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# Roadmap to Rural Self-Reliance

## Pre Conference Draft Report
## Working Group 1

The Kalam Conference Team

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# ROADMAP FOR RURAL ENERGY SELF RELIANCE

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# Preface

This is the first of the Working Groups for the First Abdul Kalam Conference. It sets the baseline for a plan to achieve self-reliance in energy in rural India, with a focused roadmap to build up enterprise in concert with the rise in energy supply and usage. In our view, this is the root of the solution to the central question before this conference: How to enable high standards of living and quality of life, while staying true to environmental responsibility and without destroying Nature.

Anyone setting out on a mission to improve the situation in rural India encounters a flurry of reasons to make them feel irrelevant. Typically these start with the latest headlines where some senior politician declares that India will have no poverty by 20xx, amazingly imminent. Followed by initiatives from half the multi-billionaires in the world, similarly located in India. And the initiatives by various Central and State Governments, and corporations, all with slick websites these days.

So it is essential to remember why we are still doing this: The lack of energy at the rural resident level is the most stark indicator of rural India's low quality of life, that in turn translates to misery in the cities. A very large number of rural residents simply have no access to power. To all who point to imminent revolutions, please ask:

*Why, 72 years after Independence, did 200 to 300 million Indians wake up today with no access to electric power?*

Their children cannot read in the evenings without burning expensive, polluting fossil fuels. They do not have access to power tools. Nor the Internet. Nor fans to blow away the disease-carrying mosquitos. Nor transport to get to a doctor when they need medical care, with the nearest help being an average of 30 kms away.

The cities are not in much better shape, impressive skylines notwithstanding: the major metropolis of Chennai, with 8.4million residents, went through catastrophic floods in 2015. Four years later Chennai is in the grip of devastating drought, literally having run out of water.

City folks are wealthy enough to call for water to be brought in by tanker truck, train, ship and desalination plants, even by air. What about the people in the villages where they do not even have roads or electricity? No newspaper or TV channel appears to have gone out there to report on how they are managing to survive.

This is the stark reality as of mid-2019.

This Report presents a Roadmap. It is not perfect, but it is a start. Please join us towards useful action.

# Summary:Rural Energy Self-Reliance

Laying out a matrix of problems facing India, it becomes apparent that better availability of energy can break many of the knots between problems and allow each to be tackled. India lags severely, and far out of sync with mactoeconomic indicators such as GDP, in per capita energy availability. The problem is much more severe when the distribution of energy access is considered at a finer level of resolution. Some 67 percent of Indians live in the vast rural areas, spread across 597,000 villages as well as more remote communities. At the macro level, India faces an extreme energy shortage to power her cities, heavy industry, transportation and other infrastructure. Once beyond this, energy for agriculture is a top priority, enabling irrigation of fields. This leaves little for villages. In 2019, India claimed that the power grid reached every village and we do not doubt that assertion. So-called *Last Kilometer Connectivity* seems to have been achieved all over India. The questions are about what actually comes through the grid to every village, in other words, last-meter connectivity, and how many villagers have either access, or the ability to pay for access, to electric power.

Electric power is only a part of the story. India does have vast resources of coal, and a few oilfields. Discoveries of vast reserves of natural gas have been reported. However, today India imports some 80 percent of the liquid fuel needed to power her transportation and mobile energy needs. These imports are paid in foreign currency, so that the foreign exchange reserves, and the value of the Indian rupee, are at the mercy of the international oil market. Kerosene continues to be a prime fuel of the least-advantaged sections of Indian society, both rural and urban. Kerosene prices are held down by Central Government subsidies, and this drains resources needed for other purposes. Fluctuating oil prices impact the sections of society that have the least disposable income: the autoricksha drivers, commuters who depend on buses, scooters and motorcycles, the farmers who need fuel for agriculture, and generally, the poor working classes of the so-called Informal Economy, who survive on hourly wages. Since Independence in 1947, the cumulative effect of oil imports have contributed very heavily to the decline in value of the Indian rupee by an apparent factor of over 1000.

Lack of energy deprives children of education: the poorest villages depend on evening-school teachers, and pervasive power cuts and outages make it impossible for children to read or focus on education. Without electric power there is no Internet, even though many Indians have access to mobile phones which they must charge at power sources far from home. Lack of pumped water forces residents, mostly women, to walk long distances to get and carry the water for the family's meager daily needs. This water is often polluted and causes diseases and again, loss of human strength and productivity. Cooking in woodburning kitchens with poor ventilation drives eye diseases and so-called *hut lung disease*. The lack of power, water, healthcare access, communications, skilled labor and infrastructure inhibit the development of enterprise that can bring disposable income, so that non-agricultural employment in rural India is stuck at a dismal level of under 5 percent.

In this context, most observers agree that a bottom-up approach with independent power generation at the rural level, is crucial to make the connection. Lack of power obstructs education and basic healthcare, even the availability of clean drinking water. It removes the business justification for better infrastructure and connectivity. Lack of business enterprises denies opportunities to build rural non-agricultural employment. Faced with at best seasonal contract-labor employment in their home villages, workers migrate to cities in search of even a marginal existence. Periodic crop failures leave farmers with no alternative but to go into deepening debt, eventually losing their one resource: land. This leads to a dismal record of rising suicides by farmers and their families. This vicious cycle has to be broken.

This report lays out a roadmap to break out, and bring full energy self-reliance using renewable, sustainable sources to rural India. It starts by summarizing the report of the February 2017 Smart Village Roadmap Conference in Atlanta, GA, USA, and a textbook on Micro Renewable Energy Systems, then goes on to build on this roadmap. The Roadmap is based on the hypothesis that *education provides the key to generate employment, entrepreneurship, wealth generation and independence, with energy as the crucial enabler*. Several technologies are proposed to be introduced in sequence, along with wealth generation through corporate and small business participation. Respecting the cultural traditions and aspirations of the villagers is extremely important - by no means should the exercise of modernization reduce the colorful kaleidoscope of rural India to a drab landscape of uniform quasi-urban sprawl. We have one chance to do this development right.

The first step is to bring electric power, followed by biogas heat and then power, to every village school. This first impacts school children, thus stemming the bleeding of opportunity for the coming generation and enabling education. Seeing their children getting a good education relieves a major stress burden and inspires parents. Next, skill training is introduced through the school, along with connectivity to the outside world. This is followed by village-based enterprise development, along with support to obtain the power resources needed for enterprise: the idea that $Energy + Knowledge = Wealth + Independence$.

Once there is a required minimum level of business activity, larger and more complex systems involving solar concentrators will bring solar thermal and thermochemical energy, as well as liquid fuel for transport needs. Extensive use of biogas from vegetation at the single-family and community levels will replace wood-fired and natural-gas fired cooking, and then generate power, complimenting solar power. The roadmap envisages accelerated transition to a clean hydrogen economy.

A pilot project has been carried out, where all initial interaction with the villages has been through the Single Teacher Schools set up by carefully-selected and experienced NGOs that have a clear track record. Fifty-five village schools illuminated with solar photovoltaic power. However, it has stalled at that level until we can find a way to convey the importance of building skill development and enterprise using that power. Developing the myriad networks needed to achieve these ambitions goals, remains a formidable task. This report attempts to lay out the Network of Incentives needed to drive each participating entity.

As much as possible, this strategy draws on current efforts of the government, and on traditional beliefs and history of rural India. Respect for Nature as being central to Creation, and the ancient traditions of distributed rural enterprise, are central elements in this strategy. The native talent for business enterprise and trading will be encouraged. Respect and talent for education will be fostered. But the crucial question remains to be answered: How can risk-taking enterprise be persuaded and inspired to light up and invest in the villages? How can the needed environment to sustain them be created, and in turn sustained? One clear direction is to create the conditions where talented, experienced city-dwelling professionals and entrepreneurs see their future as being in rural India. The required revolutionary changes in these aspects are considered in the other four Working Group Reports.

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# Chapter 1

# Rural Energy Self-Reliance

## 1.1 Main Ideas

There are three ideas driving this conference and particularly this document, on why rural energy self-reliance is the nucleus of sustainable development and growth.

1. The first is that $Energy + Knowledge = Wealth + Freedom$. Removing the dependence on external entities for energy is the first step towards freedom and growth. Intelligent use of energy also leads to wealth generation on one's own terms, providing flexibility and disposable income because of increased productivity.
2. The second idea is that of Rural Enterprise generation, to sustain the growth of energy towards self-reliance, and sustain growth of rural wealth. Ways must be found to base a variety of enterprises, many of which are not related to agriculture, in rural India.
3. With current technologies, and those still on the horizon, it is possible to build a distributed economy in rural areas, that is at once modern, sustainable, and offering a clear growth path.

## 1.2 Background for Working Group 1

Energy and fresh water are recognized as the most important resources for human civilization. Abundance of energy can ensure availability of fresh water, even if it has to be obtained by distilling sea-water or pumping water uphill. Thus energy is the focus of our efforts.

We start with the assumption that much of rural India has dismally low access to energy. India's average per capita access to energy is an order of magnitude below that in the USA and other developed nations, and about a factor of 4 to 7 below that of the People's Republic of China. The average does not tell the story properly: much of the energy access and usage is in industrial plants and cities, leaving the rural resident with a far lower average. A human unaided by powered devices, can do as much work as 0.5 kiloWatt-hours of electrical energy in a day. That would be worth about 7 rupees or 0.1 US dollars. With access to modern electric power, the same human can generate work worth thousands of dollars in a day.

Absent energy for the most part, and lacking knowlewdge on what can be done with energy, rural India also does not appear to have significant non-agricultural employment. When energy is available, it is not used to generate income. It is usually seen as a luxury to be used to watch movies, or acquire refrigerators (which are not irrelevant), washing machines and airconditioners. Transportation fuel and most other fuel has to be imported, much of it from abroad at global prices. We know that fuel prices have gone steeply up, with very large and rapid fluctuations. The farmer's family is entirely at the mercy of these immense forces, far beyond their control or prediction power. Similarly, much of Indian agriculture, the predominant source of income in the rural areas, is intimately tied to the timing, distribution and intensity of the Monsoon rains. Irrigation is mostly by open gravity-driven channels dug into the raw earth, often with manual labor used to divert it as needed. Fully 87% of India's freshwater usage is for agriculture. Losses of water to evaporation and seepage are nearly 75 percent.

## 1.3 Mandate for Working Group 1

The primary thesis driving this Group is that Energy self-reliance at the rural level is the key to prosperity. This is not about debates of Solar vs. Coal or Nuclear vs. Fossil, or about Big Dams vs. Wind. We leave those debates to others. What is presented here is a roadmap to be followed one system, one school, one village at a time until all of India has basic self-reliance for sustainable energy sources. All ideas and energy sources have a role in this, with the intention being to set up the entrepreneurial framework to allow all to succeed to the best of their merits. The portfolio to be adopted will be diverse and tailored to local resources. It will evolve as capabilities, technology and needs evolve. Success in this endeavor will require success in meshing the interests and aspirations of various stakeholders in a coherent network.

Self-reliance with local energy extraction provides stability of prices, for electricity as well as transportation and cooking fuel. The implication is that through energy self-reliance, rural India will have plenty of wealth-generating rural-based enterprise. This in turn will drive expansion of the power grid, both in supply and reach: we do not intend that every home remain off-grid forever, but even when grid-connected, local generation will provide independence and resilience to upheavals. There will be no need to migrate to the cities in search of subsistence: in fact there will be reverse migration from the overcrowded cities to the rural areas. In the other Working Groups we will see how to use this new reality to ensure that the other Sustainable Development Goals are achieved. Thus the above notion of rural energy self-reliance is the crucial enabler.

## 1.4 The Indian Economic Lamp Base

Most Indians are poor by global wealth standards. The problem is much worse than what Prof. C.K. Prahlad famously described as Reaching The Bottom Of The Pyramid. The Indian economy and income distribution are not 'Pyramids': the name has been rather thoughtlessly applied as in *Bottom of The Pyramid*. A pyramid has straight edges and flat sides. As the left side of Figure 1.1 shows, the traditional view of an Income Pyramid implies a robust middle class and some semblance of a reasonable, sustainable income distribution with a viable path for downward and upward propagation of change. This is compared against the Lamp Base model on the right of the figure. In such a model, most of the population is at a very flat base. Change that percolates down from the top may reach down *most of the way down to the bottom* and yet not reach *most of the population!*

The Indian distribution (perhaps similar to those in much of Africa and perhaps Central/South America) is more like a very stable spire on a huge and very flat base, perhaps similar to that in Figure 1.2. The top of the spire is over $20B per year and not shown on this figure: Many of the top billionaires in the world are now Indian and India-based. The overall GDP ranks fifth in the world, projected to rise to number 3 at the present rate of growth. Technological achievements are many and impressive. If one wears a leather jacket and boots and dark glasses, and zips around in chauffered limousines between 5-star hotels, airports and parties and takes all one's vacations abroad, as the top 0.5% can afford to do, one could entirely miss the reality, and imagine that one is living in a true Paradise (interspersed with a liberal sprinkling of villains as in the Bollywood movies). If you stretch down


*Figure. 1.1: The traditional view of an Income Pyramid compared to the lamp base model.*

98 % of the way from this level, and bring some amenities to everyone in that income bracket, you will have missed well over 75% of India's population entirely. Many of these people live in the rural areas.

The data in Figure 1.2 indicate that the above model is sickeningly on target. *If you bring some advancement to India, top-down, and reach down 99 % of the way down from the top, you will miss over 90 percent of the population of India!*

This is the magnitude of the challenge. The base is also very, very *stable to change*: Even very large efforts disappear like ripples on an ocean. Achieving SUSTAINABLE change that actually PROPAGATES is an immense challenge.

## 1.5 Debate on Rural Realities

Why is any of this even needed? India is a vast nation with 1.3 billion people with around 67% living across 597,000 villages (that number is from the last census, and subject to various definitions of villages, towns and rural areas). That much seems agreed. Below we take a detour into different narratives about India, all existing today.

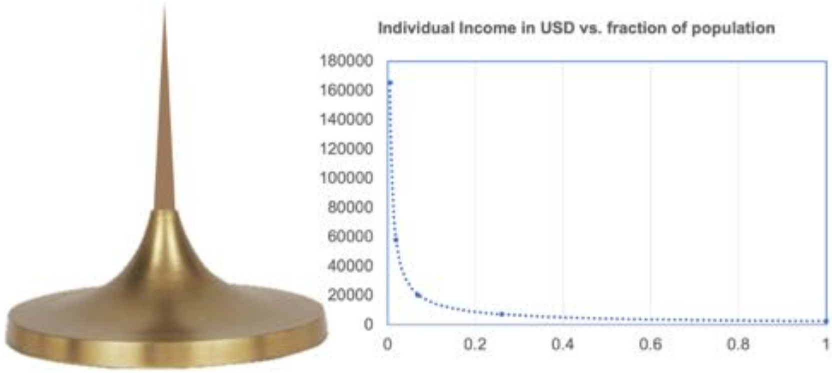



*Figure. 1.2: A more realistic model for India's income distribution is the Lamp Base shown. The data on the right show the income level reached by each fraction of the population. For instance only 0.5 percent of the population has an income above $165,000. Nearly 74% have income below about $2500.*

### 1.5.1 The Patriotic Activist View

A view of rural India projected by some Indian social activists on the Internet is given below. These experts (encountered in our search for journalists to cover this conference!) maintain that news items about poverty and distress in rural India are malicious propaganda by Academia and Intelligentsia coupled with Foreign Interests. Projects funded from the Indian diaspora as well as other entities, focused on rural India, are attributable to the ignorance of these entities, conned by cynically greedy entities in rural India. Presumably the argument is that villagers dress down and appear pathetic to pose for photographs to fool the silly foreigners. The French Revolution allegation about Queen Marie Antoinette's asking "Why don't the peasants eat cake?", used to rationalize her arrest and beheading, pales in comparison to these attitudes seen in modern India towards their rural compatriots.

Rural Indians are quite happy and much smarter than urban Indians, in this narrative. This is aligned with the notion that all development in energy use, infrastructure, medical access, clean water etc is destructive to the environment. That aligns with the narrative of the loudest proponents of Reducing Global Warming, which in turn fits well with the European narrative demanding that Indians and Africans refrain from using indigenous fuels, and otherwise scale back economic development. Thus the Activists, ironically, find the most applause from their erstwhile Colonial Superiors.

### 1.5.2 The Cry Syndrome

At the other extreme, many large and well-funded entities owe their wealth to the Cry Syndrome. They post pathetic pictures of starving children, victims of cruel oppression in (India) and request continuing donations from people in wealthy nations, and by extension in westernized urban India who depend on western sources for news. Several of these organizations are not set up purely for personal gain or as outright fraud. Instead they fund operations to Save Souls and convert the Heathen. This turns out to be a well-oiled business model, refined for centuries, where newly-minted converts are given a set of good clothes and some money, followed by a lifelong obligation to hand over 10% of gross earnings to multi-national organizations that are also busy with real-estate and other lucrative business and political influence. These entities, therefore find it to be in their interest to project a picture of abject poverty, oppression and hopelessness in rural India (and urban India).

### 1.5.3 The Investigative Media

A third growth business is that of anti-government reporting. In the guise of Investigative Reporting, media entities project very negatively slanted reports on government initiatives and projects, showing only the parts that encountered problems, as well as people with grievances against government projects. The famous agitations against the Sardar Sarovar Narmada Dam project, and more recently the Koodamkulam nuclear power plant, both perhaps started with a nucleus of unresolved grievances. However, they mushroomed into very well-funded agitations that cost the Indian taxpayer a huge amount of money, and subjected the people of the area to decades of deprivation. In a telling incident, when the canals enabled by the Sardar Sarovar project finally brought running water to the arid villages of Kutch in Gujarat, the locals wept openly: the end was in sight to the decades of misery, carrying pots of water for miles every day for basic necessities. The long delay was the result of a criminal obstruction of basic human rights. There was indeed a real and harsh tradeoff: the poor people living upstream of the dam had to be resettled as the dam filled up. Several communities actually turned into islands, cut off from their neighbors except for access by boats. The displaced people had to be transplanted to places where they had no experience of making their subsistence living, and this process was no doubt aggravated beyond all reason by needless and heartless official delays and negligence. On the other hand, the parched villagers of Kutch waiting for drinking water were never mentioned in the media in reporting on the project. Similarly, nor were the millions who were waiting for the Koodamkulam project for electricity. In the Koodamkulam case, the Prime Minister eventually lost patience and came out bluntly with the evidence of foreign manipulation behind the agitations - and ordered the project completed.

### 1.5.4 The Official Data

A fourth narrative is that of the government of the day, and of the ardent followers of the political parties that constitute the governments at the State and Central levels (which in India may be diametrically opposite in philosophy!) Government data are often viewed with suspicion, with good historical reasons. As one retired veteran of the Kerala State Electricity Board (KSEB) remarked: *"We worked on numerous projects. But we were* ***never*** *asked the basic question: Did the customer actually receive the benefits that were intended?"*

As of 2019, the Central Government reports that the number of Indian *villages without electric grid connection* is zero. We take that statement at face value. With 300 million new bank accounts established in the past 5 years, and many of those accounts accumulating savings despite starting with a zero balance, there is certainly reason to take pride: why are people able to save if they are that poor? Access to healthcare, per the Activist school of thought mentioned at the top of this section, is perfectly OK in rural areas. Of course it is not viable to have Specialty Hospitals in villages, but Indian doctors who live in villages are used to going out and treating patients at home, and one simply has to walk over (driving is probably not an option, absent roads and vehicles) and knock on their door even at 4AM (telephone is also probably not an option).

### 1.5.5 Subsidies, Loan Forgiveness and Internal Migration

On the other hand, others argue that is not surprising that such rosy views have traction. Many Indians have simply become jaded with the daily experience of stark contrasts that would shock a newcomer. In this narrative the 'domestic servants' who include children who do not get schooling, are happy to have the generosity of their employers. As one instance, the state of Kerala is itself not a rich state, its budget being in a perpetual state of brinkmanship in deficit financing. The State has a long history of extreme anti-business policies - and hence of lack of opportunity, that have forced many of the skilled workers - and hungry students, the Editor of this Report being an example, to emigrate in search of higher education and employment. Today many rural areas in Kerala sound like West Bengal and Bihar if one listens to the voices and accents in the public places: those are of the migrant laborers, a large segment of the population, who come from those distant states. Per the above narrative these laborers are there by choice, things are quite OK in their home states. As for the rural population itself, there is a maze of problems. Farm Subsidies and Loan Forgiveness lead to fraud and demoralize honest endeavor. Rural residents use loan money to splurge on weddings and consumer items, then expect Loan Forgiveness. The honest ones seek loans from loan-sharks who then force them out of their land and homes.

Money supply in the villages has risen in the past decade with the Right To Work Act and the election-time largesse of ruling parties, but this rise has not led to a rise of rural enterprise: it has generally gone into rising consumer demand for imported goods.

### 1.5.6 Purchasing Power Parity

The fall of the Indian rupee relative to the US dollar can be viewed in the context of India's dependence on imported fuel. This can be seen from Figure 1.3. India today imports some 18 times as much petroleum fuels as she did in the 1970s. The price of a barrel of oil in US dollars has gone up from around 3 dollars a barrel in the early 1970s, through several so-called oil shocks, up to $130 and now back down to around $80. In the 1960s five Indian rupees bought a US dollar. In 1978 it was 6 rupees to a dollar. In 2019, it is 68 Rupees to a dollar.

Others argue about Purchasing Power Parity. In this narrative, the real equivalence in terms of purchasing power of specific goods and services is around 10 rupees to the dollar. It is true that a good meal at a nice State Tourist restaurant on the highways can be had for around 200 rupees, worth every bit as much as a 20-dollar meal in the USA. In villages a meal might cost much less, with the small esablishments being extensions of homes.

One way to reconcile these views is that urban India has contact with the outside world. They live in a world where costs have shot up. In turn, growing congestion in the cities has driven the cost of real estate exponentially upwards.

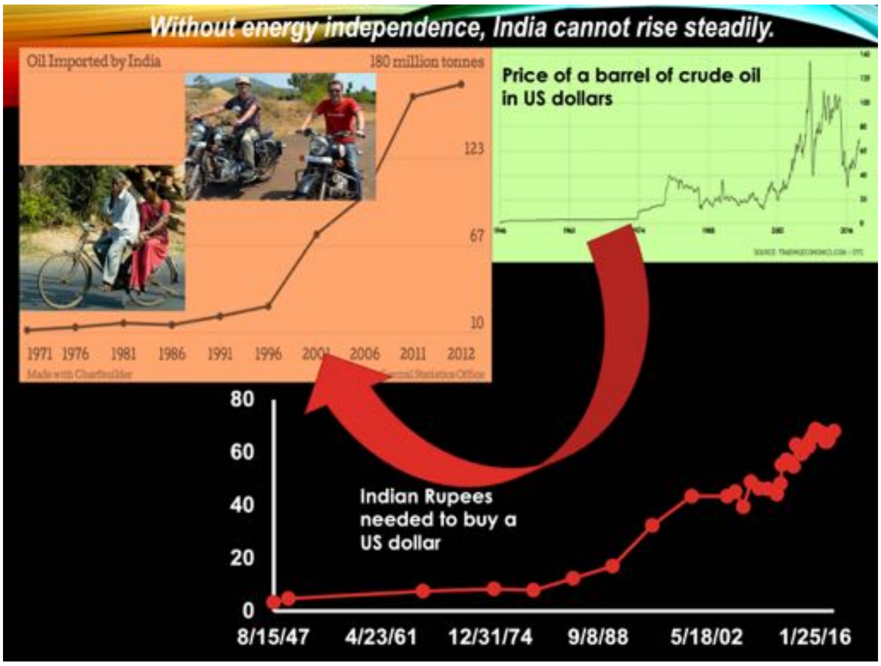



*Figure. 1.3: The triple whammy of energy imports on the value of the Indian Rupee.*

Several Indian cities have real estate costs higher than those in most US cities, in converted dollars. These costs require salaries that are, say, at least 25 to 50 percent of salaries in wealthy nations. However, rural India has largely been left out of this growth, so that salaries available from the few jobs available in rural India are perhaps 25 to 50 percent of those in urban India. Costs are low, but many essential services are simply not available or accessible. Access to medical care is dismally poor. Many rural 'health centres' simply do not have staff, let alone qualified physicians. Medical graduates are often required by State law to practise for a couple of years in rural areas as a condition of public financing of their education, and most try very hard to dodge that. The presence of large numbers of migrant laborers, to states where they cannot even speak the language, is due to the very poor prospects in the villages of the migrants' home states. The children of domestic workers - and migrant laborers if they bring their uprooted families, often do not have access to education.

### 1.5.7 Is there evidence of all this?

Yes. The presence of over 100,000 Village Single Teacher Schools, with a demand for many more, shows that children of elementary-to-middle school age in at least that many villages (out of the 597,000) have no other access to education. While every village may have a connection point to the power grid, what actually comes through the grid - and when - is an embarassing question. Often the answer is "fluctuating power for about 1 to 2 hours a day at best". As one NGO worker responded to our question of " Why does your school need solar power when I can see bulbs and power lines in these pictures?" *"Sir, yes there are bulbs and lines but no power. The government gave Free Power to the farmers, to run irrigation pumps. The villagers were smart: they redirected the power to their homes. The government was smarter: They cut the power except from midnight to 4AM when pumps can be run. So the children have no power in the school in the evenings"*. The question of how many villagers have money to pay for electric power is even more dubious.

The question of why the Central Government's "Swachh Bharat Abhiyan" (Clean Bharat Exercise) is needed - along with why at least 100,000 villages so far have had to build separate toilets for boys and girls where they had none, also suggests that things were perhaps not that great in the past, and the problems are far from solved.

Recently, the Niti Aayog, the government entity that replaced India's Planning Commission, announced a project to employ women engineers, and train rural women to set up solar photovoltaic systems in their villages and use them to generate employment in the villages. Why, if the villages all have enough power? Similarly, a video prepared as part of the Prime Minister's electionc campaign featured a family enterprise in a village adopted as Model Village by the Prime Minister, in his Varanasi constituency. They were using solar photovoltaic power that they generated locally.

Per capita availability of energy in India is only a fraction of the values in developed nations, and much of this is concentrated in the cities, whereas over 70 percent of Indians live in rural areas. Estimatds vary widely but they are all bad. Rao [1] in 2015 estimated that 32% of Indian homes received no power. By latest counts [2] 214 million people still do not have any access to electric power; this is more than 50 million households. Of the villages that are deemed electrified, many may not have any more than a power grid extension reaching the village, but with rarely any power flowing through it. Villages are deemed to be electrified by government metrics if there is electric power reaching 10 percent of the public buildings or offices, though most of the villagers may not have any access. Thus the need is still huge.

It appears that many people simply do not 'see' any urgent need for improvement of rural India. The above debate, even when not fraught with political overtones, is a major reason for the apparent apathy of Indians towards their rural areas. Many have stopped thinking about it, and those who do may have stopped believing that anything can change drastically for the better. We have encountered many well-educated Indian urban youths who are amazed and incredulous at the suggestion that hundreds of millions of their compatriots do not even have access to electric power.

It is wise to have a sober recognition of the above, in embarking on a mission to do what hundreds of millions of people do not really believe to be serious, much less feasible. Hundreds, perhaps thousands, of other well-intentioned and determined people have gone before us trying to solve these problems. They have succeeded in small part in some cases, but these cases are fragmented and no one built on them. Many more others simply gave up, or the jungle closed again over their efforts when they lost steam.

However we hold that we must try our best.

## 1.6 Why Would People Move To Rural Areas?

We will present the results of a very unscientific, anecdotal survey conducted over the past year. First, very well-educated urban residents nearing or in retirement, were asked what they would expect in a rural life. Having led successrul and productive lives, they were nevertheless keen on moving to a rural-based retirement community, but indicated the following priorities:

1. Plenty of clean water.
2. Access to healthcare
3. Electric power
4. Connectivity
5. Some road infrastructure: they had their own vehicles so public transport was not seen as an essential priority.

People of working age would have add several other needs as essential.

1. Access to good schools, K-12
2. Parks, playgrounds, sports facilities

3. Shopping
4. Access to workplace
5. Cultural facilities
6. Social entertainment

Entrepreneurs would add some more essentials:

1. Access to suppliers
2. Access to enough customers
3. Access to workers
4. Transport infrastructure to get materials and supplies, and ship products
5. Broad and fast access to financial services.
6. Good security and law enforcement protection.
7. Utility, fuel and transportation costs that are competitive with city locations.
8. Reasonable access to train stations and airports.

The challenge is to satisfy all these needs - without turning the village into another suburban sprawl with piled garbage, backed-up sewers, smoky air, filthy water and traffic jams.

# Chapter 2

# Solutions

A matrix of interconnected problems is shown in Figure 2.1. One can trace most of them to the paucity of energy as seen in Figure **??**. India is clearly short of energy on a per capita basis: the situation is not much better than in central africa or other undeveloped regions, as seen from Figure 2.2.

While increased availability will not prevent occurrence of other problems, it is certainly a prerequisite to a sustainable solution. Thus from these figures, it appears plausible that Rural Energy Self-Sufficiency is the first objective to meet, on a priority basis.

We also know that enterprise development in rural areas is absolutely vital, both to take the energy self-sufficiency movement spreading rapidly, and to solve the other problems.

## *2.1 Present Realities*

Lack of access to energy resources, holds back progress. Today the lack of just electricity access is counted as costing some 7 percent of present Gross Domestic Product (GDP). The negative impact and opportunity cost of students not being able to study at night is huge. Lack of medical facilities in villages, due to lack of power, has an immense healthcare cost.

What could the GDP be if the 70 percent of India that lives in rural areas had reliable, abundant, affordable access to power? Let us imagine a rural India that is self-sufficient in energy, eliminating dependence on imported kerosene, transportation fuel and cooking gas. Several hours per day that are now lost for lack of power, will be productive for work or leisure. Today the high cost of kerosene eats into the disposable income of the most needy. Poor

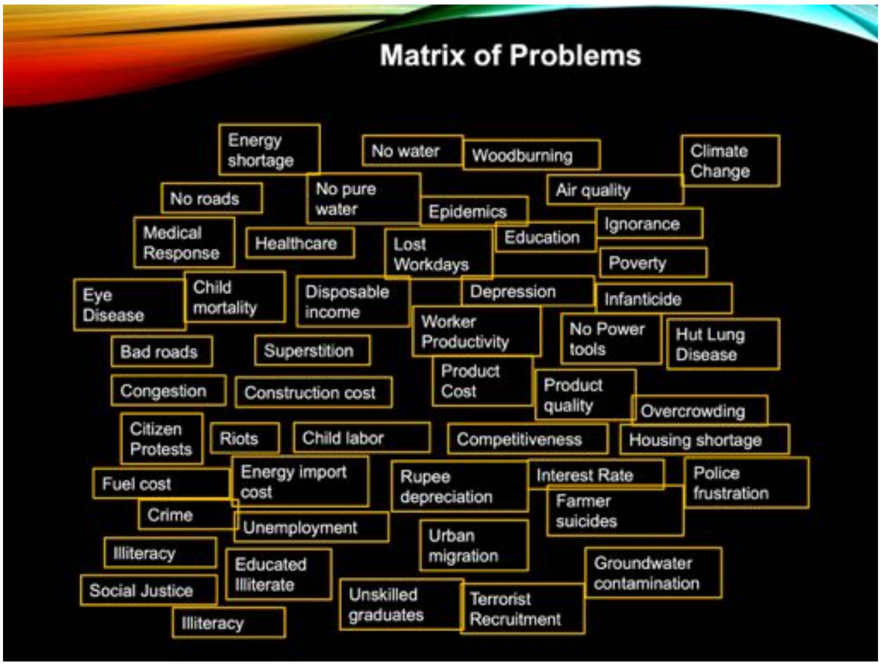



*Figure. 2.1: A rough matrix of problems*

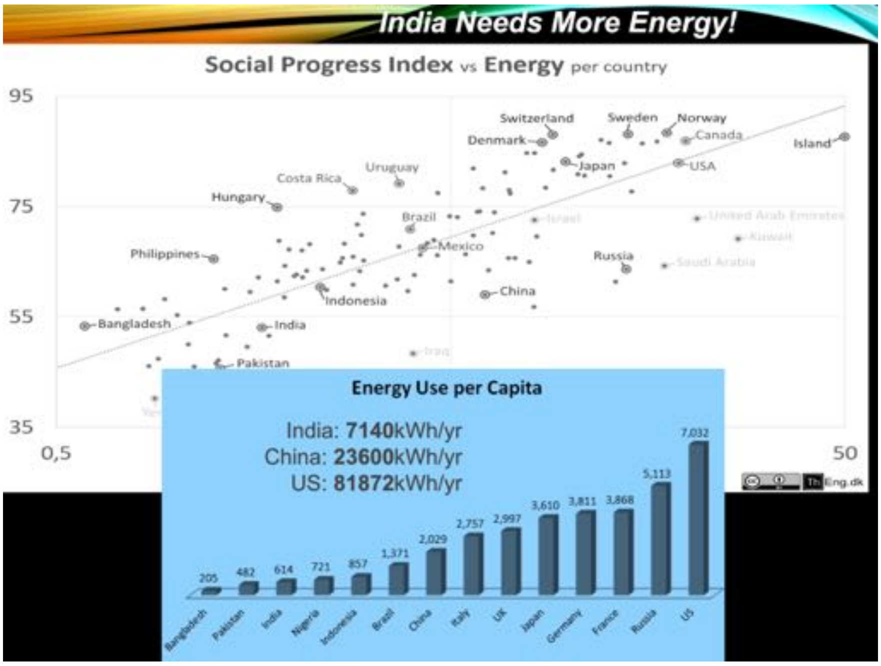



*Figure. 2.2: Per capita energy availability in India is as low as in undeveloped nations.*

infrastructure makes transportation fuel expensive in villages, and discourages wealth-generating enterprises. It is easily shown that *the poorest segments of society pay several times the cost per unit energy that their wealthier urban counterparts pay.* Viability arguments based on developed nations or urban India, are irrelevant to the realities in rural India. Tomorrow, given clean locally generated power and fuels these people will be freed to generate much more wealth. What this will do to GDP growth can be left to the imagination.

Meanwhile, there is no shortage of revolutionary technologies. Since time immemorial, micro renewable energy systems have been used worldwide to empower humans. Examples are micro windmills in 17th century Europe, [3–5]ancient China and Ethiopia. Sad to say, even this technology would make a large difference to many villages of contemporary India. The advent of the alternating-current power grid appears to have destroyed all initiative in Indian villages to adopt distributed-generation technologies [6–8]. Today, there is worldwide consensus to adopt power-generation technologies that reduce carbon emissions into the atmosphere [9, 10]. With a well-planned and well-coordinated project, the time is right to break through the obstacles and link the best of leading-edge technology to rural India, all the way to a self-sustaining, independent, clean and abundant energy economy [11–18].

The above summarizes the thesis of this project: Urj Svavalambi, Energy Self Reliance. Not merely installing solar panels, LED lamps and batteries; but providing a comprehensive suite of solutions that support Indian villages to become self-reliant in power generation, in producing transportation fuel and clean storage media such as hydrogen-oxygen. Along with this come clean air, clean water, excellent education, rural-based career-long employment in both agricultural and non-agricultural pursuits, modern connectivity for village-based farm produce and small-scale manufacturing to participate fully in the global economy and as Indian citizens. Overall, a situation where the village once again becomes the desirable and viable location to live, work and bring up a family. All this, it is true, sounds highly optimistic. It all hinges on persistent, focused executing starting with getting the first step done right: bringing basic, sustainable access to clean renewable energy in every village. That is our project.

There are numerous and large projects underway in India to extend the electric power grid and increase the quantity and quality of power that is available through the grid. India is on a roll, to install 175 GW of renewable energy capacity, of which 100 GW will be solar and 60 GW from wind. Recent events such as the explosive growth of mobile phones in India drive optimism. Other changes are less known. Since 2014, *several hundred million new bank accounts* have been set up and tied with catastrophic-insurance coverage through the Aadhar national identity card. Government assistance under the Right To Work law and other payments, now directly reaches the end-recipient without intermediaries eating the bulk of these as was happening before. Cashless transaction technology and mobile banking reduce the need for physical access to banks or ATMs. Universal access to electric power would in turn alleviate the water situation, open up employment and boost the case for infrastructure. We commend all of this, and all other projects that have objectives similar to ours. It is a wide-open playing field and marketplace. Seeing others on the same path provides encouragement, inspiration and lessons to learn.

However, the need is dire, for end-user distribution and reach beyond the power grid. This is particularly true in India's remote tribal areas situated in mountainous, forested and arid regions. In many other villages where there is a nominal grid presence, power delivery is insufficient to non-existent. Consul-General Shri Nagesh Singh, inaugurating the conference, requested that we deliberate on the implementation issues, along with scalabiity. Part of the real difficulties that will be encountered, is a culture of not paying for utility services - an example is the violence which has befallen highway toll collectors. Because of this, distributors and private entities tend to stay out of villages - it is too risky. Likewise, we should add that experience shows the inadequacy of well-intentioned efforts that simply go and install systems, without the framework to take it forward in a sustainable manner. Villagers (understandably) see such government efforts as their rightful due as citizens, but feel no ownership of the systems. Maintenance lags, and systems deteriorate. The poor performance is of course blamed on the government.

The reader will see that we have a hypothesis to deal with this. People ask us: To how many homes in a village will you provide power? Our answer is "None". Our approach is to have all dealings with the villagers go through well-established, experienced NGOs who use a careful mix of incentives and rigorour discipline in achieving the progress that they have achieved. One model is seen in contemporary efforts to set up toilets under the Government-sponsored "Swacch Bharat Abhiyan" initiative: the toilets are set up associated with the Schools (that is the Government law), but their maintenance is assigned to a village family, with the gentle reminder that the responsibility and income from that will be taken away if the job is not done. Now the villagers have provided land rights to set up bathrooms (under NGO donor funding) - this is in fact the roof space that we initially identified, to set up solar panels. The winning NGO approach appears to consist of getting group endorsement for projects with the help of the village elders, and then maintaining a well-informed but nearly arms-length policy of requiring and rewarding self-help and initiative from the villagers.

We will provide power for the Single Teacher Schools in villages first. This will bring real, immediate advantages for children who must work all day so that their families can eat, and can study only at night: we will provide enough power for the School to operate for a few hours, brightly lit, and eventually with access to the outside world through the Internet and computers. We will provide power strips so that villagers can charge not only their mobile phones, but items such as power drills and screwdrivers, boosting productivity in their skilled and semi-skilled occupations. As we move along, we will bring in biogas digesters, that generate and purify biogas, providing benign fertilizers as well. We will teach villagers to become the maintainers, data collectors and then installers of various types of renewable energy systems, building a market for their occupations as skilled technicians. We will provide education and linkages to set up village-based small and distributed enterprises, connecting to the leading edge of the technological marketplace.

## 2.2 Need and Aim of the Project

*Figure. 2.3: Ultimately, we aim for a rural India that is happy and proud of its diverse heritage, culture and nationality, and able to deal as equals with the best all over the world. The picture is from a performance in Atlanta in February 2016, by a visiting troup of Ekal Vidyalaya alumni. Graduates of the Single Teacher Schools.*

India has approximately 1 million localities. Of these approximately 70 percent are rural. For initial planning, we took the figure of 660,000 villages, with an average of 1000 people per village and 4 per familiy, and set out what it will take for every family to have at least 1 kW of renewable power generation available. This requires 165 GW, which is not unreasonable given today's official target to bring 175GW of renewable power generation. This is the figure needed to bring a good quality of life to every family. People also need clean water, and a healthy, sustainable environment. They need education and healthcare. They need connectivity and transportation. They need agriculture and employment. All this requires entrepreneurship.

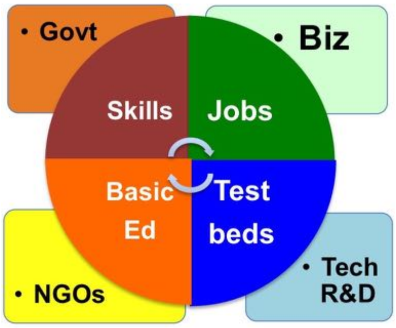



*Figure. 2.4: Synergies and Roles*

We seek to achieve this through a roadmap that aims for total energy independence and self-reliance, with a transition to sustainable development at the leading edge of technology. We aim to do this through a path that ensures that cultural freedom, pride and traditional values are strengthened. The picture shown in Figure 2.3 is of a troupe of youngsters from the tribal villages in India, enthralling an audience in metropolitan Atlanta, Georgia, USA, on a cold February evening. The picture reminds us that these are the people who will lead India's energy revolution. Energetic, superbly skilled and trained, well-educated, able to converse in multiple languages and perform at a professional level anywhere in the world. And very steeped in their own ancient culture and traditions.

Our roadmap starts with basic photovoltaic electricity access for one village, delivered through a One-Teacher School , then growing to 1kW of combined biogas and electric power to every village. To this we will eventually add clean cooking, biogas-powered electric generators, thermochemical fuel generation, energy-enabled employment, DC microgrids, the Internet of Things, and on to a post-modern, clean hydrogen economy. But first come education, clean water, health, skill development, basic access and most of all, opportunity.

The challenge of bringing energy independence to rural areas is as massive as it is transformative. Even 200 Watts of solar photovoltaic power installed in each village school would transform rural life by providing communications, access to emergency services, and access to the outside world via the Internet and television. These are projected to provide employment opportunities to jump-start economic growth. Solar photovoltaics (PV) offer the first and fastest power installation all over India, limited by the cost of energy storage.

Biogas would fuel clean cooking and heating, and turn waste into fertilizer. In due course, as business access improves, local extraction of transportation biofuels will provide mobility, free from imports. Locally powered wireless connectivity will revolutionize knowledge and opportunities. Urban migration will be reversed, the villages again becoming superior for work and living.

The Smart Village Roadmap 2017 conference on rural energy independence, was conducted in Atlanta, Georgia, USA in March 2017. This conference brought together the various stake-holders and participants in the necessary roadmap. The holistic approach aims for far more than a simple installation of basic power systems: the aim is total energy independence, and a transformation of India from the villages outwards, while maintaining the things that really matter about Indian culture and traditions. The synergistic approach to the problem is summarized in Figure 2.4. At the village level, schools operated by Non Governmental Organizations (NGOs) offer the best venues to install and maintain power-generating systems initially. The teacher becomes the conveyor of the knowledge needed to operate the systems, and some basic knowledge to understand the technology. Soon her students are expected to take 'ownership' of the systems, and become comfortable with the technology, similar to what occurred when cellular telephones were introduced in India. Thus basic education is at the core of our approach. The installed systems are expected to provide field experience and skills for villagers. The power generated from the systems will enable other skills. Thus skills training is the natural and required outgrowth of installing energy systems in the schools. In this endeavor the government's support is vital, in order to provide access to training and certification, so that villagers can learn skills that will enable them to earn or augment their living without migrating to cities in search of employment. Businesses have a crucial role to play in providing jobs for the skilled workers, within manageable commuting distance of the villages. This job growth will have to be matched to the growth of incomes and buying power in the villages. The culture of using new technical solutions opens opportunities to adopt a testbed approach, where technical advances are brought in to update the village systems. In this endeavor, the participation of university faculty, their facilities and students, is crucial to advancing technology and tuning the systems for best performance in the local conditions.

This calls for thoughtful cross-disciplinary, coordinated innovation. The end-users start in abject poverty, so standard models of fast revenue do not work. Following the inspiring example of Single Teacher Schools which employ their own graduates as teachers when they complete the Plus-Two program in the outside world, trained technicians must be retained with attractive opportunity, to maintain multiple technologies and systems. Rapid rise in power-related employment is needed to sustain the installed systems and their benefits. Innovative funding and knowledge models are needed. Public policy issues are paramount when bringing solutions to the most vulnerable people in society. Experience and data are invaluable in refining the approach for the next attempts.

In March 2017 we held a small 1-day Workshop at Georgia State University in Atlanta, USA, called the Smart Village Roadmap for Energy Self-Reliance. it was a conference of researchers, product developers, retailers, micro-credit financiers , NGOs working at grassroots in targeted areas, government representatives and businesspeople assembled for focused discussions on what is possible, and what is needed. The initial focus is now on India in order to integrate solutions in a context where there is clear support from the government, with adequate humanpower and educational resources available. From the conference participants, it is evident that the relevance to Africa has been noticed as well. This first conference touched at an introductory level on the multiple facts of this ambitious project:

- Summarizing the problem and opportunity.
- Thermochemical fuel production.
- Biogas heat, cooking and power
- Micro DC grids and innovative storage
- Waste burning for power and clean air
- Rural employment using power
- Skill development and training
- University testbed / incubator models
- Reaching the villages
- Business case for village level plants
- NGO education and mentoring
- Corporate Social Responsibility (CSR)
- Templates for mass replication
- Continuous refinement and adaptation
- Integrating retail trade with power.

## 2.3 Summary Plan

To bring 1kW of renewable power to all 660,000 of Indian villages, would take only about $1.3B - a number that seems shockingly low, making one wonder why this has not happened yet. However, installing generators is not enough: they must generate income and employment to be sustainable and grow. The roadmap starts with education. One-teacher schools run by NGOs in tribal villages are chosen for the first Solar PV installations. The manuals are translated into the local language by the teachers, and the kids will grow up comfortable with technology. DC micro grids will be incorporated. At 50 units, Internet of Things (IoT) technology will begin to tie the systems. Biogas systems will be added through the schools in Level 2, growing past 1000 systems. Corporate Social Responsibility plans will be tapped to go beyond 10,000 systems. Skill Development and a quasi-commercial model will enable 100,000 systems and beyond.

The 2nd iteration will bring in thermochemical systems to localize fuel production. As the number of systems grows past a million, public-private partnerships with firm ties to the research leading edge will bring full energy self-reliance, build the rural economy, and reverse urban migration. The twin monsters of fuel imports and environmental pollution will never be allowed to dominate again.

## 2.4 Technology Survey

The first part of the report goes into some detail on two technology streams. The first is a diverse portfolio approach [8], developing opportunities that arise from concentrating solar power to achieve very high intensity and temperature [16, 19, 20]. This intense energy can be used either to run mechanical heat engines, or to energize thermochemical reactions that can break down various materials to produce combustible gases, and even liquid hydrocarbon fuels for use in cooking and transportation.

Air quality in India, particularly in the north during winter, is severely impacted by outdoor burning. Technologies to incinerate urban and rural waste without smoke, are combined with power generation techniques. Associated with this are high-efficiency choolhas, or cookers [21–25]. Community-level waste incinerators may also provide much of the heat needed for thermochemical fuel production when the sun is not shining. Segregation and reprocessing of waste into useful materials will provide an avenue for rural employment.

The second line of approach is to stick with solar photovoltaic technology exclusively, on the belief that the prices will keep coming down, [26] obeying the trends for semiconductor manufacturing. There are arguments for both. We see solar PV as the way to start, but then the other technologies will provide a much more diverse porfolio of choices for the villagers, in different parts of the country. Finally, scaling up to large power levels in a growing rural economy may again be done with an expanded use of solar photovoltaics.

## 2.5 Reaching 660,000 Villages

This presentation from a major US corporation will discuss the logistics of reaching each village, adapting techniques used by home delivery services in the US. Optimal routes can be developed. A smart integration of transportation logistics, data collection and health monitoring of systems provides several unique opportunities. Setting up the infrastructure to create energy independence raises the issue of knitting together a network of 660,000 villages spread over a wide variety of terrain to support these technologies with spares and knowhow. This section will discuss the logistics of reaching each village: adapting learnings used by delivery services in the US and painting a picture of a future where data, technology and good old-fashioned informal networks (aka crowdsourcing) come together to achieve this goal.

## 2.6 Internet Of Things: Massively Distributed Synergistic Architecture

Every power generator and power user system is potentially a node in the Internet Of Things [27, 28]. Close on the heels of the first power generators, we hope to bring in cellular network connectivity using towers connected by beamed microwaves, as has been successfully demonstrated all over India in an amazingly swift revolution. On the other hand, uninhabited autonomous aerial vehicles *(UAVs) offer very interesting possibilities, not only for package delivery and pickup, but also as transient Internet nodes to pick up and deliver information.* DC microgrids [29–31] along with Internet connectivity, allows remote monitoring of every device. In turn, this allows the data collection and analysis that is crucial to optimizing power generation and usage. Once established, Internet connectivity also brings revolutionary advances in cashless transactions, BlockChain technology [28] for transparent access to the global economic and trading space, and boundless knowledge resources. It is quite realistic to consider a future where a small entity located in a remote Indian tribal village, is able to negotiate a contract over the Internet Of Things, receive materials, produce a 3-D printed part of a very complex machine, and ship those parts, all within 36 hours, using the IoT, cashless BlockChain technologies and UAVs. In other words, village-based enterprises can particulate fully in a fast-paced global economy and trading place. The village can again become a much nicer place to live, work and do business than the crowded cities, with no inherent disadvantage.

## 2.7 Economics of Rural Energy

How can people who are so poor pay for these energy systems? Without the systems, how can they generate income? In our scheme, NGO-operated schools are used to bring the first energy, followed by skill development and employment generation using the energy. A combination of NGO support, Corporate Social Responsibility resources [32–34] and microcredit financing [35–42] brings the expansion towards a self-sustaining economy, tilting the scales to reverse urban migration with accelerating development.

## 2.8 Corporate Social Responsibility

Corporations operating in India are required to spend 2 % of profits on social uplift causes. This is an avenue to construct linkages where the money spent by a corporation provides short-term resources and benefits to develop and install systems, and conduct education. The money and technical expertise are also investments in long-term strategic benefits to the corporation. Corporations can stay informed of opportunities to use their technical and logistics expertise, thus building relationships with future customers.

## 2.9 NGOs and Skill Development

Non-Governmental Organizations (NGOs) provide the crucial grassroots resources without which good intentions cannot lead to success in bringing technology and advancement to rural populations. The One Teacher School program that has caught on in many States of India, is based on Mahatma

Gandhi's call to urban dwellers, to take education to the villages in the villagers' context. The One Teacher sent to each village, especially in India's remote tribal and forest villages, carries a huge responsibility. S(he) must teach students all the way from elementary grades to 8th grade, and teach all subjects. Increasingly, NGOs see this as a way to encourage education and employment of women, in turn setting up role models in the community. We see this as a way to reach the children of the villages who, we hope, will grow up comfortable with the latest in technology.

NGOs are also the route to build skill development programs that bring employment. In our experience, people in villages often have not had experience of using electric power to augment their income, such as by using power tools and machines. In fact, informal surveys asking villagers what they would do if they had plentiful electricity, showed that they had not thought beyond lighting, charging mobile phones, fans, refrigerators and possibly airconditioners and washing machines. They had no sense of how electricity and power could help them make money. Developing the local workforce to install, maintain, collect data and grow energy independence, is a crucial part of the roadmap. NGOs enable the link to mainstream educational and R&D institutions as well as commercial installers.

## 2.10 Small Business Ties

The above summary glimpses just a few of the myriad opportunities for small business ventures in rural India, as energy independence grows. Our aim of 1kW for every village is a drop in the ocean, but enough to establish the logistics, education, skill development and connectivity for massive growth. With a middle-class target of 2kW installed power per 4 people, every village should eventually reach 500kW, along with the economic growth and buying power to sustain and benefit from that. That is at least a 500-fold expansion from our program. Enthusiasts supporting different technologies may note that there is more than enough room for their favorite technology to win in the free market and dominate market share with well-informed customers.

Several anecdotal examples follow: Any grand solutions that we suggest in the present effort, must face these anecdotes, and the massive data that probably show that these anecdotes understate the problems.

# Chapter 3

# Urj Svavalambi: Energy Self Reliance

*Figure. 3.1: Starting Reality: Village home in rural Tamil Nadu. Courtesy of Sri Vivekakanda Rural Development Society*

Many commendable efforts lead and parallel ours at least for part of the way. The Government of India uniquely has an entire Ministry devoted to New and Renewable Energy. Under this Ministry is a Rural Electrification Corporation. The World Bank has funded numerous initiatives to bring in clean-burning, fuel-efficient cookstoves around the world, including India: this is focused perhaps more on reducing carbon dioxide emissions than on providing villagers with energy resources, but it has significant benefits to health by reducing lung disease, harshly known as the Hut Lung Disease.

The Institute of Electrical and Electronics Engineers (IEEE) has a well-publicized initiative to bring basic electric power to rural residents all over the world. They plan to invest \$10M to reach 50 million residents with basic electric power. Generally this is a level of 40Watt of solar photovoltaic power per home for 6 to 7 homes, used to power LED lighting and a mobile phone charging port, along with larger systems intended to bring a computer as well as some street lighting to the village. As of the start of 2017, they had reached

34 villages, including a widely-publicized effort in the high-altitude villages near Leh in Ladakh by a visiting volunteer team. The IEEE model is for a team of their engineers to work with local for-profit vendors. One enviable aspect, that may be hard to replicate, is that their teams incorporate retired and practising engineers who bring top-notch state-of-the-art experience from the best establishments in the world. It is hard for vendors and installers growing up in India to match the experience base of these experts. We intend to learn as much as we can from them, in order to reduce the knowledge to what can be mass disseminated in rural India.

The organization *Gram Oorja* (Village Energy), centered in Maharashtra, has brought electric power to remote villages in Maharashtra and Madhya Pradesh. Their model is a team that takes on turn-key projects with villagers helping installation. Professor Jhunjhunwala at the Indian Institute of Technology, Chennai, has pioneered the DC microgrid system based on a 48Volt, low-power circuit in parallel to the standard 240-volt AC power grid. When power shortage forces a rolling blackout, the power utility company shuts off the 90% of power that flows through the AC circuit, leaving 10% flowing through the DC circuit. Controllers in each home recognize this event, shut off AC appliances, and power a few DC appliances. Experience shows that most users do not even recognize when the AC power is off, since their usage is mostly from DC devices. They have also worked with vendors of efficient DC devices for LED lights, fans, TV sets and Internet routers. Their systems have been installed in several urban and suburban areas, reaching hundreds of thousands of grid users. A separate effort by the same teams focuses on off-grid, remote communities. They typically provide a 40-watt or 20-watt solar PV panel to each home with an LED bulb and a cellphone charging point, in remote villages in Tamil Nadu and Rajasthan lacking other access to electric power.

Several non-governmental organizations (NGOs) teach and support self-reliance in rural areas. The Ekal Vidyalayas now run nearly 30,000 Single Teacher Schools spread over different states of India. Many are in remote mountain and forest villages where there is no access to electric power, and no other access to schooling.

*Given all these efforts, why is our effort necessary?* The answer is simple: This morning over 300 million Indians woke up with no access to basic electric power. An example of a rural home is shown in Figure 3.1. Lack of access to electric or other ways of augmenting human/animal power, leaves these people at an extreme disadvantage compared to their city-dwelling, grid-connected compatriots. This situation must change!

What do we bring? This project has three key features that may not be part of other efforts:

1. Our project depends on, and synergizes, several stakeholders: Education through single-teacher schools, skills training of villagers, opportunities to invest Corporate Social Responsibility resources, research and development in universities and national laboratories, both in India and abroad, and a determined effort to network retail business for the villages.
2. NGOs and Corporate Social Responsibility resources tied to vendors, installers, trainers and local enterprise.
3. An integrated roadmap to energy independence.

Figure 3.2 presents the initial roadmap towards Indian rural energy independence as a high-level fishbone diagram. The top part of the figure shows the technologies to bring energy. The bottom shows the methods towards self-sustainment and progress. We start at the left end, with 250W PV installations in each village where is no or dysfunctional access to electric power. As given on the bottom, the first 1,000 such systems will be installed in schools through NGOs that have extensive experience and grassroots access as well as the confidence of the villagers. The schools, usually Single Teacher Schools, serve to bring education to the children, and educate adults in the use of electric power to generate skills, employment and income. Electric drills, power screwdrivers and sewing machines are shown as some of the instruments to raise productivity, technology awareness, and access to employment. A clean-burning *choolha* is also shown; while this is not yet a direct power generator, it can bring important benefits in fuel efficiency, reducing pollution and again, educating villagers in the potential of technologies and good modern practices. These can also bring in some funding interest through carbon reduction initiatives. Construction and maintenance of choolhas is a viable village-based economic activity.

Back on the top, the next technology is that of biogas reactors, currently anticipated to be a standard constant pressure (floating lid) model with 10kg capacity, now available through government-supported renewable energy manufacturing programs in India. These systems can greatly reduce the need for other fuels for routine cooking. Tests have shown that they generate over 4 kWh or energy per day. Placed in clusters of 4 or more in village environments where there is plenty of access to animal dung and waste vegetation, these systems produce enough gas to justify installing gas scrubbing columns and gas-powered generators to operate irrigation pumps directly, or to produce electric power. These small generators are still being developed, but prototypes have been shown in several university projects. Larger systems are commercially available in plenty.

This brings the role of the university testbed to the fore. With these testbeds comes the integration of biogas systems with electric storage and optimizing system controllers. Experience shows that the primary problem with solar PV systems is the inability to match load (the demand for power) to the supply of sunlight. Thus, when the sun is shining brightest, the supply exceeds the capability of most systems to store the energy, because of the high cost of battery storage. And then when the demand picks up in the evening, the sun sets, leading to the battery being exhausted before the full rated capacity has been delivered.

With larger PV systems it becomes worthwhile to put in Maximum Power Point Tracking (MPPT) Controllers that optimize the load and adjust it to match supply, but these controllers are 3 to 4 times as expensive as basic controllers, since they have to be imported into India. An alternative arises when biogas systems are combined with PV systems. The PV generates enough electricity to power pumps in order to compress the biogas, drive it through the purification column and into the electric generator for optimal usage. In turn, the energy stored in biogas complements the battery's storage capacity, allowing the system to function late through the night, or cloudy and rainy days. Extensive experience generated through university testbeds and systems fielded in the villages, will optimize these systems for Indian rural profiles. We anticipate these efforts spanning the installation of the first 10,000 systems.

The funding for the first 10,000 PV and biogas systems is expected to start with a donor/NGO model, but then transition as rapidly as possible to Corporate Social Responsibility (CSR) project funding. The CSR phase is expected to pick up beyond 10,000, and carry us to the first 100,000 systems combining different types of energy systems. During this phase, as seen above, we expect to add Intensified Solar power systems, using the high intensity and temperatures to operate various types of fuel generation and industrial processing systems. CSR should bring in small-scale manufacturing and a massive boost in Skills Training and employment, along with seeding rural-based entrepreneurship.

Along the top, we then bring in the natural addition of thermochemical fuel generation in the villages, along with a smooth transition to a hydrogen economy. We have not mentioned wind energy until now, because in our view that is the most complex of systems to operate satisfactorily on a small scale. With other systems in place, it makes sense to add micro wind and micro

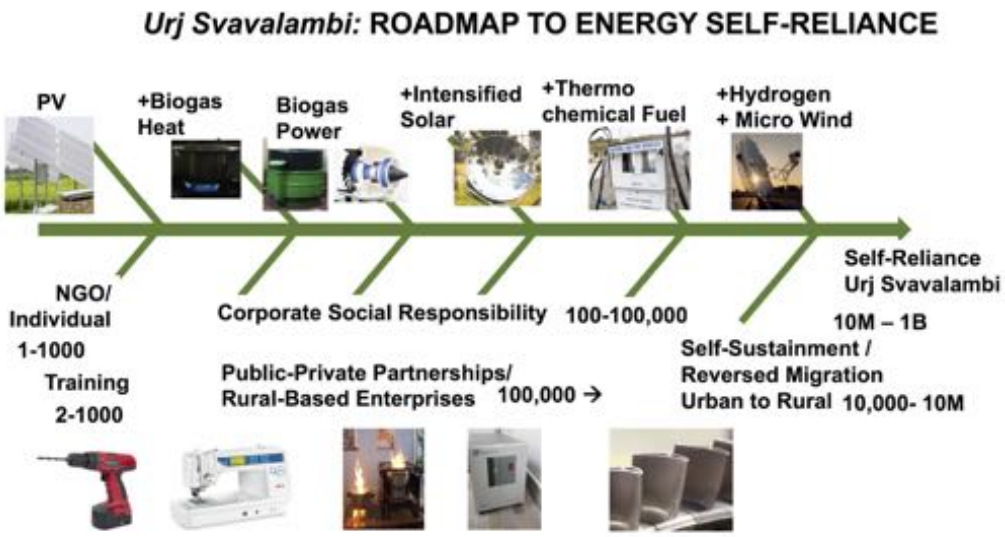



*Figure. 3.2: Initial roadmap to Indian rural energy independence. From N. Komerath by permission.*

hydro systems to the portfolio. Meanwhile, along the bottom, CSR brings in more ambitious public-private partnerships as the numbers of systems rises towards 1 million. At this point, each village has local power generation exceeding 1 kW, but also a base of skills, rural-based enterprise and trading market access to fund further energy installations in a self-sustaining manner. As the technology level and economic viability of the villages rise, we expect to see a reversal of migration from the urban to the rural areas, accompanied by rise in land prices and infrastructure. This will also be the most difficult phase to manage, in order to ensure that the best features of the traditional Indian culture survive and flourish as wealth and modern amenities rise. Thus beyond 1 million systems, we expect to see self-sustainment and continuous growth.

### 3.0.1 Tribal Villagers and Technology Ownership

Professor Komerath spent some time considering a question that often comes up in discussions of technology infusion. Can villagers who have had little access to education and the outside world handle the infusion of new technology? His answer is a resounding positive. He uses a picture that he took at a recent performance by a visiting troupe from India, at a local school in metropolitan Atlanta. Figure 3.3 shows an instant from a dance performance by a troupe of alumni, of the Ekal Vidyalayas who run over 29,000 Single

Teacher Schools spread over several states of India. Many of these villages are in the tribal areas of India, where the residents enjoy the privacy guaranteed by the Constitution for their aboriginal way of life, should they choose that. In reality, these protections also prevent such things as being able to obtain a home or business loan (land and houses in these areas have no collateral value as lenders have no right to go claim them in case a loan defaults). Larger schools cannot function there because the population is dispersed. Students have a very difficult time getting to school, hence the Ekal Vidyalayas, schools with only one teacher that are established where they can get a minimum of 30 students to enroll.

*Figure. 3.3: Picture of the Ekal Vidyalaya performance at Berkmar High School, Lilburn, Georgia, USA March 12, 2017. From N. Komerath by permission.*

The picture tells quite a story, as Komerath pointed out. The troupe, whose trip to the USA was sponsored by the Government of India, had come across continents, handling the stresses and complexities of present-day international air travel. They had had a hard day of traveling by bus across the USA, part of a tight schedule. It was February, with temperatures around or below the freezing mark, far below the worst they had encountered in most of India. They are in a land with strange language and customs, and technology features and expectations that are often strange to most people in India regardless of education and sophistication level.

The dancers are each carrying a hand microphone. This is because they are also doing the singing, in perfect choreography. The accompanying music comes from the young gentlemen sitting to the left side of the stage. One is handling an electronic keyboard - an instrument that takes a great deal of practice.

All the difficulties vanished as their performance started, and they enthralled the audience for several hours with absolutely awesome energy, enthusiasm and expertise.

Komerath points out that these students, coming from all over India, have learned to communicate in at least 3 different languages and interact with many other cultures. He asks why learning to operate a solar PV system, a power screwdriver, a sewing machine or a biogas generator can be anywhere nearly as difficult as what these people clearly demonstrate. During the intermissions the organizers provided some glimpses into the realities from where these young people came. Enough said on that. The point is made, that technology readiness and adaptability are not valid issues to worry about, though of course competent training, instruction and support must be provided.

### 3.0.2 Transition through technologies

Solar photovoltaic systems are the easiest to install, but they are expensive. The actual ability to use and store, are huge issues. Compressed air and water turbines appear to be the simplest devices to build, but they have not caught on in a big way yet.

Biogas systems are the most obvious next step to boost rural energy. At present, one can obtain 4 times the energy per unit cost as PV, and one can make an immediate impact on the cost of cooking fuel to the villagers. Biogas systems have proved hard to maintain, and messy, in the past. The reasons for this are not far to seek: the constant-volume systems that were buried in pits, were difficult to maintain for the owner-operators. The modern constant pressure (floating lid) systems appear to be much more user-friendly. In nearly a year of operation in urban Kerala, the system has actually improved in generation efficiency, without any problems encountered. With proper data collection, training and study, we believe that these systems can be optimized and made a transparent part of the rural landscape in India. The usage of the sludge as fertilizer is still a matter that has not been studied enough; and its value has not been quantified.

To generate electric power from biogas, small generators are needed. As mentioned before, IC engine-based generators are the more obvious route, since shopowners all over India use such generators powered by diesel to tide over the frequent power cuts. They are noisy and polluting. To work with biogas, they have to be modified. The gas also must be cleaned to remove the CO2 that reduces its heating value, and the sulphur compounds that cause an offensive smell and can corrode the generator. Cleaning and compressing the gas requires a small pump or compressor, in turn requiring power (we note that in the old Petromax systems, the user hand-pumped the fuel, and this was a routine aspect well-known to householders all over urban and rural India).

Thus, power generation from biogas needs attention to quality and uniformity of composition. As small gas turbines in the 1kW to 10kW range become affordable and efficient, generation can be migrated to these systems, which can be much quieter and cleaner than IC engines.

At extreme temperatures such as those generated by intensified sunlight, electrolysis of water, like thermochemical decomposition of other compounds, becomes quite efficient. Thus fuel generation in rural areas will become routine, but it will take a few years.

As acceptance of biogas systems becomes established, we project that a major problem can be addressed. This is the field of biomethanation, referring to the use of human waste for gas generation. At present, this poses objections from villagers regarding the suitability of fuel generated from human waste in cooking food, often phrases in religious terms that brook no argument. We project that as biogas cleaning systems become more common, the objectionable smell will disappear, and bio-methane generated from vegetation will be indistinguishable from that generated from human waste. The economic benefits will slowly make the objections disappear.

Ammonia, available from urine as well as from other manufacturing processes, is a very attractive fuel for gas turbines, as its combustion generates no carbon dioxide. Ammonia ($NH_3$) is a compound of nitrogen and hydrogen; its combustion generates oxides of nitrogen, but mostly water vapor. At present, gas turbines have to be started with a mixture weighted more towards methane, but as the wall temperature rises inside the combustor, the ammonia content of the fuel mixture can be increased. Better machines will, we project, make it possible to use a uniform mixture.

Thus, in a few years, we project that the energy portfolio in Indian villages will include solar photovoltaics, biogas from kitchen waste and animal dung, biomethanation of human waste, ammonia fuelled generators, intensified solar thermal and thermochemical systems, thermochemical fuel generation and electrolysis of water to generate hydrogen for a clean economy. This describes total energy self-reliance and independence, a clean environment with clean air, water and surroundings, and a viable, self-sustaining entrepreneurial economy.

### 3.0.3 Standardized Energy Solutions

We are deliberately departing from the usual practice seen, where donors and NGOs focus on one village or set of villages and attempt to turn them into Model Villages for others to emulate. As commendable as these efforts are, the reality appears to be that there is no driver to ensure that there is any emulation and replication on a large scale. Eventually, without such growth in their surrounding villages, the Model Villages are unable to sustain themselves beyond the period of the initial funding.

Instead of the above, our focus is on bringing a useful level of energy resources to as many villages as possible, and then systematically returning to each village and increasing the level. Meanwhile there is a drive to get the villagers to attain skills and knowledge, start earning money, attract financing and business investment, and thus lead to a pervasive growth and development over entire States or at least large clusters of villages. We hold that the best support system to ignite self-reliance and self-sustainment is the confidence that comes from seeing one's neighbors and neighboring villages also beginning to do well.

Accordingly, we attempt to define certain 'standard systems' for easy replication and later improvement. In Phase 1, this consists of

1. A 200-250Watt solar photovoltaic (PV) system with batteries.
2. A set of 5 to 7 LED bulbs and/or LED tubes, and a power strip to recharge DC devices.

In Phase 2, we plan to add the following:

1. A 10-kg biogas digester with a stove.
2. In some villages where animal dung and vegetation are available in plenty, a cluster of 4 to 6 of the above digesters, with a gas purification column, compressor and a biogas-powered electric generator, whose waste heat is also used for cooking.

In Phase 3, new technologies and processes will be introduced into the villages:

1. Compressed air / pumped water and/or turbine power generation systems.
2. biogas+ ammonia heat and power generation using gas turbines. Ammonia can be generated locally. It has been shown that with some biogas added, ammonia can be burned in gas turbine generators. Ammonia combustion does not release carbon dioxide.

3. Biomethanation and groundwater cleanup. The term biomethanation generally means using sewage in some form. Although sewage can be used to generate plenty of biogas, this gas has a stigma associated it, for use in kitchens. The cultural hangups here can be overcome, at which point, biomethanation offers a tremendous solution that brings plentiful energy, and helps in cleaning up groundwater, a huge problem over much of India.

In Phase 4, we bring in a broader portfolio of technologies.

1. Intensified solar thermal
2. Thermochemical fuel generation, both liquid and gaseous.
3. High temperature electrolysis, hydrogen, fuel cells.
4. The use of vehicles as power generators.

### 3.0.4 Skills to Employment to Entrepreneurship

The funding model utilizing individual donors and NGOs is limited to about 1000 systems, costing roughly $400,000 to $800,000. Note that since the end-users have little money, they cannot expand the energy portfolio by purchasing more systems. Education is needed to maintain the systems, and skilled technicians need a livelihood if they stay in their villages. Thus villages need business growth for increased purchasing power. The way to break out of this cycle of despair is by using the NGOs as the culture bridge to villagers, in order to access education and skill development. Corporate Social Responsibility (CSR) provides a market pull for skill development and for product innovations. The CSR-NGO alliance transitions to local business, developing entrepreneurship among the villagers.

Figure **??** schematically represents the roles of the different entities. NGOs bring basic education to the villagers. They develop skills among the villagers, by supporting and encouraging them to take and complete government-sponsored skills training and certification programs. Such programs are typically offered through local colleges, so that corporate social responsibility projects and NGOs can collaborate in getting villagers through such programs. With skills developed, the villagers are able to take on good jobs in the villages, as businesses start entrepreneurship and small manufacturing and services in villages. These developments set the stage for university research and development to bring in testbeds of advanced technology into the villages, drawing on the skills of villagers, and contributing to the advancement of the schools and basic education.

# Chapter 4

# Objections

In this chapter, we list objections/frustrations cited by experts on the basic premises and directions adopted in the document. We are most grateful to the people who supplied these. We post them completely here (except for identifiable personal details). These are to be heeded as warnings., and considered in developing solutions. In some if not most of these, there are clear solutions and workarounds.

1. They (The USA) would like to burn coal but like India to switch to solar and wind, and any other costly energy, including nuclear. They would fund conferences in India to corrupt the thinking along their choice. Already like the adage ?fools rush in where the angels fear to tread, India has overcommitted itself at Paris to reduce emission to GDP by 33-35% from 2005 levels over 15 years. This would imply 40% of the installed electricity capacity by 2030 would come from non-fossil fuel plants. This would translate to 100 GW from solar, 60 GW from wind, 10 GW from biomass and 5 GW from small hydro.

2. Ironically, large hydro, with big dams, which are both renewable and most cost effective, are left out of counting under ?renewables?. Post 2015, I now hear from National Hydro Power Corporation bulletin, that large hydro is finally admitted to the renewable group, as if by an act of favour.

3. In contrast, US had pledged to cut emissions only by 26 to 28%.

4. Incidentally for global CO2 emissions, as on 2015, India?s contribution was barely 6%, against China?s 28%, and US?s 16%.

5. On a emission per capita basis, the figure is miniscule for India, and for development India could claim a per capita emission right on par with

other developed countries, as a development discount.

6. Of course, you know, even this meagre commitment of US was not ratified, and now is overturned.
7. India (and China) are leading the world in the use of super critical and ultra supercritical coal based power plants, which use coal most judiciously, and claimed green label for them, in view of their energy efficiency and minimizing CO2 emission. On this basis World Bank wanted to fund these projects, but had to backtrack since some NGO?s in US objected to it.
8. In around 2011, World Bank wanted to have a consultation workshop at IIM Bangalore on low carbon paths, and Ministry of Power, irritated by the development of retraction of funding coal power plants–refused to give permission for the consultation.
9. The ground reality in India is both solar and wind are not viable, in as much as they are intermittent energy and steal capacity from large hydro plants by feeding into the grid.
10. Therefore the full cost of solar and wind should be compared with the marginal energy cost of coal thermal, which, today is around Rs.1 per kwh. Till they reach this figure, they are not viable.
11. People have a simplistic idea that because there is ample sun shine and it is free, solar should be eminently viable, forgetting that the capital to concentrate that energy, convert it into electricity and feed it into the grid is a fairly costly process. Solar is ok for producing direct heat , like on hot water, but not for producing electricity.
12. India is also not upto competition in Solar PV cell manufacture; its cells are at least 10% costlier than those from US, and China. But Government insists on a Domestic Component requirement, thus making it unviable for assemblers; so this route itself is avoided by domestic assemblers.
13. India, China and the US are rich in Coal. Of the 3, India is most poor, and the only options to it are coal and large hydro. The latter is blocked by US trained environmental experts and the laborious litigious procedure.
14. Even in coal, several domestic mines are blocked from being mined through a ?no go? decision by the environmental ministry.
15. India?s Non performing assets by Public Sector Banks, about half of it, around Rs.3.5 trillion is due to funding power sector generation,

including the renewables, most of which are in stand still.

16. In summary, Coal is what India has, and that is what it should use to produce electricity. Also, considering its poverty, coal is the only affordable fuel, to fuel development.
17. Environment is a public bad, and as such it will suffer the fate of ?tragedy of the commons?.
18. The situation of Trump walking away from Paris agreement, but US goading India to go for renewables, is most ridiculous.

# Chapter 5

# Needs and Approach

## 5.1 Needs

Figure 5.1 shows the number of localities divided between the States and Union Territories of India. They add up to many more than the number of PIN (postal index number) codes as there are many villages served by each Post Office. The localities total nearly a million. Some 70 percent of these are rural or otherwise removed from urban conveniences: the percentage of rural population reaches 90 percent for some states. The figure shows that the largest number of localities by far are in Uttar Pradesh, but other States such as Tamil Nadu, Bihar, Jharkhand and West Bengal have large numbers as well. On average, there are about 1000 persons per locality, except in the Delhi National Capital Region where there is a much higher density of population. This it is a good approximation that the average Indian village has 1000 people. Some 300 to 500 of them may be assumed to be school-age or younger children.

The true extent of need in Indian villages is open to debate. In many villages, even quite close to major cities, and well-served by bus and rail conveniences, we find that there are power lines and telegraph lines, but the one School available to the villagers has no *functional* electric power. Arguably, the solution in such cases is citzen activism to direct lawmakers' attention to solve the problem. However, saying that does little good for the children there. We used a few such villages as our initial installation points simply because they offer more access and communication to solve initial problems. Many villagers there worked in factories; the pioneering school teacher is a young lady with a BA in education and has a day job in the government school not far away. The Single Teacher School is where she helps village kids in the evenings. It also helped that people there were at least aware of electricity and its conveniences. But as soon as practical thereafter, we are moving the installation efforts into the truly isolated areas where villagers have very little resources, and no familiarity with modern conveniences.

We take the view that we will shoot for the upper limit in setting project scope, and then hopefully find that the need is being met by other initiatives in many or even most of the villages. The aim is to bring energy self-reliance, which we trust will slash India's dependence on foreign oil and gas imports, increase GDP by a sizeable factor through rural productivity, and bring all of India's population into the mainstream of modern amenities so that they can contribute fully as citizens in India's civic and economic life. Thus the actual number of villages with particular needs is irrelevant at this point.

The needs as we see them are as follow in some order:

1. Education.
2. Skills
3. Employment opportunities
4. Access to medical facilities
5. Capital for entrepreneurship

## 5.2 Approach

### 5.2.1 The Village School

Our approach is to first bring one basic system to every village school. The emphasis is clearly on the school, as the bridgehead to knowledge and development. It is not our objective in the project to 'bring electricity to every home': we believe that those things will happen with self-sustenance.

### 5.2.2 The NGO

We plan to approach the village through an NGO that runs the village school. This is because such NGOs are able to earn the trust of the villagers, and are good at listening and understanding their true needs. We have some experience of studying and working with the NGOs whom we have chosen initially.

In the whole project, the NGOs are the keys. Different NGOs have strengths in different States. Our aim is to engage with the diaspora communities, and through them the local communities, in the different states, and use the NGO connection to set up the project in each state. Local installers will be selected in consultation with the community and the NGO in each case. The NGOs will select the villages, and the order of villages in which to install. They will inform and involve the teachers and villagers. Our role will be to provide assistance in the form of connections, organize fundraising, and provide a knowledge clearing house.

### 5.2.3 Corporate Social Responsibility Resources

The NGO will also be our link to Corporate Social Responsibility resources. The first NGO selected is directly mentored and guided by a corporate entity, so that a seamless link to CSR projects was established. They were also able to bring in CSR resources from other companies in the area (a battery supplier). Going beyond, the NGO with their CSR partners are well-positioned to link with area engineering schools and training institutes, to train selected villagers in the skills needed to become installers of the systems. Thus our approach has the opportunity to establish a viable link to skill training, and in turn, employment generation.

### 5.2.4 Link to Medical Resources

GIBC is striving to build the links to the medical community, starting with experts who attended this conference, and going beyond to national organizations of physicians. A plan to provide basic energy and education provide a major boost to our chances of getting medical facilities established in each village.

### 5.2.5 Internet/ mobile phone links

Whether it is more feasible to establish Internet links or Mobile phones first, depends on the village location and neighborhood. In most of India, mobile phone service appears to be easier to establish, with antenna towers co-located with the railway network. However in some forested/mountainous areas, Internet transmitters and receivers may be the first resources to be established. We plan to install data logging devices on each PV and other energy system, with different strategies used to transmit the data periodically to central locations.

Modern Internet of Things (IoT) technologies offer very interesting solutions for rural-based distributed enterprises, linked through the Internet. With these links, small-lot manufacturing can be done in villages.

### 5.2.6 Capital

With India's new digital-access banking, micro-finance options have expanded. The above links to small manufacturing, energy installations, and other enterprises open opportunities for microfinance as well.

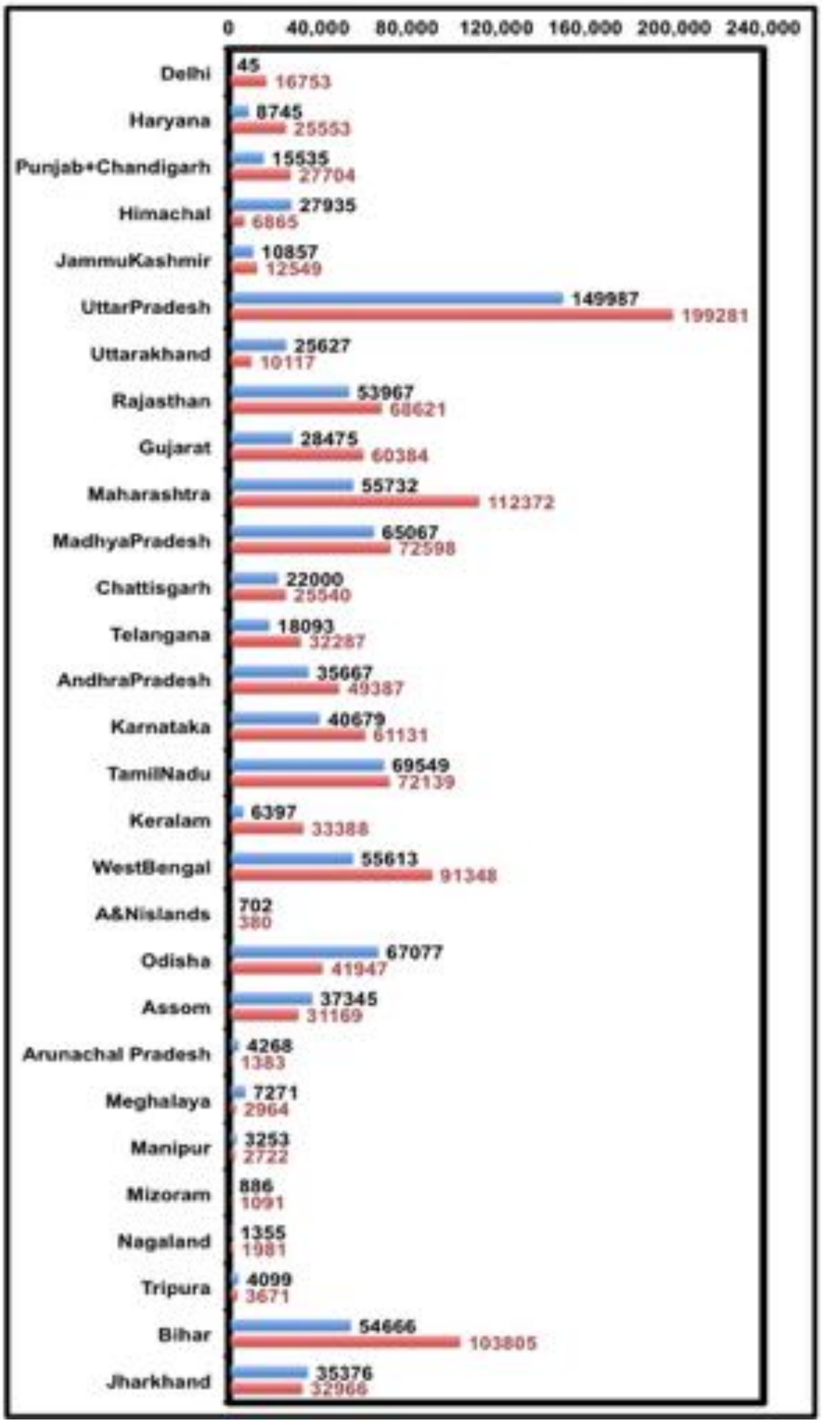



*Figure. 5.1: Number of localities (blue), and population in thousands (red), classified by State. Data for Sikkim and the Union Territories not included.*

# Chapter 6

# Technology Survey

It is our firm belief that there is no single technology that provides a complete solution in India, or anywhere else. Particularly in India, there are abundant energy resources from solar heat and light, from biomass, water and wind. Each has its own special advantages and difficulties. Our approach is to seek a synergistic combination of technologies that can be adapted to the realities of each village. As the first installation providing electric power, solar photovoltaic presents an attractive solution. However, other resources then become viable and useful. The variety of technologies and their usage are explained in [8]. In this conference, we brought in experts to speak on two technologies in particular. The first is the extraction of energy and fuel through solar thermochemical means. This has immediate as well as long-term and much broader potential, transitioning eventually to a clean hydrogen economy. In the shorter term, solar photovoltaics are attractive.

## *6.1 Survey of New Technologies*

### *6.1.1 Thermo-Electric Modules (TEM)*

Professor Narayanan Komerath glimpsed a set of technologies in his presentation. These are shown in Figure 6.1. The first is the thermoelectric converter shown in part [**a**], powering a fan using the waste heat from a few candles. Komerath passed around a sample thermoelectric module (TEM), a square slab of ceramic semiconductor (mostly Bismuth Telluride) approximately 50mm x 50mm x 2mm, to the audience. Such a module is rated at 20 Watts when there is a temperature difference of 250 degrees Celsius across the


*Figure. 6.1: A quick survey of new technologies. (a) Thermoelectric module (b) Solar tracking intensifier. (c) Biodiesel from algae. (d) 4-stroke machine that generates hydrogen from methane, courtesy Georgia Institute of Technology. (e) Natural gas filling station. (f) 3-D printed gas turbine engine model. (g) The NASA Mars Rover is a solar PV-powered mobile lab. (h) Gas turbine combustor burning a mixture of ammonia with methane. (i) UAV-based package delivery from a delivery van.*

two faces. Maintaining the temperature difference poses some challenges: it usually requires a heat sink circulating liquid, when used in the laboratory. Some luxury automobiles use such modules fixed to their exhaust pipes to generate a small amount of power for auxiliary devices, permitting them to advertise this 'green' technology. Komerath stated that students in his university laboratory have been trying to develop an "EduKitchen" device suitable for the wood-burning basic 3-stone stoves used by the most needy people around the world. The 20 Watts is more than sufficient to operate a small computer fan (8W) to optimize combustion in the stove as well as blow pollutants out through a vent - a very important need to protect the lungs of the cook [25, 43–45].

Another 4W would power a steady DC LED light so that children can study under the supervision of their parent in the kitchen, without hurting their eyes or lungs. The TEM would in fact charge a battery, which would provide the steady power to the devices regardless of the flickering of the flame. A few milliWatts would be enough to power a 254-276 nanometer LED placed over a drinking water filter, which has been shown to eliminate essentially 100 % of the deadline *e-Coli* bacteria responsible for cholera and other epidemics. Thus this small add-on device could have tremendous benefits to education and health of people at the very "bottom of the pyramid". Audience members from Africa showed great interest, in adopting such technologies to countries such as the Congo. They asked if TEM devices were in practical use.

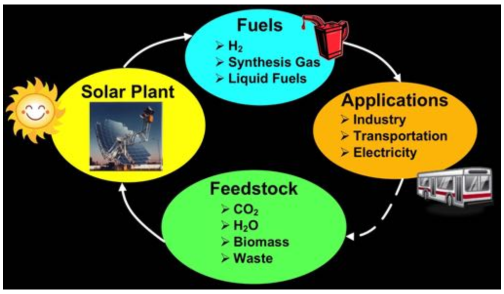



*Figure. 6.2: Fuels for the future will include liquid fuels, synthesis gas and hydrogen. From J. Davidson, by permission.*

Komerath responded that other than the luxury vehicle application discussed above, TEM devices were originally developed to power spacecraft that went on decades-long missions to the Outer Planets, where sunlight is far too weak to be of use. In that application, a small nuclear radioactive isotope provided steady heat, enough to reach about 260 degrees Kelvin (about -17 deg. C). However, the other side of the device is exposed to the deep vacuum of Space, where the background radiation temperature is approximately 6 degrees, Kelvin above Absolute Zero, so this is enough. This use has been in vogue for decades now [12, 46–58], very successfully. Mass-produced TEM devices should be low enough in cost to allow mass distribution to villagers, once the device is fully developed. The challenges for this room-temperature application are in removing the waste heat from the sink side, and present indications are that this requires forced water convection.

### 6.1.2 Solar Tracking Intensifier

Item [**b**] in the figure is a solar tracking intensifier. This device is relatively large, but suitable for installation in a village. It is basically a parabolic dish that uses tracking motors to stay aligned with the Sun during the day, allowing a precise and compact focal region to form at the entrance to a reactor vessel. The intensification that is achieved depends on the area of the device and the quality of the focus. Depending on the quality of the reflectors and the materials used, intensification can reach up to thousands of times that of the average midday Sun.

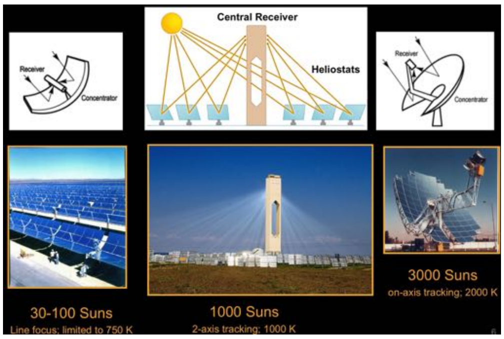



*Figure. 6.3: Concentrating Solar Plants. From J. Davidson, by permission.*

The resulting temperatures can theoretically exceed 3000 Kelvins. At those temperatures, water (steam) can be easily broken down into hydrogen and oxygen in future systems, with very little need for electricity except for pumps and the tracking system. Any small amount of electric power needed can be easily obtained from a small solar panel and batter added to the system. The high temperatures generated can also be used to operate many different types of 'heat engines' such as steam turbines and other gas turbines. The waste heat from cooling water used to protect the materials can be used in cooking.

The major disadvantage of the solar tracking intensifier is that is no good on a cloudy day: only direct sunlight can be intensified, not diffused light. As a result, this system may be better suited to dry deserts, or high altitude sites. In addition, such systems must therefore be used in conjunction with other systems that do operate in poor weather. It is possible, of course, to generate storable fuels using this system when the sun is shining, and use those fuels at other times. More on this in the section on thermo-chemical fuel generation, below.

### 6.1.3 Algae and other Bio-Diesel Production

Biodiesel from many renewable sources [59–63] and particularly from algae [64–71], is a topic that continues to attract much attention . Shown in part **[c]** is a representation of algae that grow on the surface of ponds, and a labeled beaker of biodiesel. Certain types of algae have been found to be as much as 85 percent extractable hydrocarbon fuel. They grow on placid and gently flowing water, feeding on sunlight, water and carbon dioxide. Thus these systems are being used with thermal power plant to efficiently remove and sequester CO2. The algae must be harvested, dried and crushed, with the resulting fuel distilled. For whatever reasons, algae biodiesel production has not succeeded on a large scale yet. However the opportunities for such systems in a distributed village-based architecture has not been explored sufficiently. One issue to resolve here, [8] is the best way to distribute the collection of wet algae, and the machinery-intensive phases of crushing and

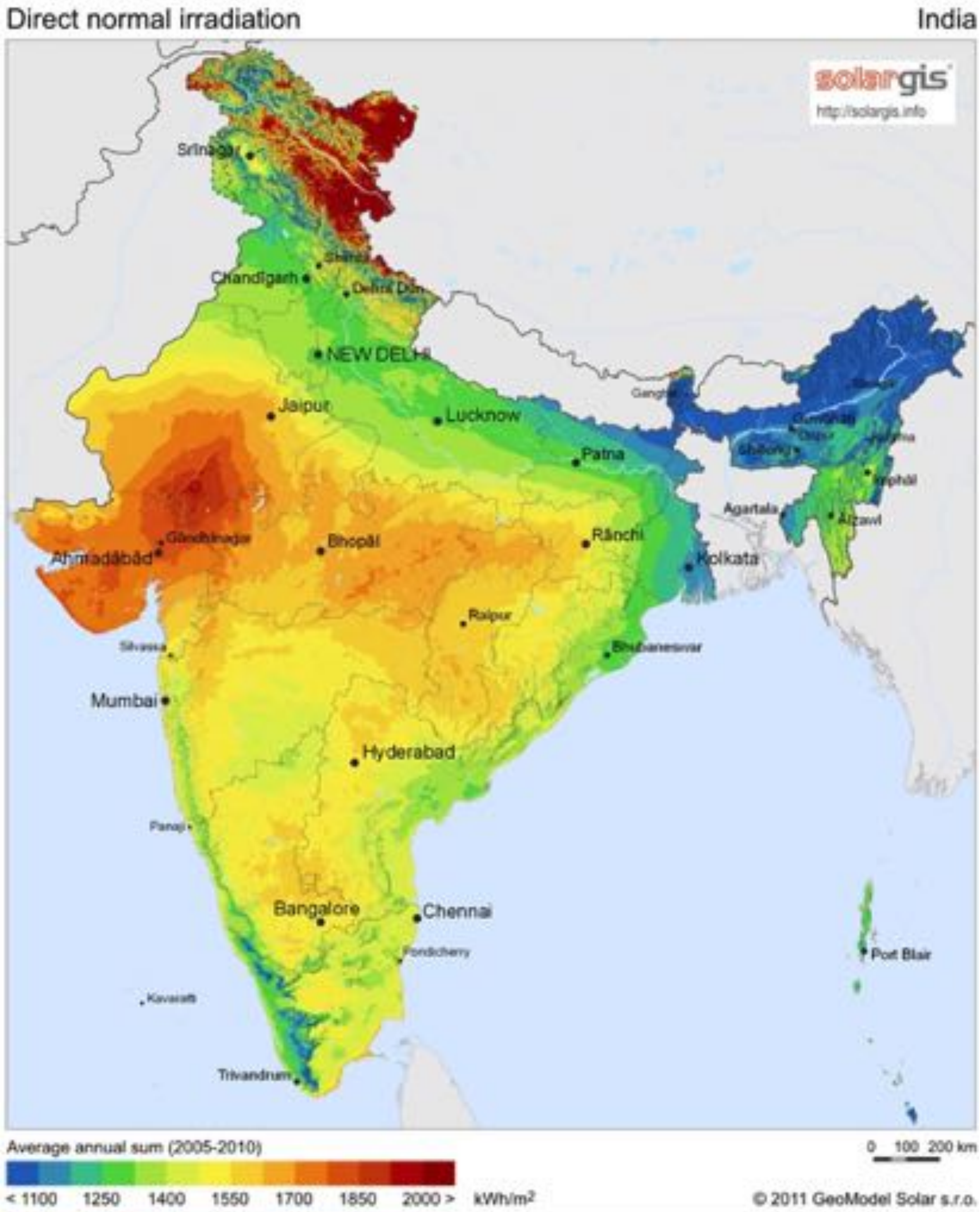



*Figure. 6.4: Solar direct normal irradiation in India, showing contours of annual sunlight in kiloWatt hours per square meter. From J. Davidson, by permission.*

distillation.

### 6.1.4 Hydrogen from natural gas

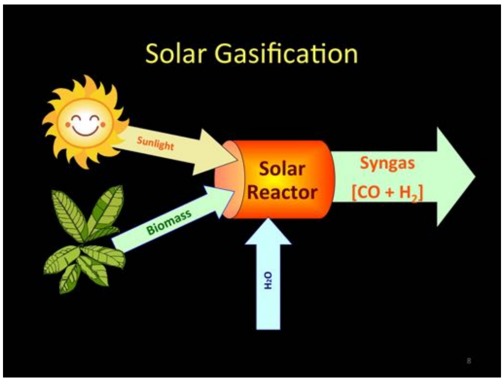



*Figure. 6.5: The process of solar gasification. From J. Davidson, by permission.*

Hydrogen-oxygen is the best fuel combination for a fuel cell to generate clean, quiet electric power. Producing hydrogen efficiently at the local distributed level, is thus a huge objective of micro-renewable energy system research and development. The device shown in the part **[d]** is a recent innovation, where a 4-cycle engine is used to break down methane, the dominant component of natural gas, into hydrogen and carbon dioxide, with the carbon dioxide sequestered. This device is of course at an experimental laboratory-scale stage. Research at Indian universities on such technologies could revolutionize the Indian rural scene. Biogas can be purified to become essentially all methane by removing the sulfur compounds and carbon dioxide through scrubbers. Thus we submit that this an important technology area that can be of great use in rural energy self-sufficiency.

### 6.1.5 Natural Gas For Transportation

This is not a new concept, but the filling station picture **[e]** just shows how routine it has become. Buses and delivery trucks routinely run on natural gas; delivery trucks are also now hybrid gas-electric. With such filling stations appearing in rural areas, the transportation infrastructure can change dramatically, with natural gas (mostly methane) derived by scrubbing biogas obtained from vegetation and animal dung, and eventually, human waste.

Gas turbine engines rotate continuously (constant pressure combustion), as opposed to internal combustion (IC) engines where the combustion occurs intermittently in very short pulses, with 2-stroke and 4-stroke engines. The latter are more sensitive to the quality of the fuel than the former. The fuel composition with biogas may vary significantly from one village to another, and even from day to day in the same village. IC engines used as power generators would thus encounter problems with the timing (ignition delay) of the combustion, which could vary. Thus, IC engines have to be modified for use with biogas, with attendant performance penalties. The present solution is to purify the biogas by removing sulfur compounds, ammonia and carbon dioxide, and bring the methane content uniformly into the high 90-plus percentages. Gas turbine engines offer much better performance, particularly as the size of the engine increases. They are also less sensitive to variations in fuel quality, as long as the heating value is sufficient to sustain operation.

### 6.1.6 3-D Printed Gas Turbines

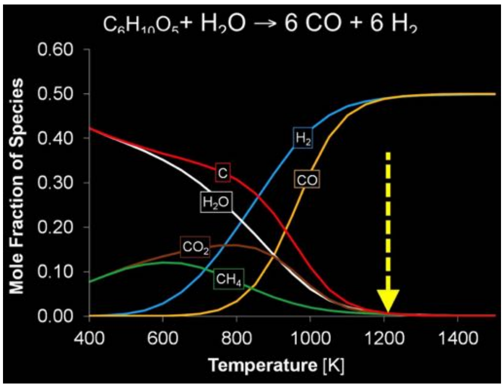



*Figure. 6.6: Thermodynamics of gasification. From J. Davidson, by permission.*

However, gas turbine engines are much more expensive, since they have many precision-built parts. In India, the precise machining required for gas turbines is difficult to obtain as yet. Damage to gas turbines, which may occur for various reasons in a rural setting, would result in long down-times while the engine is being repaired.

This is why the picture shown in [**f**] is particularly interesting. Companies are demonstrating that the extremely complex parts needed for a small gas turbine, can be developed using 3-D printing, directly from computer-aided designs. Each part can be built in a relatively small facility, that can be located in rural areas. Spare parts for blades etc can be replicated and supplied locally. Certainly, many of these parts require manufacture from metal alloys. However, recently major companies such as Siemens are demonstrating gas turbines operating with metal parts made using 3-D printing. Turbine inlet temperature (the highest temperature in a gas turbine engine) exceeding 1000K has been shown with machines made by 3-D printing. This is not sufficient for aircraft jet engines, where the design is driven by the need for highest thrust to weight ratio, but it is sufficient for ground-based rural gas turbines. Although this sounds like an extremely "high-tech" undertaking, at ground level, manufacturing each part is a carefully-specified, standardized operation. As discussed by Professor Madisetti under the Industrial Internet of Things, this type of manufacture can be brought and effectively sustained in rural India through a distributed manufacturing architecture based on Cloud computing.

### 6.1.7 The Mars Rover: A Micro Renewable Power System

NASA's Mars Rover, shown in part [**g**] is an example of a Micro Renewable Power System, designed to operated for a long time in extremely hostile conditions, with no hope of maintenance or repair beyond what it can achieve by itself. It is powered by solar PV panels. The sunlight on the Martian surface is only about half as intense as it is at Earth's surface. The system is a self-contained vehicle, that also serves as an imaging platform, 2-way communications base, a robotic sampler arm, a chemical laboratory and weather station. This is an extreme example of what can be done with even a small amount of renewable power, and a small system.

### 6.1.8 Ammonia-based power generation

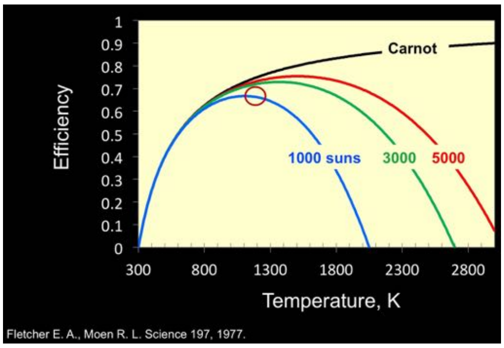



*Figure. 6.7: The process must be matched to concentration. From J. Davidson, by permission.*

The picture shown in [**h**] is unremarkable: just a blue glowing jet shooting out of a small nozzle attached to a pressure vessel. What it shows is the exhaust from a combustion system for a gas turbine generator, that runs on a mixture of ammonia with some methane added. Ammonia has a relatively low heating value, so methane is added to increase the heating value and make the machine run. In fact the machine is started with a methane-rich mixture, but once it catches on and spins up, the ammonia content in the mixture is increased. Ammonia is a very interesting fuel because it is available in plenty, and because its reaction produces only oxides of nitrogen and water vapor, no carbon dioxide. Ammonia can be obtained in rural areas partly from urine, and from other chemical processes.

### 6.1.9 UAV-based last kilometer delivery

Picture [i] shows a multirotor Uninhabited Aerial Vehicle (UAV) carrying a large package under it, presumably from the delivery van on top which it normally resides. This is one of the options for last-kilometer delivery of packages, being adopted by major corporations. It offers breakthrough potential in rural India, where the road infrastructure is quite bad, and causes major costs and delay in delivering packages.

## 6.2 Thermo-Chemical Fuel Generation

*If there is one defining message of our conference, it is to urge Indian businesspeople, university researchers, technocrats and lawmakers to pay attention to this technology area, and bring it into Indian villages.* This is because of several aspects:

1. It uses solar energy to directly produce liquid fuel in the villages in the very near term. This fuel can be used for transportation, and stored for use on demand in agriculture and homes year-round. It can thus break the stranglehold of petroleum fuel cost, on the most needy and largest section of Indian society.
2. It offers an evolutionary pathway to several techniques of producing hydrogen-oxygen storable fuel distributed over the rural areas of India. Thus a transition to a clean hydrogen economy can be made, leapfrogging the conventional objections of the cost of pipeline and hydrogen liquefying/compression systems.
3. If is fundamentally compatible in logistics with systems for algae biodiesel generation as well as biogas generation and purification.
4. The feedstock is essentially waste vegetation.
5. When Indian entrepreneurs see the way to incorporate such systems in villages, India will break out of the dependence on imported oil, with dramatic improvements in the value of Indian currency to follow shortly thereafter.

Professor Jane Davidson of the University of Minnesota was invited to present work from her laboratory on the subject. Some of their prior work can be found in [72–76]. While solar photovoltaic systems dominate the renewable energy market today, systems that use intensified solar energy are growing in effectiveness towards the dream of plentiful hydrogen-oxygen generated from sunlight and water. University R&D in the US aims to take intensified solar converters to 2000K where they can achieve close to 100% efficiency in electrolysis of water. At 1000K, today's small reactors generate liquid hydrocarbon fuels by anaerobic reactions of green wastes such as tall grasses. Rural India is a promising venue to develop this technology and its limitless market towards its ultimate promise.

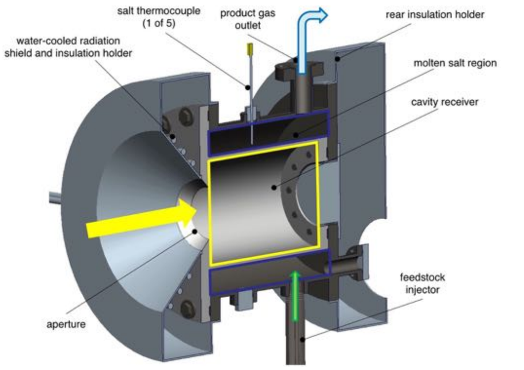



*Figure. 6.8: Research solar reactor with instrumentation. From J. Davidson by permission.*

Intensified solar systems have many other uses as heat engines in powering a rural economy, with and without conversion to electricity. Combined heat and power systems may be integrated with fuel generation facilities in villages. Professor Jane Davidson of the University of Minnesota, presented this line of research and development, and its potential for swift adaptation to Indian villages. Her presentation is titled "Sungas: Solar Thermochemical Fuels".

It is reasonable to project that liquid hydrocarbon fuels will remain a primary energy carrier for some time to come. On the other hand, solar energy is a primary energy resource for a future with reduced carbon dioxide emissions. In the generation of liquid fuels using solar energy, carbon dioxide becomes a valuable commodity. The feedstock for fuel generation include carbon dioxide, water, biomass and waste. The applications are in industry, transportation and electric power generation.

Power plants that concentrate solar power take different forms. Linear troughs are used in many solar power plants today. These consist of long rows of reflectors with curvature in only one dimension, and a liquid-carrying pipe running along the focal line. Oils mixed with salts are heated by passing through this pipe, and then used to run steam heat engines to generate electric power. Intensities of 30 to 100 Suns have been shown. The temperature is limited to about 750K.

Two-axis tracking reflectors situated in a large open field are used to focus sunlight on to a central receiver located on a tower. This can achieve 1000 Suns of intensity, and reach 1000K temperature. Parabolic reflectors with on-axis tracking are used to achieve 3000 Suns of intensity, enabling temperatures of 2000K. Obviously, the highest intensities and temperatures are harder to achieve and to handle. But when these difficulties are overcome, this means that sunlight can be directly used to split water into hydrogen and oxygen, with very little electricity needed for the process. Long before that becomes routine, we can reach the lower intensities needed for 1000K temperatures, which enable generation of liquid hydrocarbon fuel - the main topic of Professor Davidson's presentation.

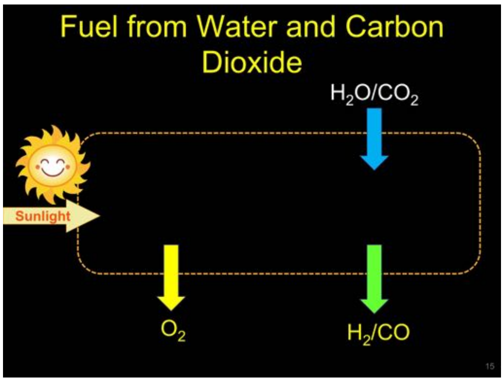



*Figure. 6.9: Direct solar thermal decomposition of water and carbon dioxide to generate oxygen and a mixture of hydrogen and carbon monoxide. From J. Davidson, by permission.*

Figure 6.4 Makes the point that all of India gets plenty of sunlight. The lowest is in the mountainous, rainy Northeast, where there is still on the order of 1000 kiloWatt-hours falling on the surface per square meter, per year. In large parts of Gujarat and Rajasthan that number is some 1700 to 2000 kWh per square meter per year, and the Ladakh/Leh region, dry and elevated, receives over 2000. Prof. Davidson emphasizes a well-known point: cold, dry places are excellent for solar plants. Solar plants are ultimately 'heat engines' in thermodynamics parlance. The efficiency of such devices increases as the heat exchange takes place across a larger temperature difference. Mountainous places get more intense sunlight and the cold on the shaded side provides a larger temperature difference.

Figure 6.5 schematically illustrates the process of solar gasification. Sunlight is allowed to focus on a solar reactor, a container which gets heated to a high temperature along with the biomass and water fed into it. The product is Syngas, a mixture of carbon dioxide and hydrogen. Solar gasification offers strong advantages. Oxygen and cellulosic biomass (vegetation) are combined in biomass gasification. Hydrogen and carbon dioxide are emitted. When synthesized, methanol and di methyl ether are generated. The process provides storage of solar energy. It eliminates waste of feedstock because of partial combustion, and thus it doubles the yield per unit mass of feedstock. The net yield comes up to 209 GGE per acre of prairie grass feedstock. The thermodynamics of gasification are illustrated in Figure 6.6. A temperature of over 1200K is required to achieve better than 98 percent conversion of carbon. Gaseous products are maximized when the reactor is operated without pressurization.

Figure 6.7 explains that the process must be matched to the concentration of solar energy (in other words the temperature reached). The highest theoretical efficiency per thermodynamics is shown by the black line denoting the ideal Carnot cycle. If the peak concentration available is 1000 suns, then the best efficiency is achieved at around 1300K, with a cycle efficiency of around 0.7. This rises to nearly 0.8 at 5000 Suns intensity, corresponding to around 1700K.

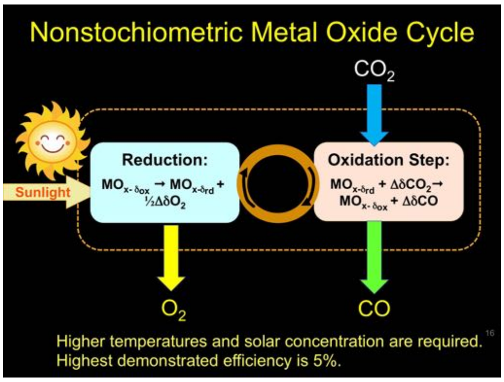



*Figure. 6.10: Non Stoichiometric Metal Oxide thermochemical process to generate oxygen and a mixture of hydrogen and carbon monoxide from water and carbon dioxide. From J. Davidson, by permission.*

Figure 6.8 from [76] shows a prototype solar reactor. The parts and their functions are self-explanatory. This is an instrumented laboratory reactor and hence incorporates a water cooled shield, which may not be necessary in fielded systems. Where water cooling is used in solar power systems to improve efficiency as in some multijunction photovoltaic systems, the heated water is used for other useful functions.

The salt used in the reactor in the University of Minnesota Solar Molten Salt Gasifier, is a ternary eutectic blend of Lithium, Potassium and Sodium Carbonate. It is provided as tablets 10 mm in diameter and 4 mm thick. Melted in the reactor, the salt improves heat transfer and thermal storage. It also serves as catalyst, accelerating the gasification and cracking reactions. It also retains the ash and sulfur, and cracks the tars, thus cleaning the product gas output. The present laboratory system is housed in a barrel roughly 400mm diameter, with the intensified sunlight simulated by a set of halogen lamps with parabolic reflectors. This allows the laboratory to operate with controlled energy input, independent of weather and day-night cycle. With continuous feed and fuel production, the system demonstrates 30 percent efficiency in using the solar power in generating fuel. With improved feedstock delivery, the efficiency is expected to reach 60 percent. The research reactor with instrumentation is shown in Figure 6.8. We project that a field test system may initially have similar instrumentation but production systems will be simpler.

### 6.2.1 Thermochemical Breakdown of Water and Carbon Dioxide

Figure 6.9 schematically illustrates how fuel may be generated directly from water and carbon dioxide. This is a future system, requiring higher solar intensity than what can today be accomplished in fieldable systems on a viable scale.

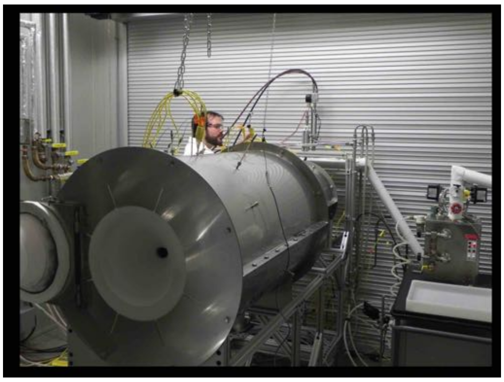


*Figure. 6.11: University reactor and experimental set up to study non-stoichiometric thermochemical fuel generation. From J. Davidson, by permission.*

Intense solar heat breaks down the feed of water and carbon dioxide, generating oxygen and a mixture of hydrogen and carbon monoxide. The following figures illustrate the processes used in this decomposition. The first is the Non-Stoichiometric Metal Oxide Cycle shown in 6.10. Metal oxides are decomposed in the reactor using direct solar heating. They release some oxygen leaving a metal oxide with less oxygen per metal molecule. This then reacts with the feed of carbon dioxide, recovering the original composition of the metal oxide but stripping oxygen from the carbon dioxide, leaving carbon monoxide. Professor Davidson points out that this requires higher solar concentration and temperature, and the highest efficiency demonstrated to-date is only 5 percent. An instrumented university laboratory system to study this type of reaction is shown in Figure 6.11

### 6.2.2 Summary Outlook for Thermochemical Fuel Generation

Professor Davidson summarized the state of technology in this field by stating:

1. The field of solar fuels is in its infancy.
2. Solar gasification / reformation / hybrid cycles are stepping stones to thermochemical cycles to split water and carbon dioxide.
3. Solar gasification is scalable and holds out the promise for hydrocarbon fuels that are compatible with fuel-use infrastructure.

The discussion following her presentation sought to explore opportunities for Indian and US-based companies to take the technologies forward at the scale suitable for an Indian village, which is much smaller than the scale required to compete in US-based production facilities.

Indian costs of petroleum fuels are typically much higher than those in the USA. Converted to purchasing power, these costs become prohibitive to Indian villagers. Liquid fuel is difficult and expensive to convey to remote villages, further exacerbating this fundamental aspect of energy dependence for villagers. When the fuel is imported, as 77 percent of Indian petroleum fuel is today per recent figures, the impact of cost fluctuations due to geopolitical and other tectonics, becomes quite drastic on the Indian villager and farmer. If small local facilities can be set up, the fuel needs of villages may be largely satisfied by just such local production, completely eliminating this uncontrollable dependence: the competitive price in this case is likely to be far above US price points, while the labor needed is much less expense, thus permitting small units to be viable. The opportunities in this regard remain to be explored much more thoroughly.

## 6.3 The Case For Exclusive Dependence on Solar Photovoltaics

Professor Rajender Singh of Clemson University presented a directly opposing view on the need for a broad portfolio of energy options. He toook the view, based on his 43-year career-long specialization in photovoltaics (PV), that the cost of photovoltaic energy capture and storage would keep on dropping so that PV constitutes an exclusive and completely sufficient solution for all of India's rural energy needs. Thus he projects that electric power will become nearly free and essentially infinite for India's population, thus uplifting underprivileged people from being poor to becoming middle class customers. The following figures and discussion summarize his argument. He argues that energy and information are two sides of the same coin.

There are different business models in this endeavor. One is where individual

NGOs (non-governmental organizations) are primary, and the government is on the sidelines. The second is a new business model where the government is a passive partner with the NGO. A new partnership for a New India might involve public, private and international partnership.

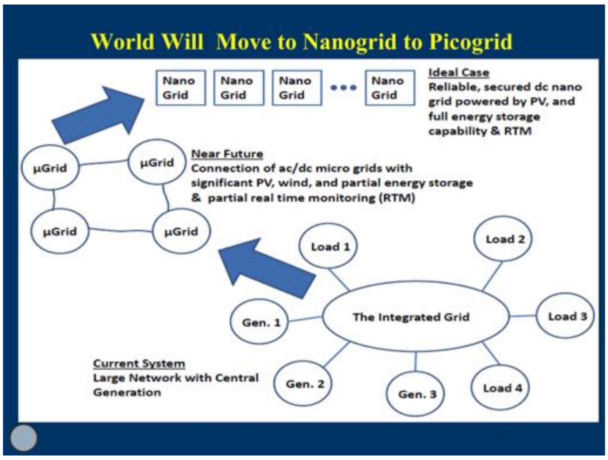



*Figure. 6.12: The world will move from micro grids to nanogrids to pico grids. From R.Singh, by permission.*

Ancient knowledge saw the Sun as the source of all energy. Solar energy is plentiful and far exceeds total resources of crude oil and natural gas based energy resources. Per the Bloomberg website in December 2016, prices for solar PV are projected to be below those for wind energy (on large scale), with deep implications for renewables use in lower-income countries. This is a 70 percent drop in cost, leading to a sharp rise in installations. The cost per watt of solar PV, installed, is down to 61 US cents in August 2016. In India, solar capacity (including solar thermal plants as well) has grown over 3-fold to exceed 10 GW inside 3 years. Accordingly, cheaper solar power allows Indian companies to dump utility supply. The cost has dropped from 12.76 Indian Rupees per kWh in 2010, to below 3 Indian Rupees per kWh in 2016. This is a result of progressive policies by the Indian government, increase competition among project developers, reduced module prices and lowered interest rates.

Prof. Singh identified several scenarios. The first is the status quo. Even as costs of solar PV fall, large entrepreneurs may not understand what PV can do for India. Like the cellphone, the cost of PV will keep on falling and become lower than that of any other form of electricity generation, however the leadership opportunities of export and job creation may be missed. A second scenario is that public policy issues are addressed so that Foreign Direct Investors (FDI) can join Indian businesses as junior partners. Prof. Singh cited US concerns about Indian government policies that disadvantaged foreign-made solar panels in 2011. He felt that with changed policies, volume manufacturing of all components could be undertaken in India leading to rural uplift, solution for unemployment and youth unrest, eradication of poverty and leadership in exports. PV-based generation costs will fall below those of coal-based power, even without taking into account the social costs of using coal such as child mortality, pre-term births, etc attributed to air pollution, and childhood leukemia and testicular cancer attributed to living close to high-voltage power lines.

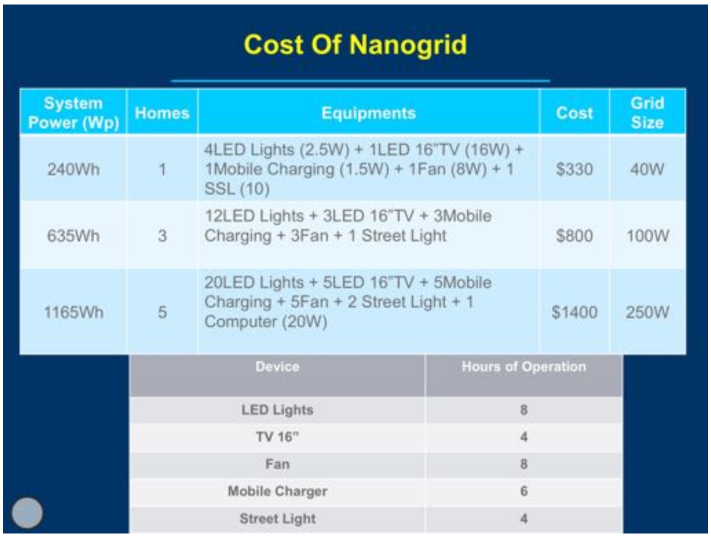
*Figure. 6.13: The Global Himalayan Expedition to install a solar photovoltaic DC network in a Ladakh Village. From R.Singh, by permission.*

Prof Singh presented a graph from Michael Liebrich of Bloomberg Finance, New York, applying linear trends to the historical prices of both solar PV modules and Lithium ion batteries. While the PV module prices have certainly followed a linear drop since 1976 despite temporary flattening of the curve, the Lithium ion data are only since 2010. After a sharp initial drop that curve appears to be very curved, flattening out, but with the data for 2012 through 2014 showing a roughly linear decrease. Energy density of batteries is also rising, along with falling cost, per the US Department of Energy. Prof. Singh projects a cost of $100 per kWh of battery storage by 2020, and ultimately less than the cost of hydroelectric storage. Longevity of solar panels also appears to be excellent, even in damp weather.

### 6.3.1 Local DC Power

Prof. Singh pointed to local DC generation and local grids as a paradigm shift, enabling minimal losses because of minimal transmission distances, saving 30 to 50 percent energy compared to a centralized AC (alternating current) grid. Where there are loads that must be operated on AC, a built-in inverter is the most convenient solution. The steep cost of high voltage AC lines, associated with wind turbine projects, is avoided. In Figure 6.12 a projected move is shown towards ever-smaller scale grids. At present, about 60 percent of solar DC power generated, is wasted by oversizing the ratio of the PV system to inverter capacity. There have been several demonstration projects of local DC power, with PV and batteries. These include an ARDA project in Burlington, Ontario, Canada, a Bosch project at a Honda distribution plant in California, a project a Moku O Lo'e, Manoa, Hawaii, the Nushima project at Kobe University in Japan, and a project at Allborg university in Denmark.

## 6.3.2 Scenarios



Cost Of Nanogrid

| System Power (Wp) | Homes | Equipments | Cost | Grid Size |
|---|---|---|---|---|
| 240Wh | 1 | 4LED Lights (2.5W) + 1LED 16"TV (16W) + 1Mobile Charging (1.5W) + 1Fan (8W) + 1 SSL (10) | $330 | 40W |
| 635Wh | 3 | 12LED Lights + 3LED 16"TV + 3Mobile Charging + 3Fan + 1 Street Light | $800 | 100W |
| 1165Wh | 5 | 20LED Lights + 5LED 16"TV + 5Mobile Charging + 5Fan + 2 Street Light + 1 Computer (20W) | $1400 | 250W |

| Device | Hours of Operation |
|---|---|
| LED Lights | 8 |
| TV 16" | 4 |
| Fan | 8 |
| Mobile Charger | 6 |
| Street Light | 4 |

*Figure. 6.14: Cost of a solar photovoltaic Nanogrid with component details, as used in the Loomba project in Ladakh. From R.Singh, by permission.*

The first scenario discussed above is that of NGOs operating projects, with the government on the sideline. The IEEE project where Mr. Paras Loomba, local vendor, installed a solar PV-powered DC network in a village in Ladakh is a recent example, described in the IEEE Spectrum magazine. Prof. Singh served as mentor to Mr. Loomba. Pictures are shown in Figure 6.13.The cost of a nanogrid is given in Figure 6.14. A 40W PV system is estimated to generate 240 Watt-hours per day, enough to power one home with four LED lights of 2.5W each, one LED 16-inch Television set using 16W, one charging point for a mobile phone (1.5W), one 6W fan, and one SSL taking 10W. The total cost of this is $330. Three homes were powered using a 100W panel driving a 635Wh system with 12 LED lights, 3 LED TVs, 3 mobile phone charging points, 3 fans and one street light, for a total cost of $800. A 250W panel provides 1165Wh, powering 5 homes with 20 LED lights, five LED TVs, 5 mobile phone charging points 5 fans, 2 street light and one 20W computer, for a total of $1400. Typically, the LED lights operate for 8 hours, the 16-inch TV operates for 4 hours, the mobile chargers for 6 hours and the street lights for 4 hours per day.

Problems include high costs because of middlemen taking too large a portion of the resources, There is an open question about the quality of components and workmanship; the blame usually goes to the PV system. Appliances with high energy efficiency and low cost are also needed. These, in Prof. Singh's opinion, provide an opportunity for India to enter this market.

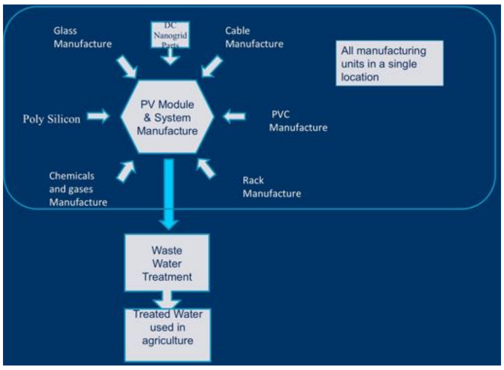



*Figure. 6.15: Argument to co-locate all parts of PV module and system manufacturing in India. From R.Singh, by permission.*

The second option is using the combined strength of NGOs. Here volume purchasing can be used to obtain discounts, but the other problems cited before, remain. The third scenario is a public-private partnership in India, using India's large and growing workforce and the opportunities provided there. The very large number of people at the Bottom of The Pyramid (BOP) constitute an unprecedented opportunity, with a huge combined purchasing power.

Prof. Singh feels that the deepest-pocketed Indian entrepreneurs do not yet understand the semiconductor electronics manufacturing enterprise and its opportunities. Thus, despite spectacular gains in quantity and quality of enterprises such as Coal India in the coal sector, and Reliance India Limited in chemicals and petroleum refining, there is no corresponding rise in manufacturing of PV modules. Those that are manufactured are not competitive with imported modules. This, he feels, is because the wrong story is being communicated to the government. Perhaps, as shown in Figure 6.15, all the components of PV module and system manufacture should be co-located, along with the waste water being treated and used in agriculture. Improved manufacturing could follow a scheme such as that illustrated in Figure 6.16. This brings in the idea of the Internet of Things as a framework using connectivity, data and analytic tools for effective bi-directional communication with machines. With better quality control of the feed ingredients and processing, much better products and productivity can result. This is at the core of a proposed approach to provide the cheapest electricity, using ultra large scale manufacturing and a new business model. He argues for a 380V DC nanoscale grid for commercial customers and a 48V DC grid for residential customers.

With such a coherent plan, PV can play a revolutionary role in the transport sector, with electric vehicles becoming prevalent. Such a plan can slash 95 percent of India's carbon emissions. Thus Prof. Singh argues that we are sitting at the tip of an iceberg today.

## 6.4 Chapter Summary

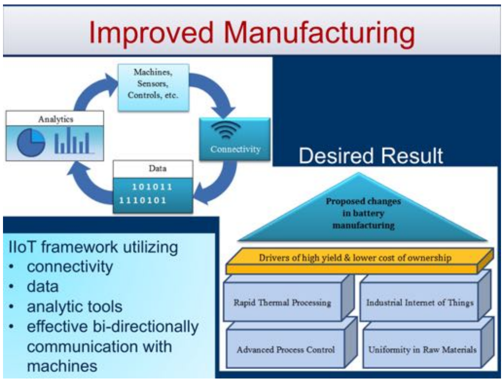



*Figure. 6.16: Schematic representation of the elements needed for improved manufacturing of PV modules and systems. From R.Singh, by permission.*

In this brief chapter we have compared two radically different lines of technology. The latter takes the view that cost reductions in PV will follow the established trends of the semiconductor industry both in the PV modules themselves, and in battery storage. This will lead to a price collapse that will make solar PV electric power pervasively available all over India, completely filling transportation and all other needs for energy. However, radically different approaches to manufacturing, going in the direction of GigaWatt scale manufacturing with all aspects co-located and vertically integrated, is necessary. This will lead to a 95 percent reduction in carbon emissions as well.

The other approach looks at a portfolio of energy technologies that again use solar energy for different levels of usage in generating fuels as stored energy for transportation and other uses. At today's technology level, solar thermochemical processing can convert waste vegetation and water to gaseous and liquid petroleum fuels, available for storage and use at the village level. This can be done economically in India to a much better extent than is possible in the developed world, and has the potential to revolutionize rural energy independence, self-sufficiency, and provide employment.

# Chapter 7

# Logistics of Reaching 660,000 Villages

India has somewhere between 660,000 and 800,000 villages, depending on the source of information. The latest census is an official source, and so is the Indian Postal Service that takes pride, in large advertisements at airports, in delivering to every location because there is no option. However, there are several villages that have been reported on the Internet where NGO personnel installed basic systems, cited as absent from Census figures. Access to these villages is arduous at best. As shown before, there are nearly a million different localities, and 70 percent or so are rural areas. The logistics problem starts with defining the precise location of every village, and then determining the best route to reach it. A presentation from Dr. Balakrishnan Ganesh and Gautam Mattey of UPS Inc. provided some glimpses into the issues, and to solutions being pursued worldwide.

With reference to installing and operating renewable energy systems, Dr. Ganesh noted that buying something is relatively easy. However, in time, something or other goes wrong. Solving such problems requires regular maintenance and replacement of some components; without such maintenance the system eventually stops working. Keeping systems operational over an extended period is the hard part. This is where good logistics are essential.

In developed areas, as shown in Figure 7.1 package delivery follows a well-established standard operating procedure. In the USA, a single multimodal network suffices, as shown in Figure 7.2. Long-distance hauling is done by airplane or truck. From a local distribution center, vans take the packages to the door of the recipient. The driver uses a materials handling cart or other machine to extract the package and deliver it. However, in many Indian villages, the road network is much less developed, as can be seen from Figure 7.3. It takes a long time to reach these villages from regional distribution centers. The balanced multimodal core Indian network being prepared, is shown in Figure 7.4. The last mile delivery network in India takes many forms, such as in Figure 7.5


*Figure. 7.1: In developed areas, delivering a package follows a well-developed procedure. From B.Ganesh by permission.*


*Figure. 7.2: Single multimodal network as used in the USA. From B.Ganesh by permission*


*Figure. 7.3: An Indian village, seen from a train. There is no road network in evidence. From B.Ganesh by permission*

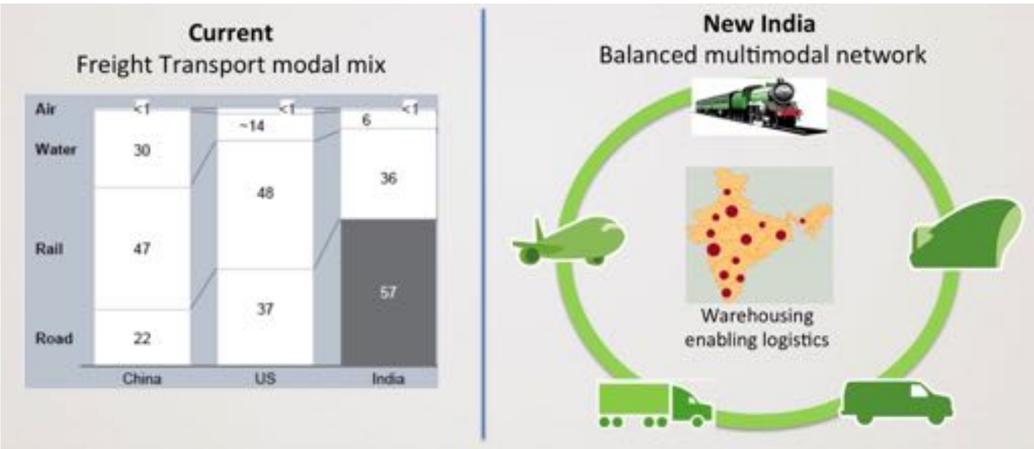



*Figure. 7.4: The Indian core network. From B.Ganesh by permission*

As shown in Figure 7.6 a digital grid network could be established, for last-mile delivery using uninhabited aerial vehicles (UAV). Such vehicles could be fixed-wing or rotary wing. The fixed-wing vehicles require more distance to land, but are more suited to longer flights and higher altitudes. The rotary wing vehicles can land and take off vertically and hence could operate directly from the delivery van. An example of delivery by fixed-wing UAVs is shown from Rwanda, where emergency supplies are delivered, in Figure 7.7. An

*Figure. 7.5: The last mile delivery network in India. From B.Ganesh by permission*

*Figure. 7.6: Digital delivery network for use with UAVs. From B.Ganesh by permission*

example of a rotary wing UAV drone operating from a ground delivery van is shown in Figure 7.8

## 7.1 Summary

In summary, there are advanced solutions, combining modern communications technology with that of autonomous or at least tele-operated vehicles, to leapfrog the infrastructure barriers in India. Indian villages could receive - and send - packages with efficiency and speed, using UAVs, coupled with


*Figure. 7.7: Delivery by fixed-wing UAV: An example from Rwanda. From B.Ganesh by permission*


*Figure. 7.8: The technology is already here. A UAV drone operating from a ground delivery van. From B.Ganesh by permission*

a national logistics network. With a digital grid, the problem of reaching any village can be solved without waiting for detailed road directions or infrastructure.

Later, we will argue that the same UAV last-mile delivery network can also be used to collect data from standalone renewable power systems, much like a postal service worker or a water meter reader visiting the neighborhood of these systems periodically. A single UAV flying over a cluster of villages could record data transmitted over short distances from transmitters attached to data logging devices, that are attached to each energy control system. This will be discussed in the next chapter, where the options and opportunities of the Internet of Things are presented.

# Chapter 8

# The Internet Of Things

## 8.1 IOT Technology and its impact on infrastructure

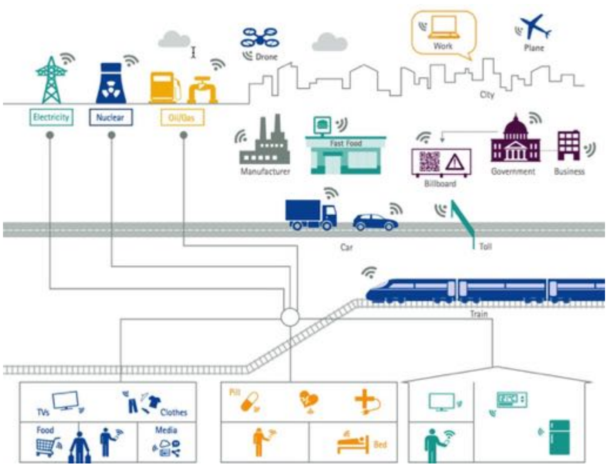



*Figure. 8.1: The connected cyber-physical world. From V.Madisetti by permission*

Professor Vijay Madisetti presented this topic. He provided a perspective on IOT, the Internet Of Things, and went on to discuss its ecosystem architectures, the state of the technology, and what corporations can implement - the seven tenets of successful IOT deployment. IOT encompasses several modern technologies such as Cloud Computing, Big Data Science and Analytics, and BlockChain applications. Some people have called this the Fourth Industrial Revolution, the first being that started by the steam engine and mechanical production equipment circa 1784, the second being that of division of labor, electricity and masss production circa 1870, and the third starting in 1969 on electronics, Information Technology and automated production. This fourth may be called that of cyber-physical systems. According to Dr. Klaus Schwab, Chairman of of WEF 2016, this fourth revolution is different from the prior ones in velocity, the exponential pace of adoption, versus a more linear pace in the past. It is different in scope, with disruptions in almost every industry on Earth; and it is different in systems impact, transforming entire systems of production, management and governance.

A connected cyber-physical world is illustrated schematically in Figure 8.1. Figure 8.2 shows a generic high-level architecture for an IOT ecosystem. Figure 8.3 shows technology options for an IOT network today. Generally, one has to accept a tradeoff between power consumption and speed. Low power, wide area custom networks offer at most hundreds of kilobytes per second (kbps) but consume only about 50 mW when active and 1 micro-Watt when asleep. These may be well-suited to routine data collection and monitoring of renewable energy systems. There is an unlicensed but not crowded band at a slightly higher power level and similar data rates. At roughly 1 million bytes per second (1Mbps) is the 2.5G Network. The licensed band with telecom operators populates a similar speed band, but with greater power. The 4G LTE networks offer 2 to 100 Mbps, but a cost of 10+ Watts. This is not fully viable yet. At low power, there are ultra-narrow band networks called sub-GigaHertz networks, such as the SigFox Network and the LoRA Consortium Prof. Madisetti projects that within 3 years, there will be 5G LTE networks and an LTE-M Standard.

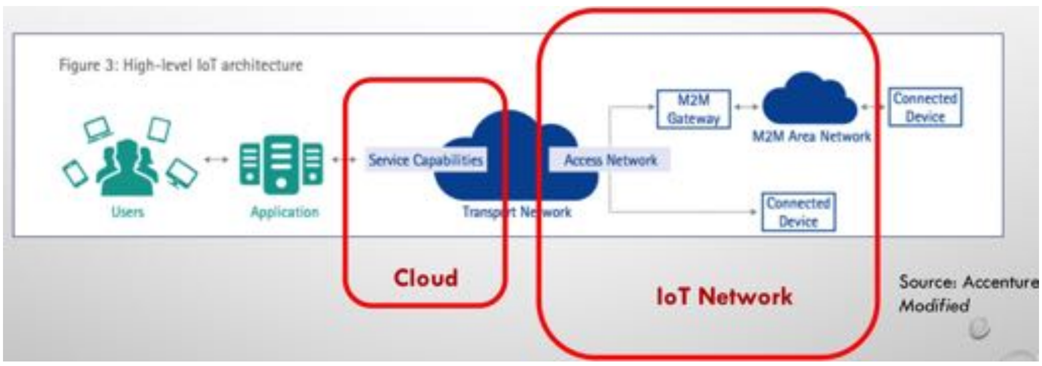



*Figure. 8.2: Generic high-level architecture for an IOT ecosystem. From V.Madisetti by permission*

There are 3 candidate architectures for IOT networks. The first is the telecom network operator model, with a 4G/5G network operator that provides both LTE Advanced Release 15/16 and LTE-M. The second is a low-power wide-area network operator such as SigFox who provide a dedicated IOT network. The third is a hybrid model - a combination of low power sensor-centric network for collecting and pooling sensor data, combined with a telecom / 5G backhaul network for aggregating data into the Cloud, such

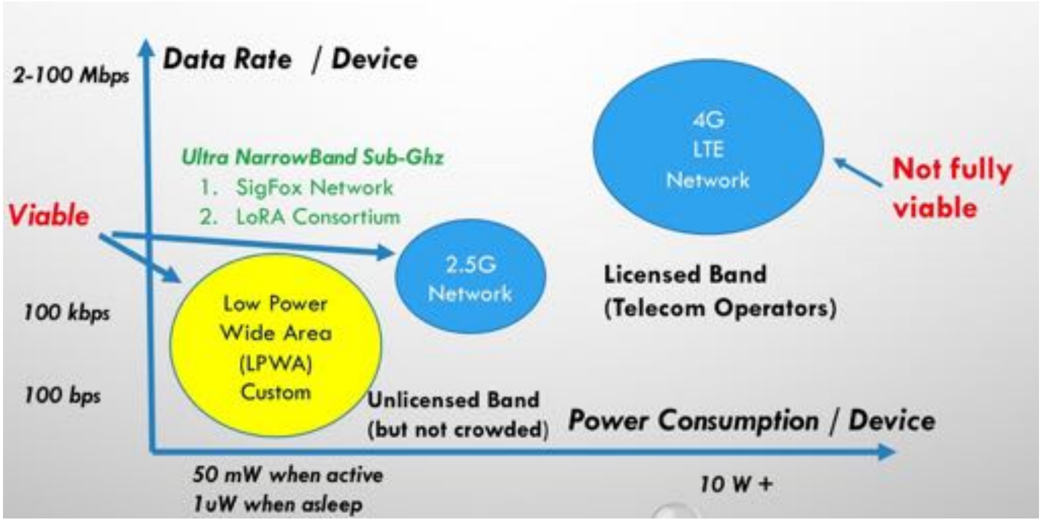



*Figure. 8.3: Options for the IOT Network today. From V.Madisetti by permission*

as the LORA Standard. It is unclear at present, which business model or architecture will prevail and how revenues will be shared. For other options, Prof. Madisetti notes that WiFi is power-hungry with limited range and high interference. BlueTooth has limited range, consumes power, and again has a lot of interference. IOT networks may have 20- 40 km range and each cell may have to support hundreds of thousands of active devices as opposed to cellular (4G) base stations that can support only around 100 active devices in a cell of around 1 km diameter.

Prof. Madisetti laid out the seven tenets of successful IOT implementation. The original 3 are Confidentiality (data not available to unauthorized parties), Integrity (Data or code cannot be changed by unauthorized entities) and Availability (network and data responsive and available to authorized users). There are 4 new tenets: Controllability, Visibility (operators should be able to view and maintain a current state of their network and its devices in the Cloud), Safety and Standardization. Safety includes self-reporting of errors.

## 8.2 Industrial Internet Of Things

An economy based on rural enterprise and manufacturing, must be empowered by a massively distributed communication and control system that can

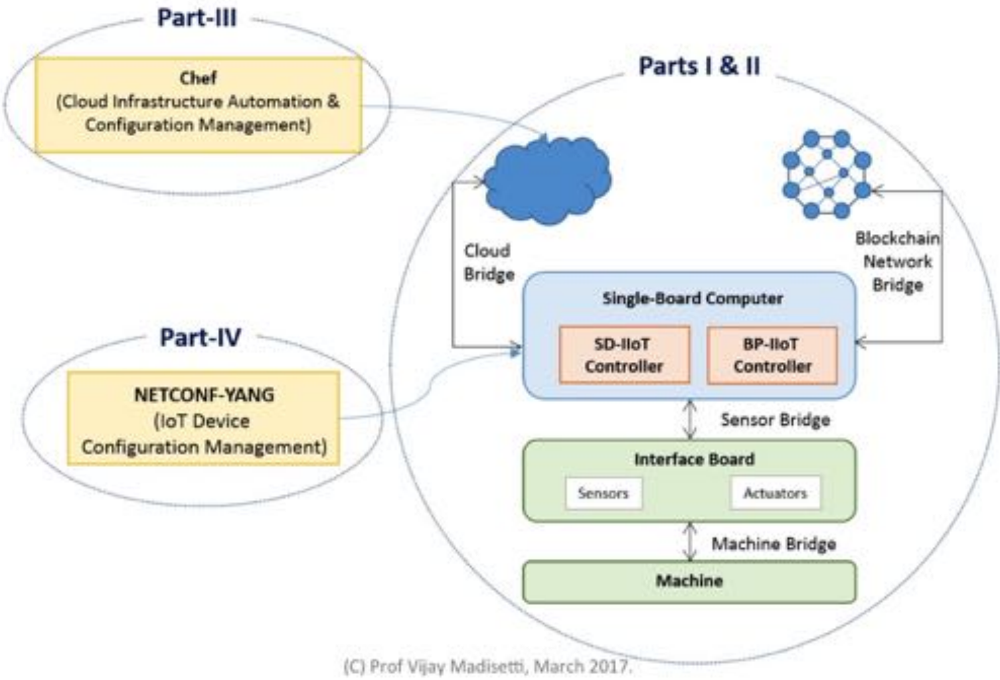



*Figure. 8.4: IOT schematic. From V.Madisetti by permission*

accommodate elements scattered over a large geographical area. The various elements of an IoT configuration are shown schematically in Figure 8.4. In the first part of his presentation, Dr. Madisetti discusses the software-defined Industrial IOT.

The Industrial IoT comprises objects (things) with unique identifiers that are connected to the Internet. The things refer to IoT devices that have remote sensing and/or actuating capabilities. These devices can exchange data with other connected devices and applications, directly or indirectly, or collect and process data locally, or send the data to centralized servers or cloud-based application backs-ends for processing. The term Cloud-Based Manufacturing (CBM) refers to a recent on-demand model of manufacturing, that is leveraging IoT technologies. CBM enables ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction.

*Why are we interested in the context of this conference? Because the creation of a modern entrepreneurial economy spanning the rural areas of*


*Figure. 8.5: SD-IIOT Realization. From V.Madisetti by permission*

*India is critical to the success of our efforts to bring in sustainable energy independence and self-reliance. It should be clear that this will not be achieved by resorting to the ancient models of low-tech labor-based cottage industries alone, not by resort to low-wage factories that simply transfer urban blight back to the villages. Yet, putting up modern technology-based industry in rural areas requires fast access to technology, and the markets for such products. The IoT provides a promising modern avenue to such a breakthrough.*

The Cloud as we know, refers to a massively distributed computing, services and supply infrastructure, accessed through the Internet. To give a small example, an order for 1000 replicas of a certain item might come in from somewhere in the world. A single manufacturing facility capable of producing that many in a short time, would be a large factory employing many people, and would be hard-put to survive in a rural environment. However, the order could be met swiftly by 500 different rural-based entities each providing two items rapidly, all with quality and standardization controlled through the Cloud, along with the logistics needed to meet the customer's requirements in a mostly automated manner. This model would enable hundreds of thousands of rural-based small manufacturing entities to thrive, catering to a vast and diverse array of markets for products and services. It is well-suited to the production of small parts using 3D Printing. This technology, that enables extreme flexibility in producing an infinite variety of small parts, is relatively easy to set up for small machines, but requires immense capital investment to scale up to mass production.

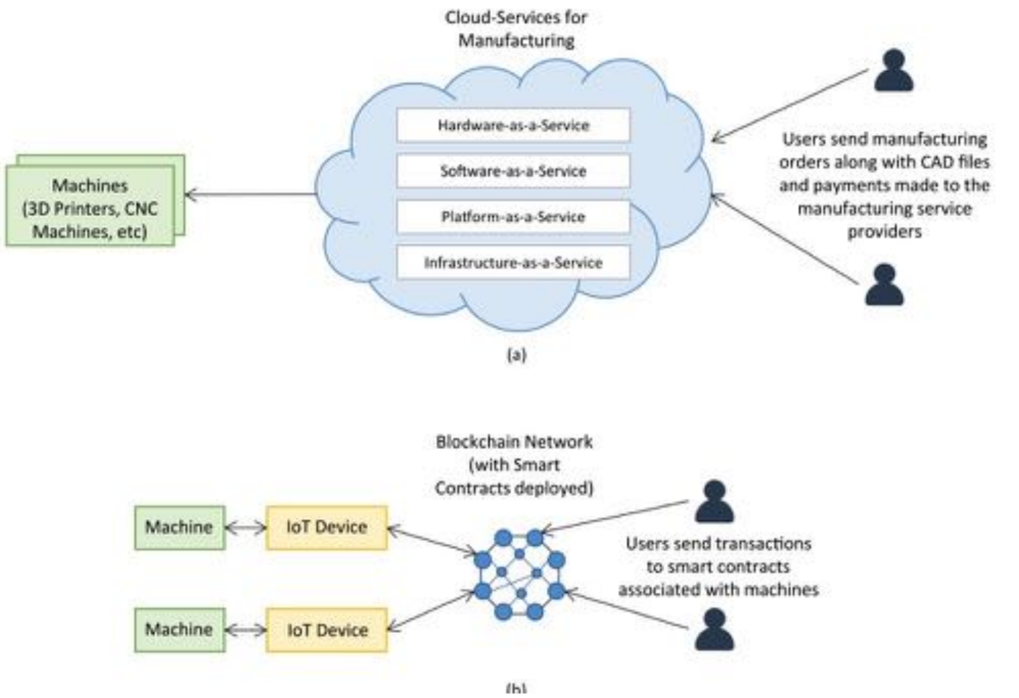



*Figure. 8.7: (a) Cloud-based manufacturing (CBM) model. (b) Blockchain for Industrial Internet of Things. From V.Madisetti by permission*

The Software-defined Industrial Internet of Things (SD-IIoT) platform is a key enabler for Cloud-Based Manufacturing. it allows rapid integration of existing legacy shop floor equipment into a flexible framework. The platform makes use of different types of IoT devices (end-nodes, routers, gateways and full nodes). The IoT devices run an SD-IIoT controller which enables the attached industrial machines to communicate with the cloud, and also allows Cloud-based manufacturing applications to access the machines. For example, engineering drawings of complex parts could be broken up and different pieces assigned to different machines located in different places, with the confidence that all are working on the same problem and drawings just as if they were located in a single factory.

The IIoT devices in SD-IIoT offer a plug-and-play solution that allows machines to exchange data on their operations to the Cloud and receive commands from Cloud-based manufacturing applications. Figure 8.5 shows one realization of the proposed SD-IIoT platform based on Beaglebone Black, Arduino UNO and LoRa SX1272 communication modules. Figure 8.6 shows a node prototype based on the above.

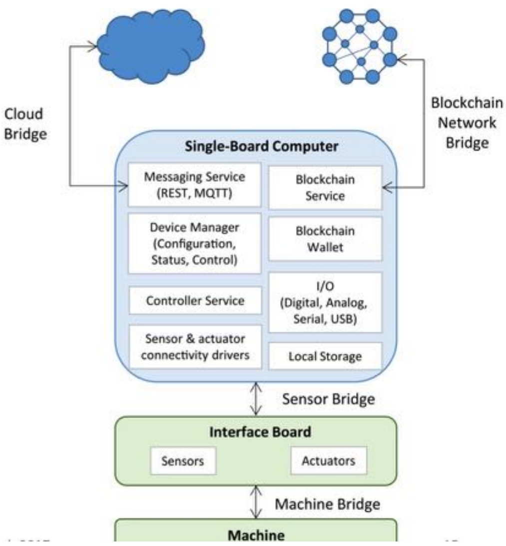



*Figure. 8.8: Blockchain platform for the Industrial Internet of Things. From V.Madisetti by permission*

Next, Prof. Madisetti discusses the Blockchain technologies, relevant to efficient and reliable financial transactions. Blockchain is a distributed data structure comprising a chain of blocks. It acts as a distributed database or global ledger that maintains records of all transactions on a Blockchain network. The transactions are time-stamped and bundled into blocks where each block is identified by its cryptographic hash. The blocks form a linear sequence where each block references the hash of the previous block, and this chain of blocks is called the Blockchain. In its first generation, Blockchain was introduced along with Bitcoin, the Internet-based transaction currency, by Satoshi Nakamoto. Bitcoin transactions are recorded in a public ledger called the Blockchain. In the second generation, Ethereum, an open and programmable Blockchain platform enables users to create and deploy Smart

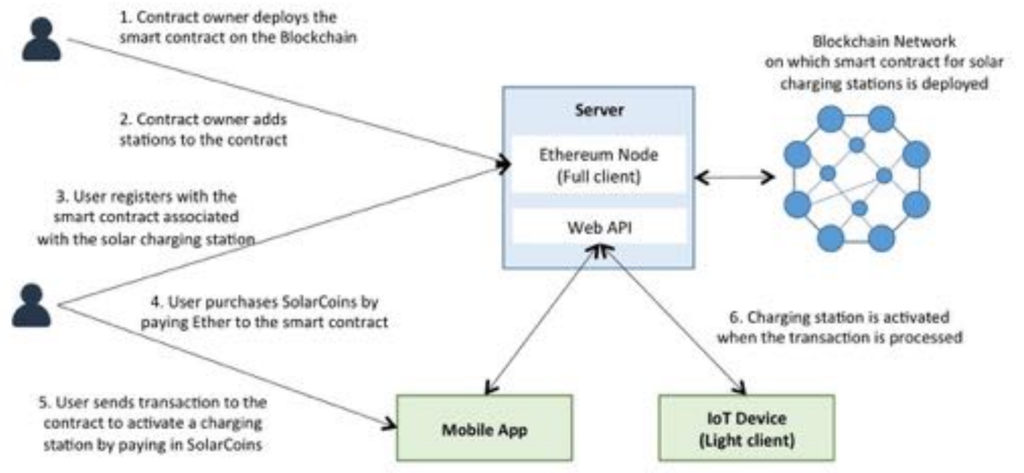



*Figure. 8.9: SolarCharge architecture, an example of a BlockChain enabled application.*

Contracts to the Blockchain platform and build decentralized applications (Dapps). A Smart Contract is a piece of code that resides on a Blockchain and is identified by a unique address. It includes a set of executable functions and state variables. The functions are executed when transactions are made to these functions. A Dapp is an application that provides a user-friendly interface to Smart Contracts.

The Blockchain platform provides a decentralized, trustless, peer-to-peer network for manufacturing applications. Smart Contracts act as agreements between the service consumers and manufacturing resources, to provide on-demand manufacturing services. Thus this platform enables legacy shop floor equipment to be integrated into the Cloud environment. This allows the development of decentralized and peer-to-peer manufacturing applications. These are illustrated in Figure 8.7. The key enabler is the IIoT device, which enables existing machines to communicate with the Cloud as well as the Blockchain network. This device is a plug and play solution that allows machines to exchange data on their operations to the Cloud, send transactions to the associated Smart Contracts and receive transactions from the peers on the Blockchain network. This is illustrated in Figure 8.8.

There are many applications already for Blockchain IIOT Platforms. They allow on-demand manufacturing. Machines will have their own Blockchain accounts. Users will be able to provision and transact directly with the machines to avail manufacturing services in a CBM-like or on-demand model. The Platform can be used to develop smart diagnostics and self-service

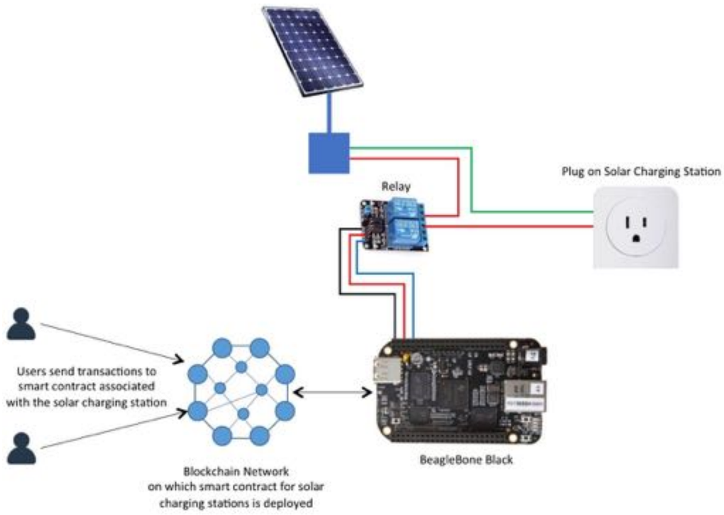



*Figure. 8.10: SolarCharge IoT device.*

applications where machines will be able to monitor their state, diagnose problems and autonomously place service, consumables replenishment, or part replacement requests to the maintenance vendors. The Platform offers traceability, supply-chain tracking, product certification, consumer-to-machine and machine-to-machine transactions, as well as tracking supplier identity and reputation. It can maintain a registry of assets and inventory.

There are many benefits of using Blockchain for IIoT. It enables decentralized and trustless peer-to-peer network where peers do not need a trusted intermediary to interact with each other. It is resilient to failures as it is a decentralized peer-to-peer network with no single point of failure. It is scalable in nature as it is maintained by a network of peers. It is secure and auditable. All transactions in the network are secured by strong cryptography. The transparent nature of the public ledger maintained by a Blockchain network knows about all the transactions and the transactions cannot be disputed. It is autonomous, enabling IIoT devices to communicate with each other and do transactions autonomously as each device has its own Blockchain account. There is no need for a trusted third-party.

Consider a set of Blockchain connected solar charging stations. They are run by a decentralized application backed by a Smart Contract. Users can register with the Contract and purchase SolarCoins with Ether. Users can send transactions to the solar charging stations from a mobile app. Transactions are validated and processed on the Ethereum Blockchain, and the charging station is activated with the transaction is processed. This architecture is shown in Figure 8.9. The corresponding SolarCharge IoT device is shown in Figure 8.10. The mobile phone app is shown in Figure **??**.

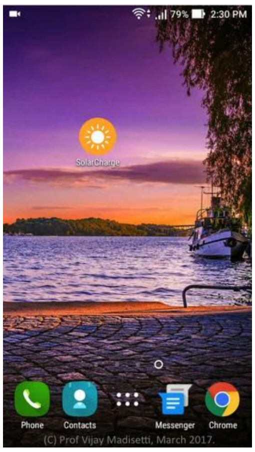



*Figure. 8.11: Mobile Application for SolarCharge.*

The complexity of the Cloud and IoT applications infrastructure increases with the growing number of components such as load balancers, application server and database servers. To minimize the manual effort needed a new paradigm of infrastructure-as-a-code has been popularized by tools for infrastructure automation and management, such as Chef and Puppet. In the Infrastructure-as-a-code paradigm, the computing, storage and network infrastructure are modeled using declarative modeling languages. A modular approach is adopted, to improve code re-usability. These models are compiled and run by infrastructure automation tools to generate the desired infrastructure. The code improves the repeatability of the infrastructure, as the same code always produces the same infrastructure. Modular code design along with the automation capabilities, improve the scalability of systems. In the event of system failures or catastrophic events, the entire infrastructure can be restored from the infrastructure code.

## *8.3 Summary*

This chapter glimpses advanced technologies that can be installed in the Indian setting, taking advantage of India's well-developed Information Technology infrastructure and associated industrial base of software and network applications development. Legacy machines can be incorporated into this advanced infrastructure. Massively distributed rural-based production and services can be tapped efficiently over the Internet, given basic access to electric power and connectivity that will come with the first phase of our rural energy self-sufficiency project. Thus these advanced technologies are key to capitalizing on new access to power, to build up rural-based clean enterprise including modern manufacturing.

# Chapter 9

# Government Role: Mississippi Experience

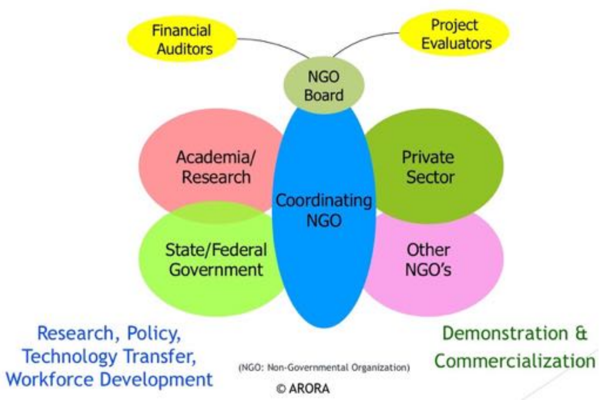



*Figure. 9.1: The Butterfly Model, an inter-organizational framework of collaboration for deploying emerging technologies. From S.Arora by permission*

Dr. Sumesh Arora of the U.S State of Mississippi Development Authority presented experience on the State Government's role in building inter-organizational partnerships to sustain technology deployment. The State's Development authority's overall goals are to grow the GDP and per capita income. The energy and natural resources division runs the State Energy Office, under which come offices dealing with energy efficiency programs and financing, energy education and workforce development, energy projects and policy development, and energy data and security. Dr. Arora showed the 'Butterfly Model', and inter-organizational framework of collaboration for deploying emerging technologies. This is shown in Figure 9.1.

Dr. Arora quotes [77] on the difficulties when NGOs are also activist, not just advisory: *"Given the heterogeneity of local views, if international NGOs are* *not familiar with local politics, they can potentially do more harm than good for local authorities by creating resentment and raising expectations.'*

Also, from [78]: *"Philosophical differences between NGOs, both local or global, can also lead to suspecting each other's motives and the following rift can be detrimental to the progress and success of the project'.*

There are five areas of Venture Risk: Technology, Market, Management, Finance and Execution. The idea of a dominant design was explained thus: A dominant design is a key technological design that becomes a *de facto* standard in their market place. When a new technology emerges, often firms will introduce a number of alternative designs until at some point an architecture or design becomes accepted as the industry standard. Dominant designs are not necessarily better than other designs in the market place, but they will incorporate a minimum required set of key features. An example is the field of micro wind turbines. Figure 9.2 shows several designs, none of which is in fact satisfactory.

*Figure. 9.2: Several micro wind turbine designs. From S.Arora by permission*

Another risk is in assessing policy impact. Is the market demand dependent or independent of policy decisions? Would you do your project or develop this technology in the absence of a specific mandate or other stated policy? One must also assess sector margins: what are the profit margins for the products you are producing - are you playing in the commodity markets or high-value-added products? What is the pricing of your raw materials based on? In assessing the target market one must assess whether the venture has an understanding of the market and clearly identify and justify the target market. A comprehensive competitive analysis is required.

In executing a project, one is faced with contracts, contracts and more contracts. These include supply side agreements, Off-Take agreements, PPAs/ Interconnect agreements, construction, permits, real property, warranties, intellectual property protection, supply chain logistics, economic modeling, job creation/workforce needs, external factors (policy, markets, geopolitics and nature). Dr. Arora presented an entrepreneurship support model which channeled private and public financial assistance to take projects from initial technology stages, by coaching and connecting, all the way to commercialization, with NGO support at the outset, and market entry at the exit point. This is shown in Figure 9.3.


*Figure. 9.3: Entrepreneurship support model. From S.Arora by permission*

# Chapter 10

# Corporate Social Responsibility

Professor Jagdish Sheth of Emory University spoke about the Corporate Social Responsibility (CSR) law and resources in India. He noted the history leading to the CSR law. In India after independence, the Constitution mandated a socialist system with a 5 year planned economy. This could be traced to the Leninist thinking of Commanding Heights. The government was unsuccessful in proper execution of this system. In 1991, India faced a severe economic crisis. Prime Minister Narasimha Rao decided that the government could not deal with both local and international economic policy effectively. The economic agenda went away from government. The government's share went down from 60 to 40 percent. The private sector became more affluent. The government was criticized for this on social media. So the government put the burden of both economic and social development on corporations. Corporate social programs were at one time at the whims and fancy of wealthy persons. Partly to pacify the rural population as the urban areas moved rapidly forward with development, the government made it mandatory in 2013 for business to spend 2 percent of their net proceeds on social programs. This was good thinking, because it short-circuited the usual system of collecting a tax, and then redistributing the funds through a complex system that needed a massive administration. All this would have taken large government resources, and caused needless worries. Corporations were free to choose how they spent the CSR funds, within fairly broad guidelines of what was acceptable. Thus in India today, the funding for social programs will be coming from CSR.

When the cell phone industry was being introduced in 1983, the US government had no idea how powerful this would be. AT&T Corporation had failed miserably with the picture phone. The highest forecast for the cellphone market was 916000 phones by the year 2000. Motorola satellite phones were $3000 each. The conventional wisdom was that the market would follow military applications, but that does not work with digital technology.

In India, 40 to 50 million phones are converting to smartphones this year. Most of these phones are going into rural areas. This government understands the power of digital technology. One billion people have already been given biometric identification cards. Over 200 million new banking customers have been registered in 2 years. This new digital platform will get all the government programs to the fingertips of the citizens, even in rural areas.

Social programs aimed at Inclusive Finance in the USA are dwarfed by Indian scales. Digital technology needs masses, and masses love digital technology. In introducing such technologies, one should think about the consumer first. Industrial people are used to looking at capital budgets, but here one must start with consumer models. Look at Apple Corporation's success - not with PCs but with smartphones . Watch the cellphone industry . In India, villagers provide the masses.

Returning to the CSR concept, note that this is now mandatory on the private sector. Indian organizations are very large in scale. At present, the CSR adds up to over 4 billion dollars in equivalent US currency. CSR allows companies to do what they want to do. Several pointers follow.

1. The best category to apply the programs is to alleviate extreme poverty and hunger. This applies in the USA as well.
2. In India, some 93 percent of the rural workforce work as contract workers, not year-round employees. Thus there is always unmet need and lack of security.
3. In India, the wife is the keeper of the family budget. Making her the economically important partner is extremely important and effective.
4. Short-term cash needs impose extreme hardship on rural people. Disadvantaged people often find themselves having to pay more than 100 percent interest on loans, driving them deeper into poverty. Thus ways to allow people to break free of debt, are valuable.
5. Vocational training is important, and it is happening in India.
6. Environmental sustainability is an important, and favored topic for CSR funding.
7. A focus on sports and talent discovery is a good idea. Sports bind people with the lowest incomes, and provides hope for advancement

through disciplined training and effort.

8. A university-based technology incubator is an excellent investment.
9. Rural electrification is so fundamental, so essential. The multiplier that this investment provides is huge. Solar PV is the right platform at the beginning. There is an enormous opportunity to revitalize the rural areas, and lessen the development gap and contrast between urban and rural areas. In America, one does not feel the gap so much because of the monopoly that was given to the Utility companies. Note that the Bell telephone company never touched rural India - they perhaps felt that it was not possible at the time to develop and infrastructure and collect money from the people. The Last Mile connectivity problem is acute in rural India. But rural-urban equalization is occurring through digital technologies.
10. Partnerships are invaluable in such an enterprise. A good example is the American Cancer Society. They pushed out smoking by denying access to smoking in public places. In India too, smoking has been cut down very heavily.
11. The best CSR resources are those available locally. In every small place there is one family that leads the technology, and must spend CSR funds.
12. Products need local distributors. Owner-family businesses want to get involved, and are often quite wealthy. An example is the Mithaiwala (sweet vendor) back in Pune many years ago. He was humble in appearance. Once he insisted on bringing a significant amount of sweets to an occasion, and would not accept payment. We then discovered that he was in fact one of the wealthiest men in Pune.
13. A local campaign is needed to get such families on board.
14. Many successful NGOs tend to be faith-based NGOs.
15. In India, many people do temple worship, not projects related to improving the livelihood of others. How can we motivate them towards projects of social importance? They need to be sensitized that there is no asset that is better than human resources. Good programs can make ordinary people extraordinary.

Professor Sheth concluded with a statement from personal experience: *"I became a refugee from Burma in my childhood, coming into India. I grew up in circumstances where we had no electricity, no running water, one lamp to study. But someone discovered my talent and nurtured me. Without that, at* *best I could have become a local merchant. It is very necessary to sensitize people. Make them aware of what they can do. An awareness campaign is needed, to co-opt lots of people. I am optimistic today about the technologies and the developments in policy."*

# Chapter 11

# Role of NGOs

The Non-Governmental Organizations have an all-important role to play in this roadmap. There are at least two, and perhaps three, levels of operation for NGOs, and typically these will be different NGOs. The first is the grassroots NGO, with volunteers who either stay in, or frequently visit, the villages where they provide service. Obviously they must win and enjoy the trust and respect of the villagers. It is also a given that the grassroots volunteers are very different from the suave urbanites whom we often see. The village volunteers walk every step of the way with the villagers, and they are there to provide leadership in the toughest of times. What motivates them? The best, in our experience, are faith-motivated people, who believe that a life spent in service to their fellow humans is the best life to be lived. Many see that as their act of devotion. Of course, there are those with very different motivations, so selecting a grassroots NGO is of utmost importance.

One of the greatest hurdles - as well as strengths- is that the volunteers are very patient, low-key people, and their villager clients are not known to be Type A personalities. Getting clear GANTT charts and schedules from these people, and expecting things to happen on western corporate timetables, is often unrealistic. Thus comes the role of the second-level NGO: the city-based organization that has access to technology, and volunteers who are quite well credentialed in technology and business, but who also wish to work for a non-profit organization. Often, these volunteers are people holding full-time jobs, or retirees from government and academic organizations. These people may understand exactly what Type A personalities are, and have encountered many of them in their careers. However, they are unlikely to be such people. Possessing good knowledge of accounting practices and government expectations, this mid-level NGO can prepare good proposals and plans with budget, and handle the paperwork to deal with national and international organizations and with the government.

The third type of NGO is the foreign-based organization. Such an organization has clear aims and program definitions. They specialize in fundraising skills and organizing cultural events for fundraising. Typically, these are tax-exempt charitable organizations registered in the States where they operate. Most importantly, they combine a determination to see projects through to fruition over decades of operation, with an equally rigorous attention to detail in meeting all legal requirements of both countries involved.

In our case, the first PV installation project was coordinated starting with the India Development and Relief Fund, a Maryland, USA based charitable organization. They have been in operation since the mid-1990s, and earned their reputation for effectiveness in the aftermath of the Kargil War of 1999, the Orissa (Odisha) cyclonic storm of 2000, the Gujarat Earthquake of January 26, 2001, and the Indian Ocean tsunami of December 2004, among numerous such disaster-recovery operations. In addition, they have successfully conducted several hundred self-help projects for the villagers of India, typically focusing on villages where few other NGOs would dare to tread. The IDRF has volunteers in several US cities, who periodically visit India to inspect and assist their projects. Their fundraising is low-key; there are rarely any fundraiser cultural events, except when disaster-recovery efforts are in full swing.

The IDRF put us in touch with two related entities in Chennai, India, where Professor Komerath went to teach a course on Micro Renewable Energy Architecture in July 2016. The first entity is the Tex BioSciences corporation, whose Chairman, Shri R.P. Krishnamachari is a philanthropist, The second is Shri Janardanan, the Overall Coordinator for the Swami Vivekananda Rural Development Society (SVRDS), which runs Single Teacher Schools (STS) in over 850 villages in Tamil Nadu, India. Thus the SVRDS-STS is the grassroots NGO, while Shri Krishnamachari's company serves as a Corporate Social Responsibility mentor and guide. The particular branch of SVRDS with whom we have worked is active primarily in Tamil Nadu and to a lesser extent in Kerala.

Other well-known NGOs include VIBHA, an organization that focuses on children's education. Dr. Vijay Vemulapalli, President of VIBHA India, and a former resident of Atlanta, spoke at the conference on VIBHA's activities, and the realities faced in schools located in cash-strapped villages. The Ekal Vidyalaya Foundation (the originators of the Single Teacher School concept), is very active in many states of India. Today Ekal has a worldwide presence, and is an example of a multilevel NGO. Photos in this report show alumni of their tribal village schools, who came up from rather desperate circumstances to become accomplished international cultural performers. Another powerful NGO is SEWA International, who have a massive grassroots service operation in several states of India. Since US President George W. Bush authorized Faith-based charitable fundraising in the USA, Ekal and SEWA are able to do their own fundraising in the US. Both Ekal and SEWA have expressed strong interest in participating as we scale up the Roadmap, but for now, the details are yet to be worked out. Smt. Manjula Reddy is a volunteer for Ekal and metro-Atlanta resident, who spoke at the Conference regarding the realities that she has observed during her visits to Indian villages.

At this writing we are in discussions with all interested NGOs to move forward, using a template derived from the Tamil Nadu experience with SVRDS. Many issues remain to be worked out, including a process for identifying excellent vendor-trainers, and setting up a reliable customer service/maintenance/support data acquisition, reporting and response network. Modalities for fund-raising and implementation remain to be worked out, but present plans are to replicate the standards set by the IDRF and draw upon their experience as leaders in the role of the 3rd (high) level NGO, while drawing upon the deep and vast expertise of Ekal and SEWA in their India-based middle and grassroots level operations.

# Chapter 12

# Skills Training

## 12.1 The Role of Skills Training

Perhaps the most game-changing ingredient in the rural energy self-reliance project is a mechanism to bring in Skills Training and Development, that is aimed to keep villagers productively employed in their home villages and areas, in good jobs with lifelong potential for advancement. Several difficulties are implied in the above statement, and those have been amply demonstrated and documented in the literature and news. A careful, staged development programme is essential to avoid these.

It is no coincidence that there is a growing sense of urgency in all of India about the need for skills training. India is changing, and needs to change, from a nation where the GDP was dominantly agricultural, to one where the GDP comes much more from value-added products that require a high degree of knowledge-based enterprise as well as leading-edge skills. India looks at a young population of over 700 million workers eager to contribute. The tasks of providing ever-better employment for this population is closely meshed with that of providing the education and skills needed in an increasingly technological workplace. As automation rapidly takes over tasks including those of writing, programming and testing the software to run the machines, the Indian workforce must stay ever ahead of the game.

The Government of India and the State governments have initiated numerous schemes and organizations to provide and improve skills training. There is a National Skill Development Corporation in India, that funds proposals to set up training institutes and conduct courses leading to official certification in numerous skills. At the same time, there are numerous moves afoot to improve and expand research and development activities led by the institutions of higher education, viz., the universities and the science/engineering/technology institutes.

All such endeavors require energy. Energy for mechanical devices, energy to process raw materials, energy to pump drinking water, and energy most basically, to read, write and learn arithmetic as the foundations of learning. This of course dovetails with the objectives of our project, as perfectly as a piece of carpentry done at one of the final examinations for skilled carpenters conducted by the NSDC.

In our project, we start with very basic issues. We are looking at a population where the children get the most bare essentials of education that can be imparted, considering what a single teacher can do after hours, in a village where electric power is a new feature. The family background of most of the students is desperately needy, on the edge of subsistence.

## 12.2 School/Energy Strategy for Skills

We must tread carefully, enthusiasm tempered by patience and thought. Our strategy is again to use the schools as the bridgehead to enter the village. The first Photovoltaic system brings a task of basic data acquisition, perhaps some maintenance as in cleaning components, safety precautions essential to working around electricity and reactive chemicals, and a system of following procedures and reporting when something goes wrong. This was the objective of the very first system, installed in Mel MaduraMangalam village Single Teacher School through the Swami Vivekananda Rural Development Society (SVRDS), under the watchful eyes and guidance of Tex BioSciences Corporation.

The next step was ambitious: we asked Tex BioSciences to pick two workers from their factory, who came from these villages, and train them using courses at a nearby engineering college, as PV installers. In the 3 months since the first installation, they have worked hard towards this, and it is clear that they used the first system for some rudimentary experiments of removing and re-installing wiring to gain confidence.

The next 4 PV systems, essentially similar to the first, have been installed at this writing, in nearby villagers, with the two villagers named as the installers. It is done under the supervision of our original and experienced installation team. We await the results of this experiment before going ahead with the next 85 to 100 systems, also through the SVRDS. The "chain reaction" model of training installers and maintainers is thus getting a small test. We aim for a model where there are at least two 'Renewable Energy Experts' operating as businesses in every cluster of about 100 villages. These businesses will handle a growing portfolio of system types and technologies, and handle all the maintenance of the systems. An Internet-based communication/ monitoring system will assist and coordinate their activities. As the village economy advances, these businesses will have an advantage in hosting the expertise to aid small manufacturing concerns including 3-D printers and makers of machine tools.

## 12.3 Training Within Industry

Shri Malla Reddy presented from the point of view of someone who has led production enterprise in German industry (Bosch) and observed their and various other approaches towards training workers in production environments.


*Figure. 12.1: The poster of Rosie The Riveter, with the inspiring exclamation, from the War Production Coordination Committee of the United States of America, circa 1941. From Malla Reddy by permission*

Shri Reddy's presentation starts with the famous picture of Rosie The Riveter shown in Figure 12.1, with the slogan "We Can Do It!" , put out by the War Production Coordinating Committee. This is from World War II, when the American industrial base was able to ramp up war-related production by a huge amount, at a time when most of the trained men had been drafted into the military, and were training or already sent overseas. Industry faced the task of training women and older men, who were unused to the industrial manufacturing setting. While the American tradition had always called on women to undertake hard work on the farm and even in defending the home and wagon trains against violent attacks, women were traditionally not present in the factory floor manufacturing workforce. The new environment called for very technology-intensive yet heavy labor in building massive numbers of aircraft, ships, tanks, artillery pieces and other sophisticated items needed for the war effort. Lives depended on quality and speed. Tasks had to be carefully broken down and integrated, so that new workers would be able to learn fast while maintaining morale. However, the engineers, trainers and the workers rose to the occasion, and in fact, large improvements in quality and efficiency were realized with the application of scientific methods. Major strides were made in job instruction, job methods and job relations. Over 600 companies were involved, and there was a claimed improvement of over 25 percent in productivity, with reduced scrap, reduced training time, and reduced number of grievances. This is the story of Training Within Industry, or TWI.

A schematic sketch of Job Instruction Training would show a cyclical, iterative process consisting of 4 phases:

1. Prepare the Team Member.
2. Study and document present operation
3. Try out performance.
4. Follow-up.

A Job Breakdown Sheet is a major tool in this process. It tabulates major steps. It lists key points for each step: Is there anything about HOW the step is done, related to safety, quality, technique, productivity or cost. It also lists the reasons for these key points. The Job Instruction method is designed to teach people how to do the work correctly (with fewer errors), safely, consistently and successfully meeting all requirements. The TWI system suggests how to present the operation (quoting Lean Associates Inc):

1. Tell and show each Major Step one at a time.
2. Tell and show each Major Step with Key Points.
3. Tell and show each Major Step with Key Points and Reasons for each Key Point.
4. Instruct Clearly, Competently and Patiently.
5. Present no more than the student can master.

With learners not expected to come from the top of the class of talented candidates, instructors were given a very tough guideline:

> If the student has not learned
> The instructor has not taught.

The next step in the cycle is to Try Out Performance. Again quoting Lean Associates Inc:

1. Have the student try while the instructor corrects mistakes.
2. Have the student explain the Major Steps as the job is done again.
3. Have the student explain the Key Points as the job is done again.

4. Have the student explain the Reasons as the job is done again.
5. Repeat until the instructor knows that the student understands.

## 12.4 Summary

In the present project, there are several crucial aspects, summarized below.

1. Working with the right NGO is critical. The NGO is the key element to develop trust with the villagers, with regular visits and close interaction.
2. Support from village elders is critical. They must encourage self help groups, and make it their initiative for long-term success.
3. The NGO must understand local needs and take input fro the villagers in prioritizing steps.
4. Local youth must be employed and engaged in the project wherever possible.
5. Manuals for owners and maintainers must be made available in the local language. This translation can be done by students in engineering colleges and polytechnic institutes who also take the opportunity to absorb what the manuals are really trying to convey. In this respect we are finding a strong tendency towards merely spelling English words in the local script. However, this may turn out to be a good strategy as technicians will eventually aspire to learn manuals and techniques that are written in English or other languages. Some careful balance must be achieved between local buy-in of the technology versus enabling locals to communicate with outsiders in commonly-accepted terminology, More on this under the Results and Experience chapter. The TWI methodology summarized above will be crucial in training installers, users and maintainers of the technology.
6. A mobile van and display, properly equipped with good visuals, may be an invaluable tool in this process.

# Chapter 13

# Role of Schools

## 13.1 Empowerment of Women


*Figure. 13.1: Definition of a Community-based Intervention. From S.Hillware by permission.*

Ms. Sarah Hillware was invited to tell us about her work on community-based approaches for Bottom Of The Pyramid Women's Health Outcomes. She discussed the benefits of a community-based approach, last-mile distribution at the base of the pyramid, women, adolescents and children's health, as a driver for household-level interventions. Figure 13.1 encapsulates her definition of Community-Based Interventions. The benefits of such an approach are that it builds trust, facilities viability and scalability, enables gender equality, accelerates change, and strengthens public health impact. There are several examples of using community networks for last mile distribution. These include clean and improved cookstoves in South Asia, health education workshops and sanitary product distribution in Kenya, cervical cancer screenings utilizing community health workers in Ecuador, and school-based child nutrition programs all over the world.

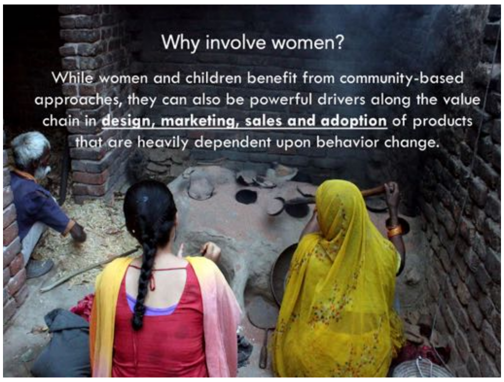



*Figure. 13.2: Why Involve Women. From S.Hillware by permission.*

Her next slide (Figure 13.2) is a powerful statement, titled 'Why Involve Women'? and this is equally applicable to our project of developing energy self-reliance. In India in particular, the family budget is primarily administered and used daily by the woman in the family.

The power of training women in last-mile distribution is well-demonstrated. For instance, take the example of the improved cookstove in Kenya. Results published in 2015 from a randomized control trial showed that empowerment training led to more than doubling of sales. Women who received empowerment training outsold men by a margin of 3 to 1.


*Figure. 13.3: Successful Solutions Require Working Across Sectors. From S.Hillware by permission.*

The economic case for investing in Bottom of the Pyramid women is that this is for low-income women, by low-income women. In order to drive private sector investment to reach the bottom half, there must be a clear path to adoption. Engaging BoP groups along the value chain is critical to adoption and thus, success and revenue.

Many critical health interventions must be done outside the health sector. Often times, the things impacting the health of women, children and adolescents the most, require action outside of the health sector. This is true of cookstoves, sanitation, menstruation and even nutrition in some cases. Figure 13.3 summarizes Ms. Hillware's strong argument. Successful solutions require working across sectors. These include Consumer education, hybrid business models, consumer finance or cross-subsidies, gender-informed design, community empowerment and job creation, public sector and NGO partnerships, all impacting product viability and strong adoption.

The lessons from these experiences are valuable as we seek to obtain buy-in from villagers for the technological solutions and lifestyle habits that are needed to progress towards energy self-reliance. The interventions in this case will certainly have huge impact on health and quality of life for the whole family, starting with education, access to information, safety, healthcare access, and participation as citizens.

## 13.2 Single Teacher Schools

Figure 13.4 shows pictures from the newsletters of the Vivekananda Rural Development Society showing scenes from their Single Teacher Schools. These provide a good glimpse of our end-user customers, and their teachers, who are the focal points and conduits of our technology infusion process.


*Figure. 13.4: Pictures from the Single Teacher Schools run by the Vivekananda Rural Development Society. From N. Komerath by permission.*

Next we look at some samples (no doubt selected from the best) done by students in these schools. The abbreviation 'Std' denotes 'Standard', referring to the grade. Thus IV Std means the equivalent of 4th grade. What we see here is that the students include at least some with excellent artistic and dramatic talents, and poetic instincts, like classes in any other locality. Figure 13.6 shows more examples, including of some mathematics that appears to be more intended to develop computer science skills than traditional arithmetic multiplication tables. The students are also clearly exposed to lessons involving children in other parts of the world.


*Figure. 13.5: Samples of work from the students of the Single Teacher Schools run by the Vivekananda Rural Development Society. From N. Komerath by permission.*

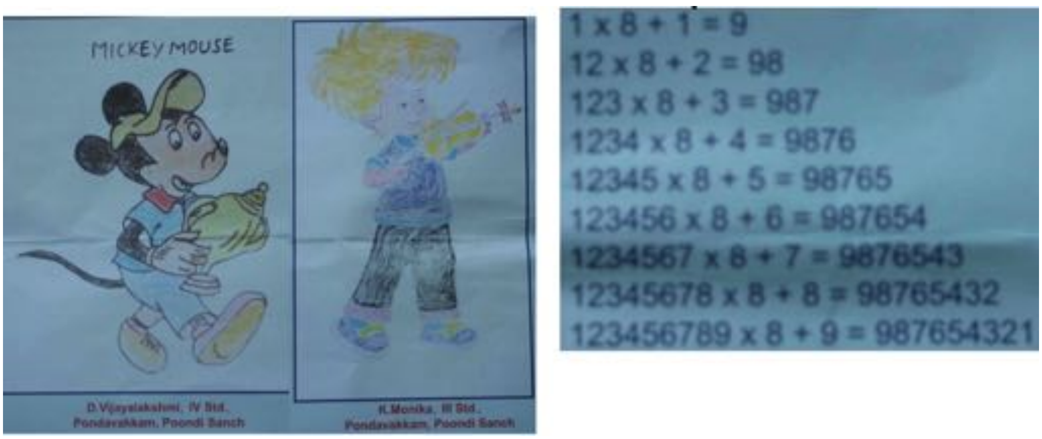



*Figure. 13.6: More examples of work by students of the SVRDS Single Teacher Schools. From N. Komerath by permission.*

The final figure in this series, Figure 13.7 shows the youngsters from these schools in several settings. The top part shows the troupe from the Ekal l 

*Figure. 13.7: Above: Another scene from the Ekal Vidyalayas performance at Berkar High School, of a fast-moving dance number. Below left: students at a village school. Middle: women doing embroidery on fabrics. Right: children practising with musical instruments. Courtesy India Development and Relief Fund.*

Vidyalayas, performing at Berkmar High School, Lilburn, in March 2017. At bottom are 3 pictures from the annual brochure of the India Development and Relief Fund based in Maryland, USA, who fund several projects via NGOs in India. At left we see a school: the children have no seating except on the bare ground. They are bright-eyed and alert, clearly somewhat interested in the camera photographing them, more than whatever lecture they are getting, as should be the case with bright youngsters. The school is crowded, and there is quite a scattering of age groups among the children. This is a feature of many of these schools, particularly the single-teacher schools. The middle picture shows women in northern India, doing embroidery on clothes. On the wall behind them can be seen electrical wall sockets, indicating that the building is at least wired for AC power. At the right is a young group with various musical instruments. That picture is clearly taken in a more well-to-do environment with a polished tile floor.

One underlying theme is that to-date, music, dance, artwork and embroidery/sewing skills are naturally absorbed, and able to be taught by the teachers. Going to technological occupations will no doubt require special attention and specially trained teachers, as well as a good deal of patience, before such occupations become accepted in the villages. Our hope is that the buy-in will occur naturally as the technology is introduced through the single-teacher schools, with the students keen to help the teacher in understanding system operations. Preliminary indications are that they are experimenting with the first solar PV system that our team installed. They managed to get the polarity of the wiring reversed, and waited for help to diagnose and correct that. That is a very hopeful sign.

# Chapter 14

# Role of Universities

Universities have a very important role that they can play in bringing energy self-reliance to rural India. One may well ask why they have not been far more active in this regard. To obtain a glimpse of what is possible, we invited Dr. Ramakrishnan Natarajan, director of the CO2 Research and Green Technologies Centre at Vellore Institute of Technology, one of India's premier private engineering universities, located in Vellore, Tamil Nadu. Dr. Natarajan's presentation was eye-opening in terms of the capabilities and funding levels available with modern Indian universities, and their chosen research directions.

One program in existence for a long time is NSS, the National Service Scheme. Under this, V.I.T has 'adopted' upto 19 villages, and hosts a Special Camp in these villages every year. These are located in Thimiri Block in Arcot Constituency. A program called STARS (Supporting the Advancement of Rural Students) provides free admission to one young man one young woman student who topped the Plus-Two public examinations from the government schools in rural areas. VIT student clubs teach in neighboring villages and create healthcare awareness. There is some industry partnership to advance technology. VIT is also adopting villages around Vellore, Amaravathi (in Andhra), Bhopal (Madhya Pradesh) and Chennai in Tamil Nadu.

The university conducts several projects related to energy and carbon dioxide reduction. These are summarized in Figure 14.1. Dr. Natarajan then spoke of wind energy projects where his concepts promise to yield large increases in the efficiency at low wind speeds. He proposes to use air pressurized during high-wind, surplus power periods as tip jets to keep the rotor speed near optimal during low-wind periods. This, as well as research on fuel cells funded by the Indian Space Research Organization, offer opportunities to integrate

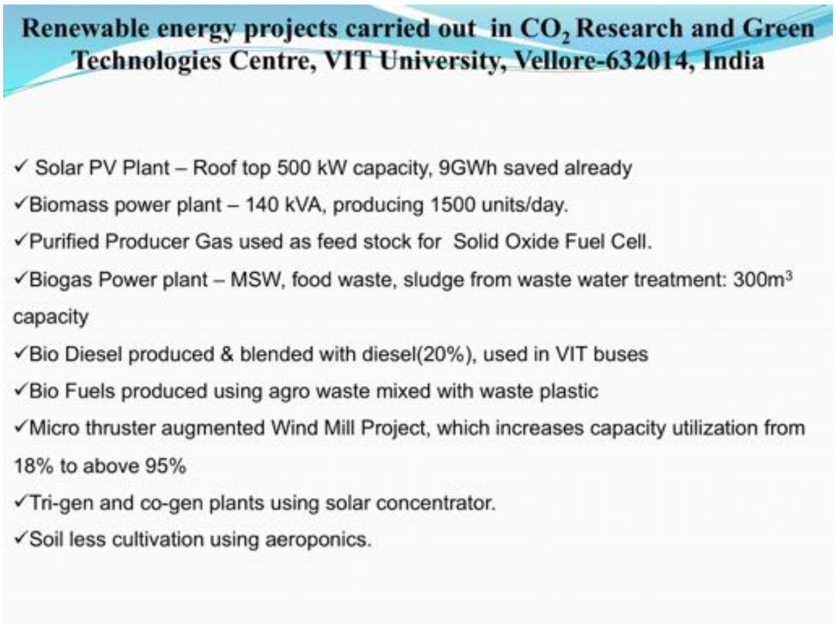



*Figure. 14.1: Renewable energy projects carried out in CO2 Research and Green Technologies Centre at VIT. From R.Natarajan by permission*

the needs of the mass rural market with the high-end capabilities present in Indian engineering schools. The notion of setting up research testbeds that will yield the right problems to solve for the Indian environment, is known but not seen to have caught on in most of India, where research problems appear for a large part to strive to compete with those in the West towards solving the problems publicized in the West. This may be an uninformed opinion; we hope the reality is very different, and that Indian universities will take leadership in developing testbeds for rural energy self-reliance.

# Chapter 15

# Rural Enterprise

## *15.1 Today's Realities*

Hermans *et al* [79] compared different *discourses* about the role of technology in rural agriculture and other enterprise in the Netherlands. They found a dichotomy of views. The more radical activists argue for a multi-level rural enterprise where agriculture is only one aspect. They reject technology unless it can be used to advance sustainability. The more traditional view is that technology should be used to increase efficiency of agriculture, which is seen as the primary role of rural areas.

Joshi and Wani [80] review the dangers of economic development, done at the cost of non-economic values. They note the erosion of moral values accompanying economic growth and argue for emphasis on moral education, better relationship between entrepreneurs and workers, judicial use of social media and the Internet. The stress the importance of Sustainable Development.

Stead and Stead [81] argued for Sustainability as a key criterion in enterprise strategy. Enterprise strategy provides a sound framework to *ethically and strategically account for the ultimate stakeholder, Planet Earth*. They argued for a value system based on sustainability.

GIBC's Shri Dhirendra Shah presented briefly on financing India's rural energy requirements. He touched upon three aspects: Venture capital, micro credit and partnerships . The rural scenario in India today is not pleasant. Seventy percent of India's population lives in rural areas. Some 350 million, or over 30 percent of India's population, live below the poverty line. Over sixty percent depend on agriculture. In the rural areas, as is well-established in the literature, non-agricultural employment is practically negligible. There is chronic unemployment. The poorest households are landless laborers. As a result there is abject poverty and a low rate of institutional credit certification. These conditions permit persistent exploitation by money-lenders due to the very low access to institutional credit.

Traditional banks and lending institutions do not lend money to low income individuals due to lack of collateral, high transaction cost, doubts about repayment capacity and lack of services in remote areas.

However, there is reason for hope. India was not always so. Professor Angus Maddison's essays in 2003 on macro-economic history, show that India's GDP in the years 1 - 1000 AD was 32.9% of the world's total, with China at 26 % and Europe at 10.8%. Between 1000 and 1500 AD, this changed to have India at 24.4 %, China at 11%, Europe at 20% and the Americas at 22%. British records from the 1850s show that India had the best educational system in the world, with an estimated 85% literacy. Every village had a school (*Pathasala*). There were several universities of higher learning. Taxation and forcible land acquisition destroyed much of the education and social/economic institutions. In less than 200 years, British rule made India a third-world country.

In free India, once freed of the shackles of extremely energy cost, there is no reason why Indian villages cannot leap towards prosperity again.

## 15.2 Venture Capital

Venture capital finances startup companies and small businesses that have strong growth potential. Venture capitalists are typically individuals with high net worth, insurance companies, large corporations, and pension funds. All want high Return on Investment (ROI) . There are more than 500 Indian companies, which have invested in over 1500 startups across many countries. One question for us is how to motivate them to finance rural energy needs, scaling back from the insistence on high ROI (perhaps by trading lowered risk for lowered expectation of returns?)

## 15.3 Micro Credit Financing

The first professional organization to implement micro credit financing is Grameen Bank in Bangladesh by Mohammed Yuounis. As economist Milton Friedman remarked, *"The poor stay poor, not because they are lazy, but because* *they have no access to capital'*. Micro finance is an economic development approach to provide financial services through institutions to low income clients. For this perhaps financial institutions with a social mission are required. Mechanisms include (a) Commercial banks and investment funds, (b) Foundations and donors including enterprises (c) Government and local bodies and (d) NGOs including Temples.

In India, demand for micro finance is estimated at $30B, but the supply is less than $3B. Microfinance has existed at least since the 1970s and has achieved significant growth, with banks participating. There are an estimated 1000 micro finance institutions (MFI) operating in India. However, Indian MFI are highly leveraged - in some cases more than 50x multiples - because they are dependent on borrowings from banks and financial institutions and because available bank funds are short term with a maximum of 2 years payback period. Some MFIs charge very high interest rates of 18 to 28 percent. The Reserve Bank of India has since the 1990s helped in attracting funding by including MF as a Priority Sector. The Government of India has created Micro Finance Development Equity Fund of about $ 300 million. Potential partnerships can be created involving the central Government of India, the State Governments, financial institutions, international institutions such as the World Bank, NGOS, entrepreneurs, individual and institutional donors, microfinance, Venture Capitalists, and corporate social responsibility (CSR) funding resources. More on the last-named in Professor Jagdish Sheth's presentation on the topic.

## 15.4 Examples of Business Opportunities

Shri Shah put up a short list of examples of products potentially suitable for developing into the Indian rural energy market place, where the Global Indian Business Council (GIBC) could partner. These include

- DC Micro-grid controller; solar water pumps, small and large.
- Solar airconditioning; biogas composition trackers; biogas sulfur removers.
- Solar maximum point tracking controllers (MPPTC); DC power tools .
- Integrated IoT/MPPTC .
- PV integrated into roofing; Micro reactor vessels for thermochemical processing.
- Plumbing integration into roofing ; small Biogas Combined Heat and

Power (CHP) units.

- Micro Tangential Wind Turbines.
- Micro axial wind turbines..
- Solar tracking intensifier..

In conclusion, the problems of financing the uplift and progress of rural India are enormous, complex and challenging. The project has to be a grassroots based model, with the participation of users, the local, state and central government bodies, donors, financial institutions, NGOs and corporations with the CSR requirements. No one individual or government organization or donor can solve the financing of such magnitude.

Most villagers in the early stages in India will have to be given energy and water purification units free through donors from India and abroad. Once a rural employment base is created, many villagers will be able to pay some portion of the cost of energy, using the financial models mentioned above.

# Chapter 16

# Initial Results and Observations

Our initial concept of the project and its different constituents is shown in Figure 16.1. The path to energy independence was assumed to be one where many institutions and businesses would participate. This is still the ultimate view of the solution, but with the very important addition of NGOs and their village schools. In the short term, the NGO/Village School opportunity opened a valuable route that is bearing immediate fruit.

The first step was to develop a university course, integrating the vast mosaic of disciplines and players needed. Such a course was developed starting in 2006 at Georgia Institute of Technology in Atlanta. It was first taught as a Special Topics course open to all disciplines, funded through a project under the International Program that was then under development.

After 4 teachings at GT in the next 6 years, the course was offered in collaboration with Prof. Rajaram Veliyath as a special offering in the Strategic Management MBA program at Coles Business College of Kennesaw State University, as well as a graduate course in Aerospace Engineering at Georgia Tech. This experience spun off one startup company, Tree Of Life Systems, directed by Paul O'Donnell. Their offering was a highly integrated but also modular system with PV lighting, thermoelectric, augmented combustion, water storage and drinking water purification.

The course was then packaged into a short intensive offering under the Global Initiative for Academic Networks (G.I.A.N.) program of the Government of India, through IIT Madras in Chennai, in July-August 2016. There were numerous results from this course. The first was release of a textbook on Micro Renewable Energy Systems in e-Book form in September 2016. The second

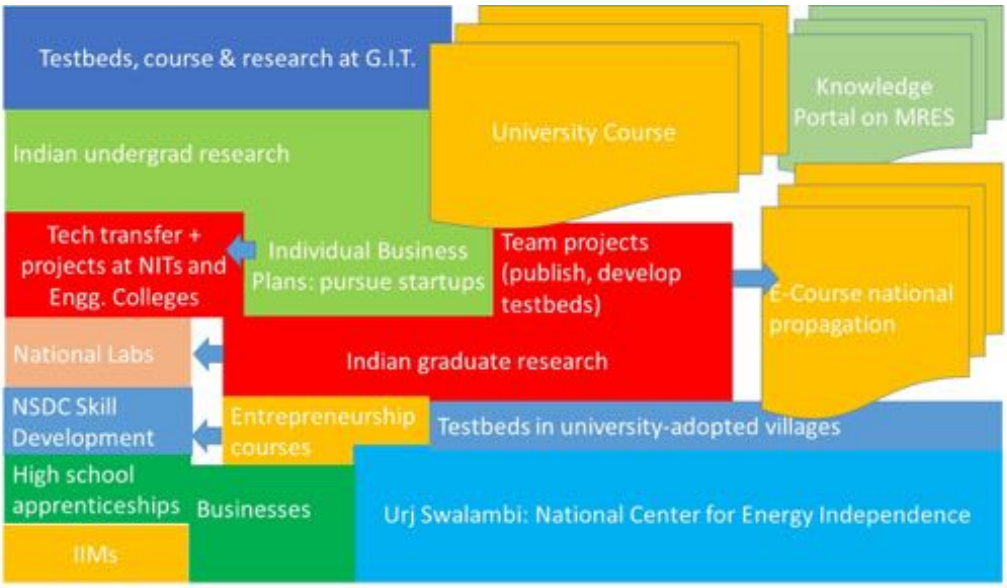



*Figure. 16.1: Initial map of the various entities and processes to be involved in driving towards rural energy independence. So far, a direct path has been followed, from the course to a book to the villages, but with established commercial off-the-shelf technology.*

was a discussion at IITM Civil and Environmental Engineering Department on BioMethanation projects in Chennai.

The third and most important step was taken with a discussion conducted at IITM in July 2016 between Shri Janardanan, representative of the Sri Vivekananda Rural Development Society, their mentor, Shri R.P. Krishnamachari, industrialist and Managing Director of Tex BioSciences, Inc., Professor Narayanan Komerath, Professor Satyanarayana Chakravarthy of IITM, and Mr.Vedant Trivedi, an undergraduate student at the IIT. This meeting was arranged through the good offices of Dr. Vinod Prakash, chief of the India Development and Relief Fund in Maryland, based on a long acquaintance with Prof. Komerath.

At this meeting, SVRDS discussed the thinking behind their project to build bathrooms adjacent to the toilets being constructed under the Prime Minister's Swach Bharat Abhiyan program in the 855 Tamil Nadu villages with whom they worked. They had obtained the rights to build such a bathroom on village land. This opened the way to install sufficient solar panel area to generate at least 200 Watts directly on the roof, thus obviating the need for any other structure or land use rights.

### 16.0.1 Village 1: Mel Madura Mangalam

In August 2016 the first PV system installation was funded directly through SVRDS, based on a quote developed after detailed discussions and optimization with a solar system vendor-installer, Augur Computers. A 40-Watt version of the system was tested for several months through the Northeast Monsoon in Kerala, which led to identifying and correcting some problems such as LED bulb burnout. The installation was delayed past the November/December monsoon season in Tamil Nadu. This proved fortunate as a severe cyclonic storm caused extensive damage in Tamil Nadu during that period. The installation team went to Chennai in February, purchased most of the items there, and transported them the next morning to the selected village.

The village is MelMaduraMangalam, PIN code 631553, located in Sri Perumbudur Taluk in Kancheepuram District of Tamil Nadu. This is only 1.5 hours drive along a fast highway from Chennai. Its coordinates are 12.936521 N, 79.8058138 E. It is 22 km SW of Sri Perumbudur and 21 km NE of Kancheepuram.

The village, though mostly populated with tribal people, is atypical. It is one of a cluster of roughly 70 villages. Most of the people there are employed in local factories and farms. There is a regular bus service close to the village. The village was thus chosen for relatively easy access, because that was the first installation. The village has, in name, a power grid connection; and some electric fixtures. However, they rarely if ever have power flowing through the lines these days. There is a mobile phone signal available in the village. The nearest railway station is 2 kms away. They do have water available, but it is of rather dubious quality. The village has 213 houses, 923 people, and covers 157 hectares.

The teacher in the Single Teacher School in this village (the lady in the blue sari) was selected because of her outstanding achievements. She works in the nearby government school but lives in the village, where she teaches at the STS in the evenings. Figure 16.2 shows pictures from the day of the installation. The man standing looking out over the roof is the qualified electrical engineer Shri Sunil. The two men standing on the blue metal roof installing the panel, are drivers of the SUVs supplied by SVRDS. In the middle picture we see the Teacher, an older lady resident of the village, another village resident sitting on a chair in front of her home in the background, and a young student with his arms raised in triumph after his enthusiastic participation in the installation proceedings. The picture at top right shows several of the students' pieces of art and other contributions attached to a clothesline inside the school room which is now illuminated by DC LED bulbs that came with the PV system.


*Figure. 16.2: First PV system installation in MelMaduraMangalam, February 28, 2017. Courtesy Augur Computers and Swami Vivekananda Rural Development Society.*

### 16.0.2 Village 2: Kallipet

Kallipet comes under Thandalam Panchayat, Wallajabad Block, Kanchipuram District. This village was chosen because out of 24 hours, for nearly 20 hours power is not supplied in this area. The transformers are intact with power cables laid but no power flows most of the time. The electrical fittings seen in the wall of the school building in Figure 16.3 may be misleading given the above reality.

### 16.0.3 Village 3: Santhanagopalapuram

This village comes under Nemeli Panchayat Tiruttani Block, Tiruvallur District. Pictures from the installation there are seen in Figure 16.4.

### 16.0.4 Village 4: Anna Nagar

Anna Nagar village, not to be confused with the posh residential area of the same name in suburban Chennai, is in Perungalathur Panchayat, Arakkonam Block, Vellore District. This is roughly an hour from Chennai by fast train, Arakkonam being a long-established rail junction town.


*Figure. 16.3: Second PV system installation: Kallipet, June 16, 2017. Courtesy Augur Computers and Swami Vivekananda Rural Development Society.*

We see that the quality of wiring done in first two installations was perhaps not up to the mark since the installers had to hurriedly buy all the components on a time-constrained visit. In the second and third installations, the wiring has been done very professionally and meticulously as the purchase of materials was well planned with quality and planned well with a 3 day stay for installation. Per the PV installer, the electricians had already done the wiring by the time the solar components were installed.

## 16.1 Training

Quoting the SVRDS coordinator:

> The process of training has been given to two local men who were part of the team in the second and third installations to get hands-on experience. Next (the vendor/installer Augur Computers) has been asked to give a formal written manual for installation with


*Figure. 16.4: Third PV system installation: SanthanaGopalaPuram, June 16, 2017. Courtesy Augur Computers and Swami Vivekananda Rural Development Society.*

diagrams and coloring of wiring so that these two men can refer to the manual as and when they require.

In fact, our mission is to involve the community in this process by making them self-reliant. we are aiming to involve village Youth ( Male and Female) in this process of training, so that they become entrepreneurs on their own, learning this trade for their village.

As you suggested, we will not keep it only to fans and lights, we will try to make use of solar power in other areas also. For example, solar powered quality motors for water pumps which is very useful and required for villages .

As planned two trained persons will be visiting all the Centres where solar PV systems are installed to have a systematic check once in a month with a diary maintaining dates to ensure proper functioning and basic maintenance.

# Chapter 17

# Plans

The first tentative steps have already been taken along the Roadmap to rural energy independence. We have an initial grasp of the scope of the problem; and a list of localities to reach. We have demonstrated the model of working through the Single Teacher School in villages, in 4 villages to-date, with a fifth scheduled in the near term. A standardized 250W solar photovoltaic system is being finalized with standard wiring and installation procedures. Local villagers have been trained by the NGO and their corporate mentor, and are doing both the electrical wiring, and the installation and testing of the PV system. Villagers are slowly being trained to have enough confidence to monitor and maintain the system.

The next step, while the installer-training and PV installations continue to the first 100-plus villages by the end of 2017, is to develop a standardized biogas installation. A pilot system is being tested in an urban Kerala setting, to work with kitchen vegetable waste and an initial charge of cowdung and water. A small 10-kg plastic reactor vessel with a floating-lid (constant pressure) design, works easily in the backyard of a home, generating enough gas to power a stove for about 4 hours per day, at roughly a 1-kiloWatt level. Clusters of such systems installed in villages could generate enough gas to operate small electricity-generating gas turbines.

A critical experiment is underway, to see how villagers will use the newly-available electric power. Ways are being sought, to encourage villagers to learn to use power tools and otherwise use the energy to start entrepreneurial activities towards growth and self-reliance. Clean drinking water systems are also being planned for installation in villages where basic power is available from the PV system installations.

Suitable standardized sensors are being sought, to collect data on the operation of the PV systems. Depending on the design selected, data transfer may be by a monthly visit by a technician, periodic reporting by the school students and teacher, automatic wireless transfer to a cellular phone, or direct communication to the Internet. Once connected, these sensors will provide the means to obtain predictive data on system operational characteristics, enabling timely maintenance and support.

To scale up and implement these advances, discussions are underway with several NGOs, with a view to develop simultaneous installation operations in numerous States of India.

The opportunities glimpsed in the chapters on the Internet of Things, Corporate Social Responsibility and Financing, paint a picture of hope towards fast development of a modern energy economy in the villages of India.

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