Developing Indigenous Solar Energy Industry in Saudi Arabia: Present Situation and Future Issues

サウジアラビアにおけるソーラーエネルギー産業育成：現状と今後の課題

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要　約

サウジアラビアは世界最大の石油輸出国であり、1日990万バレル以上を生産している。ただしサウジアラビアの国内石油消費量は、ドイツ、フランス、イギリスなどの工業国を上回るレベルにある。さらに人口と経済の高い成長率から、サウジアラビアの電力消費量は2010年の43GW（ギガワット）が2030年には120GWに増加することが見込まれている。サウジ国内の電力需要を化石燃料で満たす現状がこのまま続けば、国際市場に対するサウジの石油供給能力と国際社会におけるサウジアラビアの戦略的能力にマイナスの影響が及ぶ。こうした状況に対しサウジ政府は2010年にアブドゥッラー国王原子力・再生可能エネルギー都市（KACARE）を設立し、経済力と政治力を維持するため、既存の化石エネルギーミックスにソーラーエネルギーと原子力を中心とする再生可能エネルギーを加える努力を行っている。サウジのソーラーエネルギー分野は可能性を秘めているものの、サウジの技術革新能力に頼るのでは国内のソーラーエネルギー産業の発展には様々な困難があるものだと考えられる。

本稿は、サウジアラビアにおけるソーラーエネルギー産業の育成について現状と今後の課題を取り上げた。具体的には、サウジアラビア国内におけるエネルギー需要増加の背景とソーラーエネルギー分野の可能性を考察する。その上でソーラーエネルギー分野におけるサウジの技術革新能力の現況を、過去のソーラーエネルギー研究開発プロジェクトを振り返り、S&Tインディケーターの国際比較を行うことで明らかにする。次に、サウジアラビアのソーラーエネルギー分野における今後の課題を、政府、産業界、学術界の取り組みを考察することで明らかにする。最後に、サウジアラビアにおけるソーラーエネルギー産業の発展について結論を示すこととする。

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ABSTRACT

Saudi Arabia is well known as having the world's biggest oil reserves with more than 20% of the total. It is in the same time the largest oil producer that is pumping out more than 9.9 million barrels a day, enough to generate 16.262 TWh of electricity. However, Saudi Arabia has another face as an energy consuming country. It is ranked 10th in the world in terms of oil consumption where almost 10% of the daily oil production in Saudi Arabia is used for domestic consumption which is more than that in industrialized countries such as France, Italy and the United Kingdom. Moreover, Saudi is ranked 4th internationally in terms of natural gas reserves and ranked 9th in the world in terms of natural gas consumption. Indeed, Saudi Arabia does not export natural gas and consumes all the locally produced natural gas. As the Saudi petrochemical industry develops, the needs for natural gas might rise and there is a possibility that Saudi Arabia might become a natural gas importing country. Furthermore, the increase of local energy consumption in Saudi Arabia is expected based on the high growth rates population as well as economy. It is estimated that the electricity consumption in Saudi Arabia will grow from 43 GW (giga watt) in 2010 to 120 GW in 2030 which means that the local consumption of fossil fuel will rise from 3.4 MBOE/D (Million Barrels of Oil Equivalent per Day) to 8.3 MBOE/D. If Saudi government maintained the present situation of supplying local for energy by fossil fuels, that might be reflected negatively on oil international markets as well as the strategic power of Saudi Arabia in the international society.

This paper aims to spot the light on the current situation and the future prospects with regard to the development of indigenous innovation capability in the field of solar energy in Saudi Arabia.

1. Introduction

Saudi Arabia is well known as the largest oil exporter in the world; the country produces more than 9.9 million barrels a day. Nevertheless, Saudi domestic oil consumption exceeds the level of a number of industrialized countries. Furthermore, based on the high growth rates of population as well as the economy, it is estimated that the electricity consumption in Saudi Arabia will grow from 43 GW (gigawatt) in 2010 to 120 GW in 2030. If the present situation of supplying Saudi local needs for energy consumption by fossil fuels continues, it will negatively impact the capacity of Saudi Arabia to supply oil to international markets as well as the strategic power of Saudi Arabia in international society. In this respect, by establishing the King Abdullah City for Atomic and Renewable Energy (KACARE) in 2010, the Saudi government attempted to add the variables of renewable energy, especially solar and nuclear energy, to the existing variable of fossil energy to maintain its economic and political powers. While Saudi has potential in the field of solar energy, there seems to be various challenges for developing national solar energy industries by relying on the Saudi indigenous innovation capabilities.

This paper aims to highlight the current situation and the future issues with regard to the development of indigenous solar energy industries in Saudi Arabia. In particular, the background of growing local demand for energy consumption in Saudi Arabia and potential in the field of solar energy in Saudi Arabia are discussed. This paper then presents the situation of the solar energy sector in Saudi Arabia. Future issues for developing an indigenous solar energy industry in Saudi Arabia are clarified by discussing the challenges in the industry and academia sectors. Furthermore, the case study of Solar Frontier is discussed in order to examine the possibilities of building national solar industries in Saudi Arabia through joint ventures with high technology foreign firm. Finally, the conclusion is presented.

2. Background of the Growing Local Energy Consumption

Saudi Arabia has the world's biggest oil reserves with more than 20% of total reserves. At the same time, the largest oil producer is pumping out more than 9.9 million barrels a day that is enough to generate 16.262 TWh of electricity. However, Saudi Arabia has another role as an energy-consuming country. As illustrated in table 2-1, Saudi Arabia is ranked sixth in the world in terms of oil consumption; 2.643 million barrels of oil are used daily for Saudi domestic consumption, which is more than the consumption in a number of industrialized countries and leading developing countries such as Germany and South Korea. Moreover, Saudi is ranked fourth internationally in terms of natural gas reserves and ranked eighth in the world in terms of natural gas consumption. Moreover, as illustrated in table 2-1, 83,940 million cubic meters of natural gas are consumed locally in Saudi Arabia. Saudi Arabia does not export natural gas and consumes locally all of the produced natural gas. As the Saudi petrochemical industry develops and local demand for power generation progresses, the domestic need for natural gas consumption will grow. In this respect, Saudi Arabia raised its gas production to 10.7 billion cubic feet per day in 2011 and plans to raise its production capacity of gas to 16 billion cubic feet per day by 2020 to reduce the consumption of oil in the Saudi local market [Alarabiya 2012]. Nevertheless, it is reported that a number of LNG global producers expect Saudi Arabia to become a gas importer in the next few years; the gas supply gap in Saudi Arabia is estimated to be 2 billion cubic feet per day by the end of the decade, possibly as early as 2017 [Dourian and Carlisle 2011].

Table 2-1: World Top 10 Countries in Terms of Oil Consumption and Natural Gas Consumption Based on the Estimated Data of 2010

Oil Consumption
Unit: Barrels Per Day (bbl/day)

Rank	Country	(bbl/day)
1	United States	19,150,000
2	China	9,057,000
3	Japan	4,452,000
4	India	3,182,000
5	Brazil	2,654,000
6	Saudi Arabia	2,643,000
7	Germany	2,495,000
8	Korea, South	2,251,000
9	Canada	2,209,000
10	Russia	2,199,000

Natural Gas Consumption
Unit: Million Cubic Meters

Rank	Country	Million (cu m)
1	United States	683,300
2	Russia	414,100
3	Iran	137,500
4	China	109,000
5	Japan	100,300
6	Germany	99,500
7	United Kingdom	94,280
8	Saudi Arabia	83,940
9	Italy	82,980
10	Canada	82,480

Source: [CIA 2012]

As shown in figure 2-1, the total energy use in Saudi Arabia grew from 7358.1 kilo tons of oil equivalent in 1971 to 157854.7 kilo tons of oil equivalent in 2009. Moreover, according to King Abdullah City for Atomic and Renewable Energy (KACARE), it is estimated that the electricity consumption in Saudi Arabia will grow from 43 GW / Y in 2010 to 120 GW / Y in 2030. As shown in figure 2-2, the local consumption of fossil fuel will rise from 3.4 MBOE/D (Million Barrels of Oil Equivalent per Day) to 8.3 MBOE/D if the Saudi government maintains its present policy of supplying local market needs for energy by relying on fossil fuels [Babelli 2011].

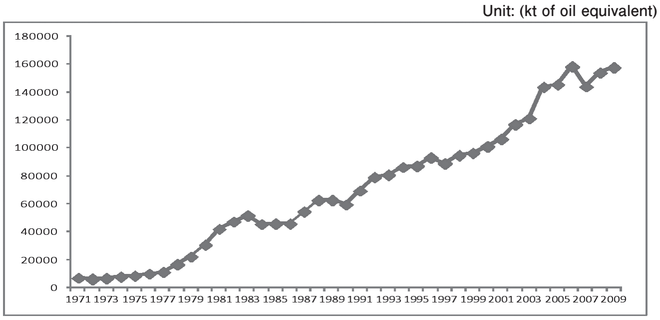

Figure 2-1: The Development of Total Energy Use in Saudi Arabia between 1971 and 2009

Source: International Energy Agency (IEA)

By looking at the data of the Ninth Development Plan in Saudi Arabia, which is illustrated in table 2-2, it appears that domestic consumption of primary energy is expected to rise from about 3 million barrels per day in 2009 to about 4 million barrels per day in 2014 based on an average annual growth rate of 6.5% with a forecast average annual growth of GDP of about 5.2% over the same period [MOEP 2010: p. 522]. It should be noted that fossil fuels, including refined products, oil, and natural gas, accounted for 100% of total local consumption in Saudi Arabia between 2009 and 2014 according to the Ninth Development Plan (the Plan), which was mentioned in table 2-2. However, the Plan in its policies for electricity sector included developing the use of solar and wind energy for electricity production as well as the use of nuclear energy for electricity production, water desalination, and other peaceful uses [MOEP 2010: p. 594]. By looking at the percentage of electricity consumption in Saudi Arabia by sectors in 2007, 52.9% of the total electricity consumption was in the residential sector. The industrial sector came second with 18.1%. These facts have led to the forecast of increasing energy consumption in Saudi in the next few years because of the high growth rate of the Saudi population as well as the rising number of factories and industrial units.

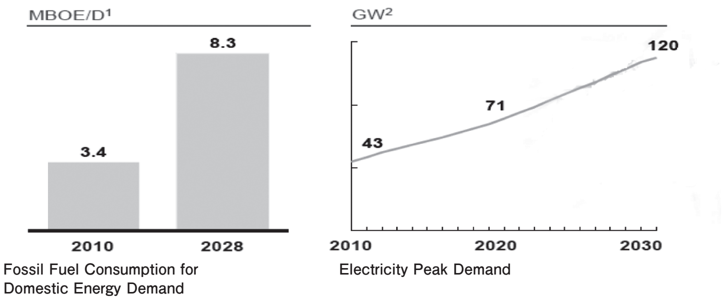

Figure 2-2: The Future Expected Demand for Energy in Saudi Arabia

Source: [Babelli 2011]

(1)MBOE / D = Million barrels of oil equivalent per day.

(2)GW = gigawatt (Power generation capacity)

(3)Corresponding annual electricity demands: 240 TWh in 2010, 400 TWh in 2020, 640TWh in 2030.TWh = terawatt hour

Table 2-2: Domestic Energy Consumption According to Ninth Development Plan in Saudi Arabia

(Thousand barrels per day)

Year	Refined Products		Crude Oil for Direct Use		Natural Gas (Fuel only)		Total Consumption
	Quantity	Share (%)	Quantity	Share (%)	Quantity	Share (%)	
2009	1667.4	56.1	363.1	12.2	942.1	31.7	2972.6
2010	1827.4	56.8	403.0	12.5	988.5	30.7	3218.9
2011	1986.4	55.2	540.7	15.0	1075.0	29.8	3602.1
2012	2110.0	54.9	569.9	14.9	1161.1	30.2	3841.0
2013	2191.7	55.5	583.3	14.8	1171.5	29.7	3946.5
2014	2269.5	55.6	624.5	15.3	1186.8	29.1	4080.8
Average Annual Growth Rate under the Plan (%)	6.4		11.5		4.7		6.5

Source: Ministry of Petroleum and Mineral Resources.
Quoted from [MOEP 2010]

The population growth rate in Saudi Arabia between 2004 and 2008 exceeded 24%. Furthermore, forecast population growth in Saudi Arabia until 2020 is more than 35 million [Balghunaim 2002]. Moreover, the number of factories in Saudi Arabia grew by more than 60% between 1994 and 2004 [MOCI 2003; 2005]. The initiatives of establishing industrial cities and supporting industrial clusters in addition to the economic cities development plans around the country would be factors that indicate more needs for energy consumption in the Saudi industrial cluster in the future. Furthermore, with Saudi Arabia's population expanding by 2.3% and its economy growing by 5% to 6% annually, the country's demand for electricity is increasing by 5% a year. Another factor is the high growth of water desalination sector, which mainly relies on hydrocarbon resources for generating power in the desalination units, which requires large amounts of electricity. Saudi Arabia produces 24% of the world's desalinated water, which is mainly for human consumption in addition to agriculture and industry. Moreover, it is reported that the water demand in Saudi Arabia is rising by 3.3% a year [IC 2012].

3. Saudi Potentiality in the Field of Solar Energy

The earth receives approximately 274 million gigawatt / year of solar energy [EcoWorld Magazine 2006]. According to Stanford University's Global Climate and Energy Project, the amount of solar energy that reaches the Earth's surface in 1 year is about twice the energy that will ever be obtained from oil, natural gas, coal, and mined uranium combined [IC 2012]. Furthermore, a number of scholars argue that 1 hour of solar energy absorbed by the Earth's atmosphere, oceans, and land masses equals the Annual Energy Consumption of the World based on 2002 data [Morton 2006; Nathan and Daniel 2006]. On the world level, as illustrated in figure 3-1, the growth of renewable energy production (e.g., solar, geothermal, and wind) grew from 6.13 million tons of oil equivalents (Mtoe) in 1973 to 101.42 Mtoe in 2009. Moreover, renewable energy is expected to account for 11.8% of the total energy generation in the year 2035; total energy regeneration in 2035 is expected to reach 18,048 Mtoe [IEA 2011, pp: 36-37]. In this respect, according to Renewable Energy Scenario to 2040 by the European Renewable Energy Council, the world's total power generation from renewable energy is expected to reach 36,346 TWh while solar energy (PV) is expected to form 25% of the total generated power by renewable energy with 9,113 TWh [Katayama 2011]. To meet the growing needs for local energy consumption and maintain its energy security, several countries have started to invest in the solar energy sector as well as other renewable energy sectors and promote the industries in this field. Countries that are geographically located closer to the equator have more potential solar energy available. As illustrated in the world solar radiation map in figure 3-2, Saudi Arabia is located in one of the most prolific regions in terms of solar radiation; Saudi Arabia receives an average of 2,500 kWh/m2 every year in comparison to an average of 1,500 kWh/m2 every year in Japan. Saudi Arabia has twice the average solar irradiation in Europe, which has thermal energy of up to 2,550 KWh/m2 a year. As a result, the low cost for generating power from solar energy in Saudi Arabia seems to be a competitive advantage for the Kingdom in comparison to other highly advanced countries in this sector (e.g., Spain). Furthermore, according to reliable forecasts, Saudi Arabia could produce in excess of 1 Gigawatt more than all European Solar Power combined within a relatively short period [Boyes 2009]. Moreover, Saudi Arabia extends over a huge area that covers 2,149,690 km2, which makes it the largest country in the Middle East region. Many remote villages and settlements can benefit from renewable energy applications. Saudi Arabia has a long history with solar power for small projects such as a 1980s "Solar Village" program to develop the use of the renewable energy technology in remote regions.

In addition, figure 3-3 shows the theoretical annual solar energy production in Saudi Arabia and selected countries. The value was 125,000 TWh in Saudi Arabia; in the United States, the value was 64,000. In India and China, the value was 20,000 ; in Spain, the value was 1,600. Even in other Arab countries in the Middle East region, the value was lower than Saudi Arabia. In Egypt, the value was 74,000, and in UAE the value was 2,000. It is reported that Saudi oil is expected to last for about 80 years at current production rates; Ali al-Naimi, the Saudi Arabian Oil Minister, stated that Saudi Arabia intends to become "the world's largest exporter of clean electric energy produced from our abundant sunlight" [Patel 2009].

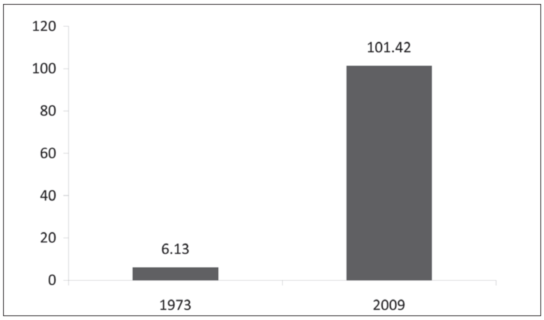

Figure 3-1: The Growth of Renewable Energy (geothermal, solar, and wind.) Production in the World between 1973 and 2009

Source: (IEA 2011, pp. 36-37)

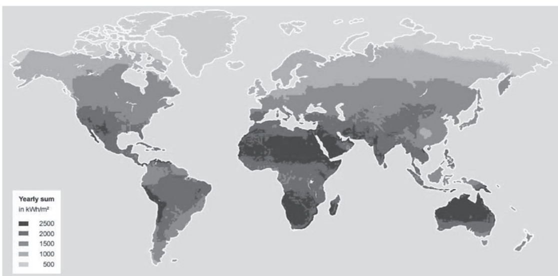

Figure 3-2: The World Sun Radiation Map

Source: Climate data/Insolation data based on the values of meteonorm

(www.meteonorm.com)

As presented in the previous section, Saudi Arabia is experiencing increasing growth with high rates of demand for energy consumption coupled with an increasing demand for the non-renewable hydrocarbon resources (e.g., oil and natural gas) to be used in generating power. Therefore, the use of alternative sustainable resources (e.g., solar energy) for generating power and producing desalinated water seems to be beneficial for Saudi Arabia in economic and political terms. In this respect, by establishing the King Abdullah City for Atomic and Renewable Energy (KACARE) in 2010, the Saudi government is attempting to add the variables of renewable energy (especially solar) and nuclear energy to the existing variable of fossil energy. Alawaji mentions that renewable energy sources are essentially considered as providing support to the Kingdom's view to use the fossil energy resources more wisely for the development of other products more beneficial and useful (e.g., petro-chemicals) rather than consuming them [Alawaji 2001].

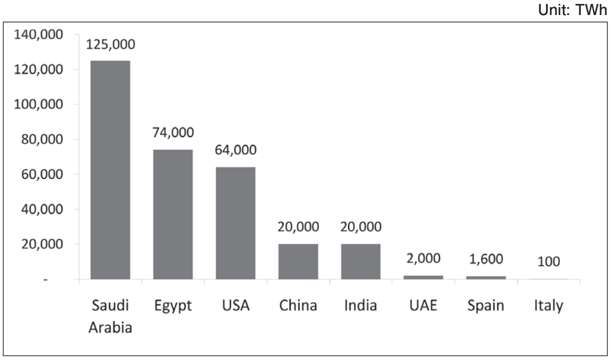

Figure 3-2: Theoretical Annual Solar Energy Production in Saudi Arabia and Selected Countries
Source: Industrial Clusters
http://www.ic.gov.sa/en/industrial-clusters/solar-energy-cluster/ (Accessed 2012.2.26)

4. Present Situation of Saudi Innovation System in Solar Energy

This section highlights the present situation of the solar energy sector in Saudi Arabia. In particular, R&D Institutions and S&T Indicators are presented and discussed.

4.1. Solar Energy R&D Institutions

In this subsection, the leading Saudi R&D institutions in the fields of the solar energy are introduced. Mainly, this paper spotlights the King Abdul Aziz City for Science and Technology (KACST) as well as the related research centers and colleges in Saudi universities.

(a) King Abdul-Aziz City for Science & Technology (KACST)

King Abdul-Aziz City for Science and Technology (KACST) was established in 1977 in Riyadh. KACST is one of the oldest and strongest R&D institutions in Saudi Arabia. One of the R&D institutions in KACST is the Energy Research Institute, which aims to transfer and develop energy-related technologies appropriate to the needs and requirements of Saudi Arabia. One of the achievements of the KACST is the solar village, which was built in 1980 as a result of technical cooperation with the United States in the field of solar energy utilization in remote regions. The solar village project for remote electrification with a 350 KW photovoltaic power unit provided electricity for three villages. The project became the first solar energy research station at both local and regional levels. Various research has been accomplished at the KACST such as the cost of solar energy generated using PV panels, wind resource assessment of eastern coastal region of Saudi Arabia, as well as air and sea pollution measurements in addition to a solar-hydrogen energy system for Saudi Arabia. Indeed, KACST executed a number of solar energy projects in both forms (i.e., photovoltaic and thermal) during the past three decades [Alaglan 2010]. One of the applied projects is lighting tunnels using solar energy in the Asir Province in cooperation with the Ministry of Transport. Another project is pumping and desalinating water in Sadowss Town using the solar energy and Reverse Osmosis technology in addition to using solar energy to dry agricultural harvest dates as well as the project of producing electricity using the heat of the sun. Recently, KACST built the largest water desalination plant in the world in Khafji city. The plant has a production capacity of 30,000 cubic meters per day through a solar plant for producing solar energy with the capacity of 10 megawatt and membranes of Reverse Osmosis. IBM Corporation is the technological partner of KACST to develop solar cells with a high concentration level and reduce the temperature of the cell to increase its efficiency to suit the climate of the Kingdom.

(b) Solar & Photovoltaics Engineering Research Center

The Solar & Photovoltaics Engineering Research Center (SPERC) is a research centre at King Abdullah University of Science and Technology (KAUST), which is a public research university located in Thuwal, Saudi Arabia. KAUST was founded in 2009 and focuses exclusively on graduate education and research using English as the official language of instruction. It offers programs in life sciences, engineering, computer sciences, and physical sciences. SPERC aims to become a leading institute in renewable energy science and engineering by providing the foundation for innovation in efficient and low-cost disruptive solar cell and energy technologies. R&D projects cover areas such as CIGS and CXYS solar cells, amorphous, nanosilicon and quantum dots solar cells, small molecule and polymeric solar cells, solid state dye sensitized solar cells, as well as optical coatings and designs for optimized solar cell performance including solar thermal and energy storage, harvesting, and fuel cells. Facilities of SPERC include deposition and thermal treatment laboratory, wet chemistry laboratory, printing and roll-to-roll laboratory, surface analysis laboratory, and ultrafast laser spectroscopy and imaging laboratory.

Another feature of KAUST is the New Energy Oasis (NEO), which is 14,500 m2 of land adjacent to the innovation cluster that provides demonstration sites for technology companies. Up to 20 locations can be provided. Initial tenants have a free 3-year contract. Table 4-1 shows solar technology demonstration and verification of industrial firms in the New Energy Oasis (NEO) of KAUST. As observed in table 4-1, 7 foreign firms are testing their products in NEO.

Table 4-1: Solar Technology Demonstration and Verification of Industrial Firms in the New Energy Oasis (NEO) of KAUST

Compnay	Technology	System Rating (KW)	No. of Panels	Date on Line
Solar Frontier	CIS	10	128	Jan-10
Sunthrough	CSP	Demo Installation	Demo Installation	Sep-09
Sulfur Cell	CIGS	1.2	21	Mar-10
BP Solar	Poly-crystalline	14	60	Jul-10
Kaneka	Amorphous Silicon	10	132	Nov-10
Circadian Solar	CPV	7		
Q-Cells	Poly-crystalline	6	24	Dec-10

Source: [KAUST 2011]

(c) Center of Excellence in Renewable Energy Research (CERER)

Supported by the Ministry of Higher Education (MOHE), the Center of Excellence in Renewable Energy Research (CERER) was established in King Fahd University for Petroleum & Minerals (KFUPM) in 2007, with the vision that Saudi Arabia would remain as a leader in the field of energy. KFUPM is recognized as one of the leading universities in the region. Indeed, it was the first Saudi university to be ranked as one of the top 400 universities in 2008 based on the "QS World University Rankings" and was the first in the Arab world that time. CERER has a number of objectives such as spreading knowledge of renewable energy, providing training and strengthening higher education, as well as facilitating technology transfer and assistance by creating industrial nuclei on both local and global levels. The fields of R&D include hydrogen and methanol fuel cells, solar and wind power, advanced energy storage systems, control systems and electrical infrastructure, and the economics of renewable energy. CERER held a joint workshop for PV technologies with University of Tokyo and held the first Saudi Symposium for solar energy in 2012. Moreover, on the level of the KFUPM, a team of 20 students succeeded in the invention of the first solar-powered car driven by university students in the Arab world. The team participated in an international race of solar cars in Australia in October 2011 and could achieve a good ranking among the 37 participating teams from around the world [Saudi Gazette 2011].

(d) SET (Sustainable Energy Technology) Program

The Sustainable Energy Technologies (SET) is a King Saud University (KSU) program devoted to the development of emerging sustainable energy technologies through distinguished research in alignment with the national economy strategies. SET provides academic Master's and PhD programs in sustainable energy, conducts research, and strives to spread awareness of the benefits of green energy in the Kingdom. The SET has a scholarships program in renewable energy; KSU received about 600 applicants from more than 30 nations in 2010. The applicants, including students pursuing Doctorate and Master's degrees as well as established researchers, have backgrounds in the fields of electrical, mechanical, and chemical engineering, as well as physics and chemistry. Their expertise includes solar energy, wind energy, and hydrogen energy. Furthermore, recently the SET program has launched funding for 20 research projects in nuclear and sustainable energy; 20 projects were selected from 46 submissions to the Program [KSU 2012]. Indeed, solar energy projects accounted for more than 50% of the total funded research projects in 2012. The SET team completed preparations for an on-site system in December 2010 including a windmill, 20 solar panels, and a hydrogen-releasing engine. It is expected to generate more than 5 kilowatts, which is enough to light the building and provide faculty and students with a valuable medium for researching and training.

4.2. Energy S&T indicators

In this subsection, S&T indicators in the field of energy for Saudi Arabia are presented. The discussion in this subsection focuses on the performance of publications due to limited information as well as data with regard to the energy, including solar energy, in other indicators. The data for this subsection was extracted from SCImago Journal & Country Rank (SJR) [1]. First, figure 4-1 shows the growth of number of publication of Saudi Arabia in the field of energy between 1996 and 2010. As observed, in the period between 1996 and 2007, no growth was seen in the number of publications in the field of energy in Saudi Arabia. However, since 2008, the number of publications grew from 66 papers to 116 papers in 2010. Furthermore, as illustrated in table 4-2, renewable energy accounted for 17.7% out of the total publications in the field of energy in Saudi Arabia in 2010. The highest percentage was for energy engineering with 38.1% while fuel technology came second with 19.9%. Next, to clarify the level of Saudi performance in terms of publications, the following discussions highlight the international comparison with other countries. Figure 4-2 illustrates the number of publications in the field of energy in 2010 in Saudi Arabia and selected countries. In comparison to other developed and leading developing countries, the Saudi performance seems to be weak with 261 papers while 5,250 papers were published in the US, 2,709 in China, and (2,481) papers in India. However, it should be noted that Saudi performance in the publication of the energy field in 2010 was better in terms of the number of published papers than countries such as Singapore, Ireland, and Israel.

Unit: paper

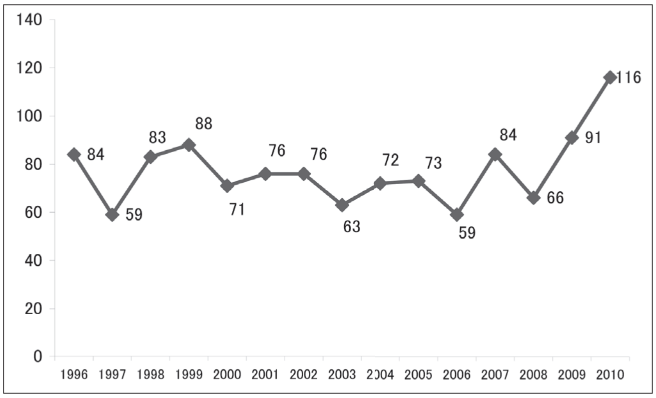

Figure 4-1: The Growth of Number of Publications of Saudi Arabia in the Field of Energy Between 1996 and 2010

Source: Retrieved by the author from the database of SJR

Table 4-2: The Percentage of Saudi Publication of by Subject in the Field of Energy in 2010

The Subject	Percentage
Energy Engineering and Power Technology	38.1%
Energy (miscellaneous)	9.4%
Fuel Technology	19.9%
Nuclear Energy and Engineering	14.9%
Renewable Energy, Sustainability and the Environment	17.7%

Source: Retrieved by the author from the database of SJR

Unit: Papers

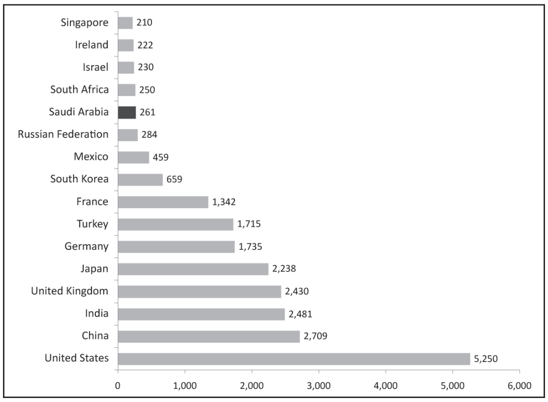

Figure 4-2: Number of Publications in the Field of Energy in 2010 in Saudi Arabia and Selected Countries.

Source: Retrieved by the author from the database of SJR

Table 4-3: The Sum of the Number of Documents, Citations, and Citations per Document for the Publications in Saudi Arabia and Selected Countries in the Field of Energy for the Period Between 1996 and 2010.

Unit: Documents and Citations

	Country	Documents	Citations	Citations per Document
1	United States	502,804	882,250	1.75
2	China	320,800	215,970	0.67
3	United Kingdom	139,683	253,482	1.81
4	Germany	130,031	228,773	1.76
5	Japan	113,246	132,808	1.17
6	France	94,740	148,995	1.57
9	India	71,975	54,588	0.76
12	South Korea	55,546	59,950	1.08
13	Brazil	45,189	35,474	0.79
16	Russian Federation	36,053	21,512	0.6
18	Turkey	30,594	20,645	0.67
26	Israel	15,243	25,330	1.66
28	Malaysia	14,407	9,053	0.63
46	Saudi Arabia	5,739	5,437	0.95
61	Indonesia	2,032	1,839	0.91
63	Viet Nam	1,890	2,261	1.2

Source: Retrieved by the author from the database of SJR

Next, table 4-3 shows the sum of the number of documents, citations, and citations per document for the publications in Saudi Arabia and selected countries in the field of energy for the period between 1996 and 2010. Saudi Arabia is ranked 46th globally in terms of documents in the field of energy. This ranking is recognised to be weak considering that Saudi Arabia aims to be the world's top solar energy producer. While Saudi researchers published 5,739 papers, the US researchers published 502,804, China published 320,800, and Russia published 36,053 papers. A similar trend of Saudi weak performance has been seen for the citation. However, for the citation per document (C/D), Saudi Arabia could record (0.95 C/D) while it was (0.67 C/D) in China, (0.76 C/D) in India, (0.79 C/D) in Brazil, and (0.6 C/D) in Russia. This might be understood as an indicator of the quality of published papers in Saudi Arabia in the field of energy. Nevertheless, although Saudi performance was better than BRICs countries, it is still lagging behind developed countries such as the United States (1.75 C/D) and Japan (1.17 C/D).

5. Challenges for Developing the Indigenous Solar Energy Industry

This section is discussing the future challenges for developing the indigenous solar energy industry in Saudi Arabia by putting the spotlight on the following topics: indigenising innovation capability at R&D units, the leadership of KACARE and its impact on the solar energy sector, developing technological capability at national firms and creating the solar energy market.

5.1. Indigenising Innovation Capability at R&D units

In this subsection, the subject of indigenizing Saudi R&D capabilities in the field of solar energy is discussed. By looking at the publications of Saudi researchers, generally international journals from KACST and KFUPM, it can be seen that a number of Saudi research projects in the field of solar energy have been presented. One of the applications that has been studied and tested is the use of solar energy in the thermal desalination process [Hussain and Rahim 1995]. In addition, a number of pilot projects had been executed, mainly by KACST research teams, concerning solar and wind energy exploitability assessment [Al-Abbadi et al. 2002]. Research projects covered the installation of a solar water-heating system [Huraib et al. 1996] and mobile renewable-energy (hybrid) systems consisting of wind generators and solar panels to produce electricity for rural areas [Alnaser 1999], as well as a PV-systems output investigation in remote locations in Saudi Arabia [Alawaji 2001]. However, it seems that most of that research, including recent papers, is focused more on using current tools and technologies for measurement and observation with regard to solar and wind energies [Rehman et al. 2007; Elhadidy and Shaahid 2007]. In other words, most of the studies that had been performed in KACST and KFUPM by Saudi scholars can be classified as "applied research".

Nevertheless, when looking at the publications of scholars at KAUST, particularly SPERC, it can be noted that the research is focusing more on renewable energy science and engineering as well as the foundation for innovation in efficient and low-cost disruptive solar cell and energy technologies. In particular, SPERC is collaborating with the University of Toronto for the "Tandem – a Si CQD Solar Cell" project, which seeks the development of silicon-colloidal quantum dot (CQDs) tandem solar cells [Ratan et. al. 2011; Lee et. al. 2011; Jabbour and Doderer 2010]. The main objective of the project is to design and fabricate high efficiency solar cells made of PbS CQDs integrated atop a high efficiency amorphous silicon (a-Si) single junction cell. Furthermore, the thin film project is a collaborative project with the Boeing Company that focuses on understanding fundamental materials and interfacial properties such as electrical, optical, chemical and mechanical, along with process engineering needed to achieve a solution based approach to high efficiency low cost CIGS solar cells [Kim et. al. 2010a; Kim b 2010b]. Moreover, under the cooperation with Stanford University, SPERC is conducting a research project with regard to the synthesis of novel solution-processable small organic molecule materials with tunable emission color, good charge mobility and high glass transition temperature. [Yang et. al. 2011a; Yang 2011b]. In addition, the collaborative project with Imperial College London deals with Engineered Structures for Energy Harvesting Devices. The project investigates novel nano-structures for energy harvesting devices and in particular solar rectenna, and establishing the scientific and engineering principles for fabrication at a low cost [Carney et. al. 2011; Beaujuge and Frechet 2011].

Another collaborative project is investigating the optical and mechanical properties of SABIC plastic substrates as candidates for the important and rapidly growing sector of rugged and flexible electronics and photovoltaics where the transparency, UV stability, durability under repeated flexing, and oxygen and moisture permeation are studied [Czajkowski et. al. 2011].

In comparison to other R&D units of solar energy in Saudi Arabia, the author argues that SPERC has the following advantages. The first one is the ability of KAUST to attract talented scholars and researchers from abroad. The list of faculty members and researchers in SPERC includes talents who were attracted from universities and institutions such as Harvard University, University of California, Berkeley, Arizona State University, and French Atomic and Alternative Energy Commission. Moreover, R&D units in Saudi Arabia do not benefit from graduate school students because of the lack of graduate programs in general, with the exception of the SET program of King Saud University.

The second advantage is that SPERC is actively involved in Industry-University-Government (I-U-G) engagement. As mentioned in the previous section, 7 foreign firms are testing and demonstrating their technologies in New Energy Oasis (NEO) of KAUST. It is reported that BP Solar inaugurated a new solar technology designed to perform more efficiently in extreme temperatures, and this technology had been tested as part of a 14 kW pilot project newly installed on the grounds of NEO [BP Alternative Energy 2010].

The third advantage is the financial power of KAUST as it has a $10 billion US endowment that gives KAUST the opportunity to build partnerships with leading universities and fund its R&D projects. According to the New York Times, the University of Texas at Austin, the University of California, Berkeley, and Stanford University started a 5-year partnership with KAUST under the agreement that American universities will help pick the faculty and develop the curriculum for KAUST. Over the five years, each university will receive a $10 million gift, $10 million for research on their home campus, and $5 million for research at KAUST as well as administrative costs [Lewin 2008].

In the following lines, the approaches of indigenizing Saudi R&D capabilities in the field of solar energy are discussed. As mentioned above, most of the studies that had been performed in KACST and KFUPM were focused more on using current tools and technologies for measurement and observation with regard to solar energies while SPERC's research is focusing more on the foundation for innovation in efficient and low-cost disruptive solar cell and energy technologies. Indeed, most of research in KACST and KFUPM was accomplished by Saudi scholars or consisted of joint papers between Saudi and foreign scholars while research in KAUST was accomplished by foreign talents only. The same trend had been seen in the students and post-doctoral fellows in KAUST particularly in SPERC. Needless to say that attracting foreign talents is an effective approach to technological capability building. However, in the case of SPERC, it seems to be difficult for linking SPERC innovation capability and Saudi innovation capability because of the absence of Saudi researchers and students in SPERC. Nevertheless, it is reported that King Abdullah City for Atomic and Renewable Energy (KACARE) is interested in developing testing capability leading into solar certification for Saudi Arabia with the cooperation of SPERC [KAUST 2011]. Moreover, as mentioned above, KAUST is implementing a joint research program with a Saudi leading firm in the petrochemical industry; SABIC.

Moreover, recently the Saudi initiatives team at KAUST had been formed in order to attract Saudi students to the university and to raise their percentage from about 15% to 30%. A number of events were held in the U.S and the U.K for attracting Saudi students who are studying in those countries to complete their studies in KAUST. Similar events are to be held in Japan as well. This might be recognized as an important step in the long term for indigenizing innovation capability of Saudi human resources at SPERC. At the same time, there is a need for bringing up the technological capability level at the other Saudi solar energy R&D units at universities as well as KACST by allocating more funds to their research projects, facilitating foreign talent-attracting programs at those units in addition to the promotion of industrial-academic cooperation programs. Indeed, King Saud University, King Fahd University of Petroleum and Minerals and King Abdulaziz University succeeded in attracting a number of highly citied researchers in various fields for the purpose of improving the quality of research at those universities. Moreover, the three universities could build a number of industrial-academic cooperative projects through endowment chairs as well as the techno-valleys in Riyadh, Dhahran and Jeddah which are working under the supervision of the three Saudi universities. In this respect, the percentage of Saudi papers in the field of energy, including solar, that had been published under international cooperation with foreign scholars raised from 28.73% in 1996 to 56.21% in 2010. With regard to the "All Fields" column, similar growth had been seen from 34.52% in 1996 to 62.07% in 2010. This might be understood as a development in Saudi capability in the level of research and at the same time the ability for attracting scholars from other nations to conduct joint research.

5.2. Developing Technological Capability at National Firms

In this subsection, developing technological capability at national firms in Saudi Arabia in the field of solar energy is discussed. The Saudi 9th national plan is stating the following remarks with regard to the indigenising energy industry technologies: "indigenisation and generation of oil-industry technologies lie in engineering design and consulting activities. Hence, it is important to develop this activity by supporting the formation of private or joint companies to provide engineering and consulting services to projects in oil, gas, petrochemical, electric power, and water desalination; not only in the Kingdom, but also in the Gulf region and the Arab World" [MOEP 2010: p. 520].

As seen above, while the Saudi 9th national plan had not mentioned "Solar Energy" directly in the fields of energy that require indigenising industry technology, solar energy applications and technology are strongly linked with electric power as well as water desalination. This subsection is examining the performance of Saudi national firms in terms of developing their indigenous technological capabilities.

Indeed, a number of firms exist in the Saudi solar energy market with different levels of technological capabilities. Based on what had been seen by the author on the available resources, Saudi companies such as MTT as well as Sun & Life tend to be contractors only for solar energy projects which can introduce a foreign firm's technologies and products to the market rather than assimilating technological capabilities within those Saudi firms. As for the nature of technological capability, the United Nations study listed the following three main aspects of technological capability building [UN 1987]: 1) The selection of machinery and equipment for producing specific goods and services, 2)The assimilation and diffusion of those technologies in the host Economy and 3)The development of indigenous capacities for innovation. According to those suggested aspects by the UN, MTT as well as Sun & Life can be recognised as companies that could develop capabilities of the 1st aspect in terms of the selection of machineries and equipment. Nevertheless, the author argues that this approach would not be beneficial for Saudi Arabia in terms of technology transfer as well as capability building. Moreover, relying totally on the foreign technologies without developing indigenous innovation capabilities would not assist the efforts of developing national solar energy industries. In this respect, Abdullah Taibah, CEO of Arabian Qudra the mother company of Sun & Life, commented that "Saudi Arabia is still lagging behind technologically in the field of solar energy and lessons should be learned from the experiences of the desalination sector as Saudi Arabia is the largest producer of desalinated water in the world. In the 20 to 25 years of production all the technologies have been imported from abroad and technology has yet to be developed locally" [AlEqtisadiyah 2011].

BP Solar Arabia is an example of a company in the Saudi market that totally relied on foreign technologies. In Riyadh, BP Solar Arabia had been manufacturing solar photovoltaic systems with technology and manufacturing that comply with the quality assurance followed by the BP Solar Group [Ahalgosaibi 2002]. Nevertheless, BP Solar has recently halted all of its solar operations due to the difficulties in restructuring its business to remain profitable after the increasing "commodification" of the solar market [PV Magazine 2012]. BP Solar Arabia changed its name to "Solar Arabia Limited" which is owned equally by two private enterprises from the Gulf region. It is expected that Solar Arabia will face challenges in terms of competing in the solar market with non-renewing technologies of BP Solar. While Solar Arabia is fully certified and accredited in ISO14001:1996 (Environment Management System) and ISO 9001:2000 (Quality Management System) [Olayan 2012], it seems that those technological capabilities are limited to the operational and maintenance levels. Indeed, it is reported that BP solar could not compete in the solar energy sector because of the BP's failure to capitalize on its own innovations while manufacturers in China developed their own versions of advance technologies and beat the company to it [Bullis 2011b]. It should be noticed that BP solar applied for a patent on the process, and in 2007, the U.S. Patent Office published the patent applications. BP solar researchers also described aspects of the technology at conferences [Bullis 2011a]. Furthermore, BP Solar inaugurated a new solar technology designed to perform more efficiently in extreme temperatures, and this technology had been tested as part of a 14 kW pilot project newly installed on the grounds of NEO in KAUST [BP Alternative Energy 2010]. The lessons learned from the failure of BP Solar are; the difficulty to compete in the global solar markets without indigenising innovation capabilities, and the importance of commercializing the technologies that were invented. If Saudi Arabia attempts to build a strong national solar industry, developing indigenous technological capabilities at Saudi firms would be essential.

Next, discussions move to the case of National Solar Systems (NSS), the Saudi leading firm in the field of solar systems integration, which had been recently participating in applying technologies in the photovoltaic industry in several projects in KAUST, Aramco, Farasan, Yanbu and Dammam. According to NSS's website, it has full in-house capability to engineer, supply, install, and support all types of solar systems ranging from small off-grid systems to large utility scale grid-connected installations [NSS 2012]. One of the main differences between NSS and other Saudi firms in the solar energy field is that while Conergy Asia-Pacific, the German firm, managed the design and components supply of the projects which were mentioned above, installation and operational management were implemented by NSS [Conergy 2009]. By looking at NSS technological capability development process, it is found that the company since 2004 began to focus on gaining experience through numerous experiments, pursuing the technical development, attending international conferences and purchasing state-of-art models and technologies. Those efforts in addition to the installation of several experimental systems made NSS able to acquire the expertise required. In 2007, the business started when NSS was able to win several contracts with a number of organizations including Aramco [Al-Riyadh 2009]. It should be noted that NSS was able to develop its own products designed for the Saudi local environment such as street lighting systems and solar plants to mobile flights [NSS 2012].

According to Ionara and Sérgio, technological capability itself is usually defined as the skill, knowledge and experience required for a firm to achieve technological change at different levels. It is acquired and accumulated over time as technological efforts are undertaken by the firm [Ionara and Sérgio 2002]. The three types of functional technological capabilities that are proposed by Ionara and Sérgio are as follows: 1) Operational capabilities, 2) Improvement capabilities and 3) Generation capabilities. Through what had been seen in the case of NSS, the company seems to have succeeded in building its operational capabilities firstly by the installation of several experimental systems before the start of the business. The operational capability of NSS had been developed through the projects that NSS implemented based on the business contracts. Furthermore, the success of NSS in developing its own products can be recognised as building its improvement capabilities. The developed products by NSS, such as street lighting systems and solar plants to mobile flights which were designed for the Saudi local environment, seem to be a customization and modification of existing imported technologies. Abdulhadi Al-Mureeh, Managing Director of NSS, commented that the company had not been relying on importing technologies and developing them later as it is not possible to develop a product without the knowledge of the full components and design. As well, the solar energy systems rely entirely on the geographical location to see the power of solar radiation at all times of the year in addition to the nature of the climate of the site from the heat and the power of wind and dust which made it necessary for NSS to create local expertise [Al-Riyadh 2009].

It is clear the management of firms plays an important role in promoting the policies of indigenising technological capabilities. However, the Saudi government can support those activities by incentives as well as setting conditions for the Saudi firms to localize the experiences and technologies through the projects of solar energy.

5.3. Promoting the Local Use of Solar Energy

In this subsection, the challenge of promoting the local use of solar energy in Saudi Arabia is presented. Creating local market seems to support the development of national solar energy industry in the Kingdome. Indeed, the first solar plant in Saudi Arabia was built more than two decades ago in Al-Onainiah northwest of Riyadh. That plant was 350 Kilowatt, which was considered a giant technological leap at that time. Solar Village was the first solar plant to flow photovoltaic energy into the national grid to feed three villages: Alonainiah, Al-joubilah, and Al-Hegrah. The plant was linked to the electricity national grid later [Alaglan 2010]. While Saudi Arabia has this history of solar energy use, it seems that creation of local solar market is still challenging. Figure 5-1 shows the development of total renewable and waste energy use in Saudi Arabia between 1971 and 2009. As observed, since 1998, there had been no growth in the total used renewable and waste energy in Saudi Arabia. While the total local renewable and waste energy use was 1.47 kt of oil equivalent (ktoe) in 1971, the number rose to 12.98 ktoe in 1994. Nevertheless, the total use of renewable and waste energy use decreased in 2009 to 4.5

ktoe. Indeed, the total energy use locally in Saudi increased from 86,513.2 ktoe in 1994 to 157,854.7 ktoe in 2009.

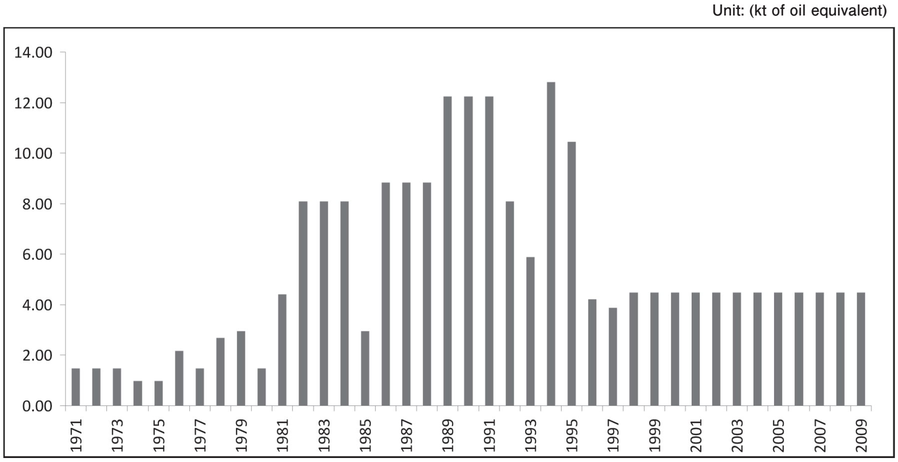

Figure 5-1: The Development of Total Renewable and Waste Energy Use in Saudi Arabia Between 1971 and 2009

Source: Calculated by the author based on the data of International Energy Agency and World Bank PPP data

Next, table 5-1 shows the development of total renewable and waste energy use in Saudi Arabia using selected countries in 1979, 1999, and 2009 to compare the Saudi performance to other countries in this field. As illustrated, in comparison to Saudi Arabia, other Arabian countries could achieve a high level of total renewable and waste energy use; the total use was 1,294 ktoe in Tunisia and 1,545 ktoe in Egypt. Even in UAE, an Arabian oil-rich country, the total use was almost four times greater than Saudi Arabia. With regard to other countries, there seems to be a big gap between Saudi Arabia and developed as well as developing countries in terms of total renewable and waste energy use. Moreover, according to the data of United Nations, Brazil has succeeded in raising the share of renewable energy to total energy production to more than 40%. This share of renewable energy was 31.1% in India, 16.1% in Canada, and 15% in China. However, the share of renewable energy seems to be zero in Saudi Arabia and other Gulf Cooperation Council (GCC) countries while it is 4.2% in Egypt [UN 2008]. Furthermore, even the small proportion of renewable energy is observed in advanced countries such as the United States (4.7%), Japan (3.2%), and the United Kingdom (2%) however, this proportion is still high in comparison to Saudi Arabia where it was (0.003) in 2009.

Currently, a number of initiatives have enabled the Saudi Arabian government to take advantage of solar energy, which includes the national initiative to produce water and electricity using solar energy. With a capacity of 10 megawatts through several means: (1) King Abdul-aziz City for Science and Technology (KACST), (2) the project for electric solar energy production of King Abdullah University of Science and Technology (KAUST) with a capacity of 2 megawatts, and (3) the project of Aramco to cover the parking lots to provide 2 megawatts of electricity in addition to (4) a similar project in Riyadh for King Abdullah Petroleum Science and Applied Research and (5) the project of electricity production through solar energy in Farasan island, which is handled by Saudi Electricity Company [Al-Hayat 2012a].

Table 5-1: The Development of Total Renewable and Waste Energy Use in Saudi Arabia and Selected Countries 1979, 1999, and 2009

Unit: (kt of oil equivalent)

Country Name	1979	1999	2009
Saudi Arabia	2.9	4.5	4.5
United Arab Emirates	-	16.9	16.9
Tunisia	489.6	896.9	1,294.0
Egypt, Arab Rep.	787.5	1,281.9	1,545.2
Korea, Rep.	-	1,103.1	3,044.1
Turkey	7,740.5	6,792.4	4,666.7
United Kingdom	-	1,785.4	5,352.1
Australia	3,545.1	4,967.8	5,783.2
Russian Federation	-	7,519.0	6,366.9
Japan	-	5,667.5	6,574.9
Germany	3,590.2	7,159.7	24,862.4
Brazil	38,786.0	50,030.4	75,897.6
United States	52,786.1	70,924.9	83,802.2
India	114,884.0	146,745.1	165,421.9
China	177,690.2	204,011.4	203,619.9

Source: Calculated by the author based on the data of International Energy Agency and World Bank PPP data

According to Al-Riyadh newspaper, Saudi Arabia plans to generate 5 Giga watts of solar energy by the year 2020, which is expected to cover 10% of Saudi local electricity and make Saudi Arabia one of the largest sources for solar energy in the world. More than $3 billion was invested into finance solar power plants in each of the ports of Yanbu in the Medina and the city of Jubail in the eastern region. In addition, $380 million was invested to build a factory to produce polysilicon on the eastern coast of Saudi Arabia, which is expected to reach capacity of primary productivity to 3350 Tons of HDPE Silicon by 2014. This material is used to produce solar energy [Al-Riyadh 2012].

Furthermore, in June 2011, the Saudi Minister of Petroleum and Mineral Resources, Ali Al-Naimi, commented that "Saudi Arabia plans to generate solar electricity equalling the amount of its energy from crude exports." According to Green Alpha Advisors, the total oil exports of Saudi Arabia is equivalent to 4,590 billion kilowatt hours per year which is almost the quarter of the world's energy demand. To produce this amount of energy, it would require 250 thousand solar PV plants with an installed capacity of 10 megawatts each [Conergy 2012].This calculation is based on one barrel of crude oil corresponding to 1,700 kilowatt hours of electricity as Saudi Arabia exports approximately 2.7 billion barrels of oil a year. According to Kawana Koichi, Representative Director of JGC, oil reserves in Saudi Arabia are estimated to have 262 billion barrels which are equal to solar energy generated from 340 PV factories with the size of 500 TW under the calculation of 1GW/year Factory with operating time of 20 years, an annual Insolation of 1,000h/year and a life time of 25 years for the PV [Kawana 2011]. The construction estimated cost for one PV factory was $1 billion US which is recognised to be high from the point view of the author because of the cheap prices of fossil energies currently in Saudi Arabia. Indeed, when discussing the development of the Saudi solar energy industry, it should be noticed that energy security ultimately means more than access to energy; it means access to cheap energy [Pentland 2008]. In addition to the current high costs of solar energy technologies, the challenge that might be faced in creating a Saudi market of solar energy is the current subsidiaries for fossil fuels in the local market that make the costs low. It is suggested that a comprehensive change in the approach to the energy policy aimed at reducing cost disparities through less subsidization of conventional energy would quickly change the equation in favour of renewable energy [Chris 2008]. Nevertheless, Alaglan is proposing the use of the word "Complementary" instead of the word "Alternative" because of the limitations of solar energy such as the expensive cost, low efficiency and periods of usage of fossil energy. It would be difficult, at the present time, for the solar energy to be a competitor of the traditional fossil fuel. However, the solar energy can be used to secure energy for remote areas with low consumption and where extending electric grids would cost huge sums of money. Moreover, the solar energy can support the public grid during the peak hours in the summer and also in some limited applications [Alaglan 2010]. While current prices of PV factories still seem too high, if a major breakthrough is achieved in the field of solar-energy conversion, Saudi Arabia can be a leading producer and exporter of solar energy in the form of electricity [Alawaji 2001]. Furthermore, unlike most other countries, Saudi Arabia is under no pressure to seek and secure alternative sources of energy and any move by the Saudi government to invest in non-conventional sources of energy now is premature given the low efficiency and high cost of existing technologies [Aljarboua 2009].

6. The Case Study of Solar Frontier

In this section, the case study of Solar Frontier (SF) is analyzed in order to discuss the possibilities of developing Saudi national solar energy industries through the technology transfer from foreign firms in the field.

6.1. Overview Solar Frontier

Solar Frontier, a 100% subsidiary of Showa Shell Sekiyu K.K, opened a new office in Al-Khobar, east of Saudi Arabia, in July 2011. Through its new office in Saudi Arabia, the Solar Frontier will be able to support several announced projects in the Saudi local market while expanding its presence in the growing markets in the region. Indeed, Solar Frontier has been involved in a number of projects in Saudi Arabia, including the 10kW KAUST installation, the 500kW power plant supplying Farasan Island's remotely installed and grid connected power plant, and the 10MW "North Park Project" with Saudi Aramco [Solar Frontier 2011]. It is noted that Solar Frontier could provide the different Saudi contracting firms as well as their foreign partners with its CIS (Copper Indium Selenide) photovoltaic modules to be used and installed in those projects. The main technological advantage of Solar Frontier is its proprietary CIS technology, which seems to be suitable for desert climates due to its lower temperature coefficient compared to crystalline silicon. This means smaller loss in conversion efficiency as temperatures increase and a strong frame reinforcement that is tapered to resist sand and dust accumulation.

6.2. Interview

In order to gain more insight regarding various questions which arose from the analysis and also to probe various issues which are not covered in the data and documents, a semi-structured interview was carried out. This section reports on the interview design and structure and discusses its findings.

Interview Methods

In order to conduct this interview, the author requested Solar Frontier's cooperation for a one-to-one interview. The respondent was requested to provide an interview both on some pre-selected topics/issues and also requested to make free comments, in general, regarding Solar Frontier's projects in Saudi Arabia. The interview therefore was semi-structured within fairly informal settings. This is believed to produce more genuine reactions to the questions.

Respondents

The interview was conducted with Shigeaki Kameda, President and CEO of Solar Frontier (SF). Masayuki Nakada, General Manager for Communications Brand & Communications at SF also participated in the interview that was conducted for approximately one hour in the meeting room of Solar Frontier office in Tokyo on March 7th, 2012.

Interview Design and Structure

The interview was primarily designed to gather deeper insights on some critical issues related to solar energy industry in Saudi Arabia. The interview was semi-structured in that there were a number of fixed questions but also some other questions that were raised as the interview proceeded. The interview included such questions as:

- Those regarding SF policy in the Middle Eastern region and especially in Saudi Arabia.
- Those about the reasons behind SF's decision to enter the Saudi market.
- Those which required opinions regarding the researcher's recommendations:
- Those which aimed to clarify SF's opinion regarding cooperation with Saudi organizations in solar energy projects.
- Those about proposing new approaches for developing solar energy industry in Saudi Arabia.
- Those in a free format. These were often questions which were a kind of follow up from the emerging communication.

Findings of the Interview

Main findings of the interview can be summarized as follows.

- Statements regarding the reasons that supported SF's entrance to Saudi solar market can be summarized as follows:

(a) The strong will by Saudi government to invest in solar industry was supporting factor for SF's decision to enter Saudi market. In particular, Ali al-Naimi, the Saudi Arabian Oil Minister, stated that Saudi Arabia intends to become "the world's largest exporter of clean electric energy". Such clear policy would increase the expectations for solar energy market in Saudi Arabia.

(b) Natural factors based on the richness in sunlight as Saudi Arabia can produce solar energy about twice as much as of Japan.

(c) The growing demand in Saudi local market for energy makes the investment in Saudi solar industry attractive for SF.

- SF is interested in entering Saudi market. Among its investments in Saudi Arabia are solar panels introduced at KAUST. In KAUST, the hybrid systems are operated and controlled from Japan through the internet. Compared to silicon and other sorts of materials, panels at KAUST, using the light soaking system, have achieved high production especially in hot climate. Another example of the investment in SA is instalment of roof-top type panels. This project is operated with support from Japanese Government.

- Having too many players in the Saudi solar industry makes the business structure complicated for SF. Mr. Kameda suggests having Aramco as a leader is desirable. However, academia, business sector and policy makers should be independent.

- As human resources are limited, licensing business has a great potential. SF already has partnership with companies in SA as well as in Europe and U.S.A. For example, SF has concluded a partnership agreement with Belectric Trading GmbH in Germany for the sale of CIS thin-film solar modules in Europe. SF also supplies CIS to a project operated by Aramco.

- Building a supply chain is essential as it creates job opportunities in all the related fields including construction, transportation, engineering and maintenance.

- Main obstacles for SF in Saudi solar market can be summarized in slow action (response), complicated organizational system and lack of counterpart companies as well as adequate market.

- Licensing technologies and training local human resources seems to be the main forms of technology transfer to Saudi Arabia through the solar projects of SF.

6.3. Discussions

While most existing Saudi firms in the solar energy sector are focusing on the integration and installation of solar energy products, this subsection is discussing the possibilities of building the national solar energy industry in Saudi Arabia through technology transfer from foreign firms. This approach of joint projects had been effective in terms of technology transfer to Saudi Arabia in the field of petrochemicals as well as oil industries. Saudi firms such Aramco and SABIC started building their technological capabilities by similar joint projects with operational capabilities which were developed into innovative capabilities as both firms are now investing heavily in R&D and patents are registered for the both firms. Nevertheless, the problem of applying this approach in the solar energy field is absent in Saudi leading firms in solar energy. A big leading firm such as Aramco and SABIC can promote the solar industry in the Kingdom and at the same time can be the counterpart of global firms in solar energy in order to create joint ventures that can support technology transfer to Saudi Arabia.

As suggested by SF, it seems that Aramco is attempting to lead the solar industry sector in Saudi Arabia. According to Ali Al-Naimi, the Saudi oil minister, Saudi Aramco hopes to become the world's biggest solar energy provider in future years by taking advantage of the desert kingdom's plentiful sunshine [Patel 2009].

Furthermore, Khalid Al-Falih, the chief executive of Saudi Aramco, aims to begin production of solar cells in Saudi Arabia in two to three years in a joint venture with a Japanese thin-film solar cell maker, Showa Shell Sekiyu KK [Reuters 2011]. Ziyad Al-Shiha, the executive director of Saudi Aramco Power Systems, declared that the Kingdom may need to burn as much as 3 million barrels of oil a day by 2020 if it doesn't improve efficiency - and that's up from 800,000 barrels of oil in 2011 - to generate power facilities that are under development [Mahdi 2011]. This might explain the reasons behind Saudi Aramco's will to invest and lead the solar industry in Saudi Arabia. After succeeding in the Saudi local market, Saudi Aramco and Showa Shell (Solar Frontier) are willing to expand their solar projects in emerging countries in the Middle East, Southeast Asia, Africa and Latin America [Saudi Aramco 2012]. In 2010, Aramco began constructing small-scale solar power pilot facilities that generate between one and two megawatts (MW) using the technologies of Solar Frontier K.K., an affiliate of Showa Shell Sekiyu, one-third of which is owned by Royal Dutch Shell and about 15 % by Saudi Aramco. Solar Frontier K.K specialises in proprietary CIS technology of solar energy, denoting the key ingredients copper, indium, and selenium [Solar Frontier 2011].

Attracting high technology foreign firms to Saudi market might support developing solar industry in Saudi Arabia. However, for localizing those technologies, establishing national Saudi firms, Such as Aramco and SABIC would be essential for assimilating those foreign technologies into Saudi organizations. With regards to the factors that attract foreign firms into Saudi market, Shigeya Kato, Chairman of Showa Shell Sekiyu, listed the following factors; (1) the size and needs of the market, (2) competitiveness and low cost, (3) the viability of talents and R&D human resources of the renewable energy field[2]. While the size of market was discussed in previous section, the competitiveness and low cost are discussed.

It is reported that 70 to 80 % of CSI's components and 20 to 30% of the PV's components are available in the Kingdom where existing glass and metal industries can accelerate the development of the solar components industry [AlEqtisadiyah 2011]. In this respect, NorSun is forming a joint venture company to construct a new polysilicon plant in Saudi Arabia to provide polysilicon to SunPower which will support 2,500 megawatts of solar cell production [PV-Tech 2008] Moreover, the Azmeel Group, Saudi group companies, will invest 8 million Saudi riyals for manufacturing PV in Al-Jubial, the 2nd industrial city which will provide factories in the petrochemical sectors with their needs of PVs [Al-Riyadh 2012b]. Establishing factories for producing PVs, CSIs as well as their components is recognised to support the efforts of localising the solar energy technologies and developing national solar industries. While the materials that are used in Solar Frontier's CIS seem not as efficient at converting light into electricity as mainstream solar cells made from polysilicon, the materials are still cheaper which might make it economically attractive [Reuters 2011].

Next, discussions move to the factor of the viability of talents and R&D human resources of the renewable energy field. While SF seems to be interested in licensing their technologies rather than developing new ones locally in Saudi Arabia, respondents showed interests in conducting collaborative researches with Saudi universities in the field of solar energy after the creation of the market and the start of business. Moreover, SF already started training programs for Aramco's staff in solar industry filed. Moreover, SF was one of the firms that demonstrated its solar technologies in the New Energy Oasis (NEO) of KAUST. However, it should be noted that there seems to be lack in the academic and training programs for Saudi human resources in the field of solar energy. As Saudi Arabia established King Fahd University for Petroleum and Minerals in order to supply the market with highly qualified Saudi human resources in the field of oil as well as petrochemical industry, it is expected to be essential to establish such new academic institutions for developing the Saudi human resources in renewable and atomic energy fields. This step would accelerate the indigenizing the technological capabilities of solar industry in Saudi Arabia.

7. Conclusion

The objective of this paper is to put the spotlight on the current situation and the future issues with regard to developing indigenous solar energy industries in Saudi Arabia. Due to the high growth rates in population, the industrial sector and water desalination sector, Saudi Arabia is one of the top consuming countries with regard to oil and natural gas. Growing local demand for energy consumption in addition to the strong will by the Saudi government seem to be factors that promote Saudi efforts in order to be the world's largest producer and exporter of solar energy. Indeed, Saudi Arabia has the intense solar irradiation, land, and natural resources that support building the supply chain of the solar energy industry. However, according to an international comparison of energy indicators, Saudi Arabia's performance in the use of solar energy seems to be weak in comparison to developed and developing countries, and even a number of neighbouring Arab countries. Recently initiatives have taken advantage of solar energy in Saudi Arabia and the government is planning to generate 5 giga watts of solar energy in 2020 which is estimated to cover 10% of Saudi local electricity by then.

As for future challenges, in indigenizing the innovation capability in the field of solar energy, there seems to be a need for supporting R&D units in KACST and universities to bring up the level of solar energy R&D projects from "applied research" to "basic research" by allocating more funds to their solar energy basic research projects, facilitating foreign talent-attracting programs at those units in addition to the promotions of industrial-academic cooperation programs in the field of solar energy. Moreover, nationalizing innovation capabilities of KAUST by attracting Saudi students and researchers without affecting the foreign talent-attracting programs that are creating a new culture in the field of solar energy researches in Saudi Arabia by the quality and topics of researches that could attract Saudi leading firm, SABIC, for joint projects. Furthermore, the role of KACARE in the solar energy sector should be clarified as the leading public organization that sets national policies and at the same time coordinates and supports the funding of R&D activities in collaboration with relevant institutions by combining the efforts of industry, academia and government to achieve the goals of national policies with regard to solar energy.

It is argued that opening the sector for many stakeholders in the solar energy sector would promote the development of the sector as well as technological capability building in Saudi Arabia. In addition, most of the Saudi firms in the solar energy sector are relying totally on the foreign technologies without developing indigenous innovation capabilities except in the case of National Solar Systems (NSS) which could develop operational capabilities through experimental installation and implementing solar installation projects on a business base later. Moreover, NSS succeeded in customizing and modifying products that match the local conditions in the Saudi market. Even NSS could not yet reach the level of generation capability; its experience might be a good reference for other Saudi firms in the solar energy sector in terms of indigenizing and developing technological capabilities in stages rather than totally relying on foreign technologies.

Furthermore, while Saudi Arabia is promoting investments in solar energy sectors and supporting the solar industries that rely on local material and components, the absence of Saudi leading firms in the solar energy field is concerning. In this respect, Saudi Aramco is establishing a joint venture with Showa Shell Sekiyu which is expected to accelerate the growth of a Saudi solar industry. Saudi Arabia might develop its indigenous technological capabilities by setting conditions that support the technology transfer of solar energy from the foreign firms that are investing in the Saudi solar market.

In summary, While Saudi Arabia is currently generating electricity mainly by using fossil fuels, developing national solar energy industries would reduce dependency on hydrocarbon resources, extend the life of hydrocarbon resources and keep them as a source of income for a longer period of time by concentrating the oil use more on exporting as well as on national petrochemical industries. Saudi academias as well as industries need to bring up their capabilities from technology consumers into technology innovators in stages. That can be achieved by building the technological capabilities in the R&D organization, universities as well as industrial firms with a strong support and leadership public sector. Developing national solar industries with relying on indigenous innovation capabilities would give Saudi Arabia the opportunity to compete globally and to change from the "Kingdom of Oil" to the "Kingdom of Energy".

8. Notes

[1] For more information about SCImago Journal & Country Rank (SJR) please visit:
http://www.scimagojr.com/ [Accessed 2011.12.23]
[2] Comment of Kato Shigeya, Chairman of Showa Shell Sekiyu, at the discussion time of the session Plenary Discussion II "Future Energies" at the Japanese – Saudi Business Opportunity Forum in Tokyo on 1st February 2012.

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