SUSTAINABLE ENERGY IN PUERTO RICO

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ABSTRACT

This paper gives an overview of the most mature Renewable Energy technologiesfocusing on their potential implementation in Puerto Rico. It includes social, technical and economic criteria. In the latter, capital, operating costs and foot print were considered. Also sensitivity analyses were performed regarding the energy generation potential of these processes. The technologies included were photovoltaic, wind energy, fuel cells, concentrated solar power and solar thermal water heating. Other medium/long term ocean energy technologies were also discussed, including tide, waves and ocean thermal. The area of transportation fuels (gasoline and diesel) was also discussed. The last section also presents an implementation plan for these processes including UPRM capabilities and potential role in this Puerto Rican SAGA (Sol, Aire, Gente y Agua).

Keywords : Renewable energy, Puerto Rico, photovoltaic energy, wind energy, fuel cells, solar power, transportation fuels, and solar thermal water heating

INTRODUCTION

During the last 15 years, a renewed interest and growth in renewable energy (RE) processes emerged. It was driven by strong environmental movements, oil dependence/depletion concerns, and lately national security concerns. Several RE technologies such as wind and niche photovoltaic are currently very competitive in certain applications versus their oil counterparts, especially in Europe and some locations in the mainland United States. Others are slowly penetrating markets such as biodiesel and fuel cells. In the discussion section that follows, we will give an overview of the most mature RE technologies, focusing on their potential implementation in Puerto Rico. It includes social, technical and economic criteria. In the latter, capital, operating costs and foot print were considered. Also sensitivity analyses were performed regarding the energy generation potential of these processes. The technologies included were photovoltaic, wind energy, fuel cells, concentrated solar power and solar thermal water heating. These are referred to as near term implementation technologies. Other medium/long term ocean energy technologies were also discussed including tide, waves and ocean thermal. The last subsection briefly considers the area of transportation fuels (gasoline and diesel). Finally, an implementation plan is presented for these processes including UPRM capabilities and its potential role in this Puerto Rican SAGA (Sol, Aire, Gente y Agua).

SOCIAL ISSUES

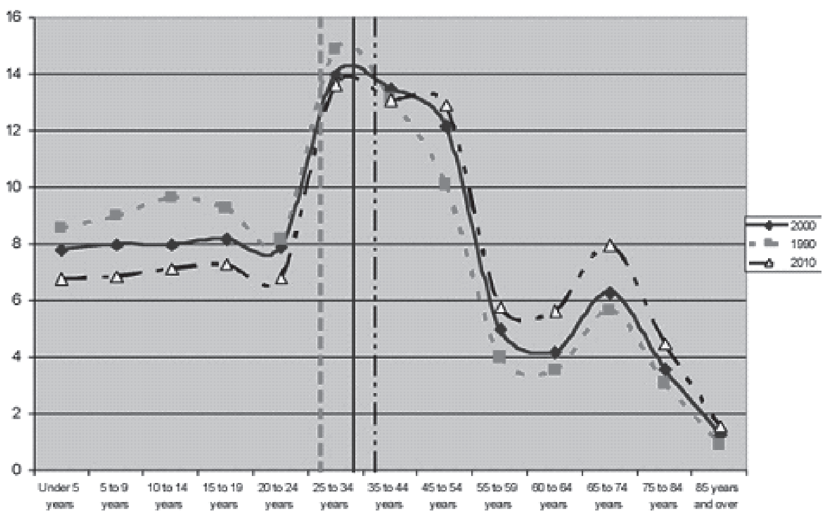
In recent years RE principles were incorporated into one of the primary objectives of Sustainable Development. According to Tester et al. (2005): "Sustainable Energy: a living harmony between the equitable (including financial) availability of energy services to all people and (Renewable Energy) the preservation of the earth for future generations".

Notice the inclusion of equitable availability required for Sustainable Energy. Some of the issues that are related to this requirement are:

- Technology literacy/acceptance.
- Include Environmental/Health/Quality of life costs (i.e., externalities) in the project estimates. Analytical techniques such as Life Cycle Analysis (LCA) and Internalization of Externalities are very powerful in this area.
- Consider all segments of the population economic resources.
- Distributed versus centralized generation.
- Population aging/location.
- Nature of new loads, such as in transportation (electric vehicles) and entertainment (electronic).

For example, population aging is changing very quickly in Puerto Rico (see Figure). Its implication regarding nature and load of their needs and their economic resources should be considered in future projections.

Graph 1
Puerto Rico Census Data



Regarding cost estimates, as mentioned above there are two powerful methodologies that are gaining acceptance especially in Europe: Life Cycle Analysis and Internalization of Externalities. In the latter, "external costs" are estimated. They are defined as follows:

> **LCA** – Process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements.
>
> **External costs** are defined as those actually incurred in relation to health and the environment, and quantifiable but not built into the cost of the electricity to the consumer and, therefore, which are borne by society at large.

Example results of these methodologies are provided in the following tables:

Table 1 – LCA Emission estimates

Generation type	SO2 (g/MWh)	NOx (g/MWH)	Particulates (g/MWH)	CO2 (g/MWH)
Nuclear	32	70	7	19,700
Coal	326	560	182	815,000
Gas	3	277	18	362,000
Oil	1,611	985	67	935,000
Wind	15	20	4.6	6,460
PV (Residential)	104	99	6.1	53,300

Table 2 – External Costs Estimates

	Urban	Metropolitan Fringe	Rural	Within 200 Miles of Minnesota
SO2 (after year 2000 - $/ton)	0	0	0	0
PM10 ($/ton)	5,060 – 7,284	2,253 - 3,273	637 - 970	637 - 970
CO ($/ton)	1.20 - 2.57	0.86 - 1.52	0.24 - 0.46	0.24 - 0.46
NO_X ($/ton)	421 - 1,109	159 - 302	20 - 116	20 - 116
Pb ($/ton)	3,551 – 4,394	1,873 - 2,262	456 - 508	456 - 508
CO_2 ($/ton)	0.34 - 3.52	0.34 - 3.52	0.34 – 3.52	0

Notice that both LCA and external costs provide a better estimate of the impact of these technologies to society.

Other critical areas that must be addressed in order to begin a cultural change in the generation, distribution and utilization of energy are the following:

- Puerto Rico's electric system is isolated, therefore limitations imposed by the laws of physics, power flow, stability, power quality, power electronics, among others, must be seriously considered.
- Energy policy issues such as net metering, wheeling and distributed generation must be brought to the table for serious technical discussions.

It should be stressed that these issues cannot be an excuse to do nothing. Again there is an urgent need for studies to understand what can be done, and how we can continue the diversification of energy sources and systems. It should be mentioned that there is little need to "import" talent to implement these changes. Puerto Rican engineers, scientists, professors and other local professionals have the expertise to study, lead and implement the changes needed.

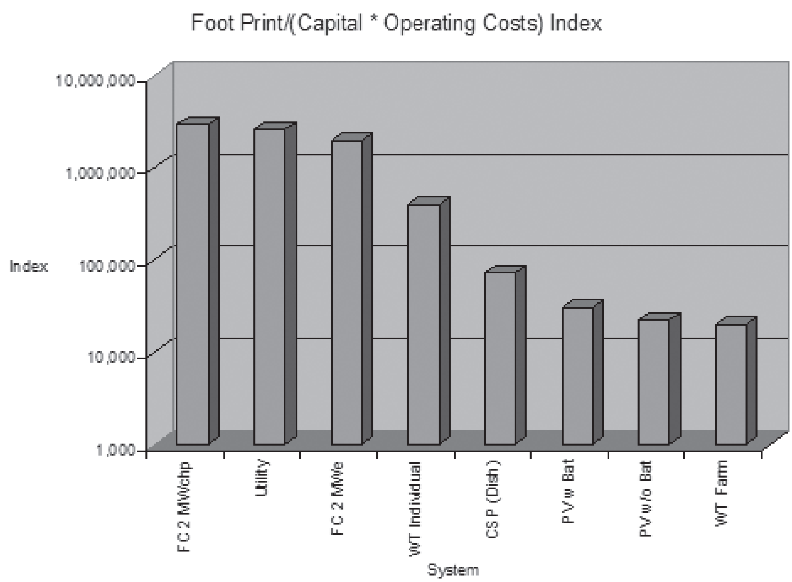
NEAR TERM IMPLEMENTATION TECHNOLOGIES

The technologies included in this section were photovoltaic, wind energy, fuel cells, concentrated solar power and solar thermal water heating given their advanced state of development and commercialization. A key variable that was considered in this analysis is "foot print", given the space limitation of Puerto Rico.

The first analysis performed included the development of a metric that included foot print, operating costs and capital investment. It is defined as follows:

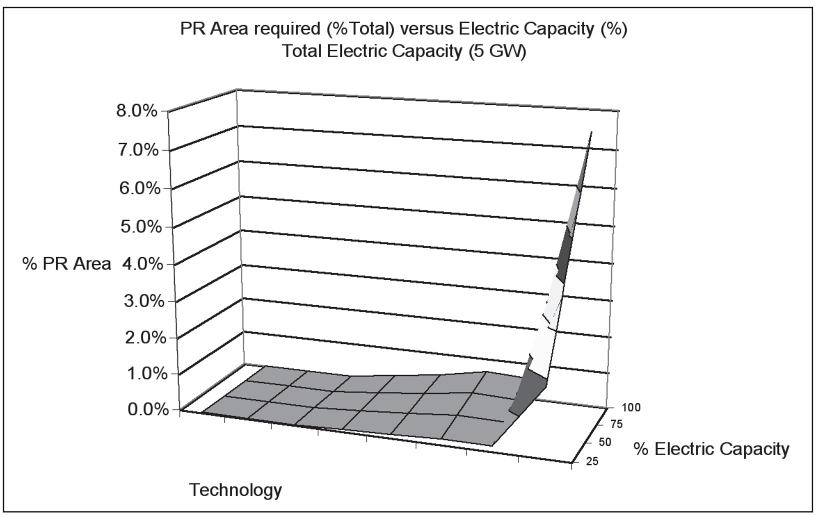
$PR^2EINDEX = \text{FOOT PRINT (W/m}^2\text{)/Operating Costs (\$/kW-hr)*Capital Investment (\$/W)}$

Graph 2 below shows the results:

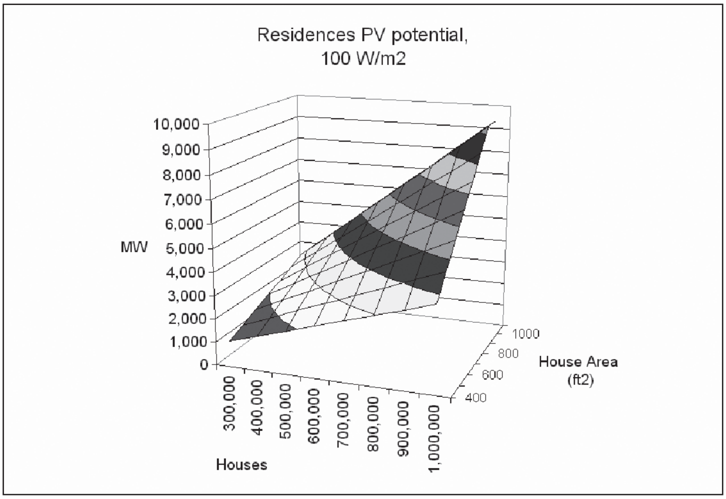


Notice that Fuel cells had a similar index as existing utilities. Another interesting result was that individual wind turbines had indexes an order of magnitude higher that wind turbine farms. This is due to the spacing required in farms. The foot print was also used to estimate the area required to implement these technologies in Puerto Rico. This is shown in the following figure. It should be mentioned that the basis for the figure is 5 GW. In general space is not an issue except for photovoltaic and wind turbine farms even for 5 GW capacity. However, given the potential of installing photovoltaic panels in residences and expressways a sensitivity analysis was performed for these two cases. The results are shown below. In both cases the energy generation potential is very promising.

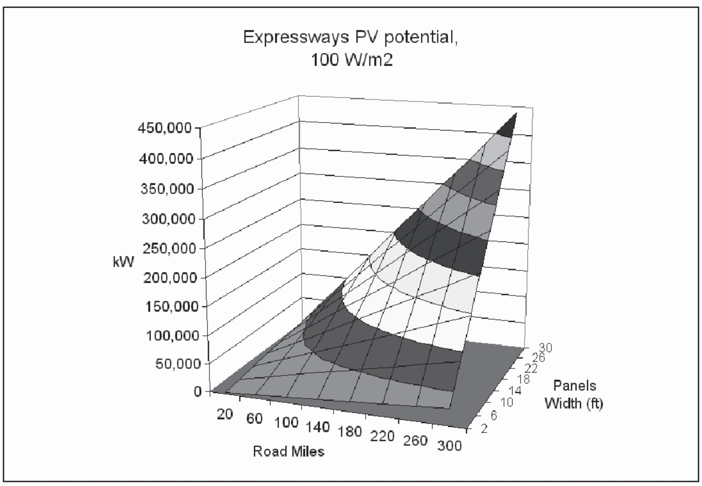
Graph 3



Graph 4

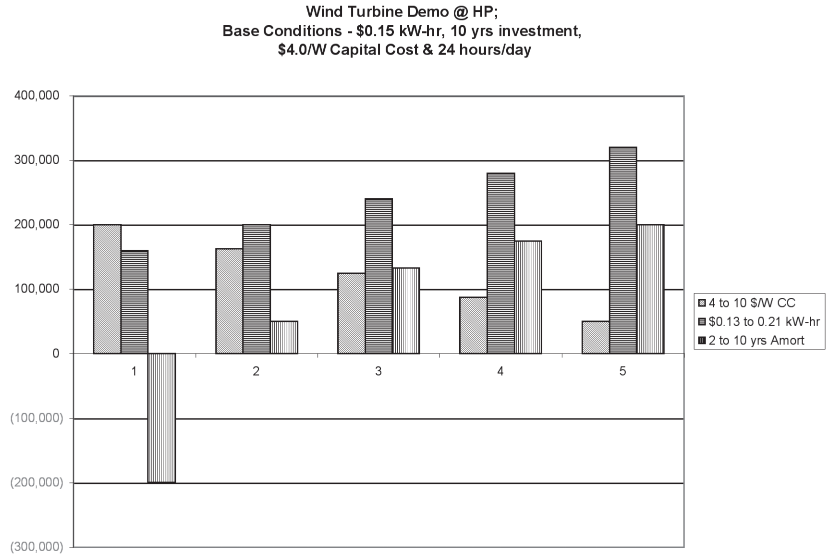


Graph 5

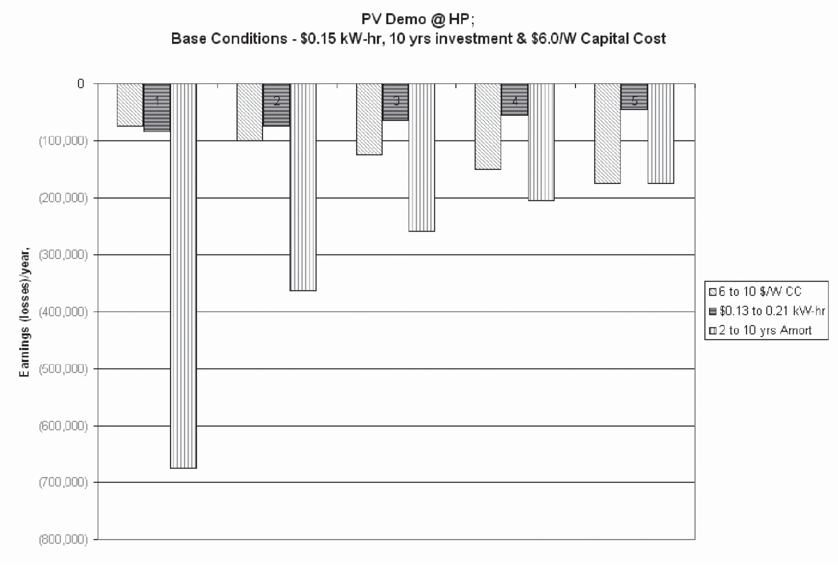


For the wind turbines, photovoltaic and fuel cells simplified capital investment and operating cost analyses were performed. The results were as follows:

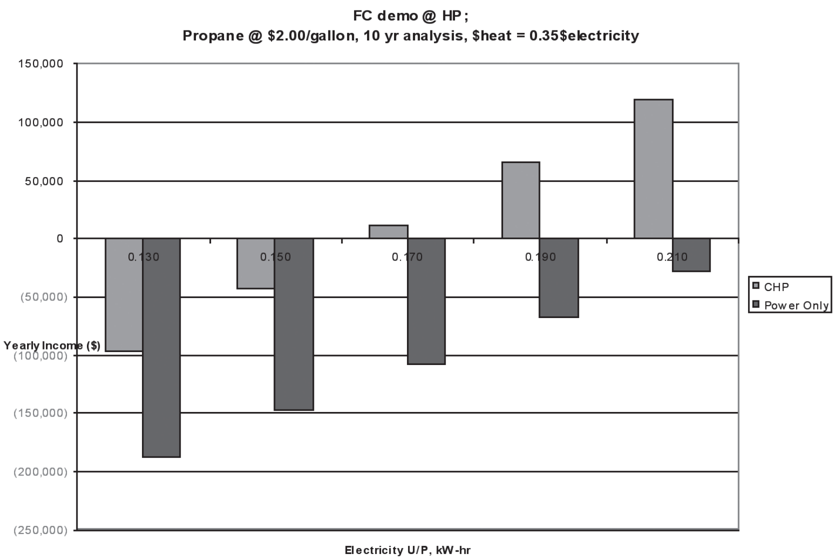
Graph 6



Graph 7



Graph 8



Positive incomes were estimated in the wind turbine figure for most cases. A base case was used to compare the sensitivity of this technology to variations in electricity costs, capital investment and expected payback. In the fuel cell analysis the most interesting result was that heat recovery is critical. The photovoltaic cases all resulted in negative incomes for all the conditions studied. Regarding implementation of concentrated solar power, the following are general comments that should be considered.

- Highly versatile 5 kW (residential) to 200 MW options.
- Competitive foot print – cost index.
- Effective in arid/desert regions with sustained high levels of direct normal insolation (i.e., Peñuelas/Guayanilla brownfields).

- Over 20 years of operating experience at MW levels (no surprises, technical or financial).
- Designed with energy storage systems to operate 24/7.

Another technology that was considered with near term implementation potential was solar water heaters. The test case that was considered assumed the following:

- Puerto Rico's average daily solar radiation is 5.52 kWh/m^2
- Puerto Rico's abundant solar resource could be exploited via Solar Thermal Water Heating to achieve generation displacement, reduced emissions and electric system losses.
- An Example of Solar Thermal Water Heating considering only Mayagüez where we assume:
    1. Total occupied housing units: 34,742
    2. Average family size: 3.41
    3. Typical U.S. household hot water consumption for 4 persons is 240 liters/day (63 US gallons/day)
    4. Water temperature rise of 75 °F (23.89 °C), corresponding to an inlet water temperature of 60 °F and water heater set point temperature of 135 °F.
    5. 85% of occupied housing units can use STWH to replace its electric water heater.

The preliminary results has been sumarized in Table 3.

Based on these results, the following benefits were identified for the implementation of solar water heaters:

- Demand reduction (increased reliability, capital investment savings since electric grid utilization is increased).
- Reduced power losses (savings for the customer through the effect in fuel and energy adjustment factor, currently quantifying this).

Table 3

	Estimated reductions
Electricity Demand	10 MW
Electric System Losses	0.36 MW and 3.9 MVAR
Electric Generation	10.36 MW and 3.9 MVAR
Emissions, lbs	CO_2 – 8,600, NOX – 6.48 and SO_2 – 5.25

- Generation displacement (increased reliability, capital investment savings).
- Reduced emissions into the atmosphere.
- An alternative to fuel diversification.

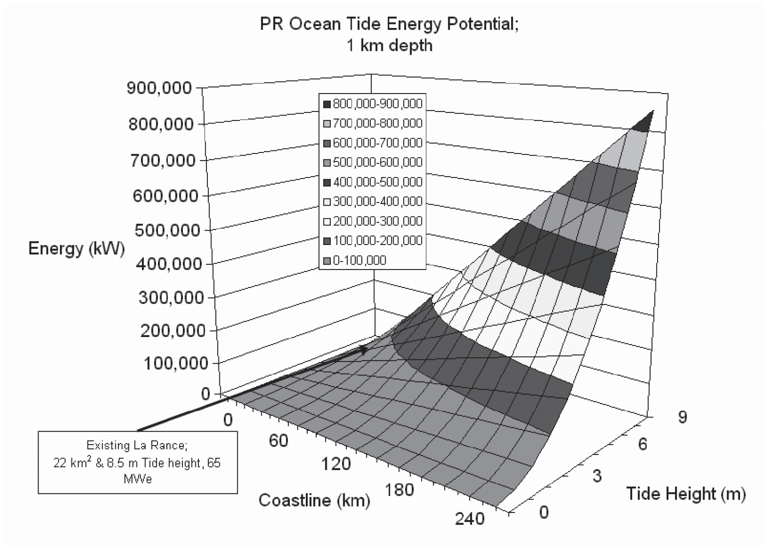
MID/LONG TERM IMPLEMENTATION TECHNOLOGIES

The technologies included in this section were ocean tides, waves and ocean thermal. Most of the information for these technologies was obtained from reference. For ocean tide, they showed a map that identified locations with high implementation potential. Puerto Rico was not singled out as one of those locations. In addition they provide a design equation that estimates the energy generation potential of this technology. The following figure illustrates the sensitivity of this technology to generate electrical energy as a function of coastline distance and tide height for a depth of 1 kilometer. In addition, the graph shows an existing facility performance which is predicted by the equation.

Notice the sensitivity of this technology especially to tide height. A recommendation would be to determine Puerto Rico's ocean tide performance parameters.

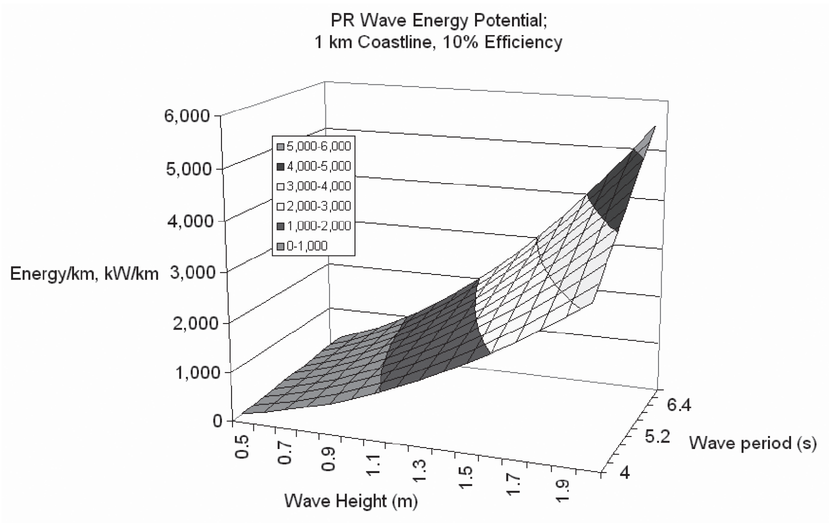
The ocean waves analysis was also very similar to ocean tides. Tester et al. (2005) also provided a design equation that was used

Graph 9



to generate a graph (see below) similar to the ocean tides graph. The critical variables for ocean waves are wave height and wave period. The graph used as the basis 1 km of coastline. Notice in the graph the excellent energy generation potential of this technology.

Graph 10



The last technology considered in this section was ocean thermal. It is well known that Puerto Rico has one of the best locations for this technology in the world due to the proximity of deep coasts that would provide excellent temperature gradients required for ocean thermal. This is also mentioned in Tester et al. (2005) and in past studies by the Center for Energy and Environmental Research.

In summary the following are general comments regarding these technologies:

- Good wave power often correlates with offshore wind power sources.
- Shoreline sites are expensive. Cost structure not well known (capital and operational).
- Aesthetic, fishing and navigation hazards concerns must be addressed.
- Tidal/Wave control changes the regular cycle of wetting and dry-out resulting in changes in the mix of species.
- OTEC may bring CO^2 and preserved pathogens to the surface from the bottom.

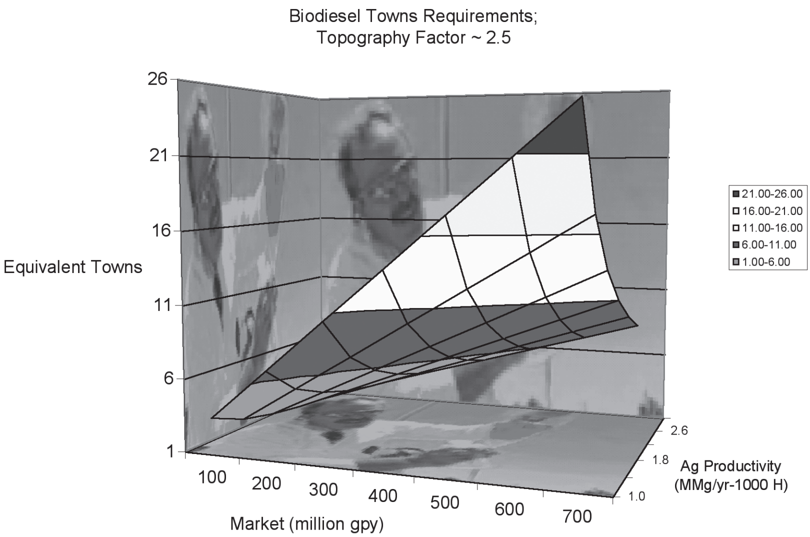
LIQUID FUELS

This section consider alternatives to replace both diesel and gasoline, which are also critical components of the Puerto Rico energy portfolio. For the former, biodiesel was considered as a drop-in replacement. An analysis was performed to estimate the amount of land required to produce significant amounts of biodiesel based on palm oil. This is a high productivity agriculture crop. As can be seen in the next graph, the land requirements are not acceptable. The same applies for other crops intended to produce fuels to replace gasoline.

Other comments regarding diesel and biodiesel are:

- Diesel: Biodiesel Option.
- 200 to 300 MGPY Non-PREPA.

Graph 10



- Land not available.
- Import Tallow (100 MGPY). This results in byproduct 10 MGPY Glycerine. Therefore a Glycerine derivative technology (i.e., propylene glycol) must be developed.
- Renewable options minimize peak turbines operation and fuel consumption (today 400 MGPY).

Regarding gasoline, 1.2 billion GPY are utilized. One alternative is the Waste to Fuel Option. This, however, could only produce 50 to 100 MGPY maximum. This is based on 2,000 to 4,000 tons/day. In general solid waste in Puerto Rico energy generation potential is limited to 50 to 100 MWe based on existing landfill gases. The generation capacity for "new waste" is limited to 120 MW. The bases for this estimate are 2,000 to 4,000 tons of waste/day basis and 30 MW/1,000 tons/day.

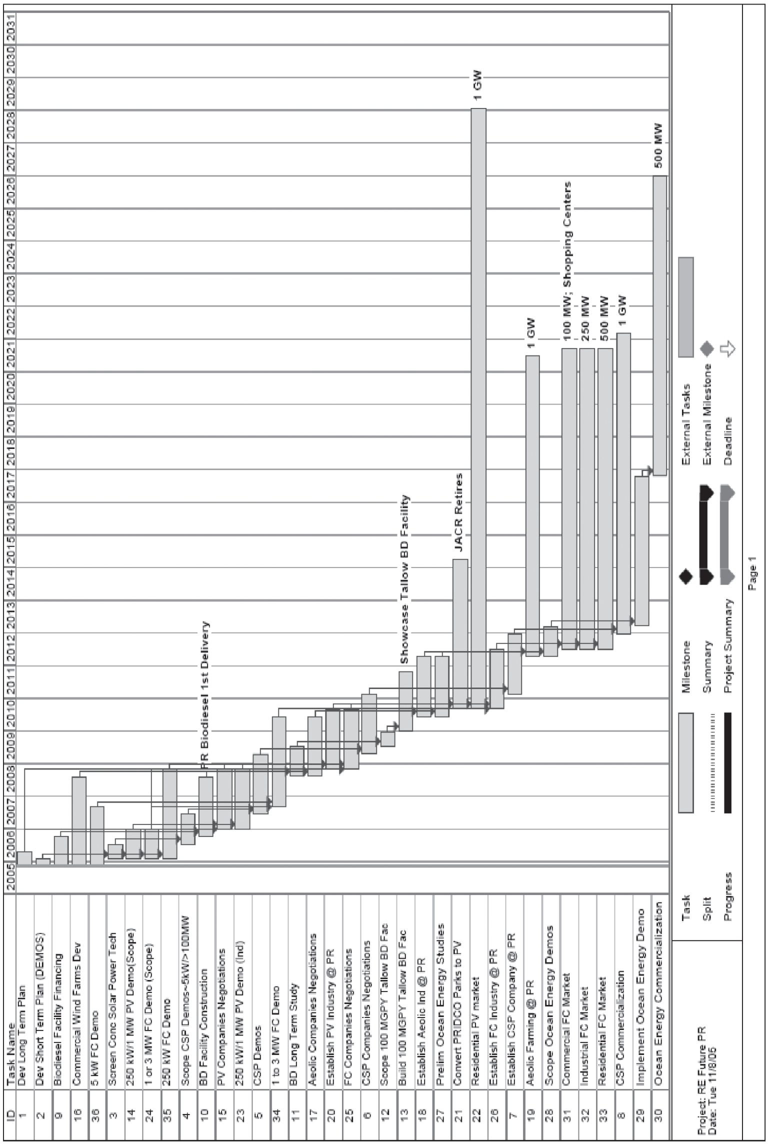
RECOMMENDATIONS AND FUTURE PLANS

Based on the analyses that were reported in the previous section a sustainable energy implementation plan was developed and is shown in the next page. A key proposed strategy is performing aggressive demonstrations in order to lure companies to consider Puerto Rico as a significant market and potential manufacturing site. These demonstrations are also vital in educating the public on energy alternatives and in improving energy consumption patterns. In addition, ocean based technologies should be studied given their high energy generation potential. As can be seen in the diagram, all of the short, mid and long term technologies have gigawatt energy generation potential.

The University of Puerto Rico – Mayagüez has the resources and expertise to partner with government and industrial sectors to implement a sustainable energy infrastructure in Puerto Rico. Some of their expertise is as follows:

- Wind
- Economic evaluation and financial risk of wind farms.
- Identification of best locations for wind farms.
- Impact of wind farms on Puerto Rico's electric grid (e.g., stability).
- Noise and construction issues related to wind farms.
- Fuel Cells
- First fuel cell testing/screening lab scale laboratory in Puerto Rico in collaboration with UPR-RP. Also brokered first fuel cell demo (5 kW) in Puerto Rico.
- Reforming collaboration with DOE's Argonne National Laboratory.
- Biodiesel/Biomass
- Thorough techno-economic study of biodiesel as an alternative fuel in Puerto Rico.

Table 4: The Plan.



- Biomass/Waste to Energy/Value Added Products collaboration with Sandia National Laboratory.
- Power Quality and Energy Studies
- Dedicated laboratory with instrumentation and 1-kW installed PV system for prototyping.
- Development of a power quality monitoring system (Joint study with PREPA).

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