The Global Energy Model (GEM)

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August 2010

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Introduction

The shortage of electricity impedes the progress of developing nations. Without electricity, water cannot be desalinized or circulated, refrigeration is not feasible, temperature-sensitive vaccines cannot be stored, controlled irrigation for agriculture is not practical, communication is limited, tourism is not attractive, and factories can't operate competitively. Education is impractical and personal security is at risk at night because public lighting is sparse. Developing nations remain dependent on subsidies and have no hope of contributing to the global economy without reliable electricity.

The poorest developing nations rely on diesel generators to provide hospitals, factories, or city centers with electricity. Diesel generators operate independently and are expensive to run, so only businesses and a few wealthy people have access to electricity. Island nations, such as Haiti and Sri Lanka, are particularly difficult to energize with fossil fuels because they must import fuel at very high cost. Haiti pays an average of $0.35/kWh, compared to the US average of $0.11/kWh[1]. This high fuel cost is not limited to developing island nations. Hawaii and the Bahamas pay an average of $0.35/kWh[2]. Based on these data, it is clear that the reliance on fossil fuel is not a sustainable solution for island nations let alone developing nations like Haiti. Additionally, it is well documented that fossil fuels are polluting and negatively impacting the local and global environment. In fact, in Massachusetts, USA, the asthma rate for children living within 30 miles of a coal-burning power plant is three-times higher than the national average[3].

Mainland developing nations, such as Ethiopia, have invested in national power infrastructure based on fossil fuel generation. According to a native-born Ethiopian source at the United Nations (UN), Ethiopia owns enough generation to reliably power the nation continuously. In fact, the Ethiopian government marketed the reliability of the new power system to attract manufacturing; however, power interruptions still occur daily. Poor reliability of power forces factories and critical infrastructure facilities to install back-up generation, essentially defeating the economic benefit of the national power system. The integration of a coordinated power grid would help, but fluctuating fuel cost exacerbates the problem. Ethiopia requires energy subsidies, despite the abundance of large-scale fossil fuel generation.

This paper envisions the creation and evolution of a Global Energy Model (GEM) to energize developing nations with clean and renewable power. GEM is not a new standard or design specification, it is a holistic and pragmatic model that captures the best ideas and documents the failures. GEM spans environment, economy, agriculture, security, and technology, with a focus on education and jobs. GEM may influence immediate projects, like the reconstruction of Haiti, but the mission is multigenerational and the true impact of GEM may not be evident for decades.

1. D.Schnitzer, EarthSpark, 2010 White Paper: Power Sector Reforms for Haiti towards Universal Electricity Service
2. US Department of Energy EIA
3. American Lung Association, 2001, "Estimated Prevelence and incidence of Lung Disease by Lung association Territory".

The GEM Working Group

GEM requires an iterative process that fosters global stakeholder input and consensus, thus I am forming the GEM Working Group. The Clinton Global Initiative (CGI) is the host organization for the GEM Working Group. Working Group members will be recruited from the CGI membership and various technical organizations, such as CIGRE, IEC, and IEEE. Additionally, a representative of government and business from each pilot project nation will serve on the Working Group.

Input to GEM will be solicited from villages throughout the developing world. In addition to local government input, the Working Group will seek input from: village elders, entrepreneurs, teachers, religious leaders, health care givers, academics, bankers, accountants, attorneys, athletes, artists, musicians, children and others. “Grassroots” support for GEM is critical to ensure sustainability of the model. It is imperative that GEM respects local cultures and that its impact enhances life as defined by those affected, not by global notion.

A GEM Internet portal will facilitate interaction for Working Group members, and a blog will be established to encourage discussion forums with anyone interested. Since most people affected by GEM do not have Internet access and many are illiterate, the Working Group will establish a comprehensive global outreach program to ensure that as many quiet voices are heard as possible.

Pilot Projects

Pilot projects are an important tool for testing and refining GEM through real-world experience. Pilot projects also offer tangible and measureable feedback to GEM. It is important to note that implementation details of pilot projects are independent of GEM. References to specific technologies, vendors, and consultants will not be included in GEM. GEM will extract the best ideas and results from the pilot projects and incorporate them into the model. GEM also will capture the pilot project failures to ensure that mistakes are not repeated.

The First GEM Pilot Project: Haiti

Haiti was devastated by the earthquake of January 12th and it needs help across all societal sectors. GEM was conceived as a result of the earthquake in Haiti, and it will capture hard-earned knowledge as Haiti is rebuilt. Haiti has very limited fossil fuel energy resources and suffers deforestation due to uncontrolled harvesting. However, Haiti has unusually high renewable energy resources. For example, Haiti's solar resource is 3115 hours/year and 8.5 hours/day average[4]. Haiti also has various hydroelectric options, including existing hydro dams, ocean hydro, and pump hydro storage. Reliable wind also is available in the north. Biomass is feasible and offers the dual benefit of energy and solid waste handling. The integration of these distributed energy resources into a coordinated power grid with a national control center is enabled by the GreenBus™ [5] platform and other open-source technology.

Haiti is in dire need of electricity in Port au Prince (PaP). GEM will guide emergency decisions so that actions taken under the stress of the situation in PaP do not have unintended results. For example, construction of a 120MW coal-fired power plant would appear to be a reasonable fix for PaP, but further analysis shows that building a fossil fuel power plant would be a mistake. The US Trade and Development Agency issued a comprehensive report[6] detailing the cost of constructing a new 120MW power plant to serve PaP. Table 1 and Table 2 are copied from the report.

Table 4-2A: Project 2, Option 2A — St. Christopher, Santo, NDM — Solid Fuel Steam Plant

Item	Item cost $(000)	ROW Cost $(000)	Constructed Cost $(000)	Annual O&M Cost $(000)	Annual Fuel Cost $(000)
St. Christopher Power Plant	$258,000	$70	$258,070	$6,733	$33,130
St. Christopher 115kV Switchyard	$8,270	$10	$8,280	$25	
St. Christopher PP - Santo - Nouveau Delmas 115 kV Line	$8,170	$544	$8,714	$17	
Santo 115 kV Switchyard	$7,580	$10	$7,590	$25	
Replace Nouveau Delmas 115-69 kV Transformers and 69 kV Circuit Breakers	$8,510	$0	$8,510	$12	
Replace Various Circuit Breakers to Increase Interrupt Ratings - Upgrade Relaying and Controls - Replace Transformer Oil	$3,030	$0	$3,030	$12	
Total (Rounded to Millions)	**$294,000**	**$1,000**	**$294,000**	**$7,000**	**$33,000**

Table 1: USTDA Report 120MW Coal Plant Estimate

4. www.climatetemp.info/Haiti
5. GreenBus™ is a trademark of Green Energy Corp
6. USTDA report 2007, HLY 009-224 EDH (06/06/07) 109999/rb.

Pilot Project: Haiti *(continued)*

Table 4-2B: Project 2, Option 2B — St. Christopher, Santo, NDM — IC Plant

Item	Item cost $(000)	ROW Cost $(000)	Constructed Cost $(000)	Annual O&M Cost $(000)	Annual Fuel Cost $(000)
St. Christopher Power Plant	$110,000	$70	$110,070	$2,881	$80,125
St. Christopher 115kV Switchyard	$8,270	$10	$8,280	$25	
St. Christopher PP - Santo - Nouveau Delmas 115 kV Line	$8,170	$544	$8,714	$17	
Santo 115 kV Switchyard	$7,580	$10	$7,590	$25	
Replace Nouveau Delmas 115-69 kV Transformers and 69 kV Circuit Breakers	$8,510	$0	$8,510	$12	
Replace Various Circuit Breakers to Increase Interrupt Ratings - Upgrade Relaying and Controls - Replace Transformer Oil	$3,030	$0	$3,030	$12	
Total (Rounded to Millions)	**$146,000**	**$1,000**	**$146,000**	**$3,000**	**$80,000**

Table 2: USTDA Report 120MW Gas Plant Estimate

Note that the forecasted annual cost of fuel for option A (coal) is $33MM and $80MM for option B (gas) at 2007 rates. Further, note that extensive infrastructure improvements are required to support a new centralized plant. Comparatively, the typical installed cost of solar power plants in the US is $2500/kW[7]. Allowing a 30% adder for costs associated with shipping, tariffs, and inconvenience, the rough cost for a 120MW solar power plant in PaP is $390MM. Since solar has no annual fuel cost and comparable operations and maintenance (O&M) costs to the proposed coal plant, the additional capital expenditure for solar power versus a coal plant is approximately $96MM. The payback on the additional capital expenditure for installing solar power is three-years, based on fuel savings alone and not considering fuel cost fluctuations, health impact, and environmental impact costs. The payback on the additional capital expenditure for installing solar power versus gas is about the same as coal based on fuel savings alone and not considering fuel cost fluctuations, health impact, and environmental impact costs. After the capital recovery is met, solar becomes highly profitable when compared with coal and even more so when compared with gas. Another benefit of solar is that it can be installed in 18 to 24 months and has minimal ecological impact. On average, solar requires 10 acres per MW, so a 120MW solar plant requires 1200 acres of land. Note that solar can be distributed with minimal additional infrastructure cost, so it is feasible to install twelve 10MW solar plants in and around PaP. Coordination of the generation would be handled by the GreenBus™ platform. Initially, the distributed 10MW solar plants can be connected to distribution circuits, so transmission line improvements are not needed to get power to 12 regions of PaP quickly. Distributed generation is not economically feasible with coal plant technology.

[7] www.greentechmedia.com/articles/read/pricing-pressure-beating-down-on-sunpower-6088/

Pilot Project: Haiti *(continued)*

The argument against solar is that it is only available in Haiti one-third of the time on average, as compared with coal or gas which typically is available 24/7. In Haiti, coal must be imported and stockpiled at the coal plant and gas must be imported and stored. Dependence on imported fuels for power plants is risky since Haiti does not have sufficient credit to secure competitive long-term fuel supply contracts. Consideration must be given to the value of immediate 24/7 power in Haiti using fossil fuels, versus a phased approach beginning with 8-hour daytime power and gradually building to a 24/7 sustainable power system using a phased plan. A benefit of GEM is that it offers options with deterministic results and includes local consensus and human impact in the decision process. If 24/7 power for PaP is the ultimate goal, how can it be reached reliably with sustainable technology? There is a conservative alternative to building a fossil fuel power plant in PaP. The answer is Pumped Hydro Storage (PHS). The installed cost of PHS in the US is $2,000/kW[8]. PHS is a proven large-scale power resource with the added benefit of energy storage for power system stability. Many US utilities rely on PHS to stabilize their power systems and the technology is highly reliable. The typical problem with PHS is that it requires a differential in elevation to work, so it is not a ubiquitous solution. However, PHS is a terrific option for the mountainous nation of Haiti. A combination of PHS and solar power would roughly cost $5,500/kW to install. This sustainable hybrid power plant would provide comparable availability to a typical coal plant at an additional capital expense of $366MM. The payback on the additional capital expenditure for installing hybrid power is 11 years, based on fuel savings alone and without considering fuel cost fluctuations, health impact, and environmental impact costs. Coal supply volatility alone may justify the additional capital expenditure for the hybrid plant if continuous power in PaP is required. Other benefits of PHS are potential population relocation from PaP and improved land irrigation. Man-made lakes must be constructed to store water for PHS generation. Villages could be constructed around the PHS lakes to attract PaP residents. Controlled irrigation also could be integrated during the construction of the PHS facilities. Multiple small (50MW to 100MW) PHS facilities are planned to minimize the impact on residents and displace as few people as possible.

Figure 1 on the following page shows a simplified schematic of the proposed hybrid power system for PaP. The diagram is expanded to include a biomass plant, electric vehicle transportation, and wind generation resources. This diagram is conceptual only and does not attempt to offer an actual schematic of the proposed pilot system. Figure 1 does, however, represent the initial expanded vision of GEM as it applies to Haiti. The Haiti pilot project offers the chance to evaluate a comprehensive sustainable power

8. www.bravenewclimate.com/2010/04/05/pumped-hydro-system-cost/

Pilot Project: Haiti *(continued)*

system plan that is free of dependence on fossil fuel. Haiti is an excellent candidate for the first GEM pilot project. Ultimately, GEM will define the roadmap for all of Haiti to be energized region-by-region. A new national 230kV transmission backbone would connect distributed generation resources across Haiti and into the Dominican Republic. The Dominican Republic would benefit from access to excess power from Haiti, and the Haiti hybrid power system would be backed-up by the DR power system. The Haiti GEM pilot project also will accommodate the connection of micro-grids and very small generation resources, which naturally will come online sporadically over decades.

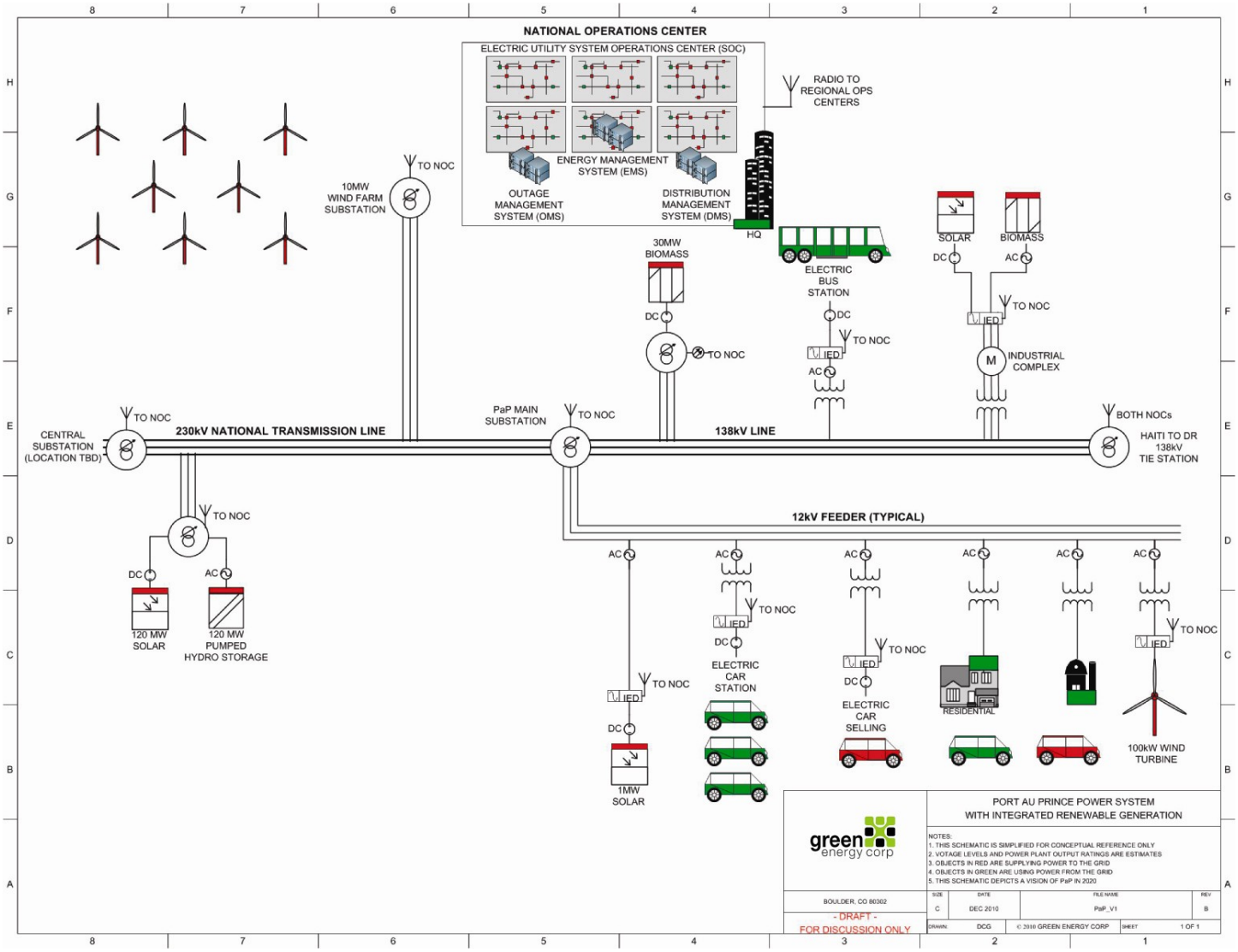

Figure 1 - Port Au Prince Power System by 2020 (conceptual drawing)

Technology and People

GEM balances the application of technology with the needs and wants of the people it affects. GEM is not a standard or a recommended practice. It offers a vision to move toward while presenting pragmatic solutions to address the immediate energy needs of developing nations. GEM defines the characteristics of all generation resources by class. Generation classes include: solar, wind, vehicle-to-grid, hydro, biomass, fuel cells, geothermal, nuclear, and steam. Furthermore, GEM identifies each type of solar technology with details about: production volume, availability, performance, installed cost, life-cycle cost, electrical characteristics, compatibility with other resources, weather resistance, environmental impact, human psychological impact, ease of theft, land requirements, and so on. GEM also identifies all available communications architectures and control system solutions that support facilitating distributed hybrid power plants, automation, and "smart grids". Power system equipment and networks will be modeled, such as: switches, substations, transformers, circuit breakers, transmission lines, distribution feeders, micro-grids, dc systems with associated lighting and motors, and protection devices. Plug-in electric vehicles, electric vehicle-to-grid interfaces, and battery storage solutions will be modeled. GEM will encapsulate unnecessary complexity while preserving the important characteristics of the solutions. The value is that leaders, planners, and engineers can refer to GEM to guide them in their decision-making process when they are designing energy solutions for developing nations. The model will provide a system view of power system alternatives with related human impact considerations. GEM is a holistic model that improves with time, thought, experience, and feedback.

GreenBus™

GreenBus™ is an open-source initiative started by Green Energy Corp. Traditional control systems are complex and use proprietary software for control functions and communications. The GreenBus™ platform is based on open standards, and all software is published to an open-source community. This vendor-independent system solution enables developing nations to take ownership of the critical Supervisory Control And Data Acquisition (SCADA) system that manages the power grid. Micro-grids are a terrific concept, but each micro-grid requires a local SCADA system, and the cost of a SCADA system per micro-grid makes the concept cost-prohibitive. GreenBus™ eliminates the unnecessary costs of proprietary technology making the installation of micro-grids practical. GreenBus™ also supports the hybrid power plant architecture described herein.

Education and Jobs

GEM establishes on-the-job training and a formal education process to support pilot projects. The concept is to recruit high school and college students to participate in the entire process of planning, designing, managing, and building their nation's power system. GEM incorporates an accredited engineering program to be established locally and designed to produce trained and globally competitive engineers and project managers. The program will offer civil, electrical, mechanical, and systems degree programs established with the assistance of US universities. The objective is to empower each nation to own and operate its power system, independent of outside resources. The retention of talented employees is a common problem in developing nations. It is imperative that a sense of pride and ownership be established with the new power system workforce to encourage employees to remain in their respective countries. GEM will model a workforce development process that will equip developing nations with the tools needed to retain their key people.

Balance of Power

Fossil fuels have powered our world for more than a century. Edison, Tesla, and Westinghouse had a vision and saw it through. Their brilliant vision has reached its end, and it is time to embrace a new vision. It is reasonable to proceed with new "smart grid" power system design for developing nations where little or no energy infrastructure exists. GreenBus™ enabled DC micro-grids offer safe, low voltage power on a local basis. Electric vehicles, such as the Nissan Leaf, offer low cost generators coupled to batteries capable of producing 90kW peak power and storing 24kWh of reserve power[9]. Communications bandwidth is increasing and microprocessors continue to double in transistor capacity every two years (a phenomenon confirmed over 50+ years and known as Moore's Law). Modern digital technology is enabling system architects to design very high speed control systems. These systems are fast enough to correct power fluctuations and balance loads between geographically dispersed generation resources. A "smart grid" power system comprised of many types of sustainable distributed generators and many micro-grids is feasible. This GreenBus™ platform enables the creation of hybrid distributed power systems that are superior to western-world standards when considering efficiency and sustainability.

9. IEEE Spectrum, April, 2010, page 36.

A Phased Approach Toward 24/7 Power

The goal for immediate 24/7 power in developing nations is clouding the more conservative and reliable approach to meeting energy needs. Breakthrough technologies including: micro-grid compatible solid-state transformers and switches[10], and open source control software[11] are under development now. It is time to begin GEM so that these new technologies are adopted efficiently and long-range implications are considered by today's decisions. The first phase power system may generate 8 hours/day of reliable electricity from renewable and sustainable resources. This conservative approach would ensure a quantum leap in societal benefits at a moderate capital expense and low operating cost. The second phase could support 12 hours/day of predictable power with support for public lighting and some refrigeration. A third phase could bring on refrigeration and lighting for homes. The fourth phase could support electric transportation, and the final phase could provide 24/7 power from a distributed hybrid renewable energy power plant[12]. The resulting power system would provide clean and reliable power with no recurring fuel cost and no vendor dependence due to proprietary technology. Developing nations could operate and own their power system and make improvements as they deem necessary. Fossil fuel dependence would be eliminated, and environmental impact would be minimized. GEM is an evolutionary vision that has immediate impact and long-term global benefits. A phased approach from eight-hour power to continuous power makes the most sense.

10. NSF FREEDM Systems Center, Gen III Engineering Research Center, NC State University
11. GreenBus™, Green Energy Corp
12. U.S. Patent and Trademark Office Publication No. 2010/0145532

Conclusion

GEM will take two-years to draft, 5-years to release version 1.0, 10-years to pilot, and may never be completed. Many people will contribute to this effort, pilot projects will be implemented, and many technologies will evolve over the course of GEM development. Initially, GEM offers guidance toward a clean, reliable, and cost effective power system solution. It starts with a pilot system in Haiti, but it evolves into a holistic model that considers the total impact of energizing developing nations. GEM requires "grassroots" support with the patience and commitment of all stakeholders to succeed. Energizing a developing nation demands cultural respect and careful consideration of socioeconomic balance. Unintended results often occur without holistic modeling. Modeling techniques, like System Dynamics[13] and Object Oriented Analysis and Design[14] offer excellent structures to ensure the long-term viability of this initiative. GEM is a vision, roadmap, and consensus tool that helps energize developing nations in a thoughtful and respectful manner.

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13. Andrew Ford, 1996, System Dynamics and the Electric Power Industry
14. Grady Booch, 1999

About Green Energy Corp

Green Energy Corp (GEC) is a leading technology company that provides software solutions and software engineering services to communications, utilities and energy companies. Our team includes senior business leaders and top industry experts with deep experience managing technology companies and building energy and communications solutions.

Our customers include established and emerging leaders in the communications, smart energy and utility segments. Our management team has the commitment, experience and depth to execute. Our employees bring exceptional 'been there, done that' skills and knowledge. Our partners are like-minded and architecturally complementary. Our engineering and project endeavors are oriented toward long-term solutions delivered via contracts with meaningful returns. We are well positioned to fulfill our mission to take a leading and sustainable role in the transformation to the smart grid at the national and global level.

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Rev. 01/2011