SMART VILLAGES

New thinking for off-grid communities worldwide

Business models for home-based electricity services

Terry van Gevelt and John Holmes

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Smart Villages

We aim to provide policy makers, donors and development agencies concerned with rural energy access with new insights on the real barriers to energy access in villages in developing countries - technological, financial and political - and how they can be overcome. We have chosen to focusing on remote off-grid villages, where local solutions (home- or institution-based systems, and mini-grids) are both more realistic and cheaper than national grid extension. Our concern is to ensure that energy access results in development and the creation of 'smart villages' in which many of the benefits of life in modern societies are available to rural communities.

www.e4sv.org | info@e4sv.org | @e4SmartVillages

CMEDT – Smart Villages Initiative, c/o Trinity College,
Cambridge, CB2 1TQ

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Executive Summary

This technical report reviews the business models used by pioneer firms in the solar home-based electricity services industry, specifically pico-solar lighting systems and solar home systems. Drawing on the grey and academic literature, the report provides a detailed industry overview, assesses key components of business models, and identifies remaining challenges and ways forward.

Industry overview

The solar home-based electricity services industry consists of pico-solar lighting systems (PLS) and solar home systems (SHS). PLS solutions have a generation capacity of between 0.1W to 10W and retail for US$6-100, with offerings spanning a continuum of electricity services, from providing lighting to mobile phone charging and powering small DC appliances. SHS solutions generate between 10W to 1000W and retail for US$75 – 1,000. SHS solutions offer broadly the same services as PLS solutions, with the option of limited motive and heat power and the ability to power AC electric appliances through an inverter.

The industry was worth an estimated US$550.5 million in 2014 and is expected to grow rapidly to US$2.4 billion by 2024. The backbone of the industry and its projected future growth is a group of pioneer firms. These pioneer firms, a mixture of small companies and social enterprises, have been operating in the industry for 5-10 years and are expected to achieve growth of between 40 and 400% per annum over the next decade. Industry trends suggest that the difficulty faced by early-entrant multi-national corporations (MNCs) in making inroads into off-grid rural areas may lead to the acquisition of existing pioneer firms and the transformation of the industry.

Business models

Business models consist of three interlinked components: a customer value proposition, key processes and a profit formula. The customer value proposition and profit formula define and create value. Key processes enable businesses to deliver value.

Customer value proposition

Access to electricity services is crucial to human welfare. At the most basic level, access to a reliable source of electricity is required to achieve basic needs: lighting, health, education and communication. Approximately 1.3 billion people are without access to electricity and its most basic services. Estimates suggest that in some scenarios the number of people without access to a grid connection could remain roughly unchanged through 2030. As a result, 25% of the unserved rural population are expected to be served through PLS and SHS solutions.

Key processes

Pioneer firms have made significant progress in delivering on two key processes along the value chain: distribution to remote off-grid areas and providing finance to end-users. Distribution and end-user financing strategies vary among pioneer firms depending on existing strengths. Among distribution strategies, all strategies are characterised by pros and cons making it difficult to select a winning strategy. Instead, pioneer firms have played to their organisational strengths and have taken into consideration contextual circumstances in their targeted geographical areas. This contrasts with multinational corporation entrants who have to date struggled to make inroads in remote, off-grid areas. A review of traditional and innovative end-user financing strategies points towards pay-as-you-go (PAYG) as a way forward for the

industry due to its ability to significant reduce transaction costs and its ability to match the willingness and ability to pay for the majority of end-users.

Profit model

Pioneer firms currently achieve a gross product margin of between 1-5% due to the need to keep products affordable and competitive. Low marginal returns on each individual PLS or SHS unit mean that pioneer firms require scale to achieve sustained profitability.

Remaining challenges and key recommendations

A number of financial and technical challenges present themselves as barriers to further growth in the solar home-based electricity services industry. Financial challenges include insufficient working capital and associated supply-side bottlenecks, end-user financing of the poorest of the poor, and inefficient subsidies and punitive tariff regimes. Technical challenges include the prices of component parts, quality issues and end-user awareness, and maintenance and end of life use. Key challenges and recommendations to address them are as follows:

1 There is insufficient investment and working capital leading to supply-side bottlenecks.

   - A common platform should be created to bring together socially oriented investors with investment opportunities in the solar home-based electricity services industry, provide information on the energy access industry to investors, and make available best practice examples to alleviate investor doubts about the social impact and financial sustainability of investments in the industry.
   - Private sector investment should be incentivised through working with the public sector and international community to 'de-risk' regulatory and technology risk.
   - Public funding should be leveraged to reduce the 'hurdle rate' of investment in the solar home-based electricity services industry.
   - Context-appropriate due diligence protocols should be adopted in the financial sector to reduce the transaction costs associated with investing in the solar home-based electricity services industry.

2 Market mechanisms fail to provide end-user financing for the poorest of the poor.

   - A pro-poor public-private-partnership (5Ps) model should be advanced. By allocating risk between the private and public sectors, this would allow pioneer firms to reach the poorest of the poor while earning a profit.

3 Subsidies for kerosene and punitive import tariff regimes create an unequal playing ground for pico-solar lighting systems and solar home systems in relation to incumbent technologies.

   - Subsidies for kerosene among rural populations should be removed in a staged process with rural populations being nudged towards pico-solar lighting systems and solar home systems.

- Countries should recognise the public good characteristics of pico-solar lighting systems and solar home systems and reduce or eliminate import tariffs on key components.

4 Component prices account for up to 75% of pico-solar lighting systems and for up to 44% of solar home systems retail prices, respectively.

- A complementary research stream should be created that focuses on designing components for rural requirements and price-points. This research stream would complement blue skies research, which is required for disruptive breakthroughs.

- Quality issues and low end-user awareness concerning pico-solar lighting systems and solar home systems lead to market spoilage.

5 Quality standards initiatives, such as the Lighting Global Quality Standards from the World Bank Group, should continue to be supported and promoted.

- Multi-stakeholder education campaigns should be established to deliver accurate and appropriate messages to end-users.

6 Technical barriers hinder the uptake of pay-as-you-go (PAYG) end-user financing.

- There is a need for coordination between regulators, telecommunication firms and pioneer firms to address incongruences in operating procedures.

- International standards regarding the standardisation of user- and business interfaces, as well as end-user data privacy protocols should be adopted.

7 Maintenance and end of life solutions are required to improve the sustainability of the industry.

- Further emphasis should be placed on the use of ICT technologies to allow for real-time monitoring and just-in-time maintenance.

- Support for vocational training of rural-based technicians should be considered by government or donor bodies.

- Technologies amiable to recycling in rural hubs should be used in the design of PLS and SHS solutions.

- Formal recycling infrastructure (both hard and soft) must be created in rural areas.

Business models for home-based electricity services

Introduction

This technical report reviews the business models used by companies in the solar home-based electricity services industry, specifically pico-solar lighting systems and solar home systems. Section 1 provides an overview of the solar home-based electricity services industry. Section 2 gives the definition of a business model used in this report. Section 3 discusses and evaluates the customer value proposition, key processes and profit formula that characterise business models in the solar home-based electricity services industry. Section 4 identifies remaining challenges and Section 5 presents suggestions for stakeholders to address for the industry to continue moving forward.

1. The Solar home-based electricity services industry

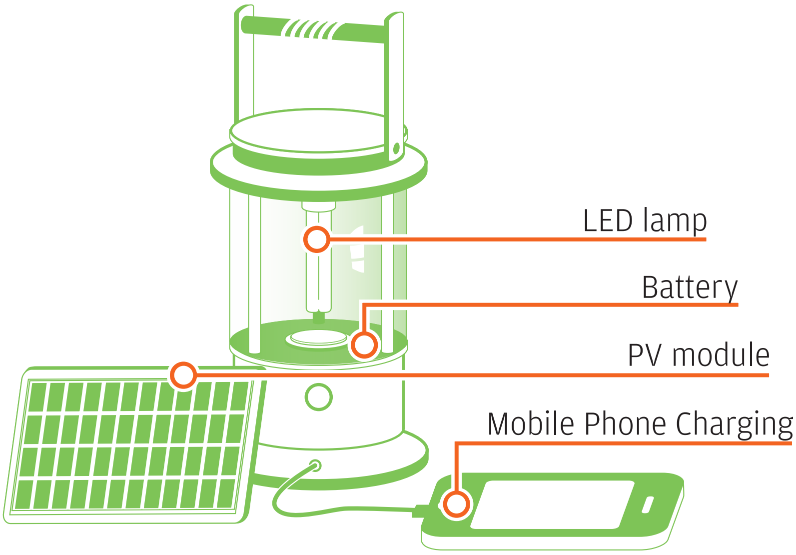
The solar home-based electricity services industry consists of pico-solar lighting systems (PLS) and solar home systems (SHS). PLS have a generation capacity of between 0.1 to 10W. The majority of PLS are plug-and-play ready and consist of a small solar photovoltaic module, a storage battery, and one or more detachable LED or CFL bulbs.[1] PLS retail at US$6 – 100 with offerings spanning a continuum of consumer services, from providing lighting to mobile phone charging and powering small DC appliances[2] [1, 2].

SHS have a generation capacity of between 10 and 1000W. Similarly to PLS, there are a variety of SHS solutions available that offer consumers a range of services. They retail at US$75 – 1,000. Comparable to high-end PLS offerings, basic SHS have multiple detachable light bulbs and are able to charge mobile phones and power an increasing range of efficient DC appliances. More advanced SHS offerings include an inverter and are able to power AC electric appliances, and allow for limited motive and heat power [1, 3, 4, 5]. At the basic level, there are an increasing number of plug-and-play SHS offerings. The more advanced SHS often tend to require professional installation [6]. Both PLS and SHS tend to have an effective lifetime of 2-5 years [1]. Effective lifetimes for both PLS and SHS tend to be limited by the need to trade-off construction quality in order to construct systems at low price points. The first major component to require replacement is the battery, which may require replacement after 3-5 years [1, 5].

1 Among others, lighting solutions currently include both light-emitting diodes (LEDs) and compact fluorescent lamps (CFL); battery types include nickel-metal hydride (NiMH), lithium ion (Li-ion), lithium iron phosphate ($LiFePO_4$), sealed lead-acid (SLA) and nickel-cadmium (NiCd); and photovoltaic panels include monocrystalline silicon, polycrystalline silicon, thin film amorphous silicon and cadmium telluride and copper indium gallium (di)selenide [2, 5].

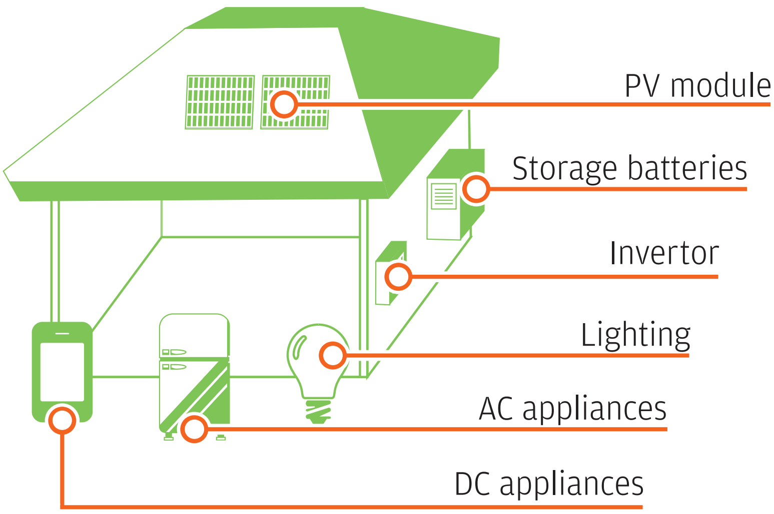
2 DC appliances may include, for example: radios, fans, e-readers and small televisions [5].

Typical Power Usages for Pico-Solar Systems



Appliance	Power Use (Watts)
Small LED light (50 lumens intensity)	0.5 W
Radio	0.5 W
Larger LED light (200 lumens)	2 W
Small mobile phone charging to 50% for 2 hours	2 W

Typical Power Usages for Solar-Home Systems



Appliance	Power Use (Watts)
Tablet/efficient laptop to charge to 50% in 3 hours	10 W
Small LCD television (DC)	20 W
Ceiling Fan	20 W
Fridge	40 W
Larger LCD television (AC)	100 W
Sewing machine	100 W
Small electric hotplate stove	1000 W

Figure 1 Pico-lighting system; Solar home system

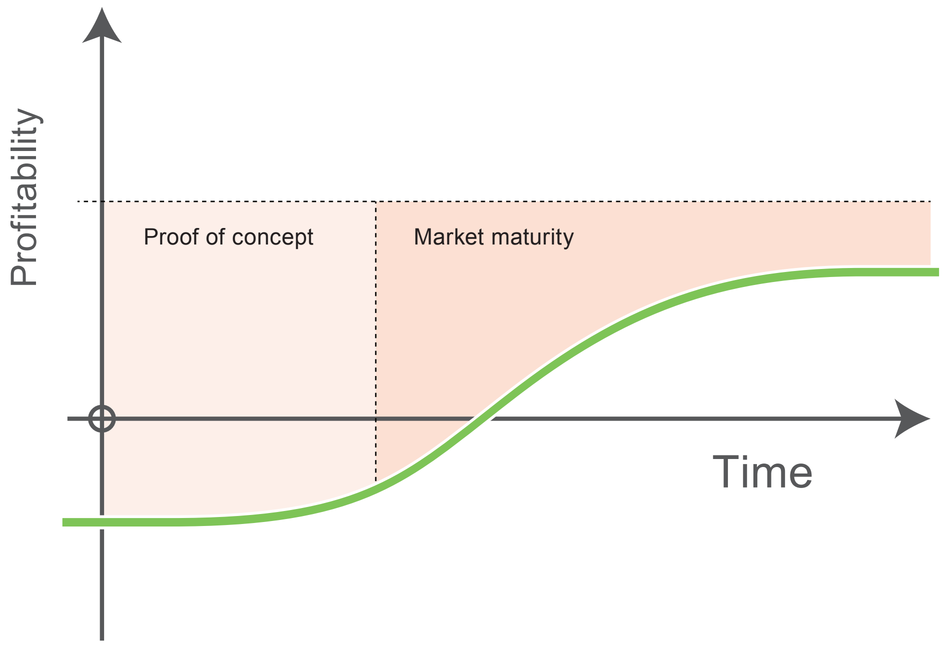


Figure 2 Two-stage market maturity process

1.1 Industry Origins

Market development tends to follow a two-phase process: proof-of-concept and maturity. During the proof-of-concept phase, governments often take a significant role through direct and indirect policies, such as investment in research and development and utility- and manufacturer-based subsidies.[1] In the second phase, private sector actors begin to operate in the newly proven market space. Initially, firms rely on a favourable policy environment during a period in which business models are trialled and refined. Eventually, firms are able to achieve profitability.

The stylised process illustrated in Figure 2, has largely played-out in the solar home-based electricity services industry. In the 1990s and 2000s, government- and donor-led rural electrification programmes[2] took advantage of the development of a range of semiconductors to experiment with the deployment of first-generation solar home-based electricity products. These programmes were often explicitly focused on technology improvement and market development. Importantly, many of these programmes were the subject of academic study and provided early insights into which business models were likely to be most successful [8].

On the back of government- and donor-led efforts, the solar home-based electricity services industry saw the entrance of small-sized businesses and social enterprises with humanitarian objectives. Although unable to initially operate viable business models and turn a profit, business model development through trial and error processes, coupled with significant decreases in the cost of photovoltaics, advancements in battery storage and end-use efficiency, and innovations in ICT have catalysed the transformation

1 *Examples include utility-based and manufacturer based subsidies for CFL bulbs, quality assurance and consumer education efforts for new lighting technologies, and significant efforts in support of commercializing solar technologies [7].*

2 *For example, in 2007 there were an estimated 44 national programmes active in which more than 1.3 million systems were installed at a total cost of approximately US$ 700 million [8].*

to a point where the market has now transitioned from the proof-of-concept phase to the maturity phase [1, 2, 7].

1.2 Current State of the Industry

The solar home-based electricity services industry is now firmly in the market maturity phase, with an estimated global annual market value of US 550.5 million in 2014 [2]. Government- and donor-led initiatives are moving towards targeting their efforts on populations characterised by extreme poverty[1] [9]. Small-sized businesses and social enterprises have now grown and form a solid base of continuously expanding pioneer firms[2] able to attract significant amounts of funding from investors. Most pioneer firms have now been operating in the industry for 5-10 years and have undertaken numerous iterations of their respective business models [4, 5]. Notably, several pioneer firms have recently proven themselves economically viable[3].

Multinational corporations (MNCs) have yet to make significant investments in the solar home-based electricity services industry. Although a number of MNCs[4] have made a tentative entrance into the industry, they have struggled to make inroads in remote, off-grid areas. The base of small-sized pioneer firms and limited entry of multinational corporations means that the industry is highly fragmented and without a clear market leader [2, 10].

1.3 Industry Trends and Projections

The solar home-based electricity services industry is estimated to grow from its current market size of US$550.5 million to US$2.4 billion in 2024 with existing pioneer firms estimated to grow by between 40 and 400% per annum [2, 4]. Growth will continue to be led through rural demand in developing countries, which is expected to grow due to rising rural incomes. The majority of unit sales are expected to come from African consumers. As the majority of these sales, however, are anticipated to be of PLS solutions rather than the more expensive SHS, the Asia-Pacific region is expected to provide the majority of revenue until 2018. By 2019, estimates suggest that African consumers will increasingly demand more electricity services leading to improved sales of SHS. This means that Africa will likely overtake the Asia-Pacific as the largest market in both sales and revenue terms through 2024 [2].

Industry trends and projections suggest that firms currently engaged exclusively in PLS solutions will move into the SHS space to capture further market share as the energy demands of consumers increase. The difficulty faced by early-entrant MNCs in making inroads into off-grid rural areas suggests that both incumbents and new entrants to the industry may acquire existing pioneer firms to leverage their distribution networks and customer base. A second mooted strategy by MNCs is to develop low-cost DC appliances offering a suite of electricity services that are branded as complementary to their PLS and SHS offerings. This could transform the solar home-based electricity services industry with PLS and SHS offerings being sold as a household's 'first' white good, enabling the purchasing of further DC appliances. This strategy is expected to see further efficiency gains and synergies, and a reduction in PLS and SHS retail prices [4].

1 Although the cheapest PLS solutions are affordable to the average poor household when compared to what is currently spent on incumbent energy technologies (e.g. kerosene), many of the extremely poor are unable to afford incumbent energy technologies and are therefore limited in their ability to take advantage of PLS [9, 11].

2 Pioneer firms refer to entrepreneurial firms that develop and deploy market-based innovations to serve the poor in areas where public sources of provision have fallen short.

3 In 2014, pioneer firms are estimated to have distributed millions of PLS and SHS in over 100 countries [2].

4 Early entrants include Panasonic, Philips and Schneider Electric, among others. Despite the difficulty encountered by early entrants in making inroads in remote rural markets, other multinational corporations are reported to be currently examining appropriate entrance points into the industry [2, 4].

2. Business models – A conceptual view

Business models consist of three interlinked components: a customer value proposition, key processes, and a profit formula. The customer value proposition and profit formula define and create value, while key processes enable businesses to deliver value [12].

Customer value proposition (CVP) refers to how a business is able to help customers through solving a problem. All things being equal, businesses achieve greater CVP when customers derive significantly high welfare from the solution offered, and customers have either no access to alternative solutions or have low satisfaction with current solutions to the problem.

Key processes are operational processes that allow a business to deliver on the customer value proposition successfully and enable the business to scale-up. Processes tend to include training and development, budgeting, planning, manufacturing, sales, and service.

The profit formula defines how a business is able to create value through providing a solution to the customer. Profit models can be disaggregated into three modelling processes. The first process is to model expected revenue. This is calculated as price multiplied by expected volume. The second process is to model direct costs, indirect costs and economies of scale. The third process is to model margins, specifically the revenue and costs required from each transaction to ensure a desired level of profits. [12, 13].

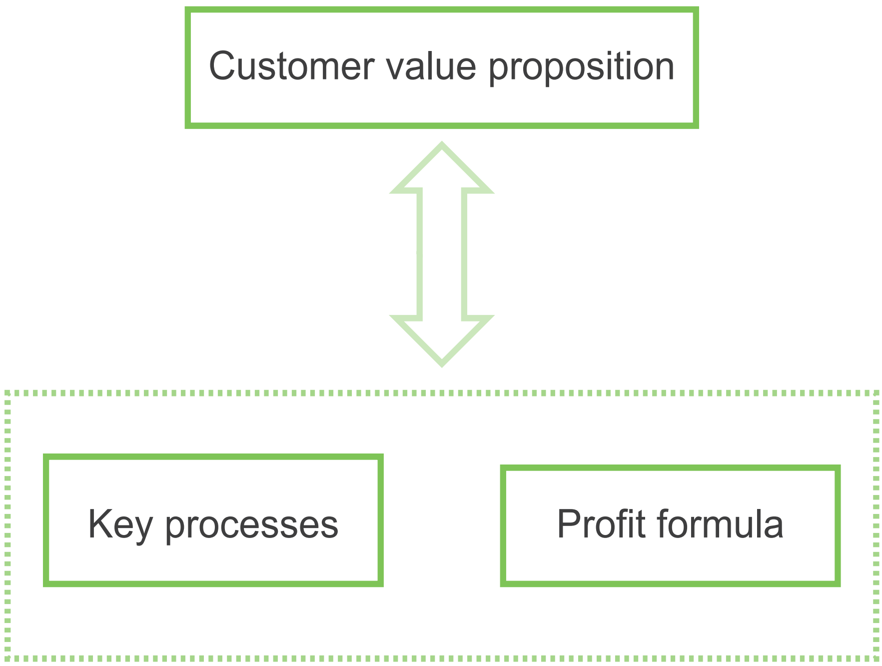


Figure 3 Components of a business model

3. Business models for solar home-based electricity services

3.1 Customer value proposition

Access to electricity services is crucial to human welfare. At the most basic level, access to a reliable source of electricity generating between 50-100 kWh per person per year is required to achieve basic needs: lighting, health, education, and communication. A further increase to 500 – 1000 kWh per person per year is deemed necessary to improve productivity in both agriculture and light industry. Around 2000 kWh per person per year is required to meet what are now considered modern society needs: use of domestic appliances, cooling, heating, advanced ICT, and more energy intensive agriculture and light industry processes [14, 15].

Approximately 1.3 billion people, however, are without access to electricity and its most basic services. Many live in remote rural areas that are off-the-grid, and many with an average income of less than US$2 per day [11, 16]. Beyond the 1.3 billion people without access to electricity, many more experience only a nominal grid connection, with significant outages denying them access to key energy services. Some estimates suggest that, with grid expansion currently only keeping pace with population growth, the number of people without access to a grid connection could remain roughly unchanged through 2030 [17]. Furthermore, for areas reached by a reliable grid connection, many people may not be able to afford to connect to the grid [18].

As a result, only 30% of the currently unserved rural population is expected to benefit from grid extension. 45% are expected to be served through decentralised minigrids and 25% through PLS and SHS solutions [1, 16, 17]. Market segmentation between decentralised energy technologies is estimated as a function

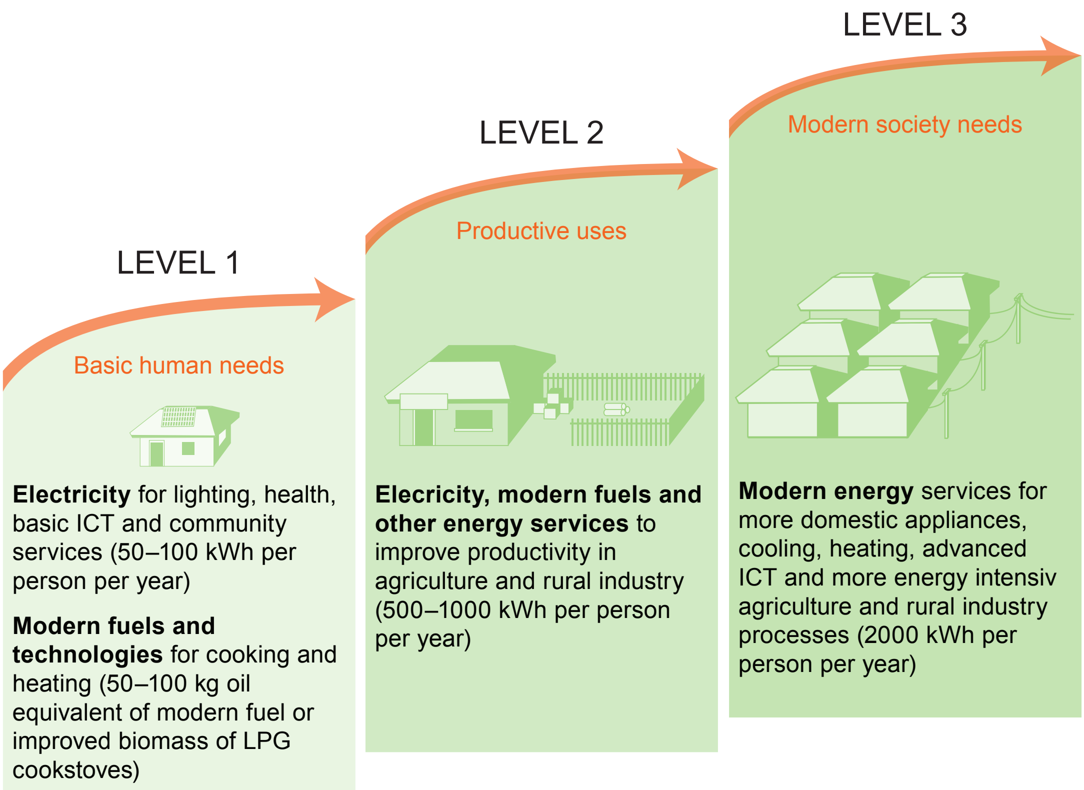


Figure 4 Electricity services and needs

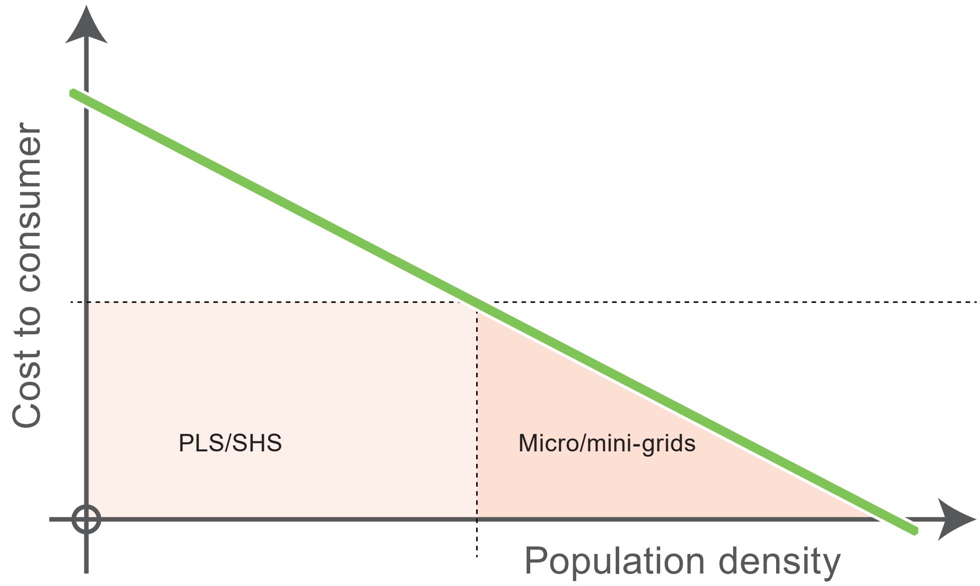


Figure 5 Market segmentation by population density

of population density, with more dense areas seen as suitable for minigrids solutions, and less dense areas as fertile ground for PLS and SHS. PLS and SHS solutions are further segmented by household income [19; 20].

To access basic services, such as lighting and communication, the unserved population currently makes use of a bundle of incumbent energy technologies [1].[1] The composition of the bundle and the frequency of use depend on household income with the extremely poor often unable to afford a reliable supply of incumbent technologies and make full use of the associated services [9, 21]. For the median household, however, the average costs incurred in consuming a bundle of incumbent energy technologies that provide basic lighting and communication services represent a significant and consistent outlay [11, 17].[2] Furthermore, typical incumbent energy technologies, such as kerosene, have been proven to be tremendously harmful to consumers [16]. Taking household expenditure on incumbent energy technologies as a baseline, shifting this expenditure to either PLS or SHS provides a much higher level and quality of services and, in some cases, significant cost savings[3] [1, 17].

3.2 Key processes along the value chain

The value chain for PLS and SHS solutions share the same general actors, activities and processes. Figure 6 presents a stylized value chain for the solar home-based electricity services industry. The value chain consists of the following activity nodes: manufacturing, distribution and retail. Manufacturing refers to the physical production of the product and typically involves three main actors: manufacturers responsible for the design of the product, contract manufacturers who manufacture components to specification, and assemblers who

1 Incumbent energy technologies include, for example: fuel-based lighting, dry cell batteries, fee-based mobile phone charging [1].

2 For example, charging a mobile phone at a pay-for-service charging station is between 10 to 100 times cheaper per kilowatt hour [17]

3 A study conducted in Kenya, Malawi and Tanzania by the charity SolarAid found that the purchasing and use of a solar pico-solar lighting system led to an average saving of US$70 per year, averaged over three years. This equates to approximately 10% of the total income of a household living on US$ 2 per day [5].

procure and assemble the individual components into final products. Distribution includes all processes from when the final product is produced to when the product arrives at retailers. This primarily involves importers, and wholesalers operating at the national and regional levels. Retail involves connecting the product with consumers. Retailers tend to include rural outlets, commissioned sales agents, and base-of-the-pyramid entrepreneurs. End-users refer to the consumers of PLS and SHS products who are overwhelmingly base-of-the-pyramid consumers living in remote rural areas. Finally, the value chain is underpinned by the cross-cutting activities of finance and ICT connectivity [4, 22].

There is significant variation among actors in terms of the degree of horizontal and vertical integration along the value chain. For example, at the manufacturing nodes there is limited vertical integration with most pioneer firms outsourcing the manufacturing of individual components and their assembly. Regarding vertical integration, pioneer firms tend to be engaged at two or more nodes of the value chain [4, 23].

Assuming minimal vertical and horizontal integration, it takes an average of two weeks for component manufacturers to deliver on specifications given to them by pioneer firms. Component manufacturers operating in this space tend not to undertake work on the basis of supplier credit finance meaning that payments from pioneer firms must generally be

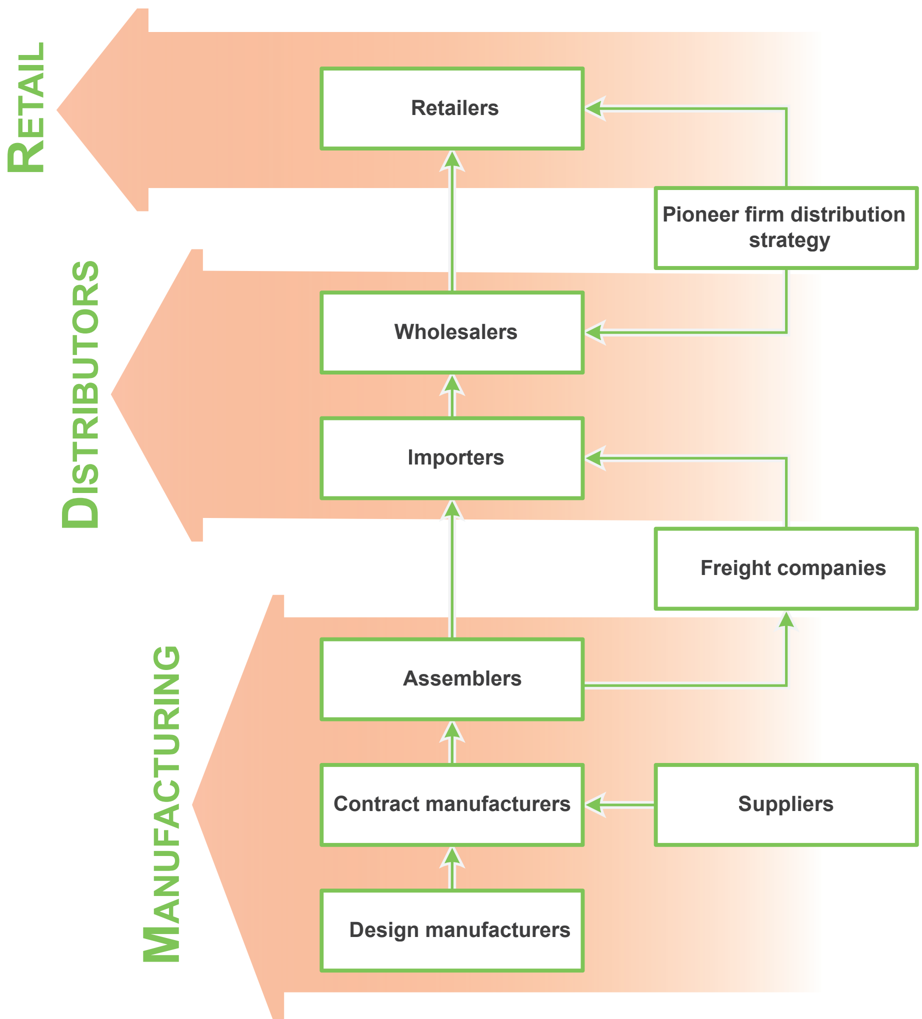


Figure 6 Value Chain

made in advance. Recently, however, more and more component manufacturers are accepting payment schemes of approximately 30% upon order placement and 70% upon full delivery. Assembly of the product takes, on average, a further 4-6 weeks.

At the next activity node of the value chain, pioneer firms require importers to pay an average down payment of 50% per product order. Typically, this 50% down payment is used by the pioneer firm to finance production of the products. In turn, importers require wholesalers to pay 100% of the order price before the product is shipped. At the retail level, larger and well established retailers often secure 15-30 days credit from wholesalers. The majority of retailers, however, are required to pay in advance. End-users, being located primarily in remote areas and with limited capacity to afford up-front payments, tend to be served by retailers through a variety of innovative and traditional methods of delivery and end-user financing [4].

3.2.1 Distribution Strategies

Distribution is a challenging key process along the value chain. This is because end-users tend to be located in remote off-grid areas. To date, pioneer firms have adopted a range of distribution strategies that can be categorised into the following approaches: distributor-dealer channels, proprietary distribution channels, institutional partnerships, and franchising.

Distributor-dealer channels are arguably the most straightforward and common model in developing markets. In this model, the product is sold through existing networks of distributors in the rural market. This allows for pioneer firms to essentially piggy-back on existing supply chains of consumer durables, which often penetrate deep into rural markets. Despite its strengths, experiences with the distributor-dealer model, particularly in sub-Saharan Africa, suggest several important factors that must be carefully considered and overcome, as well as a handful of intrinsic limitations to the model. For example, it is difficult to identify the right distributors and establish an effective relationship. Similarly, and arguably more importantly, there is often a lack of product understanding by actors in the distribution channel. Unless mitigated through initiatives to raise awareness and through basic hands-on training, this can have a negative effect on sales.

Providing after-sales support services and an effective e-waste management programme is another big challenge facing pioneer firms engaged in the distributor-dealer model. This is because it is difficult to coordinate these activities in an already established and often large dealership network. Another significant issue that must be overcome is the limited availability of capital to many of the retailers in the dealership network. This lack of working capital can become a serious bottleneck to meeting demand.

Perhaps the two most prominent limitations of the distributor-dealer channel model are the need for the pioneer firm to continuously monitor the distributor network to ensure that high standards are maintained and brand value built; and that gross margins are shared among multiple players along the existing network of distributors. Although costs are reduced by leveraging an existing distribution channel, it is possible that the net result is lower margins for the pioneer firm [19].

A second distribution strategy is proprietary distribution, where the pioneer firm creates its own distribution capabilities. This generally means acquiring in-house storage facilities, and the development and operation of a dedicated salesforce. This salesforce is responsible for delivering the product to the end-consumer. The proprietary distribution strategy allows for complete control to be kept over product quality and after-sales services, as well as branding. A particular strength of the model is that the salesforce are able to teach end-consumers about PLS and SHS directly, thereby overcoming information issues. It also allows for margins to be kept in-house and makes it easier to incorporate continual product feedback into the overall business model. These advantages come at a high cost, particularly in relation to the investment required to meet fixed costs in setting up distribution networks in each targeted sales region. High fixed costs are further considered risky due to the potential for market saturation before costs are recouped, and the difficulty in shifting geographic focus to respond to changes in market demand [4, 10].

A third distribution strategy seen in the solar home-based electricity services industry is the formation of institutional partnerships. This strategy involves the pioneer firm partnering with an institution with pre-existing linkages to large numbers of target consumers. Partners have included, among others: non-governmental organisations (NGOs), microfinance institutions (MFIs), rural banks and government institutions. To date, the most common institutional partnerships have been with MFIs due to the potential for synergizing end-user financing. The main benefit of an institutional partnership is that the pioneer firm gains an existing network of target consumers, access to established distribution channels into this network, and a detailed understanding of this consumer base from its partner institution. Experiences in the industry have shown, however, that institutional partnerships can lead to crippling disputes between partners regarding risk sharing, cost sharing, roles and responsibilities. Furthermore, working in partnership with organisations with different objectives and governance structures may hinder rapid and flexible responses to changes in market demand [10, 19].

The final distribution strategy typically seen in the solar home-based electricity services industry is franchising. To date, two types of franchising have occurred in the industry. The first approach to franchising has seen pioneer firms engage with a limited number of relatively large in-country franchisees. This approach is typical of franchising models seen in other industries. The second and more novel approach, however, sees pioneer firms develop micro-entrepreneurs into an extensive network of micro-franchisees. To do this, the pioneer firm typically provides a franchising package to micro-franchisees that includes, among other features: training, financing, marketing support and income generating opportunities. The franchise model, particularly the micro-franchise approach, has a number of strengths. These include being able to rapidly scale-up sales, penetrate rural markets and share logistics and marketing costs. These strengths, however, are accompanied by the need to share profit margins with a network of micro-franchisees and by relatively high branding and quality risk, especially in regards to ensuring the provision of quality after-sales services [4, 10].

3.2.2 End-user financing strategies

Another key process in the value chain is providing end-users with the means, through a variety of end-user financing options, to purchase and to use PLS and SHS solutions. To date, a number of traditional end-user financing processes have been used. These include: fee-for-service, hire purchases, and consumer loans and revolving credits. More recently, microfinance and crowd-funding solutions have been advanced, as has the innovative pay-as-you-go (PAYG) system that has proved so successful in enabling growth of the mobile phone industry.

A fee-for-service model sees the PLS or SHS continue to be owned by the retailer, with the consumer paying a fee for use of the system.

Retailers are often micro-entrepreneurs, who rent out products on an hourly/daily/weekly/monthly basis. This model has seen demonstrated success in India, Central America, Sub-Saharan Africa and South East Asia. Key advantages of the model are that it makes products affordable to end-users through a convenient platform with minimal end-user commitment and risk. Appropriate maintenance of systems is likely to be undertaken due to the importance of the product's longevity for the micro-entrepreneur. Case studies have documented various challenges and risks to the fee-for-service model. These include, for example, the high capital investment that must be undertaken by the micro-entrepreneur and the inability for customers to own their energy source [24].

In the situation where consumers prefer to own their energy source, a hire-purchase option is arguably a more effective strategy. Under the hire-purchase model, consumers pay fixed monthly instalments to pay off the PLS or SHS. A crucial weakness of this model, however, has been the difficulty in guaranteeing repayment. This has led to the use of a number of different collection methods. One such prominent method has been for monthly payments to be deducted from the employee's salary. This, however, limits the consumer base to those employed in the formal sector – a minority of the rural unserved. Additionally, the hire-purchase approach requires that retailers have significant capital due to the relatively long repayment times [19].

The third traditional strategy is the use of consumer loans. In this strategy, individuals are offered either general consumer loans or loans intended solely for the purchase of a PLS or SHS. Often, loans have been issued through revolving credit[1] schemes – a more flexible and arguably appropriate instrument for base-of-the-pyramid consumers. Loans and revolving credit schemes, however, have generally been advanced by donor bodies, often through commercial banks. Without donor support commercial banks tend not to be willing to lend as transaction costs outweigh revenue opportunities [19, 24].

Resulting from the issues associated with the three traditional strategies, a body of literature arose arguing that microfinance institutions (MFIs) can play a key role in bridging the end-user financing gap. Key arguments in favour of microfinance include the deep penetration of MFIs in rural areas, their intimate knowledge of end-user financial positions, and their ability to overcome information asymmetries with relatively low transaction costs. In practice, loans from MFIs are limited to relatively large ticket size SHS. This is because a 3-5 year loan on a system below a price point of US$250 is deemed unprofitable by the majority of MFIs, thereby excluding the financing of PLS and more basic SHS for poorer segments of the consumer base. Additionally, the relatively high interest rates characteristic of MFI loans is suggested to be a barrier to this approach. Therefore, despite some successful initiatives, most notably in Bangladesh and India, the microfinance approach has yet to reach scale and evolve beyond the pilot phase [24, 25].

Recently, a handful of firms have emerged with business models that provide end-user finance to PLS and SHS through crowdfunding [26]. To date, companies have largely banked on reward crowdfunding: a crowdfunding variant where relatively small donations are sought from 'warm glow-giving' investors. Donations

1 Revolving credit schemes do not have a fixed number of payments. Instead, the consumer is allowed to withdraw, repay and redraw the loan amount as frequently as desired until the credit scheme expires.

are used to provide loans for end-users and are reinvested by the firm to achieve its rural electrification objectives. In return, investors are assured of the social benefit of their donations through transparent reporting from the firm about the impact of their investment on end-user welfare [27]. There is currently no consensus on the long-term viability of crowd-funding approaches in general and in the use of long-term viability of reward crowdfunding in the solar home-based electricity services industry in particular.

Arguably the most exciting approach to end-user financing is the use of pay-as-you-go (PAYG) system. Driven by its success in deepening mobile phone penetration and connectivity in the developing world, PAYG is increasingly gaining acceptance as an effective strategy for providing end-user financing for PLS and SHS and is expected to further accelerate growth in the industry [2, 9, 24]. To date, 28 firms in 32 countries use a variety of PAYG systems to finance end-users [28]. In general, PAYG systems appear to have significantly reduced transaction costs associated with end-user financing and allow for a payment stream suitable to end-users in terms of both willingness and ability to pay [1].

Conceptually, PAYG systems can be seen as microfinance platforms that enable end-users to afford PLS and SHS solutions that otherwise would be unaffordable. Essentially, manufacturers and/or distributors finance the high initial capital costs through a combination of working capital and other funds, with the total cost of the system being paid back over periods ranging from 10 weeks to 3 years. Central to PAYG systems is an information technology system that reduces transaction costs through allowing for payments to be automated and for the PLS or SHS system to be remotely activated and, in some cases, monitored [1, 24, 28].

PAYG systems operate across a continuum and vary according to a number of dimensions, including: customer relationship and connectivity. Two[1] types of customer relationships have emerged in the PAYG space. The most prevalent is where the relationship with the end-user takes the form of a micro-loan. This typically relies on a situation-appropriate credit check and down payment, as well as agreement of a payment series through either a proprietary or licensed platform. In this relationship, the end-user takes ownership of the system. The second relationship is one where the end-user effectively purchases electricity as a service. This sees a periodic contribution in addition to either an installation fee or deposit. In contrast to the micro-loan variant, the end-user does not own the system [28].

PAYG systems differ in respect to the level of connectivity between the PLS or SHS system and the firm's servers. There are three categories of connectivity: full connectivity, periodic connectivity, and indirect connectivity.

In a full connectivity system, the system is often embedded with a GSM[2] component to allow for a close to real-time connection with the energy system. This allows for the company to monitor use of the system and gather data on usage, and respond proactively to issues of maintenance. In a full connectivity system, the typical payment platform tends to be a mobile money network payment.

1 *In addition to the above mentioned two types of customer relationships, there has been an emergence of firms that focus solely on the production and support of specialized PAYG software and hardware. These firms focus on business-to-business offerings. Furthermore, more and more early-adopters who developed in-house hardware and software platforms have begun to license their platforms for use [28].*

2 *GSM or Global Systems for Mobile communications, is an open, digital cellular technology that is used to transmit mobile voice and data services. The inclusion of a GSM component allows for mobile phone machine-to-machine transfer of data [28].*

The second level of connectivity, periodic connectivity, sees PLS and SHS periodically connect with smart phones. Typically, smart phones are either owned by the end-user or by a dealer agent. An application on the smart phone is used to log customer credit and unlock the PLS or SHS. Payments tend to be undertaken either through mobile money networks or through direct cash payments to the dealer.

The third level of connectivity, no direct connection, is characterised by the absence of any direct connection between the PLS and SHS and a central sever. In this system, PLS and SHS systems tend to be unlocked through scratch cards purchased from dealers. Alternatively, systems can be unlocked through the use of SMS generated codes – where mobile airtime is used as a virtual currency – and through cash payments to dealers with dealers unlocking systems through cable or Bluetooth connections [28].

3.3 Profit model

Pioneer firms tend to sell a range of products varying in retail price from US$6 – 100 for PLS products and US$75 – 1,000 for SHS products [6, 28]. Successful pioneer firms currently achieve a gross profit margin[3] of 1-5%. Low margins are explained by the need to keep products affordable and competitive for the main target market: base-of-the-pyramid rural consumers. Despite the low marginal returns on each individual PLS or SHS unit, pioneer firms are confident of improving their profitability through increasing sales volume and reducing direct and indirect costs across the value-chain [4].

The cost structure in the PLS and SHS markets differ significantly in the share of component prices and distribution and retail.

3 Gross profit margin is defined as how much revenue is left over after paying the cost of goods sold.

For PLS approximately 44% of the retail price is accounted for by components, with the remaining 56% going into distribution and retail. In comparison, components account for 75% of SHS retail price with distribution and retail costing approximately 25% of the retail price.

Typically for PLS, the solar PV panels and storage batteries each account for approximately 11% of total retail price. Other component costs, such as the charge controller, housing and their assembly, account for approximately 22% of total retail price. Distribution and retail account for over half of total retail price, 56%. A breakdown of distribution and retail costs finds that international transportation from manufacturing and assembly centres comes in at 7% of retail price. Taxes and tariffs are responsible for approximately 15% of total retail price. In-country distribution and wholesale and the retail process account for around 34% of total retail price [10].

For SHS, the solar PV panels currently account for approximately 50% of the total retail price. Storage batteries are estimated to account for 15%, with wiring, LEDs and product add-ons accounting for between 5-15% of the total retail price. The remaining 16-29% of total retail cost goes to transportation, taxes and tariffs, in-country distribution and wholesale, the retail process of the product, and provision of aftersales services [4].

The profit model for pioneer firms appears to be robust in the short-term. There is projected to be continued growth in demand for both PLS and SHS, meaning that pioneer firms are, subject to supply-side constraints, able to continue their growth in sales. Significant reductions in manufacturing costs are projected. It is estimated that by 2020, the cost of a median solar PV panel will decrease by around 60-65% as a result of technology advances, industry maturation and economies of scale. Storage batteries

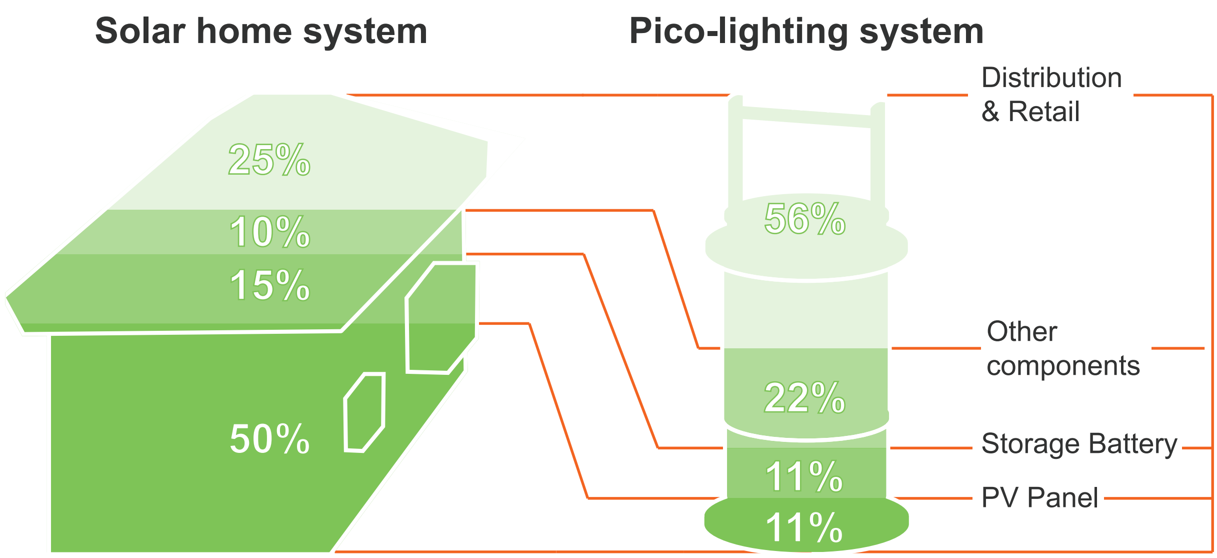


Figure 7 Representative cost structures of PLS and SHS products

are predicted to not only decrease significantly in price by 22% by 2020 but also to have significantly superior lifetimes. Counteracting some of these manufacturing gains, however, is rising labour costs in current manufacturing and assembly hubs, particularly China. Despite rising labour costs, it is estimated that manufacturing efficiencies will result in a net decrease in production costs [10].

In the medium-to-long-term, however, an expected aggressive entrance into the industry by multinational corporations (MNCs) is likely to threaten the profit model of existing pioneer firms for two main reasons. Firstly, MNCs may drive down production costs due to their established manufacturing and assembly capabilities. Secondly, MNCs are expected to leverage the breadth of their production capacity and to create an ecosystem of energy-efficient DC appliances targeted to off-grid rural consumers. PLS and SHS models will serve as an entry-point into the ecosystem and conceivably be sold at cost price or below cost price with losses being recouped from the sale of DC appliances [2, 4].

4. Remaining challenges

The solar-home based electricity services industry has experienced tremendous growth over the past two decades and has firmly entered the market maturity phase, with a current market value of approximately US$550.5 million in 2014 and high growth expectations [2, 4]. Despite these upward trends, the solar home-based electricity services industry continues to face significant financial and technical challenges that require concerted efforts by multiple stakeholders to create an environment that can enable these challenges to be overcome.

4.1 Financial Challenges

Financial challenges in the solar home-based electricity services industry can be disaggregated into: investment and working capital, end-user financing, subsidies and taxation regimes.

4.1.1 Investment and working capital

To date, the majority of investment and working capital has been provided through a variety of equity and debt financing channels, including: social impact and venture capital investment funds, Angel investors, and social institutions/development financing providers. With the industry having entered the market maturation phase, new channels of investment and the further leveraging of existing channels is required in order to meet capital requirements. Although difficult to calculate, in 2014 annual capital requirements at the manufacturing node of the value chain were estimated to amount to US$ 65 million, with distribution and retail capital requirements coming in at US$207 million. In order for the solar home-based electricity services industry to reach its medium-to-long term market potential, annual capital requirements for manufacturing are estimated at US$2.8 billion. Annual capital requirements for distribution and retail are estimated to be US$7.4 billion [29].

Capital financing from existing sources of finance has been hindered by a number of issues. These include, for example: impact investors applying commercial criteria in assessing the financial sustainability of their investment and failing to take into account associated societal gain; a lack of best practice examples and a poor understanding of the energy access industry, leaving impact investors doubting the financial sustainability of investments in the solar home-based electricity services industry; and social institutions/development financing providers solely targeting the least-developed countries and foregoing investment opportunities in other developing countries. An additional challenge has been the absence of a common platform that brings together impact investors with investment opportunities [29].

In addition to challenges in further leveraging existing sources of finance, it is important to attract investment from more traditional sources of private investment, such as strategic investors, private equity and commercial banks [1, 2]. Arguably the main challenge to attracting capital from more traditional sources of private investment is that the solar home-based electricity services industry does not match investment norms of developed financial markets. For example, private sector investors and financiers consider three main parameters: the return on investment, the risk of investment and the scale of investment. Regarding the return on investment, private sector investors and financiers generally require a ‘hurdle rate’ that is significantly higher than what can be expected given the low margins inherent in PLS and SHS business models. Furthermore, return on investment is expected to be achieved within a time frame that is generally unachievable for the industry [4, 30].

The risk of investment, although significantly reduced in recent years due to the success of pioneer firms in demonstrating a profitable business model, remains high relative to other potential projects. This is especially the case, given that regulation of the industry is nascent and there are recent examples of significant regulatory changes being made that affect the financial sustainability of the industry. A further risk comes from the impact that currency fluctuations, again a function of the unstable macroeconomic environment characterising many developing countries, can have on the already low profit margins [20, 28].

A further challenge is the discrepancy in the ticket size sought by pioneer firms (approximately US$ 900,000) and investors in the solar home-based electricity services industry [29]. This is typically significantly less than what a traditional private sector investor sees as attractive due to the cost and time taken to understand the industry, the business model, and undertake appropriate due diligence [30,31].

4.1.2 End-user finance

The challenge of providing end-users with the means to purchase and use PLS and SHS solutions has been approached through a number of traditional and innovative end-user financing strategies [24]. Among these strategies, pay-as-you-go (PAYG) has largely been identified as a particularly effective strategy due to its ability to significantly reduce transaction costs associated with end-user financing and allowing for a payment stream suitable to end-users' willingness and ability to pay. Experience of PAYG systems among the 28 pioneer firms currently employing such systems, suggests that in order for PAYG to fully develop into a comprehensive end-user finance tool, several challenges must be overcome [28].

The first challenge facing PAYG is the lack of working capital to extend to end-users. Industry estimates suggest that in 2014 the total capital requirement for end-user financing was US$ 15 million. In the medium-to-long term, this capital requirement is estimated to grow to US$ 1.30 billion annually [29].

Arguably the most significant challenge facing end-user finance, however, is the inability of traditional and innovative strategies such as PAYG to reach the poorest of the poor—who cannot afford to regularly use incumbent technologies—through purely market-based strategies [9]. An approach that shows potential, is harnessing the strengths of the PAYG approach within a pro-poor public-private-partnership model. The '5Ps model' occupies the middle ground between the private and public sectors and is able to allow companies to reach the poorest of the poor while earning a profit through allocating risk between the private and public sector. An assessment of existing initiatives using variants of the '5Ps model' highlights their potential in reaching the poorest of the poor but stresses the need for local and/or national champions and the inclusion of multiple stakeholders in the planning and implemention processes [21].

4.1.3 Subsidies and tariff regimes

The solar home-based electricity services industry is hindered by inefficient subsidy and tariff regimes. Approximately half of the world's governments subsidise fossil fuel energy, either directly or indirectly. Many subsidies are historical, often enacted to win domestic political support and are difficult to withdraw [32]. These subsidies, totalling approximately USD$328 billion a year, distort price signals and make solar home-based electricity services products more expensive relative to incumbent technologies, such as kerosene [1, 33]. These subsidies are a major challenge to the growth of the solar home-based electricity services industry [19].

Many developing country import tariffs and duties regimes and taxation policies continue to be similarly punitive to the solar home-based electricity services industry. As shown in section 3.3., taxes and tariffs are responsible for approximately

15% of retail cost for a middle-range PLS product. With gross profit margins being 1-5% for successful pioneer firms, taxes and tariffs are a significant barrier to the growth of the industry [4, 20]. Favourable import duties and taxation policies, such as the relaxation of import duties on PLS and SHS components and VAT have been adopted by a number of developing countries, although experience to date shows that governments often lack capacity to implement these select policies [19, 31].

4.2 Technical Challenges

Technical challenges facing the solar home-based electricity services industry include: the cost of components, quality issues and end-user awareness, technical barriers to the uptake of pay-as-you-go (PAYG) end-user financing, and maintenance and end-of-life use.

4.2.1 Component prices

Component prices currently account for approximately 30-50% of the total retail price for a middle-range PLS and for between 70-80% of the total retail price for a middle-range SHS [2, 10]. By 2020, estimates suggest that technology advances, industry maturation and economies of scale will see significant reductions in the costs of solar PV panels, LED bulbs and storage batteries. By 2020, advances in solar PV production, particularly organic solar cells and organic-inorganic hybrids, such as perovskite solar cells, are expected to reduce cost by 22%. Similarly, LED bulbs are expected to continue their downward cost trajectory over the next decade due to innovations, such as growing the semiconductor material required for current LED lights, Gallium Nitride, on silicon wafers instead of more costly sapphire or silicon carbide wafers [19, 20, 34].

The cost of storage batteries—currently US$160 and US$600 per kWh for lead-acid batteries and lithium-ion batteries, respectively—is predicted to decrease by 22% by 2020. At current growth rates, however, estimates suggest that it will take between 24-26 years for lithium-ion batteries—widely seen as superior[1] to lead-acid batteries—to achieve cost-parity due to expected decreases in the cost of lead-acid batteries due to improvements in energy density and materials cost [4, 19, 35].

A challenge facing the industry, however, is the rising cost of labour in current manufacturing hubs which may offset much of the cost-saving from technological advancement [19]. For example, China, which is currently responsible for approximately two-thirds of all PLS and SHS manufactured and assembled, is estimated to have seen its excess supply of labour—an indicator of low labour costs—peak in 2010. Economic projections suggest that by 2020-2025, demand for Chinese labour will outstrip supply. Although conceptually simple to switch manufacturing hubs to countries with lower labour costs, such as Vietnam and Sri Lanka, current experience suggests that this is beset with issues, such as unreliable supply chains and lower labour efficiency [36].

4.2.2 Quality issues and end-user awareness

A major problem facing the PLS and SHS industry is the presence of numerous cheap and low quality products [18, 37]. These products have led to market spoilage due to their poor quality shaping end-user perspectives and attitudes. A further issue surrounds end-user awareness of PLS and SHS, with end-users frequently displaying unfamiliarity with products and unrealistic expectations of the range of electricity services a PLS or SHS can provide [38].

To address the issue of cheap and low quality products spoiling the market, stakeholders have

1 *Advantages of lithium-ion batteries include, among others, high energy density, no initial prolonged priming, low self-discharge rates and no need for any periodic discharge [35].*

lobbied for the introduction of quality standards. In April 2013, the International Electrotechnical Commission[1] (IEC) enacted standard IEC/TS 662257-9-5 setting baseline levels of quality for solar-powered LED lighting products. Building on the IEC's standard, Lighting Global – a World Bank Group initiative – has developed a set of quality standards covering PLS[2]. The Lighting Global Quality Standards ensures that certified products display truth in advertising, are durable and well assembled, maintain a minimum of 85% of initial light output after having been in operation for 2,000 hours, and are available with at least a one-year retail warranty. To date, 51 products have been certified following rigorous laboratory testing [39].

In order for quality standards to have an impact, it is important to make consumers aware of the benefits of buying a certified product. Similarly, it is crucial for end-users to be made aware of the electricity services[3] provided by PLS and SHS solutions. Other areas that end-users need to be presented with a clear and simple explanation of, include: the end-user financing model and how it compares to expenditure on the incumbent technology bundle; end-user maintenance and operating protocols; and the available after-sales service support and how this is accessed [40].

To achieve this, a variety of rural marketing techniques are required. These involve: experiential education campaigns[4], village forums focused on answering detailed consumer questions, public service announcements, and training distribution agents to share important marketing messages[5] with end-users [6]. Importantly, increasing end-user awareness requires collaboration among private, public and community stakeholders, as well as the need to ensure that the specific design of each marketing technique takes into account the local context [37].

4.2.3 Technical barriers to the uptake of pay-as-you-go (PAYG) end-user financing

The uptake of pay-as-you-go (PAYG) end-user financing is hindered by a number of technical challenges. The first challenge relates to the transaction fees for mobile money payments charged by network operators. Currently, these transaction fees constitute approximately 15-20% of end-user costs. Although transaction fees cover necessary services, current business models operated by network operators charge proportionally more for lower-value transfers, such as those made through PAYG. Changes to these business models would greatly reduce transaction fees for PAYG and help overcome a significant barrier to PAYG growth [1, 28]].

Being a relatively new technology in the PLS and SHS space, PAYG further suffers from incompatibility issues between user interfaces and business to business interfaces that are key to managing the relationship between the PAYG system and mobile money providers and telecommunications firms. Standardisation of interfaces is required for future growth. A further emerging challenge is for standardisation regarding data privacy. This is because the majority of PAYG systems collect data on end-user behaviour. End-user focus group participants have displayed universal concern about these being used publically [28].

1 The International Electrotechnical Commission (IEC) publishes consensus-based international standards for electrotechnology. IEC standards are used as a basis for the drafting of national standardization and as a reference for international tenders and associated contracts [39].

2 Stakeholder consultation is underway concerning the drafting of standards for SHS products [39].

3 As an example of unrealistic expectations of electricity services, a village leader in Papua New Guinea asserted that "...one [low-end] solar home system can create enough energy to power a computer, copy machine, lights in every room, television, and appliances, all from a pretty small device." [38]

4 Campaigns often consist of key educational messages being interspersed with music performances [40]

5 These include, for example, economic savings, the ability to charge mobile phones, and health benefits [40].

4.2.4 Maintenance and End of life use

Maintenance of PLS and SHS through a robust after-sales service system is necessary for pioneer firms to establish trust with end-users and experience growth in rural areas [4]. Quality assurances through maintenance and after-sales services are crucial for end-users, for many of whom a PLS or SHS represents a significant investment.

Due to the deep rural networks required to reach end-users, few suitably trained and licensed repair technicians, and the lack of a supply-chain for official spare parts, ensuring adequate maintenance and after-sales services remains a barrier to growth in the solar home-based electricity services industry [5, 6, 14]. A potential solution that is being increasingly trialled is the use of ICT technologies, such as SMS gateway technology or data connectivity, to allow for real-time monitoring of PLS and SHS. Real-time monitoring allows for an understanding of supply logistics for spare parts, preventative maintenance, and the timely dispatching of repair technicians [1, 28]. Combined with the creation of a robust network of trained repair technicians, awareness campaigns to ensure end-users are able to properly use their product, and a ready supply-chain of spare parts, it is possible that the ICT-enabled after-sales service systems for PLS and SHS will not only create an adequate maintenance and after-sales service system but create skilled employment opportunities in rural areas [5].

PLS and SHS products are not currently designed for end-of-life use [31]. To date, there has been little upfront consideration of recycling key components, such as PV panels and batteries [20]. Broadly speaking, designing PLS and SHS products for end-of-life use has the potential for increased sustainability and for creating economic value at the local level, through recycling of the systems through local value chains [5].

Recycling of key components requires novel breakthroughs to overcome the traditional barrier of economics of scale. For example, the recycling of lead-acid batteries – a key component for many PLS and SHS – has traditionally required significant capital investment in industrial-scale high-temperature furnaces, with appropriate facilities to control for discharged gases, dust and water. These capital restraints make it uneconomical to recycle lead-acid batteries in rural areas necessitating the development of extensive logistical chains. Recent technological breakthroughs[6], however, have overcome the issue of economies of scale as a limiting factor to the recycling of lead-acid batteries [41].

These examples suggest that links between research institutions and other key stakeholders, such as business, policymakers, and on-the-ground enablers and end-users need to be strengthened to ensure that novel technological breakthroughs translate to effective recycling of PLS and SHS components and help play a role in the development of local rural economies. In order to enable the uptake of the recycling of PLS and SHS components, an appropriate regulatory environment is crucial. It is important that policy makers avoid the use of blunt instruments, such as higher import tariffs on components such as solar PV panels and batteries, with the goal of reducing the quantity needed to be recycled [5]. Such measures have the inadvertent impact of turning pioneer firm business models from being feasible to being non-feasible. What is needed is for a broad stakeholder engagement, to catalyse recycling while ensuring that recycling of core components does not obstruct efforts to provide electricity services to rural communities.

6 The solution, devised at the University of Cambridge, is for residual battery paste to be dissolved in a solution of carboxylic acids (leached from plants) to produce lead organic material. This material is subjected to high temperatures and converted to lead monoxide and metallic lead, allowing for the preparation of new battery paste [41].

5. Conclusions and a way forward

This technical report has reviewed business models used by firms in the solar home-based electricity services industry. The industry, consisting of pico-solar lighting systems and solar home systems, has entered the market maturation phase and was worth an estimated US$ 550.5 million in 2014. The industry is expected to grow rapidly to US$ 2.4 billion by 2024. The backbone of the industry and its projected future growth is a group of pioneer firms. These pioneer firms, a mixture of small companies and social enterprises, have been operating in the industry for 5-10 years and have made tremendous strides in delivering on the customer value proposition: providing electricity services to off-grid consumers.

Through a process of trial-and-error, pioneer firms have made significant progress in delivering on two key processes along the value chain: distribution to remote off-grid areas and providing finance to end-users. Distribution and end-user financing strategies vary among pioneer firms depending on existing strengths. The various distribution strategies are characterized by pros and cons making it difficult to select a winning strategy. Instead, pioneer firms have played to their organisational strengths and have taken into consideration contextual circumstances in their targeted geographical areas. This is in stark contrast to new multinational corporation entrants who have to date struggled to make inroads in remote, off-grid areas. A review of traditional and innovative end-user financing strategies, however, points towards pay-as-you-go (PAYG) as a way forward for the industry due to its ability to significant reduce transaction costs and to match the willingness and ability to pay for the majority of end-users.

Further growth in the solar home-based electricity services industry is necessary for two reasons: 25% of the unserved rural population is estimated to require PLS and SHS solutions to meet their basic electricity needs; ; and low margins per unit sold mean that scaling up is required for pioneer firms to achieve sustained profits. This further growth requires the tackling of financial and technical challenges by concerted multi-stakeholder action.

5.1 Overcoming financial challenges

5.1.1 Investment and working capital

The industry suffers from supply-side bottlenecks because it does not attract sufficient investment from existing channels (e.g. social impact and venture capital investment funds, Angel investors, and social institutions/development financing providers) and is now at a stage where new channels of investment are required in order to meet capital requirements.

In order to attract further investment from existing financing sources, a common platform needs to be set up that can bring together socially oriented investors with investment opportunities in the solar home-based electricity services industry. This platform could further provide information on the energy access industry to investors and make available best practice examples to alleviate investor doubts about the financial sustainability of investments in the solar home-based electricity services industry.

Private sector investment can be harnessed through the 'de-risking' of the industry. Pioneer firm business models in the solar home-based electricity services industry are arguably sufficiently field tested and robust to de-risk operational risk and customer payment risk. De-risking regulatory risk, however, requires the government and international community to work together to create a universally respected framework for regulation of the solar home-based electricity services industry. The creation of a framework at the international level would dissuade governments from imposing unilateral and punitive regulatory changes. Technology risk requires the advancement and further adoption of internationally recognised and enforced standards, such as Lighting Global advanced by the World Bank Group.

Addressing the relatively low rate of return and longer timeframes of return inherent in the industry may require collaboration between private investors and the public sector. Given the public good characteristics of access to electricity services, the public sector may be able to part-fund investment in pioneer firms. Sources of public funding should be made available for this purpose from, for example, the development banks.[1] A further measure that may reduce the 'hurdle rate' criteria imposed by private financiers is the design of less costly, context-appropriate due diligence protocols. If adopted more widely in the financial sector, this may bring down the transaction costs associated with investment in pioneer firms allowing for a lower mandated rate of return.

5.1.2 End-user financing

Further effort is required to provide end-user financing to the poorest of the poor who remain underserved through purely market-based strategies [9]. A promising approach that should be further explored and implemented is to harness the strengths of the PAYG approach within a pro-poor-public-private-partnership (5Ps) model. By allocating risk between the private and public sectors, this would allow pioneer firms to reach the poorest of the poor while earning a profit [21].

1 *There is historic precedent for the public sector of developing countries taking out loans from donor bodies and banking institutions to guarantee private sector financing in rural electrification over long-term periods (e.g. 30 years) [42].*

5.1.3 Subsidies and tariff regimes

Removing energy subsidies is difficult due to the politicised nature of subsidies. If, however, subsidies for kerosene among rural populations were targeted, a staged process of removal could nudge end-users towards pico-solar lighting systems and/or solar home systems. This approach would need to be staged to ensure the availability of systems. A further condition would be the need for a targeted awareness drive sharing the benefits of PLS and SHS relative to kerosene. It is likely that this approach would benefit from having a first-mover province or nation to serve as a champion for the removal of kerosene subsidies.

Taxation regimes are arguably more straightforward to reform than energy subsidy policies. To date several countries have reduced or eliminated import tariffs on key components of PLS and SHS solutions due to the public good characteristics of solar home-based electricity services. Implementation, however, has been hampered due to a lack of capacity and transparency. A first step would be to encourage countries that have not yet moved to a favourable tariff regime to do so. This could be achieved through conversations at regional or international levels, through for example the World Trade Organisation. However, ensuring that countries implement favourable taxation regimes requires much more deep seated institutional change.

5.2 Overcoming technical challenges

5.2.1 Component prices

With component prices accounting for an average of 44% of retail price for PLS and 75% of retail price for SHS, reducing component prices would help pioneer companies expand their consumer base and improve their profit margins. To do this, it is important for public and private sector financing to sensitise leading researchers to real-world situations. This can help create a complementary research stream to blue skies research—which is required for disruptive breakthroughs—that focuses on designing components for rural requirements and price-points. Together, this two-pronged approach will increase the likelihood of component prices decreasing in the solar home-based electricity services industry.

Another method to reduce component prices is to facilitate either partnership with, or acquisition of, pioneer firms by multinational corporations (MNCs). To date, MNC entrants in the solar home-based electricity services industry have struggled to make inroads in rural off-grid areas. Partnership or acquisition would allow for some reduction in component prices through combining the on-the-ground expertise and rural distribution networks of pioneer firms with the sizeable manufacturing capabilities of MNCs.

5.2.2 Quality issues and end-user awareness

Ensuring that the industry is not spoiled by the proliferation of low quality products is an important challenge. The development of internationally recognised quality standards, such as the Lighting Global Quality Standards from the World Bank Group, is a notable milestone in overcoming this challenge. What is required moving forward is the need for concerted action to make consumers aware of the benefits of buying a certified product. This is likely to require national government support for certified products, and multi-stakeholder engagement through education campaigns that deliver the appropriate message to end-users.

5.2.3 Technical barriers to the uptake of pay-as-you-go (PAYG) end-user financing

Focusing on the most promising end-user financing approach—pay-as-you-go (PAYG)—end-user financing faces some technical challenges. Specifically, in order for the PAYG approach to scale, it is important to have technical regulation at the international level to ensure that user and business interfaces are standardised and compatible. At the national-level, cross-sector regulation is required between telecommunication firms, mobile money providers and pioneer firms to address current bottlenecks in the growth of the solar home-based electricity services industry and to ensure appropriate regulation regarding end-user data privacy.

5.2.4 Maintenance and end of life use

Maintenance of PLS and SHS has emerged as crucial for pioneer firms to establish trust with end-users and experience growth in rural areas. Traditionally, maintenance requires deep rural networks, trained and licensed technicians, and a ready supply of official spare parts. Given the limited resources of pioneer firms this has proven to be a significant challenge. To help overcome this challenge, further emphasis should be placed on the use of ICT technologies to allow for real-time monitoring and appropriate maintenance response. The use of ICT technology will allow for a just-in-time approach to maintenance by pioneer firms. Support for vocational training of rural-based technicians should be considered by government or donor bodies, with the added benefit of creating a skilled employment base in rural areas.

PLS and SHS solutions need to be designed with end-of-life use in mind. This suggests the use of technologies amiable to recycling in rural hubs and the creation of a formal recycling infrastructure in rural areas. Achieving this will require close cooperation between researchers, pioneer firms and the public sector.

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