Technical assistance report on Photovoltaic Solar Cell Design and Manufacturing in Iran.

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Abstract

This report provides the outcomes of the CTCN technical Assistance Response plan regarding the assessment of current PV production capacity and initial assessment to identify status of local PV technology, material supply and, knowledge infrastructure, that need to be resolved to establish a striving PV industry in Iran. Following an initial visit to Iran a study on the involvement of the Iranian government with respect to countries implementation plans and policies regarding PV solar production capabilities was performed. Moreover, the report comprises a gap analysis to determining the necessary grade of local manufactured panel efficiency in order to keep competition with foreign import produce. In addition a 200 MW PV manufacturing plant analysis is exercised to identify the value chain for production in Iran. Advise on solar cell type to be produced locally and a solar cell and panel roll out scenario is part of the report. Supporting the private sector Industry recommendations are provided regarding the establishment of a local applied research center.

Source: The Photo Society

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Appendices

Summary

The CTCN activities proposed in this technical assistance report will support Iranian stakeholders to move towards building the country's first photovoltaic (PV) cell and solar panel manufacturing plant (at an initial pilot scale) and to build up the necessary associated capabilities of the national photovoltaic industry. The technical assistance report comprises five major activities that will span about 12 months. A natural follow up (not included in this plan) of these activities would be to develop detailed technical specifications regarding the manufacturing plant as input to a tendering process for an eventual construction phase.

The two main outputs of this technical assistance report encompass:
1. Assessment of current PV production capacity and initial assessment to identify status of local PV technology, material supply and, knowledge infrastructure, that need to be resolved to establish a striving PV industry in Iran.
2. A study on the involvement of the Iranian government with respect to countries implementation plans and policies regarding PV solar production capabilities and feed in tools.
3. A gap analysis to define the necessary technology level for production of PV cells and panels. The emphasis is on determining the necessary grade of local manufactured panel efficiency in order to keep competition with foreign import produce. In addition a 100 MW PV manufacturing plant analysis to identify the value chain for production in Iran.
4. Advise on solar cell type to be produced locally including a solar cell and panel roll out scenario. Supporting the private sector Industry recommendations are provided regarding the establishment of an applied research center.
5. A report covering the assessment.

Partners involved are from the government (notably the CITC and Ministry of Energy); Research institutions, universities and other key organizations such as the Renewable Energy Organization of Iran (SUNA), as well as representatives from the private sector that are active in the PV industry in Iran.

The activities outlined in this technical assistance report have been refined in consultation with the above key stakeholders during and after the initial inception missions.

Source: Sterling College

1 Introduction

The Islamic Republic of Iran has defined photovoltaic technology as one of the key technologies in its transition to a larger share of renewable energy in the energy mix in Iran. Based on these ambitions, CITC, as one of the public institutions involved in the realisation of Iran's renewable energy program, has identified the wish to realize and further a sound base for the production of local photovoltaic (PV) solar cells and panels.

The CTCN assistance aims to support Iran in developing intervention strategies and facilitating their implementation and dissemination to increase access to high quality PV technologies and installation.

The first step in the intervention addresses the interviews of selected stakeholders to analyse the current PV situation in Iran. Supporting questions for the interviews were formulated (see Appendix A, Interviews) and shared with relevant members of the government, university, research Institutes, and the private manufacturing companies.

Main stakeholders are the government entities of the Renewable Energy Council and CITC, Professor Soleymani of the PV R&D department at the University of Tehran, Niroo (Renewable Energy Research Institute of Iran) and Noursun Energy Aria (private company aiming towards the production of solar cells and panels).

An analysis based on the interviews was carried out to completely understand the current situation in the fields of Government policy towards implementation of Renewable Energy, tax exemptions, feed in laws and local draw back situations.

Government oriented CITC, that also acts as the local NDE for Iran has the position to act as an enabler for the furthering of solar energy production in Iran. CITC operates closely with the R&D institutes and the private sector.

Chapter 4 of the report addresses a 50 MW PV case study for cell and panel manufacturing. This study was exercised in close cooperation with Noursun. The aim of the study was to analyse the necessary level of PV panel locally produced efficiency in comparison to costs for imported panels from abroad.

Based on the interviews and studies, a gap analysis has been established to help identify the status of local PV production, material supply, knowledge infrastructure, that need to be resolved to move forward to a striving PV industry in Iran.

The PV department of the University of Tehran has access to a complete pilot line for the R&D of solar cells. Education level and know how regarding Solar Energy technology at Tehran University is at an intellectual level ready to assist in R&D for private PV producers. Lack of practical experience and missing cooperation between University and private entities can be solved by founding an applied research center. This center can focus on support of the local PV industry. Recommendation regarding this center can be found in chapter 6.

To this end, the final conclusions are reported in chapter 8. The scope of these conclusions can be used as a base for a funding proposal to support the set up for PV production in Iran. Recommendations for preliminary design for PV industry in Iran and a specific pilot-scale PV cell manufacturing plant and associated financial analysis are considered beyond the scope of this technical assistance report.

2

Objectives of the CTCN assistance

2.1 Overall objectives

The overall objective of the CTCN assistance is to provide capacity building and advice to guide the development of Iran’s photovoltaic (PV) manufacturing industry.

Within the overall objective a number of sub-objectives can be defined:

- To improve the R&D capacity of Iranian stakeholders with regards to PV cell manufacturing and characterization.
- To organize a local workshop on solar cell manufacturing technologies for Iranian stakeholders.
- To establish a detailed funding proposal together with a private entity in Iran that is willing to launch PV production. The proposal would be based on recommendations for preliminary design with emphasis on local PV industry, a specific pilot-scale PV cell manufacturing plant and financial analysis.

Table 1: Overview of deliverables in this report

Deliverables
1. Initial assessment of PV cell and module R&D capabilities in Iran
2. Determine status on additional facility and equipment needs for the R&D phase
3. Collection of information on existing solar PV manufacturers, local material suppliers and resources in Iran through close cooperation with national entities
4. Gap analysis, comparison of costs for local PV panel production compared to imported panels. Material supply chain and manufacturing plant analysis
5. SWAT analysis for high & low cell efficiency with cell type recommendation for production in Iran. Information on a roll out of a cell and module production process.
6. Advise on an applied research facility to support local PV industry

Based on the interviews and studies a gap analysis has been executed to identify the status of local PV production, material supply, knowledge infrastructure compared to the needed state for a healthy and independent PV industry in Iran.

In addition to the objectives and deliverables formulated above, the technical assistance report was extended by request of the Iranian stakeholders. Detailed case studies have been added. One study addresses the competitiveness of local PV panel production compared to costs of imported panels. A second study addresses a PV manufacturing plant analysis with focus on the material supply. In addition recommendations are provided for the set-up of a local applied research center.

2.2 Main partners

The table below shows the stakeholders engaged for the CTCN technical assistance team.

Table 2: The stakeholders of the CTCN technical assistance expert team

Stakeholder	Role
Ministry of Energy	Implementation of Iran government policies and regulations related to the energy sector, which encompasses renewable source of energy.
Centre of Innovation Technology Cooperation (CITC)	NDE and government research centre
Solar panel manufacturers	To manufacture solar panels locally, and to accelerate deployment.
University & Research Institutes	Research & development to increase efficiency and improve manufacturing quality
UNIDO Country Office	Coordinate and facilitate communication with stakeholders

The central role of the NDE/CITC will be to act as facilitator and coordinator of the planned activities. These activities will also receive support from the local UNIDO office in Tehran.

The ECN expert team has inside knowledge in the field of state of the art PV solar cell and panel/module R&D questions. Technology support, technology transfer and capacity building for the worldwide solar industry are another facet on the team's activities. Aspects are policy, strategy issues with strong emphasis on consultancy.

2.3 Synergies

The Iranian government has made commitments to improve energy supply and community health care, with special focus on rural communities that are dependent on diesel generators, and made plans to invest in photovoltaic solar energy to achieve these goals. The CTCN intervention will make technical assistance services available to assist in realizing these plans.

The intervention can also complement the technology expertise at Iranian universities and contribute to capacity enhancement in the field of solar as key asset to further develop the industry.

2.4 Monitoring and Reporting

Milestones for each of the activities and deliverables have been detailed at the outset of the intervention in 2016. Regular and efficient communication was established to allow for adaptive management and refine the approach as more information was gathered and produced. Noursun contributed to those efforts and supported the timely implementation of the activities and the reports.

3

Background information and current status

3.1 Government organisations

Presently there is approximately 2MW of PV installed in the Islamic Republic of Iran. Of this the largest currently connected installation is a 1MW project sponsored by the Ministry of Energy. Last year, however, there were 6 Purchase Power Agreements (PPA) signed. Of these Noursun will play the role of Engineering, Procurement & Construction (EPC) company and Developer for a 1.5MW installation and a 25MW installation.

The current price of retail electricity is very low in Iran. It is reported to be around $0.08/kWh. For residential, the price is scaled by the amount of electricity used. For wholesale, the rate is scaled by the time of day for electricity usage and can be as much as a 75% reduction for off-peak usage. Approximately $0.01/kWh on the grid is collected as a tax for development of renewables. In addition there is a 9% VAT added on all electricity bills. Tax for renewables is given to renewable power plants based on Feed-in tariff and a 20 years PPA with 30% bonus for the usage of local manufactured components like solar panels.

Due to the low cost of electricity, the payback time for residential solar installations is on the order of 12 years: the economic incentive is thus very thin. Smaller residential or commercial solar installations are done for off-grid projects as there are many vacation villas where solar PV installation is desired as they are not connected to the energy grid. PV with storage is a solution to diesel generators with less noise, pollution, and maintenance. Current systems are often combined with solar thermal for hot water as well. These currently make up a large amount of business for companies like Noursun and about 15 other competitors.

The governmental structure overseeing the renewable energy sector in the Islamic Republic of Iran is a multi-layered decision structure. The diagram below outlines the existing governmental bodies that will play a role in decision making about renewable energy research, deployment, investment, and industrial support. In addition, these organizations will also play a role in integrating PV in the overall electricity industry and market. Below is a summary of the role played by each entity.

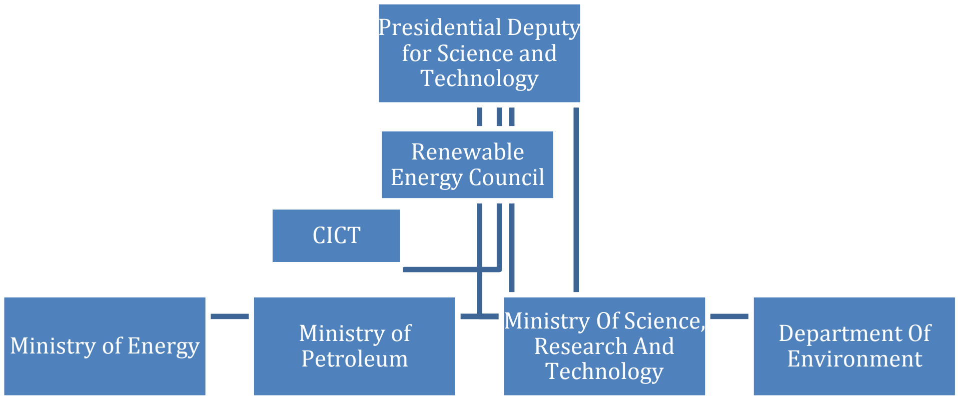

Figure 1: Existing governmental bodies that will play a role in decision making about renewable energy research, deployment, investment, and industrial support

Office of the President. The president has to give final approval of the plans and actions proposed by the ministries towards renewable energy.

Ministry of Science, Research, and Technology. This ministry is responsible for both the research and implementation of new renewable energy technologies in Iran including interaction with and supporting new industrial opportunities. In addition, this ministry is also responsible for research institutions and universities and institutes of higher education.

Presidential Deputy for Science and Technology. The Deputy Minister has direct oversight on two key decision making bodies for renewable energy and specifically PV in Iran. These oversee both the development of industry in renewables and the government programs that will support the research and industry.

Center for Innovation and Technology Cooperation (CITC). This center is responsible for supporting the collaborations between innovations and technology for the renewable energy sector. CITC's support is essentially the implementation and use of resources allocated by other branches of government in order to attain the goals drafted by the Renewable Energy council and approved by the Office of the President. In addition, this organization was responsible for the technology needs assessment (TNA) of Iran for the Paris climate agreements maintaining technology connections with the international community through Iranian embassies and consulates around the world. This office is also the National Designated Entity for CTCN projects.

Renewable Energy Council. The council is also under direct oversight of the Presidential Deputy for Science and Technology. It acts in parallel to the CITC in order to set policy and priorities for the development of renewable energy research and technology deployment. Specifically, they organize key stakeholders in renewable energy projects to meet targets set by the council, and will support the knowledge based companies with infrastructure, market development, and relationships. The Council has recently created a roadmap for renewable energy in Iran that entails the following:

- 5% of electricity provided by renewable energy sources by 2021.
- 10% of electricity provided by renewable energy sources by 2026.
- First in technology development for renewable energy in the Middle East region.

This is currently judged by ISI papers and educational milestones, but there seems to be support for adapting the evaluation parameters towards IP generation and more industrially important factors:

- Fifth in manufacturing and production in renewable energy in Asia; and
- Reduction of 10M tones of CO_2 according to COP21 agreements.

In this roadmap, it is not currently specified how the 10% of electricity produced will be divided over the different renewable energy resources. Once this roadmap is approved and signed by the government, the Council will create a set of committees to decide the budgets and key players for various renewable energy technologies. Although it has not been finalized, solar PV will likely be a top priority for the Council.

*Ministry of Econom*y. Amongst other activities, the ministry of the economy oversees the Organization for Management and Planning and the Office of Foreign Investments. This ministry will provide the financial support for the roadmaps, targets, goals, etc. of the other ministries.

Management and Planning Organization of Islamic Republic of Iran. Amongst other targets, this organization oversees much of the financial support of initiatives and plans set forth by the other ministries. This organization oversees foreign investments.

Organization for Investment Economic and Technical Assistance of Iran. The office is responsible for enacting the Foreign Investment Promotion and Protection (FIPPA, investiniran.ir) and facilitating the flow of foreign investments into the country.

Ministry of Energy. This ministry owns the grid and oversees the Renewable Energy Organization (SUNA). By owning the grid, it becomes a key end user of electricity produced by renewable energy and the ministry responsible for paying the feed in tariffs (FITs); a significant subsidy for the renewable energy sector. More details on the infrastructure and ownership of the electricity distribution network are found below.

Renewable Energy Organization of Iran (SUNA). This is an organization under the Ministry of Energy plays a key role in setting and paying the Feed in Tariffs (FITs) set every 9-12 months for renewable energies. In 2015, they extended the power purchase agreements (PPAs) for renewables from 5 years to 20 years and established a different set of FITs for each type of renewable. These values were updated in 2016. The current values of the FITs for solar can be found in the table below.

Table 3: Current feed in tariffs for solar

Capacity of PV Power Plant	IRR/kWh	€/kWh
More than 30MW	3200	0.08
10 MW -30 MW	4000	0.10
0.1 MW – 9.99 MW	4900	0.12
20 kW – 100kW	7000	0.17
Up to 20 kW	8000	0.19

It should be noted that the FIT's are much higher than the retail price of electricity mentioned above. This demonstrates the significant subsidy of the government for renewable energy production.

Non-Governmental Organizations. There are two key non-governmental organizations that also appear to play a role in the decision making and allocation process. The first is the Renewable Energy Association. This association is a group of companies and industry interests that acts as a lobby for the renewable energy industry in Iran. They have recently lobbied for a 30% bonus on the FITs for Iranian made products.

The second organization is the National Development Fund of Iran. This fund was established in 2001 in order to set aside money from the vast resources and income of the oil and gas industry for investments in other sectors according to the priorities of the leader. In this case, it would include renewable energy industry and production. Therefore, a significant portion of investment may come from this fund in addition to the government agencies listed above.

The Islamic Republic of Iran is divided into 31 states. Each state has its own power distribution company that interfaces with the central government through the Ministry of Energy. Also most of the land in each state belongs to a national resource organization. Each state is overseen by the Ministry of Agriculture. The national government (Ministry of Energy) owns the national grid defined as voltage above 63 kV. For smaller grids below 63kV, the infrastructure is owned by Power Distribution Companies (private but with special restrictions). The electricity production is done by private entities and investors that sell the electricity directly to the government.

The local distribution operator receives 10% for each payment based on a PPA with SUNA. At present 25 states of the 31 signed the agreement with SUNA to provide service to residential and commercial renewable projects below 100 kW.

3.2 Financial incentives and tools available

In addition to the FIT's set by the Ministry of Energy and described above, there are a number of other possible financial tools available for PV producers in Iran.

Special & Free Economic Zones. These zones have been setup in border areas (Free) and specific central areas (Special) of Iran in order to stimulate industry. Benefits of the zones include:

- Tax exemption for 10-15 years;
- Customs free for imports;
- Good transportation and infrastructure support;
- Allowance of foreign companies;
- International laws are applied;
- Potential for up to 10 year land leases;
- 30% of production can be imported into Iran, custom free; and
- Exportation is greatly simplified.

Iranian Production Bonus. As mentioned above, a 30% bonus on the FIT's will be given in the PPA for electricity generated by Iranian made products. For mixed systems, i.e. systems with some domestic and some imported components, the portion available for 30% will vary depending on the breakdown of component cost and importance.

3.3 Private sector list of local PV panel producers

Recently PV panel production with imported solar cells mainly from China started in Iran. The companies involved are listed here. Overall production level of PV panels is significantly low. It is unclear if these companies will or have the option to invest in solar cell production and technological development. The scope of the Renewable Energy Council is to support future manufacturers that are investing in a strong knowledge intensive and R&D based industry.

1- Yazad Hedayat Noor Solar Energy Company
Central office Address:
No.68, fifth floor, Sardar intersection, Mokhberi Moradi Street East, Poonak,Tehran, Iran
http://www.hedayatenoor.ir/en/
Factory Address: Shahid Ghandi Blvd., Janbaz Sqr., Safaeieh, Yazd, Iran.

2- Sazan Electronic Industrial Company
Address: No.G44, Besharat St, East Industrial city, Semnan, Iran.
http://www.sazanelectronic.com/

3- Sanaye Tolide Energy Pak Atie Company
Address: No. 3 – Ateie Companies Building - Plak 17 – Fakori Blv. – Mashad – Iran.
http://www.pakatieh.ir/Contactus.aspx

3.4 Public awareness

The general public is very unfamiliar with PV systems. People who are exceedingly aware have generally travelled more extensively and been exposed to PV systems in other countries. As mentioned above, most small private installations are in locations with no grid connection. Some banks and other companies are within the cities, specifically in Tehran, want to install solar as early adopters and branding, not necessarily for real electricity production.

The public is aware of climate and nature concerns and considers these to be very important. The media often produces stories on the local environment and natural issues including animals and climate. However, a gap exists in the public awareness of these issues and the possible solutions offered by solar.

Source: Middle East Institute

4

Private Sector Resources

4.1 Gap analysis

A key component of this technical assistance is identifying the resources, opportunities, and risks for production and manufacture of PV cells and modules in Iran for use inside of the country. In this section, we will look at this question from a variety of perspectives. First, we will look at the demand side or market side in Iran to gauge what the boundary constraints are for efficiency, cost, and availability of PV components for an internal national pipeline. In the next two sections, we will look at the supply side. A gap analysis is conducted of the necessary levels of local expertise and experience for achieving solar manufacturing. Finally, we will look at the necessary resources for the supply side of a 100 MW production plant for both cells and panels.

4.1.1 Demand Side Analysis: A 50 MW case study

One of the key decisions for any new potential PV cell and panel manufacturer is whether to invest in the proven technology of c-Si Al-BSF technology around 16% system level efficiency that is proven in mass manufacturing around the world and accounts for roughly 85% of the global market or to invest in a higher performance technology that offers product differentiation and technology value. This decision is highly dependent on the market application target. In the case of Iran, we understand that the stakeholders are mostly interested in utility scale electricity generation.

The purpose of this case study was to determine the necessary PV cell and panel efficiency that have to be realized for local production in Iran to compete with imported panel. The fundamental question is: What type (efficiency and price) of domestic made module would convince an investor (customer) to purchase locally versus buying an imported panel? We look at both possible panel manufacturer profit and project owner levelized cost of electricity (LCOE) profits. A solar installation producing locally 50 MW

was used for the study to analyse the costs for the development, construction and operations. Based on this starting point a PV module efficiency was calculated that need to be locally produced to compete with imported panels.
In addition the case study is used to identify all of the key players and important issues in the demand value chain for consumption of 50 MW of PV electricity production. It is assumed that this will be supplied by a production line with nominal capacity of about 200 MW per year.

Methodology
Specific data for this analysis comes from a variety of sources. The primary source for information specific for Iran comes from interviews with relevant parties in Iran as specified in Appendix A and followup conversations with Noursun. This data is quantified and specified in the following section. Data for average cost of PV modules and performance is compiled from a various market and pricing reports.

- International Technology Roadmap for Photovoltaics 8th Ed. 2017. http://www.itrpv.net/Reports/Downloads/

- SPV Market Research, Photovoltaic Manufacturer Shipments: Capacity, Price, & Revenues 2015/2016. Paula Mints. April 2016.

- Solar PV Tech Webinar. Solar Technology Manufacturing & Landscape for 2017. Solar Media Ltd. 29 September 2016.

- National Renewable Energy Laboratory. U.S. Solar Photovoltaic System Cost Benchmark: Q1 2016. Ran Fu, Donald Chung, Travis Lowder, David Feldman, Kristen Ardani, and Robert Margolis. September 2016. http://www.osti.gov/scitech.

- Photovoltaics Report. Fraunhofer Institute for Solar Energy Systems, ISE and PSE AG. 17 November 2016. https://www.ise.fraunhofer.de/content/dam/ise/de /documents/publications/studies/Photovoltaics-Report.pdf.

For LCOE calculations, we use the following formula[1]:

$$LCOE = \frac{CAPEX + \sum_{t=1,lifetime}[OPEX_t/(1+WACC_{nom})^t]}{\sum_{t=1,lifetime}[Utlization_0(1-Degredation)^t/(1+WACC_{real})^t]}$$

For our model we assume a t=20 year lifetime with 0.5% per year degradation rate. Nominal weighted average cost of capital ($WACC_{nom}$) is the amount charged by the bank or lending institution. The value may vary based on the source of capital (domestic or foreign). Real weighted average cost of capital ($WACC_{real}$) is corrected for inflation. Inflation is assumed to be 7% based on conversations with Noursun. CAPEX and OPEX are calculated from the interview information and published pricing for various inputs (further elaborated in the next sections). Utilization for Iran is assumed to be 1800 kWh/kWp. All other specifics are outlined in table below.

[1] Vartiainen, E., Masson, G., Breyer, C., *PV LCOE in Europe 2015-2020*, 31st European Photovoltaic Solar Energy Conference, 2015.

50MW Case Study

We will break the business case down into 4 parts: development, construction; operation; and capital availability and cost.

For each part there are three key items we will identify: inherent costs, timeline, and any issues that we can foresee. In addition, there may be other aspects that bring additional information. The information for each part was collected through interviews with Noursun and publically available information for similar systems.

Part 1. Development

Description: Development includes finding a suitable site for the PV installation, acquiring the land leases, determining a suitable price for the land, setting up all necessary permits, finding an investor, and establishing a timeline for the total project.

Considerations: Land availability in Iran is not a limitation of project development. Land for solar farms on the scale of 50 MW is available from two sources; either for purchase in free economic zones or for rent in agricultural zones. In the free economic zones, the costs are in the range of €5/m^2 for purchase with access roads and utility connections. In agricultural zones, the model is usually renting at a rate of about €2/m^2, but access roads and utility connections will have to be built. Land leases in agricultural zones can be attained for 2 years and are likely to be extended up to 10 years. After 10 years, there is pressure to purchase the land. These leases are well protected but there are some restrictions in that the land must be used for the designated project and the project must be started in timely matter. The leases can be secured in about 2-3 months, however, there are 11 permits that must be obtained from various organizations and petroleum industry must approve that land is not intended to be used for petroleum production. For improving the land, adding transmission lines, access roads, and water utility, the land manager is responsible for arranging but the renter is responsible financially. The final rental price can be re-negotiated after improvements are made. For purchasing land in free economic zones, it can take as little as a month to secure land rights.

Foreign entities can secure land rights in the free economic zones, however, often international insurance is necessary and very difficult/expensive to obtain. This has limited foreign development.

Obtaining land is dependent on getting a signed PPA with SUNA. In addition, there is a timeline that the project must be connected to the grid within 18 months of PPA signature. This means that the all pieces of the project should be essentially secured at the signing of the PPA and land lease should be negotiated in parallel with the assumption of PPA approval.

On average, 6 months is the typical necessary time for arranging a land agreement, connection permit, and construction tender, after PPA is secured.

Conclusions: For the sake of this case study we will assume use of a free economic zone, therefore permitting is essentially included in the price of the land and it is ready for PV development. Assuming a rate of purchase of €5/m^2 with 50% overhead direct costs due to feasibility studies (35%), connection studies (10%), and site control (5%). We also include 30% developer overhead for selling, general, and administrative costs . The total development cost is approximately €10,50/m^2.

Part 2. Construction

In this part, we will consider the construction issues, costs, and timeline of sourcing the technology and installing. This will also include the balance of systems availability and supply chain as well as taxes and construction costs.

Considerations: There are many good construction companies in Iran that are competitive and available for larger infrastructure projects. In free economic zones, the government has created attractive models for capital expenditures for solar due to custom tariffs and imported goods. Sales tax is typically 9%. Due to the 18 month timeline on the PPA agreement, construction must be fast. A tentative timeline is 4 months for construction, 1 month for installation, and 1 month for inspection. Subsequent to the development phase, this results in 3 months buffer for project. Currently, there are very high import tariffs on power components (inverters, power optimizers, etc.) brought into Iran. In addition, since panels must be secured from the international market, there are currently very high custom tariffs. There is also a lead time of 1-4 months for shipping of these components. This introduces risk into the project. Another issue is that there is not currently a flash tester in Iran to test the quality of incoming products. It has already occurred that underperforming modules have been shipped to Iran from overseas suppliers.

Conclusions: Noursun has provided numbers from an existing project for €1100/kWp, including the 9% sales tax in a free economic zone. Assuming 0.90 €/Wp for inverter, 0.36 €/Wp for balance of systems, we find that this correlates to about 0.58€/Wp for a 16% efficient foreign module. This is in excellent agreement with average costs of shipped modules in 2016 as published by the International Technology Roadmap for PV (ITRPV), SPV Market Research, and Solar PV-Tech.

We will also include labour from 5 electricians and 15 labourers for 6 months and assume a 30% wage burden at a total construction cost of approximately 94,000€ for installation and construction of the 50 MW project.

Part 3. Operation

This part considers issues like operations and maintenance necessary in the selected site, performance degradation, maintaining land leases, limited contracts, and possible resale of the asset to a third party.

Considerations: Based on international projects (none exist in Iran currently), Noursun estimates the need for 7 operational employees per 10MWp installed. These employees include: one manager, one accountant, two engineers, and three labourers and/or security. In addition they also assume €5000/year/10MWp in other maintenance. Insurance is approximately €15k/year/10MWp. We also assume the inverters will need to be replaced after 10 years.

In case the electric grid is not functioning, the PV plant owner is remunerated for average production during that day. If there is a problem in the power plant, there is no penalty applied to producing less, but missing production is not paid. A readiness factor is applied based on the time of production. This number is multiplied with the actual electricity production to determine the payment. For instance, during peak hours, from 11:00 – 14:00 in the summer time, the readiness factor can be as high as 2 or 3. This is a big advantage for solar over wind as solar productions is highest at peak times.

Module degradation is not well understood at this point in Iran as very few systems are operational for longer times. It is assumed by most investors and others that warranties and guarantees by manufacturers will be upheld and are an indication of performance over time.

Conclusions: From this discussion, we calculate operating costs of approximately €190.000/year for a 50 MW plant. In addition, we will assume that for foreign modules, 2% hardware backup is necessary for replacement. For domestic modules, we assume 2,5% backup due to less demonstrated technology and time.

Phase 4. Capital Availability and Cost

Description: The cost of capital is a large determinant of the levelised cost of electricity generated in a 50 MW plant. The specific issues in the financial environment in Iran make the country a unique situation. Regarding the material supply, several materials necessary for solar cell production are currently not available.

Considerations: Investment in Iran is limited by international sanctions. Foreign banks may have interest rates of 7% but National banks have assumed interest rates of 10%-14%. This requires foreign capital, limiting development to the free economic zones. However, weighted average cost of capital (WACC) will likely end up being effectively higher because of needed insurance and sanctions. There are some additional risks for foreign investments in that the PPA is paid in Rial where inflation may also end up as an additional risk factor. Historical rates of inflation in Iran are on the order of 7%-50%. Of course, the situation with the sanctions is currently changing on a daily basis. Many foreign investors are interested in markets in Iran.

Conclusion: For the sake of calculations we will assume that foreign investment WACC is on the order of 10% and local WACC is approximately 14%. We will also assume this includes a 7% inflation rate.

Evaluation

From the above considerations, we can evaluate the possible market, pipeline, and cost structure for a PV cell and module plant in Iran. This will allow us to make a recommendation on what type of cell/panel technology to choose for local Iranian manufacturing.

We will make a few basic assumptions:

(1) Imported modules will be of an average 16% system level efficiency with a cost of €0.58/W_p. This is in agreement with price numbers provided by Noursun as well as numerous average price models from various global sources. Of course, higher efficiency modules are available on the global market but these numbers offer a good global average for comparison purposes. Balance of systems costs are based upon either information provided by Noursun in the details above and/or supplemented by the NREL Cost of PV Report 2016.
(2) Balance of systems costs are divided into three independent parts: (1) Power-related costs (€/W_p) including module, inverters and power electronics, support structures, and supply chain costs; (2) Area-related costs (€/m^2) including cabling and land development costs; and (3) Fixed costs (€/50 MW installation) including construction costs, EPC management and profit, transmission lines and interconnection to the grid.
(3) O&M costs are based on estimates provided by Noursun, a minimum wage of €3600/year and a 30% wage burden on employers. In addition, it is assumed that an additional investment of 2%/yr of original capital investment for operational maintenance is needed. For cells and panels made in Iran, we assume a 2.5%/yr budget since these panels would not have proven bankability initially.

Technology Premium

Higher efficiency modules offer savings at the LCoE level in projects. The amount of possible value in higher efficiency cell and panel technologies can be derived by looking into the various components of the balance of systems. This allows us to derive how much extra value a higher efficiency panel can generate in the whole value chain.

By looking at the full project development, we separate the balance of systems costs into area related costs, power related costs, and fixed costs as mentioned above. From this, we can determine the additional value of higher efficiency panels compared to the reference case of a 16% efficient panel.

In Figure 2 below, we see the potential value of a higher efficiency panel in an area-limited system (such as a commercial rooftop or commercial lands) and a power-limited system (such as a utility power system). The efficiency on the x-axis represents a system level panel efficiency. We use our baseline case of 16% panels with a price of €0.58/W_p as reference. The balance of systems is taken from the case study.

For rooftop or limited area applications, a 20% system efficiency module could be sold in Iran for as much as €0.67/W_p and the system developer could make a similar profit. In a power-limited project, as assumed in this exercise, a 20% system level efficiency module could be sold as high as €0.63.

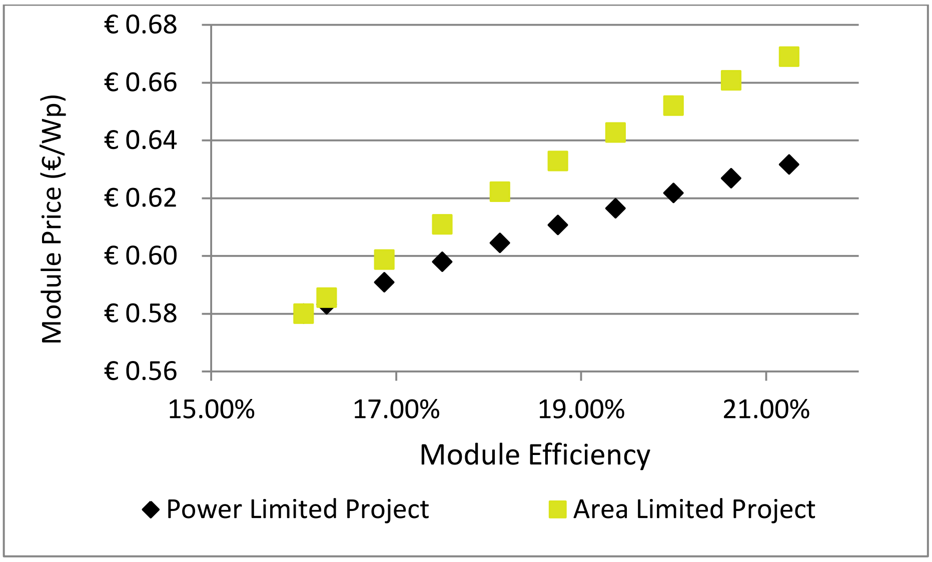

Figure 2: Potential value in Euro per kW depending on efficiency of solar panel

In the table below, there are three models. In all local cases cells and panels are manufactured in Iran. The first model labelled 'Local (LE)' is a low efficiency panel (16%) technology manufactured in a local factory. The second model, labelled 'Local (HE)' is a high efficiency (20%) technology manufactured in an Iranian factory. The last model is based on the model of using foreign panels with 16% sold in Iran for 0.58€/Wp. The inverter is assumed to be foreign and all other balance of systems are assumed to be made locally.

Table 4: Three models for local low efficiency, local high efficiency and foreign panels

	Local (LE)	Local (HE)	Foreign
Panel Efficiency	16%	20%	16%
Panel Cost	€ 0,410	€0,427	€0,580
Panel Manufacturer Profit	4%	7%	--
Utilization (kWh/kWp)	1800	1800	1800
Panel Price (€/Wp)	€ 0,425	€0,458	€0,580
Power Related BOS (€/kWp)	€ 0,43	€0,43	€0,43
Area Related BOS (€/m2)	€ 33,47	€33,47	€33,47
Fixed Costs (€/Wp)	€ 0,15	€0,15	€0,17
Total Project Capital (kWp)	€1.218,44	€ 1.210,46	€ 1.395,29
O&M (€/kWp/yr)	€ 14,42	€15,23	€15,39
WACC$_{nom}$ (including 7% inflation)	14%	14%	10%
LCOE (€/kWh)	€ 0,0755	€0,0756	€0,0656
Local Manufacturing Bonus	26,9%	26,9%	10,2%
FIT Price (€/kWh)	€ 0,1015	€0,1016	€0,0881
FIT – LCOE (Profit/kWh)	€ 0,0260	€ 0,0260	€ 0,0226
Margin (Profit)	34,4%	34,4%	34,4%

The foreign model acts as a reference project. In this project, the system owner could expect a 34.4% profit. Electricity production could be done for as little as 0,066 €/kWh. Using this reference for profit, we find that the local manufacturer could competitively sell a low efficiency module (16% efficiency) at a price of 0,425 €/Wp. Based on current module manufacturing costs (addressed in more detail below), we expect this could result in about a 4% profit margin for the panel manufacturer.

The higher efficiency module (20%) could be sold for 0,58 €/Wp. This would allow for almost twice the profit margin for the panel manufacturer.

Therefore, the recommendation would be to aim for a technology that can enable greater than 20% efficient panels. This not only allows more a competitive economic model but also product differentiation for choice over the foreign purchased panel. Finally, the increased profit margin would also allow investment in future technology and performance advancement.

4.1.2 Material supply chain & local material producers

In Appendix B, an overview is presented of basic PV material needs and Iranian supply. The main discrepancies are:

- Polysilicon supply
- Crucible supply
- Wire saw and slurry chemistry
- Silane
- HF (hydrofluoric acid)
- Silver paste.

Listed points cover most of the important supply materials. These materials will need to be either developed in Iran or need to be secured by contracts. Silane and HF should be developed in house, since transport will be very expensive.

Silver paste production for the metallisation of the solar cells need to be outsourced with sufficient suppliers available. The same holds for wire saw and chemistry, crucible, and polysilicon. The material overview will be used for a production value chain analysis in chapter 4.1.4.

4.1.3 Level of local expertise need

The success of a PV manufacturing plant depends on the quality of the people. Most important qualifications needed are:

- Purchasing and logistics expertise;
- Mass production managers, material experts and installation engineers;
- Process engineering.

Other expertise should be in maintenance and facility management. In a wider scope human capital development and capacity building are essential.

Human capital development and capacity building is an important ingredient in the successful implementation of solar projects, especially in the areas of product design, development, and manufacturing.

Skill gaps in the solar sector are identified as: knowledge and exposure in advanced areas like wafer technology, PV semi-conductor technology, design and manufacturing skills in solar cells, and low skills in PV panel assembly.

The skill gap can be addressed by offering customized training programs across the entire solar energy value chain.

As the renewable sector, solar, in particular, is at very nascent stage - graduates having renewable sector knowledge are not finding lucrative job offers from renewable sector compared to other emerging industries like IT, e-commerce, retail, etc. Local PV industry should increase interaction with academic institutions and build awareness about career opportunities in the renewable sector before launching local manufacturing.

PV training Center within the Applied research Center (see chapter 6) can take skill development/upgradation programs to a higher level. Through the PV training center the solar sector is expected to benefit the most.

General framework

Effective capacity building programs for the PV industry are based on current and future PV solar energy policy issues and priorities in the country. They address the whole PV solar energy policy chain and should be embedded within the country's organizations and institutions to become a self-sustaining structure that serves to continue the building of human capacity. In such an approach the capacity development program focuses on three target groups: (1) national/regional policy makers; (2) university education; (3) the private sector.

1. National/regional policy makers are trained in energy planning analysis and in formulating sound energy policies, making optimal use of available renewable resources, promoting renewable energy and energy efficiency, increasing access to electricity, environmental analysis, accessing climate finance, and social and instituitional issues. The uncertainties related to future GDP growth and the expected change in economic structure with a much higher share of extractive industries makes proper and continuous energy planning even more necessary.

2. Universities and Polytechnics are assisted in expanding existing, or setting-up new, education programs on energy, with particular focus on PV. This may comprise developing new curricula and educational material, training lectures on new topics and running the new educational programs. To strengthen the sustainability it is important that the research conducted at the universities becomes applicable and that universities establish long lasting cooperative relationships with private sector companies and governments to stimulate the commercial development of successful research projects and the commercial exploitation of PV energy expertise available at the university in consultancy work.

3. Private sector energy entrepreneurs are trained in the technical aspects of PV solar energy technologies and how to establish a business, develop bankable projects and deal with financial institutes. This may involve training in cost-benefit analysis, business plan development and risk analysis. Financial institutes may be trained in technical, financial and energy policy issues to enable them to better underpin decisions on investments in the energy sector.

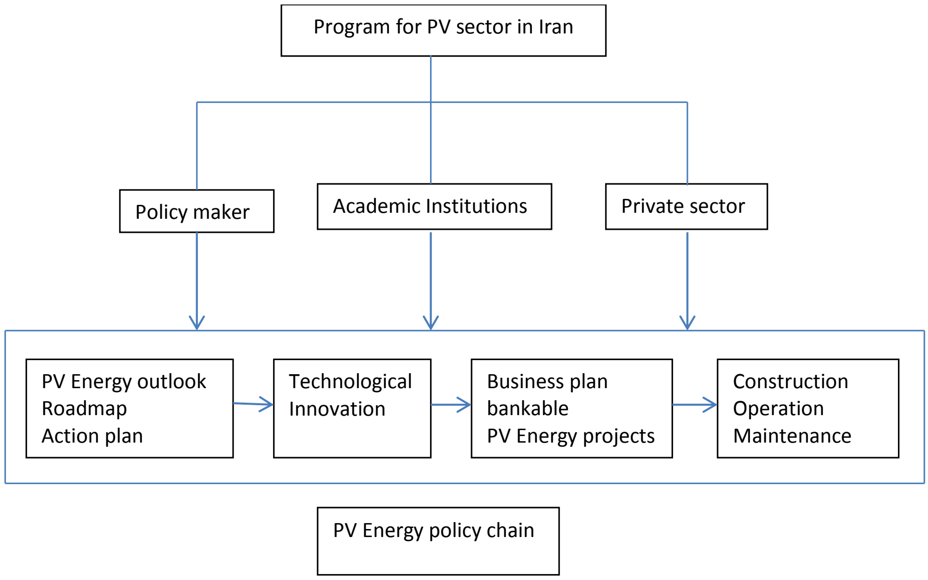

Figure 3: PV energy policy chain

The energy policy chain, depicted in the above figure, is defined as a path starting from the formulation of energy policies and development of a regulatory framework to energy actions plans and technological innovation, to development of bankable energy projects and, finally, the construction of the energy project.
It is important that the capacity development program addresses the whole energy policy chain and that synergies are created between the training activities for the three target groups through, for example, alignment of training materials, the sharing of facilities and regular interactions between policy makers, universities, private sector and other stakeholders.

It is also important that the program is embedded in existing structures that are part of annual planning and budget cycles and will remain intact in the foreseeable future. Working together with existing knowledge institutes in Iran is likely to be more sustainable than creating new institutional entities. Nevertheless, an applied research facility supporting of and guided by the industry can lead to much faster implementation of advanced PV products. In chapter 6 a description and set- up of such a facility is provided.

4.1.4 200 MW PV manufacturing plant analysis

The purpose of this case study is to identify all of the aspects in the value chain for production of 200 MW/y PV solar cells and panels in Iran.

Iran has a protected market and price of PV that is not directly related to price in other countries. This presents an opportunity for at-home manufacturing. To be successful, it is important that the supply of materials is secured for an acceptable price. Therefore, we need to know what part of the product could be manufactured in Iran. First, we need to look at what materials are manufactured in Iran and what materials could easily be produced in Iran, see Appendix B.

For example Argon gas used to purge the impurities in the molten silicon is one of the major gases in use. There are several large air separation plants in Iran producing the gas. However, the available volume and logistic are not able to fit with the needs of a local Si Ingot plant. Another example is the low iron glass used for the panel manufacturing. There are many large glass producers in Iran nevertheless the relatively small market demand for solar glass can hamper the production and slow down scale up.

Moreover, there are some materials that even if locally produced need to have a certain volume for the local or export markets. Several years have to be invested to get these materials qualified for PV application. For example EVA (Ethyl Vinyl Acetate) encapsulant material for panel production can be made in Iran. However, convincing a customer to use an EVA product without any long term filed reference is not very easy.

For the analysis terms of CapEx and OpEx are used. Based on consistency with best accounting practices, we define capital expenditure (CapEx) as the sum of physical property, plant, and equipment, as well as the engineering, procurement, and construction expenses of the manufacturing facility itself. CapEx does not change with utilization rate (i.e., the ratio of actual production to nameplate capacity). Thus, CapEx is a fixed cost.

An operational expenditure (OpEx) is the money a company spends on an ongoing, day-to-day basis in order to run a business. There is a direct correlation between OpEx and the value of the enterprise, in that when the OpEx decreases, while maintaining the same level of production and quality, the overall value of the enterprise increases.

Regarding the productions of cells, panels and wafer production in Iran here are the main conclusions:

- For panel production, all materials are available in Iran, it is not clear whether solar glass production is at large enough scale. Of course, cells are not available yet. Cells form 60% of the operational costs.
- For cell production, many of the crucial materials are not available: wafers (60%), silver paste (10%), silane, and, hydrofluoric acid as well as equipment cause a high CapEx.

- For wafer production, main OpEx drivers are not available in Iran: poly silicon costs (50%), crucible costs, slurry costs as well as equipment introducing high CapEx. Local electricity costs are also key for production in Iran.
- For polysilicon costs: main OpEx driver is the CapEx and electricity costs, which should be very low (<2 €ct/kWh) to make polysilicon cost competitively. Equipment has to be imported. Crucial know-how and IP are very difficult to obtain on the free market for high quality and low cost. Scaling is extremely important, with a minimum silicon production for 10 GWp/y of PV panels.

In Figure 4 the typical investments needed for producing a PV panel are displayed in semi-products (poly-silicon, wafer, cell, and panel)[2].

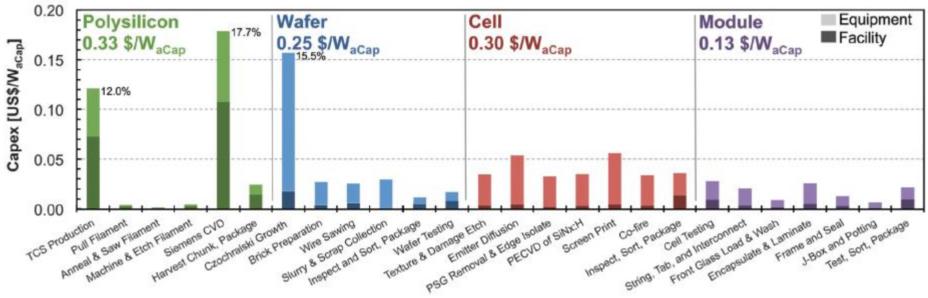

Figure 4: Costs of CapEx for manufacturing PV panels from Powell, et al., 2015.

The main investment costs are in the front-end, for poly-silicon and wafer production. This is also reflected in the main OpEx, or operation costs of PV panel production which for silicon PV panels is the wafer. Listed in OpEx the wafer is 35%, cell 23% and 41% in panel production.

Local module production by importing solar cells is an interesting case because most of the costs are OpEx and very little in CapEx. However, the solar cells will have to be imported and securing a reliable and cost competitive supply is crucial and very difficult. In times of shortage, cells are either used for in-house production or sold to the largest customer. Price volatility can be very high for that reason.

An upstream shift towards cell production is therefore a logical choice to protect against such volatility. However, cell production is more CapEx oriented and supply of wafers and metallisation pastes become essential. Wafer supply is dominated by two major suppliers: GCL and Longi from China. Nonetheless, both companies are shifting downstream towards in- house cell and panel production as well, and therefore hampering independent supply in times of shortage. Securing wafer supply is imperative to survive, hence, this can become very costly in times of shortage with long term contracts negotiated that can obstruct prospects and lead to bankruptcy.

A shift even further upstream towards wafer and polysilicon production becomes heavily CapEx oriented and scale of operation is compelling. Polysilicon supply is controlled by a limited number of Chinese players, with some other companies surviving in the margins of the business. Starting at small level in this market is very

[2] Powell, D. et al. *The capital intensity of photovoltaic manufacturing barrier to scale and opportunity for innovation*. Energy Environ. Sci., 2015, 8, 3395.

difficult from a business and operational aspect, making growth from pilot scale to full manufacturing a near impossibility.

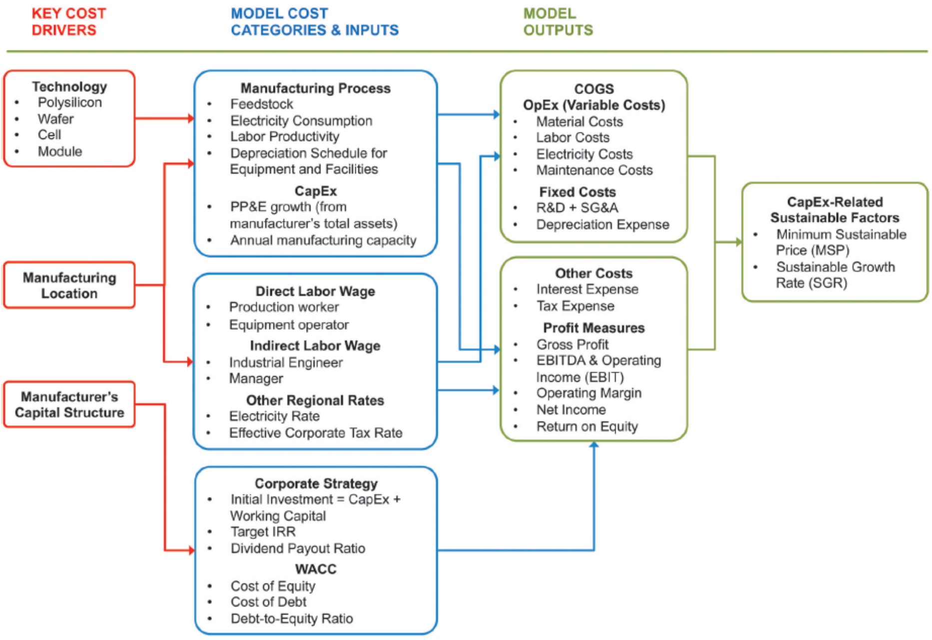

Figure 5: Summary of the linkages between the key elements, including CapEx, working capital, variable costs, operating income (EBIT) and margin, depreciation, WACC, IRR, and MSP. Also extracted from Powell, et al., 2015.

4.2 Key success factor

Production of PV panels is a commodity business where the lowest costs of production is key for success. Key success factor is therefore economy of scale. A clear growth strategy is needed towards 2-5 GWp/y production. A smaller scale cannot be competitive on the global market. It is important to have access to enough capital to grow the business towards this scale. In total, at least 1000 M$US should be available at competitive interest rates compared to Chinese interest rates, excluding operational cash. A second success factor is to establish a secure supply chain, for wafers and or cells. A long term relationship with suppliers has to be developed early on. Next to the availability of cash and reliable suppliers, it is essential to also develop supporting industry. Main industrial developments are in the supply of chemistry, glass, and low electricity prices. An overall strategy is needed to develop these supporting industries. The strength of the PV industry is that the costs of R&D is shared among all players, including public support. Iran has to tap into this pool of development. Strategic alliances with industry leaders and research leaders is key for a competitive future.

5

Assistance and planning

After a review and gap analysis presented above, a number of potential aides may be proposed for further buildup of the manufacturing sector and technology development within the Islamic Republic of Iran. In this section, we will outline a number of considerations and perform an analysis of some different options for further progress to achieve the main targets for PV and renewables.

5.1 Choice of technology

In the section 4.1 we identified two general types of modules, high efficiency (20% systems level) and low efficiency (16% systems level). Based on the market analysis in section 4.1.1, we have recommended targeting a higher efficiency technology for Iran development. Here we outline the current state of various technology solutions. We will only consider cell architectures here that have turnkey systems available for purchase.

Currently, more than 80% of global production is mc-Si based Al-BSF (Al Back Surface Field) cells with an efficiency of about 17.5% - 19.0% cell level efficiency. These are made into the common 16% panels. However, the average cost of this technology has dramatically declined in the second half of 2016 to an average global sales price of approximately $0.42/Wp. Therefore, it is expected that only manufacturers with more than 3 GW capacity of this technology will be able to continue to compete at these price levels. This makes new manufacturer market entry almost impossible.

There are a number of technologies now available and gaining in market capacity that are higher efficiency technologies. p-PERC (Passivated Emitter and Rear Contact) is a line upgrade from a standard Al-BSF line to include new passivation and laser processing. Typically, the technology is based on mono-crystalline Si (although it can also be made with mc-Si) and is expected to exceed 30 GW of installed production capacity in 2017. This technology has current efficiencies of about 19.5% at cell level and around 17%-18% at panel level. This is expected to be the market dominant technology in PV over the next 10 years. Average cost of processing at this moment is about 20% more expensive than Al-BSF, but expected to decrease due to volume manufacture and learning.

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However, p-type silicon is also facing an inherent challenge for higher operational efficiency. Due to the boron used to dope the silicon, most wafer material suffers from light induced degradation (LID). At this moment, there is no known and industrial solution for LID. Therefore, it is believed that to reach higher cell efficiencies, n-type Si cell technology is needed. The inherent properties of n-type silicon are more favourable for solar cell technology and therefore almost all cells made with efficiencies higher than 23% have been made with n-type silicon[3]. Unfortunately, at this moment n-type silicon wafers are approximately 10%-15% higher cost due to lower production volumes.

Here, the entry level technology is n-PERT (Passivated Emitter and Rear Totally diffused) cells which is in production with more than 2 GW capacity globally. Average cell efficiency is currently around 20.5%-21%. The costs are approximately 10% higher than p-PERC due mostly to more expensive n-type Si wafers. The main advantage of this technology is the ability to more easily upgrade equipment to higher efficiency cell architectures (still mostly in development) such c-Si/a-Si heterojunction, passivated contacts (PERPoly[4]), or IBC (Interdigitated Back Contact).

Both n-PERT and p-PERC can also be made in a bifacial manner such that the rear side of the cell collects light from the environment (albedo) and converts it into current. These are generally referred to as n-PERT+ and p-PERC+. It is generally expected that 20% albedo light could be available in standard system installation. At the cell level, n-PERT+ has been demonstrated with more than 95% bifaciality while p-PERC+ is typically lower, around 85% bifaciality. This corresponds to a relative power gain of 15%-18% for the module. Additionally, bifacial modules are made glass-glass with potential for longer lifetime and reliability.

5.2 Roadmap

As competitive entry to the Al-BSF production is probably very difficult and based on the market analysis in Chapter 4, higher efficiency offers significant advantages, we envision two possible routes and roadmaps for Iran in terms of cell and panel technology.

Roadmap 1. Initial investment in p-PERC cell and module development into p-PERC+ (bifacial)
PERC cell technology defines a solar cell architecture that differs from the standard cell architecture that has been in use for three decades. The PERC architecture essentially enables to improve light capture near the rear surface and to optimize electrons capture. Based on the material supply challenges, p-type based Silicon should be used for the manufacturing of the solar cell. In order to reach higher efficiencies as identified in chapter 4, mono- p material should be used. The production can be adapted for bifacial modules as well. It is expected that efficiency of this technology will increase and costs will decrease in the next decade. While this learning will be very useful, it may prove difficult to compete with aggressive cost reductions of the same technology driven by the Asian manufacturers.

[3] There is a notable exception in the p-PERC cell made by UNSW in 1995 with 25% efficiency.

[4] Combination of a thin oxide and doped polycrystalline silicon (polysilicon or poly) to obtain low recombination junctions is applied for creating passivating contacts to cSi solar cells. The poly is deposited by Low Pressure Chemical Vapour Deposition (LPCVD). Cell efficiency can be boosted with this technology to ~25% for n-type Si material based solar cells. Used as a follow up for the p-type based PERC, PERPoly would lead to an efficiency of 23% with a resulting panel efficiency of more than 20%.

Key Benefits:

- Equipment is readily available
- p-type silicon wafers are lower cost and easy to source
- Bifacial modules possible

Key Risks:

- Limited efficiency potential (mostly due to LID)
- Lower bifaciality limits potential
- Production will have to compete economically with large cell and module manufacturers in India and China.

Roadmap 2. Initial investment n-PERT with development into n-PERT+, passivated contact (PERPoly) or IBC

n-PERT offers a higher efficiency, differentiated product from p-PERC technology. Currently at 20.5%-21% cell efficiency in production there is significant potential for higher efficiency. Additionally, it offers the ability to easily upgrade to much higher efficiency cell and module concepts. Cell and module turnkey lines are readily available, however the initial capital expenditure is higher for this technology. There is a large community globally working on similar concepts and therefore learning is possible from various R&D institutes and departments. The dependence on n-type silicon requires slightly higher cost but the material potential is higher.

Key Benefits:

- Highly differentiated product from p-type technology
- Easily upgradable to higher efficiency

Key Risks:

- Dependent on more expensive n-type wafer production
- Higher initial capital expenditures and production cost

Recommendation:
Based on the gap analysis of Chapter 4 and the technology considerations discussed here, we recommend following ‘Roadmap 1: Initial investment in p-PERC cell and module development into p-PERC+’. This is due to the need to secure p-type silicon wafers at a lower price and availability of more equipment manufacturers for the specific case of Iran.

5.3 Solar cell & panel production roll out scenario

This section describes the details of the roll out activities for a solar cell & panel production. The activities can be carried out either concurrently, if activities and resources permitting, or sequentially in the cases where one activity can only proceed upon the completion of other activities.

Relevant project milestones to define the status of the cell production line are:

- Project start: p-PERC client has signed the purchase order

- Factory acceptance test (FAT)-1: Equipment is hooked up to the utilities and ready for base process[5] installation.
- FAT-2: Base process is installed; equipment is ready for process ramp-up.
- FAT-3: Equipment fully accepted by p-PERC client.

Roll out activities are subdivided into 5 categories:
- Activity 1. will take place between initial starting phase and FAT-1.
- Activity 2. has to take place between initial starting phase and FAT-2.
- Activity 3. will take place between initial starting phase and FAT-1.
- Activity 4. will take place between FAT-1 and FAT-3.
- Activity 5. will take place between initial starting phase and FAT-3.

Activity 1: p-PERC production equipment specification

Expected duration: 2 months
The equipment for all wet chemical processes and diffusion processes are specified and offered by chosen companies.
For all other processes: When standard equipment is available from selected suppliers, the equipment has to be evaluated. When necessary, experiments will be defined and executed to benchmark the industrial equipment against the licensee providers lab equipment.
Although equipment for general process steps is often widely available, some of the equipment has to be designed for certain specific processes. Instead of developing full equipment specifications, the process specifications will be discussed with (potential) interested suppliers so they can modify their equipment dedicated for the process. The equipment specifications set-up by the equipment supplier will be evaluated against the process specifications.

Activity 1. is closed when all processing equipment has been ordered. Activity 3. cannot start if Activity 1. is not finalized.

Partner	in scope
Client	
Machine vendor	Delivery of p-PERC dedicated tube furnaces
Wet chemistry machine provider	Delivery of p-PERC dedicated wet Chemistry equipment
License & Technology provider	Specification of the tool requirements for the p-PERC process (functional requirement, specification) Upon participation in IAT (Initial Acceptance Test at vendors site)

Activity 2: p-PERC Cell Process Transfer
Expected timeline: 3 months

3 Base process is defined as: individual process stations run satisfactory at initial specifications with wafers storage in between the process stations. On each individual process station short process runs (e.g. 2-5 hours) are done. Overall process yield is well below specifications, and the expected average cell efficiency is about 18%, depending on material quality.

This activity has three objectives:

- To transfer providers know-how for the p-PERC solar cell technology to the client. Provider will disclose the technology package in the form of a full detail process and material specification document. In addition provider will administer one-week training on these additional processes to the clients personnel at providers location or client facility.
- Demonstration of p-PERC cell technology capability on the providers pilot line (if available) with a batch of 100 solar cells.
- Transfer of full detail cost of ownership model

Activity 2. is closed when all training on providers site has been done with process demo executed. In addition, all process and CoO documentation has been received by the customer.

partner	in scope
Client	Deliver as specified p-type wafers to provider Provide qualified personnel for training
Machine vendor	p-PERC know how transfer on machine vendor equipment CoO disclosure
Wet chemistry machine provider	p-PERC know how transfer on wet chemistry machine provider's equipment CoO disclosure
License & Technology provider	Full process specification transfer CoO disclosure Provide training

- One week at provider theoretical and practical training with focus on material and processing aspects for p-type production.
- Production and analysis of 100 sample demonstration production run which can be used for pre-start up optimisation tests.
- Documentation preparation.

Activity 3: p-PERC Equipment installation
Expected timeline: 3 months

This activity has the objective to install the p-PERC equipment.

Activity is closed when working solar cells can be produced and all cell production equipment, quality control equipment and automation is installed. The equipment has to be individually accepted on functionality by the customer. Activity 4. Can only start when Activity 2. Is finalized.

partner	in scope
Client	Prepare facilities and utilities for all equipment hook-up Install and accept equipment outside technology package
Machine vendor	Install and test equipment from technology package
Wet chemical machine vendor	Install and test equipment from technology package
License & technology provider	Advise on process start up and SAT

Activity 4: p-PERC Cell Process Implementation & Validation
Expected timeline: 3 months

When a production line is build, individual processes have to be optimised and combined into a fully integrated and optimised process. The license & technology provider together with the machine vendors prepare start-up strategies for the individual processes and an optimisation strategy for the whole cell production line has to be implemented.

p-PERC Cell Process Implementation
This activity has an objective to support the implementation of p-PERC solar cells at the client facility using the information disclosed in activities 1 & 2. The support can be carried out either off- or on-site at client facility.
The first p-PERC cells of reasonable quality should be used for panel fabrication, characterisation, testing and certification.

Provider support between FAT-1 and FAT-2
Expected analysis by the client are mainly metallisation line resistance measurements, metallisation line definition measurements, spectral response and reflection measurements. Moreover, IV measurements, microscopic evaluation of SiN coating, and carrier lifetime measurements are also part of this activity.
At the end of this period the base process has been installed.

License & machine vendor support between FAT-2 and FAT-3
A milestone table has to be established that denotes three phases: i) initial phase; ii) stabilization phase; iii) final phase

i) initial phase
In this phase optimisation of the individual processes and process integration between the various process stations will be done. At the end of this phase continuous solar cell production of several hours has to be achieved.

- To evaluate the status of processing or individual process steps and advice on improvement of the processing, the provider will:

    - perform characterisation of complete cells or semi-fabrics produced by the p-PERC client.
    - analyse the process data logged by the p-PERC client.
- Provider will give onsite support to the p-PERC client to set-up and stabilize the processes. Focus will be on the chemical and diffusion processes. Provider will only advise and guide p-PERC clients engineers. p-PERC client, machine and wet chemistry machine vendor are responsible for the operation of their own equipment.

ii) stabilization phase
The background of this phase is to stabilize the process by running production. Experience has learned that this will improve the output of the line.

- When processing issues are observed the provider will:
    - analyse the process data logged by the p-PERC client

Provider will do a continues analysis of the process data of the p-PERC client. This will shorten the time before actual process issues will be observed.

At the end of this phase a continuous 24 / 7 production should be possible. Line output has improve close to the final specifications.

iii) final phase

- To evaluate the status of processing or individual process steps and come to advices of improvement of the processing, the provider will:
    - perform characterisation of complete cells or semi-fabrics produced by the p-PERC client.
    - analyse the process data logged by the p-PERC client.

- Give onsite support to the p-PERC client to fine tune the processes. Focus will be on the process integration. The p-PERC client and machine vendors are responsible for the operation of their own equipment.

p-PERC Cell Validation
Towards the end of this activity, a validation experiment on a cell level will be carried out to assess the implementation of the p-PERC cell technology. The aim of this validation is to determine the efficiency target in the p-PERC cell technology on the specified wafer quality.

Activity 4. is closed when the final cell efficiency and yield FAT is signed.

Activity 5: p-PERC panel process

Expected timeline: 2 months

The panel manufacturing of p-type PERC cells will require an optimisation of material use and panel processing. To reach the panel power output and certification for a p-PERC module the following steps have been defined:

Option 1:
The panel equipment vendor guarantees power output and provides BoM testing. Provider is only required to give minor support consultancy and FAT review.

Option 2:

The panel equipment vendor does not guarantee power output and provides BoM testing and therefore provider delivers BoM testing, panel equipment start-up and FAT support to be able to guarantee power output of the panels.

OPTION 1:

Supplier discussions and negotiation support

When standard equipment of tabber-stringer, back-end equipment and laminator is available from selected suppliers, existing equipment has to be evaluated. Although equipment for general process steps is often widely available, some of the equipment has to be designed for certain specific processes. Instead of developing full equipment specifications, the process specifications will be discussed with (potential) interested suppliers so they can modify their equipment dedicated for the process. The equipment specifications set-up by the equipment supplier will be evaluated against the process specifications.

Know-how transfer and general consultancy

Transfer of the know-how on p-PERC panel manufacturing including recommended process settings has to be executed.

BoM set-up for panel and sourcing support

Materials for the manufacturing of the complete panel will be listed in the BoM. Applicable material will be specified ready for purchasing. Provider assists in delivering material vendor details and will support the sourcing. Purchasing and contracting with vendors is with the customer.

On-site support

The panel equipment supplier provides guarantee to the client. Support of the equipment supplier is only required during FAT. The FAT procedures will be monitored and pre-check should be executed.

On- site support has to be provided during start up until production. The support will focus on the core interconnection process and the auxiliary equipment.

Auxiliary equipment readiness for monitoring of panel process:

The flash testing equipment will be tuned for quality IV measurement on site where p-PERC modules will be manufactured. Calibration of the flash testers will be done with reference modules to standardize the IV measurements. Spectral response will be targeted following IEC measurement standards.

In order to analyse yield loss on the panel production mainly governed by the interconnection process of the cells a set-up for Electro Luminescence (EL) imaging has to be used. Provider will use the set-up to detect cracked cells in the finalized panel. Training will be provided for clients co-workers to operate the set-up in production.

Interconnection, in particular solder spot failure, will be verified by infrared imaging set-up (IR). Hot spots i.e. low quality solder spots are visible during IR scanning and are used for quality control. The IR scanning is mandatory during start- up of the tabber- stringer machines and for quality enhancement including monitoring during the production process. Training has to be provided for clients co-workers to operate the scanner in production.

The available laminators will be real time analysed regarding temperature time profiling. Calibrated test panels equipped with temperature sensors will be used during lamination cycles to optimise the settings of the laminators. Gel testing of the encapsulant supports the real time measurements. Providers support is available for process review during FAT.

OPTION 2

Compatibility of panel material and Incoming material control

With this option where the module equipment vendor does not provide guarantee power output and BoM testing a major input has to be delivered by the license & technology provider. Module material delivered by the different vendors demands testing. Most critical is the compatibility of encapsulant and back-sheet. Assuming that material is sourced from three vendors material tests have to be conducted based on small size panels. The small size panels comprise four solar cells. With three vendors for encapsulant and three for back- sheet a total of 36 small size panels have to be manufactured. The panels will contain p-PERC cells, back-sheet, encapsulant, stringing material, soldered interconnection, and the front side glass. Junction box and framing will not be applied.

The testing has to be conducted in climatic chambers such as damp heat (DH) for compatibility of the foil based material. In order to test the interconnection materials in combination with cell and foil material temperature cycling (TC) has to be done. The testing is based on the IEC61215 protocol for panel type approval and consists of 1000 hours of DH and 200 cycles TC.

Peel strength testing

Peel strength on coupons has to be conducted to test the bonding strength of the encapsulant on the back-sheet for all sourced foil materials.

Processing and compatibility testing

The approach for this part of the work would be to manufacture 4 cells panels, determine fill factor and perform climatic chamber testing.

The application and reliability of four small size-panels consisting of back-sheet foils, encapsulants and p-PERC cells with solder as interconnect will be tested. I/V flash test, EL and IR imaging have to be performed before and after climatic chamber testing. After climatic chamber testing modules will be opened and the interconnection between tab and cell will be inspected using microscopy. The results will be compared and compared with a reference interconnection at t=0 (initial stage).

Timeline for panel process

Timeline after contract approval and p-PERC cells available:

- 4 weeks for ordering materials
- 2 weeks for panel manufacturing
- 1 week for EL, IR and I/V characterisation after manufacturing
- 2 weeks for interconnect inspection after manufacturing (in parallel with DH and TC testing)
- 8 weeks for climatic chamber testing and I/V, EL and IR measurements after testing
- 2 weeks for panel inspection after climate chamber testing

Total throughput time: 15 weeks.

Full size panel manufacturing

If the material compatibility tested with small size-panels turns out to be successful, full size (60 cells) panels can be manufactured at the site of the tabber-stringer producer.

Timeline for full size panel manufacturing

- Ordering materials: 4 weeks
- Manufacturing full size panel: 1-2weeks (depending on amount of panels) in agreement with tabber-stringer producer

- I/V, EL and IR measurement of panels: 1 week

Total time for manufacturing full size panels: 5 weeks.

IEC testing at provider, customer or TUV depending on test equipment. Duration will take about 8 weeks.

On-site support

Duration of the on-site support will take three weeks of audit, process review and optimisation consultancy by two experts, including FAT support.

On- site support has to be provided during start up until production. The support will focus on the core interconnection process and the auxiliary equipment.

5.4 Summary specification of a 200 MW_p PV cell production factory and potential equipment suppliers

In the following table a listing is present regarding equipment needed for a solar cell manufacturing plant for a bifacial PERC cell production of 200 MWp/y. The list was provided by Schmid Group Germany.

Table 5: List of equipment needed for a needed for a solar cell manufacturing plant for a bifacial PERC cell production of 200 MWp/y

6600 mono PERC SE Bifacial	Turnkey Cell Line, 6.600 wafer/h	
Equipment Type	Equipment Description	Qty.
MLL BC RFID 1070	Multi Lane Loader with Breakage Control and RFID, 10 Lanes, 7000 wafers per hour	1
AL-TEX 6600	Alkaline horizontal wet process for wafer texturing with pretreatment, 10 Lane System, 6600 wafers per hour	1
L/UL twin HTF	Loading/Unloading twin HTF	2
POCl3	Horizontal Tube Furnace POCl3 Diffusion, 4 Tubes	4
SE Jet 2200	Inkjet system for masking, 2200 wafers per hour	3
SP-ETCH SE 6600 PERC	Single Side Edge Isolation with Selective Emitter Process and PSG Removal for PERC, 10 Lane System, 6600 wafers per hour	1
Alox deposition	Rear Side Passivation for Crystalline Silicon Solar Cells, 3400 wafers per hour	2
SiN deposition	Antireflective Coating Equipment for Crystalline Silicon Solar Cells, 3400 wafers per hour	2
Laser Opening 3300	Laser for Backside Opening, 3300 wafers per hour, with Loading and Unloading	2
SP Rearside 1	Screen Printing Line Rearside 1, 2 lanes, 3300 wafers per hour	2
SP Rearside 2	Screen Printing Line Rearside 2, 2 lanes, 3300 wafers per hour	2
SP Rearside 3	Screen Printing Line Rearside 3, 2 lanes, 3300 wafers per hour	2

6600 mono PERC SE Bifacial	Turnkey Cell Line, 6.600 wafer/h	
SP Frontside 1	Screen Printing Line Frontside 1, 2 lanes, 3300 wafers per hour	2
DF 3300	Drying Furnace for Screen Printing, 2 Lane System, 3300 wafers per hour	6
DFF 3300	Drying Firing Furnace for Screen Printing, 2 Lane System, 3300 wafers per hour	2
CS inline	Cell Sorter, inline	2
CL 536 BC RFID	Carrier Loader with Breakage Control and RFID, 5 Lane System	3
CU 536 BC GC RFID	Carrier Unloader with Gap Closing, Breakage Control and RFID, 5 Lane System	3
CL 1070 GC RFID	Carrier Loader with Gap Closing and RFID, 10 Lane System	1
CU 1070 BC GC RFID	Carrier Unloader with Gap Closing and RFID, 10 Lane System	2
CL 240 RFID	Carrier Loader for Screen Printing with RFID, 2 Lane System	2
TL	Tray Loader for PECVD	4
TU	Tray Unloader for PECVD	4
CFS	Carrier Factory Set	2
OFM	Offline Measurement Equipment Package Cell	1
OFC	Overall Factory Control System (MES)	1

In the following figure, we included a layout for a 200 MW_p/y cell factory for the manufacturing of mono type PERC+ (bifacial) solar cells.

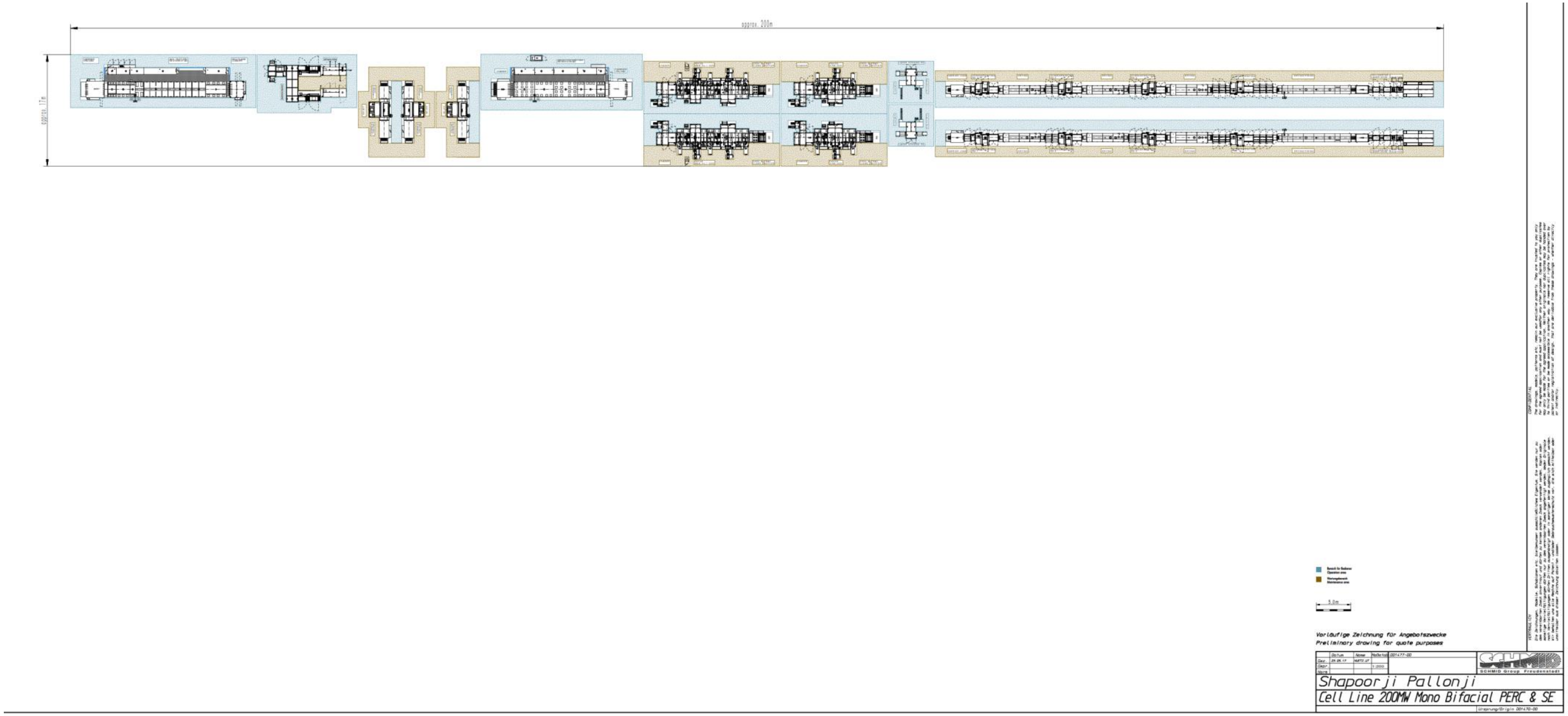
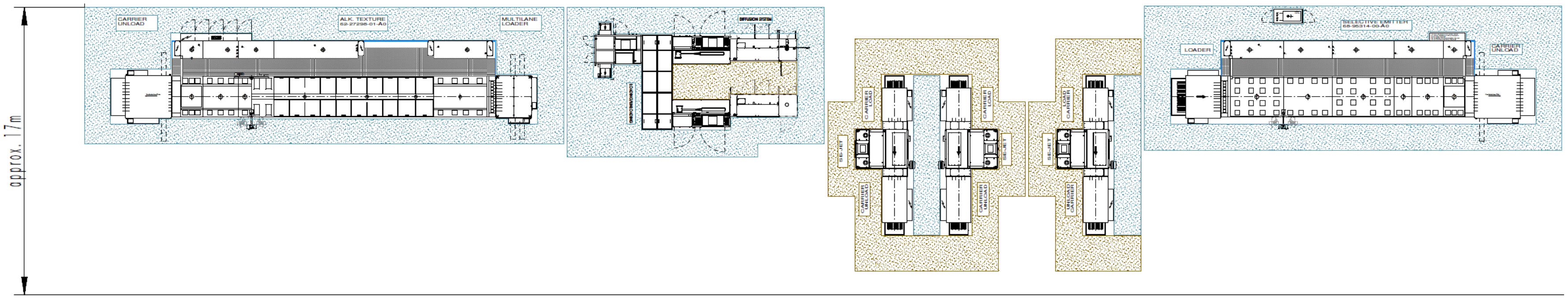


Figure 6: layout for a 200 MW_p/y cell factory for the manufacturing of mono type PERC+ (bifacial) solar cells


approx. 17m
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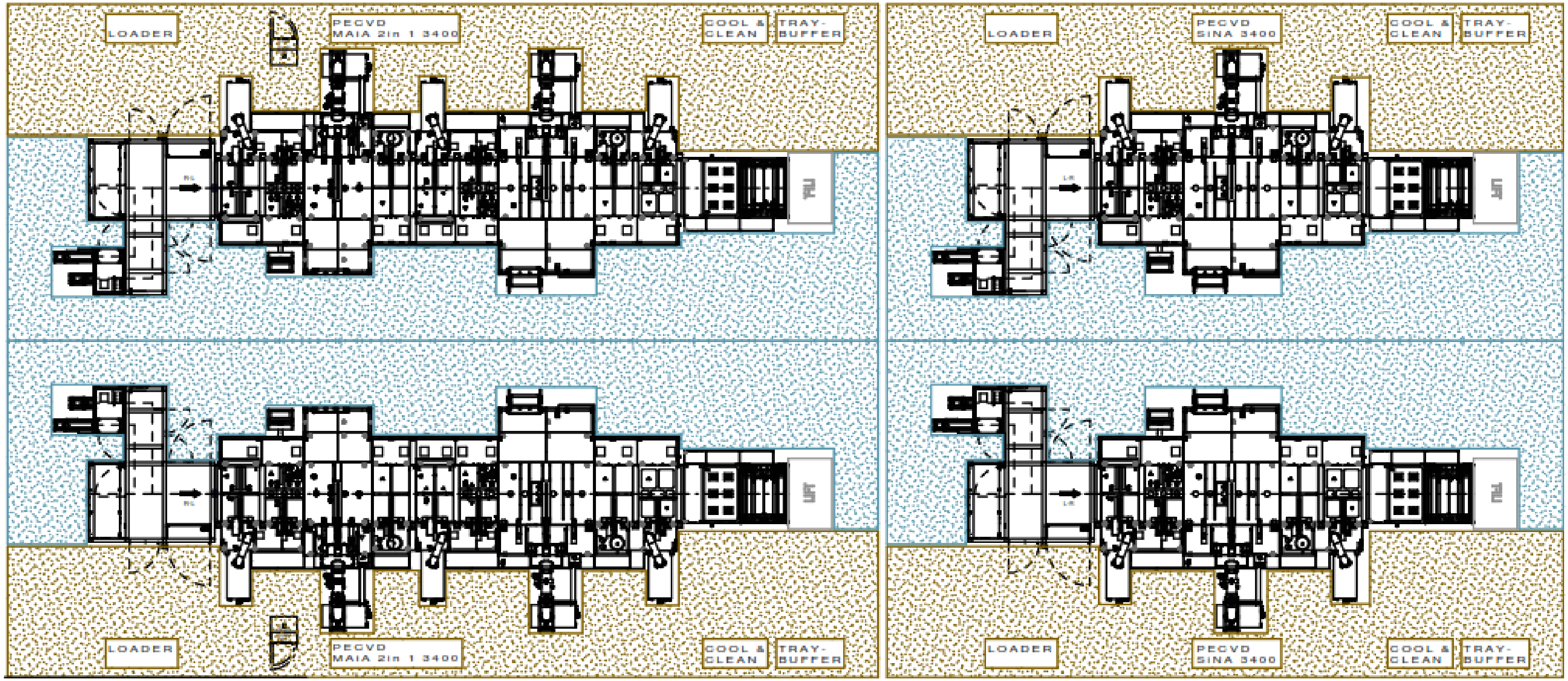
CARRIER UNLOAD


LOADER
PECVD
MAIA 2in 1 3400
COOL &
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TRAY-
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LOADER
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SINA 3400
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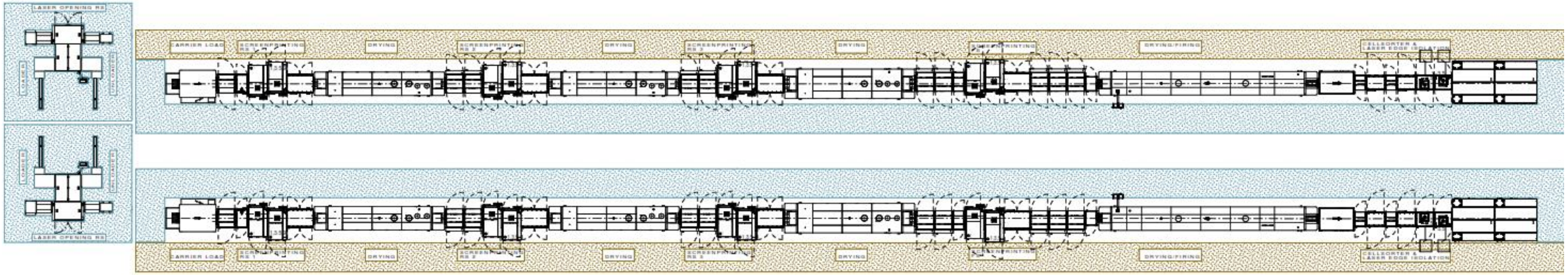
LASER OPENING RS
CARRIER LOAD
SCREENPRINTING RS 1
DRYING
SCREENPRINTING RS 2
DRYING
SCREENPRINTING RS 3
DRYING
SCREENPRINTING
DRYING/FIRING
CELLSORTER &
LASER EDGE ISOLATION

Potential equipment manufacturers are displayed In the following table.

Table 6: Potential equipment manufacturers

Potential supplier solar cell manufacturing equipment	Equipment
Schmid Group	wet chemistry, APCVD, furnace, module, turnkey, automation
Tempress	diffusion, PECVD, LPCVD, ALD, turnkey
Centrotherm	diffusion, PECVD, turnkey
Singulus	PECVD, wet chemistry, turnkey
Meyer Burger	PECVD, wafering, module, flash testing
RCT	turnkey
Baccini	printing
Dek	printing
Asys	printing
Rena	wet chemistry
Rofin	laser
Innolas	laser
3D Micromac	laser
Halm	cell characterisation
Potential suppliers list for PV panel manufacturing equipment	Equipment
Team technik	tabber stringer, lay up & back- end module line
Mondragon	tabber stringer, lay up & back- end module line
Ecoprogetti	tabber stringer
Bürkle	back- end module line
Meyer Burger	laminator
Bürkle	laminator
Eternalsun	flashtester
Meyer Burger	flashtester

In this table information is presented regarding characterisation tools for solar cell production and possible vendors.

Table 7: characterisation tools for solar cell production and possible vendors

Position in production line	Parameter to be measured	Measurement tool	Possible supplier
Incoming wafer	Thickness	Balance	
	Dopant concentration	Sinton lifetime tester	Sinton
	Lifetime	Micro- PCD	Perkin Elmer
	Oxygen content	FTIR	
	Carbon content	FTIR	

Position in production line	Parameter to be measured	Measurement tool	Possible supplier
	Structural Integrity	Stress tester	
Texture	Etch depth (weight loss) Reflection Concentration analysis Hydrophilicity	Precision balance Spectrophotometer Concentration analysis Goniometer (contact angle)	KERN or Satorius Metrohm
Doping + diffusion	Sheet resistivity	4 point probe	Sunlab
Single side etch	Etch depth	Precision balance	Kern or Satorius
Isolation	Edge isolation	Edge isolation tester	GP solar
Laser process	Surface condition + etch depth	x-y coordinate automatic microscope	Zeiss or Classic Optiv 321GL
PSG removal	Delta sheet resistivity	4 point probe	Sunlab
Passivation	Reflection minimum RI+thickness Bond densities Surface passivation	Spectrophotometer Elipsometer FTIR Sinton lifetime	 Sentech Perkin Elmer Sinton
Screen printing and firing	Screen quality Deposited weight Wet line height and width Fired line height and width Busbar to busbar resistance	Microscope Precision balance x-y coordinate automatic microscope x-y coordinate automatic microscope	 Kern or Satorius Zeiss or Classic Optiv 321GL Zeiss or Classic Optiv 321GL Sunlab
IV characteristics	Electronic properties solar cell Pseudo Fill Factor ((Sinton FF) Corescan IQE Photo luminescent Limolit shunt mapping	 Sinton Contact resistance Micro PCD or LBIC EL/PL	Neonsee Sinton Sunlab Corescan PV tools BT imaging

6

Applied Research Centre

Another important target of Iran's roadmap for renewable energy is to become the 1st in technology development in the region and 5th in production in Asia. To reach these goals, government policy for renewable energy implementation should be directed towards PV production by the private sector. Next to incentives and a long term production roadmap, it is recommended to support the private sector with an applied research center (ARC) for PV technology and applications. This research center should focus on applied research to support the local PV industry, and the research activities and topics should be guided by the industry. In addition the center should provide training facilities for operators, engineers and managers.

6.1 Innovation Vision and Structure

The vision for the ARC is to become the leading research center in the region for PV for the region with a focus of research that will support the local industry. The structure of the ARC needs to be supported by internationally leading PV research centers and an open collaboration is crucial. This will enable the ARC to quickly become operational as well as supportive of the industry.

Within the ARC, scientists from the University and research institutes will work together on a project basis. A core team of permanent staff will be responsible to maintain knowledge collection and keep it updated.

The facility should act as an open innovative platform for solar energy research to enhance technology innovation. Open innovation is anticipated where all participants benefit from intellectual property with clear IP rules. In addition, clear financial and non-financial benefits for the participating partners have to be formulated. Leading Universities and institutes will be invited to partner and form the ARC. Setup of a Masters and PhD program with a local University is foreseen and forms another educational component. In addition, a PV training center has to be established for employees of private entity manufacturers. The PV training center as part of the ARC is described in Section 6.5.

Focus of the PV research can be described as best of class solar cell & panels for Iran using wafer based silicon. On the manufacturing side topics are high efficiency and low cost concepts for crystalline silicon. In addition, testing and reliability including test fields and certification are anticipated. Adaptation to the local environment will be also a target regarding development for PV panels. With respect to PV deployment and applications R&D areas are solar farm utilities for residential, BIPV, storage, smart grid, electrical transportation and policy studies.

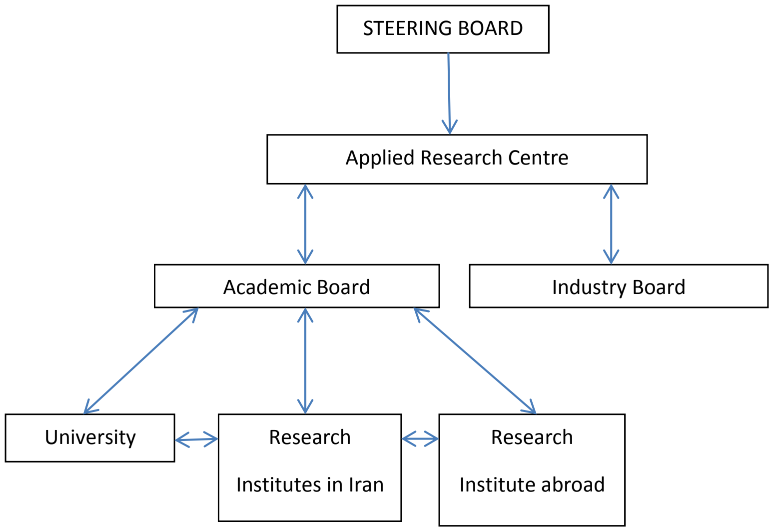

Figure 7: Governing structure of the applied research centre

6.2 Challenges and Solutions for Success

Joining partners have to see benefit by supporting the ARC. Therefore, co- developed IP should be available to partners through clear IP rules. In order to realise sharing of IP by the national and international partners, all employees are working on secondment to the ARC.

The ARC has a very wide scope. Special topics have to be identified for the initial phase and the long term. Focus during the launching phase should be on PV activities only. Storage and smart grid can be dispatched in a later stage.

To become operational quickly, a longer term financial support structure from the government is needed before the ARC becomes dependent on commercial orders.
It is important to involve the industry quickly and also have clear agreements with the industry on operational and financing. However, in the business plan, only a small contribution by industry can be expected. A clear commitment for government support is needed.

6.3 Governing structure

Management will comprise a steering board, academic board, and an Industry board implemented into the ARC (see figure 6).

Each partner has a seat in the steering board and all partners are responsible to appoint the director of the ARC. The long and short term research and development plan is the responsibility of the steering board. The researchers are coming from different institutes. Therefore, it is important that the managers of these institutes are well informed and involved in key operational and strategic decisions of the ARC. Regular meetings are advised with the steering board where each Institute is represented by one person.

The ARC will typically work on Technology Readiness Levels (TRL) levels between 3 (ideas) and 6 (ready for pilot production). Executing this work can demand research work at lower TRL levels. Therefore, it is important to have a good connection with various academic institutes that could take on the work at lower TRL levels. For this purpose an academic board would be beneficial with representatives from various academic institutes. They will advise on the strategy of the applied research institute and the board can then evaluate how this links with activities within the academic institutes.

Industry partners of the private PV manufacturing entities are forming the Industry board. Task of this board is to advise on R&D plans.

The R&D plan should reflect the capabilities of the employees and infrastructure and on the other hand, it should also match with future needs of the industry. That is the role of the industrial advisory board. This board has to advice the ARC about important industrial trends and how the ARC should position itself to follow these trends and remain attractive for the industry. The industrial customers of the applied research institute are the most important stakeholders.

The ARC will be organized around a number of research programs. Industrial customers can become a member of one or more of these research programs. In return for a (small) yearly fee these industrial customers receive all rights onto the research results that result from such a program. This can only work if these industrial customers are actively involved in the operations and the strategy of such a research program. That can be done by organizing technical program review meeting where (technical) representatives from all industrial customers are briefed on the latest results from the program. Besides these technical briefings, the ARC should also organize a program strategy review meeting. Here discussions will be held, with representatives from each industrial partner, focusing on the roadmap of the research program. These strategy review meetings give industrial customers the opportunity to steer and influence the content of the research programs such that it matches with the needs of the company.

In summary, all three boards have a direct link to the ARC where the R&D and operational plan is prepared and executed. The ARC has to report to the Steering board.

6.4 Financial and IP Arrangement

All partners in each peer group should be treated equal. Benefits have to be related to quality of the research and contribution done. In order to attract foreign scientists, special care should be taken regarding the remuneration.
Regarding IP arrangements, partner background IP is offered to the ARC on market conform conditions. The foreground IP is owned by the ARC. Partners will obtain license rights on the foreground IP in relation to their background IP.

Project planning for start-up ARC
Project planning to start-up the ARC will focus on 5 distinctive phases. In phase 1, a roadmap and long term R&D plan has to be established involving aim, activities, partners and equipment. Most importantly is to establish arrangements with international research institutes to form the core of the organization as a start.

Design aspects of the facility will be dealt with in phase 2 focusing on procedures, equipment and utilities.

In phase 3 the condition is on building facilities, solar cell production and lab equipment. Moreover, SAT, FAT and equipment start-up is part of this phase. Start of operation will be done in phase 4 where the procedures have to be implemented and reference processing has to be initiated.

Finally, in phase 5 research and development activities will be unfolded. This phase requires detailed research plans and execution. It is mandatory to have capable PhD level personnel hired at this point.

Projection of the complete start up time is set to be two years before the ARC is fully operational. Initial start- up and defined action plan of the ARC project will be followed by design of the facilities and agreed equipment specifications with a duration of six month. Finalizing the facilities should be realized in another 6 months. Drive in of the equipment will take 1 month. Another 3 months will be needed to get all equipment functional, as well as engineers and operators hired. Once this milestone is reached functional research teams should be ready to start in parallel the R&D activities. After that it can be expected that the first R&D based solar cells will be produced. In order to have a standard solar cell line running at competitive level another 3 month have to be invested. Stable baseline R&D processing will take the final 5 month.

Capital investment needed for the ARC are estimated to about 100 million Euro including 10 million Euro for the facilities, 20 million Euro for equipment and 10 million Euro for start- up costs. In the first year only start- up costs are considered. For the second year costs are estimated to 10 million Euro for first running projects and the remunerations of the scientists and personnel. Full-scale running projects in the third year need an investment of 20 million Euro.

In a five year time frame foreseen are 90 scientists, technicians, engineers and operators working at the ARC and 10 scientists and engineers from a foreign based research institute. All together the costs for the 100 scientists are at about 20 million Euro during mentioned time period. Moreover, material costs and depreciation costs are set to 5 million Euro. Overall margin is estimated to 5%.

Technology development

Main activities regarding development for solar cells and panel production is phased into proof of manufacturing for Iran producers. Followed by upscaling of new technologies, testing of new materials and equipment and also testing of locally produced materials needed for the production.

On the research side the program will follow the credo of choosing the right technologies for PV and the Iranian industry by proof of Concepts and other inventions. Functionality of the concept, tuning of equipment, processes and material choices will be taken into account.

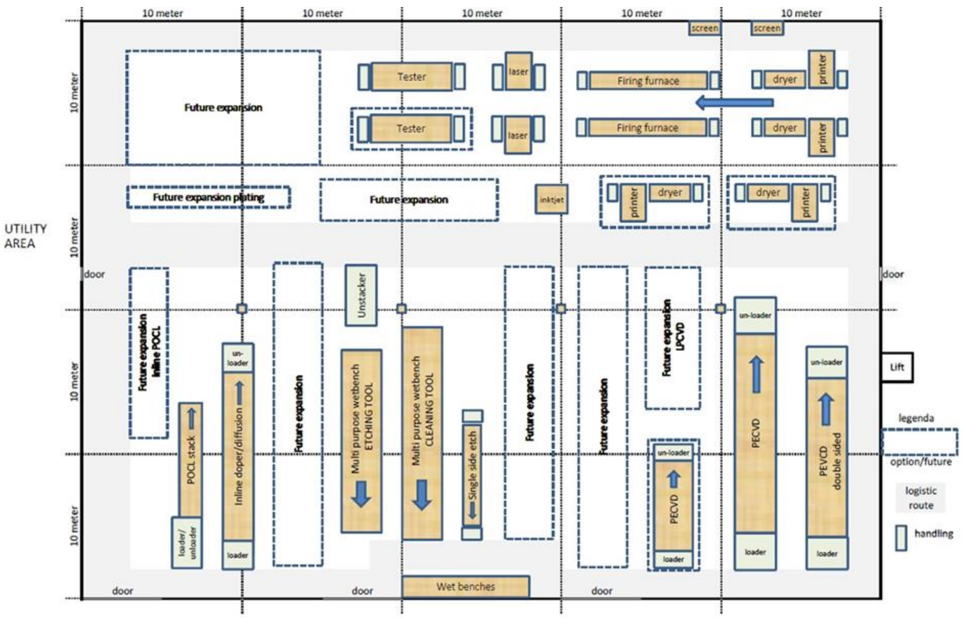

Figure 8: Proposed Floorplan for PV cell laboratory

6.5 PV Training Center as part of the ARC

The courses to be offered by the PV training Center consist of practical and theoretical training modules for operators, engineers and managers working in the silicon photo-voltaic industry. Training will take place on a state-of-the-art pilot production line with industry-compatible equipment. New employees can be trained in a representative practical production situation without the high costs of disturbing the regular production process.

The market size of training requirements of in particular training for the higher educated process engineers has to be estimated for the Iranian situation depending on the expected production capacity increase in the coming four years. As a (conservative) rule of thumb 0.16 process engineer per MW production are working currently in the industry.

Applying a similar metric to operators would lead to training demand of 1 operator per MW production capacity, including production in multiple shifts.

Part of the operator training demand may be addressed by offering short courses in safety and maintenance next to process control and operation.

The training should comprise the following training products:

- 1 month intensive training for engineers: extensive theory, design of experiments,
- Performing experiments and cell quality analysis
- Solar manufacturing managers training (short 2-day course)
- 5 day practical and theoretical introductory course.
- Specific courses in maintenance, safety and other specific subjects (5 day courses).
- Solar cell Technology Masterclasses.

Optional commercial activities:

- Training of process engineers and making them available on a temporary Interim basis to solar cell manufacturers.
- Complete pilot rental line for dedicated activities of research organizations
- In-company training to single solar cell manufacturers, that hire the complete line (e.g. for competitive reasons).
- Creation of franchises of the PV training activities to other countries, delivering the curriculum and training know how (longer term).
- Integration of short term operator training.
- Organization of theoretical training in sustainable energy markets and technologies for solar company management and services suppliers.
- Development of virtual production training programs.

Expected staff to operate the PV training Center:

- 2 professional teachers (PV theory, free- lance) hired in tune with course development.
- 4 pilot line engineers (for practical teaching and maintenance).
- 1 professional teacher (Design of Experiments, freelance).
- 1 office assistant resp. for planning and scheduling.
- Bookkeeping and accountancy: outsourced.

7

Long-term impacts of the assistance

7.1 Expected climate benefits

There will not be any short term direct climate benefits of this assistance due to its scope and limited size. However, it lays the groundwork for increased awareness and capacity for solar PV technology and domestic manufacturing benefits. In this sense, it has the potential to contribute to substantial GHG mitigation benefits in the longer term should ongoing assistance be secured and the government of Iran continues to promote domestic solar PV production and use.

7.2 Co-benefits

The CTCN assistance will contribute to the following medium and long-term benefits in Iran, if it would end in the development of PV technology and related market introduction:

- Considerable annual energy savings, compared to conventional generation of power for the household and commercial sectors;
- Reduction of transmission losses, CO_2 emissions, NO_x emissions, and energy demand during peak usage;
- Expected huge annual opportunity cost for the government; Potential market share of the technology in the region;
- Creation of jobs in the industry.

7.3 Post-assistance plans and actions

The core objective of this assistance, beyond raising awareness and understanding of solar cell manufacturing technologies and benefits, is to prepare a detailed funding proposal together with a private entity in Iran that is willing to launch PV production for longer term support to the Iranian solar industry. The proposal would be based on recommendations for preliminary design with emphasis on local PV industry and a specific pilot-scale PV cell manufacturing plant and financial analysis. In this sense, post-assistance planning is built into the short term response.

8

Recommendations and follow-up

The following steps have to be taken before concrete implementation of a solar cell and panel manufacturing can be decided:

1. Establish a high level solar industry development roadmap.
2. Develop associated market development plan.
3. Prepare supply chain development plan.
4. Prepare a concrete project plan to start a solar industry from the current situation.
5. Prepare a human capital development plan.

1. *Iran solar industry development roadmap:*

This roadmap should contain the following elements:

- strategic vision for the solar development in Iran
- targets for solar PV implementation
- LCOE price targets that can be offered based on the proposed manufacturing facility
- targets for local production & manufacturing job numbers,
- supply chain
- technology targets regarding cell/panel efficiency and Cost of ownership (CoO)

We advise to do this for a shorter term scale (2025) and a longer time scale (2040), and to do this for each individual market segment (private, commercial, public, as well as on-grid and off-grid), including incentive schemes for each individual market segment.

2. *Concrete PV market development plan:*

This plan should contain the following elements to be successful:

- concrete actions to implement the overall strategic vision to lead to the agreed targets
- These actions are: establish legal framework and establish the public organizational framework.

3. *Supply chain & manufacturing development plan:*

   This plan focuses on how the targets on local production and manufacturing for PV cells and panels can be achieved from very little local production initially to the proposed target of local production. A material and component take- off has to be analyzed what it entails to supply it from abroad and how to manufacture it local by including a detailed cost benefit analysis. This has to be done in first place for 2025. Therefore, a supply chain plan has to be developed. For instance, the local manufacturing of 200 MWp/y of solar cells and modules has to be fully analyzed before any investment is done. This involves definition of major elements, like wafer supply, but also small elements, like spare parts for all the equipment items.

4. Human capital development plan

This plan is aimed to provide well educated personnel as well as know-how to the Iran solar industry. The contents of the plan should cover:

i) Establishment of the applied research center, academic infrastructure, including PV laboratories & PV pilot line & test infrastructure for residential, on-grid, off-grid, as well as commercial infrastructure and test fields.
   a. Define infrastructures.
   b. Specify detailed parameters.
   c. Make an investment plan & get approval.
   d. Detail a Request for Quotations for infrastructures.
   e. Build infrastructures.
ii) Academic and engineering curriculum for PV manufacturing as well as PV application.
iii) Establish a research alignment between Iran and international research community.
iv) Start-up human capital development with a training program.
   a. Training of engineers and academics at international institutes.
   b. Training at new Iran's infrastructure by international specialists.
v) Run program and train new engineering and academics specialists.
vi) Defining costs of the human development plan.

5. Concrete project plan

a. A stepwise approach from 1. to 4. (see above) regarding the current situation towards the envisioned state of the solar industry in Iran.
b. Stepwise approached linked together with the associated investment figures.

Appendix A. Stakeholder Interview questions

The following document will serve as a guide for the interviews and data gathering for the first stage of the CTCN Iran Assessment from July 15-July 25.

Vision for Iran

1. Where do you see the Iranian PV community today? In 2020? In 2030?
2. How will the Iran PV community and industry contribute to the global industry and community?
3. What is the potential market opportunity in PV in Iran? At what point in the value chain?
4. Is the predominant applications market utility scale, commercial scale, or residential/distributed power?

Current Status

5. What is the current status of PV in Iran?
6. Who are the key players and stake holders in the industry?

Your Company/Institute

7. What role do you/your company play in the energy industry in Iran?
8. What are your interests in PV? What kind of product/service/research are interested in providing/contributing to the community?
9. What are you key competencies? What makes your company unique in Iran? In the global market?
10. How do you envision you/your company role in PV today? In 2020? In 2030?

Government

11. What is the government role in the current energy industry?
12. What is the government policy to stimulate and support PV research and private entities in the long run?
13. Do you know of any government sources and programs to draw subsidies for research? For manufacturing? For installation?
14. What is unique about the government/industry interaction in Iran?
15. How can the government either support or disturb the PV industry?

International Interactions

16. What is you/your company understanding and knowledge of the global PV industry?
17. What kind of interactions do you/your company/institute have with the international PV community?
18. In your opinion, what kinds of international relationships are missing?

Resources

19. What resources, government or private, do you have access to for PV?
20. Who are the possible investors for the long term (private equity, banks, etc.) for research? For manufacturing? For installation?
21. What key resources are missing for further expansion?
22. What raw materials does Iran currently have that might play a role in the PV value chain?
23. What is the cost of capital in Iran?

Education

24. How would you assess high tech education and availability of highly trained specialists?
25. What is the state of the materials and semiconductor research communities?
26. Which universities/institutes do you think of for high tech education?
27. What is the current understanding and opinion of the general population of PV and solar?
28. What are the current beliefs and understanding of global climate change?
29. What other renewable energies are popular or widely deployed?

Appendix B. Material list & local producers

Material Name	Unit	production in Iran	Producer name
BBr_3 [toxic]	kg	no	
PH_3 pure [toxic]	g	no	
N_2O [toxic]	liter	no	
SiH_4 [toxic]	g	no	
CF_4	kg	yes	
$POCl_3$ [toxic]	kg	no	
Rena mTex (or other texture solution)	liter	no	
Ag	g	yes	
Ar	m3	yes	Shiraz Petrochemical/ Fajr Petrochemical
comp. dry air (CDA)	m3	yes	novin Petrochemical/Fajr Petrochemical
conductive adhesive for module	g	yes	
cooling water (cH_2O)	liter	yes	
DI water (D-H_2O)	liter	yes	
He	m3	yes	Novin Petrochemical
HF (49%)	liter	no	
KOH (50%)	liter	no	
H_2O_2 (50%)	liter	no	

Material Name	Unit	production in Iran	Producer name
H_2SO_4(30%)	liter	yes	Razi Petrochemical/ Orumiyeh Petrochemical
HNO_3	liter	yes	Shiraz Petrochemical/ Karoon Petrochemical
HCl (30%)	liter	yes	Karoon Petrochemical/Shiraz Petchem
N_2 (m3)	m3	yes	Isfahan Petchem/Mobin Petchem/Fajr Petchem
NH_4OH(24.5%)	liter	yes	
NH_3	liter	yes	khorasan Petchem/Shiraz Petchem/Razi Petchem/Pardis Petchem
O_2	m3	yes	novin Petrochemical/Fajr Petrochemical
solar grade glass		yes	Balon Sanat Co.
EVA(Vinyl acetate/Vinyl alcohol/Ethylene Vinyl Acetate)		yes	Arak Petrochemical [vinyl acetate]/ Fara Polymer Shimi/پتروشیمی استهبان
tabbing			
stringing			

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