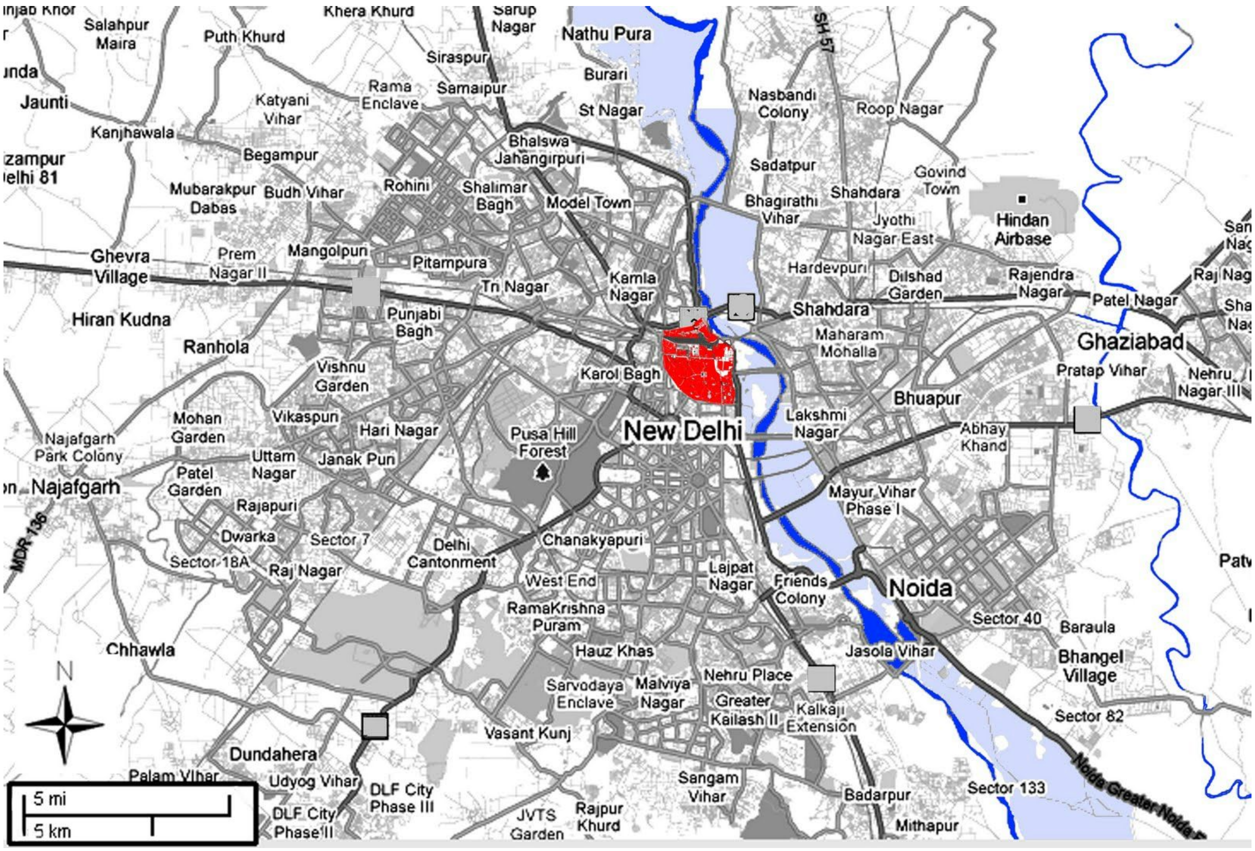
Energy Crisis in New Delhi:
Renewable Energy in an Emerging Economy



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GE 1110 - Fall 2013
10:30 AM

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Abstract

India has one of the fastest-growing economies in the world. On top of this exponential growth of wealth in the country is the rapid increase in population. This leads to the tell tale sign of a growing capitalist country , very rich people living alongside the very poor. Another sign of that is poor infrastructure, in particular in regards to utilities. India has a very large energy problem and one city with a particular big problem in New Delhi, the capital. We developed a three prong approach to solving the energy problem for the city. The plan uses all of the available avenues of change, namely the government and the education system. We plan on working with the government to make sure that those who choose to follow a path of renewable energy are rewarded for it in the form of tax breaks. Also those companies who are looking to improve the functionality of the solar panel, we plan on asking for the government to invest on those types of ventures. We also want to create a culture of a leader in renewable energy. We plan on influencing this culture by using the education system to teach about the glory of being green and by offering informational classes on the benefits of using renewable energy both personally and as a country. Our plan looks to both improve the solar panel in a technical sense as well as make sure that the country is invested as both a government and as a people so that this solution is a long term culture change for the people of New Delhi and India as a whole.

Introduction

In New Delhi, India, sufficient energy is not reaching the population. As the nation's capital, the city has a large energy demand, yet the nation is not able to fulfill it. Many citizens, particularly those who fall below the poverty line, do not have access to energy. Our goal is to make energy more accessible to the general public of New Delhi in terms of minimizing cost, increasing general knowledge on the subject, and making the process more efficient.

A sample of the patents out there is the implementation of III-V semiconductors (Appendix A). This use of an improved semiconductor in the original solar panel patent improves the efficiency of the voltage by thirteen percent. This design helps to make sure more voltage is created per solar panel.

New Delhi, India's capital, has a population of approximately 20,439,000 people, based upon the 2012 census. By the year 2020, it is expected to increase by almost 40 percent. Because of the high and growing population, energy demands are also sharply increasing. If patterns continue, annual energy demand in India is expected to rise to six billion barrels of oil in upcoming years. The demand is growing, but supply is not; approximately one third of the nation's population does not have adequate access to energy. This is especially true of those living below the poverty line.

New Delhi's climate is humid and subtropical. The average high temperature, occurring in May and June, is 42 degrees C, and the average low temperature is 15 degrees C, which occurs in January. The monsoon season, or rainy season, falls between June and September and usually produces as much as 300 mm of rain in a month. The rest of the year is relatively dry; October receives only 30 mm of precipitation.

Methodology

To begin, we created a list of general design goals that pertained to the energy situation in New Delhi. These are:

- **Sustainability -** the solution's ability to retain its effectiveness over time

- **Minimum Cost -** the ability to create a solution at the lowest possible cost to the Indian population
- **Ease of Maintenance -** the solution should require a low level of maintenance to function properly
- **Accessibility -** the availability of the solution to all socioeconomic levels of the Indian public
- **Durability -** the solution's ability to withstand time and physical stresses, like weather
- **Safety -** the level of harm associated with operating any part of the solution should be minimal
- **Efficiency -** the solution's overall output compared to energy inputted
- **Aesthetics -** the visual attractiveness of the solution

We then assessed the significance of each when compared to the others. Our process can be found in the table below:

	Sustainability	Minimum Cost	Ease of Maintenance	Accessibility	Durability	Safety	Efficiency	Aesthetics	**Total**
Sustainability	-	1	1	1	1	1	1	1	**7**
Minimum Cost	0	-	0	½	1	0	1	1	**3.5**
Ease of Maintenance	0	1	-	0	1	0	0	1	**3**
Accessibility	0	½	1	-	1	1	1	1	**5.5**
Durability	0	0	0	0	-	1	0	1	**2**

Safety	0	1	1	0	0	-	1	1	**4**
Efficiency	0	0	1	0	1	0	-	1	**3**
Aesthetics	0	0	0	0	0	0	0	-	**0**

We then used these conclusions to assign a weighting system to the design goals, with the goals with the highest totals weighted the most heavily. From these we developed a list of specific design goals:

- **Make energy affordable for all citizens of New Delhi** - we aimed to reduce the cost of energy production so that all socioeconomic classes could access it.
- **Find a renewable source of energy that does not rely on foreign imports -** these imports were costly and put the Indian economy on the verge of crisis; they needed to end.
- **Provide all people, not only the wealthy, access to energy** - currently, one third of the population - primarily rural poor - does not have access to energy.
- **Create awareness about alternative forms of energy -** the citizens of New Delhi will be more likely to accept alternative energy if they are knowledgeable about it, so we thought that a system of education was necessary.

We also brainstormed a list of possible solutions using a Duncker Diagram (Appendix B) and Why-Why Diagram (Appendix C). When creating the list we took into account the climate of New Delhi; it is not particularly windy, and sufficient energy can only be collected from rivers during the monsoon season, which spans a mere four months. We decided that out of the possible types of renewable energy, solar had the most potential for creating change in New Delhi's energy situation. With these findings and those from the tables and diagrams, we analyzed our options in a decision matrix, found below:

	Sustainability (100)	Accessibility (90)	Safety (85)	Minimum Cost (70)	Ease of Maintenance (65)	Efficiency (65)	Durability (50)	Aesthetics (10)	Total
Implement alternative energy classes in public schools	8	6	10	6	4	3	8	7	3535
Provide public information on solar energy	8	10	10	7	7	2	2	8	3805
Work with community leaders to develop greener neighborhoods	9	3	9	3	4	6	6	8	3175
Develop supports for easier mounting of solar panels on homes	5	5	3	8	8	7	6	2	3060
Develop cheaper/ more efficient method for manufacturing solar panels	7	9	4	10	7	9	7	2	3960
Push for government subsidies for solar panels	8	8	9	5	6	5	5	3	3630

With this information, we realized that we would need to take a three-pronged approach to the problem. One section would need to focus on acquiring funds for the plan, one would involve making the actual solar panel manufacturing process more efficient and therefore more easily available to the public, and the third section would need to promote public awareness about solar energy. We finally sharpened these ideas until we developed specific solutions that were both tangible and feasible.

Alternative Solutions

One alternative solution we were considering was to use natural gas to power the city, as an estimated 1330.26 billion cubic meters total of natural gas are on reserve throughout the country (as of 2012). This possibility was quickly discarded, since India's oil reserves are low (as of 2012, Indian oil reserves contain an estimated 759.59 million tons of crude oil) and we wanted to steer away from nonrenewable energy and better utilize available renewable energy resources. Moreover, India has the largest oil import bill out of all the G-20 (Group of Twenty Finance Ministers and Central Bank Governors) nations. Public sector dominance has stalemated the development of Indian oil and gas fields, to the point where the government has proposed a mandate that would require private oil and gas companies to invest 10% of their profits into renewable energy research and development.

One clean solution we contemplated was nuclear power. However, we realized that in an area as populous as New Delhi, the threats of radiation in residential areas surrounding nuclear plants is great. Protest has arisen among the people on the subject of possible nuclear energy because of safety concerns. Another alternative solution we considered was using local fossil fuels to power New Delhi. As of now, however, India receives almost 70% of its electricity from coal, and a limited domestic supply (293.50 billion tons of domestic coal present in India as of 2012, but only 118.15 billion of which have been proven to actually exist) means that they must rely more on imported coal, which is highly costly and goes against our intent to keep New Delhi self-sufficient and self-reliant on its own resources. We thus eliminated the possibility of fossil fuels altogether, both domestic and foreign, as viable solutions. Rationing energy across the city's population was also a proposed but impractical solution, as carrying this out would severely hinder economic growth.

Given the current energy situation in New Delhi and India as a whole, we decided to narrow down potential solutions to implementing some form of renewable energy. Unfortunately, New Delhi has very little potential to harness renewable energy into power, as 0 MW of wind, small hydro, biomass, and cogeneration-bagasse power are currently being utilized. The 131 MW of waste energy power that could potentially be harnessed is the sole contributor to the mere 0.15% total distribution level of renewable power across the city. With very limited possibilities in these areas of renewable energy, we naturally turned to solar energy as the most practical, realistic option for providing sufficient power to the people of New Delhi. Grid interactive renewable power, namely biomass, wind, and small hydro power, have all made negligible gains in their installed capacities over the past couple years, while solar power has increased its capacity from 2.14 MW in 2011 to 2.53 MW in 2012. The presence of off-grid (decentralized) renewable energy systems and devices in New Delhi strongly illustrates the city's capacity to utilize solar energy, as 90 solar photovoltaic pumps, 301 solar photovoltaic street lighting systems, and 4,807 solar photovoltaic lanterns are installed throughout the city as of 2012. On an ideal day, solar photovoltaic power plants can pump out a maximum of 82.00 kW of power (82.00 kilowatt peaks). All things considered, solar power is the best alternative solution to the energy crisis in New Delhi.

Final Design Solution

Technical/Mechanical Aspect:

Solar panels have been a big part of the renewable energy movement since its start, and as the renewable energy movement has evolved so has the technology surrounding solar panels.

The generally accepted but older method for solar panels was based on large silicon crystal technology. When these crystals are arranged properly and are struck by light an electric current is produced. Silicon was the best choice at the time due to the high efficiency with which its electrons were able to achieve their excited state. Unfortunately the necessary large silicon crystals were very hard and expensive to grow.

The manufacturing process of these panels can be broken down into four main steps. The first step is the actual growing of the crystal. About 250 pounds of polysilicon rocks are stacked in a crucible with a silicon disk with a trace amount of boron amongst them. The polysilicon rocks are heated until the mixture reaches the desired temperature of about 2500ºF, at which point a silicon seed crystal is lowered into the mixture. The crucible is spun while the mixture is cooled, causing the crystal to grow. The mixture cools for about two days, allowing the crystal to grow to a good size.

After the crystals have completed growing they are cut into a uniform width and length. The width varies while the length remains about two feet long. The cylindrical crystals are cut to have corners making them essentially square edges. The cylinders are then cut into very thin slices. The slices are about the thickness of an average business card and there are about 20 wafers per millimeter of thickness.

The next step in the manufacturing of the solar panel is the actual production of the solar cells. The wafers that were cut in the previous step are changed from their original grey cells through heat and chemical processes into productive blue cells. The top layer of the silicon cells are taken off to reveal the patterns that absorb the light and collect the energy. Once the patterns are exposed the wafers are then put into a chamber where they are infused with phosphorus gas, which gives them a negative potential electrical orientation. In tandem with the positive orientation that the silicon – boron disk from step one yield, a positive negative junction that is necessary forms. Then silicon nitride is deposited on top of the wafers in order to assist them in reflecting away less of the precious blue light. And finally metals are printed onto both sides of the panel which are what allow the crystals to collect and forward the light that they absorb. Once the actual mechanism is made all that remains is the assembly.

The last step of the manufacturing process is the assembly of the panel itself. The entire assembly process proceeds robotically. The cells that were just formed in step three are arranged into strings of ten cells. Then six separate strings of ten cells are arranged into a matrix. Once this matrix is assembled the matrix is laminated in glass and then framed. Once the panel has been framed, the panel proceeds to its final checkpoint where it is inspected by actual humans.

Since the implementation of this silicon crystal technology newer, quicker, more efficient, and therefore more cost effective technologies have come onto the scene. For instance there are panels that can operate using smaller crystals made of elements such as copper, indium, gallium, and selenide. These smaller crystals are taken and shaped together to form small flexible films that are used to absorb sunlight, in a method now know as thin – film solar technology. Another alternative that will actually work with the pre-existing silicon panels are new gallium arsenide panels.

This new technology called Sollnk was released by Sol Voltaics. Sollnk employed gallium arsenide nanowires that are made through a newly developed process called aerotaxy. These nanowires allow for light concentration without using any sort of mechanical or optic components. Also the nanowires only need to cover a small part of the surface of the panel to achieve success. These nanowires can be installed into pre-existing silicon crystal and thin – film panels, and with as little as 12% of the panel covered with nanowires, the panels' productivity was said to increase by nearly 15%. While this new method, at $.60 per watt, is a bit more costly than the former methods, at $.45 per watt, the ability for retrofitting and the fact that the gallium arsenide panels are more efficient make this method more cost effective.

We chose to go the route of employing the new Sollnk technology (Model in Appendix D). We made this choice not only because gallium arsenide can increase the potential of solar cells to 400 watts per square meter, but also because the necessary gallium is readily available in India and will make for easier manufacturing. It can be located in natural resources such as copper, bauxite, and coal, all of which can be found and purchased locally in India, therefore stimulating the Indian economy in the process.

Governmental Aspect:

Engineering is not just always centered around the nuts and bolts and the designing of the technology. You also must work with the avenues of the real world to get the goals and the systems that you develop into place. A major avenue through which the world operates is through the government, and Engineers must be able to do that if they plan on creating anything that will work in the real world.

For our project we looked at how working with the Indian government could fulfill some of the goals that we wanted to accomplish with our plan. Our plan is to essentially make solar power a big part of providing energy to the people of New Delhi. The way that we use the government to accomplish portions of that is to essentially make the purchase of solar panels both easier and cheaper. We do that through tax breaks and government funding to help make solar panels more efficient and cheaper. The government helps us on our path to create a “culture of sustainability” that will hopefully lead to a public that cares about renewable energy and tries to integrate it into their everyday lives. The other side of this is to create more energy in the grid so that we can eventually power everybody’s homes in the New Delhi area.

So in order to create this government side of the project we researched on the workings of the Indian government and drafted a mock proposal of our plans that included the government in them (Appendix E). Through this we showed how the government worked into our overall system to help the people of New Delhi.

Just to reiterate some of the aspects of the proposal we provided tax breaks to those who buy a solar panel as well as companies that buy them in bulk. We also provided funding to manufacturers of solar panels to allow them to make their solar panels better and cheaper for the public’s use. The government is essentially the vehicle where we get lots of the money to use to make our dreams happen. This is an important lesson to learn because as engineers much of our grants and research money actually comes from the government who are looking for the advancement of society.

The Indian government did have some issues that we were worried about. In particular, corruption is rampant and much of the time ineffective in solving the problems of the urban poor.

This led us to make the demands straightforward. Also we will want to make sure that along the zway the money that we are asking for is going to the places where we specified it should and being used in the ways that we believed that would be best. Also we will make sure to take advantage of a new Ministry in the Indian government, the Ministry of New and Renewable Energy. This new department hopefully will be transparent and not yet taken over by the corrupted.

Overall the government will be a vital tool in accomplishing our goal of giving renewable power to the Capital of India. The government will provide much needed funding and support on this venture to make India a better and more sustainable place.

Educational Aspect:

Another avenue with which we need to work in order to establish a stable energy situation in New Delhi is the education system. Without public awareness of the issues at hand, the population will not fully be able to make the changes necessary to create a greener India. We realized that there are many different areas within widespread education, so we broke educating the public about alternative forms of energy into three parts: public school curriculum, classes for adults, and informational materials (Proposal found in Appendix F).

The main age demographic that will invest time and money into the solar panel plan is working adults, so we plan to begin a series of optional adult night courses on alternative energy. There will be a charge for the classes, but if an interested person falls below a specified income level, then the government will reimburse him or her for the cost of the course. In addition, if a person passes the end-of-course examination, he or she will be eligible for a slight tax break on energy-related expenditures. The fee for the class will cover the instructors' $3000 salaries, based upon national averages; any differences between salary and actual income from students will be made up by the government. The class will span twenty-five hours total, scheduled as works best for the instructor and/ or students. Its curriculum will cover the harmful effects of the nation's current energy situation, both economically and environmentally, various forms of alternative energy and how they work, and ways to turn India into a greener community through these forms of alternative energy. At the end of the course, the exam mentioned above will be administered.

Considering that the adult classes are optional, we do not expect a great enough turnout to fully educate the public, so our plan includes education in the public school system. We believe that by educating the nation's children on alternative energy, they will bring it home and infiltrate families and neighborhoods. The curriculum will be virtually the same as that of the adult classes but will become a mandatory part of the federally-mandated science curriculum, as specified by NCERT. It will occur throughout upper primary school (ages 11-12) and high school (ages 13), at which ages students are able to retain the critical information and before the national dropout surges. To ensure that schools are complying with the curriculum, a section on alternative energy will be included on the examinations for the Indian Certificate of Secondary Education (ICSE).

Finally, our plan includes the creation and distribution of informational materials (Appendix G). They will be available to the public at government-run locations like schools and post offices and, ideally, at some privately-owned operations.

Conclusions

Our solution satisfies all of our original design goals to some extent. By incorporating the public education system and public informational flyers, we are maximizing accessibility to education. Also, government tax breaks and subsidies will allow more people access to solar energy. Our system should also be sustainable because unlike fossil fuels or coal, sunlight does not run out. We aimed to minimize cost for the individual consumer, but we did not take into account overall government expenditures. Though cost is low for the Indian public, it is still high for the federal government. Another goal, safety, is also fulfilled; by educating the public about solar energy, we are increasing knowledge about how to safely handle it. The production of panels with gallium arsenide is not any more unsafe than the original process for manufacturing solar panels, so safety is maintained in the technical realm as well.

We are not only approaching the program from an "improving the solar panel" standpoint but also from the systematic way in which we are making sure that our plan is effective. To do so, we are also utilizing the government and the education system to educate the public and make solar panels an attractive option. With this foundation we found ways to increase output of each solar panel and improve the manufacturing processes to allow for a more affordable product. This combination of approaches should allow for a solution that both fixes the problem in the short term and the long term.

Recommendations

Despite the exhaustive planning and organizing that went into the development of this proposal, there are still some areas that we want to look to improve in the future. One area that could use some improvement is the overall cost of the project. Though the cost to the individual consumer is low, we are relying heavily on government funding. Fortunately, once a culture of renewability is established then there will need to be less of a public marketing plan and therefore less money needed to be spent getting the information to the public. Those initiatives in the government are there to make sure that people understand and know about renewable energy. If our plan goes how we want it to then eventually renewable energy will just become part of the culture.

Another area in which we can improve for the future would be making the solar panels more portable and aesthetically pleasing. People may be more likely to buy solar panels if they are not bulky eyesores attached to the top of their houses. This will hopefully add more people to the many that will be buying into renewable energy New Delhi.

Besides these little improvements our main goal for the future of this project is to continue to grow. This is a long term project; as we get more of a green culture and more energy is produced through renewable means, New Delhi will become less dependent on nonrenewable energy sources. As people see that solar energy works they will invest in it for their homes and businesses. More people and more energy will develop because we are laying the foundation for the a sustainable future in New Delhi.

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Appendix

A. Existing Patents
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C. Why-Why Diagram
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E. Proposal to Indian Government Requesting Funding
F. Proposal to National Council for Educational Research and Training (NCERT)
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