SOLAR CAPABILITIES:
PROMOTING TECHNOLOGICAL LEARNING IN SOUTH AFRICA'S PHOTOVOLTAIC SUPPLY INDUSTRY

by

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Submitted to the Department of Urban Studies & Planning in partial fulfillment of the requirements for the degree of

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ABSTRACT

I explore the mechanisms through which technological capabilities have been built in the market for photovoltaic (PV) module and balance of system (BOS) manufacture in South Africa. Drawing on the literature on technology transfer and economic development, my aim is to identify the relative influence of three types of learning mechanisms – enterprise specific, supplier driven, and government induced – on the acquisition of technological capabilities in firms. Qualitative case studies provide the context through which the influence of each learning mechanism is assessed.

My research suggests that South African firms rely far more heavily on learning relationships associated with their suppliers, than learning derived from human resources internal to the firm or the policy and regulatory framework promoted by the national government. South Africa's approach differs greatly from latecomer countries with more advanced module manufacturing industries: in India, for example, local firms have relied heavily on government policy and regulation to facilitate their entrance into more technologically complex areas of operation. The implications of this finding are discussed, and recommendations put forth for how the national government can bolster industrial learning activities.

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so won't you help to sing?
these songs of freedom.
all i ever had
redemption songs
these songs of freedom
all i'll ever have

my redemption song

- robert nesta marley -

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INTRODUCTION: THE HUSH

BACKGROUND

The fervor with which environmentalists and energy specialists embrace the use of photovoltaic (PV) systems for remote power generation has dwindled to a quiet lull in recent years. In sub-Saharan Africa (SSA), the decline in optimism stems from persistently low levels of household and village electrification, despite large-scale investment in the promotion of PV systems. By most accounts, sluggish rates of adoption result from a host of demand-side constraints. PV systems are self-contained electric power generation and distribution units.[1] Essentially, they operate by using semiconductor material to convert solar radiation directly into electricity for lighting and powering small appliances. Although the costs of maintenance and operation are minimal, the purchase price of a PV solar home system ranges from $275 in Ghana[2] to $1,300 in Kenya.[3] PV-powered lanterns are slightly cheaper, selling for between $40 and $150.[4] At these prices, most rural households are unable to afford the cost of either application without access to financing or end-user subsidies.[5]

Undoubtedly, the price of PV applications presents a significant impediment to the growth of markets in SSA. But, whether reductions in demand-side constraints will alone spur rates of adoption is a point of contention. Since the early 1990's, development practitioners have advised African countries to foster PV markets by creating greater opportunities for households to access (read afford) these devices (see for example Cabraal et al 1998; Foley 1995; Weiland 2002). Few policy advisors consider the division of labor in the international supply chain to be a significant obstacle to market development. When policy advisors counsel on supply-side interventions, the prevailing recommendation is that SSA countries reduce import duties as a means to encourage foreign manufacturers to sell in local markets. Little attention is given to the implications of the geographic distribution of manufacturing activities, or the value added by encouraging local firms to acquire production competencies.

To shed light on these issues, this thesis explores on the nature of the PV supply chain and the geographic distribution of manufacturing activities in the industry. My aim is to determine the level of technological capabilities in the domestic market for PV module and balance of system (BOS) manufacture in SSA. This introductory chapter proceeds with a brief overview of the evolution of the market for PV devices in SSA. It outlines my motivations for exploring the topic of PV technology through the literature on technological capability building and industrial learning. Subsequently, I make more explicit my objectives in conducting this research and the methodological approach employed.

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[1] Anil Cabraal, Mac Cosgrove-Davies, Loretta Schaeffer, 1998, Accelerating Sustainable PV Market Development (Washington, D.C: Asia Alternative Energy Program, World Bank) 2.

[2] National Renewable Energy Laboratory, 2002, "Gansu Province Solar Home System Project," in Energy Efficiency and Renewable Energy Technology Development in China (Golden, CO: National Renewable Energy Laboratory) 2.

[3] Anil Cabraal, Mac Cosgrove-Davies, Loretta Schaeffer, 1996, Best Practices for Photovoltaic Household Electrification Programs: Lessons from Experiences in Selected Countries. World Bank Technical Paper No 324. (Washington, D.C.: Asia Alternative Energy Program, World Bank) 9.

[4] Ibid 12.

[5] Cabraal et al note that variance in the purchase price of PV solar home systems and lanterns can be attributed to differences in sales volume, subsidies, taxes, and accessibility of components.

Era of High Expectations

Following the escalation in oil prices during the 1973 embargo, a wide coalition of stakeholders gazed optimistically on the potential for PV technology. Environmentalists found promise in the possibility that PV systems could reduce emissions of greenhouse gases associated with the degassing of coal mines and generation of electric power. Since PV systems produce no emissions during operation, environmental advocates anticipated that the technology could augment abatement efforts. Among energy specialists, the allure of PV germinated from the need to accommodate demands for electric power in areas where low load densities and capacity utilization rates rendered grid-extension economically unattractive.[6] For example, in SSA rural population densities and energy consumption patterns have historically discouraged investment in the extension of national power lines. As a result, the region has ranked persistently low in international comparisons of the percentage of the population with access to electric power services. According to Barnes, van der Plas, and Floor (1997), SSA was far behind its regional counterparts in 1970 and in 1990 (**Table 0.1**).[7] More recent figures suggest that the situation has not improved much over the last decade. Accounting for the dual influences of population growth and declining investment in the maintenance of existing transmission and distribution lines, some authors contend that the rural areas of SSA have witnessed a 2 – 3 % increase above 1990 figures at best.[8] At worst, there have been no improvements at all.

If the status of rural electrification in SSA appears dismal when viewed against its regional counterparts, historical progress is even more telling when national figures are compared (**Table 0.2**). What the regional total belies is that improvements in the provision of electricity have been driven largely by South Africa, where the percent of rural households with access to electricity grew from 8 % in early 1970[9] to 25.72 % in 1993.[10] In contrast, with the exception of Cote d'Ivoire, most other countries confronted household electrification rates of less than 5 % by the beginning of the 1990's. Unfortunately, similar estimates are unavailable for electrification rates for rural agriculture, small-scale industry, and public facilities.

That household access to electric power services remained so low comes as no surprise when the historical development of the electric power industry is considered. Prior to 1945, electric power generation in SSA was virtually nonexistent. With the exception of South Africa, whose Railway Administration constructed the first coal-fired power station in 1897;[11] most countries built generating capacity in the post-WWII period.[12] Their entrance into the sector was motivated by the surge in financial resources that early-industrializing countries made available to the developing

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[6] Cabraal et al. 2.

[7] Barnes et al draw on World Bank project reports, sector assessments, and a review of national electric power service reports to compile regional data from national findings.

[8] Jonas Redwood-Sawyer, 2002, Widening access in the context of Power Sector Reform – An Overview of the Institutional Challenges in Africa, Paper prepared for Meeting on Power Sector Reform and Sustainable Development, 21-22 May 2002 (Paris, France: United Nations Environment Program) 9.

[9] Christopher Purcell, 2002, The SA PV Market: Some Key Critical Developments, Paper Prepared for International Centre for Science & High Technology, UNIDO (Trieste, Italy: UNIDO) 1.

[10] National Electricity Regulator, 2001, Annual Report 2000/2001 (South Africa: National Electricity Regulator) 11.

[11] Anton Eberhard, 2003, The Political, Economic, Institutional, and Legal Dimensions of the Electricity Supply Industry in South Africa. (Paper presented at the "Political Economy of Power Market Reform Conference," convened by the Program on Energy and Sustainable Development at Stanford University, 19-20 February 2003) 7.

[12] In South Africa, the location and nature of diamond and gold industry deposits required heavy equipment and intense amounts of water and power supplies to facilitate extraction. These factors were primarily responsible for the country's early investment in a rail system and use of coal fields for the generation of electricity.

world at the onset of the Cold War.[13] With the aim of cultivating allies overseas, agencies such as the U.S. Agency for International Development (USAID) and International Bank for Reconstruction and Development (World Bank) offered funding for basic infrastructure as a means to build a coalition against communist regimes.

Table 0.1: Percent of Population with Access to Electricity by Region [14]

Region	Urban 1970	Urban 1990	Rural 1970	Rural 1990
North Africa and Middle East	65	81	14	35
Latin American and Caribbean	67	82	15	40
East Asia and Pacific	51	82	25	45
South Asia	39	53	12	25
Sub-Saharan Africa	28	38	4	8
Total served (in millions)	320	1,100	340	820

Source: Barnes et al 1997

Table 0.2: Percent of Electrified Rural Households in Select Countries

Country	%*	Rural Pop (mill)^	Country	%	Rural Pop (mill)
Botswana	2.09	0.76	Mozambique	0.66	10.41
Cote d'Ivoire	12.7	7.12	Namibia	5.00	0.93
Eritrea	2.10	2.42	South Africa	27.2	18.96
Ethiopia	0.20	46.01	Swaziland	2.00	0.58
Ghana	4.30	9.93	Tanzania	1.00	21.06
Kenya	2.00	17.90	Uganda	0.72	14.79
Lesotho	4.00	1.49	Zambia	2.00	4.46
Malawi	0.32	8.23	Zimbabwe	0.60	7.28

* Percent of electrified rural households estimated for period between 1988 and 1993.
^ All rural population figures are for 1990.
Source: ESMAP, Energy & Development Report 2000; Sawyer; UNCHS 1990

The provision of financial and technical assistance from international development agencies had significant implications for the evolution of electric power industries in the region. Donor agencies transferred preferences for (i) centralizing generation in plants of increasing scale and (ii) extending services to rural industry and commerce before reaching the domestic sector.[15] In the United States and many parts of Europe, early-industrialized countries relied primarily on the 'inter-connected grid' model of distribution. This model was based on the presumption that the best way to increase coverage was to incrementally expand lines from central stations, rather than to invest in the development of innovative solutions for decentralized generation. Since rural areas tend to lie

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[13] David Morton, 2000, A Survey History of Electric Power Technology since 1945, Report prepared for the Institute of Electrical and Electronics Engineers (New Jersey: Rutgers University) 31.

[14] Although these regional estimates may appear slightly lower than what would be presumed when examining national survey data, it should be noted that Barnes et al. are one of few sources that attempt to calculate the proportion of the population with access to electric power services, rather than the proportion of households. Since occupation of a housing unit requires a certain level of income and human resources, estimates of household electrification would presumably be somewhat higher than those corresponding to total population. For a critical assessment of household surveys, see Kristin Komives, Dale Whittington, and Xun Wu, 2000, "Annex: Energy use around the World – Evidence from Household Surveys," in Energy Services for the World's Poor (Washington, D.C.: Energy Sector Management Assistance Program, World Bank) 14.

[15] Morton 35.

farthest from central stations, they are the last to receive service and the most expensive to connect to the grid. In contrast, the preference for extending power to small-scale industries was a byproduct of the longstanding debate over the prerequisites for economic growth. Many development practitioners viewed rural electrification as a tool for stimulating the expansion of rural industries. John Mellor (1976) was among the most vociferous advocates of this line of thinking. He argued that developing countries should adopt decentralized industrial development strategies, structured around large investments in electric power and rural infrastructure.[16] Many donors shared these sentiments. As a result, rural electrification schemes initially targeted rural industry as the primary beneficiary. Improving services for the rural household sector was a lesser aim.

This brief review of the significance of international financial and technical support is not meant to imply that low levels of rural electrification are the byproduct of externally imposed forces. To the contrary, the demographic profile of rural areas and energy use patterns in villages has kept demand for commercial energy low. Throughout SSA, households are the major consumers of rural energy. Households meet their energy needs through multiple-fuel use or fuel switching. They base fuel selection decisions on the relative cost of supply, and opt for those sources that are deemed necessary for basic activities. Consequently, woodfuel constitutes the bulk of rural energy consumed by households, because it allows for and can be obtained without cash transactions. Electricity, which is predominantly used in lighting, figures less prominently in the rural energy mix. When it is available, utilization rates remain low and often do not justify the capital costs required for network expansion.

For comparison, the agricultural sector also relies more heavily on traditional fuels and animate energy sources (human, animal). As Karaekezi notes: "The energy needs for agricultural production in rural areas range from intensive power use in transport, water, lifting, and pumping, land preparation, primary and seedbed cultivation, to weed control, planting, transplanting and harvesting."[17] For most of these activities, the level of mechanization remains quite low. As a result, commercial energy sources such as electricity, diesel, and kerosene are used sparingly. Similarly, in the commercial/service sector, small-scale and informal businesses rely on electricity as an input into production activities only when it is absolutely necessary. In businesses such as baking, beer brewing, and tobacco curing, biomass remains the predominant energy source.[18] When lighting and refrigeration are necessary, electricity from the grid is used.

Since the resources invested in incremental extension of centralized power services did not improve access to electricity, policy-makers and industrialists turned their attention to decentralized generation technologies. Most governments in SSA began to give priority to PV systems in the early 1980's.[19] PV was praised as an innovative technological solution, because it could provide the small amounts of power needed for lighting, water pumping, and powering repeaters for remote telecommunications. Many PV systems were installed as part of pilot projects and technical demonstration programs. For example, the Japan International Corporation Agency funded project-specific activities and the development of a photovoltaic master plan for Botswana in 1982.[20] By 1997, the Government of

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[16] An overview of Mellor's (1976) arguments is provided in Douglas Barnes, 1988, Electric Power for Rural Growth: How Electricity Affects Rural Life in Developing Countries, (Colorado: Westview Press, Inc.) 67.

[17] Stephen Karakezi and Waeni Kithyoma. 2002. "Renewable Energy Strategies for Rural Africa: Is a PV-led renewable energy strategy the right approach for providing modern energy to the rural poor of Sub-Saharan Africa?" Energy Policy 30: 1079.

[18] Ibid 1079.

[19] Ibid 1073.

[20] Peter Zhou and Buti Mogotsi, 2001, Solar PV Dissemination Efforts in Botswana. Report prepared for the "Implementation of Renewable Energy Technologies – Opportunities and Barriers" Project. (Denmark: Collaborative Center on Energy and Environment, United Nations Environmental Program) 4.

Botswana instituted a National Photovoltaic Rural Electrification Program. Namibia also benefited from donor support. In 1993, the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) of Germany disbursed funds to the Namibian Ministry of Mines and Energy to support market-oriented dissemination of photovoltaic solar home systems.[21] The literature on the use of PV technology is replete with studies on its evolution in Kenya (see for example, Duke, Jacobson and Kammen 2002). Given the abundance of information on this setting, I will not provide further detail here. But, it is important to note that similar, though admittedly less successful, attempts to commercialize PV have been undertaken in Ghana, Mali, Namibia, South Africa, Uganda, Zimbabwe, and Zambia.[22]

Experience with PV Systems

Unfortunately, substantial investment in and promotion of PV systems has not brought tremendous increases in levels of household electrification – a fact leaving many enthusiasts with a sense of frustration. In part, disappointment emerges from the lofty ambitions associated with this technology. Advocates have only recently realized that no technical device can offer simple solutions to the complex challenge of commercial energy provision in rural areas. In addition, a quiet optimism prevails, because the same demand-side factors that impede extension of the power grid prevent PV systems from being more widely used. The cost of PV solar home system ranges from \$275 in Ghana[23] to \$1,300 in Kenya.[24] PV-powered lanterns are slightly cheaper, selling for between \$40 and \$150.[25] Without access to financing or end-user subsidies, most rural households are unable to purchase these systems. Farmers are in a slightly better position to obtain PV-powered water pumps, but this is only because agricultural activities remain highly subsidized in most SSA countries.

And to some extent, a hush engulfs the energy and environmental community, because early attempts to promote PV technology failed due to lack of interest in imparting the technical skills necessary to build local capacities to maintain and service the systems.[26] As reported by Martinot et al (2002): "...a large number of the early donor programs encountered a variety of technical problems; 'many programs badly underestimated problems of repair and maintenance in the mistaken belief that PV systems were virtually maintenance free and could be cared for by untrained, local people."[27] Adoption of PV technologies rarely occurs in conjunction with commercial and institutional cooperation between firms in early-industrial countries[28] (where almost all renewable energy technologies have been developed) and local industry in SSA. Ownership and control of manufacturing rests largely with multinational companies, whose headquarters are located in the United States, Japan, Germany, and parts of Western Europe. Many of these firms have dominated the industry since the early 1980's, when Agarwal, Bartlem, and Hoffman (1983) observed:

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[21] Hansjorg Muller and Njer Wamukonya, 2001, The Transition from Pilot Projects to Large-Scale Programmes: The Case of Namibia, Report prepared for the "Implementation of Renewable Energy Technologies – Opportunities and Barriers" Project (Denmark: Collaborative Center on Energy and Environment, United Nations Environmental Program) 36.

[22] Njeri Wamukonya, ed, 2001, Experience with PV Systems in Africa: Summaries of Selected Cases (Denmark: Collaborating Centre on Energy and Environment, United Nations Environmental Program) 2.

[23] National Renewable Energy Laboratory, 2002, "Gansu Province Solar Home System Project," in Energy Efficiency and Renewable Energy Technology Development in China (Golden, CO: National Renewable Energy Laboratory) 2.

[24] Cabraal, Cosgrove-Davies, Schaeffer 9.

[25] Ibid 12.

[26] Eric Martinot, Akanhsha Chaurey, Debra Lew, José Roberto Moereira, and Njeri Wamukonya. 2002. "Renewable Energy Markets in Developing Countries," Annual Review of Energy & the Environment 27: 313.

[27] Martinot 313.

[28] Throughout this document, the term 'early-industrializing countries' refers to those countries with manufacturing experience prior to World War II.

"...companies most involved in exporting new energy technologies to the Third World have generally been those associated with better financed, multinational firms. Hence, the field has been dominated by well known firms such as Dornier, M.A.N., Arco Solar (Atlantic Richfield), C.G.E., Solar Power Corporation (subsidiary of Exxon), Photowatt, Siemens, Mobil, and Martin Marietta."[29]

Table 0.3 Percent of Solar Cell and Photovoltaic Module Production for Consumer and Commercial Markets (In percent of total MW manufactured)

Country*	2001	2000	1999	1998	1997
Europe	22.1	21.1	19.9	21.6	24.2
Japan	43.8	44.7	39.7	31.6	27.8
United States	25.7	26.1	30.2	34.7	40.8
Rest of World	8.4	8.1	10.2	12.1	7.2 %
Total	100 %	100 %	100 %	100 %	100 %

* Manufacturing in these countries includes subsidiaries of multinational companies (e.g. BP Solar India for 'rest of world'), along with those companies that are locally owned.
Source: P. Maycock, PV News, Vol. 19:3 (March 2000); P. Maycock, PV News Vol 22:3 (March 2003)

Table 0.4 Percent of Solar Cell and Photovoltaic Module Production in Rest of World (In percent of total MW manufactured)

Country	2001	2000	1999	1998	1997
Australia	21.3	24.6	26.8	27.2	---
China	9.20	10.7	9.8	8.5	16.0
India	44.6	51.1	48.8	49.2	55.3
Hong Kong	4.0	---	---	---	---
Taiwan	19.9	12.8	13.7	13.9	26.6
Other Countries	1.0	0.8	0.9	1.2	2.1
Total	100 %	100 %	100 %	100 %	100 %

Source: Paul Maycock, 2002, The World Photovoltaic Market 1975 – 2001 (Virginia: Photovoltaic Energy Systems) Appendix

Most firms have been slow to establish branches for distribution in SSA; a small number have set up system integration facilities or PV module manufacturing plants. Between 1997 and 2001, the percent of solar cells and PV modules produced in countries outside of Europe, Japan, and the United States ranged between 7 % and 12 % (**Table 0.3**). Of this figure, India contributed the greatest proportion (**Table 0.4**). In 2001, India accounted for 44.6 % of the total photovoltaic power produced in the 'rest of the world,' a figure slightly lower than its contribution of 51.1 % in 2000.[30] When the manufacturing activities of Australia and Asia are considered, the contribution that SSA countries make to world production falls somewhere between 0 % and 2 %.[31]

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[29] Anil Agarwal, Todd Bartlem, and Thomas Hoffman, 1983, Competition and Collaboration in Renewable Energy: Problems and Opportunities of Technology Transfer to the Developing Countries (Washington, D.C.: International Institute for Environment and Development) 3-12.

[30] Paul Maycock, 2002, The World Photovoltaic Market 1975 – 2001 (Virginia: Photovoltaic Energy Systems) Appendix; Paul Maycock, 2003, PV News Vol 22:3.

[31] SSA countries likely fall at the lower end of this range, because I have not been able to account for manufacturing in Brazil. Heliodinamica, Ltd. and other Brazilian firms had an emerging presence in the industry during the early to mid-1990s. Unfortunately, most industry reports have been unable to account for production from these companies post 1995, although they remain operative.

Among those donor agencies, governments, and firms that consider the effects of this gulf in manufacturing capabilities, several believe that more explicit emphasis should be placed on technology transfer arrangements. For example, Martinot et al reveal: "In reviewing its portfolio of [photovoltaic] solar home systems in the 1980's, the German aid agency GTZ, one of the most active donor agencies promoting PV....said: 'there has not been a single project that was designed expressly to disseminate the technology". In response to this finding, GTZ established the Information Advisory Service on Appropriate Technology (ISAT). ISAT promotes North-South technical cooperation, with the aim of transferring technical know-how to developing countries to support their problem-solving capacity.[32] In addition, the 1992 UN Conference on Environment and Development (the Rio Earth Summit) increased multilateral assistance for field and research projects designed to promote sustainable technology diffusion.[33] Unfortunately, project implementation has been slow for each of these initiatives. Consequently, the experience gained on how best to promote technology transfer and what activities countries in SSA should undertake to build technological capabilities is only now beginning to emerge.[34]

OBJECTIVES

The debate on the relevance of the technological lead of early-industrializing countries and the international division of labor in markets for photovoltaic modules and solar cells raises several important questions about how countries in SSA should proceed if they want to continue to promote PV technology. Given the pattern and pace of advances made by countries at the technological frontier, should SSA attempt to enter the supply side of the market? If so, what activities do firms need to undertake to build the capabilities to manufacture, assemble, and/or service systems locally?

My thesis focuses on addressing these questions. My aim is to examine the extent to which capabilities for the manufacture of photovoltaic systems have been acquired and to identify the processes (or paths) through which they emerged. The scope of this paper is limited to the nature of capability-building, or more succinctly, the relationship between learning-related activities and the acquisition manufacturing capabilities.

CONCEPTUAL FRAMEWORK

The literature on technological learning and industrialization suggests that capability building has much to do with the type of relationships firms establish with suppliers (Fine and Whitney 1996; Veugelers and Cassiman 1999); the managerial and technical capacities existing in firms (Amsden 2001; Marcelle 2002); and the incentive structures created by government (Amsden 2001; Kim 2001). I consider the relative influence of each of these factors on the acquisition of technological capabilities in the market for the manufacture of PV systems.

What are technological capabilities?

As a preliminary task, it is necessary to define the basic concepts and definitions relating to technological capability building. Reviewing these definitions not only ensures that common

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[32] Wolfgang Hillebrand, Dirk Messner, adn Jorg Meyer-Stamer, 1994, Strengthening Technological Capability in Developing Countries: Lessons from German Technical Cooperation. Working Paper 12/1994. (Berlin: German Development Institute) 9.

[33] Martinot 314.

[34] Ibid 314.

language is used throughout this paper, but also bridges the gap in treatment of terminology among the different theoretical frameworks from which the research is drawn. In the field of energy and environmental policy, what technology transfer entails and the mechanisms through which it occurs are not treated explicitly. For example, Song (1997) broadly details how Korean firms sought information-sharing with Japanese companies, in hopes of commercializing PV technology. His analysis is unclear about what information Korean firms wanted to obtain or how they planned to obtain it. Mellecker (1997) is equally ambiguous about the activities and objectives of the technology transfer arrangements of Spire Corporation, a leading photovoltaic equipment manufacturing company in Massachusetts. He describes how Spire Corporation provided the equipment to establish a module assembly business in South Africa, but does not detail the learning processes involved. Mellecker's review offers no information on whether skills were developed to use the new machinery.

Both Song (1997) and Mellecker (1997) imply that the processes through which technical information is transferred are synonymous with the processes through which technological capabilities are developed. In contrast, economists differentiate between the two. David (1997) contends: "Technological capability does not inhere in the knowledge that is possessed, but in the ability to make effective use of technological knowledge to satisfy material wants."[35] Kim (1997) concurs, noting that whereas technical knowledge comprises a set of information, technological capabilities denote:

> ...the ability to make effective use of technological knowledge in efforts to assimilate, use, adapt, and change existing technologies. It also enables one to create new technologies and to develop new products and processes in response to a changing economic environment. It denotes operation command over knowledge. It is manifested not merely by knowledge possessed, but more importantly, by the uses to which that knowledge can be put and by the proficiency with which it is used in activities of investment and production, and in the creation of new knowledge.[36]

Lall (1997) and Amsden (2001) disaggregate technological capabilities according to function and degree of complexity. In the manufacturing sector, three generic functions are: project execution capabilities (investment), production capabilities, and linkage capabilities. Project execution capabilities refer to the skills needed before a new facility is commissioned or an existing plant is expanded. They involve the ability to determine business needs, obtain the necessary technologies, and identify and contract staff. Production capabilities denote the knowledge and skills required for the operation of plants. These capabilities enable firms to transform inputs into outputs. Linkage capabilities allow companies to effectively transmit information, skills, and technology to and from suppliers, subcontractors, and consultants. At the intra-firm level, linkage capabilities affect productivity; inter-firm linkages shape how knowledge diffuses throughout the economy,

Throughout my thesis, I use the term 'technological capabilities' as it has been defined by David (1997) and Kim (1997) and classified by Amsden (2001) and Lall (1997). An adaptation of the functional classifications for technological capabilities is provided in **Table 0.5**. This typology provides a rough overview of the indicators of technological capability examined throughout remainder of this document.

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[35] Paul David, 1997, "Rethinking Technology Transfers: Incentives, Institutions, and Knowledge-Based Industrial Development," in C.H. Feinstein and C. Howe, eds., Chinese Technology Transfer in the 1990's: Current Experience, Historical Problems, and International Perspectives (London: E. Elgar) 3.
[36] Linsu Kim, 1997, Imitation to Innovation: The Dynamics of Korea's Technological Learning (Cambridge, MA: Harvard Business School Press).

Table 0.5: Functional Classification of Technological Capabilities for Manufacturing Firms

Level	Project Execution	Production	Linkage
Routine	Feasibility assessment; Engage contractor and select site; Monitor and control feasibility studies	Oversee operation; Routine quality control; Significant technical assistance Minor adjustments in design	Local procurement of goods and services; Exchange with suppliers
Intermediate	Equipment procurement; Engineering assessments; Staff recruitment; Staff training	Major adjustments in design; Limited technical assistance; Product meets national design/ performance standards	International procurement of goods and services
Advanced	Partial adaptation of equipment	Production meets international design/performance standards	Collaborative manufacturing
Innovative	Equipment design and supply	Certified as 'best in class'; Develop own product specifications	Turnkey capabilities for domestic firms

Source: Adapted by author from Amsden 2001, Figueiredo 2002, and Lall 1997

The Relationship between Learning and Capability Building

In SSA, firms move into a business with routine capabilities and seek to advance based improvements in the competencies of staff, information they gather from suppliers, or support they receive through government sponsored programs. Therefore, a firm's effectiveness in the market is dependent on the learning mechanisms it undertakes. In this sense, learning can be thought of as the processes of building and accumulating technological capabilities over the lifetime of the firm.

Marcelle (2002) divides learning mechanisms into two categories: private and collective.[37] Private learning mechanisms may be internal or external to the firm. Internal learning activities include in-house training or the education and training employees bring to the firm. External learning involves relationships with suppliers and interactions with other firms through subcontracting, industry networks, and hiring of consultants. Collective mechanisms consist of (i) technical support services provided by NGOs, business associations, and (ii) the policy and regulatory framework established by government.[38] This dichotomy underscores the distinction between mechanisms whose benefits accrue at the level of the enterprise and those mechanisms that confer benefits to all firms within a national, innovative system.

In the literature on economic development and industrialization, large amounts of information are available on how learning activities contribute to the acquisition of technological capabilities. Based on a rapid scan of sources, I identify likely explanatory variables for this research. Drawing on the classification scheme used by Marcelle (2002), I divide these learning mechanisms into: enterprise specific, supplier-driven, and government-induced learning mechanisms. Enterprise-specific learning mechanisms are internal to the firm. They involve the processes through which learning derived from individual characteristics, education, and business competencies is converted into organizational learning. Supplier-driven mechanisms concern relationships between manufacturers and suppliers. Of particular importance is the nature of the relationship with respect to its formality, length, and the balance of power/dependency between parties. Government-induced learning mechanisms provide the third set of learning mechanisms. But, admittedly, the mechanisms that encourage learning in firms that 'learn by doing' rather than undertaking 'research and development' are not well

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[37] Marcelle 7.

[38] Gilliam M. Marcelle, 2002, Reconsidering Conventional Wisdom on Technology Transfer (Paper prepared for International Conference on Science, Technology, and Innovation: Emerging International Policy Issues, Harvard University, September 2002) 5.

understood (see below for additional explanation). My research methodology involves (i) determining the relative importance of learning associated with each set of mechanisms and (ii) explaining why a particular set of mechanisms is/is not more salient. A brief description of each explanatory variable and the rationale for its definition follows:

Enterprise-specific learning mechanisms

- Formal education of general manager: The education of employees and managers is important for several reasons. First, higher levels of education enable individuals in firms to process more sophisticated technical information and teach themselves any advanced skills they did not acquire in universities. Second, the process of being educated (i.e. belonging to an educational institution) can be integral in building networks with the potential leaders of firms in complimentary fields. This variable is defined with respect to the level of education, regardless of whether the degree was engineering-related or otherwise technical.

- Prior work experience of general manager: Prior work experience was the second learning mechanism I considered. Previous experience in a similar firm imparts knowledge of business practices and project management skills that are generally not acquired in educational institutions. Moreover, experience in the same industry means that knowledge of production processes and operational systems can be transferred from one firm to another. This variable is defined with respect to whether prior employment of the general manager was/was not in the photovoltaic supply industry.

- Firm History/Upward diversification: Amsden (2001) demonstrates that in inter-country comparisons, the historical context in which pre-WWII manufacturing experience took place was a significant determinant of the type of technological capabilities that emerged among late-industrialized countries. At the level of the firm, a somewhat analogous argument can be made. If equipment and technology are versatile enough to allow firms to transition from a less technologically complex field into the high technology field of photovoltaic module manufacturing, then these firms should be able to extend skills accumulated in previous industries. The definition of this variable can not be succinctly defined, as it relates primarily to the firm history over time. Broadly, observable implications of this variable are that firms transitioned from related, but less technologically complex fields into the photovoltaic supply industry.

Supplier-driven learning mechanisms

- Number of suppliers: The number of suppliers (equipment and components) provides an indication of each firm's dependency on a particular supplier relationship and the overall power balance in supplier-manufacturer dealings. If a manufacturer has more than one supplier for the same input, the manufacturer may exert greater influence (real or perceived) over the nature of the relationship. This variable will be determined by whether manufacturing firms have one supplier for a given input or more than one supplier.

- Formal/Informal relationship with suppliers: The formality of the manufacturer-supplier relationship can be denoted by whether a contract governs interaction between these two parties. A formal relationship exists if a contract is present; an informal relationship exists if a contract is not. I assume that formal contracts will facilitate learning better than informal contracts. In formal arrangements, equipment and inputs suppliers have an obligation to engage with recipient firms. Through channels of communication, recipient firms obtain information about process improvements, quality control, and market opportunities.

- Length of interaction with suppliers: This variable is defined by the approximate number of years that recipient firms have relied on a supplier. My hypothesis is that longer interactions provide greater opportunities for learning.

- Implicit/Explicit learning relationship with suppliers: I judge explicitness of the manufacturer-supplier learning relationship using very obvious indicators, such as evidence of technology transfer agreements and technical training. Both of these latter indicators suggest that an explicit learning relationship exists. If such an arrangement is present, I will also attempt to gain information on its duration.

Government-Induced Learning Mechanisms

- Incentives and Mandates: The relationship between the (i) policy and regulatory environment and (ii) learning activities is quite complex, particularly for firms that do not undertake research and development (R&D). Presumably, the existence of 'control mechanisms'[39] such as performance mandates encourages firms to meet targets for efficiency and productivity that they might not otherwise achieve. To meet these targets, firms may be forced to 'learn quicker' and 'learn better' in the short term. With respect to financial incentives, however, the rationale is quite different. If the manufacturers are involved in R&D, then financial incentives give them the option of reserving more funds for R&D activities. In contrast, for firms that do not undertake R&D activities, financial incentives may enable them to obtain new technologies and /or equipment that they might not have acquired otherwise.[40]

RESEARCH DESIGN & METHODS

Approach & Hypotheses

I rely on qualitative methods, because of the importance of obtaining an appropriate level of detail about the history of each firm, its production activities, and manufacturer-supplier relationships. Firm-level case studies provide the context through which each of the above variables is assessed. The analytic approach involves first examining the role that each variable assumes in shaping the level of capabilities and manner in which they are acquired. Second, I evaluate if one of the broader categories of learning mechanisms have been more dominant in shaping the development of technological capabilities in South African firms.

Drawing on the experience of firms in India, a country that has entered into the PV supply market through government-induced learning, my hypothesis is that policy and regulation should assume the most prominent role in building technological capabilities in South Africa. India's experience mirrors that of other countries that entered the market 'late'. The history of government financial support and

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[39] Alice Alice, 2001, The Rise of the Rest: Challenges to the West from Late Industrializing Economies (New York: Oxford University Press) 8.

[40] Howard Pack, 1999, Modes of Technology Transfer at the Firm Level, (Paper prepared for the World Bank Research Project 'The Micro-Foundations of International Technology Diffusion') 4.

performance mandates suggests that public sector involvement is a critical determinant of the extent to which firm are able to acquire capabilities.

Case Selection

At the outset of the research process, the search for firms involved in the photovoltaic supply industry in SSA was long and difficult. To understand if and how local capabilities are being required, I restricted the universe of cases to all firms that currently (i) have manufacturing facilities for PV modules, solar cells, or ancillary components located within a country in SSA and (ii) are owned or staffed by natural residents of the associated locale. South Africa and Kenya were the only countries that contained one or more firms that fit these criteria.

The case material is drawn from two firms, both located near Johannesburg, South Africa. Solar Vision, a photovoltaic system assembler and module manufacturer, produces solar home systems for distribution within the national rural electrification program. Liselo Solar, a module manufacturer, services the rural telecommunications market and has recently become involved in supplying photovoltaic modules for use in rural clinics and schools.

Sources of Information

Secondary information is drawn from a review of the literature on energy and industrial development. Primary information was collected via phone and in-person interviews with firm employees, energy associations, and research centers in South Africa and the United States. Unfortunately, no government officials within the Department of Minerals and Energy were able to be interviewed.

To develop the firm-level case studies, data was collected using two different questionnaires. The first questionnaire helped me identify which firms were involved in the industry, the type of relationships they maintain with their suppliers, etc. This questionnaire was directed toward the concessionaires for national rural electrification scheme. The second questionnaire facilitated the actual development of the case studies. A series of phone calls were conducted to obtain preliminary information on each firm. In person interviews with managing staff were completed using the semi-structured questionnaire to obtain information. Follow-up correspondence was done when information needed to be clarified.

STRUCTURE OF THESIS

In Chapter 1, I provide a brief overview of the PV manufacturing process and structure of the international supply industry. This review is based largely on a generic model for solar home systems. I present two central arguments. First, PV systems derive from not one, but several distinct manufacturing segments. These manufacturing segments are associated with solar cell fabrication, module manufacture, BOS component manufacture for operation, and BOS component manufacture for billing. The second argument in this chapter is associated with the geographic distribution of these manufacturing segments. In high technology industries, the capital and skills required for primary manufacturing are generally so great that these activities are undertaken in early-industrializing countries. With the exception of India, this characterization holds true. Firms in early-industrializing countries continue to dominate the market for manufacture of solar cells and modules, although the share of modules produced in developing countries is growing steadily.

Chapter 2 provides an overview of the non-economic factors that have influenced the development of the market for the supply of PV components and systems in South Africa. Sixty firms are currently involved in the manufacture and distribution of PV devices. Most companies engage in distribution and production of BOS components. The number of South African firms involved in the market has declined rapidly since the late 1980's, because of changes in the electric supply industry and political climate. In this chapter, I examine how each of these factors has influenced firms' decisions to enter the market and opportunities for performance.

In Chapter 3, I investigate the learning trajectories of two South African firms. My discussion centers on the relative importance of each type of learning mechanism in the acquisition of capabilities. The case studies suggest that with respect to module manufacturing South African firms rely far more heavily on learning relationships associated with their suppliers, than learning derived from the human resources internal to the firm or the policy and/or regulatory framework developed by government. For BOS manufacture, industry information suggests that government intervention has also assumed a limited role. That South African firms have entered this market without significant public-sector support is astonishing, given the history of PV market development in other countries. In India, for example, local firms have relied heavily on government policy and regulation to facilitate their entrance into more technologically complex areas of operation. The implications of this comparison are that South African government should pursue a more explicit framework for promotion of industrial learning, if it hopes to build manufacturing competencies in markets for renewable energy devices and other high technologies.

In the concluding chapter, I critique alternative strategies for promotion of industrial learning and make recommendations for further policy and research.

CHAPTER 1: FINDING A NICHE IN THE GLOBAL MARKET

In this chapter, I examine how the nature of the photovoltaic manufacturing process and structure of the international supply industry influence opportunities for local production in South Africa. My analysis emerges from the presumption that the levels of capital intensity and technological sophistication associated with manufacturing are significant determinants of where along the supply chain firms enter the market. For example, in high technology industries, primary manufacturing requires equipment that is costly and specialized. Staff is expected to have university training, generally at the graduate level, so that they are capable of overseeing the technical aspects of production and managing business processes. These combined prerequisites constrain primary manufacturing to those regions where basic infrastructure is good, the supply of inputs reliable, and access to universities and other technical institutions proliferate. As a result, firms in countries with developing economies are often restricted to undertaking secondary manufacturing or business activities that take place at the lower end of the downstream sector (e.g. distribution and servicing).

A brief review of the manufacturing process for solar home systems (SHS), an application of PV technology commonly used for rural lighting and basic power supply, suggests that the international distribution of manufacturing activities in the PV industry should fit the 'high-technology model'. However, case evidence from India reveals that this model is questionable when the public sector spearheads market development. Over the last six years, India has consistently ranked among the largest producers of PV modules outside of industry leaders in Europe, Japan, and the United States. Public sector investment in firm development and research activities in India dates back to the late 1970's, while private sector-led activities did not emerge until early 1990. The implication of this finding is that if firms in South Africa wish to build sufficient capabilities to enter this market, the public sector should assume a prominent role in promotion of learning.

PHOTOVOLTAIC SYSTEM MANUFACTURE

The following section offers a review of the manufacturing process and basic operations of Solar Home Systems (SHS). For simplicity, I review a generic SHS model comprised of the following specifications: 50 Wp PV array,[41] a rechargeable battery for energy storage, a battery charge controller, fluorescent lights, mounting hardware, and a variety of electrical components for power control. My aim is not to detail the intricacies of each step in the production process, but rather to identify the complexities and input requirements (capital, technical, human) of various stages. This information provides a basis for examining under what conditions manufacturing in developing countries is possible.

Solar Cell Operation and Early Applications

PV systems contain two major sets of hardware: PV modules and balance of system (BOS) components. PV modules, which consist of a series of packaged solar cells, are generally wired together into an array (**Figure 1.1**). Arrays can range from one module to hundreds, depending on how much power is required for the system (**Figure 1.2**). BOS equipment refers to ancillary components needed for mounting arrays, power storage, conversion from direct current (DC) to alternating current (AC), and site-specific installations.

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[41] The capacity of a photovoltaic module is defined in terms of Watts peak (Wp) of power output. Watts peak is defined as the output under peak sunshine conditions of 25°C and irradiance of 1 kilowatt per square meter (1 kW/m^2.

Figure 1.1 Flat Plate PV Array[42]

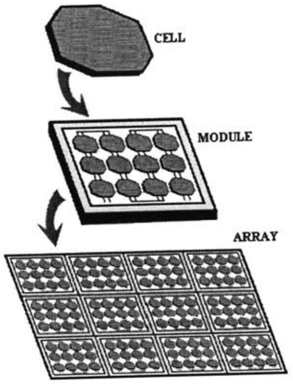
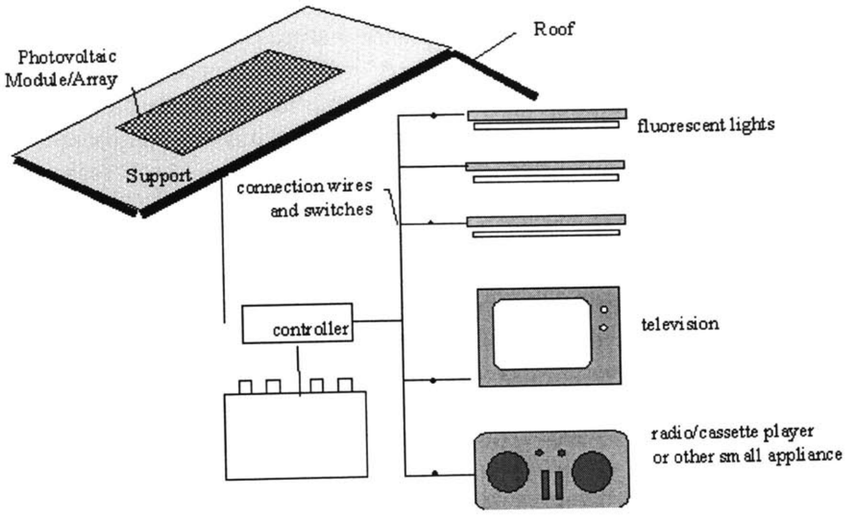


Figure 1.2 Typical Solar Home System[43]



Solar cells are the fundamental power conversion unit of PV modules. They operate based on the ability of semiconductors to convert sunlight directly into electricity by means of the photoelectric effect. Simply put, the photoelectric effect involves the emergence of electric voltage between two electrodes when they are struck by light. This phenomenon was discovered in 1839 by the French physicist, A. Edmund Becquerel.[44] However, applications for use of this technology did not develop until the 20th century, because incident light to electricity conversion efficiencies[45] were rather poor at just 1% - 2%.[46] In 1954, American scientists at Bell Labs developed the first solar cells, as a byproduct of research they were conducting on the use of silicon technologies for transistors and integrated circuits.[47] Their research into silicon-based solar cells raised conversion efficiencies to just under 6 % by 1956, and motivated interest in applications of PV technology for space vehicle power supplies.[48] In 1958, the first solar cell-powered satellite, Vanguard I was launched by the US space

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[42] This picture presents a flat-plate PV array. Concentrating collectors are an alternative designed that, given the limitations of space, are not discussed in this chapter. Concentrating collectors use a lens to focus the sunlight onto the cells.

[43] Solar home systems are an example of one type of application that is common in household rural electrification schemes. With respect to system design and manufacture, I will be referring to this model.

[44] Raphael Edinger and Sanjay Kaul, 2000, Renewable Resources for Electric Power: Prospects and Challenges, (Westport, CT: Quorum Books) 24.

[45] The conversion efficiency of a solar cell is the proportion of solar energy that the cell converts to electric power. If the conversion efficiency is low, more cells are needed to produce a given amount of power, which in turn increases the price of the system. Conversion efficiencies were so low during the 19th and early 20th century that system prices remained above commercial market levels.

[46] Richard Acker and David Kammen, 1996, "The Quiet (Energy) Revolution: Analysing the dissemination of photovoltaic power systems in Kenya," Energy Policy 24(1): 81 – 111.

[47] Solar cell technologies have benefited tremendously from innovations in the microelectronics industry, as evidenced by the fact that solar cells developed in 1954, just six years after the first transistors was created at Bell Laboratories. For further information on the synergistic relationship between these two technologies, see Michael Fitzgerald, 1999, The History of PV, Colorado: Science Communications, Inc; Tomas Markvart, Ed. 1994, Solar Electricity, New York: John Wiley & Sons.

[48] John Perlin, 1999, From Space to Earth – The Story of Solar Electricity (Ann Arbor, MI: AATEC Publications) 53.

program. The approximately 100 cm^2 system powered a 5 milliwatt backup transmitter for 8 years.[49] From that period on, solar cells became the preferred solution for power supply to satellites and spacecraft. Research into solar cell applications in space improved conversion efficiencies to 10 % by the beginning of 1960.

Commercialization of terrestrial applications of solar cell technology did not occur until mid-1970, because manufacturing costs were too expensive for most private firms to enter the market and governments exhibited little interest in subsidizing either research or production processes. While some American firms continued to conduct research on silicon-based solar cells, it was not until the OPEC oil embargo of 1973, that the technology captured the attention of private investors and governments alike. The reductions in world oil supply and associated spike in consumer prices sparked international interest in the potential of solar (PV) systems as a means to decrease reliance on oil imports. Taking the United States as an example, the effects of the oil embargo on the market for solar cells are clear: in 1974, the U.S. government allocated $ 400 million per year for solar cell research, a figure up from $1 million during the previous fiscal year.[50] The Japanese government responded similarly. Japan accelerated research into solar cell technology in 1974 and again in 1978.

Solar Cell Materials and Fabrication

A typical solar cell consists of semiconductor material, an anti-reflective layer, a front contact to allow the electrons to enter the circuit, and a back contact to allow the electrons to complete the circuit. Of these components, the semiconductor layers are the most important, because within these layers the electric current is created and contained. A number of different materials are suitable for fabricating semiconductor layers, but the market for terrestrial applications has been dominated by silicon, in its monocrystalline (x-Si) and polycrystalline (poly-Si) forms (**Table 1.1**). Crystalline silicon currently account for 96 % of total world shipments of solar cells.[51] Despite the complicated manufacturing process through which crystalline silicon cells are produced, they remain popular, because field efficiencies are high and the technology to manufacture them is mature. Over the past three decades, research laboratories have invested significant resources into the development of lower-cost approaches. But, existing alternatives are either at the level of research and development or have not achieved conversion efficiencies comparable to crystalline silicon in the field.

Table 1.1: Conventional and Emerging Materials for Solar Cell Development

Cell Material	Stage	Typical Module Efficiency	Maximum Recorded Module Efficiency
Monocystalline Silicon (x-Si)	Conventional	12 – 15 %	22.7 %
Polycrystalline Silicon (poly-Si)	Conventional	11 – 14 %	15.3 %
Amorphous Silicon (a-Si)	Intermediate	5 – 7 %	---
Cadmium Telluride (CdTe)	Emerging	---	10.5 %
Copper Indium Diselenide (CIS)	Emerging	---	12.1 %

Source: Goetzberger et al. 2002; Margolis 2002; Green 2000

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[49] Peter Holihan, 2001, "Technology, Manufacturing, and Market Trends in the U.S. and International Photovoltaics Industry," in Renewable Energy 2000: Issues and Trends. Washington, DC: National Energy Information Center, U.S. Department of Energy.

[50] Michael Fitzgerald, 1999, The History of PV (Highlands Ranch, Colorado: Science Communications, Inc).

[51] Robert Margolis, 2002, Understanding Technological Innovation in the Energy Sector: The Case of Photovoltaics (Unpublished Dissertation, Princeton University) 62.

Table 1.2 Share of World PV Market by Solar Cell Material (1980 – 2001)

	1980		1991		2001	
Cell Material	MW	%	MW	%	MW	%
x-Si	1.9	57.6	19.7	35.6	136.8	35.5
Poly-Si	1.0	30.3	20.9	37.8	184.9	47.9
a-Si	0.3	9.1	13.7	24.8	47.7	12.3
Other*	0.1	3	1.0	1.8	16.3	4.3
Total	3.3	100	55.3	100	385.7	100

*Other includes Cadmium Telluride, Crystalline Silicon Concentrator, Copper Indium Diselenide, and Thick Film Polycrystal.

Source: Information compiled by the author using Margolis 2002, EIA 1999, Maycock 2003

Heavy reliance on crystalline silicon technologies trades efficiency for cost. Crystalline silicon cells are derived from large wafers of purified silicon. The processes of purifying, crystallizing, and slicing the silicon to create wafers are the most expensive stages of the solar cell manufacturing process (for an overview of manufacturing process see **Figure 1.3**). The expense derives primarily from (i) the cost of purchasing feedstock, (ii) the amount of material needed in the fabrication process, and (iii) the capital costs of equipment. Semiconductor-grade silicon costs about $60/kg.[52] Historically, silicon crystal growing and casting plants have evaded paying this price for feedstock by relying on 'waste' silicon[53] from firms that make semiconductors for integrated circuits. The average cost of waste silicon is $25/kg,[54] a figure that translates into annual feedstock costs of $500,000 for a plant that generates enough cells to produce 1 MW of power per annum (**Table 1.3**). Unfortunately, recent growth in the PV industry has increased the demand for waste silicon in excess of what is available from the semiconductor industry. Since no silicon supply industry exists specifically for PV applications, feedstock supplies are diminishing rapidly. This relative shortage has varied prices considerably and set feedstock costs have been on a steady upward trajectory since the mid-1990.

Table 1.3: Estimated Cost of Silicon Feedstock by Plant Size (Figures in Million USD, 2003)[55]

	Cell Plant Size (MW)*						
Cost of Feedstock ($/kg)	0.125	0.25	0.5	1.0	10	25	50
25	0.063	0.125	0.250	0.50	5.00	12.50	25.00
35	0.088	0.175	0.350	0.70	7.00	17.50	35.00
45	0.113	0.225	0.450	0.90	9.00	22.50	45.00
55	0.138	0.275	0.550	1.10	11.00	27.50	55.00

*For comparative purposes note that in India, cell plant sizes range from 0.5 MW to 2.10 MW. In the United States and Japan, production facilities range from 10 MW to 50 MW.

Source: Figures compiled by the author, assuming that feedstock consumption is 20 g/W.

The amount of silicon required to produce crystalline-silicon cells also contributes to its high manufacturing costs. Once silicon crystals as grown, they are placed in casting units to cool. The

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[52] M.R.L.N. Murthy, 2002, Financial and Funding Aspects of Solar Photovoltaic Energy Projects in Developing Countries, Draft Report (Paper prepared for the Meeting of the Consultative Group for Solar Energy Research and Applications, UNIDO, September 30 – October 1, 2002) 8.

[53] Waste silicon refers to silicon that does not fulfill the strict quality specifications of the integrated-circuit industry.

[54] Murthy 8.

[55] Note that these costs pertain only to feedstock and do not include the other inputs required for the production of silicon wafers.

cooled silicon is then sliced to form wafers. The silicon slicing is both cumbersome and materially wasteful, as up to 50 % of the material is generally discarded. Clearly, industry reliance on crystalline silicon greatly increases material consumption needs. In comparison to material alternatives, Goetzberger et al (2002) report that use of crystalline silicon absorbs 20 to 100 times more than the amount of material needed for amorphous silicon (a-Si). In 2001, amorphous silicon accounted for 12.3 % of global cell and module production (**Table 1.2**). Invariably, industry shifts toward amorphous silicon could reduce material costs. Unfortunately, this transition would reduce module efficiencies to the 6 % - 8 % range.[56] Typical module efficiencies for monocrystalline silicon modules are on the order of 12 % - 15 % (**Table 1.1**).

The feedstock costs and production processes for crystalline silicon have significant implications for the international distribution of manufacturing activities, assuming that the market continues along its current path (i.e. no breakthrough innovations in research over the next 10 years). The capital costs and sophistication of the manufacturing process serve as barriers to entry for small firms in early-industrializing countries[57] and for firms in countries without significant experience in semiconductor manufacturing for integrated circuits. According to Solarbuzz (2003), a solar energy consulting company, solar cell plants must be quite large to achieve efficient manufacturing scale and plant utilization. Average sizes in the United States and Japan range from 10 MW to 50 MW in capacity. These facilities consume over 5,000 square feet of plant area. A rule of thumb guide to the capital investment required to build a solar cell plant is that feedstock costs account for just over half of all direct costs. Therefore, based on my estimates of expenditures for silicon feedstock, the cost of operating a plant for the production of crystalline silicon cells is $1 M per MW. Solarbuzz also notes that because this is a highly capital intensive segment in the manufacturing chain, the industry has developed such that solar cell manufacturers are centralized at a few locations within a given country. Solar cell production will typically service both domestic and international markets from one or two facilities.[58]

Photovoltaic Module Manufacture

A flow chart illustrating the basic steps in the manufacture of PV modules is provided as **Figure 1.3**. This stage of the manufacturing process begins once the solar cells have been fabricated. The first step involves the testing and sorting of solar cells to determine the amount of current that each can produce. Sorting maximizes the total power output of modules, because integrating low current cells with high current cells limits the power of the entire module. The next stage is module assembly. Module assembly involves linking cells together to produce a cell string (generally 36 cells or longer). This string of cells is subsequently laminated between protective glasses to form a finished module. Frames are also applied to allow for mounting in the field, or the laminates may be separately integrated into a mounting system for a specific application.[59] Once the module is complete, it is submitted for performance testing.

As can be quickly discerned from this overview, the intricacies of module manufacture are less technologically complex than solar cell fabrication. This segment of the manufacturing chain is very

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[56] Adolf Goetzberger, Joachim Luther and Gerhard Willeke, 2002, "Solar Cells: Past, Present, Future," (Solar Energy Materials & Solar Cells 74: 1-4) 27.

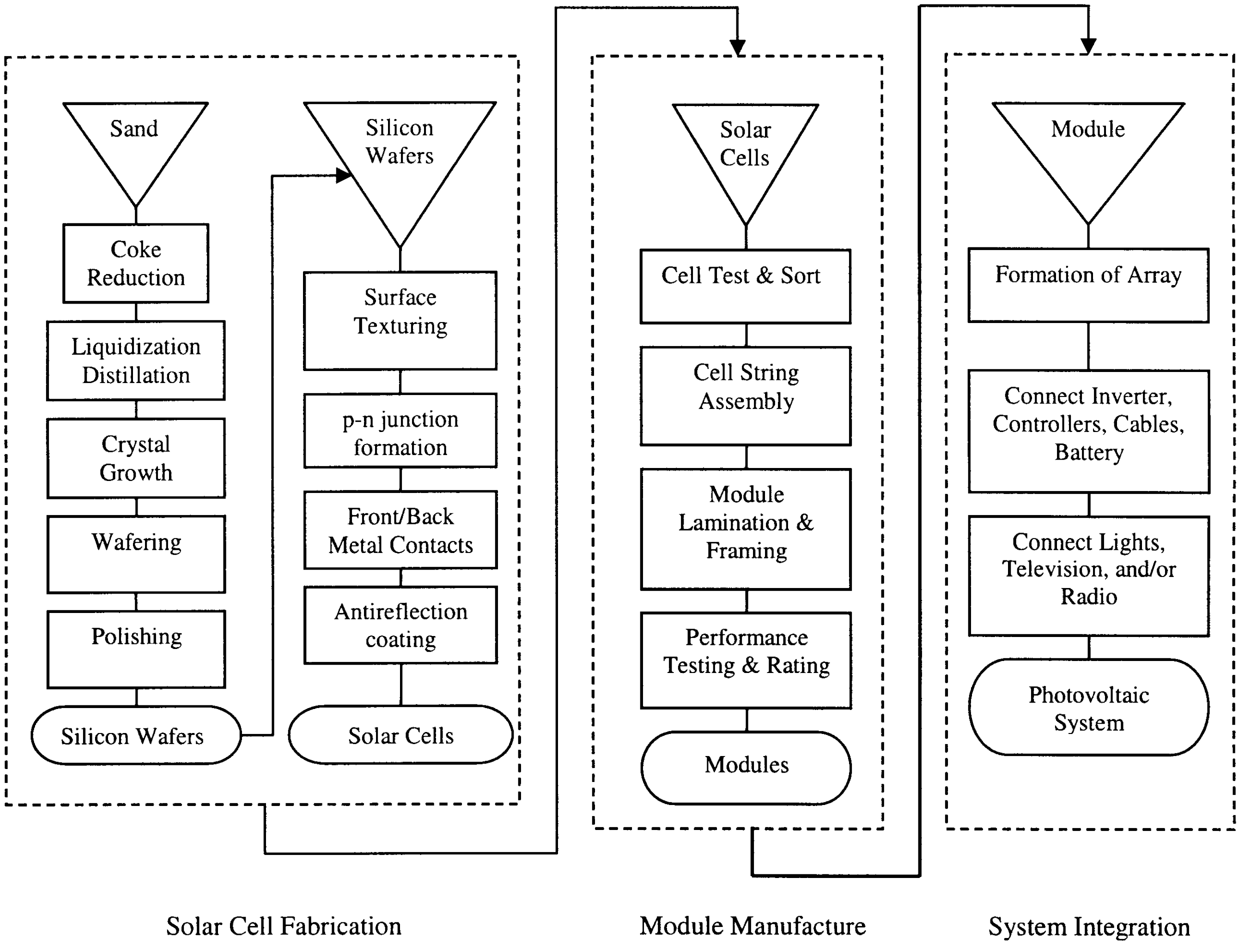
[57] The term 'early-industrializing countries' refers to those countries that industrialized prior to World War II.

[58] Solarbuzz, 2003, "Solar Cell Manufacturing Plants," Uses of Solar Technology [ONLINE] www.solarbuzz.com.

[59] Solarbuzz 3.

labor-intensive and complex to automate.[60] With respect to total manufacturing costs, purchase of the solar cells represents the largest direct expenditure. Menna et al (2003) estimate that the purchase of solar cells represents 76.7 % of the total cost of module manufacture for a 'hypothetical' assembly plant with production capacity of 5 MWp in North Africa.[61] These estimates are based on the assumption that the plant can function efficiently with 7 managerial staff, 2 R&D engineers, and 78 workers for operation and maintenance. Menna et al (2003) derive labor costs from four job categories (administrative, generic, specialized, and managerial), local market conditions, and salary estimates for Morocco. Total labor costs comprise 1.87 % of the total manufacturing cost of $18.31 million (USD 2003) per annum. Roughly, this figure translates into $3.65 million per MWp of silicon-based modules produced. However, I should not that these figures are slightly higher than expected based on case study evidence from select countries.

Figure 1.3 Process Map of Manufacture of Photovoltaic Solar Home System
(Diagram developed by author using Markvart 1994 and Little et al 1997)



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[60] Roger Little, Michael J. Nowland, Keith W. Matthei, and Ghazi Darkazalli, 1997, "Low-cost solar module manufacturing," (Solar Energy Materials and Solar Cells 47) 254.

[61] P. Menna, U. Ciorba, F. Pauli, K. Komoto, K. Kato, J. Song, and K. Kurokawa, 2003, "Analysis of the impacts of transferring a photovoltaic modules manufacturing facility," (Solar Energy Materials & Solar Cells 75) 522.

The manufacturing process enables module assembly to be undertaken in smaller plants closer to end markets, although many cell fabrication companies are also involved in module manufacture. Economies of scale in module assembly can be captured in plants with an annual capacity of 5 MW or greater, and that the cost of equipment for this scale comprises 10 % of total annual costs.[62]

Balance of System Components & System Integration

Assembling modules into arrays and integrating them with BOS components are the final two stages of the manufacturing process. The first step involves the mechanical integration of solar modules into a given array structure (**Figure 1.1**). Arrays are variable in terms of sizes (i.e. the number of modules it contains) and shapes. Whereas the sizing of the array depends on the amount of power required, the shape is a function of the final end use, which could involve mounting the system on a pole or placing it on a roof, etc.

Ancillary equipment, referred to as the balance of system (BOS) components, is necessary to install and deliver electricity from the PV module. For SHS, BOS components include the mounting frame, batteries, inverters, charge controllers, and a variety of cables, clips, switches, and other items for operation and billing. Since the demand for electric power does not always coincide with the availability of solar energy supplies, batteries allow for power storage. Nearly all batteries used in SHS are 12-V lead-acid batteries. Nickel-cadmium batteries are also used when smaller amounts of electric power are required. The various electronic devices attached to PV modules accommodate the variable nature of power output and convert the DC power produced by the module into AC output for use in electric appliances.

System integration is the least capital intensive process of the three major segments in the manufacturing chain. System integration doesn't require the construction of large plants, as much of the work can be performed by sales companies or technicians charged with installing the system for end use. For countries with developing economies, an added benefit is that existing electronics firms should be able to manufacture BOS components with a few minor adjustments in their product lines. Unfortunately, few sources provide data on total manufacturing costs for BOS systems and system integration functions. Presumably, for BOS components, manufacturing costs derive from the cost of introducing new products in the well established electronics industry. System integration represents a relatively labor-intensive process in which personnel accounts for much of the expenditure.

GEOGRAPHIC DISTRIBUTION OF MANUFACTURING ACTIVITIES

If the international distribution of manufacturing activities in the PV technology parallels that of most other high-technology industries, then more technically sophisticated and capital-intensives processes should be centralized in early-industrializing countries. With the exception of India, this characterization is largely correct. The production of silicon wafers and solar cells is concentrated in the United States, Japan, and select countries in Europe. The industry profile of firms involved in less automated processes, such as cell-string assembly, is more diversified. Subsidiaries of multinational solar energy companies developed module assembly facilities in Brazil and Kenya in the early 1990's. Locally owned module assembly plants emerged somewhat later. Toward the lower end of the manufacturing chain, local ownership of productive activities is more widespread. Numerous system integration companies can be found in countries where photovoltaic systems have been widely utilized in off-grid applications. Among many others, these include Brazil, Indonesia, Kenya,

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[62] Solarbuzz 3.

Mexico, and Sri Lanka. In addition, many developing countries supply the BOS equipment necessary to install the module and deliver power from it.

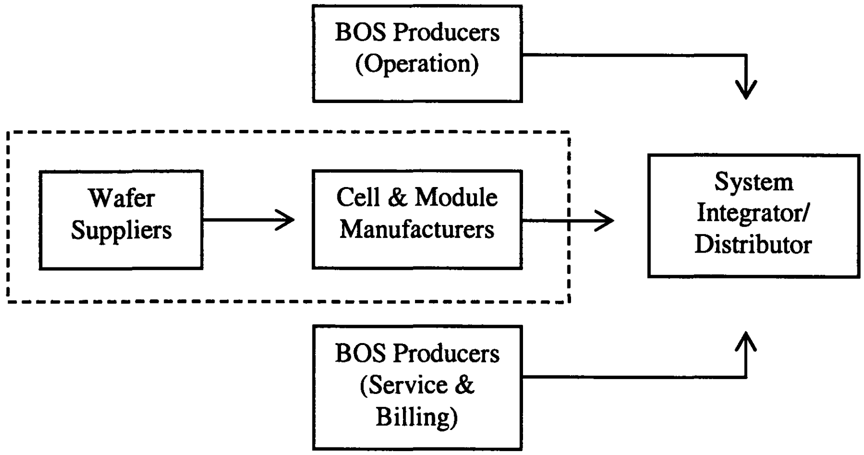
India stands out, because, unlike most developing countries, it has significant local capacity to produce silicon wafers, solar cells, and finished systems. In terms of manufacturing output (MW), India produces more finished cells and modules than Australia, China, and Taiwan. The Government of India has facilitated the country's entrance into more technologically complex areas of production. As Maycock (2002) states: "[Since the 1970's,] the [Indian] government emphasized indigenous PV technology development with duties over 60 % and government funded construction of manufacturing plants at [the public sector, electrotechnology companies] Central Electronics, Ltd and Bharat [Heavy Electrical, Ltd.]. While the early programs were criticized, they did result in 3-4 MW of in-country cell production and established an early supply market."[63] No privately held firms entered the supply market until the early 1990's. State-owned enterprises dominated the market and support research activities for more efficient silicon wafers and solar cells.

From Production Pipeline to Industry Structure

Along the manufacturing segment of the global supply chain, the structure of the PV industry aligns closely (but not exactly) with the various stages of the production process. Broadly, manufacturing firms assume one or more of the following functions: wafer supply; cell manufacture; module manufacture; BOS component supply for billing; and BOS component supply for power storage; and system integration. At the end of the downstream sector, non-manufacturing firms are primarily involved in revenue collection, system distribution, and servicing.

Vertical integration of manufacturing tasks is increasingly common. This trend is particularly true with respect to cell and module manufacturers. While some companies purchase ready-made solar cells, the vast majority of firms operating in the United States, Europe, and Japan align cell and module production in one facility. A similar trend is taking place at the service end of the supply chain. Since the system integration process is not capital intensive, one company generally undertakes system integration, distribution, and servicing functions. Considering these trends, a broad schematic overview of the structure of the industry is provided in **Figure 1.4**.

Figure 1.4: Production Pipeline Accounting for Industry Structure



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[63] Paul Maycock, 2002, The World Photovoltaic Market 1975 – 2001 (Virginia: Photovoltaic Energy Systems) 28.

Wafer Suppliers

Little information is available about the structure of the industry for wafer supply. Anecdotal evidence suggests that most companies involved in the manufacture of crystalline silicon cells produced their own wafers until around 1990.[64] At this juncture, growth in the supply sparked interest in the development of a market for independent wafer supply. Currently, the most prominent wafer suppliers are located in Europe, Japan, and the United States: Deutsche Solar (formerly Bayer Solar of Germany), Hemlock (US), PV Crystalox Solar (UK, Germany), Scan Wafer (Norway), Tokuyama Soda (Japan) and Wacker Chemie (Germany). Combined, these firms account for the majority of silicon wafers produced for the PV market.[65] Among developing countries, India has local capacity to produce about 2 million wafers. There are approximately 9 solar cell manufacturers in India.[66]

Cell and Module Manufacturers

Large firms operating out of America, Europe, and Japan dominate the cell and module production segment of the manufacturing chain. Japanese manufacturers accounted for 43.8 % of the 391 MWp global market in 2001 (**Table 1.4**), while European and American manufacturers respectively held 22.1 % and 25.7 % (Maycock 2003). Not all of the global production of 391 MWp was used in applications for electric power to residential and industrial users. Of the 391 MWp produced in 2001, about 40 MWp was created for use in consumer products such as calculators, watches, and other electronics. The remaining 351 MWp was devoted to power supply for either residential markets connected to the grid or industrial and residential markets in areas where the national grid has not been extended.[67]

Table 1.4 Percent of Cell and Module Production for Consumer and Commercial Markets (In percent of total MW manufactured)

Country*	2001	2000	1999	1998	1997
Europe	22.1	21.1	19.9	21.6	24.2
Japan	43.8	44.7	39.7	31.6	27.8
United States	25.7	26.1	30.2	34.7	40.8
Rest of World	8.4	8.1	10.2	12.1	7.2 %
Total	100 %	100 %	100 %	100 %	100 %

* Manufacturing in these countries includes subsidiaries of multinational companies (e.g. BP Solar India for 'rest of world'), along with those companies that are locally owned.

Source: P. Maycock, PV News, Vol. 19:3 (March 2000); P. Maycock, PV News Vol 22:3 (March 2003)

Table 1.5 distributes cell and module manufacturing activities by firm ownership and plant location. Unfortunately, the relative distribution of ownership can not be viewed strictly in term of those countries listed above. A tremendous amount of consolidation has taken place over the last 13 years. Holihan (2000) reports: "In the early 1990's, ownership of PV manufacturing capacity consolidated as Siemens purchased Arco Solar in March 1990 and ASE purchased Mobil Solar in 1994. By 1997, about 80 percent of PV shipments from the United States were attributable to manufacturing capacity

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[64] Paul Maycock. Interview: January 13, 2003

[65] S. Narayanan, 2002, "Large area multicrystalline silicon solar cells in high volume production environment – history, status, new processes, technology transfer issues," Solar Energy Materials and Solar Cells 74: 110.

[66] Ibid.

[67] Maycock 10.

owned by Siemens Solar and ASE Americas, both German firms, and BP Solarex, a British firm."[68] These mergers were followed by the amalgamation of ASE and RWE in 2002; the company has formerly retained the name RWE, but operates its solar division under ASE. Also, in April 2002, Shell acquired Siemens Solar.

Table 1.5 Cell & Module Manufacturing Output (MW) by Firm 1997 - 2001

Firm (Owner)	**Plant Locations**	**1997**	**1998**	**1999**	**2000**	**2001** (Global Share)
ASE (German)	USA	4.00	4.00	4.00	4.00	5.00 (1.28 %)
	Germany (RWE)	2.00	3.00	7.00	10.00	16.00 (4.10 %)
AstroPower (USA)	USA	4.30	7.00	12.00	18.00	26.00 (6.66%)
BP Solar (US)	USA (Solarex)	14.80	15.90	18.00	20.47	25.22 (6.46 %)
	Spain	11.30	4.50	5.00	9.16	12.16 (3.11 %)
	UK	11.30	4.50	5.00	---	---
	Australia	---	5.10	5.50	5.76	6.96 (1.78 %)
	India	---	3.80	4.00	6.50	8.06 (2.06 %)
Kyocera (JAP)	Japan	15.40	24.50	30.30	42.00	54.00 (13.83 %)
Helios (ITA)	Italy	1.40	1.50	1.30	1.50	2.20 (0.56 %)
InterSolar (UK)	UK	1.20	1.30	2.00	2.50	3.00 (0.77 %)
Isophoton (SPA)	Spain	2.70	4.20	6.10	9.50	18.02 (4.61 %)
Sharp (JAP)	Japan	10.60	14.00	30.00	50.40	75.00 (19.2 %)
Sanyo (JAP)	Japan	4.70	6.50	13.00	17.00	19.00 (4.87 %)
Photowatt (FRA)	France	5.70	12.00	10.00	14.00	14.00 (3.58 %)
Shell (USA)	Neth/Germ (Shell)	2.00	2.00	2.00	2.20	2.80 (0.72 %)
	USA (Siemens)	22.00	20.00	22.20	28.00	39.00 (9.99 %)
	Germany (Siemens)	0.00	0.00	2.00	2.00	2.00 (0.51 %)
Other	Various	12.4	21.1	25.36	44.66	62.58 (16.00 %)
WORLD TOTAL		125.8	154.9	201.3	287.65	390.54 (100 %)

Source: Holihan 2000; Maycock 2002; Maycock 2000

Manufacturing activities that take place on Japanese soil are generally owned by Japanese firms. Like their American counterparts, Japanese companies have been in the market for more than thirty years. Since 1995, Japanese companies have been gaining market share over firms that operate in Europe and the United States. In 2001, Sharp's 75 MWp (19 % of the global share) secured its place as the leading producer of cells and modules for the second year in a row. Kyocera's 54 MWp (13.83 % of the global share) placed it in second. What is most notable from the above figures is that the period during which the Japanese economy so-called 'slumped' coincides with a significant rise in the region's global market share. This finding suggests that the Asian financial crisis did not slow down the output of existing production facilities, though it certainly may have postponed plans for expansion.

Japan's entrance into the PV supply market has antecedents in the early 1960's, when the Ministry of International Trade and Industry (now referred to as the Ministry of Economy, Trade, and Industry) commissioned one of its independent consulting agencies, the Industrial Structure Council (ISC), to examine the environmental effects of the country's industrial development strategies. The ISC's final report, referred to as "A Vision for the 1970's," was made public in May 1971. Among its many

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[68] Peter Holihan, 2000, "Technology, Manufacturing, and Market Trends in the U.S. and International Photovoltaics Industry," in Renewable Energy 2000 (Washington, DC: U.S. Department of Energy) 2.

recommendations was the development of the 'New Energy Technology R&D System," which has become known as the Sunshine Project.[69] This project catapulted the Japanese into the most capital-intensive and technologically advanced segment of PV production. From 1974 to 1983, the Sunshine Project was largely devoted to solar cell production, with a particular emphasis on the manufacture of raw crystalline silicon materials. The Japanese did not move into the less technologically-sophisticated downstream sector until 1984. During the second decade under this program (1984 – 1993), the largely government-driven research effort expanded its efforts from material research to operational initiatives for improving PV system development. In 1993, the New Sunshine Project was initiated as a more comprehensive attempt to promote research and dissemination of the technology.

Outside of Europe, Japan, and the United States, the percent of solar cells and modules produced in other countries has fluctuated between 8 % and 12 % (**Table 1.4**). The total output of 'the rest of the world' increased steadily from 6.35 MWp in 1995 to 32.62 MWp in 2001, although the share of global production share declined owing to Japan's increasing performance. Much of the improvement in manufacturing in the rest of the world can be attributed to India. In 2001, India accounted for 44.6 % of the total photovoltaic power produced in the 'rest of the world,' a figure slightly lower than its contribution of 51.1 % in 2000 (**Table 1.6**).[70]

Table 1.6 Percent of Solar Cell and Photovoltaic Module Production in Rest of World (In percent of total MW manufactured)

Country	2001 (%)	2000 (%)	1999 (%)	1998 (%)	1997 (%)
Australia	21.3	24.6	26.8	27.2	---
China	9.20	10.7	9.8	8.5	16.0
India	44.6	51.1	48.8	49.2	55.3
Hong Kong	4.0	---	---	---	---
Taiwan	19.9	12.8	13.7	13.9	26.6
Other Countries	1.0	0.8	0.9	1.2	2.1
Total	100 %	100 %	100 %	100 %	100 %

Source: Paul Maycock, 2002, The World Photovoltaic Market 1975 – 2001 (Virginia: Photovoltaic Energy Systems) Appendix

India contains roughly 22 module manufacturers and 50 system integrators. Most of these companies are small businesses. In terms of manufacturing output (MW), the largest module manufacturing plant is a joint venture between BP Solar and Tata Power.

BOS Component Suppliers & System Integrators

BOS component supply and system integration activities are decentralized. Quite often, they take place in the country in which the systems will be installed, because manufacturers benefit from the feedback they receive from end-users. If a country has a well established electronics industry, then companies that manufacture BOS components for operation tend to be locally owned. BOS component suppliers ship batteries, wires, and inverters to system integrators for completion of the solar home systems and distribution. If a country does not have a relatively well developed electronics industry, it may choose to import finished solar home systems or other PV devices.

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[69] Suren Erkman, 1997, "Industrial Ecology: A Historical View," Journal of Cleaner Production.

[70] Paul Maycock, 2002, The World Photovoltaic Market 1975 – 2001 (Virginia: Photovoltaic Energy Systems) Appendix; Paul Maycock, 2003, PV News Vol 22:3.

On the billing and servicing side of operations, developing countries have been able to make significant innovations in BOS component design. For example, South African manufacturers have partnered with US companies to design prepayment devices that allow households to pay in advance for monthly use of PV solar home systems. Households supply cash to local vendors, and in exchange receive a token that will operate the PV device for a specified period (approximately 1 month). When that period expires, households return to the vendor to purchase another prepayment token.

INDIA'S ENTRANCE INTO THE PV SUPPLY INDUSTRY

India's evolution in the PV supply industry is worthy of discussion, given the country's strong performance over the last five years. Programs to promote photovoltaic research in India date back to 1976, when the government allocated funding to investigate solar cell design and simple applications. Between 1976 and 1993, the Department of Non-Conventional Energy Sources promoted photovoltaics through sponsorship of two public companies, Central Electronics, Ltd (CEL) and Bharavat Heavy Electrical, Ltd. According to Agarwal et al (1983): "CEL was established as a public company to research solar cells, and to develop production facilities with a 1 MW peak capacity by 1983. So far, CEL has been importing silicon ingots and making cells from them, but it hopes to produce an all-Indian product (silicon made, sliced, and doped in India) by 1985. With a 1980-1985 budget of over $19 million USD, CEL is also keeping abreast of worldwide developments in other cell producing technologies such as ribbon growth, amorphous silicon, and the use of other materials such as gallium arsenide for the cells."

Through CEL and other ventures, the India government promoted technological learning through significant investment in R&D and strong protectionism. For example, the Indian Department of Science & Technology promised 430 million rupees ($47.4m) for R&D alone between 1980 and 1985. This figure includes funds directly allocated to CEL for its research activities. In addition, the Government of India explicitly prohibited competition from overseas manufacturers. The government refused to grant import licenses to American companies or to Indian firms interested in collaborating with foreign multinationals for the manufacture of PV devices. Any PV systems that were imported came strictly as demonstration projects, allowing CEL and Bharavat to become familiar with the operation of various applications. Partnership with foreign firms did not occur until 1993, when BP Solar established a joint venture with Tata Power. The outcome of their collaborative efforts was Tata BP Solar India, which is presently the largest manufacturer in the country. Tata BP Solar India accounted for 42 % of the country's cumulative output in 2001.

Additional measures to foster technological learning concern the institutional environment within the national government itself. India's institutional approach can be characterized by two central features. The first concerns the creation of special-purpose bodies whose sole mandates are to develop indigenous technological capabilities in this field. India has the only national ministry devoted explicitly to promotion of renewable energy sources in the world. MNES demonstrates a clear political commitment to renewable energy. MNES is primarily responsible for policy formulation, resources assessment, R&D, and large-scale utilization of new and renewable sources of energy. The ministry has three broad divisions: rural energy, power generation, and energy from urban and industrial wastes. The second feature is directly related to the organizational structure of MNES. MNES oversees several government-sponsored institutions that provide it with technical support. The responsibilities of these institutions thematically cross the entire spectrum of renewable energy activities, but they are essentially R&D labs. The Solar Energy Center, the Center for Wind Technology, and National Institute for Renewable Energy test devices, upgrade production technology, and improve the efficiency of operating systems in their respective fields.

Examination of India's approach to the promotion of technological learning must include some qualification, however, because many authors contend that the country has overly committed itself to producer-subsidies and government-sponsored R&D. Since 1990, the Indian Renewable Energy Development Agency (IREDA), a government body within the Ministry of Non-Conventional Energy Sources (MNES), has labored to balance the government's supply-side interventions with growth of the consumer market and end-user financing. Certainly, IREDA's mandate is overwhelming. India has one of the most well developed institutional structures for promotion technological learning among manufacturers in the renewable energy field. And, as specified above, India maintained restrictive licensing systems that allowed foreign imports only in very specific circumstances. Clearly, the country's approach makes it an outlier. Nevertheless, the case has several lessons to offer South Africa, particularly with respect to the institutional setting in which policies emerged.

CONCLUSION

The first section of this chapter demonstrates that PV systems comprise not one, but several distinct manufacturing segments. The structure of the manufacturing chain loosely aligns with the major production activities. Firms fall into one of the following industries: solar cell fabricators, module manufacturers, BOS component suppliers for operation, and BOS component suppliers for billing and services. Of these industries, solar cell fabrication is by far the most complex and, as a result, is largely concentrated in early-industrializing countries. Given the structure of the market and capital required for investment in production of solar cell technology, few developing countries will be able to enter this market in the short-term. Greater opportunities lie in the markets to supply modules and BOS components. Nevertheless, India's entrance into the more technologically complex segments of manufacturing, suggest that technological leaps are indeed possible. With strong government promotion and investment, public policy may be the key to establishing an institutional and operational environment where manufacturing capabilities can be developed.

CHAPTER 2: THE COSTS OF LOCAL GENERATION

The result of over twenty years of experience with the use of PV technology is that South Africa contains about 60 firms that are involved in the manufacture and distribution of PV devices. These companies primarily supply PV systems for use in off-grid electrification and remote telecommunications. Local supply of solar-powered water pumps is also quite common. In regard to firm activities, a large percentage of companies distribute international brands (39 %) manufactured by Shell (Siemens), BP Solarex, and Kyocera. South African firms manufacture balance of system (BOS) components (21 %) and undertake system integration functions (15 %) locally. Only three firms assemble modules. Majority ownership of module manufacturers rests with European holders, but small shares are held by South African investors.

The structure of the PV supply industry provides a clear indication of the challenges inherent to entering this market and the costs of undertaking production activities, rather than sourcing products from foreign manufacturers. The small number of module manufacturers and BOS component suppliers relative to the number of distributors suggests that South African firms exhibit strong interests in entering into this market. But, as discussed in Chapter 1, the requirements for capital and technological sophistication are prohibitive barriers. In additional, several non-economic factors must also be taken into consideration. In particular, the political transition and ongoing efforts to liberalize the electric power industry have significant implications for the composition of the local market to supply PV devices. In this chapter, I investigate how each of these issues influences firms' decisions to enter the PV supply market and the risks associated with these choices. What follows is a contextual overview of the development of the electric power industry in South Africa. I outline critical junctures in its evolution, and the implications of industry structure for opportunities in the market for PV systems.

SOUTH AFRICA'S ELECTRIC POWER INDUSTRY

Brief History

Historically, low cost electric power generation has assumed an important role in South Africa's mining and industrial development strategies. The discovery of diamonds and gold in the latter half of the nineteenth century created an immediate demand for electric power generation. According to Abedian and Standish (1992): "The diamond and gold fields were situated in the then undeveloped interior of the country. In addition, gold deposits were rarely of the alluvial type, so heavy equipment, power supplies, and large forces of organized labor were required to extract and process the ore." Spurred by the capital invested in the mining industry, the electric power industry quickly expanded. By 1895, Cape Town, Johannesburg, and Pretoria had steam-powered and hydro-electricity generating stations. In 1897, Rand Central Electric Works constructed the first commercial power station, mainly to serve the gold industry around Johannesburg.[71] During this period, ownership of generation capacity was distributed among a host of municipalities and private investors. Eberhard (2003) observes that it was not until 1920 that connecting individual power stations into a single network was viewed as an effective mechanism for supplying low cost electricity for the gold and iron industries.[72]

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[71] Anton Eberhard, 2003. The Political, Economic, Institutional, and Legal Dimensions of the Electricity Supply Industry in South Africa. (Paper presented at the "Political Economy of Power Market Reform Conference," convened by the Program on Energy and Sustainable Development at Stanford University, 19-20 February 2003) 8.

[72] Ibid 7.

With the Electricity Act of 1922, the Electricity Supply Commission (ESCOM) was created and given a mandate to generate and distribute electricity at the lowest cost possible. South Africa's large supply of low-grade coal and a system of subsidized pricing for the consumer market allowed ESCOM to pursue its directives. By 1950, ESCOM acquired most of the generation capacity in the South Africa. By 1978, it also owned the vast majority of the transmission network.[73]

In an assessment of power-grid integration efforts in the United States and Soviet Union, Morton (2000) writes: "An unanticipated result of the growing scale of regional power networks was the increased possibility of massive outages. Utilities faced new technical and organizational problems both in controlling power flows within these huge networks and coordinating their activities."[74] South Africa's generation troubles between 1978 and 1984 mirror those of early-industrializing countries. By 1983, ESCOM had 22,260 MW of generating capacity on order, a figure that was twice the size of the current operating capacity.[75] ESCOM's overcapacity and pattern of overinvestment resulted in several power outages. Although outages were far less frequent than those encountered in African countries like (and even in the United States during the same period), they sparked immense concern from industry stakeholders. Vociferous calls for reform led the government to establish a commission to investigate ESCOM's financial standing and management procedures. In 1983, the De Villiers Commission heavily criticized the utility, citing a history of overinvestment and inappropriate accounting. The Commission's findings resulted in the transformation from ESCOM to Eskom, a change denoting a new governance structure and more corporate approach to operations.[76]

This period marks the first of several attempts to reorient the electric power industry toward commercialization and eventual privatization. The shift in policy does not reflect concern about Eskom's efficiency and financial standing, but rather changing ideologies about the role of the state in economic activities. To understand why, it is first necessary to benchmark Eskom's performance in relation to its peer utilities in both Africa and the rest of the world.

Generation Capacity & Distribution

Currently, Eskom produces 96 % of the electricity generated[77] in South Africa. Independent power produceRs generate slightly more than 3 %; municipal generators provide the remaining portion (**Table 2.1**). In terms of both capacity and performance, Eskom's role cannot be understated. In 1997, it ranked among the top five utilities in the world based on both capacity and sales.[78] Eskom currently ranks seventh.[79] Regionally, the utility dominates the electricity market of sub-Saharan Africa (SSA). Its generating capacity is more than sufficient to allow it to produce two-thirds of the electric power generated on the continent. The company provides services to Botswana, Lesotho, Mozambique, Namibia, Swaziland, and Zimbabwe.

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[73] Ibid 10.

[74] Morton 7.

[75] Eberhard 5.

[76] Eberhard 9.

[77] This figure refers to the effective generating capacity of each plant. Licensed capacity denotes what plants are technically capable of producing. This figure differs from effective capacity, because of changes in ratings, improvements, and/or usage trends.

[78] Lael Bethlehem, 1997, The Bottom Line: Industry and Environment in South Africa (Cape Town: University of Cape Town Press) 32.

[79] Eberhard 9.

Table 2.1: Power Production by Plant Type and Ownership (2000)

	Eskom		Industrial		Municipal/IPP	
Plant Type	Licensed (MW)	Effective (MW)	Licensed (MW)	Effective (MW)	Licensed (MW)	Effective (MW)
Coal-fired	35,627	29,277	768	728	1,932	646
Hydroelectric	661	660	3	2	4	3
Pumped Storage	1,400	1,542	---	---	180	176
Gas Turbine	342	172	---	---	320	188
Nuclear	1,840	1,810	---	---	---	---
Total	39,870	31,461	771	730	2,436	1,013

Source: Lynch (2002)

Operationally, Eskom performs quite well. It issues bonds in both domestic and international capital markets as a means of financing new investment. Moreover, since the price of South African coal is regarded as being among the cheapest in the world and investments in new capacity have not been made for some time, the prices of Eskom's inputs are relatively small. The manufacturing industry contributes steady revenue toward operations and has enabled the utility to remain financially viable.

Nevertheless, the utility's performance does not suppress incessant calls for privatization. Advocates of privatization argue that inefficiencies in the investment and distribution system require long-term attention. Their rationale follows that although Eskom may appear viable in the short-term; but, its financial and operational activities are not sustainable. Few policy advisors in South Africa support this thinking. However, those that defend this position have the backing of multilateral agencies, such as the World Bank, and strong international interests.

Implications for the PV Supply Industry

When accounting for generation capacity and distribution infrastructure alone, the profile of South Africa's electric power industry mirrors that of an early-industrializing country. The capacity figures demonstrate that the country can produce more than half of the electricity in Africa, given current levels of investment. In light of these characteristics, the emergence of a market for applications of PV technology appears surprising. One reason may be that PV systems have the advantage of being more ecologically and environmentally friendly than coal-derived power. Bond, Dor, and Ruiters (2000) write that per capita emissions of greenhouse gases associated with electric power generation in South Africa are twice as high as the rates recorded in the rest of the world. They continue, "...electricity generation has been associated with high levels of greenhouse gases, very high levels of acid rain, enormous surface water pollution, badly regulated nuclear supplies, and ineffectual health/safety standards in coal mines."[80] Unfortunately, if the environmental implications of Eskom's generation activities are prominent concerns, development of a market for PV systems presents an unlikely solution to this problem. The mineral and transportation industries consume most of the generated capacity from Eskom. The market for supply of can do little to stem green house gas emissions associated with these industries; as outlined in Chapter 1, most applications of PV systems have emerged to service household and public uses.

To understand when and how the PV market has emerged, we must consider the history of Eskom's distribution activities and the maldistribution of investment in infrastructure during the apartheid period. Between 1950 and 1990, a large backlog in service provision to rural areas accumulated. The

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[80] Patrick Bond, George Dor, and Greg Ruiters, 2000, Transformation in Infrastructure Policy from Apartheid to Democracy. Background paper prepared for the Municipal Service Project. (Johannesburg, South Africa: Graduate School of Public and Development Management at the University of Witwatersrand) 9.

apartheid policies institutionalized Eskom's complete disregard for the commercial energy needs of Black households, who resided in township and rural areas. Over this period, the vast majority of rural households (less than 5 %) did not have access to electric power services. Estimates are not available for the rural agricultural, public, and small-scale industrial sectors, but evidence suggests that the coverage statistics are similar.

THE RURAL ENERGY CHALLENGE

The history of under-investment in extending power lines into rural areas has contributed significantly to this backlog in service delivery, but the influence of energy use patterns must also be examined. In this section, I provide a brief overview of the demand-side factors that have also contributed to persistently low levels of electrification in rural areas.

Energy Use Patterns

South Africa's rural areas contain 21 million persons, a figure corresponding to about 3.8 million households.[81] Most of the country's poor are concentrated among this population: the proportion of the rural population classified as poor (based on the international rule of thumb measure of $1 per day) is over 70 % in rural areas, in comparison to 30 % in urban zones.[82] Limited access to income has meant that rural people rely on a diversity of energy sources, particularly those for which cash exchange is not necessary.

Energy services support four major consumption sectors: agricultural, household, industry, and public services. Households account for the majority of energy consumed, as international studies estimate that the household share of gross rural energy consumption lies between 70 % and 90 %.[83] Households use energy for domestic needs, including cooking, communication, entertainment, lighting, and water and space heating. Using data collected by the South African Labor & Development Research Unit (SALDRU) and World Bank for the Project for Statistics on Living Standards and Development (PSLD), Davis and Ward (1995) estimate that wood and paraffin figure most prominently in the household energy consumption mix. Paraffin remains the most widely used fuel – as much as 82 % of households rely on it. In comparison 78 % of households use wood; of this figure, the majority collect it, while a significant percentage (27 %) of wood-users purchases it.[84] Although estimates of the relative dependence on these fuels for specific uses are unavailable, the majority of paraffin and wood consumption are associated with cooking. Davis and Ward (1995) note that households traditionally rely on a combination of these two fuels for boiling water and warming food. Since these activities require significant amounts of energy, reliance on wood for cooking activities will remain a trend in the near future.

Rural households consume far less electricity. Since few attempts at household data collection were made during the apartheid era, the earliest estimates of household rural electrification are for the early 1990s. The evidence is somewhat mixed, but among the most widely cited figures are that 5 % (Eskom 1995), 10 % (Purcell 2002), or 16 % (Davis and Ward 1995) of rural households had access

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[81] Julian May, Ed., 2000, Poverty and Inequality in South Africa: Meeting the Challenge (Cape Town: David P. Publishers) 30

[82] Ibid.

[83] World Energy Council, 1999, The Challenge of Rural Energy Poverty in Developing Countries (London, U.K.: World Energy Council) 45.

[84] Mark Davis and Sarah Ward, 1995, Household Energy-Use Patterns in Rural Areas – The Effects of Access to Electricity (Cape Town: Energy & Development Resource Center, University of Cape Town) 4.

to electricity in 1992. By 1996, Eskom and the Department of Minerals and Energy compiled sufficient data to examine levels of service provision on a national and regional basis. Their data indicated that Eastern Cape and KwaZulu Natal, two provinces that operated as former homelands under the apartheid regime, confront the most significant development hurdles. In 1996, 87.50 % of rural households lacked access to electric power services in the Eastern Cape. The figures were only slightly better in KwaZulu Natal (82.41 %).

Households without access to electricity rely predominantly on candles and paraffin for lighting; they also use car batteries to power entertainment appliances. Davis and Ward's (1995) findings suggest that 45 % of un-electrified households use a candle-paraffin combination, and that the proportion of households that use this combination of fuels is relatively similar across income groups. Among households with access to electricity, many still use candles as a means to decrease expenditures for electric power services.

Table 2.2 Rural Energy Use Patterns & Supply Options

Sector	Activity/Use	Conventional Energy Supply Options	Application for Photovoltaic Devices
Agriculture	Industrial Farming/Irrigation	Diesel Pumps, Electricity	No
	Subsistence Farming	Animate	No
Commerce/Industry	Sewing	Animate, Electricity	No
	Tuckshop	Candles, Electricity	Yes (Lighting)
Household	Thermal (Cooking)	Wood, Paraffin	No
	Non-Thermal (Lighting, Entertainment, Communications)	Candles, Car Batteries	Yes
Public	Schools, Clinics	Electricity	Yes

Source: Davis and Ward 1995; Department of Minerals & Energy 2001

Consideration of household energy needs should not overshadow the demands for energy services for agriculture, industrial, and public use. The type of energy sources used in rural agriculture differs according to levels of mechanization. Some farmers rely on electric motors and pumpsets or diesel engines for irrigation. For subsistence farming, use of animal and human energy is far more common. Energy supply options for health services, education, and community functions have gained increasing attention in recent years. Electricity has assumed particular importance, because it can be used to power educational equipment in schools and to provide refrigeration for vaccines that are critical to the provision of health services in clinics. Unfortunately, outside of a number of disaggregate case studies, no information is available on levels of service provision for this sector.

Although wood remains the primary energy source in rural areas, the role that electric power assumes in the rural energy consumption mix is still significant. Development practitioners have long argued in favor of the promotion of electricity as a means to spur economic development and improve quality of life for rural households. [85] While electricity certainly does not substitute for traditional fuels, research has shown that it serves as a vital input into agricultural, commercial, household, and public activities.[86] Rural households place significant value on electric power for the convenience of having light in the evening. Rural businesses have also been known to laud electricity for enabling food distributors and seamstresses to undertake activities that would not otherwise be possible.

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[85] Barnes, Douglas F., Robert van der Plas and Willen Floor, 1997, "Tackling the Rural Energy Problem in Developing Countries," in Finance & Development 6.

[86] Cecile Thom, 1999, Rural Electrification Policy in South Africa: Some Recommendations (Paper prepared for the "Domestic Use of Electrical Energy Conference, 1999, Cape Town, South Africa) 77.

Addressing the Rural Energy Challenge: Shift in Political Priorities

Despite the role that electric power assumes in the rural energy mix, high regard for its utility among rural dwellers and a shift in government priorities during the early 1990's spawned a number of initiatives to develop alternative solutions for providing power in rural areas. Given the backlog in service delivery to rural areas, infrastructure provision ranked high among the priorities of the transitional government. In 1991, Eskom began a concerted effort to extend grid electricity throughout the country via the 'Electricity for All' campaign. This campaign aimed to extend the grid to an additional 700,000 households by 1997.[87] Progress was made during the first few years of operation, but overall, the pace of the program was quite slow. The ANC established the goal of providing 2.5 million (previously unserviced homes) with electric power services by the year 2000. This target was exceeded and by 2001, leaving the total proportion of non-electrified rural households at 50.90 %.

Table 2.3: Percent of Non-Electrified Rural Households by Province (1996 - 2001)

Province	2001	2000	1999	1998	1997	1996
Eastern Cape	62.34%	66.09%	68.04%	72.54%	76.72%	87.50%
Free State	50.47%	52.41%	39.27%	41.32%	41.37%	62.84%
Gauteng	57.48%	57.48%	46.30%	45.03%	43.83%	46.56%
KwaZulu Natal	64.43%	68.90%	69.66%	71.62%	74.64%	82.41%
Mpumalanga	30.95%	33.70%	24.64%	25.52%	28.55%	49.88%
North West	45.92%	49.97%	45.82%	52.72%	61.73%	72.43%
Northern Cape	40.84%	44.54%	25.25%	25.78%	29.17%	36.39%
Northern	41.89%	45.75%	49.45%	55.01%	61.19%	69.78%
Western Cape	31.39%	34.14%	35.09%	34.75%	35.70%	50.44%
South Africa	50.90%	54.25%	53.71%	57.41%	61.91%	73.03%

Source: Department of Minerals and Energy 1996; Department of Minerals and Energy 2000

SOUTH AFRICAN PHOTOVOLTAIC SUPPLY INDUSTRY

The historical development of the electric power industry and an emergence of the 'Electricity for All' campaign mark critical junctures in the evolution of South Africa's PV Supply Industry. These trends help to contextualize both the costs associated with a firm's decision to enter the market and those costs associated with the firm's decision to undertake production activities.

Early Developments: 1982 - 1992

The local market to supply PV systems dates back to the mid-1980's, when companies emerged to distribute PV systems (primarily solar home systems) to power lodges in game farms and supply electricity to wealthier rural households. Purcell (2002) notes that specialized applications of PV technology also emerged for use in remote telecommunications, network controls, security devices, and water heating.[88] To satisfy this demand, South African companies began to distribute systems manufactured by international suppliers. Between 1982 and 1990, Purcell estimates that

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[87] Paul J. Mare, 1999, Eskom Electrification Beyond 1999 (Paper presented at the Domestic Use of Electrical Energy Conference) 5.

[88] Purcell, Christopher. 2002. *The SA PV Market: Some Key Critical Developments.* Paper Prepared for International Centre for Science & High Technology, UNIDO (Trieste, Italy: United Nations Industrial Development Organization) 3.

approximately 60,000 solar home systems were sold by private distributors.[89] These systems were not aligned with the government pilot projects undertaken at the time.

In 1985, the national government began to explore opportunities for use of PV technology, but limited its activities largely to research reports and pilot projects. The following review of the government's activities is adapted from Purcell (2002): "The Department of Minerals and Energy (DME) funded substantial research into technology problems, cost niches, application niches, and best practice aimed at developing a market for PV devices. A number of pilot and demonstration projects were initiated at the national level to gain experience in applications, such as school and clinic electrification, water pumping, and household electrification. Between 1996 and 1997, the Ciskei Clinic Electrification project was implemented through the Department of Public Works. The project was donor financed and resulted in the provision of PV-powered lights, radios, and vaccine refrigerators for 300 clinics. In 1989, Eskom initiated an ambitious hybrid/diesel project for 14 farms in Northern Cape."

Although opportunities for entrance into the PV supply industry were limited during the early 1980's, they expanded toward the latter end of the decade. Lack of familiarity with PV applications, combined with government policies that impeded opportunities for Black households to exploit this technology, meant that the risks of entering the market were initially high. As government priorities shifted and South Africa gained increasing international attention, a host of local PV supply companies emerged. Many functioned along the lower-end of the supply chain, by opening distribution channels for manufacturers in the United States and Europe. During this period, existing electronics companies also became involved in the production of BOS components. Anecdotal evidence suggests that the market – in terms of total number of firms operative – was somewhat larger. Moreover, competition among locally-owned firms was greater during this period.[90]

Disruptions in the Market: 1992 – 1998

My interviews with firms in the industry and institutional affiliates suggest that the inception of the 'Electricity for All' campaign had a disastrous impact on the market for PV devices. Just as changes in the political climate opened opportunities for local firms to market services to the majority Black population, the national government's pledge to 'extend electric power to all' raised the expectation that households would shortly receive conventional service provision.[91] The national campaign did not eliminate the market for private suppliers, but reoriented it as follows: First, many private companies were forced to work through publicly sponsored programs for the delivery of solar home systems. Essentially, this meant that the market was confined to those areas that Eskom did not target for grid extension. Second, companies scrambled to find niche markets for their applications. Several local firms took advantage of the emerging telecommunications industry. Small single-panel PV systems can accompany rural phones, when grid electricity is not available. Large systems are needed for powering cellphone masts and repeater stations, in places where grid electricity is not at hand. In 1994, commercial initiatives led the way in establishing cell phone industry base stations using 100 x 50 Wp panels.[92]

The adoption of the Reconstruction and Development Program (RDP) accelerated these two trends. RDP was a policy framework developed in 1994 to outline the national priorities of the new government. RDP placed significant emphasis on access to basic services and the development of

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[89] Ibid.

[90] Marlett Wenzel, Interview, March 26, 2003.

[91] David Risk, Interview, March 26, 2003.

[92] Purcell 4.

policies to redistribute wealth across racial lines. The policy formalized the goal of providing 2.5 million new households with conventional electric power between 1994 and 1999.

Foreign Competition

By 2000, South Africa's achievements in extending electric power to rural households were laudable. Despite these accomplishments, however, progress left almost half of rural households without access to electricity. Eskom realized that many of the remaining households would not receive conventional service, given the level of investment required and current pace of connections. Significant numbers of rural schools and clinics were also without service. To address the continued backlog in service provision, the Department of Minerals and Energy (DME) assumed responsibility for promoting extension of off-grid service for private use in rural areas. In 1999, DME developed a concession in which private operators were given rights (though not exclusive) to offer solar home systems in six geographic areas. The first contract was awarded to a joint venture between Shell Renewables and Eskom. Concessionaires are responsible for installing 50,000 systems over the next 5 years. Concessionaires receive a capital subsidy of approximately $320 per installation. To encourage growth in the market, all concessionaires offer lease agreements, in which they are responsible for maintaining the systems throughout their projected 20-year life. Households pay a monthly fee (which is also subsidized) to obtain this service.

The concession for off-grid electrification widened opportunities for foreign manufacturers to operate in South Africa. Based on manufacturing capacity, foreign companies are better suited to deliver the required manufacturing output. As a result, four of the five concessions[93] are comprised of a foreign firm that supplies finished PV modules and a locally-owned company that assists with system distribution, billing, and servicing. In some cases, South African companies supply BOS components. Damian Miller, Director for Shell Renewables operations in South Africa and India, revealed that CONLOG, a South African electronics firm, supplies pre-payment meters for use in the systems distributed by the Shell-Eskom joint venture. Miller notes: "CONLOG aggressively approached ESKOM about supplying pre-paid meters. They worked very hard to secure the deal."[94] CONLOG's contract is short-term. Unfortunately, the Shell-Eskom joint venture does not intend to use this company's services in the future. Miller perceives the systems as unnecessarily complex, and believes that more efficient devices may be attained by foreign manufacturers.

CONCLUSION

This chapter provides an overview of how the structure of the electric power industry and changing political climate influenced the market for PV supply. Must persons affiliated with the industry believe that even if firms can accumulate the capital required to facilitate entrance into the market, the incentives for undertaking manufacturing in-house are few. For local companies, competition for market share is fierce.

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[93] One of the concessions has not been awarded.

[94] Damian Miller, Interview, February 25, 2003.

CHAPTER 3: SOLAR CAPABILITIES

This chapter presents an overview of the experiences of Liselo Solar and Solar Vision, two of three module manufacturers currently operating out of South Africa. Through the use of qualitative case analyses, I explore the relationship between the technological capabilities of each firm and the learning-related activities that have facilitated their development. To the extent possible,[95] I first detail the life history of each firm and identify their level of manufacturing capability. I then examine the nature and relative importance of learning activities that are enterprise-specific, supplier-driven, and government-induced.

My findings suggest that the South African government has assumed a relatively weak role in the promotion of the local PV supply industry. The national government has assumed a more demand-oriented perspective, focusing much of its policy and legislation on the ensuring that poor, rural households have access to lighting. A few capacity building and technical training programs have emerged over the past few years.[96] But, few regulatory mechanisms promote growth of local industry or provide financial incentives for top performance.

LISELO SOLAR

Liselo Solar is a module manufacturer with headquarters in Centurion (Gauteng Province), a small industrial center that lies midway between central Johannesburg and Pretoria. The firm has one module assembly plant in South Africa and employs approximately 40 full-time staff. Additional technical persons are contracted when large orders for PV modules are placed. Although the company's most profitable market segment is rural telecommunications, Liselo also produces building-integrated PV (BIPV) modules for rural clinics and schools, PV-powered street lights, and solar water pumps.[97]

Origins

In 1991, Liselo Solar was established as the second manufacturer of photovoltaic modules in South Africa. The company, initially named Helios SA and then Africa Solar,[98] was the outgrowth of a joint-venture between Italian-based Helios Technology and Dr. Mark Voloshin, a Russian-born entrepreneur. From the time of Liselo's inception until the present, Voloshin has served as Chairman of the holding company, Marvol Group, whose diverse subsidiaries include Marvol Management, Marvol Project Consulting, and the defense-related systems producer, Marvotech. According to David Risk, General Manager of Liselo since early 2000, the company emerged out of Voloshin's interest in developing a module manufacturing firm in South Africa.[99] Risk (2003) notes: "After drafting business plans in early 1991, Voloshin traveled to Europe to explore opportunities for partnership with companies in Italy and Germany."[100] His interactions with Italian-based Helios

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[95] The case studies have several limitations. First, each of these firms has a relatively high turnover of managerial staff. As a result, much of the contextual information about institutional histories lies with staff who are no longer employed with this organization or current employees who no longer reside in South Africa.

[96] Marlett Wenzel, Interview, March 26, 2003.

[97] Liselo Solar, 2001, Liselo LTD Company Profile. Centurion, South Africa: Liselo Solar.

[98] The company changed its name over the years in effort to be more marketable in a South African context. The transition from Helios SA to Africa Solar occurred shortly after 1995, certainly in response to the political transition to leadership under the African National Congress (ANC). The company formerly changed its name to Liselo about five years later to reflect its strong affiliation with the domestic market.

[99] David Risk, Interview, March 26, 2003.

[100] Ibid.

Technology resulted in Helios agreeing to assist with the development of a manufacturing plant in South Africa and to supply equipment (including lamination machines and string assembly lines), manufacturing know-how, and technical assistance to local staff for a period of one year.

With respect to the motivations for this partnership, Helios was interested in expanding its portfolio from photovoltaic products to photovoltaic services. Incorporated in 1981, Helios is the oldest European solar cell producer. The company spent its early years refining its own manufacturing processes for cell fabrication and module development. In particular, it's R&D centered on improvements in the performance of silicon-based solar cell technologies. Helios later moved into the market for equipment manufacture. Its next business endeavor was to transition from hardware supply to software, by selling manufacturing competence as an integrated package with its equipment products. Worldwide, Helios' approach has resulted in technology transfer arrangements in Europe (module manufacturing lines in Sweden and Croatia), India (solar cell and module manufacturing), China (module manufacturing), and South Africa (module manufacturing).[101]

The motivations for Voloshin's entrance into the photovoltaic industry are decidedly more complex. Voloshin is a multi-millionaire who gained both his wealth and notoriety from a lucrative arms dealing career at the height of the apartheid era. Clips from media sources suggest that in the late 1980's, Voloshin facilitated the illegal smuggling of top-secret military equipment between the Russian and South African governments. The shipment included highly sensitive jet engines for fighter aircraft, as well as state-of-the-art Russian missile technology.[102] The transfer of goods took place between 1991 and 1993, prior to the removal of the mandatory arms embargo that the U.N. Security Council levied against South Africa in 1977.[103] Since the embargo prevented countries from direct arms sales to the South African police, military, or Bureau of State Security, the Russian government sold the equipment to Marvol Group, a company formally incorporated in Germany. Reports suggest that the equipment, estimated at a value of $80 million (1991 USD), was shipped from Russia to Marvol Group headquarters in Germany, and then onto South African shores.

Voloshin was supposed to assume the role of middleman to conceal any links between the Russian government and ARMSCOR (now called Denel), the state-owned defense company in South Africa. Presumably, his charge was orchestrate the deal and facilitating the transfer of goods and payment between the two parties. However, Voloshin actually pocketed the $80 million that ARMSCOR intended to be paid to the Russian government in exchange for the engines and military know-how. Immediately following the transaction, Voloshin relocated to South Africa and applied for citizenship. He invested in a number of business endeavors, including the purchase of a wine farm in Eastern Cape (1991), the conversion of real estate property into a five-star hotel[104] (1992), the launch of a Russian Art Gallery (1993), and the establishment of a PV module manufacturing company (1991). Currently, Voloshin retains his position as Chairman of Marvol Group, which continues to

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[101] Helios Technology, 2002, Helios Know-How, [ONLINE] www.heliostechnology.com.

[102] Paul Kirk, 2001, "Modise linked to used MiG dealer (former Russian citizen with close links to the former KGB)," Abtop [ONLINE] www.agentura.ru/Forum/archive2001/1575.html.; Boris Kagarlitsky, 2000, "The Logic of Gain," Moscow Times [ONLINE] Lexis Nexis.

[103] On November 4, 1977, the U.N. Security Council adopted a mandatory arms embargo against South Africa. The embargo was levied in support of the increasingly visible anti-apartheid movement underway within the country and abroad. The mandatory embargo was spearheaded by the Cater administration, but unfortunately, neither the Security Council nor the U.S. government took many strides to enforce the regulations. Anecdotal evidence has often suggested that U.S. intelligence agencies had knowledge of violations of the embargo; they not only did little to stop them, but in some instances may have even encouraged them.

[104] The property, which is located in Pretoria, is called the Marvol Manor House. It owned by Armscor, prior to Voloshin obtaining it from the company in 1992. After living it for a short period, he converted the mansion into a luxury hotel.

promote and develop defense-related systems for both Russia and South Africa. He also serves as one of three Directors of Liselo Solar.

What sparked Voloshin's interest in photovoltaic manufacturing is unclear. However, I speculate that Liselo Solar presented Marvol Group with an opportunity to diversify its investment and to initiate a series of non-arms-related business dealings in South Africa. Knowledge of Voloshin's involvement in ARMSCOR's military upgrade did not surface until late 2000. Upon receipt of the equipment in 1991, ARMSCOR revealed that it was able to improve the South African Defense Forces' planes with Russian engines and missiles; but knowledge of the means through which they obtained the technology was never disclosed.[105] Thus, if Voloshin had no formal ties to ARMSCOR at the time, then his presence in South Africa needed justification through some other type of business endeavor. Since his real estate acquisition and philanthropic involvement in the promotion of Russian art appear to be more personal in nature, I speculate that investment in Liselo Solar presented a unique business opportunity. Moreover, based on the evidence I can gather, Marvol Group has made no further investments in PV modules production or solar cell fabrication outside of this initial venture into the market. Marvol Group remains actively involved in the South African defense industry and retains its ties to the members of the ruling elite under apartheid (former Ministerss of Defense and Foreign affairs under apartheid have previously served on the Board of Directors of Marvol Group). Marvol also continues to facilitate the export of Russian-made weaponry.[106]

Operations & Market Segment

Liselo's largest market has been rural telecommunications, but it has recently supplied PV systems to power rural clinics and rural schools. In the telecommunications market, the company's major client is Telkom SA, a commercialized telecommunications utility. Since 1997, Telkom has operated a Digital Enhanced Cordless Telecommunications program (DECT), which essentially allows for the provision of telephone services in off-grid, rural areas. Liselo Solar received the contract to supply photovoltaic modules for the DECT program, and has produced over 60,000 solar systems for use in solar-powered phone booths, highway call boxes, and mobile repeaters. The company has also branched into applications to provide power for rural schools and clinics. Liselo was offered an opportunity to participate in the rural electrification concession, but declined involvement. The general manager notes that the "administrative work" involved in entering a 20-year concession agreement with the Department of Minerals and Energy (DME).[107] With respect to firm strategy, Liselo is currently focused on increasing its market share within the telecommunications market arena. The general manager hopes to expand it's the companies ventures in other parts of Southern Africa and is actively searching for market opportunities in Eastern Europe.

Manufacturing Capabilities

Liselo operates a module assembly plant in Pretoria. The company manufactures PV modules and packages finished systems, using BOS components supplied by other firms. Its current portfolio of products includes both monocrystalline and polycrystalline silicon modules with power outputs ranging from 5 Wp to 75 Wp. The firms module testing procedures are certified by an accredited PV

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[105] Kirk.

[106] I must note that if the depiction of Voloshin is unfortunately one sided, it is not my intention to depict it this way. Although I was able to obtain information on the manufacturing activities of Liselo Solar, less primary information was available on its ownership structure and governance. Voloshin no longer resides in South Africa, and was not reachable either via email or fax at the time at which primary data collection took place. Therefore, this overview is admittedly not balanced with information that he might provide.

[107] David Risk, Interview, March 26, 2003.

testing laboratory (the Joint Research Center of the European Commission in Ispra, Italy) according to applicable international standards. The company's operating procedures and manufacturing plant are accredited with an international quality management certification (ISO 9002 rating), which is provided by the International Quality System Standard Board to ensure customers that the internal procedures of a firm meet certain requirements for management systems, financial analysis, and organizational performance.

Liselo's output has grown considerably over the past decade. When operation began in 1992, Liselo supplied 100 kWp per annum. During the past two years, output has exceeded 1.5 MWp per annum, a figure which indicates that output has increased by a factor of 15 in a little more than a decade. Under current levels of investment, Liselo's plant has the capacity to scale up operations to 2.5 MWp.

Table 3.1 Typology of Liselo Solar's Manufacturing Capabilities

Level	Project Execution	Production
Routine	Feasibility assessment; Engage contractor and select site; Monitor and control feasibility studies	Oversee operation; Routine quality control; Significant technical assistance Minor adjustments in design
Intermediate	Equipment procurement; Engineering assessments; Staff recruitment; Staff training	Major adjustments in design; Limited technical assistance; Product meets national design/ performance standards
Advanced	Partial adaptation of equipment	Production meets international design/performance standards
Innovative	Equipment design and supply	Certified as 'best in class'; Develop own product specifications

I rank Liselo's project execution capabilities as intermediate and its production capabilities as advanced. After more than 11 years of business, the company has proven both its capacity to expand operations and recruit competent staff. Upon inception, Helios Technology undertook major decisions about plant specifications, equipment, and operations. But, after its 1-year contract period expired, Helios assumed a rather limited role in project management activities. Helios continued to supply Liselo with used equipment for cell string assembly, framing, and lamination; it also offered some advisory services, when necessary.[108] As a result, the staff whom Helios trained to oversee manufacturing were left to manage the company. Liselo has since upgraded its equipment with new stock, but continues to rely on equipment suppliers in the U.S. and Europe. The firm actively recruits managerial staff (e.g. Derrick Botha), who have significant experience in leading PV manufacturing firms. Production capabilities are certainly more difficult to ascertain. Ideally an assessment of the firm's ability to transform inputs into outputs would include some measures of operational efficiency over time. Since that information is not readily accessible, my attention turns first to the quality of products produced. Module performance and specifications meet standards outlined by the International Electrotechnical Commission (IEC 6-1215), the leading organization for preparing and publishing international standards for electronic devices.

SOLAR VISION

Solar Vision operates as one of five concessionaires for the national rural electrification program administered under the Department of Minerals and Energy (DME). The company hopes to produce photovoltaic-powered systems for applications in water pumping, lighting, and telecommunications,

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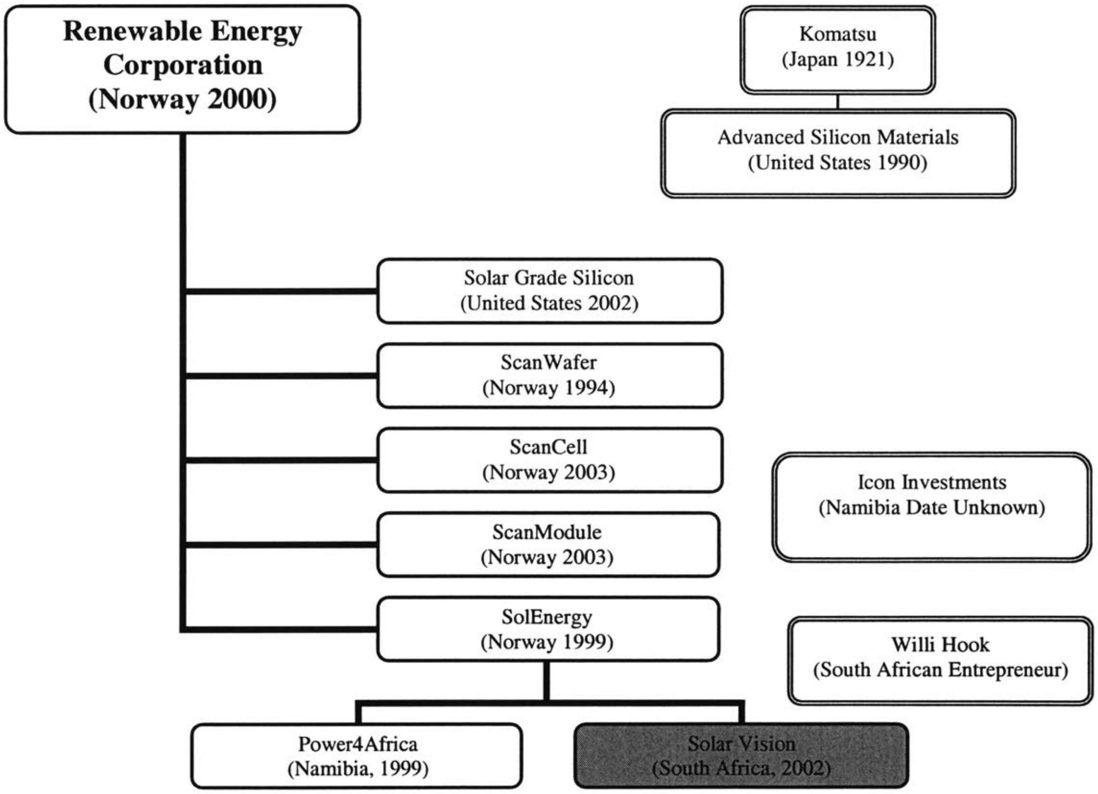
[108] Risk.

but its main focus is currently assembling solar home systems for its designated service areas within Northern Province.

Origins

Solar Vision is a member of a family of firms under the Renewable Energy Corporation (REC), a Norwegian holding company whose origins date back to 1994 (**Figure 3.1**). That year, Alf Bjørseth, a professor of physical chemistry and the Director of Research at Norsk Hydro, established ScanWafer AS to manufacture multicrystalline silicon wafers for use in solar cells and photovoltaic modules.[109] ScanWafer began production in 1997.[110] Ever since, the company has increased output on an annual basis. It currently operates three production plants and holds the distinction of being among the world's largest producers of silicon wafers. ScanWafer's customers include cell and module manufacturers such as Mitsubishi Electric Corporation and Shell Solar Energy.

Figure 3.1: Organizational Model of Renewable Energy Corporation and its subsidiaries



In 1999, Bjørseth's ambitions broadened substantially. His objectives expanded from gaining market share in one segment of the global supply chain to operating along the whole supply chain for solar PV – from the manufacturing of silicon feedstock to the distribution and marketing of photovoltaic systems to consumers. To achieve this goal, he established SolEnergy AS to manage solar energy plants, solar utilities, and distribution companies in areas in developing countries that did not have

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[109] ScanWafer, 2002, History, [ONLINE] http://www.scanwafer.com/index.php/6541.

[110] Ibid.

access to grid-based electricity. Shortly thereafter, Bjørseth founded the Renewable Energy Corporation (REC) as a holding company for ScanWafer, SolEnergy, and each of his new ventures.

SolEnergy has made two major investments in transferring manufacturing technology and operational systems to Southern Africa. In 1999, the company established Power4Africa in Namibia as its first endeavor; three years later, Solar Vision followed as its second. Power4Africa assembles modules and produces 35 W – 100 W photovoltaic modules for applications in rural electrification. Majority ownership of the company is retained by SolEnergy (51 %); the remainder (49 %) is held by the Namibian investment firm, Icon Investments. Currently, the factory employs approximately 20 people and intends to reach production capacity of 3 MWp by 2005.[111] Current output is about 1 MWp. Between 20 % and 30 % of the modules it produces are sold in Namibia; the remainder in Southern Africa.[112] Since Power4Africa's inception, SolEnergy and Icon Investments have been working to establish fee for service projects, in which systems will be leased and maintained in exchange for monthly payment. In April 2002, SolEnergy set up Solar Vision as a joint venture with Icon Investments and a South African entrepreneur, Willi Hook. SolEnergy is the majority shareholder (84 %) in this arrangement.

The motivations for Solar Vision's operations are clear, both in terms of the objectives that its parent company hopes it to fulfill and its mandate from the Department of Minerals and Energy (DME). The concession for the national rural electrification scheme presented Solar Visions parent companies with an opportunity to expand operations in the downstream sector, particularly with respect to consumer services and community management. The investment is time delineated, as Solar Vision's mandate from DME is to provide systems and operate services for the next 20 years. Once the concession expires, Solar Vision's obligations will be fulfilled and the venture will most likely dissolve.

Market Segment & Operations

The concession agreement for the National Electrification Program (NEP) stipulates that Solar Vision must meet a target of 25,000 installed SHS in Northern Province within its first five years of operation. During its full first year of operation (officially ends July 2003), the company will have installed 4,700 systems, a figure representing 18.8 % of its five-year goal. Solar Vision's progress to date is in line with what the largest concessionaire, the joint-venture between Shell Solar and Eskom, has been able to achieve in KwaZulu Natal.[113] Each of the concessionaires is obligated to lease each system to the end-user on a fee for service basis. DME provides both capital and operating subsidies. The purchase price of the system is R4500, and DME supplies a capital subsidy of R3500. In addition, a connection fee of R100 is required to be paid by the user. Between the inception of NEP in 2001 and March 2003, consumers paid R58/month to lease the systems. Beginning March 2003 onwards, DME instituted a lifeline tariff to bring the operating costs required by consumers down to R18/month.

The General Manager, Gary Whalley, has been with the company since December 2002. He was formerly employed by Icon Investments in Namibia and has also previously worked with Siemens. His exposure to photovoltaics began when he was employed at Icon. Whalley holds a B.S degree in construction management. Solar Vision employs eleven full-time staff. Responsibilities are divided among four administrative personal (general manager, operations manager, and two administrative assistants) and seven technical/field staff.

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[111] Gary Whalley, Interview, March 27, 2003.

[112] Ibid.

[113] Miller.

Manufacturing Capabilities

The technical specifications for the solar home systems produced by Liselo are specified in the concession contract, which is enforced by the National Electricity Regulator (NER). These specifications are broad, and refer basically to the capacity of the system and the components that it must include:

- 50 Wp Panel
- 90 – 105 Battery
- High efficiency light bulbs (typical consumption of +/- 85 Wh/day)
- Radio (adapter plug @ typical consumption of +/-30 Wh/day)
- Monochrome television with 12V plug
- Charge controllers and cabling
- Control system to facilitate revenue management

In-house, Solar Vision has the capacity to assemble systems. It obtains solar modules from Power4Africa. Most of the ancillary components are purchased from Rural Area Power Supplies (RAPS), a local business that manufactures pre-payment devices and offers energy consulting services. The RAPS prepayment devices are among the more innovative features of its SHS models. The prepayment devices are based on a technology developed in Dallas; they are coin operated so that once a chip is placed in the system, the controls download the credit information of the user. When users go to recharge their chips, information on the technical status of the system is loaded into databases at certified outlets. These outlets are generally available at local taverns and tuck shops.

Since Solar Vision's partnership with Power4Africa enables it to enter into PV production and distribution activities that would not otherwise be possible. This vertically disintegrated arrangement allows each firm to specialize in two respective fields (module assembly and system distribution/project management), and to eventually acquire the capacity to scale into larger and more complex arrangements. While this arrangement is novel, it is nonetheless complex from an evaluative standpoint, as several important questions arise as to the actual boundaries of these firms. Since I have included Solar Vision in my assessment, one can quickly discern that I analyze this partnership as a one-production system, operated by two distinct firms.

Table 3.2 Typology of Solar Vision/Power4Africa's Manufacturing Capabilities

Level	Project Execution	Production
Routine	Feasibility assessment; Engage contractor and select site; Monitor and control feasibility studies	Oversee operation; Routine quality control; Significant technical assistance Minor adjustments in design
Intermediate	Equipment procurement; Engineering assessments; Staff recruitment; Staff training	Major adjustments in design; Limited technical assistance; Product meets national design/ performance standards
Advanced	Partial adaptation of equipment	Production meets international design/performance standards
Innovative	Equipment design and supply	Certified as 'best in class'; Develop own product specifications

Since Solar Vision and Power4Africa are still relatively new ventures, I judge both their project execution and production capabilities routine. Solar Vision has relatively few staff and needs to increase its managerial staff quite quickly, if the company hopes to fulfill its 5-year mandate. The current General Manager, Gary Whalley, initiated heavy recruiting efforts in early 2003 and hopes to increase core staff from 11 to 25 by the end of the year. Information was not available on the specifications of the modules that Power4Africa produces. But, the major innovations in design of the systems are supplied by companies that provide Solar Vision with BOS components.

LEARNING MECHANISMS: ENTERPRISE-SPECIFIC & SUPPLIER-DRIVEN

Since Liselo Solar was established as a new venture, any learning activities specific to the firm must be associated with the competencies and experiences of its managerial and engineering staff. Between 1997 and 2000, Derick Botha served as general manager of the firm.[114] In this capacity, Botha was responsible for all procurement, manufacturing, and marketing functions. Prior to joining the company, he served as the Divisional Director of Siemens Ltd., South Africa. His experience at Siemens gave him exposure to a variety of business systems in the Telecommunications and Power Transmission and Distribution Divisions.[115] Botha left to assume an executive position at the South African subsidiary of AstroPower. David Risk assumed the position of General Manager in 2000.

In comparison to enterprise-specific learning activities, Liselo has gained much of its knowledge about technical and managerial processes from Helios Technology and its components suppliers. Liselo receives solar cells from a number of international producers, but its largest contributor is Intersolarcenter (Russia). Since 1999, it has also established supplier relationships with BP Solarex, which ships semi-finished solar cells to Liselo's manufacturing plants. This arrangement is formal and has been negotiated under an explicit contract. A host of local electronics companies supply Liselo with the ancillary components for its systems. Liselo is not directly involved in BOS manufacture, but packages PV modules for the convenience of end-users.[116]

Similar to Liselo Solar, Solar Vision and Power4Africa are each brand new ventures. Again, my attention focuses on the education and experience of the companies' managerial staff, since neither firm has evolved from less complex production activities. The General Manager of Solar Vision, Gary Whalley, has been with the firm since December 2002. He holds a BS degree in construction management and is quite new to the photovoltaic supply field. Formerly, he worked with Icon investments for about two years. Based on his leadership and familiarity with the consumer market, he was recruited by REC to lead Solar Vision.

Given the family into which Solar Vision was born, that the company relies on a small group of suppliers is not surprising. All necessary inputs into PV module manufacturing process are delivered through Power4Africa. BOS components are supplied by two companies.[117] Solar Vision hopes to reduce its reliance on a small number of suppliers for ancillary components, and hopes that more competition will improve the quality of the products they receive.

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[114] Risk.

[115] AstroPower, 2000, "Corporate Announcement: AP Expands International Marketing Staff," AstroPower Press Release [ONLINE] www.astropower.com.

[116] David Risk, Interview.

[117] Rick Beugeling and Henko Vijge, 2002, Solar Energy in South Africa. (Report prepared for the Renewable Energy Development and Training Centre, Durban Institute of Technology) 4.

GOVERNMENT INCENTIVES & REGULATIONS

Regulation

The regulatory framework governing the photovoltaic supply industry is principally administered by the Department of Minerals and Energy (DME). However, because Solar Vision produces products for the National Electricity Program (NEP), its activities are also monitored by the National Electricity Regulator (NER). NER publishes guidelines and oversees the specifications of the system and the tariffs charged to end-users. NER's interventions concern the quality of output from systems and the pricing behavior of the concessionaires. NER has little direct involvement in promotion of technology development.

Further insight into the nature of the regulatory mandates for the PV supply industry can be gathered from DME and the Department of Science and Technology (DST). Both entities broadly commit to promotion of technology development and strengthening technological capabilities of local firms. However, actual policies or programs toward this end are virtually nonexistent. DST has recently undertaken research in the areas of agro-processing and biotechnology, but not into PV technologies or the renewable energy field. DST's relative inactivity is not specific to this sector, however. Since 1995, DST has issued several national guidelines for creating an 'innovation system' in South Africa. Unfortunately, implementation of DST's framework has not progressed beyond policy guidelines for the country as a whole (as opposed to particular sectors or fields) and lobbying for organizational changes within government institutions. DME's regulatory intervention appears equally lacking. DME has sponsored capacity building and technical assistance programs have been initiated,[118] but information on how long these initiatives existed and which firms participated in them is scarce. Additionally, DME has established the Renewable Energy Demonstration Centre (REDC) in Silverton (Pretoria), as a joint venture with the Department of Agriculture. REDC serves more as a promotional entity, however; it is responsible for creating awareness and educating the public, two initiatives that are clearly demand-oriented.

Indirectly, DME's commitment to carry out the national Black Economic Empowerment (BEE) Framework may represent the only sustained departmental initiative to bolster local involvement in the PV supply industry. The BEE Framework emerges out of a national commitment to increase the presence Black-owned firms in a variety of sectors. Operationally, this has often meant that tenders are awarded to firms that demonstrate their commitment to promoting BEE, either because they are themselves Black-owned or have entered into a joint partnership with a Black-owned firm. Although this policy framework has not affected the two firms investigated for case research, it has ensured that a number of the concessionaires in the NEP organize themselves as joint ventures between an international PV manufacturer and a local, Black-owned firm. Unfortunately, the distribution of responsibilities has been allocated such that Black-owned firms distribute systems and provide some technical support. International manufactures retain much of the knowledge of system operation. Damien Miller, Director of Shell Renewables ventures in South Africa, concedes: "[The black staff we work with] learn basic managerial skills. They obtain business experience, and become more familiar with financial skills and project management. Many of the firms that work with us have a high turnover rate internally. Their staff moves on to pursue careers in government, with other firms, or go into energy consulting."

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[118] Wenzel.

Financial Incentives

Adopting the definition used by the Gielecki et al, the intended effect of a financial incentive is to increase the production or consumption of the good or service above what would otherwise have been without the incentive.[119] A financial incentive may involve a reduction in the price paid by the consumer or increases the price attained by the producer. The mechanisms generally applied to execute incentive schemes are production payments, tax credits, trust funds, and low cost loans. Alternately, financial incentives may involve the government intervention to create or expand a market for producers. Government-funded research may also be considered a financial incentive program for industry. Assuming that such research filters into the industry, the government essentially subsidizes the learning activities of firms. These research efforts have the potential to enhance the commercial viability of products through improvements in efficiency and reductions in system price.

My efforts to identify financial incentive programs in the form of tax credits or production payments were unsuccessful. I could not detect any formal programs. I must acknowledge, however, that the research is limited by the lack of formal interviews conducted with DME. The industry consultants[120] with whom I spoke are not aware of any financial incentive programs, but their knowledge of the breadth of government policy is of the course limited.

Within the 'government sector,' three institutions are involved in R&D activities: state-owned corporations, science councils, and universities/technikons. Presumably, DME would be the state-owned entity primarily responsible for undertaking research on PV technology. Its research activities appear minimal at best. South Africa has several science councils that have investigated uses of PV technology and its applications in remote electrification schemes. The National Advisory Council on Innovation (NACI) was created in 1997 to advise the Minister of Science and Technology on the contribution of science, mathematics, innovation and technology in promoting national objectives. Unfortunately, NACI's research activities are minimal. The body serves as a promotional vehicle; its main activities involve developing channels of communication and building working relationships among diverse government bodies and industry. The Council for Scientific and Industrial Research (CSIR) has sponsored research on manufacturing high efficiency PV devices. Much of the research is outsourced to University scientists throughout the country. The insights obtained from these experiments do not appear to have had discernable effects on the firms operating within the market. Few companies are aware of the objectives of research activities performed by government or the outcomes.

CONCLUSION

The industry overview and case research indicate that South African firms are involved in three of the four major market segments for PV manufacturing. The bulk of companies produce BOS components for use as electrical controls and power storage devices. A handful of firms undertake module manufacturing activities locally. The capabilities of module manufacturers range from routine to intermediate, and largely derive from the relationships firms establish with component and equipment suppliers.

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[119] Mark Gielecki, Fred Mayes, and Lawrence Prete. 2000. "Incentives, Mandates, and Government Programs for Promoting Renewable Energy," Renewable Energy 2000: Issues and Trends. [ONLINE.] www.eia.doe.gov/cneaf/solar.renewables/rea_issues/incent.html

[120] Marlett Chris Purcell. Email Correspondence. May 13, 2003.; Marlett Wenzel. Email Correspondence. April 18, 2003.

As the case evidence makes clear, firms derive knowledge about production processes and plant operations from their formal interactions with component and equipment suppliers. Government ministries have few financial or regulatory mechanisms to facilitate learning. What R&D that is conducted through government sponsorship takes place in universities and technikons; does not diffuse widely throughout the industry. The education and experience of managerial staff certainly contribute to the knowledge firms acquire at the organizational level. But, the varied backgrounds and expertise of the management lead me to believe that the influence of enterprise-specific learning mechanisms remains marginal at best.

The case findings suggest that the South African government does not assume an activist role in the promotion of technological development in the PV supply industry – an approach that differs markedly from nations that have accelerated the expansion of PV markets. As noted in Chapter 1, India historically coupled ambitious targets for installation of PV systems with government sponsored R&D into solar cell design. Until the 1990's, the Indian government maintained a series of regulatory mechanisms that encouraged local manufacture of modules and Indian ownership of manufacturing capacity. In regions as diverse as Germany, Japan, Spain, and the United States, national governments have undertaken similar activities. The combined experiences of these countries indicates that if the South African government hopes to build a culture of learning and dynamism in renewable energy industries, such as photovoltaics, far more government promotion is necessary.

CHAPTER 4: STRATEGIES FOR INDUSTRIAL LEARNING

In this thesis, I set out to examine the nature of technological capabilities among South African firms in the PV supply industry and to identify the relative influence of various learning-related activities through which manufacturing capabilities have emerged. Thus far, I have argued that relative to its peers, the South African government has assumed a limited role in encouraging a local market for production of PV modules and BOS components, two segments in which the country could surely compete. The national government's approach suggests that technological learning does not figure prominently in either energy or industrial priorities. But, not surprisingly, the Departments of Minerals and Energy (DME) and Science and Technology (DST) claim to wholeheartedly embrace opportunities for technology transfer and technological learning in official policy documents.

In this final chapter, I examine strategies which the national government might undertake to facilitate the transition from sustaining commitment to industrial learning to building a culture in which innovation and learning thrive. Of the many interventions which the national government could undertake, I recommend the following actions to DST and DME:

- Fund collaborative research between BOS component manufacturers, science councils, and Universities.
- Institute local content and local skills requirements for publicly-sponsored electrification and telecommunication programs. Any foreign firms that establish joint ventures with local partners should meet mandates using locally-manufactured components and training South African workers to undertake manufacturing activities.
- Identify clear lines of institutional responsibility for promotion of technological learning in this sector.

At the outset, I must acknowledge that the national government has not prioritized local manufacture of renewable energy technologies in its industrial development strategy. The national energy strategy encourages further investigation into applications of photovoltaics, but emphasis has not been placed on development of the supply-side of the market. Therefore, in putting forth these recommendations, I have kept in mind the need for technological learning to be broadly integrated into national economic development strategies, regardless of the particular industry in question.

OVERCOMING INSTITUTIONAL AMBIGUITY

In the PV supply industry, South Africa promotes technological learning through collaborative efforts between the DME and DST. DME has formally issued policy commitments to strengthening the skills base of the local PV supply industry,[121] while DST maintains a broad commitment to improving the diffusion of technological knowledge in the energy industry more generally. Other than including a few broad assurances in policy documents, neither department has allocated responsibility for implementation of these objectives to a particular entity. And from what information I gather, there are either very few or no individuals charged with overseeing implementation of this mandate.

India's experience suggests that South Africa stands to benefit from an institutional structure that creates more explicit lines of responsibility. Though South Africa certainly need not go so far as to create a separate ministry for promotion of renewable energy technologies, indication of the division held responsible for encouraging learning and skill development among PV module manufacturers is

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[121] White Paper on the Promotion of Renewable Energy and Clean Energy Development.

required. The sector could dually benefit from a policy process that outlines the instruments through which these activities will take place. Even if R&D is outsourced to university departments, further investment is developing partnerships between DME and executing agencies is required.

ALIGNING PV PRIORITIES & ENERGY POLICY

This section situates the objective of promoting technological learning in the PV industry in the broader context of South Africa's energy policies. Significant contradiction exists between efforts to promote electricity at lowest cost and efforts to increase access in rural areas. The former can only be performed through use of coal-derived electric power, while the latter requires stronger promotion and development of PV technologies.

The government's lack of investment in promotion of technological learning may also be explained by the relative incompatibility of PV promotion with the aims of offering low-cost energy supplies. As noted in Chapter 2, Eskom holds the distinction of being one of the top utilities in the world, in terms of both total sales and nominal capacity. The commercialized utility has long prided itself on price reductions, which it hopes to continue to achieve through productivity improvements and cross-subsidies from the mining industry to residential consumers. If the promotion of the PV industry is viewed against these objectives, the government's to willingness to invest in PV manufacturers is questionable. A clear tension exists between growth of the PV market and the government's commitment to extend power at lowest cost to end-users. Since the latter can only be accomplished through use of coal-derived electricity, a preference exists for Eskom to act as the 'first-choice' energy provider. The PV supply industry follows as a close second. If investment in the capabilities of module manufacturers requires that DME steadily increase the proportion of residential users serviced by PV companies (and in turn not serviced by Eskom), the government will remain hesitant to adopt stronger policies for aiding the local PV supply industry.

The state's hesitance to invest in promotion of the PV industry has little to do with the potential sales that Eskom stands to loose. Chapter 2 made clear that Eskom derives most of its profits on the sales of electricity from its mining customers, industry, and bulk sales to municipalities. Eberhard (2003) indicates that these three customer categories account for 82 % of its revenue and 89 % of its sales. The funds allow Eskom to provide a cross-subsidy to residential consumers in excess of $100 million annually.[122] Since residential consumers represent a drain on financial resources, the principal attraction of servicing them cannot be financial. Instead, it is largely politically. Promotion of the electric power at lowest-cost to residential consumers reinforces Eskom's commitment to improving basic infrastructure services. For the utility, its ability to serve the residential market reinforces the notion that the state remains capable of providing basic services. This remains particularly important, given prevailing preferences for liberalization and competition in electric power markets internationally. Since the late 1980's Eskom has undergone a series of corporatization reforms. In 1988, procedures were instituted to make internal policies more transparent and reorganize governance of the entity. Since 1996, plans have been developed to liberalize the market. Although Eskom remains able to generate sufficient revenue to cover its expenses, the national government continues to pursue competition in the industry on the basis of efficiency gains. Therefore, it seems plausible that Eskom hopes to hold onto the rural market as a means to demonstrate that viability of state-sponsored infrastructure services.

This argument is reinforced by the arrangement of concession areas. DME restricts the concessionaires in the National Electrification Program (NEP) to very specific sales areas within each

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[122] Eberhard 10.

province. These areas are referred to as 'permissibly designated zones,' and generally comprise a few districts. Private PV suppliers are not allowed to market or sell their products outside of pre-approved neighborhoods, because outlying areas have been slated for grid-electrification at some point over the next 10 years. Essentially, this arrangement places PV suppliers and Eskom in two distinct markets, with Eskom having access to a much larger consumer base. Again, this practice allows Eskom to retain a monopoly over a particular market segment and legitimate its existence as a state-operated entity that can service the needs of the poor.

The structure of Eskom's coal market provides an additional incentive for its interest in securing the residential market. Traditionally, production of export-quality coal has resulted in large quantities of coal discards. These discards represent the biggest volume of industrial waste. To reduce stockpiles, Eskom relies on these lower-quality, discards to provide energy for domestic power needs. Continued reliance on coal discards suggests that the competitiveness of the export market for coal depends, at least in part, on the viability of methods for using coal discards and high-ash coal in the domestic sphere. Until the country can identify other technological solutions for reducing the amount of discard coal, coal-derived electric power will remain the preferred source of supply for the many rural customers, who have yet to receive electric power services.

Each of the aforementioned challenges may be overcome, but addressing these issues will require a shift in the organization of line departments and changes in government priorities. For these combined reasons, the national government may lack the political will to promote technological learning in the PV industry as an energy development strategy. Following continuous changes in the structure of government bodies at both the sub-national and national level since 1994, presumably, bureaucrats will not welcome further organizational shifts. Changes may be easy to achieve through strict government mandates. However, I fear that they will not be welcomed. Reducing reliance on and promotion of coal-derived power appears even more unlikely, given the intimate connection between the electric power industry and industrial sector.

INDUSTRIAL STRATEGY FOR TECHNOLOGICAL LEARNING

Promoting technological learning in the PV supply industry through the government's existing industrial development framework appears more feasible. National priorities already lend themselves in favor of further technological learning. Achievable targets and action steps are what are required for further these objectives. I therefore recommend that DME and DST collaborate on the following:

- <u>Fund collaborative research between BOS component manufacturers, science councils, and Universities.</u> DST's current research and development strategies favor 'world class' and 'frontier' innovation in primary manufacturing over incremental design improvements in secondary manufacturing. Clearly, the department has adopted a 'run before you walk' approach to industrial development. Taking the PV industry as an example, significant opportunities exist for local industry to build capacity in well-established markets by steadily diversifying into more complex sectors. Learning is an involved process and will require significant investments in time and resources. International research demonstrates that investing in firms with a strong foundations and experience results in greater achievements than would be attained by investing in new start-ups. Therefore, I recommend that DST and DME orient their research and development activities toward supporting the industry for BOS component manufacture. Innovative adaptations in this industry can make substantial improvements to declines in end-user costs and system efficiency, even though such improvements may not be widely regarded as 'frontier inventions'.

- Institute local content and local skills requirements for publicly-sponsored electrification and telecommunication programs. Any foreign firms that establish joint ventures with local partners should meet mandates using locally-manufactured components and training South African workers to undertake manufacturing activities. That two firms have successfully established themselves as module manufacturers indicates that small-enterprises can devise innovative ways to integrate themselves into the PV supply market. The increasing emphasis on opening markets for foreign multinationals leads me to question whether the services of small firms will be utilized in the long term. Clearly, Solar Vision and Liselo Solar will remain viable as long as they confine their activities to publicly-subsidized programs. But, if forced to compete with large, foreign manufacturers, the relatively small production capacities of these companies will render these ventures unviable.

  To encourage greater use of capabilities that already available in the local market, I recommend that DME establish strict requirements for local content and training of South African staff. In this regard, technical (as opposed to general business) competencies are critical and should be emphasized whenever possible.

APPENDIX A: QUESTIONNAIRE I

Based on South Africa's concession agreement for non-grid electrification, I've identified INSERT NAME OF COMPANY as a company with significant involvement in the sector. Since INSERT NAME OF COMPANY has so much experience with the industry, I wanted to obtain your opinions about it.

I would like to be clear that I'm not conducting an evaluation of the company and that none of the information that you share with me will be used for such purposes. Rather, I am trying to understand the structure of the industry in South Africa and where INSERT NAME FO COMPANY is located along the chain of suppliers and/or distributors.

I'll primarily be asking you questions about the history of your organization (or venture) and your role in the production and/or distribution of photovoltaic systems. Do you have any questions before we begin?

History of Organization

I'd first like to begin by obtaining information on your role in the company and move on to the history of your organization and how it came to be involved in the photovoltaic industry in South Africa.

1. What are your responsibilities within the organization, both in terms of the department and the geographic area?

2. How long have you worked in this position? How long have you been with the company?

3. Can you provide some background information on when your organization was actually established? Where were the headquarters located and in what industry did it develop?

4. [IF NOT FOUNDED AS DISTRIBUTOR OR SUPPLIER OF PHOTOVOLTAIC EQUIPMENT] When did your company become involved in the photovoltaic industry? What were the motivations for its transition into the photovoltaic industry?

5. [FOR NON-RSA COMPANIES] When did your company first become involved in South Africa? Was your initial involvement in the photovoltaic industry?

6. Why was your company interested in becoming one of the concessionaires for off-grid electrification? What attributes distinguished your company during the selection process?

Service Activities & Operating Environment

7. Are you exclusively involved in the development and/or distribution of photovoltaics for solar home systems (SHS)? Or, do you also use photovoltaics for other applications?

8. Under the Department of Minerals & Energy Concession Agreement, when did you begin distribution of solar home systems?

9. For what geographic areas are you responsible? To date, how many solar home system (SHS) units have been distributed?

10. Of that number, how many solar home system (SHS) are currently installed?

11. Several concessionaires have noted that theft of installed systems presents a significant challenge to their operations? To what extent has theft of systems posed a challenge for your organization?

12. Do you face other significant constraints, with respect to installation and/or maintenance of the system?

13. If you look at the current demand for solar home systems (SHS) in your concession area, do you see significant potential growth in this market in the next few years? If so, what factors are driving this growth?

14. Both the capital costs and consumption of solar home systems (SHS) are heavily subsidized by the government, such that 80 % of the capital costs are subsidized and households pay R58/month for use of the system. Currently, there are discussions underway to further subsidize the monthly service costs for households. What influence do you think this will have on future demand? What influence do you think a deeper subsidy will have on your revenue projections?

Product Characteristics & Supplier Information

15. Do you develop solar systems?

16. [IF THEY DEVELOP SOLAR SYSTEMS] Do you have your own production facility for the development of solar systems? If so, in what province is it located? If not, where do you buy your products?

17. What kind of suppliers do you work with (for both systems and components)? Where are your main suppliers of systems and components located?

18. How long have you used these suppliers (systems and components)?

19. Do you maintain contracts with your suppliers (systems and components)? If so, are these contracts long-term?

20. Could you spend a few minutes discussing the features of your solar home system (SHS)? How does your product compare to those of other concessionaires?

21. How do you finance the development of systems and components?

THANK YOU FOR YOUR ASSISTANCE!

APPENDIX B: QUESTIONNAIRE II

General Protocol

Business History

- When was the firm established/founded?
- Was it established as a private venture?
- Was it established to produce PV modules and/or BOS components?
- What is the current ownership structure?

Management & Ownership

- Who is the current owner? How long has he/she been in this position?
- What is his/her educational background? Where was he educated?
- Who is the general manager? How long has he/she been in this position?
- How many individuals are employed in the firm? What proportion of these individuals are engineers?

Operational Activities

- Are you involved in the manufacture of ___ cells, ____ modules, _____, BOS components, ____ system integration?
- What is the range of your product line?
- What is your biggest selling product? What are its typical specifications?
- How many PV systems do you produce per year during first year of operation? Second year of operation?
- For system production and inspection, do you follow national standards regarding performance/specifications?
- For your major products, what are your target markets?
- Do you currently participate in any government sponsored programs? Have you participated in any such programs in the past?
- How long has this assembly plant been operative? Was it always used/owned by your firm, or did you acquire it from another company?
- Where do you obtain your equipment for:
  - cell sorting:
  - string assembly:
  - module lamination:
  - Module performance testing:

Suppliers

- Do you import solar cells from abroad? If so, from what country/company are you using?
- Do you maintain contractual relationships with suppliers? Are these contracts long-term?

Government

- How has government policy assisted your firm?
- Do you receive any financial incentives for performance?
- Do you participate in any capacity building, research, or training programs sponsored by government?

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