon PV still features higher cost levels than most thin-film PV and solar thermal technologies. There is room for significant cost reduction with a multitude of approaches. Thus, R&D activities mainly need to tackle the cost issue.

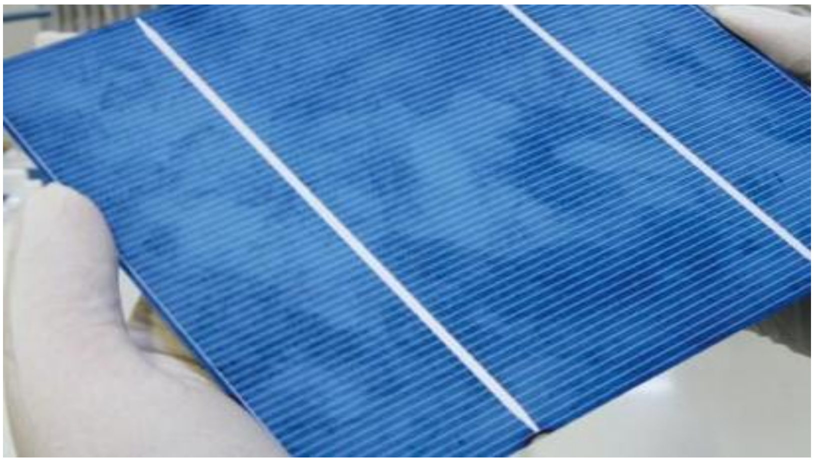

Figure 47: Crystalline silicon solar cell[21]

[21] Source: Q-Cells AG, 2009.

Within crystalline silicon PV, there are two main technologies – multi-crystalline (or 'polycrystalline' used in relation to silicon as the raw material) and monocrystalline silicon. Multi-crystalline silicon is composed of a number of multiple crystals, whereas in monocrystalline silicon the crystalline structure is homogenous. The ribbon technology represents a niche manufacturing technology, Figure 48.

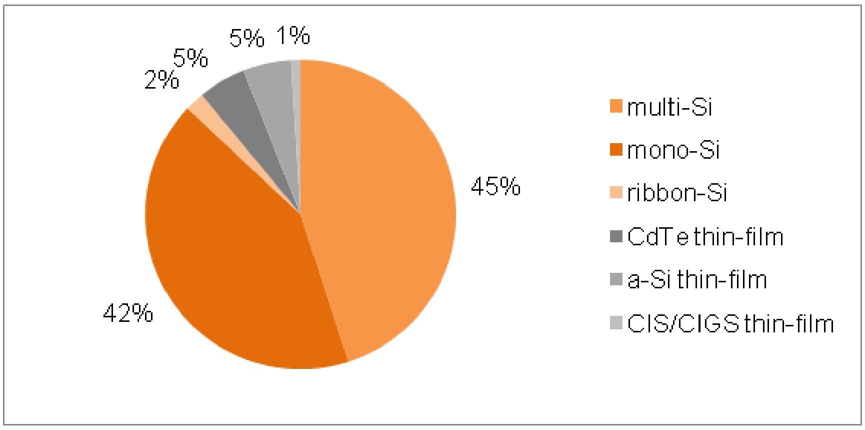

Figure 48: Market share PV technologies (Source: Photon International, March 2008)

Evidently, silicon being the most relevant raw material strongly influences the price for the silicon-based cell. For the efficiency of the cell, the thickness of the silicon wafer does not matter. Hence, reducing the wafer's thickness is an important tool to leverage cost reduction. Today, wafer thickness is approximately 200 µm, with a forecast reduction to less than 150 µm by 2012 with less kerf loss.[22] Wafer thickness is but one example among several approaches used to drive down costs. Taking a close look at the crystalline silicon PV value chain reveals vast potential for R&D activities, which Figure 49 makes visual:

[22] Source: MEMC, 2008.

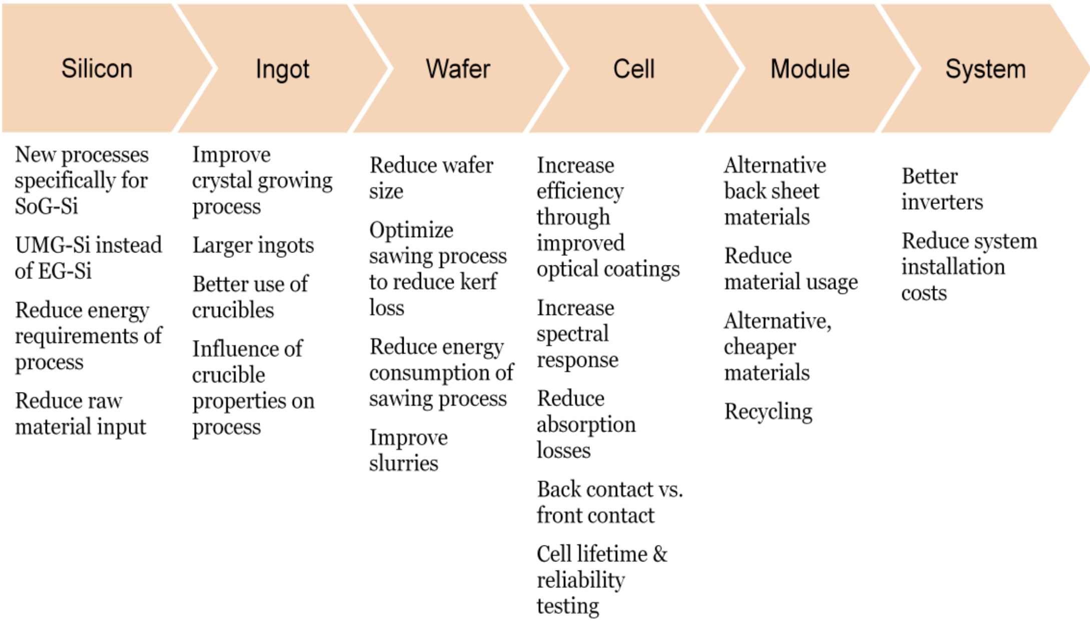

Figure 49: Crystalline silicon value chain with R&D tasks

From the variety of methods to tackle the cost issue, it is recommended to concentrate activities on selected R&D topics. The research fields listed below have been recommended in the study:

Research field 1: cost reduction at silicon level – improvement of the characteristics of UMG silicon

Upgraded metallurgical (UMG) silicon can be produced at a lower cost than polycrystalline silicon (USD 10-15/kg vs. USD 35-60/kg)[23] due to its greater impurity. Furthermore, the manufacturing process requires less energy and the environmental impact is smaller as no chlorosilane supply is needed. Although there are significant advantages, degradation problems related to the higher impurity of the material are still hindering a large-scale utilization of UMG silicon in cell manufacturing. Hence, minimizing these impurities has to be the objective of R&D activities.

Research field 2: cost reduction and improvement at cell level – cheaper materials and enhanced surfaces

[23] Source: CaliSolar, 2008.

Silicon is an expensive feedstock. Thus, reducing its usage will drive down costs for solar cells. In addition, the efficiency of cells can be improved by avoiding reflection of a substantial portion (currently at a rough 1/3) of the sunlight hitting the cell. Consequently, the objectives of R&D activities on the cell level will be, on the one hand, to replace silicon by alternative, cheaper materials (e.g., by applying a thin-film silicon layer on top of a low-cost substrate) and, on the other hand, to enable cells to absorb sunlight from any angle and absorb a wider spectrum of light by applying optical coatings.

Research field 3: reduction and improvement at module level – reduced material consumption and a longer lifetime

Low Level concentrated PV (LCPV) is an interesting technology to save cost on the module level by replacing part of the silicon with cheap plastic optics. Up to 50% of the crystalline silicon can be saved this way without facing a drop in efficiency; the average LCPV module efficiency is roughly 12%. Commercial flat rooftops are particularly suited for this application. Often, installations are combined with multi-axis trackers. A current concern about this technology is the tendency of the LCPV modules to heat up. Furthermore, modules are getting more complex as seen by the optical devices applied, shown in Figure 50.

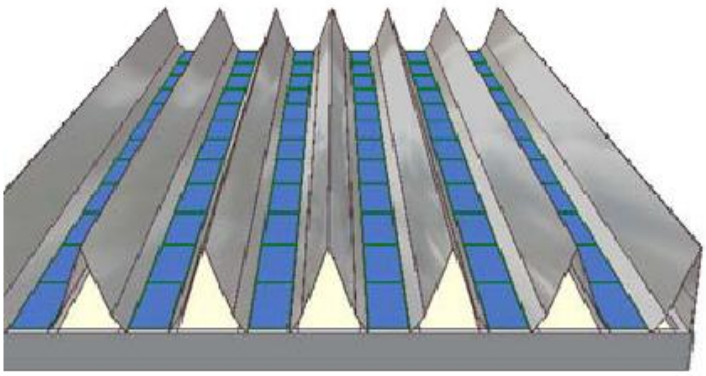

Figure 50: LCPV module[24]

[24] Source: JX Crystals, 2009.

Consequently, a major R&D focus is to optimize systems so that the heat impact is reduced. In this context, a promising approach is to develop glass coatings with concentrating effects to eliminate the need for additional optical devices, which would also reduce complexity. Another approach is to improve the tracking systems in order to ensure a maximum harvest of sunlight. Finally, as with every new technology, more testing is required to gain longtime experience.

B. Thin-film CIGS

Thin-film CIGS offers vast market potential in both forms of rigid and flexible application, Figure 51. Particularly flexible cells will offer an array of very interesting new applications, such as integration in buildings, consumer electronic products or in textiles.

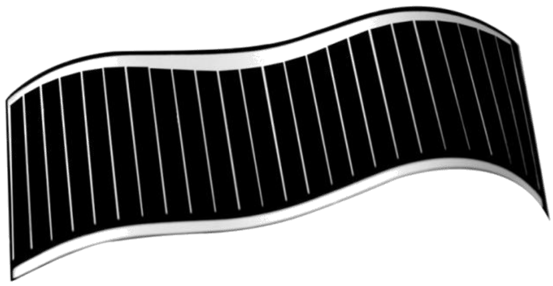

Figure 51: Flexible CIGS cell[25]

In the selection process, CIGS emerged as the superior thin-film technology, mainly due to offering the highest potential for efficiency improvement, thus being able to boast efficiencies in the range of crystalline silicon solar cells (~20%) in the future, which Figure 52 makes visual.

[25] Source: Solarion AG, 2009.

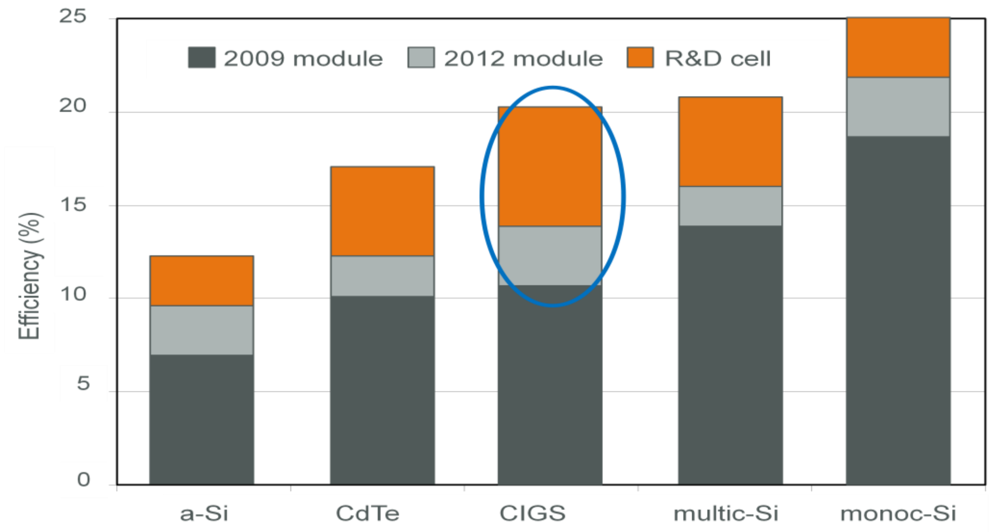

Figure 52: Potential for efficiency improvement (Sources: NREL, Apricum research, 2008)

Logically, with an efficiency being equal to crystalline silicon cells and by avoiding usage of the expensive feedstock silicon, CIGS will feature significant cost advantages once it is a totally mature technology. Hence, transitioning the very promising lab performance features into large-scale production is one of the major R&D challenges.

Research field 1: Transition of lab results into large-scale production

Today, the efficiency gap between lab (~20%) and large-scale production (7-13%) is significant. One of the main concerns lies in absorber layer stoichiometry and crystal structure. A tightly controlled stoichiometry and crystal structure across the whole width and length of the substrate needs to be achieved in a large-scale manufacturing process, in order to reach lab efficiencies for the production of CIGS cells. Hence, the control and stabilization of production processes will be an important R&D objective.

Research field 2: Improvement of efficiency and lifetime

To really reach the full potential that lies in CIGS technology – performance comparable to crystalline silicon technology at a lower cost – efficiency improvements both on rigid and flexible substrates are needed. Current concerns in this regard are the occurrence of electrical losses, a mismatch of layers and a reflection of light. Hence, R&D objectives will be to reduce electrical losses, optimize layer matching, enhance light trapping, and develop photon conversion layers as well as tandem concepts.

Research field 3: Flexible CIGS cells – development of better and cheaper barrier films

Especially CIGS technology on flexible substrates bears enormous potential in a multitude of applications. The current problem that hinders the introduction of commercial products today is the availability of affordable barrier layers with very low water vapor transmission rates (WVTR < 10^{-5} g/m²/day). As moisture intruding into the cells will degrade or even destroy it, barrier films which guarantee lifetimes of the cell of at least twenty years are needed. Hence, an R&D objective will be to develop new approaches for encapsulation, such as multi-layer inorganic-organic barrier film materials.

C. Concentrating PV (HCPV)

HCPV is the PV technology with today's highest efficiency. As its potential can only be fully exploited in areas with high direct sun irradiation (DNI > 1,800 kWh/m²/a), the Kingdom (DNI 2,200 kWh/m²/a) would be excellently suited for local application. In addition, there would also be opportunities for local manufacturing activities as HCPV technology requires steel-/aluminum-made trackers and optical devices which could be supplied by Saudi's metal processing, glass and plastics industries, Figure 53.

Figure 53: HCPV installation[26]

From an R&D perspective, HCPV needs further improvement in cell designs, in the design of the optical system, and in extensive field testing to validate reliability and system performance.

Research field 1: Improvement of cell designs

As in HCPV, the cell accounts for 20-30% of total system costs; higher cell efficiencies directly translate into lower system cost. Hence, improvement of cell efficiency is a very relevant research topic. Moreover, utilization of alternative materials and the improvement of the manufacturing process for multi-junction cells are important areas for R&D.

Research field 2: Improvement and cost reduction of optical designs

As already stated above with the LCPV technology (crystalline silicon, research field 3), R&D activities need to focus on improvement and cost reduction of optical designs. Cheaper reflector materials would reduce complexity, and thus cost.

Research field 3: Improvement and cost reduction of trackers

[26] Source: SolFocus, Inc., 2009.

Although being rather low-tech, there is still room for improvement of the tracker. Making it more reliable and at the same time cheaper will be an R&D objective.

D. 'Third generation' PV

'Third generation' has become synonymous for an array of varying solar technologies. Although all of them are tiny for the time being regarding market share and efficiency figures, they possess an abundant market potential in the rather distant future due to their expected ability for the generation of electricity at a very low cost, such as shown in figure 54.

Figure 54: Organic PV cell[27]

The following chart, Figure 55, may give an overview of third generation technologies.

[27] Source: Konarka, 2009.

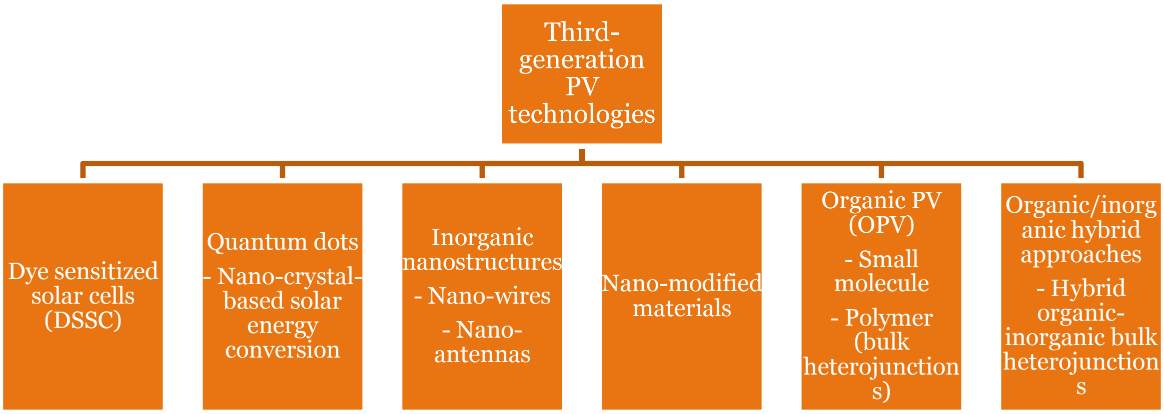

Figure 55: Third generation PV technologies

As multi-faceted as technologies are, research fields are abundant. Here is a selection of key fields:

Research field 1: Development of test methods

As known from other, more mature solar technologies, degradation is a major issue. In order to tackle degradation issues most stringently, tailored test methods to understand degradation behavior must first be developed.

Research field 2: Improve lifetime

Once suitable test methods exist, as in the case of organic PV, better laminating/encapsulating materials need to be developed to counteract the atmospheric and UV degradation of cells, thus improving their lifetime/stability.

Research field 3: Development of air-stable materials

Today, many third generation technologies perform only under special lab conditions. In order to prepare a transition from technological development to a commercial application environment, more air-stable materials must to be developed.

Research field 4: More suitable transparent electrodes

Reducing cost and improving the performance of transparent electrodes for third generation solar cells (for example, those made of graphene, carbon nanotubes and silver wires) is another relevant R&D objective.

E. Solar thermal heat and solar thermal power

There are four solar thermal technologies: power tower, parabolic trough, linear fresnel and dish engine. With an installed capacity of over 400 MW, the parabolic trough technology is, by far, the most widespread and mature technology today, Figures 56, 57, 58 and 59.

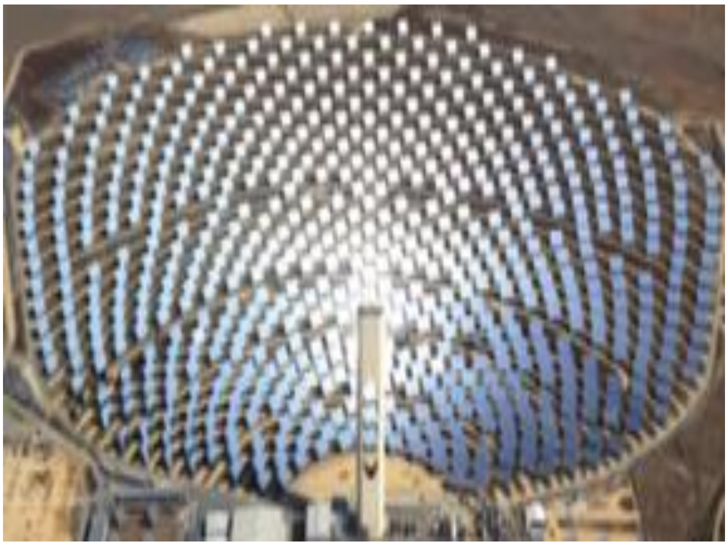

Figure 56: Power tower[28]

Figure 57: Parabolic trough[29]

[28] Source: Abengoa Solar, S.A., 2009.

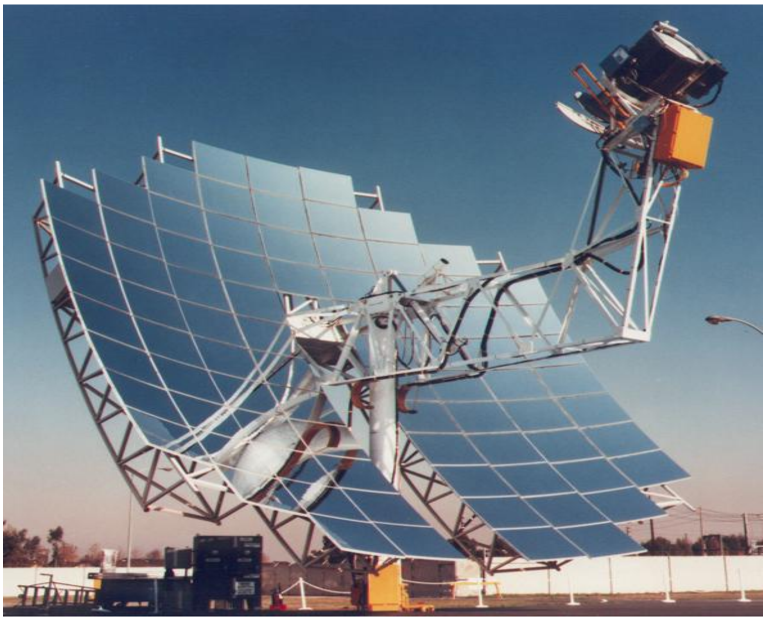

Figure 58: Dish engine[30]

Figure 59: Linear Fresnel[31]

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29 Source: Flagsol GmbH, 2009.
30 Source: http://blog.sellsiusrealestate.com, 2009.

Solar thermal technology	Parabolic trough	Linear Fresnel	Power tower	Dish engine
Installed capacity (MW, 2008)	469	7.4	12.5	0.15
Time to market	Now	2-5 years (estimated)	0-2 years	5 years (estimated)

Figure 60: Comparison of solar thermal technologies[32]

Parabolic trough being the most mature and widespread technology features an installed cost of 4-5 USD/W (2008) and an electricity generation cost of 0.12-0.20 USD/kWh (2008). The cost reduction potential with other solar thermal technologies is substantial but, due to the low capacities installed at present, no representative cost figures are yet available. Figure 60 shows a table that compares the different types of Solar thermal technologies from an installed capacity and time to market stand point.

Whereas photovoltaic technology finds its origin in semiconductor physics, solar thermal technology relates to thermodynamic physics. From that background, it is obvious that the majority of research topics in solar thermal are tackling different issues from the ones previously presented. As mentioned before, solar thermal technologies are an excellent fit to the Kingdom due to their suitability for local application and manufacturing. Thus, R&D activities related to solar thermal technologies are recommended to play a major role in overall solar R&D activities in the Kingdom.

Research field 1: Improvements of solar receiver tubes

There is a simple correlation between the operating temperature of a parabolic trough system and the efficiency of the system: the higher the temperature, the higher the efficiency. Increasing the operating temperature from ~400 °C to 450 °C will significantly enhance the efficiency of the system. In this context, receiver tubes

[31] Source: Novatec Biosol AG, 2009.
[32] Sources: ABS Energy (2005), NREL (2008), ESTELA (2008), Northwest Power & Conservation Council (2008), Renewable Energy World (2008), UBS (2009), DLR (2008).

are a key component of the system, which need to withstand these enormous temperatures. Today, there are still various problems caused by the heat which needs to be addressed by R&D. Hence, the development of a new, highly solar absorbing, low thermal emitting, heat-resisting, durable coating at lower cost than today will be the objective of R&D activities.

Research field 2: Improvement of the reflector

The reflectors (mirrors) in parabolic trough systems are usually made of low-iron flat glass being sagged into a parabolic shape. Today, mirror breakage in the manufacturing process is a major concern. Thus, a replacement of these glass mirrors by cheaper, lighter, less breakable materials possessing a better reflectivity is needed. Hence, R&D approaches include the development of thin-film glass mirrors and front surface reflectors on film, such as a plastic substrate with a reflective silver coating. In addition, R&D efforts into cleaning methods or the development of anti-soiling coatings are needed to improve reflectivity of the reflectors and reduce cleaning maintenance.

Research field 3: Development of cheaper support structures

As the support structure accounts for approximately 40% of the cost of a parabolic trough solar field, there is no way around developing cheaper support structures when striving for reduced installation costs. The R&D objective will be to adapt alternative materials, such as aluminum or composite materials, to the specific requirements.

Research field 4: Development of direct steam generation

In today's typical solar thermal process, a circulating heat transfer fluid is heated by sunlight and transfers its heat to a water cycle, which finally drives the turbine for power generation. By directly heating the water, the entire system would become more simplified and efficiency losses caused by applying a heat exchanger to produce steam would be eliminated. Thus, an R&D objective will be to develop a direct steam generation process which can be commercialized.

Research field 5: Development of thermal storage technologies

Obviously, by not shining at night, the sun is an intermittent resource. In order to be able to generate power around the clock, thermal storage technologies are required. Today's best available technology enables power generation through evening hours. Better thermal storage solutions are needed to generate power by solar thermal power plants without interruption at night. An R&D objective will be to develop low-cost storage materials, such as sand, high-temperature phase-changing materials, and the design of better charging and discharging strategies.

Research field 6: Development of integral systems, as for cooling and desalination

Besides power generation, solar thermal technology can be employed for air-conditioning ("solar cooling") and water desalination by directly using the heat generated. These two forms of application perfectly match the Kingdom's needs, thus R&D in this field should be of vital interest. R&D objectives are to develop and improve solutions striving to integrate various applications, such as power generation, cooling, heat production for industrial processes and desalination. Moreover, process control and monitoring the system's functions are recommended to be in the focus of R&D.

4.3. Establishment of solar R&D in the Kingdom

Driven by the necessity for constant technological improvement, R&D activities are an integral part of sustainable solar manufacturing activities. Solar R&D activities will:

- Provide the knowledge base for a domestic solar industry,
- Enable the design of locally applicable solar products,

- Help attract solar companies and experts from abroad,
- Create jobs and contribute to the GDP.

From the background of the relevance of domestic solar R&D, the goal is straightforward: the Kingdom of Saudi Arabia shall become a globally leading solar R&D location – the leading one in the Gulf Region and among those in the top group in a global context. KAUST shall be the nucleus of solar R&D activities in the Kingdom and develop into a globally leading solar research center.

After having selected those solar technologies which have the highest market potential and offer synergies to the Kingdom and KAUST, and having identified the most relevant research fields, the logical next step is to derive best practices from the leading countries and solar institutes worldwide.

4.3.1. Best practice analysis solar R&D

As there is no need to reinvent the wheel, taking a close look at solar R&D activities around the globe, both on a country and an institute level, makes a lot of sense in order to derive best practices for the implementation of solar R&D activities in the Kingdom, particularly at KAUST.

This analysis will thus take two perspectives – a country perspective and an institute perspective.

A. Country perspective

A best practice analysis on a country level has the objective to identify best practices in solar R&D promotion by national governments and to evaluate their applicability in the Kingdom.

First, a set of benchmark countries needs to be determined. The following criteria have been applied for the selection of leading countries in R&D:

- R&D expenditure in absolute figures
- R&D expenditure per capita
- Number of scientific papers – general and solar

- Ratio of R&D personnel per total employees

As a result, the global R&D leaders - USA, Japan and Germany - have been selected as benchmarking countries as well as three nations that are particularly strong in solar R&D: China, Australia and Singapore.

USA – Strong in R&D spending

The USA is exceptional for heavy R&D spending, both from government and industry sources as shown in Figure 61.

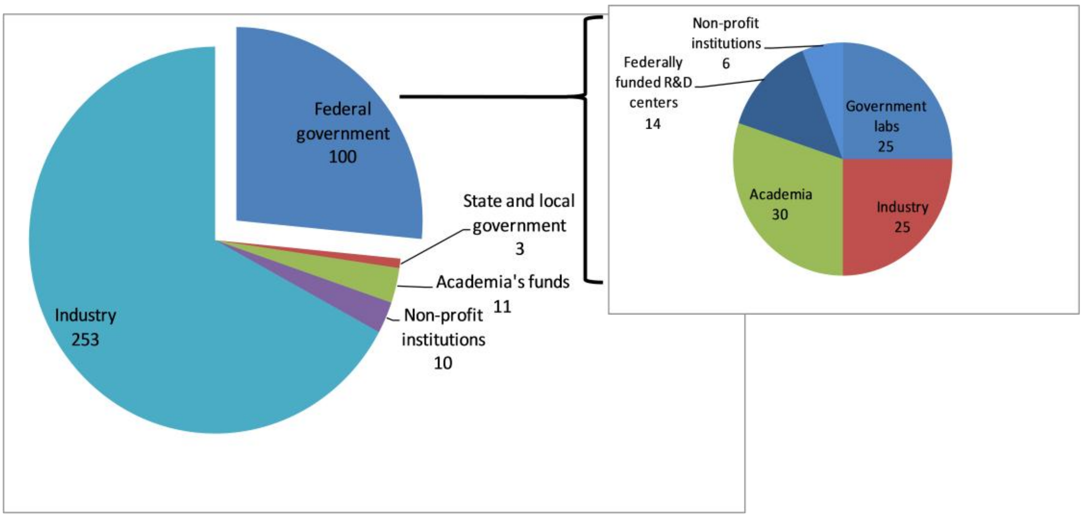


Figure 61: Sources of US R&D funding in billion USD, 2008 (Source: Reuters, 2009)

So, USA R&D funding totaled $377 billion USD in 2008, the lion's share of industry spending. This amount accounts for 2.6% of the country's GDP.

Other global R&D leaders who have spent in the same range: Japan 3.3% and Germany 2.5%.[33] Saudi Arabia reportedly spends $600 million USD per year on R&D[34], in relation to the country's GDP of $583 billion USD the R&D/GDP ratio stands at a mere 0.1%.

- The message which can be derived from this comparison is very clear: An augmentation of R&D expenditures in the Kingdom is necessary in order to catch

33 Source: Battelle Report, 2009.
34 Source: KAUST, 2009.

up with the countries around the globe leading in R&D. Setting an R&D/GDP ratio of 2% as the goal, R&D budgets of industry and government would need to total roughly $12 billion USD. That would be a twenty-fold increase in today's spending.

The Department of Energy (DOE), Figure 62, is the major investor in energy-related R&D on the federal level. DOE's funding policy for solar is to share funds quite equally among the most prominent solar technologies.

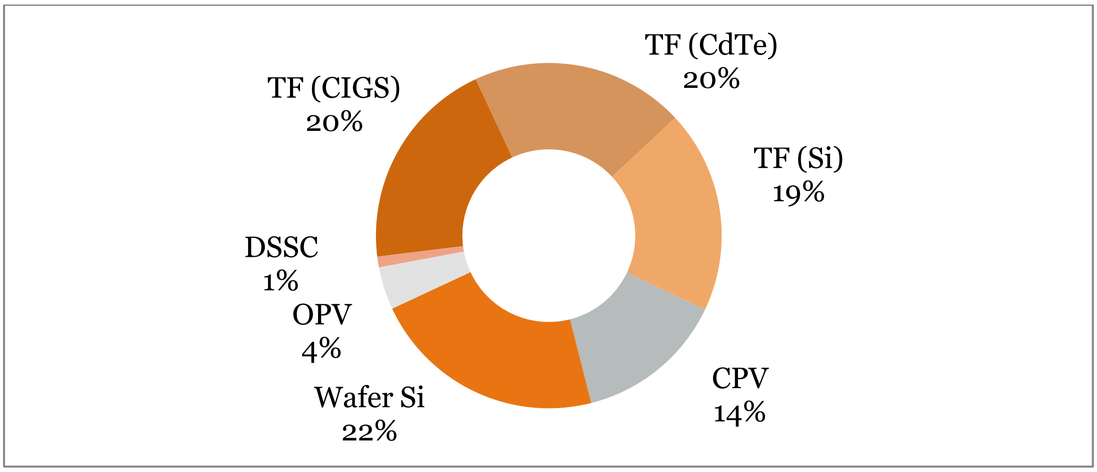


Figure 62: DOE's PV research funding by technology, 2007 (Source: DOE, 2008)

With this allocation of funds, DOE demonstrates that sharing R&D funds among solar technologies can do both – lead to excellent research results and maintain all options in the future. Taking into consideration that solar energy is a comparably young technology with a variety of approaches, there is no certainty today about the dominant technology in the long run. Therefore, it is necessary not to limit future options by exclusively focusing research on a single solar technology today.

Commercialization of technologies – USA, Singapore, Germany

To begin with the USA, as part of the American Recovery and Reinvestment Act (ARRA), two new programs have recently been launched that aim at an acceleration of the commercialization of solar technologies:

1. National Renewable Energy Laboratory (NREL) Photovoltaic Technology Incubator Program: with an anticipated funding of $9 million USD, the program's goal is to shorten companies' timelines for the transition of prototype and pre-commercial PV technologies into pilot- and full-scale manufacture.

2. NREL Pre-Incubator Program: funding is anticipated at $6 million USD. The goal of the program is to bridge the gap between the concept verification stage of a technology and the development of a commercially viable prototype.

Another best practice example in this context is the Clean Energy Research Program launched by Singapore's government. Provided with a funding of SGD 50 million (~$35 million USD), the goal is to achieve a contribution from the Cleantech industry to the GDP in the amount of SGD 1.7 billion (~1.2 billion USD) and the creation of 7,000 jobs by 2015. The funding process works in the following way: each year two calls for proposals are released in identified research areas. Bidders are Singapore-based foreign and local public institutions and private companies.

Germany sets an additional best practice. With the establishment of the 'High-Tech Gründerfonds' (high-tech founders' fund), Germany has reacted to the difficulties it often faces regarding financing high-tech companies including Cleantech ones. The concept foresees an investment of up to 0.5 million EUR (~0.8 million USD) in companies not older than one year. In addition to funds, management support is given if required. Funds are jointly provided by the government and large corporations in a public-private partnership model.

- Those three examples from the USA, Singapore and Germany show two things: first, governmental institutions have realized the potential of solar/Cleantech and, second, the necessity to provide funding to innovative companies for the commercialization of their products.

Research collaboration – Germany

Apart from funding start-up companies by 'High-tech Gründerfonds', Germany sets another best practice example by fostering close collaborations between universities, research institutes and companies. Through a government initiative, 130 'Networks of excellence' have been established in a variety of industries, including Cleantech. This strong interaction between academia, industry and government has largely contributed to the creation of regionally focused industry clusters. An outstanding example of such clusters is the 'Solar Valley', the world's largest solar cluster which was established within one decade.

- Collaboration between academia and industry will also be decisive for the successful establishment of a solar cluster in Saudi Arabia. To really benefit from cluster effects, it is highly advisable to focus activities related to the solar industry in a certain region. Excellently suited for Saudi's future solar cluster is the region around Jeddah with KAUST, KAEC and other industrial sites.

R&D focus on testing and demonstration – Japan

Japan bundles governmental R&D funding into renewable energy in the New Energy and Industrial Technology Development Organization (NEDO). NEDO's budget in 2007 accounted for 216.5 billion JPY (~2.3 billion USD). What makes Japan a best practice example is NEDO's given focus to spend a majority of funds for field testing and demonstration (~290 million USD) and activities aiming at a local introduction of renewable energy technologies (~455 million USD).

- Making KSA a regional hub for testing, certification and demonstration activities for solar applications is highly attractive as established solar companies are eager to enter the Middle Eastern markets. What they need is proof of the quality of their products under the special geographical conditions. Furthermore, certification and demonstration can function as a perfect bridge for translating lab results into marketable products.

First manufacturing, then company R&D – China

China is among the top three countries in the world regarding the manufacture of solar products. More and more, the country is also becoming an attractive location for R&D activities. A recent example is DuPont, a chemical company supplier to the solar industry that has established a technical center for PV in Shanghai. With an investment of 25 million USD, their purposes are the provision of integrated R&D and technical support for the company's customers in the country, a support of material developments for the PV market as well as an exchange and collaboration with China's universities and research institutes.

- China's example shows that an established pool of solar manufacturers attracts key suppliers. Thus, the establishment of manufacturing activities in the Kingdom is a prerequisite for the attraction of large corporations' R&D activities. Moreover, a comprehensive R&D environment, such as the one being established at KAUST, will be essential to attract company R&D interests.

Local applicability of products – Australia

Australia's government has launched numerous initiatives to make the country a solar hub. One of them is the 'Renewable Energy Fund'. From a total fund of 380 million USD, 330 million USD has been dedicated to demonstration programs that are designed to accelerate the commercialization and deployment of advanced renewable energy technologies for application there. The explicit goal is the adoption of renewable energy technologies in the country by supporting a range of technologies across a range of geographic areas in Australia.

- Australia perfectly demonstrates how to tailor a solar R&D program to the country's needs and geographic conditions. As Saudi Arabia has a vivid interest to apply solar installations locally, R&D activities and programs should promote locally applicable technologies.

B. Institute perspective

A best practice analysis on an institute level has the objective of identifying best practices in solar R&D activities by research institutes around the globe and evaluating their applicability at KAUST.

First, a set of benchmarking institutes needs to be determined. The following criteria have been applied for the selection of leading solar research institutes:

- Number of scientific papers

- Citations in most important journals

- Scientific contributions at conferences (speeches, posters)
- Reputation of the institute's director
- Technologies covered

As a result, the following institutes have been identified for a best practice analysis:

Europe:	Fraunhofer ISE, Germany; ISFOC, Spain
USA:	NREL, Colorado; Georgia Tech, Georgia; Fraunhofer CSE, Massachusetts
Asia-Pacific:	ANU, Australia; UNSW, Australia; SERIS, Singapore.

Fraunhofer Institute for Solar Energy Systems (ISE) and National Renewable Energy Laboratory (NREL) – R&D span from fundamental to market relevant

Fraunhofer ISE (founded 1981), being Europe's largest solar energy research institute, covers most solar technologies and ranges from fundamental R&D, through the development of production technology and prototypes, to the construction of demonstration systems. Furthermore, Fraunhofer ISE is especially known for its integration into a network of national and international cooperation and collaboration with companies.

NREL (founded 1977) covering all solar technologies including PV and solar thermal has been a benchmark in renewable energy research for more than 30 years. A key strength is NREL's collaboration with industry and universities through 'Technology Partnership Agreements' that promote the transfer of knowledge and technologies. Furthermore, NREL is a provider of independent solar cell calibrating results.

- Germany's Fraunhofer ISE and USA's NREL are excellent examples of doing solar research from a wide foundation – from fundamental research to applied research preparing products for market entry. KAUST is well advised to span research activities from fundamental to market relevancy as well as to cover a broad band of solar technologies.

Instituto de Sistemas Fotovoltaicos de Concentracíon (ISFOC) and the Australian National University (ANU) – Focus on locally applicable technologies

ICFOC, being founded in 2006 with the exclusive goal of and focus on commercializing HCPV technology, the institute carries out R&D projects on utility-sized concentrated PV power plants. The focus is on the characterization of components and the generation of installation standards and procedures. Although comparably young, ISFOC has developed into one of the very first addresses when it comes to HCPV.

ANU (founded in 2003) has set its focus not on concentrated PV as ISFOC has but on concentrated solar thermal technologies. Although equipped with a relatively low budget of 300,000 USD annually, ANU provides an excellent example how research can be very successful with a well set focus.

- Spain's ISFOC and Australia's ANU are excellent examples of how solar research can successfully be done when focusing on the development of applications for the particular local conditions. For KAUST it is highly advisable to follow suit by focusing on locally applicable solar technologies.

Georgia Institute of Technology (Georgia Tech) – Specialization in process technologies

Georgia Tech founded the 'University Center for Excellence in Photovoltaics' (UCEP) in 1992. Due to its offering full-scale commercial equipment and extensive cell modeling capabilities, UCEP is among the most advanced material characterization labs in the world.

- USA's Georgia Tech has demonstrated that a focus on process technologies can be very successful. Knowing that the transfer of lab results into results under real-life conditions is a major concern for all solar technologies, KAUST is well advised to commit to process technology research. These types of research activities will help to prepare (on-site) commercial-scale production.

Fraunhofer Center for Sustainable Energy Systems (CSE) – Specialization on a few research fields

Fraunhofer CSE was established at the Massachusetts Institute of Technology in 2008. Although very young and equipped with a rather small budget (5 million USD initially, 1 USD million annually over five years), the institute has already achieved significant research results. Their success factors have included their client centric approach and their limitation to a selected number of research fields, such as improvement of the solar module production process. Backed by MIT and several Fraunhofer institutes, Fraunhofer CSE assembles customized teams of experts to address clients' research needs in a flexible, adaptive manner.

- USA's Fraunhofer CSE has proven that successful research does not necessarily require enormous budgets. The institute has successfully started operations by concentrating on a few research topics and leveraging partnerships. KAUST, being a newcomer in solar research as Fraunhofer CSE once was, is advised to concentrate its research activities on selected research topics. Although the range of solar technologies can be wide, the number of research topics needs to be limited. With the selection of technologies and research fields, KAUST has, in particular, laid the foundation for a concentration of activities.

University of New South Wales (UNSW) – Industry collaboration

UNSW with its ARC Photovoltaic Center of Excellence (founded in 2003) can boast an enormous track record of incubated solar companies, such as Suntech Power, Trina Solar, JA Solar and Yingli Green Energy. This is a result of the strong effort UNSW has taken in regard to industry collaborative research, academic teaching and, of course, incubation activities.

- Australia's UNSW's example shows that incubation can truly pay off. It is recommendable for KAUST to push activities related to incubation and industry collaboration. Given the country's goal of establishing a solar industry, KAUST shall play the role of being the most important research and education partner for Saudi Arabia's solar industry.

Solar Energy Research Center of Singapore (SERIS) – Attraction of excellent research staff

SERIS (founded in 2008), having the 'first mover' advantage in the South-East Asian region, has been very successful in attracting world-renowned solar researchers into their executive management team (former ISFH, ISE, UNSW directors). Thus, the establishment of a world-class solar research center in a very short period of time can be achieved.

- Singapore’s SERIS gives a best practice example of the relevance of recruiting excellent staff and a renowned institute director. With the nomination of Prof. Ghassan Jabbour as Solar Center Director, KAUST has already taken a major step in staffing. More effort will have to be made to attract a significant number of experienced solar research staff from abroad., It is advisable to employ research staff at a later stage who have been educated in-house.

4.3.2. Recommendations for the establishment of solar R&D

In the best practice analysis presented in the previous chapter, some suggestions about the establishment of solar R&D in the Kingdom of Saudi Arabia could have been derived. They can be narrowed down to the following six strategic recommendations for the establishment of solar R&D in the Kingdom:

- R&D spending: provide governmental funding for solar technologies on the order of 100 million USD per annum.
- R&D scope: pursue solar R&D in a variety of technologies. Cover the entire range from fundamental to applied research and demonstration activities.
- Commercialization: seriously promote the commercialization of technologies, e.g., by establishing a center for the testing and demonstration of solar applications.
- Domestic application: focus R&D activities on locally applicable solar technologies.
- Industry collaboration: provide education and R&D collaboration opportunities for manufacturing partners in the country.
- Expertise from abroad: make KAUST the gateway to the Kingdom for technology-driven companies. Keep on recruiting excellent research staff.

A. R&D spending

As shown above with the best practice example of the USA, there is no way to become a leading nation in terms of technological know-how without significant R&D spending, as shown here in Figure 63.

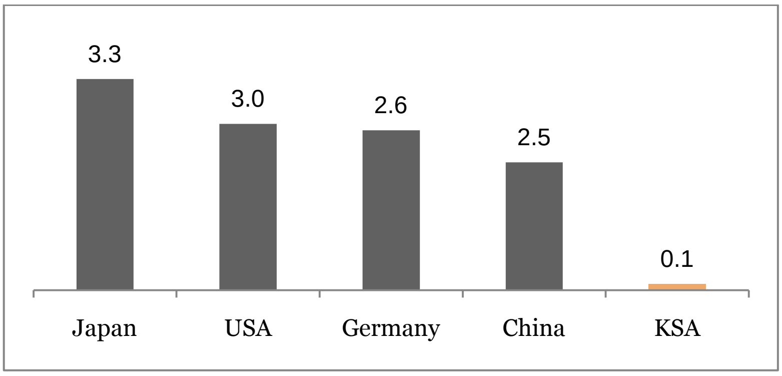


Figure 63: R&D expenditures of the leading countries as percentage of GDP, 2008
(Source: Battelle Report, Apricum research (2009)

The leading countries spend 2 to 3 percent of their GDP per year on R&D, public and private spending combined; in KSA merely a rough 0.1 percent is being spent. Catching up with the leading countries will require at least a twenty-fold increase in today's spending. Given KSA's GDP of 583 billion USD (2008), the country will need to raise R&D expenditures to a minimum of 12 billion USD.

Regarding solar R&D, the recommendation is to provide public R&D funding dedicated to solar technologies on the order of 100 million USD per year (for reference: USA: 229 million USD; Germany: ~110 million USD). As companies decide independently on their R&D budgets (and cannot be forced to augment them), the Saudi government is advised to take the lead in R&D spending, thereby encouraging the industry to raise R&D budgets.

With the establishment of KAUST, Saudi Arabia has already taken a big step towards becoming a world-renowned R&D hub. But as developing a sustainable R&D landscape in the Kingdom requires a comprehensive approach, the Saudi government is required to draw up a general solar R&D funding scheme tailored to the

Kingdom's needs by putting industry collaboration and commercialization of products in the focus.

B. R&D scope

As the best practice examples of Fraunhofer ISE and NREL have shown, it is highly recommendable to stretch R&D activities over a broad band of technologies. The advantages are obvious – limiting the risk of betting on the "wrong horse" and, what seems to be even more relevant, securing a constant stream of marketable products over a long period of time, Figure 64.

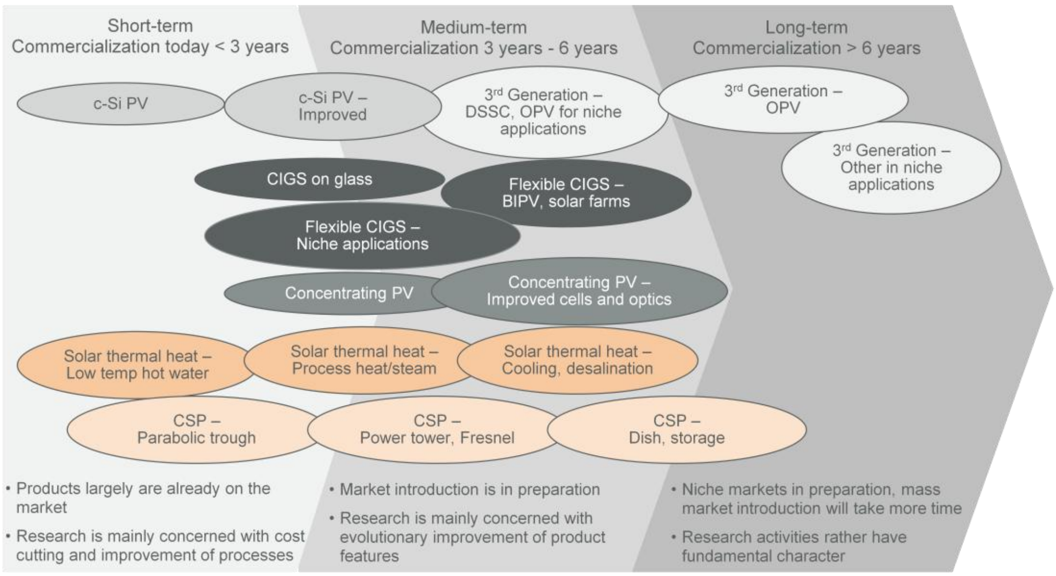


Figure 64: Market readiness of selected solar technologies, 2009 (Source: Apricum research)

By focusing research activities on the solar technologies selected within this study, a constant stream of marketable products over the years to come will be certain. Fundamental research, particularly in advanced solar technologies such as third generation PV, shall not be neglected in this context as it provides the basis for the provision of cutting-edge marketable products in the rather distant future, from today's perspective.

C. Commercialization

Market introduction of new products and the improvement of products already placed in the market are key purposes of all research activities. The aim of giving solar R&D in the Kingdom a commercial focus is to translate R&D results into scalable products that shall be manufactured domestically. Thereby, R&D activities directly foster the establishment of the solar industry in the Kingdom.

There are several recommendable instruments for fostering the commercialization of solar products:

R&D funding for those technologies with the highest potential for successful commercialization

It is a fact that when a new (solar) technology is introduced to the market, it will have a higher rate of success if the commercialization time is short term as opposed to one where the foreseen time to commercialization is long term. Thus, it is highly recommendable to place a strong emphasis in solar R&D funding on those technologies which have already been introduced to the market or those where commercialization is due within a few years. Figure 64 (above) shows that crystalline PV and solar thermal applications are the most mature technologies, hence providing a large proportion of R&D funds for those technologies will pay off in the form of short-term marketable products.

Establishment of a center for testing, demonstration and certification of solar technologies

The Gulf Region will probably develop into one of the most attractive and aspired regions for most solar manufacturers, regardless of PV or solar thermal, for the deployment of their products during the next years. Interviews with solar manufacturers conducted in the course of this project have confirmed that companies are standing poised to roll out their products in the region as soon as the regulatory environment supports solar applications.

This development bears the unique chance for the Kingdom, and KAUST in particular, to position itself as the leading regional hub for applied solar research.

The problem those manufactures are facing is the lack of empirical evidence about the performance and durability of their products under the specific geographic and climate conditions, such as the impact of sand, heat, salt and the lack of fresh water. Hence, there is an enormous interest among solar manufacturers to empirically test their products on-site as well as to demonstrate performance and durability features of their applications to potential clients. Another very important step towards regional market introduction would be the certification of products in order to obtain an official document of proof.

As a consequence, the recommendation is to establish a center for testing, demonstration and certification of solar products at KAUST, thus making KAUST the gateway to the Kingdom and the entire region for solar manufacturers. As activities involved in testing, demonstration and certification are, to a large extent, equal or similar, it is recommendable to establish a center in which all three activities are performed. In the following, three dimensions shall briefly be introduced:

Empirical testing

As mentioned above, solar manufacturers have a vivid interest in empirically testing their products under the harsh environmental conditions of the Gulf Region. By providing test facilities, KAUST could very well attract solar manufacturers that are striving for market introduction of their products in the region.

To establish a test center, a sufficient amount of state-of-the-art testing equipment for the relevant solar technologies and of course staffing with solar scientists, engineers and technicians are required.

The next steps to establish a testing center would be to officially start planning, allocating funds, clarifying the testing equipment, asking for bids from test equipment manufacturers and finally marketing the test center within the global solar community.

Demonstration

Considering the huge solar market potential in the Kingdom and neighboring countries, solar manufacturers need to demonstrate the stability of their products under the region's particular conditions. By establishing a demonstration center, KAUST would position itself as the natural place being chosen by solar manufacturers when it comes to demonstrating state-of-the-art solar products and applications to the Arab world.

For the establishment of a demonstration center, a plot of land dedicated to such kinds of activities as well as grid connections with metering, water and technicians to operate the demonstration installations are needed.

The next steps would be to allocate and prepare a plot of land, ideally close to the test/certification center, as well as to find an agreement with SEC on handling the electric power fed into the grid, and eventually to market the demonstration center within the global solar community.

Certification

There is no way to confirm, officially, proof that the quality and reliability of a solar product will be a good long-term investment. Hence, consumers and corporate clients request a certificate when considering an investment in a solar application/installation. As certificate standards are probably not strict enough regarding the harsh environmental conditions in the Gulf Region, there is a demand for elaborating new, stricter standards and establishing an authority to certify solar products. Such authority would ideally be set up at KAUST's Solar Center. It is recommended to establish such certification facilities together with a shared center with testing and demonstration activities in order to measure product features at the certification standards and to leverage for further synergies in all directions.

The requirements for establishing a certification center would, in addition to providing lab space and technical know-how, assign an authorized certification provider who would take the lead for the elaboration of product standards and guarantee a smooth certification process.

The next steps for the initiation of a test center would be to cover the clarification of requirements for certification in the national market, the release of a call for proposals for the selection of a certification provider, and certainly marketing of the certification opportunities within the global solar community.

Design of a Saudi Solar VC Fund

Germany has been very successful in providing start-up funding to early stage high-tech companies, thereby helping them to transfer lab results into pilot production and prepare them for a future strategic investment by a venture capitalist or large corporation.

One of the recommendations of this study is to set up a venture capital (VC) fund of similar character in the Kingdom, managed by KAUST:

The goal of a Saudi Solar VC Fund would be to prepare companies for market readiness and funding by 'real' VC or strategic investors at a later stage.

First, this type of fund would be extremely supportive for the desired attraction of solar start-up and pilot-stage companies to the Kingdom/to KAUST. This opportunity would perfectly match companies' current needs to secure financing for growth plans as this is the major concern of early-stage companies. In this respect, a Saudi Solar VC Fund would be an excellent marketing instrument to promote the Kingdom as a dedicated forthcoming solar manufacturing location as well as to promote KAUST as an excellent solar R&D location with outstanding scientific facilities which also functions as an incubator.

Second, the Kingdom would thereby be given the chance to acquire technological know-how, particularly in those solar technologies which are most beneficial to the Kingdom. Local recruiting of technical staff would encourage Saudi nationals to become educated in upcoming solar technologies.

The concept is recommended to take after the German model. Funds would have to be provided in the form of public-private partnerships both from the Saudi Ministry as well as from large corporations. An initial fund volume with a minimum of $20 million USD is suggested. Fund management could probably be best provided by executives having expert knowledge in solar technologies as well as being experienced in management.

Funding would consist of an equity investment in selected solar companies of up to $2 million USD each with a maximum funding period of two years with a possible extension. Supervision and – upon need – management support will be provided.

Technology focus

The fund will exclusively fund solar technologies, particularly those which have been selected in the scope of this study. Furthermore, a prioritization in the light of technologies and applications is highly advisable. Priority 1: solar products which are ready for commercialization within the next three years and/or solar products which can be used domestically; Priority 2: other solar technologies.

Applicant requirements

As a number of applicants are likely to be large, applicants will need to fulfill strict requirements, including:

- Superior technology in one of the selected solar technology fields
- Possession of a relevant IP
- Experience in management, otherwise the business angle will be assigned
- Work needs to be executed at KAUST campus
- Funds need to be spent for R&D and preparation of market entry
- Commitment to set up manufacturing activities in the Kingdom

Application process

Initially, a short business and technology description needs to be submitted by the applicant. Within a maximum period of two weeks, an initial response will be sent by the fund management and if the candidate is desired, they will obtain the full set of application forms. It is then the applicant's responsibility to submit comprehensive application documents and include a detailed business plan. By examining the documents handed in and assisted by an externally provided due-diligence, the investment decision will be made. Assuming a positive investment decision, a funding offer to the applicant will be made followed by a closing of the deal.

Collaboration between industry and academia

Fostering the collaboration between industry and academia (e.g., by designing collaborative R&D programs) will highly support the commercialization of solar technologies. Please refer to the next portion of this document for a reflection of industry collaboration opportunities outlined in a broader context.

Emphasis of R&D on manufacturing processes

As shown above, there is an enormous potential for reducing costs and increasing efficiencies of solar products by improving manufacturing processes. In the light of costs, often a smooth production process is lacking and the output yield is too low. Regarding efficiencies, it is still a major problem to translate lab results into fab results.

Therefore, setting a focus of R&D activities on the improvement of manufacturing processes will support the commercialization of technologies.

D. Industry collaboration

Collaboration between industry and the scientific community covers a variety of aspects. Regarding solar R&D in the Kingdom, the following fields of industry collaboration seem to be feasible:

- Education of workforce for domestic solar manufacturing activities
- Contract-based joint R&D projects, particularly centered at KAUST (KICP)
- Collaborative research programs, initiated by the government
- Joint marketing and lobbying efforts for solar manufacturing and R&D
- Formation of a national solar industry association

- Incubation, VC funding
- Testing, demonstration and certification of solar technologies

Education

R&D is not only about developing new products or improving existing ones. The education of people is a major distinction of R&D activities and a core activity in the context of research-industry collaboration. Solar being a high-tech industry requires experts and trained staff for both research and manufacturing activities. It is obvious that substantial effort has to be made in order to provide a specialized solar national workforce for the Kingdom's ambitious plans regarding solar research and manufacturing. KAUST is excellently positioned to be the Kingdom's educational center regarding solar technologies. Of course, different solar technologies require a different focus of education. The same is true about the activities along the manufacturing value chain. The following chart, in Figure 65, may illustrate the diverse qualifications needed for running a fully integrated crystalline silicon manufacturing line.

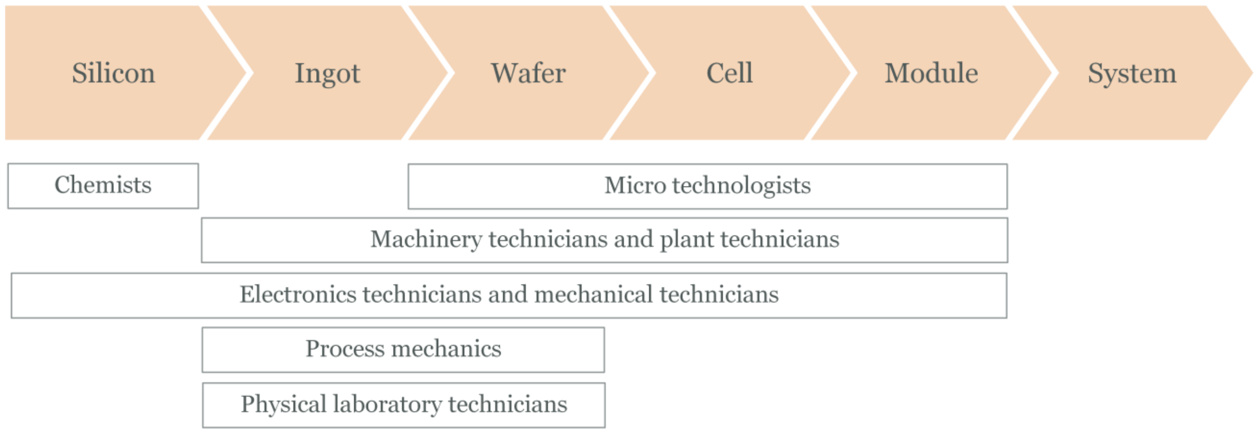


Figure 65: Professions along the crystalline PV value chain

Thus, for determining educational opportunities in relation to solar at KAUST/in the Kingdom, it is necessary to first determine which technologies and value chain activities should be pursued.

Joint research projects centered at KAUST

KAUST, with its strong focus on applied research and with its various industry opportunities being reflected in the establishment of KICP (KAUSST Industrial Collaboration Program), has already laid the foundation for very close research-industry collaboration. Calibrating research activities based on manufacturing challenges should become a focus for projects at KAUST. Herein, joint research projects between scientific working groups at KAUST and company representatives should establish a form of collaboration. Such joint research working groups should be allowed to make use of KAUST's facilities, such as the glass shop or the supercomputer.

Collaborative research programs

As discussed above, Saudi government is advised to initiate solar research activities in the Kingdom. As soon as corporations take the lead in solar research funding, government activities can be reduced. Government should aim at fostering research collaboration between scientific institutions and companies active in the Kingdom. For designing collaborative research programs, the right instrument to accelerate research activities is needed. For example, a collaborative research program could feature the following main characteristics:

- Aim: develop an encapsulated layer for flexible PV cells with a lifetime of > 20 years
- Working groups: 1-2 Saudi scientific institutes, 1-2 companies per project team
- Funding: an overall budget of between 1 and 3 million USD should be calculated which should be partly provided by the companies (50% of the project budget) and the government (50% of the project budget)
- Period: 18 months with presentations of intermediate results after 6 and 12 months

- Incentive: upon achieving aimed goals, the government will provide another 1 million USD for commercialization activities

Joint marketing and lobbying efforts

Saudi solar-related industries and research communities both have high interest in promoting solar energy, both domestically and abroad.

Within the Kingdom there is still a need for convincing some decision makers about the enormous potential of solar energy, therefore lobbying activities seem advisable. Ideally, industry and research players should join efforts when promoting the establishment of solar energy in the Kingdom.

The promotion of the Kingdom as a solar manufacturing and research location is necessary for the attraction of solar competence regarding both companies and scientists as well as to make the Kingdom more recognizable on the global map of solar energy.

Hence, within the industry-research collaboration, joint marketing and lobbying efforts are recommended whenever feasible.

Formation of a national solar industry association

A national solar industry association in the Kingdom would be another relevant instrument to foster collaboration between the industry and the solar scientific community. The main purpose of such an association would be to create a platform for the exchange of information between members of industry and science, as well as between external stakeholders in solar, such as governmental organizations or the financial community. From the high interest of solar energy within the Kingdom and the multitude of initiatives being launched, it seems highly advisable to establish a national solar industry association. Besides fulfilling coordinated tasks such as the provision of information on the solar market, manufacturing and research environment in the Kingdom, and being a point of first contact for inquiries which would be forwarded to the respective institutions, a solar industry association would provide lobbying for the solar industry in the Kingdom as well as promote Saudi Arabia abroad through marketing and PR activities.

Hence, this study's recommendation is to form a Saudi solar industry association to give solar a single voice in the Kingdom.

Incubation, VC funding

Incubation activities foreseen at KAUST and the proposed creation of a solar VC fund are to be mentioned in reference to industry collaboration activities.

Testing, demonstration and certification of solar technologies

The establishment of a test center would be a truly tangible project to bring industry and research together.

4.4. Attraction of solar research competence

There is no denying the fact that compared to leading solar-related research countries, the Kingdom will need to make a significant effort in order to catch up and develop its own leading position. Nevertheless, with a vision, a smart strategy and by taking powerful action, the goal of becoming a prime solar R&D location in a global context is achievable. At the beginning, it is evident that knowledge from abroad needs to be initiated to kick-start research activities. In the following chapter a strategic approach for the attraction of solar research competence concerning both companies and researchers will be presented.

4.4.1. Goals and target groups of marketing activities

The goals of marketing activities related to solar R&D are threefold:

1. Creation of awareness for Saudi Arabia and KAUST as a solar R&D location

2. Image building for Saudi Arabia and KAUST as an excellent solar R&D location

3. Attraction of researchers and R&D-focused companies to the Kingdom/to KAUST

Whereas image building is a long-term goal, the creation of awareness can be realized in the short term. The attraction of researchers has already commenced with regards to KAUST. Further activities in this context are necessary, especially for the attraction of companies.

Target groups have already been mentioned. In fact, there are two:

1. Companies and institutions

- R&D focused start-ups and pilot-stage companies
- Established companies
- Research institutions

2. Individuals

- Researchers, post docs
- Master/PhD students

In fact, pursuing the goals of creating awareness and image building can be realized in a joint approach for each of the target groups. In contrast, pursuing the goal of attracting R&D competence in the form of companies and research institutions requires both individuals such as researchers, as well as individual approaches.

4.4.2. A match for demand and opportunity

There is a significant correlation between the desires of the companies and the researchers as for the opportunities that are being offered by the Kingdom/KAUST. Based on that match, the value proposition has been developed in the following step.

Country perspective: The Kingdom's opportunities match the companies' desires.

Facing difficulties to raise funds for expansion, particularly for start-up and pilot-stage companies, there is a strong need for financing. The Kingdom could well provide solutions to this need by the establishment of the proposed VC fund, by granting investment incentives for the establishment of an R&D center, and by co-funding collaborative research projects.

Another concern of solar companies in the past few months has been weak sales in some key markets. It is evident that companies' desire to enter into markets around the Gulf has increased. Facing this desire, the Kingdom offers a large market potential and could position itself as the first address for entry into these regional markets.

Institute perspective: KAUST's opportunities match companies' desires.

Although several institutes are very renowned, working conditions for researchers are sometimes poor. Hence, researchers can be drawn to KAUST by providing an attractive working environment. In detail, researchers strive for freedom in research, availability of special equipment, a highly integrated R&D environment, an attractive salary and a pleasant living environment. KAUST can provide a perfect match by meeting these "needs."

4.4.3. Value proposition

Consequently, the value proposition regarding solar threefold R&D has been developed based on the match between the needs/desires among the solar R&D community and the Kingdom's/KAUST's opportunities:

A. Finance opportunities

The Kingdom can provide funding in terms of financing offered by financial/strategic investors and investment incentives provided by governmental organizations.

B. Market potential

The Kingdom and the entire region are a sizable future market for solar applications. KAUST can be the gateway for companies into the entire region.

C. Research environment

KAUST offers an outstanding research environment in a variety of ways.

These three key factors will form the value proposition for the presentation of the Kingdom/KAUST as a solar R&D location. Thus, they will be placed as outstanding arguments in marketing efforts for the promotion of the Kingdom and KAUST as a solar R&D location abroad.

4.4.4. Status quo of attraction efforts

Within this course of study, the promotion of the Kingdom and KAUST within the global solar community has already begun: 19 superior companies in one of the selected technologies have been approached regarding the establishment of research activities in the Kingdom. Moreover, there are three research institutes in discussion about collaborative activities at KAUST. As a result, nine leads among the companies and two leads among the institutes have been generated. KAUST's Economic Development Group is following up.

5. Conclusion

As a key result, the study has shown that the Kingdom offers very attractive conditions for the attraction of *solar manufacturing* activities from abroad. A key asset is the very low energy cost in attracting photovoltaic companies that are active in energy-intensive manufacturing steps, such as silicon and ingot/wafer production. In addition, solar thermal companies will find very attractive business conditions in the Kingdom, but require a domestic market to set-up operations. Thus, the establishment of a domestic solar market is essential. Taking the very competitive global FDI environment into consideration, the attraction of solar manufacturers to the Kingdom will only be successful if investment incentives are granted.

The Kingdom can well attract research-driven solar companies based on the very attractive research environment being established at KAUST. An important enabler would be the provision of funding opportunities to innovative solar companies. Such funding opportunities can be seen in the creation of a solar VC fund and in matchmaking with Saudi financial investors. As another result of this study, the establishment of a center for testing, demonstration and certification of solar products is recommended, thereby paving the way for commercialization of solar technologies in the Kingdom.

Numerous actors in the Kingdom have already realized the enormous potential of solar technologies for energy supply and job creation. So, several regulatory and governmental authorities, utilities, large corporations, academic institutions and private people have launched activities aimed at the establishment of solar energy in the Kingdom in recent months. Although all these efforts deserve appreciation, it is highly recommended to bundle activities in the future. A concerted action is needed to establish the essentials –regulation, market preparation and finance – for solar energy generation, manufacturing and research in a timely manner. Therefore, the establishment of a national Saudi solar energy authority steering single activities and powerfully pushing forward the establishment of solar energy in the Kingdom is required. As a framework for all solar-related activities and as an action guideline for a future Saudi solar energy authority, a national Saudi solar energy strategy needs to be developed as the next step.

The opportunities for the Kingdom presented by solar are vast. The time is now to establish solar as a key industry and benefit from the enormous potential solar offers to the Kingdom in terms of job creation and energy generation.

6. Appendix – Acronyms

Acronym	Explanation
ANU	Australian National University
ARRA	American Recovery and Reinvestment Act
billion	1,000 million
BIPV	Building Integrated Photovoltaics
Capex	Capital expenditure
CSP	Concentrating Solar Power
CST	Concentrated Solar Thermal
DHW	Domestic Hot Water
DOE	U.S. Department of Energy
EPIA	European PhotoVoltaic Industry Association
GDP	Gross Domestic Product
GERD	Gross domestic R&D expenditure
IEA	International Energy Agency
IP	Intellectual Property
ISFOC	Instituto de Systemas Fotovoltaicos de Concentracion (Spain)
LCOE	Levelized Cost of Energy
MCI	Ministry of Commerce & Industry
NEDO	The New Energy and Industrial Technology Development Organization (Japan)
NREL	National Renewable Energy Laboratory (NREL)
OECD	Organization for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PPP	Purchasing Power Parity exchange rate
PV	Photovoltaics
SERIS	Solar Energy Research Institute of Singapore
T, t, MT	Metric tonne (1,000 kg)
UNSW	University of New South Wales (Australia)
W	Watt
MW	Mega Watt (10^6 Watt)
GW	Giga Watt (10^9 Watt)
TW	Tera Watt (10^{12} Watt)
Wh	Watt-hour
Wh	Watt-hour

Acronym	Explanation
α-Si, α-Si/m-Si	Amorphous silicon
α-Si:H	Hydrogenated silicon
α-SiNx:H	Hydrogenated silicon nitride
α-SiNx:H	Hydrogenated silicon nitride
α-SiOxNy:H	Silicon rich oxynitride
α-SiOxNy:H	Silicon rich oxynitride
ALD	Atomic layer deposition
CdS	Cadmium Sulfide
CdTe	Cadmium Telluride
CIS	Copper Indium Selenide
CIGS	Copper Indium Gallium Di-Selenide
c-Si, mc-Si	Crystalline silicon, multi-crystalline silicon
CST	Concentrated solar thermal
DNI	Direct Normal Irradiation
DSSC	Dye sensitized solar cells
EG-Si	Electronic grade silicon
EVA	Ethylene vinyl acetate
HCPV	High Concentrating Photovoltaics
LCPV	Low Concentrating Phtotovoltaics
MG-Si	Metallurgical grade silicon
OPV	Organic Photovoltaics
PECVD	Plasma enhanced chemical vapor deposition
RTP	Rapid thermal processing
SEGS	Solar energy generating systems
Si	Silicon
SiN/SiNx	Silicon nitride
SiN:H	Hydrogenated silicon nitride
SiOx	Silicon oxyde
SoG-Si	Solar grade silicon
TPT	Tedlar-polyester-tedlar, plastic material for backsheets of thin-film solar cells
UMG-Si	Upgraded metallurgical silicon

Appendix – Presentations

APRICUM
THE CLEANTECH ADVISORY.

Saudi Arabia Solar Energy Study
Final Report - revised -

Riyadh
July 28, 2009

www.apricum-group.com

Agenda.

Solar energy as an opportunity for Saudi Arabia

Strategic approach

Implementation concept

APRICUM 2

Solar energy: A solution to Saudi Arabia's energy-related as well as environment-related concerns.

Energy-related concerns	Solutions provided by solar energy
• Growing energy demand (35 GW in 2008 → 70 GW in 2023; 150 TWh in 2007 → 300 TWh in 2017)[1] • Necessity to diversify energy supply beyond oil	Solar energy • Helps meeting growing energy demand • Is an attractive alternative for necessary investments into power generation capacity and infrastructure
• Power shortages during peak hours • Expansion of power grid (10% of population do not have grid access)[2]	Solar energy • Harnesses KSA's high solar irradiation when power is needed the most – during peak hours • Is highly suitable for generation and usage at remote locations

Environment-related concerns	Solutions provided by solar energy
• Necessity to cut CO_2 emissions (15.8 million tons CO_2/capita)[3]	Solar energy • Contributes to reaching emission targets (Kyoto Protocol ratified by KSA in 2005)
• Air quality affecting health due to combustion of lower quality liquid fuels	Solar energy • Is clean, thus not having any negative effect on health

Source: 1) ECRA, Business Monitor; 2) Arabian Business; 3) UN Statistics, figure for 2006

APRICUM 3

Solar energy: A solution to Saudi Arabia's economic concerns.

Economic concerns	Solutions provided by solar energy
• Unemployment (>10%), necessity for Saudization • Limited number of high-tech jobs	• Solar manufacturing creates large number of diversely qualified jobs along the value chain, esp. compared with conventional energy sources. • Solar R&D contributes to building globally competitive intellectual capital in KSA
• Dependence on oil (~1/3 of GDP), chemical and petrochemical sectors	• Solar energy helps diversify national economy and generate additional income • Presence of chemical and related industries aides development of solar industry
• Potential for improvement in productivity, export performance (only 10% are non-mineral products), competitiveness	• Solar manufacturing offers potential to export high value-added investment goods • Solar energy allows more profitable and efficient oil use (e.g. for high-growth industries) • Domestic solar energy generation opens path for export of electricity (e.g. Desertec)

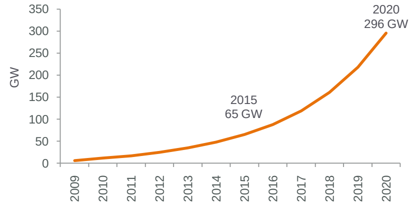
The establishment of a solar industry will contribute decisively to the strategic goals set out by the Ministry of Commerce and Industry (MCI). It will also promote Saudi Arabia's industrial centers and future projects. Furthermore, a commitment to solar energy will contribute to the country's environmental efforts.

Source: Economist Intelligence Unit.

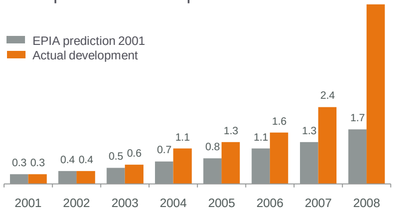
APRICUM 4

Long-term demand projections and announced solar projects in the Middle East indicate strong opportunities.

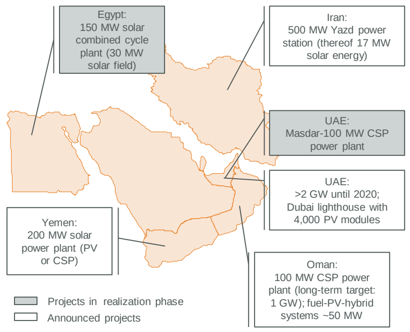
Global solar market volume [GW] – forecast



Annual global PV installations [GW] – actual development vs. 2001-predictions[1]



Ongoing solar activities in Middle East



A sustained and decisive engagement for solar in Saudi Arabia is justified and exemplified by activities already initiated in neighboring countries.

Note: 1) Additionally ~436MW of CSP-power was installed at the end of 2008. Sources: Apricum 2009, European Photovoltaic Industry Association (EPIA), Schott Solar, Greenpeace.

APRICUM

Saudi Arabia has the potential to become a major solar player in the medium term.

Vision and targets for solar in the Kingdom:

	Supply	Technology	Demand[1]
Short-term (next 2 years)	• Attraction of 2-3 PV projects (silicon, ingots/wafers, thin-film) involving $200-500 million capex each and >1,000 jobs total. • Attraction of a CSP production project (>50 MW) based on one or more solar power plants in KSA.	• Attraction of solar expertise to KSA, preferably to KAUST[2]: • 5-10 established solar manufactures with R&D/demonstration activities • 10-20 solar start-up/pilot stage companies to incubator at KAUST • Renowned solar researchers (>20) • Excellent Master/PhD students in solar related subjects (>100)	• Government initiatives and public procurement should lead to domestic market of 50-100 MW of new PV installations and min. 50 MW in CSP. • Solar demand incentive scheme in force.
Medium-term (3-5 years)	• Further downstream development (min. one cell and one module manufacturer). • Establishment of solar industry 'cluster' involving 2-3 leading R&D institutes, 2-3 industrial parks, >5 manufacturers and installers.	• Solar R&D as integral part of KSA's solar industry→ Annual government funding for solar R&D ~$100 mill. • KAUST as leading solar research institute in Middle East with strong focus on market end of R&D → Hub for testing and demonstration of solar technologies	• Gradual peak demand replacement (~2GW), remote Diesel generation replacement.
Long-term (>5 years)	• Solar to become one of the main industrial pillars (>50.000 jobs, $10 billion sales; export share >50%). • 2/3 of local demand to be covered by domestic production.	• KAUST as globally recognized solar R&D institute • Leading in testing and demonstration • Best-practice in start-up funding (min. 5 incubatees successfully operating mass-manufacturing plants in KSA)	• Potential to become solar energy exporter through large-scale installations and initiatives such as Desertec (goal for all MENA: 100 GW exportable power by 2050)

Note: 1) Not part of current project. 2) Also referring to other research institutions in KSA.

APRICUM

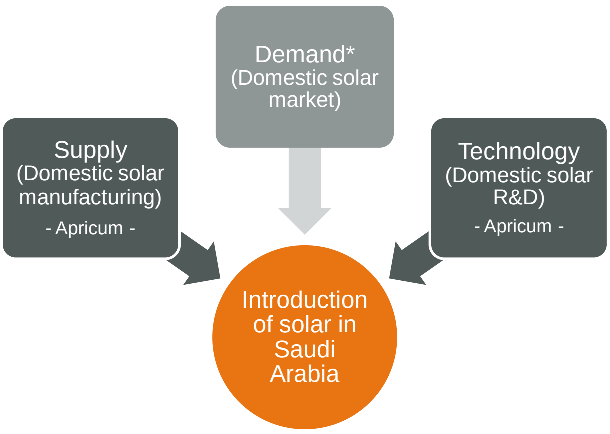
Agenda.

Solar energy as an opportunity for Saudi Arabia

Strategic approach

Implementation concept

Developing a solar industry requires a three-dimensional approach.



Note: *) Not part of current project.

1st Dimension – Supply.

Aim

- Make KSA a leading solar manufacturing location.

Relevance

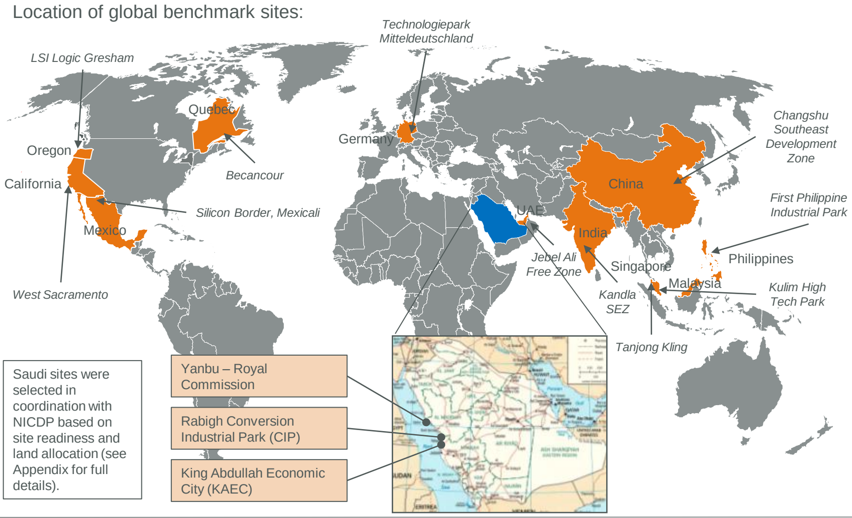
- Solar manufacturing
  - has the potential to create a high amount of diversely qualified jobs
  - will diversify the Saudi economy with high value-added downstream activities.
  - draw foreign direct investments and know-how into the Kingdom.

Strategic approach

- Benchmark potential locations for solar manufacturing in KSA with competing sites worldwide.
- Identify most promising solar segments for investor attraction.
- Develop KSA's value proposition as a solar manufacturing location.
- Identify top companies in target segments and generate investment leads.

In a benchmark analysis KSA sites have been evaluated vs. a number of alternative locations around the world.

Location of global benchmark sites:



A typical decision model for a solar manufacturing site selection formed the basis for the benchmark analysis.

Criteria in site benchmark analysis:

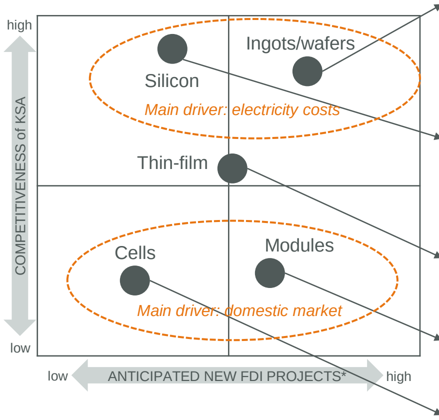
Environment factors
- Political environment
- Business environment
- Solar environment
- Labor availability
- Employee qualifications
- Employment relations
- Quality of life

Site-related factors
- Status of development plan
- Land characteristics
- Companies on site
- Port accessibility
- Airport accessibility
- Rail access
- Road access
- Electricity availability to schedule
- Electricity sources
- Water availability to schedule
- Waste water/ recycling capacity
- Availability of technical gases

Economic factors
- Labor costs
- Electricity price
- Electricity price stability
- Water price
- Corporate tax rate
- Other taxes
- Cash incentives
- Corporate tax holidays
- Other incentives
- Construction costs
- Real estate costs

The benchmark analysis delivered a clear prioritization of target segments in PV.

Top PV target segments based on KSA's competitiveness and investment potential:



Ingots/wafers – Priority 1
- Energy-intensive (~15% of total costs)
- High leverage of cash grants due to high capex (~$1 mill./MW)
- Relatively low demands on local supplier infrastructure
- Synergies with expected local silicon production
- Independent of local market, export business; products easy and inexpensive to ship

Silicon – Priority 2
- Energy-intensive (~20% of total costs)
- High leverage of cash grants due to high capex (~$100 mill./1,000t)
- Independent of local market, export business
- Long project lead times and affinity to chemical industry
- Potential for KSA to become global cost leader in current environment of high cost pressure

Thin-film – Priority 3
- High leverage of cash grants due to high capex
- Potential synergies with local glass producers
- Low shipping costs, time advantage vs. Southeast Asia
- Final product – local market critical

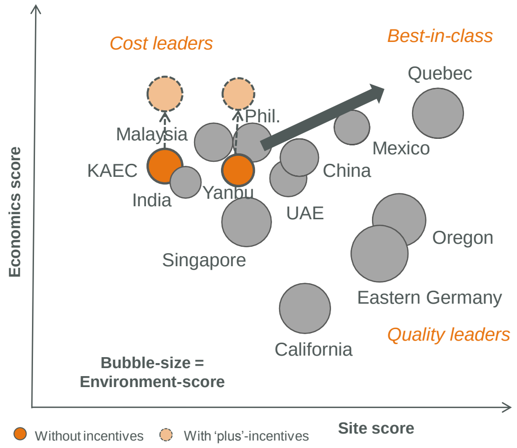
Modules – No short-term priority
- Lower-tech production (primarily assembly work)
- Final product – local market critical

Cells – No short-term priority
- Demanding in terms of local supplier infrastructure
- Currently low capacity utilization in industry
- Existence of local market highly supportive

Note: *) Global scale, Apricum assessment.

Whereas qualitative site factors should be improved, investment incentives are essential to make-up for deficits.

Cost and quality-matrix for a sample silicon project



Main insights

- Particularly with investment incentives, KSA sites are among the cost leaders globally but lag behind most of the competing locations in terms of environment- and site-related factors.

=> In order to become a viable investment location for the solar industry qualitative factors need to be tackled.

Note: Please see Appendix for specific site locations.

A value proposition for the solar industry should focus on economic benefits and successes to-date.

Top competitive advantages common to Saudi Arabia sites[1]:

Factor	Category
Land characteristics	Site
Port accessibility	Site
Electricity costs	Economics
Cash incentives[2]	Economics
Employment relations	Environment
Labor costs	Economics
Corporate tax rate	Economics
Other incentives	Economics
Road accessibility	Site

Favorable economics are needed to make up current deficits in environment factors. Site-factors can be worked on.

Top competitive disadvantages common to Saudi Arabia sites[1]:

Factor	Category
Status of development plan	Site
Electricity availability	Site
Employee qualifications	Environment
Labor availability	Environment
Solar environment	Environment
Political environment	Environment
Rail access	Site
Electricity sources	Site
Water price	Site

Priority arguments for KSA investor attraction based on competitive advantages *and* typical solar investor's priorities:

1) Financing/incentives

2) Electricity costs

3) Track record FDI attraction

Notes: 1) Unweighted results from benchmark model. For full results by value chain segment, see Appendix; 2) Assuming 'plus'-package.

The benchmark analysis confirmed the competitiveness of Saudi sites and identified scope for further improvement.

Suitability of Saudi sites for segments in PV value chain:

Yanbu – Royal Commission	Rabigh Conversion Industrial Park	King Abdullah Economic City
Suitable for entire value chain, but best-prepared for upstream segments	Suitable for module assembly	Suitable for entire value chain, but best-prepared for downstream segments

Main factors for further improvement of KSA sites[1]:

Environment

- Pursue solar demand incentives and make solar priority for investment incentives (short-to-medium-term)
- Improve and demonstrate labor availability through tailor-made recruitment schemes for foreign solar investors
- Work with companies and schools to set up relevant solar training programs
- Demonstrate high quality of life for expats in 'microcosms' such as KAEC, KAUST

Site

- Resolve electricity supply situation and offer high transparency with regards to expected timelines for infrastructure upgrades, utility hook-up fees etc.
- Show readiness to make dependable commitments according to investor's specific requirements
- Offer transparent procedures for land allocation and other administrative procedures and streamline necessary processes
- Improve public information provision (internet presence)
- Organize company meetings with existing investors ('success stories')

Economics

- Offer long-term power price stability through extended contract periods
- Offer 'plus'-incentives to first movers and regular cash grants to other solar investors

Note: 1) For further details, see Appendix.

Aside from PV, concentrated solar thermal power (CSP) is a major focal point for investor attraction.

CSP Technologies

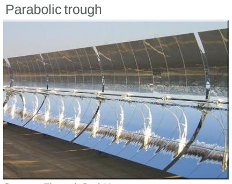
Power tower

Source: Abengoa Solar, S.A.

Dish engine

Source: http://blog.sellsiusrealestate.com/

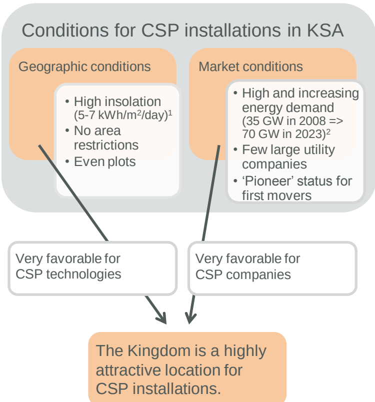
Parabolic trough



Source: Flagsol GmbH

Linear Fresnel

Source: Novatec Biosol AG



Source: 1) NASA; 2) ECRA.

CSP is a local business: The establishment of attractive market conditions for CSP will lead to the creation of jobs.

Attractive conditions for CSP → CSP installations (> 50 MW) → Local assembly required → Local manufacturing

- Geographic and **market conditions** (see previous slide) enforced by a **market incentive program**
- Local large-scale CSP installations are key to local assembly/manufacturing.
- Particularly of large and sensitive parts

Create jobs
- Assembly/ manufacturing (with suppliers)
- Installation
- Operation

Build-up know-how
- Manufacturers
- Installers
- Operators
- Local suppliers

Generate power
- Grid-connected
- Off-grid => remote areas

CSP is a perfect fit for the Kingdom:

- Less incentive-driven than PV due to higher price competitiveness, esp. of large installations (cost of electricity – PV: > USD 0.30/kWh; CSP: USD 0.17/kWh)[1]
- Involvement of the existing local industrial base as suppliers (mirrors, aluminum mounting etc.)
- Centralized utility-scale projects – familiar to traditional electricity infrastructure
- Landmark projects have the potential to create global attention
- Potential to even export electricity in the future[2]

Source: 1) PV: average, Apricum research; CSP: Nevada Solar One, 64 MW; 2) e.g. DESERTEC project

Several leads have already been generated from an initial targeted investor attraction approach.

Overview of target companies met for supply module:

	Target segment				Leads[1]
	Ingots/ wafers	Silicon	Thin-film	CSP/ Other	
Abengoa Solar				■	■
CaliSolar	■				
Deutsche Solar	■	■			
Inventux			■		■
MEMC	■	■			■
PV Crystalox	■	■			■
Q-Cells			■		■
Schott Solar			■	■	■
Solaria				(L-CPV)	
Solarion			■		■
Sovello	■				
Sulfurcell			■		■
WackerSchott	■				■

27 companies identified/ contacted[2] → 17 companies met[3] → 9 leads

Notes: 1) For further details, see Appendix. 2) Not including companies contacted within technology module (esp. CSP). 3) Including First Solar, Total (meetings to be organized) and Kaneka, ShowaShell (met independently).

2nd Dimension – Technology.

Aim

- Make KSA a globally leading solar R&D location.
- Make KAUST a globally leading solar research center with huge benefits for the Kingdom.

Relevance

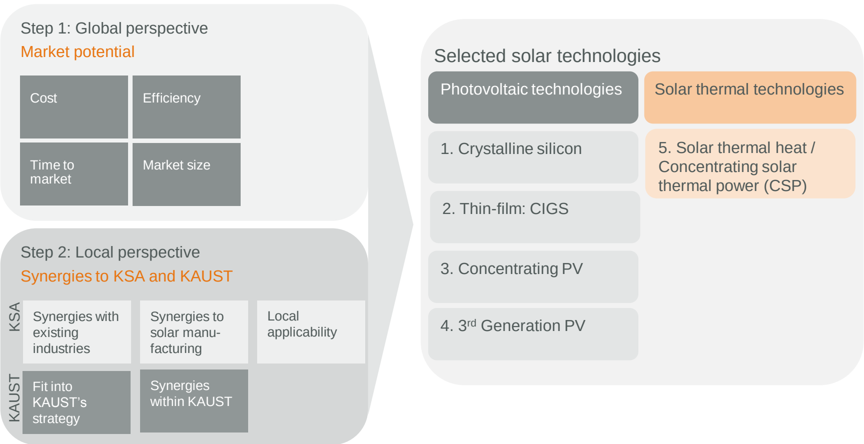
- Solar R&D activities
  - Will provide the knowledge base for a domestic solar industry.
  - Help attract solar companies from abroad.
  - Create jobs and contribute to GDP.

Strategic approach

- Select those solar technologies which have the highest potential for successful commercialization and offer the biggest synergies to KSA and KAUST.
- Identify the most relevant research topics.
- Derive best-practices from countries and solar institutes leading in solar R&D.
- Develop KSA's value proposition as a solar research location.
- Actively promote KSA and KAUST in particular as solar R&D location abroad.

Five solar technologies have been selected based on market potential and synergies within KSA and at KAUST.

Two-step approach to identifying solar technologies:



Selection of solar technologies – Overview of assessment.

Step	Technology/criterion[1]	1. Crystalline Si	2. Thin-film: CIGS	3. Concentrating PV	4. 3rd Generation PV	5. Solar thermal heat / CSP
Step 1	Installed Cost 2007 ($/W)	5.70 – 8.58	5.00 – 10.00	5.85 – 10.11	N/A	3.00 – 4.00 (CSP)
Step 1	Efficiency – cell (best, lab) Efficiency – module	18 – 24% 12 – 20%	21% 7 – 13%	41% 20 – 30% (system)	10 – 11% 3 – 6%	N/A 11 – 24% (CSP system)
Step 1	Time to market	Today	0-3 years	0-3 years	5-10 years	0-3 years (solar thermal heat) Today (CSP)
Step 1	Market size (Cumulative,YE 2007)	8.2 GW	46 MW	16 MW	<< 1 MW	154 GWth (solar thermal heat) 430 MW (CSP)
Step 2	Fit in KAUST's strategy	Yes	Yes	Yes	Yes	Yes
Step 2	Synergies at KAUST	Yes	Can be high	Can be high	Yes	Yes
Step 2	Synergies with industries in KSA	Yes	Potentially	Yes	Potentially	Yes: metal processing, glass
Step 2	Benefit from KSA's manufacturing location factors	Yes, particularly low-cost energy.	Yes, but requires expert knowledge.	Yes	Yes, potentially.	Yes
Step 2	Potential for domestic application	Good	High (BIPV)	High	High (BIPV)	High

Note : 1) All numbers reflect a range and are based on multiple sources (US Department of Energy; Greentech Media; Deutsche Bank; Lux Research; Displaybank; CPV Today; Zentrum für Sonnenergie- und Wasserstoffforschung; company infos (Applied Materials; First Solar; Oerlikon; Sopogy; Sol3g; Sulfurcell; Wuerth

APRICUM 21

Selection of solar technologies – Comparison of economics.

		Thin-film technologies				For comparison
Technology/criterion[1]	Crystalline Si	Thin-film: α-Si / µ-Si	Thin-film: CdTe	Thin-film: CIGS	Concentrating PV	CSP
Efficiency – cell (best, lab)	18 – 24%	11.7%	16%	21%	41%	N/A
Efficiency – module	12 – 20%	6 – 10%	7 – 10%	7 – 13%	20 – 30% (syst)	11 – 24% (syst)
Module manufacturing cost in 2007 ($/W)	2.40 – 3.15	1.50 – 1.80	1.15 – 1.30	1.80 – 2.00	N/A	N/A
Installed cost in 2007 ($/W)	5.70 – 8.58	6.55 – 7.37	5.00 – 6.00	5.00 – 10.00	5.85 – 10.11	3.00 – 4.00
LCOE in 2007 ($/kWh)[2]	0.275 – 0.30	0.30	0.18 – 0.24	0.30	0.31 – 0.38	0.12 – 0.17
Time to market	Today	Today	Today	0-3 years	0-3 years	Today
Best geographic application	Global; loss of efficiency at high temp	Global; diffuse light; better at high temp	Global	Global	High DNI (> 1700 kWh/m2/yr)	High DNI (> 1700 kWh/m2/yr)

Notes: 1) All numbers reflect a range and are based on multiple sources (US Department of Energy; Greentech Media; Deutsche Bank; Lux Research; Displaybank; CPV Today; Zentrum für Sonnenergie- und Wasserstoffforschung; company infos (Applied Materials; First Solar; Oerlikon; Sopogy; Sol3g; Sulfurcell; Wuerth); 2) LCOE numbers based on 1 MWp commercial installation and 5 kW/m2/day solar irradiance

APRICUM 22

1. Crystalline silicon: Proven technology with significant cost reduction potential.

Reasons for selection

Market potential
- In the market for many years with a PV market share of 80%; dominant technology today
- High efficiency

Synergies to KSA/KAUST
- Raw material and supplies largely available
- Availability of low cost energy as manufacturing factor
- Domestically applicable in a large variety of ways
- KAUST: Strategic fit to materials engineering at Solar Research Center

Source: Q-Cells AG

Research fields

- Cost reduction and improvement at raw material level: UMG silicon
- Cost reduction and improvement at cell level: Cheaper materials, improved coatings, and enhanced surfaces
- Cost reduction and improvement at module level: Reduced material consumption, cheaper materials and longer lifetime

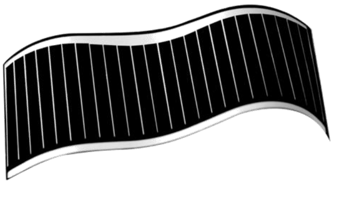
APRICUM 23

2. Thin-film CIGS: Highest potential for efficiency improvement within thin-film technologies.

Reasons for selection

Market potential
- Highest potential for efficiency improvement within thin-film technologies => similar efficiencies to those of c-Si cells achievable at lower cost
- Large market potential due to flexibility in areas such as building-integrated PV and consumer electronics

Synergies to KSA/KAUST
- Large potential for domestic application in solar parks and integrated in buildings



Source: Solarion AG

Research fields

- Improvement of process control to replicate lab-stage efficiencies in mass manufacturing
- Improvement of efficiency and lifetime/stability of flexible CIGS cells
- Development of cheaper barrier films with improved characteristics for encapsulating flexible CIGS cells

APRICUM 24

3. Concentrating PV (HCPV): Very well suited for locations with high solar irradiation, such as the Kingdom.

Reasons for selection

Market potential
- III-V multi-junction cells have the highest efficiency of all solar cells (>41% in lab)
- Medium sized power plants based on HCPV are already in operation → ready for large-scale deployment

Synergies to KSA/KAUST
- Excellent potential for domestic application due to abundant solar irradiation
- Raw material and supplies largely available (aluminum, steel, glass, plastics) => local manufacturing feasible
- Matches KAUST's research agenda, e.g. optical science

Source: SolFocus, Inc.

Research fields

- Improvement of III-V cell designs and manufacturing processes
- Improvements in the design and manufacturing processes of the optical system
- Improvement of tracker design and reliability

4. 3rd Gen solar cells: Today's research for a new generation of solar cells applicable in the future.

Reasons for selection

Market potential
- Expected to have very low material and manufacturing costs, thus having the potential for a great technological advancement
- Potentially very large markets

Synergies to KSA/KAUST
- Climate conditions in KSA, namely high temperatures, are in favor of efficiency of organic PV (OPV) cells
- KAUST's Solar Center Director Prof. Jabbour is committed to research on 3rd Gen technology

Source: Konarka Technologies, Inc.

Research fields (sample)

- Development of alternative cheaper and better transparent electrodes
- Improvement of methods for testing reliability and degradation
- Improvement of lifetime and stability of OPV cells by improving laminating and encapsulation materials
- Development of growth procedures of nano-crystals

5. Solar thermal heat / CSP: Large domestic market with potential for KSA to become an electricity exporter.

Reasons for selection

Market potential
- Least cost of all solar technologies when being applied in large power plants (USD 0.17/kWh already realized)
- Market readiness today for parabolic trough technology
- Large domestic market, potential for KSA to export electricity in the future

Synergies to KSA/KAUST
- Local availability of most raw materials, such as steel and glass
- Very wide range of local applications: residential, commercial, industrial with their needs for hot water, process heat, cooling, desalination

Research fields

- Improvements to the design and materials of reflector, receiver tube, and support structure – Leading to reduced cost
- Development of thermal storage solutions
- Development of solutions integrating the provision of heat, cooling and desalinated water
- Development of more durable, better reflecting or absorbing, high-temperature resistant coatings for reflector and absorber

Apricum recommend six strategic actions for KSA to become a globally leading solar R&D location with KAUST as its nucleus.

Recommendations for the Kingdom / for KAUST regarding solar R&D

1. R&D spending
Spend annually min. 2% of the GDP on R&D in general. Provide governmental funding for solar technologies in the order of USD 100 million p.a.

2. R&D scope
Pursue solar R&D in a variety of technologies. Cover the entire range from fundamental to applied research and demonstration activities.

3. Commercialization
Strongly promote the commercialization of technologies. Establish a center for testing and demonstration of solar applications.

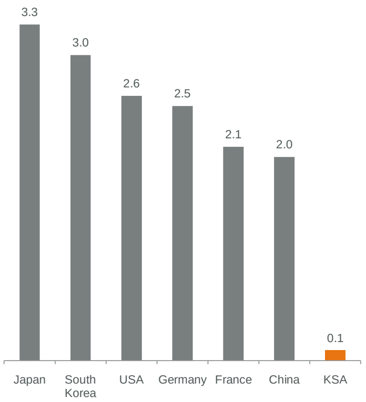
4. Domestic application
Focus R&D activities on locally applicable solar technologies.

5. Industry collaboration
Provide education and R&D collaboration offerings for manufacturing partners in the country.

6. Expertise from abroad
Make KAUST the gateway to the Kingdom for technology-driven companies. Keep on recruiting excellent research staff.

1. R&D spending – Becoming an R&D leader requires significant public and private spending.

R&D expenditures of the leading countries as percentage of GDP, 2008

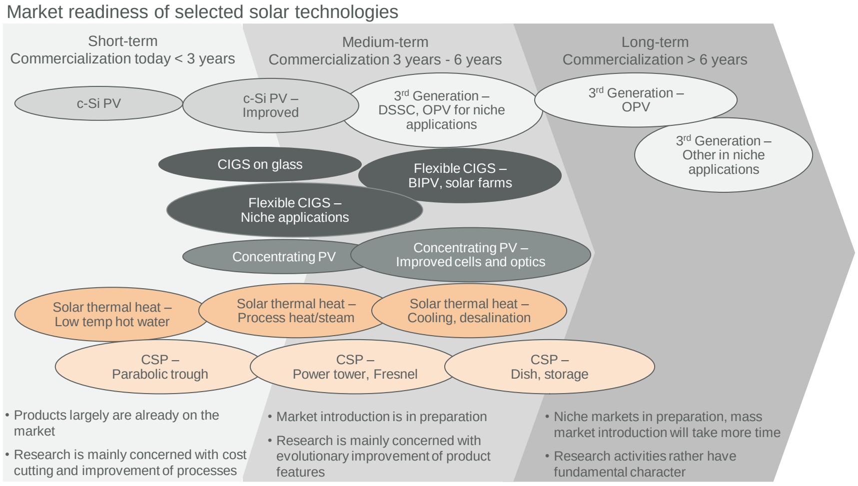


- The leading countries spend 2 to 3 percent of their GDP per year on R&D, public and private spending combined; in KSA roughly 0.1 percent is being spent.
- Catching up with the leading countries will require an at least twenty-fold increase of today's spending. Given KSA's GDP of USD 583 billion (2008), the country will need to raise R&D expenditures to a minimum of USD 12 billion in total.
- Apricum recommends for KSA to provide public R&D funds dedicated to solar technologies in the order of USD 100 million per year (for reference – USA: USD 229 million, Germany: ~ USD 110 million).
- As companies decide independently on their R&D budgets and cannot be forced to augment them, Saudi government is advised to take the lead in R&D spending, thus encouraging industry to raise R&D budgets.

Source: Battelle Report 2009; Apricum research

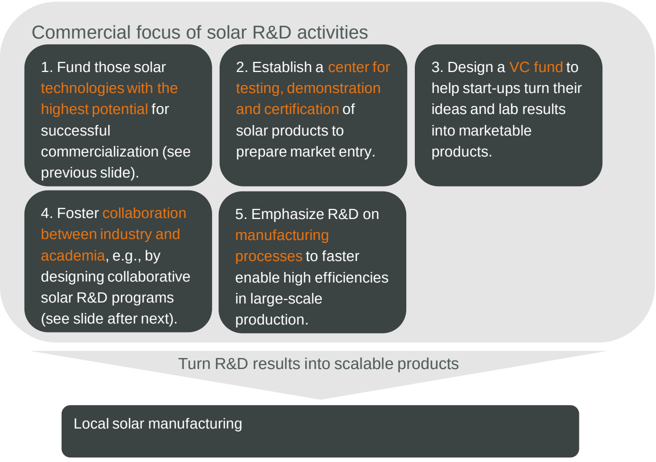
2. R&D scope – R&D funding in the selected technology fields will secure a constant flow of marketable solar products.

Market readiness of selected solar technologies



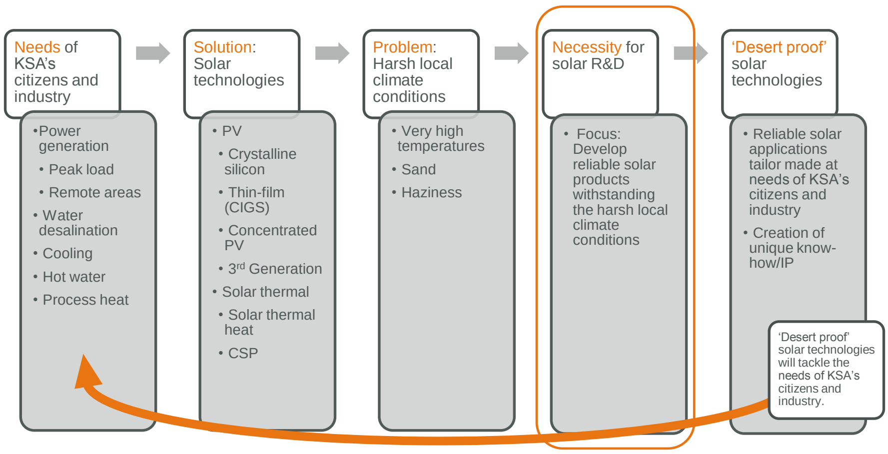
Source: Apricum Research 2009

3. Commercialization – Sustained local solar manufacturing requires R&D activities at the market end.



APRICUM 31

4. Domestic application – Special local conditions require particularly proven solar technologies, hence focused R&D.



APRICUM 32

5. Industry collaboration – Highly profitable for both solar research institutions and solar industry.

KSA solar industry

Education of workforce	Contract-based R&D projects	Comprehensive research programs (initiated by the government)	Joint marketing activities promoting KSA as solar manufacturing and R&D location
Joint lobbying for solar in the Kingdom	Formation of a national solar industry association	Establishment and operation of a test-/ demo-center	Incubation activities at KAUST

KSA solar research institutions, namely KAUST

Initially, collaboration activities between NICDP representing KSA's solar industry and KAUST representing solar research in the Kingdom need to consist of a joint promotion of the location abroad as well as joint lobbying activities in favor of solar within the Kingdom.

6. Expertise from abroad – Attraction of both companies and research staff will be essential to set solar R&D on track.

Goals of marketing activities
- Create awareness for KSA and KAUST
- Build a positive image
- Actively attract researchers and investors

Target groups
- Companies
  - Start-up/pilot stage
  - Established
- Research institutions
- Individuals
  - Research staff
  - Master/PhD students

Value proposition
- Access to finance
- Huge regional market potential
- Attractive research environment at KAUST

Recommended marketing instruments
- Mailing
- Company visits
- Website
- Journal ad
- Headhunting
- Scientific award
- Conference presentation
- Conference event
- PR – Press

Apricum recommend to align marketing activities regarding manufacturing and R&D whenever feasible.

The Kingdom’s value proposition for solar R&D highlights economic benefits, market opportunities and soft factors.

Main competitive advantages of KSA and KAUST regarding solar R&D

- Financial support for start-up and established companies involved in R&D and manufacturing
  - VC fund [proposed]
  - Incentives [proposed]
  - Grants [proposed]
- Huge domestic market potential
- Proven FDI record in the existing chemical and petrochemical industries
- World-class research facility in KAUST
- A wide choice to pursue research
- Pleasant living environment (KAUST, KAEC)
- Favorable working contract (attractive salary and other benefits [proposed])

Priority arguments for attraction of R&D expertise

1) Financing/incentives
2) Market potential of new solar technologies
3) Research environment

Several leads among R&D-focused companies and research institutes have already been generated.

Research focused companies

19 contacted → 11 met → 9 leads generated

	Target segment						Leads generated[1]
	c-Si	CIGS	CPV	3rd Gen.	Solar thermal heat	CSP	
Ausra					■	■	■
FlagSol						■	■
Global Solar		■					■
ISET		■					■
MAN Solar Millennium						■	■
Mirroxx					■		
Novatec Biosol					■		■
SolFocus			■				■
Solyndra		■					■
Sopogy						■	
Telio Solar		■					■

Research institutes

3 contacted → 3 met → 2 leads generated

	Target segment						Leads generated[1]
	c-Si	CIGS	CPV	3rd Gen.	Solar thermal heat	CSP	
Fraunhofer ISE	■		■	■	■	■	■
Helmholtz Research Center	■	■		■			
Solar Institut Jülich					■	■	■

Notes: 1) For further details, see Appendix.

3rd Dimension – Demand*.

Aim

- Make KSA a user of solar energy and create a sustainable domestic market.

Relevance

- A domestic solar market
  - will be one of the main drivers for manufacturing and R&D development in the Kingdom.
  - can be a key solution to dealing with energy supply issues (peak demand, rural electrification).
  - will contribute to reducing carbon emissions.
  - will free up oil and gas for higher value-added uses.
  - has the potential to turn KSA into a net energy exporter.

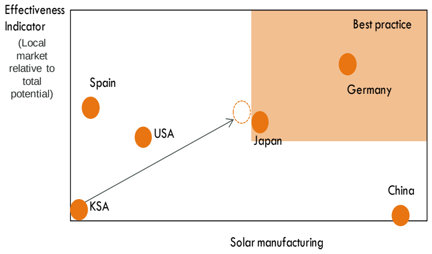
Potential strategic approach

- Develop a solar energy market incentives program and policy framework for Saudi Arabia.

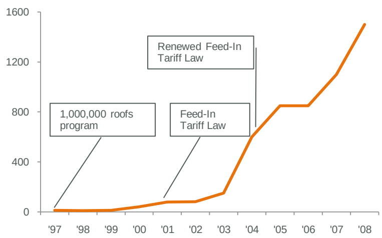
Note: *) Not part of current project.

The development of Germany and Japan shows the importance of strong domestic market support.

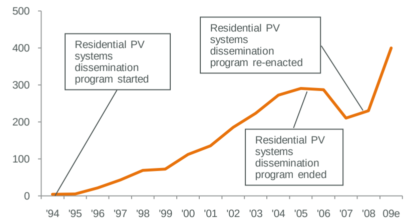
PV application and manufacturing in selected markets



Annual PV market volume in Germany



Annual PV market volume in Japan

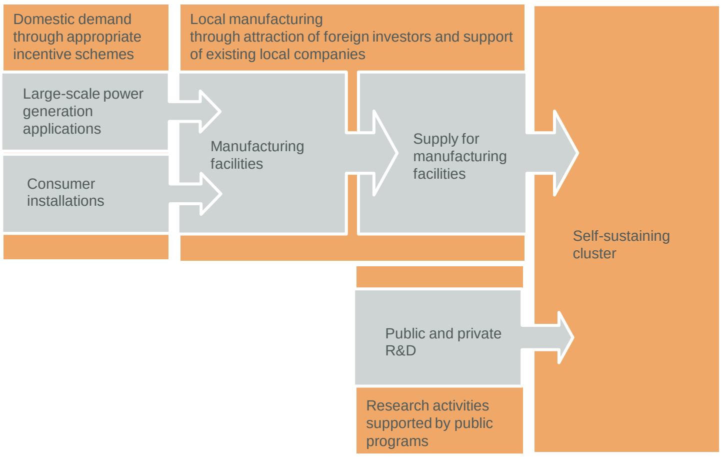


Reliable government support led to fast dissemination of installed PV power and development of local manufacturing.

Sources: EPIA, Photon International, Apricum research.

Apricum proposes an integrated approach for supporting solar industry and cluster development.

Domestic demand as well as local manufacturing and research activities will interactively create a self-sustaining cluster.



Agenda.

Solar energy as an opportunity for Saudi Arabia

Strategic approach

Implementation concept

Action items.

	Supply	Technology	Demand*
Priority 1	• Competitive advantage in upstream part of value chain → Company follow-up: PV Crystalox, MEMC; WackerSchott. • Focus investor targeting on ingot/ wafer and polysilicon producers. • CSP and thin-film company follow-up: Sulfurcell, Inventux, Showa Shell,, Abengoa, Schott, Novatec Biosol. • Pass 'plus'-incentive program given high attractiveness and positive company feedback. • Financing bottleneck: Identify Saudi partners committed to solar and organize investors conference.	• Follow-up with the R&D leads initiating pilot projects at KAUST – CSP: Novatec Biosol, MAN Solar Millennium/ Flagsol, Ausra, Abengoa; CPV: SolFocus; CIGS: Solyndra. • Establish a solar VC fund and market it abroad. • Establish a center for testing, demonstration and certification of solar products at KAUST. • Roll-out global marketing campaign promoting KAUST as solar R&D location.	• Initiate local market development indicated as crucial by solar companies → incentive scheme, government procurement.
Priority 2	• Marketing campaign and further company targeting: Thin-film and CSP segments. • Execute recommended site improvements regarding investment conditions (esp. electricity, training programs, 'red tape'-reduction).	• Increase governmental spending on solar R&D; allocate funds towards technologies and initiatives provided in this study. • Include R&D centers in investment incentive scheme.	• Introduce PV manufacturers to Emaar concerning potential installations at KAEC.

Note: *) Not part of current project.

Highlighted action items – Manufacturing-focused company follow-ups.

Company	Priority	Specification
WackerSchott	1	Co is planning expansion out of current site; has been open to and interested in opportunities in KSA; likely several 100MW-ingot/wafer facility; site selection planned in Q1/Q2 2010.
PV Crystalox	1	No immediate plans for expansion but looking at medium-term options; given clear upstream focus KSA provides attractive environment; potential partnering with ongoing IDEA-project.
Sulfurcell	1	Co is looking at further expansion for when new 75MW-Berlin facility is fully ramped; has been open to and interested in opportunities in KSA.
Solarion	1	Co is looking for financing and location for first mass production facility; has been open to and interested in opportunities in KSA .
MEMC	1	Currently leveraging existing capacities in US, Italy to serve growing solar business; interested in medium-term greenfield options; has plans to vertically integrate the value chain; expansion plans – in the process of conducting an economic analysis of potential sites; very interested in KSA's offerings.
Abengoa Solar	1	Very interested in entering the Middle East; various solar thermal and PV technologies, particularly those of KSA's and KAUST's interests.
Schott Solar	2	No immediate plans for expansion but co. is active in several high-potential PV segments for KSA (wafers/ingots, thin-film) and CSP; looking for opportunities in Middle East-region.
Q-Cells	2	Thin-film subsidiaries likely to start site selection in 1st half of 2010; several other potential fields of cooperation, e.g. local R&D relationships, landmark solar project, module testing, financing options.
Inventux	2	Plans for substantial further expansion exist, either at current or new site. High leverage for attraction to Saudi Arabia if local (financing) partner can be found.
First Solar	Tbd	Indicated interest in opportunities in Saudi Arabia.
Total	Tbd	Indicated interest in opportunities in Saudi Arabia.
All others		Keep in contact, check back regularly, especially prior to industry events. Send relevant updates.

Note: See Company Meetings and Company Profiles in Appendix for further details on individual companies.

Highlighted action items – Solar research institutes and R&D focused companies follow-ups.

Institute/ Company	Priority	Specification
Fraunhofer ISE	1	Largest European solar energy institute engaged in fundamental and applied R&D of PV and solar thermal technologies; very open for collaboration with KAUST, has already proposed possible fields for joint research; push exchange with Institute Director Professor Weber, get him in touch with Professor Jabbour, evaluate offerings for joint research project
Solar Institut Jülich	1	Specialized in solar thermal technologies, solar power tower installed on-site; interested in a collaboration with KAUST – hybrid solar power towers with integrated desalination units, desert sand as thermal storage medium are some of the research fields of mutual interest; get in touch with Head of Division Professor Hoffschmidt for preparing next steps
MAN Solar Millennium	1	CSP technology (Fresnel and parabolic trough); R&D, manufacturing, and project development expertise offering turnkey solutions in the range of 50 MW to 100 MW; on-going discussion about project ideas in KSA
Novatec Biosol	1	CSP Fresnel technology; strongly interested in collaboration with KAUST – Installation of a Fresnel CSP plant and R&D collaboration with KAUST regarding water desalination and cooling; NDA in execution
ISET	1	CIGS; requires financial support to scale-up its 30 MW pilot operations; KAUST can leverage ISET's resources, e.g. by benefiting from CEO's know-how and network and providing test facilities
Solyndra	1	CIGS, expansion plans; 3rd factory preferably close to a local market; already investigated locations around the world; very interested in KSA's offerings; provide information on incentives, intensify discussion
SolFocus	2	HCPV; local market for large-scale projects (> 50 MW) is required for establishing local operations; interested in demo projects with a partner; open for collaboration with KAUST; come up with precise offering/partner suggestion
Ausra	2	CSP Fresnel technology; local market for large scale projects (> 50 MW) is required for establishing local operations; interested in local installations; open for collaboration with KAUST; come up with precise offering
Flagsol	2	CSP parabolic trough technology; a subsidiary of Solar Millennium; interested in collaborating with KAUST; project < 50 MW and with a local partner; follow-up together with MAN Solar Millennium
Global Solar	2	CIGS flex, specialized in BIPV; recently expanded production capacity; sees potential for R&D collaboration with KAUST; introduction to Prof. Jabbour as follow-up
Telio Solar	2	CIGS; interested in the Middle East regarding manufacturing and manufacturing processes-related R&D; develop ideas for R&D project at KAUST

Note: See Appendix for further details.

Highlighted action items – Marketing efforts.

The marketing campaign is an integral part of a global positioning of Saudi Arabia within the solar realm

Goals
- Create awareness for KSA and KAUST
- Build a positive image
- Actively attract researchers and investors

Target groups
- Companies
  - Start-up/pilot stage
  - Established
- Research institutions
- Individuals
  - Research staff
  - Master-/PhD students

Value proposition
- Attractive cash incentives, access to finance
- Proven FDI destination
- Low energy costs
- Large regional market potential, favorable conditions
- Premium research environment at KAUST

Instruments
- Mailing
- Company visits
- Website
- Journal ad
- Headhunting
- Scientific award
- Conference presentation
- Conference event
- PR – Press

- A combination of marketing activities for manufacturing and R&D should be pursued.
- Apricum estimates an annual marketing budget of ~ $600,000 and ~ $1,000,000 to kick-start manufacturing-related and R&D-related investment promotion, respectively.

Highlighted action items – Marketing activities: Roll-out campaign, host solar investors' conference.

Recommended initial marketing budget

• Direct approach (mailing, direct contacting)	USD 55,000
• Website	USD 15,000
• Print (brochure, solar journal/ career journal ad)	USD 225,000
• Talent marketing (career fair booth, career event)	USD 50,000
• Scientific research award (award, ceremony, and campaign)	USD 180,000
• Conferences (sponsor, host, event, presentation)	USD 305,000
• Press PR	USD 100,000
Total	USD 930,000

Next steps

- Approve marketing budget
- Mandate PR/advertising agency
- Prepare solar investors' conference
- Coordinate with NICDP, SAGIA

Solar investors' conference

Hosts
KAUST (lead)
NICDP, SAGIA (co)

Location
KAUST venue

Concept
Match-making event between established/pilot-stage solar companies and potential financial/ strategic investors from KSA

Cost
Very much depending on size and offerings, min. USD 100,000

Goal
Hook up solar companies with investors from KSA to facilitate solar manufacturing or installation projects in the Kingdom

Time frame
- Preparation period min. four months
- Promotion/ contacting min. two months in advance
- Execution two days

Highlighted action items – VC fund: Excellent tool to attract start-ups and prepare market entry of solar products.

Saudi Solar Venture Capital Fund – proposed –

Goals
- Attract solar start-up/pilot stage companies by providing funding
- Build-up technological know-how in the Kingdom, particularly in those solar technologies which are most beneficial for the Kingdom
- Prepare companies for market readiness and funding by "real" VC or strategic investor
- Use fund as marketing tool for promotion of KAUST as incubator abroad

Funds
- Min. USD 20 million initial fund volume
- Provided by a Public-Private-Partnership (responsible ministry as well as Saudi companies such as Aramco or Sabic)

Concept
- Equity investment in selected solar companies of up to USD 2 million each
- Funding period max. two years, extension possible
- Exit when it makes sense economically
- Supervision and management support

Technology focus
- Solar technologies exclusively; particularly those which were selected in the scope of this study (slide 18)
- Prioritization
  - Priority 1
    - Solar products which are ready for commercialization within next three years (slide 29)
    - Solar products which can be applied domestically (slides 21 to 26)
  - Priority 2: Other solar technologies

Requirements on applicants
- Superior technology in one of the selected solar technology fields
- Possession of relevant IP
- Experienced management, otherwise business angel will be assigned
- Work needs to be executed at KAUST campus
- Funds need to be spent for R&D and preparation of market entry
- Commitment to set-up manufacturing activities in KSA

Application process
1. Submission of short business description by applicant
2. Quick initial feedback with provision of application form by fund management
3. Submission of comprehensive application documents inc. business plan by applicant
4. Examination by fund management, assisted by externally provided due diligence; investment decision
5. Funding offer to applicant, closing

Highlighted action items – Solar test center at KAUST as an asset for attracting solar manufacturers to the Kingdom.

KAUST Solar Center for Testing, Demonstration & Certification

	Empirical testing	Demonstration	Certification
Motivation	Solar manufacturers have a vivid interest in empirically testing their products under the harsh environmental conditions of the Middle East region.	Given the huge interest in the Middle East markets, solar manufacturers need to demonstrate the stability of their products in practice under the particular regional conditions.	Being very important for market introduction, solar manufacturers require a certification of their products as an official proof of quality and reliability.
Require-ments	State-of-the-art testing equipment in sufficient quantity for the relevant solar technologies; land, power, staff	A plot of land dedicated to demonstration activities; grid connection, water, staff	Authorized certification provider
Next steps	Start planning, allocate funds, clarify testing equipment, ask for bids, market test center within global solar community	Allocate and prepare plot of land, address SEC on handling of electric power fed into the grid, market demonstration center within global solar community	Clarify requirements for certification in the upcoming Middle East markets, call for tenders from certification providers, market certification facilities within the global solar community

APRICUM 47

Highlighted action items – Investment incentives.

The 'Plus' incentive package is a competitive advantage:

- Company meetings clearly confirmed the high attractiveness of 'plus'-incentives.
- In order to provide increased planning security and gain credibility, 'plus'-incentives should be made officially available (each application can still be decided on individually).

Incentives for corporate R&D centers will be a differentiator in the global location competition :

Trend

Global players keep outsourcing their R&D activities driven by labor cost and the necessity to be close to their markets.

Thus, investment locations have the chance to attract corporate R&D centers.

Requirements for attracting corporate R&D centers

- Local market of significant size
- Local manufacturing activities
- IP protection
- Qualified staff
- Research environment

KSA as location for corporate R&D centers in the solar industry

- KSA and the entire region are about to become very important solar markets
- Huge efforts for attracting solar manufacturing are being taken
- IP protection is secured
- Qualified staff will due to KAUST be more and more available
- Excellent research environment at KAUST

Include corporate R&D centers in the incentive program.
Market the Kingdom early as corporate solar R&D location.

APRICUM 48

Action items – Proposed time-frame.

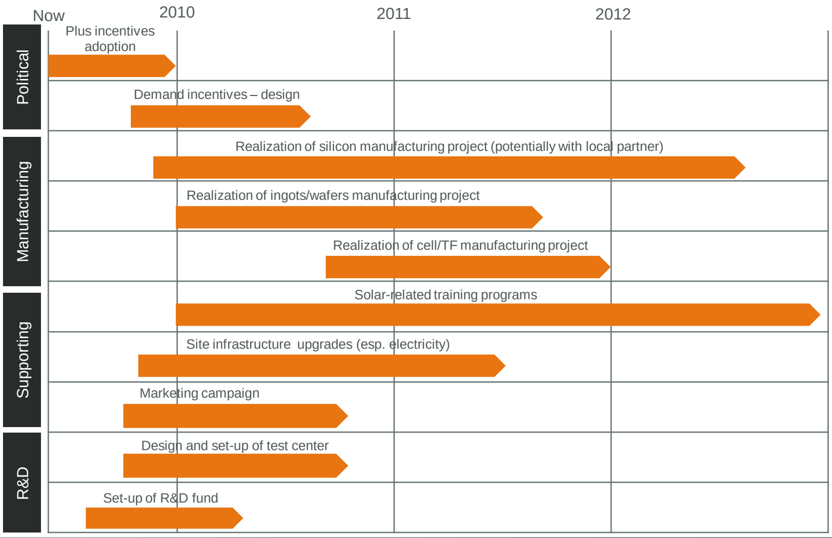


Table of acronyms.

Acronym	Explanation
EPIA	European PhotoVoltaic Industry Association
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
IP	Intellectual Property
LCOE	Levelized Cost of Energy
MCI	Ministry of Commerce & Industry
T, t, MT	Metric tonne (1,000 kg)
W	Watt
MW	Mega Watt (10^6 Watt)
GW	Giga Watt (10^9 Watt)

Solar-Specific Technical Acronyms	
Acronym	Explanation
BIPV	Building Integrated Photovoltaics
CdS	Cadmium Sulfide
CdTe	Cadmium Telluride
CIS	Copper Indium Selenide
CIGS	Copper Indium Gallium Di-Selenide
c-Si, mc-Si	Crystalline silicon, multi-crystalline silicon
CSP	Concentrating Solar thermal Power
DNI	Direct Normal Irradiation
DSSC	Dye sensitized solar cells
HCPV	High Concentrating Photovoltaics
LCPV	Low Concentrating Phtotovoltaics
OPV	Organic Photovoltaics
PV	Photovoltaics
Si	Silicon
UMG-Si	Upgraded metallurgical silicon

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Additional slides for Appendix.

The benchmark analysis confirmed the competitiveness of Saudi sites and identified scope for further improvement.

Main factors for further improvement – Environment:

Factor	Scope for action	Factor weighting[1]	Timeline for potential improvement
Political environment	Very limited.	3	Long-term
Business environment	Very limited.	3	Long-term
Solar environment	Pursue solar demand incentive scheme, make solar priority for investment incentives.	2	Short/medium-term
Labor availability	Improve and demonstrate labor availability through tailor-made recruitment schemes for foreign solar investors.	3	Short-term
Employee qualifications	Work with companies and schools to set up relevant solar training programs.	4	Short-term
Employment relations	Currently no action required.	2	n/a
Quality of life	Demonstrate high quality of life for expats in 'microcosms' such as KAEC, KAUST.	2	Short-term

Note: 1) For wafer segment.

The benchmark analysis confirmed the competitiveness of Saudi sites and identified scope for further improvement.

Main factors for further improvement – Sites:

Factor	Scope for action	Factor weighting[1]	Timeline for potential improvement
Status of development plan	Provide transparent information on zoning & restrictions and clear indication of necessary administrative steps for land allocation and procedures.	4	Short-term
Land characteristics	Provide clear timeline for land preparation, if not finished. Prepare soil analysis.	3	Short-term
Companies on site	Continue targeted investor attraction efforts.	2	Continuous
Port accessibility	Currently no action required.	3	n/a
Airport accessibility	Improve ground transportation.	3	Long-term
Rail access	Study possibility of future rail access to park.	1	Long-term
Road access	Currently no action required.	3	n/a
Electricity availability to schedule	Resolve electricity supply situation and offer high transparency with regards to expected timelines for infrastructure upgrades, utility hook-up fees etc.	5	Medium-term
Electricity sources	Very limited	2	Long-term
Water availability to schedule	Offer high transparency with regards to expected timelines for upgrades, hook-up fees.	3	Short-term
Waste water/ recycling capacity	Offer high transparency with regards to expected timelines for upgrades, hook-up fees.	4	Short-term
Availability of technical gases	Clarify excess capacities and liaise with suppliers to identify potential supply routes and expansions.	2	Short-term

Note: 1) For wafer segment.

The benchmark analysis confirmed the competitiveness of Saudi sites and identified scope for further improvement.

Main factors for further improvement – Economics:

Factor	Scope for action	Factor weighting[1]	Timeline for potential improvement
Labor costs	Very limited.	5	n/a
Electricity price	Currently no action required.	4	n/a
Electricity price stability	Offer long-term price stability through extended contract periods	1	Short-term
Water price	Currently no action required.	2	n/a
Corporate tax rate	Limited. Ensure competitiveness in long-term.	4	Long-term
Other taxes	Limited. Ensure competitiveness in long-term.	2	Long-term
Cash incentives	Offer 'plus'-incentives to first movers and regular cash grants to other solar investors	3	Short-term
Corporate tax holidays	Very limited. Can be compensated by cash incentives.	4	Short-term
Other incentives	Currently no action required.	2	n/a
Construction costs	Very limited.	1	n/a
Real estate costs	Be prepared to make concessions if required. Ensure competitiveness in long-term.	1	Short-term

Note: 1) For wafer segment.

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Saudi Arabia Solar Energy Study
Appendix – Solar Manufacturing

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Readiness of the site by 2010 and land allocation were determined to be the decisive site-related factors.

KSA sites according to identified requirements.

No.	Site	Readiness of the site before 2010	Land allocation
1	Ahsa 1	X	Open
2	Ahsa 2	X	Not yet started
3	Arar	✓	Not yet started
4	Asir	X	Open
5	Baha	X	Not yet started
6	Dammam 1	X	Closed
7	Dammam 2	X	Open
8	Dhiba	X	Not yet started
9	Gurayyat	X	Not yet started
10	Hail	X	Open
11	Jazan	✓	Not yet started
12	Jeddah 1	X	Closed
13	Jeddah 2	✓	Not yet started
14	Jouf	X	Open
15	Jubail 1	✓	Closed
16	Jubail 2	?	Closed

No.	Site	Readiness of the site before 2010	Land allocation
17	**KAEC**	✓	Open
18	Kharj	✓	Not yet started
19	Macca	X	Closed
20	Madinah	X	Open
21	Najran	X	Open
22	Nawan	X	Not yet started
23	Quassim 1	X	Open
24	Quassim 2	X	Not yet started
25	**Rabigh**	✓	Open
26	Riyadh 1	X	Closed
27	Riyadh 2	X	Closed
28	Sudair	✓	Not yet started
29	Tabouk	X	Open
30	Taif	X	Not yet started
31	**Yanbu**	✓	Open
32	Zulfi	✓	Not yet started

Apricum‘s benchmark analysis was built on a typical decision model for a solar manufacturing site selection.

Weighted cost and quality-scoring

Block	Criteria	Weight Silicon	Weight Ingot	Weight Wafer	Weight Cell	Weight Module	Weight Thin film
Environment	Political	3	3	3	3	3	3
	Business	3	3	3	3	3	3
	Solar	1	1	2	2	3	3
	Labor availability	3	3	3	**4**	**4**	**5**
	Employee qualifications	3	3	**4**	**5**	2	**4**
	Employee relations	2	2	2	2	2	2
	Quality of life	1	1	2	2	2	2
Site	Status development plan	2	3	**4**	**5**	**5**	**5**
	Land characteristics	3	3	3	3	3	3
	Companies on site	2	2	2	2	2	2
	Port accessibility	3	3	3	3	**4**	**4**
	Airport accessibility	3	3	3	3	2	3
	Rail access	1	1	1	1	1	1
	Road access	3	3	3	3	3	**4**
	Electricity availability to schedule	**5**	**5**	**5**	**5**	2	**5**
	Electricity sources	1	1	2	2	2	2
	Water availability to schedule	2	2	3	3	3	**4**
	Waste water/ recycling capacity	**4**	3	**4**	**4**	2	**4**
	Availability of technical gases	2	2	2	**4**	1	**4**
Economic factors	Labor costs	3	**4**	**5**	3	**5**	3
	Electricity price	**5**	**4**	**4**	3	2	3
	Electricity price stability	2	2	1	1	1	1
	Water price	2	2	2	3	2	3
	Corporate tax rate	**4**	**4**	**4**	**4**	**4**	**4**
	Other taxes	2	2	2	2	2	2
	Cash incentives	**4**	**4**	3	3	2	3
	Corporate tax holidays	3	3	**4**	**4**	**4**	**4**
	Other incentives	2	2	2	3	2	3
	Construction costs	2	1	1	1	1	1
	Real estate costs	1	1	1	1	1	1

Criteria weightings were adjusted for each segment.

Assumed block weightings:
- Environment 200
- Site 300
- Economic 1,000

Note: 5 – most important, 1 – least important

Source: Apricum research 2009

Environment scoring: Factors, indicators and sources.

Factor	Indicators	Source
Political	Government Effectiveness	The World Bank
	Corruption	Transparency International
	Stability Risk	Economist Intelligence Unit
Business	GDP/capita	CIA World Factbook
	Foreign Trade & Payments Risk	Economist Intelligence Unit
	Ease of Doing Business rank	The World Bank
	Average expected inflation rate 2008-2010 (%)	Economist Intelligence Unit
	Intellectual property protection rank	WEF Global Competitiveness Report
	Property rights rank	WEF Global Competitiveness Report
Solar	Political support	Apricum assessment
	Medium-term market size	Apricum assessment
	Manufacturing and R&D	Apricum assessment
Labor availability	Population in catchment area	Apricum assessment based on local sources
	Unemployment rate (%)	National statistics agencies, local sources
	Employment semicon/chemical/ PV	Apricum assessment
	Expat regulations	IMD World Competitiveness Report
Employee qualifications	University graduates	Local sources
	Secondary enrollment rank	WEF Global Competitiveness Report
	Tertiary enrollment rank	WEF Global Competitiveness Report
Employment relations	Strike rate (national level)	National sources
	Unionization rate (national level)	New Unionism, national statistics agencies
	Attrition rate	Apricum assessment, company sources
Quality of life	Cost of living Index 2006	Mercer HR Consulting
	Health care system (physicians per 1,000)	Economist Intelligence Unit
	Crime rate (car thefts per 1,000 people)	UN

Environment scoring in detail – Political criteria.

Government Effectiveness (1-least, 100-most)	
Singapore	100
Quebec	96.2
Germany	92.4
California	91.5
Oregon	91.5
Malaysia	82.9
UAE	79.1
China	61.1
India	57.3
Mexico	60.2
Philippines	56.4
KSA	51.2

Source: World Bank

Corruption, 2008 (1-most, 10-least)	
Singapore	9.2
Quebec	8.7
Germany	7.9
Oregon	7.3
California	7.3
UAE	5.9
Malaysia	5.1
China	3.6
Mexico	3.6
KSA	3.5
India	3.4
Philippines	2.3

Source: Transparency International

Stability Risk (1-least, 100-most)	
California	5
Oregon	5
Quebec	5
Singapore	15
Germany	20
India	30
Malaysia	40
Mexico	40
UAE	45
Philippines	55
China	55
KSA	60

Source: Economist Intelligence Unit

Note: Figures reference date 09/05/15

APRICUM

Environment scoring in detail – Business criteria.

GDP/capita (PPP) (US$, 2008)	
Singapore	51,142
California	46,859
Oregon	46,859
Quebec	39,183
UAE	38,830
Germany	35,442
KSA	23,834
Mexico	14,560
Malaysia	14,072
China	5,963
Philippines	3,546
India	2,762

Source: International Monetary Fund

Foreign Trade and Payments Risk (1-least, 100-most)	
Singapore	4
Quebec	7
Germany	7
Oregon	14
UAE	14
California	14
Mexico	21
KSA	21
Philippines	29
Malaysia	32
China	36
India	54

Source: Economist Intelligence Unit

Ease of Doing Business (rank of 181)	
Singapore	1
Oregon	3
California	3
Quebec	8
KSA	16
Malaysia	20
Germany	25
UAE	46
Mexico	56
China	83
India	120
Philippines	140

Source: World Bank

Average Expected Inflation Rate 2008-2010 (%)	
Quebec	2.0
Germany	2.3
Singapore	3.2
Oregon	3.3
California	3.3
Mexico	4.1
Malaysia	4.1
KSA	4.7
China	5.0
India	6.2
Philippines	6.4
UAE	8.2

Source: Economist Intelligence Unit

Intellectual property protection/Property rights (rank of 134)	
Singapore	2
Germany	6
Oregon	18
California	18
Quebec	19
UAE	24
Malaysia	33
KSA	38
China	53
India	57
Mexico	82
Philippines	89

Source: World Economic Forum

Note: Figures reference date 09/05/15

APRICUM

Environment scoring in detail – PV environment.

Political support	
Germany	high
UAE	med
China	med
India	med
Oregon	med
California	med
KSA	low
Quebec	low
Mexico	low
Malaysia	low
Singapore	low
Philippines	low

Source: Apricum assessment

Medium-term market size	
California	large
Germany	large
China	med
India	med
Mexico	med
Oregon	med
KSA	small
Malaysia	small
Philippines	small
Quebec	small
UAE	small
Singapore	small

Source: Apricum assessment

Manufacturing and R&D	
Malaysia	high
Germany	high
China	high
Singapore	high
Oregon	med
Mexico	med
California	med
Philippines	med
KSA	low
Quebec	low
UAE	low
India	low

Source: Apricum assessment

Environment scoring in detail – Labor availability.

Population in catchment area (million)	
Singapore	4.7
Rabigh	4.0
KAEC	4.0
China	3.6
California	2.3
Oregon	2.2
Philippines	2.0
India	1.5
UAE	1.4
Mexico	1.0
Germany	1.0
Quebec	0.3
Malaysia	0.3
Yanbu	0.1

Source: Apricum assessment

Unemployment rate (%)	
Rabigh	10.0
KAEC	10.0
Yanbu	10.0
Germany	8.4
Quebec	7.8
California	7.3
Philippines	7.3
India	6.8
Oregon	5.5
China	4.0
Mexico	3.7
Malaysia	3.2
UAE	2.4
Singapore	2.1

Source: Local sources

Expat regulations (0-worst, 10-best)	
Singapore	7.1
Quebec	6.52
Malaysia	5.81
China	5.85
Germany	5.84
UAE	5.7
Mexico	5.62
California	5.57
Oregon	5.57
Philippines	5.56
India	5.1
Rabigh	N/A
KAEC	N/A
Yanbu	N/A

Source: IMD World Competitiveness Report

Employment semicon/chemical/PV	
Germany	High/high/high
China	High/high/medium
California	High/low/high
Singapore	High/medium/medium
Malaysia	High/medium/medium
Mexico	High/medium/low
Philippines	High/low/medium
Oregon	High/low/medium
Yanbu	Low/high/low
India	Medium/medium/low
Quebec	Low/medium/low
Rabigh	Low/medium/low
UAE	Low/medium/low
KAEC	Low/low/low

Source: Apricum assessment

Note: Figures reference date 09/05/15

Environment scoring in detail – Employee qualification.

University graduates p.a.	
India	215000
Malaysia	32000
China	25000
Quebec	15970
KSA	N/A
Oregon	N/A
Philippines	N/A
Germany	N/A
Mexico	N/A
UAE	N/A
Singapore	N/A
California	N/A

Source: Local sources

Secondary education enrollment (rank of 134)	
Quebec	6
Singapore	21
Germany	25
KSA	39
Oregon	48
California	48
UAE	56
Mexico	67
Philippines	79
China	92
Malaysia	95
India	104

Source: World Economic Forum

Tertiary education enrollment (rank of 134)	
Oregon	6
California	6
Quebec	24
Singapore	31
Germany	43
KSA	70
Malaysia	71
Philippines	72
Mexico	74
UAE	79
China	81
India	98

Source: World Economic Forum

Note: Figures reference date 09/05/15

Environment scoring in detail – Employee relations.

Strike rate 2001-2005 (national level)	
Germany	4
Oregon	13
California	13
Quebec	202
KSA	N/A
Mexico	N/A
UAE	N/A
China	N/A
Philippines	N/A
India	N/A
Malaysia	N/A
Singapore	N/A

Source: Local sources

Unionization rate (national level)	
KSA	0
UAE	0
Singapore	0
Malaysia	7.8
India	8.0
Mexico	10.0
Philippines	11.0
Oregon	15.4
California	15.4
Germany	28.0
Quebec	39.2
China	90.0

Source: Local sources

Attrition rate	
Malaysia	high
Mexico	high
China	high
India	high
Rabigh	med
KAEC	med
Yanbu	med
UAE	med
Singapore	med
Philippines	med
Oregon	low
Quebec	low
Germany	low
California	low

Source: Apricum assessment

Note: Figures reference date 09/05/15

Environment scoring in detail – Quality of life.

Cost of living Index 2006 (NYC=100)		Health care system (physicians per 1,000)		Crime rate (car thefts per 1,000 people)	
Philippines	56	Germany	3.7	KSA	0.21
Germany	68.1	Oregon	3.1	India	0.6
Oregon	69.7	California	3.1	Germany	1.01
Mexico	71.6	UAE	2.0	Mexico	1.32
KSA	73.5	Quebec	1.9	Malaysia	2.33
Quebec	77.6	Mexico	1.8	Oregon	3.88
California	85	Singapore	1.6	California	3.88
UAE	86	China	1.5	Quebec	4.89
Malaysia	69.3	KSA	1.4	Philippines	N/A
India	90.3	Philippines	1.2	UAE	N/A
Singapore	92	Malaysia	0.7	China	N/A
China	98.3	India	0.6	Singapore	N/A

Source: Mercer HR Consulting

Source: Economist Intelligence Unit, Nationmaster/United Nations.

Source: Nationmaster/United Nations.

Note: Figures reference date 09/05/15

Site evaluation in detail – Status of development plan

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Status of development plan	Is the land development plan in force? If yes, does it have to be amended/ changed? If no, how long does review and adoption take? Any prerequisites on investors' side?	Land is being developed. Timeline unknown. Administrative processes unclear.	Land is under preparation, finished early 2010. Land allocation and administrative processes could be difficult/time-consuming.	No impact on project timeline - industrial park, already zoned for heavy industries, no further steps required.

Suggested points for improvement

- Provide straightforward information on zoning of potential plots as well as on potential red lines for production activities (times, noise, building height, chemicals storage etc.)
- Provide clear indication of necessary administrative steps for land allocation, including timing and costs
- Offer 'guaranteed fast-track permitting' and execute all pre-zoning and investor-independent administrative steps in order to speed up process.

Site evaluation in detail – Land characteristics

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Land characteristics	Size/shape/flexibility of suggested plot? Condition of soil/ground and preparation for construction? Availability of geotechnical analysis?	Ample space, level surface. Sand/rock ground (tbc); geotechnical analysis available for overall location.	Ample space, level surface. Sand/rock ground (tbc - soil analysis available).	Flat terrain, graded, ready for construction. Soil tests and environmental analysis completed. Full flexibility in terms of shape, rectangular possible.

Suggested points for improvement

- Provide clear timeline for land preparation, if not finished.
- Do soil analysis for high-potential plots – cost and time saving for investor.

Site evaluation in detail – Companies on site

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Companies on site	Company fit (competition/supplier/ partner). Which companies are located in the industrial park and in the vicinity? Headcount of the main companies?	Currently two tenants in industrial park, main future focus is plastics. KAUST nearby.	Mostly petrochemical industry, two glass manufacturers.	REC, Alcoa, other aluminium and steel producers, chemical industry.

Suggested points for improvement

- Work out potential supplier/services-capabilities of existing companies in park and region.
- Medium- to longer term: Attract other investors from complimentary and related industries.

Site evaluation in detail – Port accessibility

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Port accessibility (goods)	Distance and truck drive time to nearest container port?	Currently Jeddah port (~2h), in future port on site.	Container port within industrial park.	One of the largest container seaports of the region within industrial zone.

Suggested points for improvement

- Determine existing port capabilities and capacities.
- Monitor and influence development process of future KAEC-container port according to potential investors' needs.

Site evaluation in detail – Airport accessibility

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Airport accessibility (people)	Distance and drive time to nearest airport? International connections?	Jeddah international airport (~1h), limited non-stop connections to Europe, Asia, US.	Yanbu domestic airport (international flights via Jeddah or Riyadh)	30min to international airport, frequent direct intercontinental flights

Suggested points for improvement

- Improve airport ground connections e.g. through future bus service from/to KAUST, KAEC.

Site evaluation in detail – Rail access

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Rail access (goods)	Rail access on site? If not, distance to nearest freight station?	None.	Rail track to industrial park is in planning stage.	Rail siding adjacent to plot.

Suggested points for improvement

- Study possibility of future rail access to park.

Site evaluation in detail – Road access

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Road access	Highway access/ road quality and capacity	Main highway 10-15km; 2-3-lane access roads; no traffic congestion.	Directly adjacent to main highway (will be diverted in future); roads in park 2-3 lanes; no congestion.	Interstate highway access adjacent.

Suggested points for improvement

- Road access is adequate at all KSA sites.
- Ensure possibility for two access ways to potential plots.

Site evaluation in detail – Electricity availability to schedule

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Electricity availability to project schedule	Given client's requirements, which infrastructure upgrades work needs to be done and what is the expected timeline? Any costs to investor?	Site is currently served from the grid (low quantities). Future infrastructure still in planning.	Currently no excess capacity (total under commitment ~1,000MW), expansion by 1,700MW facility planned until 2014. Interim solution is being studied.	Substation adjacent to plot, fully redundant feed. 8MW available immediately, additional 48MW with minimal upgrade within 3 months.

Suggested points for improvement

- Yanbu: Determine excess capacity of substation adjacent to plot; work out indicative timeline for necessary infrastructure upgrades to supply e.g. 20-40MW (dual feed) within 1-2 years.
- KAEC: Work out details of potential power supply in park (voltage, capacity) and intended timeline; explore possibility to supply e.g. 20-40MW (dual feed) within 1-2 years.
- Both: be ready to make commitments with regards to power supply; be prepared to answer questions on approximate expected costs of upgrades to investor.

Site evaluation in detail – Electricity sources

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Electricity sources	Composition of electricity supplies (e.g. nuclear, coal, hydro etc.) and availability of energy from renewable sources?	100% fossil fuels (gas, oil)	100% fossil fuels (gas, oil)	97% hydro power, rest wind and nuclear.

Suggested points for improvement

- Very limited scope for action – possible approaches could be PV power generation for manufacturing plant, energy efficiency measures (e.g. on-site trigeneration plant)

Site evaluation in detail – Water availability to schedule

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Water availability to project schedule	Given client's requirements, which infrastructure upgrades work needs to be done and what is the expected timeline? Any costs to investor?	Water capacities and connection tbd. Given ongoing site development, infrastructure can still be adapted.	Water capacities and connection tbd. Given ongoing site development, infrastructure can still be adapted.	All industrial facilities are directly adjacent to site or on opposite side of road. Capacity: 27,110 m^3; line size and pressure: 300mm/ 6.9bar; 1.5 of 7 pumps running.

Suggested points for improvement

- Water connection should be up to plot boundary and included in land costs.
- Clearly point out existing water capacities and timeline for realization, if not done; be ready to make commitments.

Site evaluation in detail – Wastewater/ recycling capacity

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Waste water/ recycling capacity	Given client's requirements, which infrastructure upgrades work needs to be done and what is the expected timeline? Any costs to investor?	Wastewater capacity and connection tbd. Given ongoing site development, infrastructure can still be adapted.	Wastewater treatment nearby in industrial park, excess capacity and connections tbd.	All industrial facilities directly adjacent to site or on opposite side of road. Excess capacity of existing treatment facility: 990 m^3/d; line size: 900mm dia, atmospheric pressure.

Suggested points for improvement

- Wastewater connection should be up to plot boundary and included in land costs.
- Clearly point out existing wastewater disposal capacities and timeline for realization, if not done; be ready to make commitments.

Site evaluation in detail – Availability of technical gases

Factor benchmarking

Factor	Description	Evaluation KAEC	Evaluation Yanbu	Global leader benchmark
Availability of technical gases	Are technical gases available within the industrial park? If not, where could they be sourced from in the region?	None on site, probably sourced from Yanbu.	Air separation unit available in industrial park, details and excess capacities tbd.	Hydrogen, nitrogen, oxygen and ammonia within industrial park; rest just-in-time through well-established regional supplies infrastructure.

Suggested points for improvement

- Establish working relationship with local gas companies.
- Determine approximate excess capacities for most important production gases and feasibility of sourcing from abroad.

Key economic factors[1] – Labor costs.

Approximate annual labor costs, 2007 [USD][1]

Location	Engineers	Operators
California	79,500	38,800
Quebec	66,200	43,800
Oregon	75,500	30,400
(Eastern) Germany	74,100	29,800
Singapore	33,100	19,900
UAE	30,700	10,400
Saudi Arabia	26,500	7,300-12,600
Malaysia	14,600	5,300
Philippines	6,000	4,000
Mexico	19,300	4,000
China	7,100	3,800
India	n/a	n/a

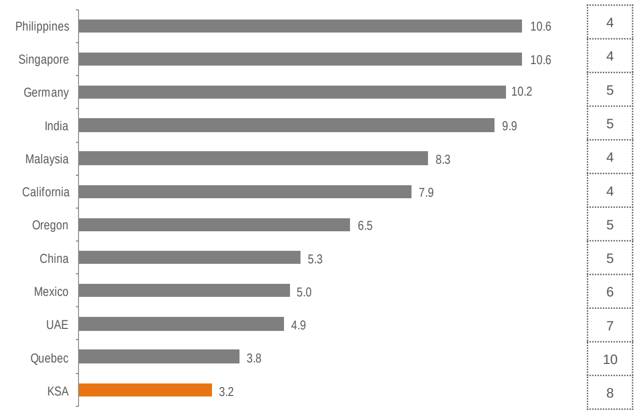
[1]converted from EUR at current rate (24/04/2009)

Note: 1) The evaluation of some economic factors is partly based on confidential information and negotiated deals at other locations and can therefore not be shared in detail by Apricum. Values always refer to individual sites and do not constitute averages for the respective countries/regions. Source: Apricum research 2009.

Key economic factors – Electricity

Electricity price [US$ct/kWh, 2008][1]

Expected price stability [10- very stable, 0- not stable]

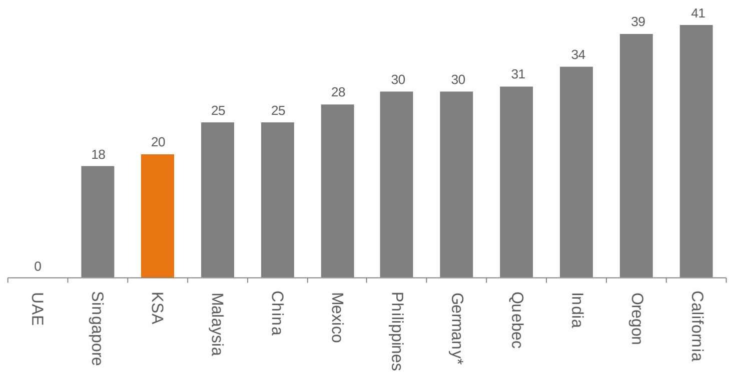


[1]converted from EUR at current rate (24/04/2009)

Source: Apricum research 2009

Key economic factors – Corporate taxes.

Corporate tax rates [%], 2008



Note: *) Average, depends on municipality.
Sources: US Tax Foundation, KPMG, Deloitte.

Key economic factors – Other taxes.

Overview of other taxes relevant to corporations, 2008

Country/region	Main other corporate taxes
California	Withholding tax (30% regular rate), social security contribution (approx. 15%), other smaller taxes.
China	Withholding tax (10%), social security contributions (up to 40%), land deed tax, property tax, other smaller duties.
Germany	Withholding tax (~16%), social security contributions (~20%), property transfer tax, other smaller taxes.
India	Withholding tax (up to 20%), social security contributions (~12%), other smaller duties.
Malaysia	Approx. 13% social security contribution, property transfer duties and other smaller fees.
Mexico	Withholding tax (up to 28%), social security contribution (15-25%), property taxes, other duties-
Oregon	Withholding tax (30% regular rate), social security contribution (approx. 15%), other smaller taxes.
Philippines	Withholding tax (15-30%), social security contribution, property transfer taxes, other small fees.
Quebec	Withholding tax (up to 25%), payroll tax, property transfer taxes.
Saudi Arabia	Withholding tax 5% on dividends; employer share of social security contribution 9%.
Singapore	Withholding tax (up to 15%). Social security contributions, property tax, water tax, other small duties.
UAE	Social security contribution for national workers (17.5%), property transfer tax.

Sources: KPMG, Deloitte.

Key economic factors – Investment incentives.

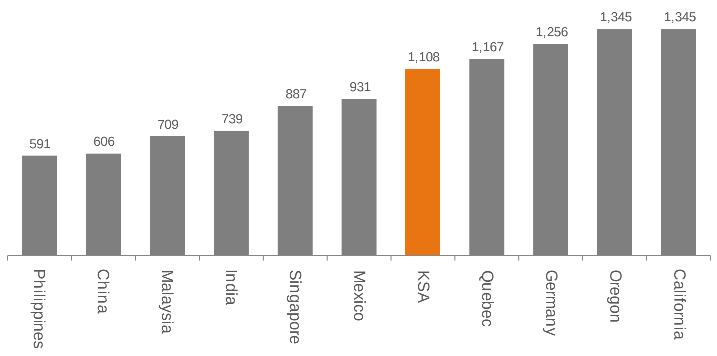
Incentives available in Saudi Arabia and at main competing locations.

Country/region	Main incentives instruments
China	Corporate tax holidays for 5 years, thereafter 50% reduction of corporate tax liability for another 5 years.
(Eastern) Germany	Cash grants of up to 50% of capex (in practice typical PV project will get ~10-13% due to capping), very limited negotiation scope.
India	Corporate tax holidays for up to 5 years, thereafter 50% reduction of corporate tax liability for another 2 years.
Malaysia	Corporate tax holidays for 5 years (standard), in practice up to 15 years negotiable.
Mexico	Standard cash grants of 10%; land grant; tax holidays have been largely phased out.
Oregon	Tax credit of up to $20 million, which can be converted into cash grant of up to $14 million.
Philippines	Corporate tax holidays of up to 8 years can be negotiated, thereafter 5% flat tax at designated economic zones.
Quebec	Cash grants of up to 15-20% can be negotiated for landmark projects; up to 20 years fixed-price electricity contracts; very inexpensive land fully developed to investor's needs.
Saudi Arabia	'Plus' incentive program would offer up to 50% of capex as cash grants, uncapped. Regular package still substantial cash grants but capped.

Source: Apricum research 2009.

Key economic factors – Construction costs.

Average construction costs for light industrial unit space, 2006 [US$ per m²]



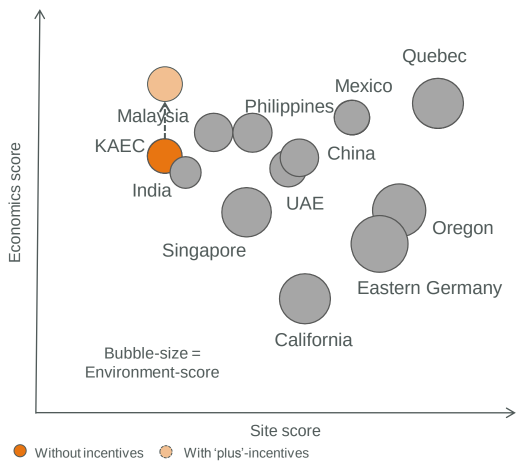
Source: Economist Intelligence Unit.

Site evaluation for KSA sites based on visits and information received.

Category	KAEC	Rabigh	Yanbu
Site/plot	Entire park is currently being set up newly, major development work ongoing. Some facilities in place, flexible plot sizes.	Site is well-prepared and practically shovel-ready. Relatively small plots. Highly professional site management.	Major earthwork ongoing but proven development experience in park. Highly flexible plot sizes. Highly professional site mgmt.
Utilities	All utilities available to plots, but capacities unclear. Need to clarify esp.power supplies and potential timelines for medium to high requirements.	Substation, waste water treatment etc on site. All utilities available to plot (underground). Electricity only sufficient for module production. Others tbd.	Substation, waste water treatment etc adjacent. All utilities available in park, need to clarify plot connections, capacities, potential timelines.
Labor	Sizeable local labor pool due to proximity to Jeddah and future residential development nearby as well as KAUST. In short-term difficult due to lack of facilities.	Small local labor pool but within reach from Jeddah.	Relatively small local labor pool. Projects will likely rely heavily on expat workers (standard procedure).
Incentives and taxes	Potentially generous cash grants (official cap on total amount is negotiable). Relatively low corporate taxes but no tax holidays.	Potentially generous cash grants (official cap on total amount is negotiable). Relatively low corporate taxes but no tax holidays.	Potentially generous cash grants (official cap on total amount is negotiable). Relatively low corporate taxes but no tax holidays.
Soft issues	In future high potential attractiveness due to flagship nature of park project and proximity to Jeddah & KAUST. Currently limited.	Sumitomo as site developer has proven track record. Jeddah within commuting distance.	Heavy/chemical industry site, some glass manufacturing. Experience with foreign investors.
Suitability	**Basically all segments except silicon, but depends on future power supplies.**	**Modules**	**Basically all segments, but best fit with front-end.**

Silicon manufacturing – KAEC competitive positioning.

Cost and quality-matrix for a sample silicon project



KAEC score card

Competitive Advantages		
Weight	Criterion	Block
5	Electricity price	Economics
4	Cash incentives	Economics
	Corporate tax rate	Economics
3	Business environment	Environment
	Port accessibility	Site
	Airport accessibility	Site
	Land characteristics	Site
	Labor costs	Economics

Competitive Disadvantages		
Weight	Criterion	Block
5	Electricity availability to schedule	Site
4	Waste water / recycling capacity	Site
3	Road access	Site
	Labor availability	Environment
	Employee qualifications	Environment

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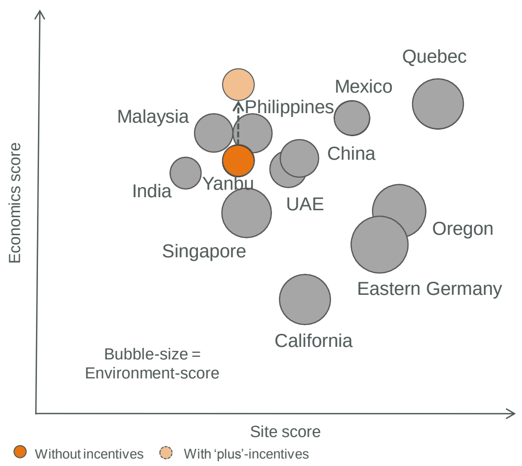
Silicon manufacturing – Yanbu competitive positioning.

Cost and quality-matrix for a sample silicon project



Yanbu score card

Competitive Advantages		
Weight	Criterion	Block
5	Electricity price	Economics
4	Cash incentives	Economics
	Waste water / recycling capacity	Site
	Corporate tax rate	Economics
3	Business environment	Environment
	Port accessibility	Site
	Land characteristics	Site
	Road access	Site
	Labor costs	Economics

Competitive Disadvantages		
Weight	Criterion	Block
5	Electricity availability to schedule	Site
3	Labor availability	Environment
	Employee qualifications	Environment
	Airport accessibility	Site

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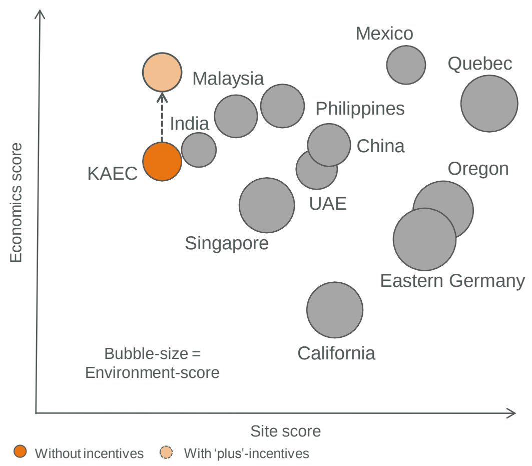
Ingot production – KAEC competitive positioning.

Cost and quality-matrix for a sample ingot project



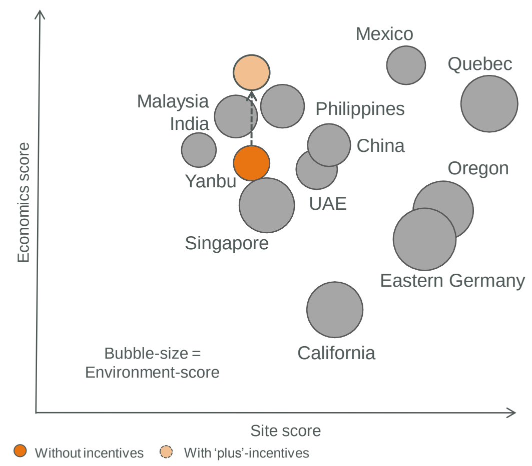
KAEC score card

Competitive Advantages		
Weight	Criterion	Block
4	Labor costs	Economics
	Electricity price	Economics
	Cash incentives	Economics
	Corporate tax rate	Economics
3	Business environment	Environment
	Port accessibility	Site
	Airport accessibility	Site

Competitive Disadvantages		
Weight	Criterion	Block
5	Electricity availability to schedule	Site
3	Labor availability	Environment
	Employee qualifications	Environment
	Status development plan	Site
	Waste water / recycling capacity	Site
	Road access	Site

Ingot production – Yanbu competitive positioning.

Cost and quality-matrix for a sample ingot project



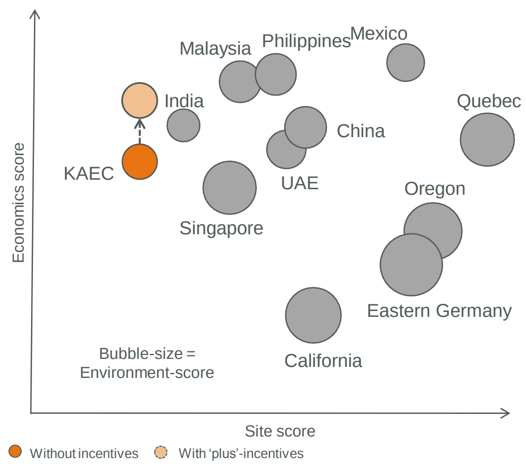
Yanbu score card

Competitive Advantages		
Weight	Criterion	Block
4	Labor costs	Economics
	Electricity price	Economics
	Corporate tax rate	Economics
	Cash incentives	Economics
3	Business environment	Environment
	Port accessibility	Site
	Road access	Site
	Waste water / recycling capacity	Site

Competitive Disadvantages		
Weight	Criterion	Block
5	Electricity availability to schedule	Site
3	Labor availability	Environment
	Employee qualifications	Environment
	Status development plan	Site
	Airport accessibility	Site

Wafer production – KAEC competitive positioning.

Cost and quality-matrix for a sample wafer project



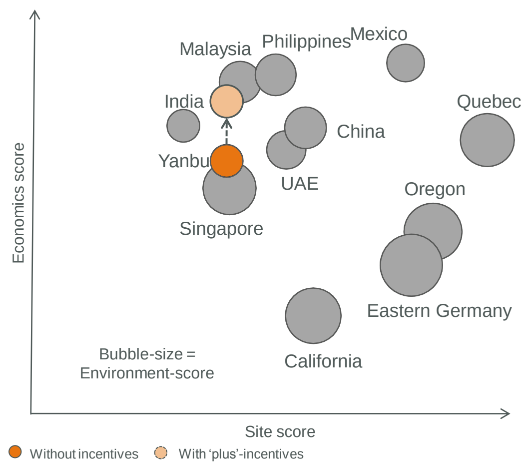
KAEC score card

Competitive Advantages		
Weight	Criterion	Block
5	Labor costs	Economics
4	Electricity price	Economics
	Corporate tax rate	Economics
3	Business environment	Environment
	Land characteristics	Site
	Port accessibility	Site
	Airport accessibility	Site
	Cash incentives	Economics

Competitive Disadvantages		
Weight	Criterion	Block
5	Electricity availability to schedule	Site
4	Employee qualifications	Environment
	Waste water / recycling capacity	Site
	Status development plan	Site
3	Labor availability	Environment
	Road access	Site

Wafer production – Yanbu competitive positioning.

Cost and quality-matrix for a sample wafer project



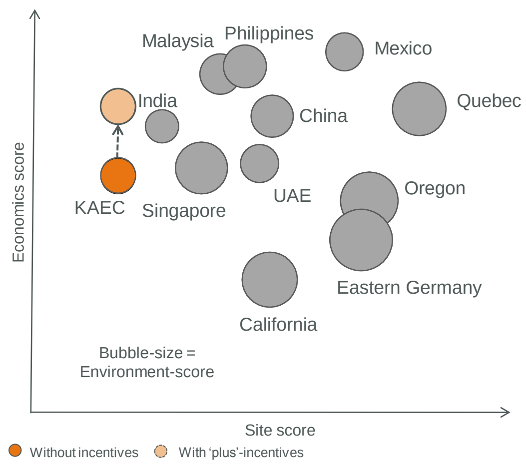
Yanbu score card

Competitive Advantages		
Weight	Criterion	Block
5	Labor costs	Economics
4	Waste water / recycling capacity	Site
	Electricity price	Economics
	Corporate tax rate	Economics
3	Business environment	Environment
	Land characteristics	Site
	Port accessibility	Site
	Road access	Site
	Cash incentives	Economics

Competitive Disadvantages		
Weight	Criterion	Block
5	Electricity availability to schedule	Site
4	Employee qualifications	Environment
	Status development plan	Site
3	Labor availability	Environment
	Airport accessibility	Site

Cell production – KAEC competitive positioning.

Cost and quality-matrix for a sample cell project



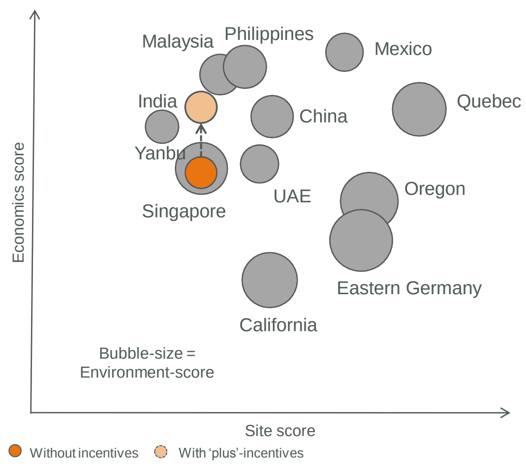
KAEC score card

Competitive Advantages		
Weight	Criterion	Block
4	Corporate tax rate	Economics
3	Business environment	Environment
	Land characteristics	Site
	Port accessibility	Site
	Airport accessibility	Site
	Road access	Site
	Labor costs	Economics
	Electricity price	Economics
	Cash incentives	Economics
	Other incentives	Economics

Competitive Disadvantages		
Weight	Criterion	Block
5	Employee qualifications	Environment
	Status development plan	Site
	Electricity to schedule	Site
4	Labor availability	Environment
	Waste water capacity	Site
	Avail. of technical gases	Site
3	Water price	Economics

Cell production – Yanbu competitive positioning.

Cost and quality-matrix for a sample cell project



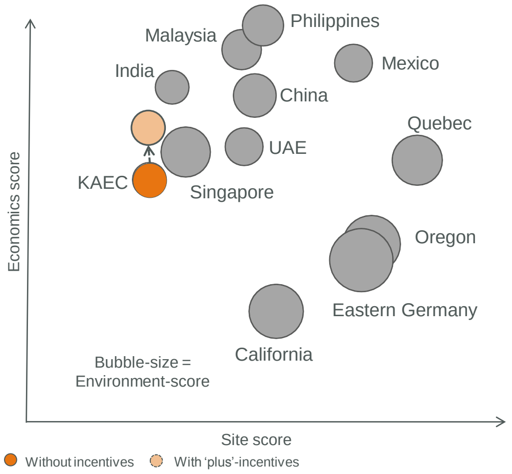
Yanbu score card

Competitive Advantages		
Weight	Criterion	Block
4	Waste water capacity	Site
	Avail. of technical gases	Site
	Corporate tax rate	Economics
3	Business environment	Environment
	Land characteristics	Site
	Port accessibility	Site
	Road access	Site
	Labor costs	Economics
	Electricity price	Economics
	Cash incentives	Economics
	Other incentives	Economics

Competitive Disadvantages		
Weight	Criterion	Block
5	Employee qualifications	Environment
	Status development plan	Site
	Electricity availability to schedule	Site
4	Labor availability	Environment
3	Airport accessibility	Site
	Water price	Economics

Module assembly – KAEC competitive positioning.

Cost and quality-matrix for a sample module project



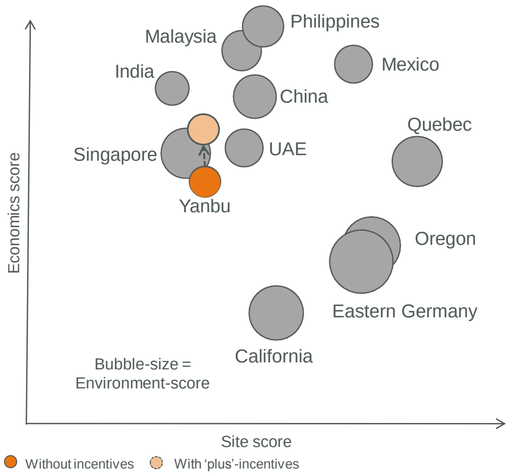
KAEC score card

Competitive Advantages		
Weight	Criterion	Block
5	Labor costs	Economics
4	Port accessibility	Site
	Corporate tax rate	Economics
3	Business environment	Environment
	Land characteristics	Site

Competitive Disadvantages		
Weight	Criterion	Block
5	Status development plan	Site
4	Labor availability	Environment
3	PV environment	Environment
	Road access	Site

Module assembly – Yanbu competitive positioning.

Cost and quality-matrix for a sample module project



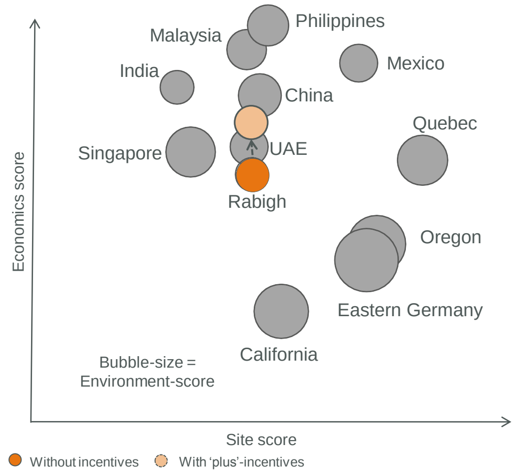
Yanbu score card

Competitive Advantages		
Weight	Criterion	Block
5	Labor costs	Economics
4	Port accessibility	Site
	Corporate tax rate	Economics
3	Business environment	Environment
	Land characteristics	Site
	Road access	Site

Competitive Disadvantages		
Weight	Criterion	Block
5	Status development plan	Site
4	Labor availability	Environment
3	PV environment	Environment

Module assembly – Rabigh competitive positioning.

Cost and quality-matrix for a sample thin film project



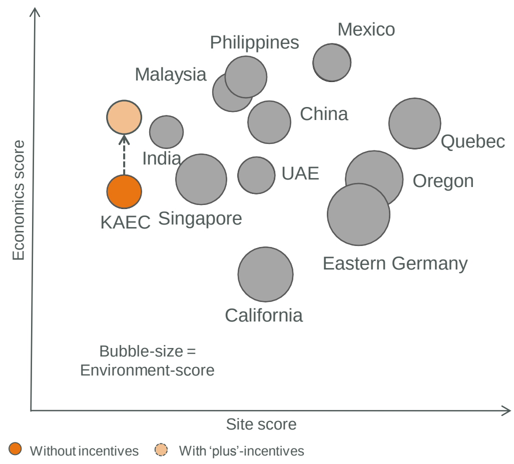
Rabigh score card

Competitive Advantages		
Weight	Criterion	Block
5	Status development plan	Site
	Labor costs	Economics
4	Corporate tax rate	Economics
3	Business environment	Environment
	Land characteristics	Site

Competitive Disadvantages		
Weight	Criterion	Block
4	Labor availability	Environment
	Port accessibility	Site
3	PV environment	Environment
	Road access	Site

Thin-film manufacturing – KAEC competitive positioning.

Cost and quality-matrix for a sample thin film project



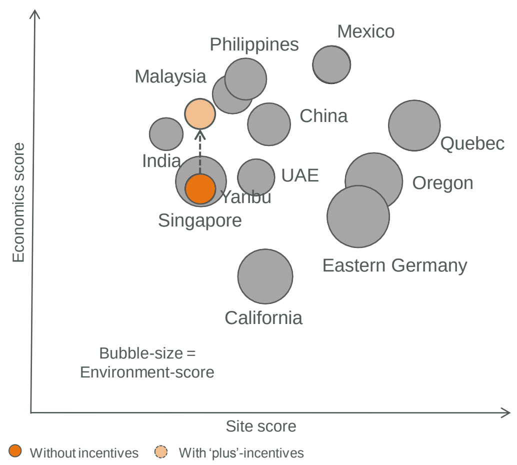
KAEC score card

Competitive Advantages		
Weight	Criterion	Block
4	Port accessibility	Site
	Corporate tax rate	Economics
3	Business environment	Environment
	Land characteristics	Site
	Airport accessibility	Site
	Labor costs	Economics
	Electricity price	Economics
	Cash incentives	Economics
	Other incentives	Economics

Competitive Disadvantages		
Weight	Criterion	Block
5	Labor availability	Environment
	Status development plan	Site
	Electricity to schedule	Site
4	Employee qualifications	Environment
	Road access	Site
	Waste water capacity	Site
	Avail. of technical gases	Site
3	PV environment	Environment
	Water price	Economics

Thin-film manufacturing – Yanbu competitive positioning.

Cost and quality-matrix for a sample thin film project



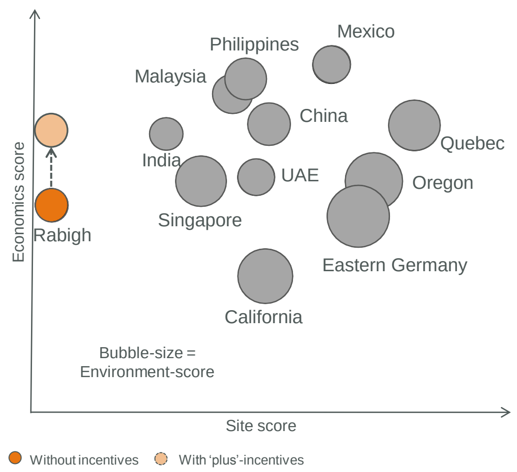
Yanbu score card

Competitive Advantages		
Weight	Criterion	Block
4	Port accessibility	Site
	Road access	Site
	Waste water capacity	Site
	Avail. of technical gases	Site
	Corporate tax rate	Economics
3	Business environment	Environment
	Land characteristics	Site
	Labor costs	Economics
	Electricity price	Economics
	Cash incentives	Economics
	Other incentives	Economics

Competitive Disadvantages		
Weight	Criterion	Block
5	Labor availability	Environment
	Status development plan	Site
	Electricity to schedule	Site
4	Employee qualifications	Environment
3	PV environment	Environment
	Airport accessibility	Site
	Water price	Economics

Thin-film manufacturing – Rabigh competitive positioning.

Cost and quality-matrix for a sample thin film project



Rabigh score card

Competitive Advantages		
Weight	Criterion	Block
5	Status development plan	Site
4	Corporate tax rate	Economics
3	Business environment	Environment
	Labor costs	Economics
	Electricity price	Economics
	Cash incentives	Economics
	Other incentives	Economics

Competitive Disadvantages		
Weight	Criterion	Block
5	Labor availability	Environment
	Electricity availability to schedule	Site
4	Employee qualifications	Environment
	Water availability to schedule	Site
	Wastewater/ recycling capacity	Site
	Availability of technical gases	Site
3	PV environment	Environment
	Land characteristics	Site
	Airport accessibility	Site
	Water price	Economics

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