QUEST FOR INTELLIGENT MITOCHONDRIA
Bio-inspired Energy Efficiency

Shoumen Palit Austin Datta*
Engineering Systems Division, Department of Civil and Environmental Engineering,
MIT Forum for Supply Chain Innovation, School of Engineering
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

ABSTRACT

Energy policies based on empirical assumptions without a foundation in granular real-time data may be limited in scope. It may sputter ineffectively in its role as the engine of energy economics. For energy efficiency and conservation, it is increasingly necessary to invest in systems, tools and practices that can facilitate bi- or multi- directional flow of energy to control or balance consumption to reduce the carbon footprint. The central dogma of an energy oligopoly and uni-directional distribution through the electricity grid is poised for a radical overhaul. An "internet" of electricity capable of executing differential distribution strategies from capacity generated by micro-supplier networks and electricity producers may evolve from the proposed Smart Grid. The future intelligent Grid (inGrid) is imminent. Development of methodologies using technologies based on rigorous scientific standards must be coupled with effective dissemination of tools and then adopted by consumers who will allow the acquisition of granular real-time data to enable feedback decision support or resource optimization. Automation driven by intelligent decision systems is key to efficacy. We advocate a closer look at the energy regulation within cells and call for the emergence of a mechanical mitochondria and convergence of innovation through service science, which may co-evolve with inGrid. It may be an amorphous nexus of engineering and management with the needs of society, industry and government. Higher levels of decision support, necessary both for strategists (policy makers) and engineers (inGrid operators) may be impotent or without global impact if we fail to promote diffusion of a grass-roots approach to seed one or more methodologies necessary to acquire data from a critical mass of users (in each environmental category from each major geographical region). Intelligent Energy Transparency (iET) should evolve to provide decision makers a secure mobile dashboard for real-time multi-directional flow and to balance the demand. Finally, however, the future of energy efficiency may be quite bleak without innovation in energy forms. We propose a convergence of solar energy with metabolic engineering for renewable liquid fuel production in the petroleum-depleted (?) post-2050 era.

Keywords: Intelligent Grid, Mechanical Mitochondria, Intelligent Energy Transparency (iET), Internet of Electricity, Dynamic Pricing, Metabolic Engineering, Synthetic Chlorophyll

1. INTRODUCTION

1.1 Background

Climate change is a global phenomenon with profound local impact. However, the relatively slow rate of climate change in combination with the nature of factors responsible for the problem, in part, makes it difficult for managers to invest their limited resources to implement the enabling technologies necessary to address environmental responsibility.

Due to the magnitude of the energy demand, the issues germane to greenhouse gases shall remain in the forefront of public discourse for another quarter century unless we encounter a disruptive innovation or acquiesce to immediately profit from an abundance of electricity from nuclear fission [1]. The latter may not address all the energy issues but

*The published version of this article is a collaborative paper with co-authors JrJung Lyu and Hui-Chiao Jen, National Cheng Kung University

allows enough time to productize sources of energy that offers a low risk profile with even better GHG emissions control. Before we arrive at the post-2050 fossil fuel free era, at least for the next few decades, therefore, it may be prudent for us to focus on how to optimize the use of available forms of energy to reduce GHG through:

(1) Conservation or waste reduction
(2) Improving efficiency (device, infrastructure and user behavior) to decrease consumption

Investment is necessary to adopt some of these measures. Return on investment is expected from:

(1) Aggregated micro-savings from decreased usage
(2) Carbon credits for reduction in carbon footprint
(3) Global certifications for sustainable efforts

1.2 Motivation

Policies to drive the mechanisms necessary to accomplish the tasks outlined above are proceeding at a frenetic pace in various global organizations. Committees and task forces are framing the structure of infrastructure to be embedded in auditing tools to mandate elements of efficiency. Carbon calculators are already featured as interactive software on a variety of decision making platforms [2]. Tools and simulation are necessary and are evolving.

Various forms and degrees of legislation [3] are making their way through governments to mandate and guide. The impact of regulation will extract a price which will influence cost of goods and services [4]. Science and engineering advances necessary to mitigate climate change will usher in a convergence through innovation in service science.

The internet was a catalyst in the information and communication revolution. Although embryonic, evolution in climate control strategy may find part of its solution in the "internet of electricity" through the intelligent grid [5] and/or the future mechanical mitochondria (Figure 1).

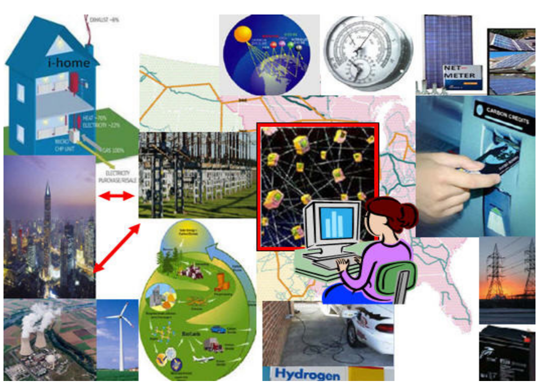

Figure 1: inGrid and the future MITOCHONDRIA

1.3 The Intelligent Mechanical Mitochondria

Using data from energy measurements, inGrid may spur growth through energy efficiency. Users may accumulate carbon micro-credits through an entrepreneurial environmental cooperative for energy eBusiness (trading carbon options) and use banked carbon credits to offset carbon footprint.

Domestic users can generate energy from a variety of sources and profit from auctioning excess capacity (electricity) on an eBay type web service, thus, contributing to the global deal [6] to reduce greenhouse gases (GHG) and/or curb emissions.

Micro-generation of electricity, micro-sales and micr-distribution via inGrid offer positive economic consequences for some rural regions and eventually, for some remote parts of the world. Rural economic revitalization may commence with the investment to generate energy by harvesting unused resources (wind, solar) and agri-waste (bio-fuels). Non-fossil energy may find its way to power air conditioners in a city-based conglomerate if waste-lands can grow oil weeds (e.g. Jatropha curcas). inGrid requires the mechanical mitochondria to evolve as a regulatory hub to balance energy needs, exercise control and optimize efficiency drawing on bio-inspired models.

1.4 Proposed Approach

To focus on energy efficiency and conservation to reduce GHG emissions and carbon footprint, it is necessary to acquire high volume granular data from monitoring wireless sensors. Data must be auditable according to established methodologies to provide a basis for further decision making. The physical and financial facets of the entire energy supply-demand value network must be taken into consideration by assigning proper weights to local and global factors which may influence decisions, directly or indirectly.

The use of data to provide a service valuable to the consumer is key. It is feasible to use proper tools to monitor and reduce energy usage. Translating the reduction in consumption to monetary savings is the incentive to invest in decision tools. The generalized framework for this translational carbon savings is still emerging. Ad hoc methods, often proprietary and without verifiable data accuracy, feeding a cobbled framework, may be detrimental to energy efficiency. If we can acquire a critical mass of accurate granular data, then, the data-driven tools will save money and resulting decision systems may become a commercial success. Policies in national and global frameworks may offer insight into the magnitude of the crisis, dimensions of the ripple effect and better clues to long term sustainability rather than short-term fixes.

The energy sector is pursuing a plethora of worthy initiatives for decision driven automation but the granularity of data, in some cases, is still poor or based on default assumptions or standard models. Tools and technologies to acquire granular data and analytics to extract meaningful associations for improved decision support are necessary. Systemic methodologies that can accelerate and catalyze the widespread systems integration and dissemination of these tools in the hands of users, in high volume, are required. The volatile energy market projects Carbon as the largest financial business commodity by 2020. Principles of operations management suggest that volatility between operational stages may be due to information asymmetry [7]. When iET matures, it will call for data acquisition and sharing. iET may reduce volatility by serving as a systems integration platform for tools, analytics and auditable data as a driver for carbon trading and reduction of global GHG.

One goal of this article is to forward the concept that enlightened energy policy and carbon efficiency related decision support may require country-specific granular data. This lofty goal is theoretical, at best. It is entirely dependent on adoption of technology to acquire the basic layer of granular data. Hence, the key assumptions in this article are:

(1) The market will steer manufacturers, suppliers, system integrators, consumers and regulators to work together to improve energy efficiency by deploying innovative technology such as stick-on sensors that can form ad hoc mesh networks and upload data through an authorized node.
(2) Oversight from global organizations (UNFCCC, IPCC) to create frameworks and methodologies through convergence of multiple technologies to improve energy efficiency and tangible savings.

2. INTELLIGENT ENERGY TRANSPARENCY (iET)

The concept of mitochondria in energy through the use of iET originates from the original proposal of Homeostatic Utility Control suggested by scientists three decades ago [8]. Such products exist today [9] but the tools are device specific with local automation control. Building on HUC and extending the conceptual Energy Box [10], the proposed iET is a pre-requisite for the mitochondria (Figure 2).

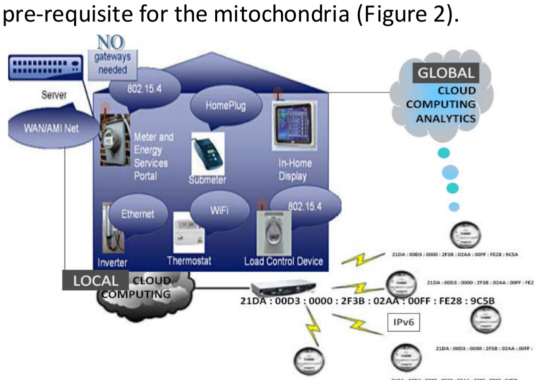

Figure 2: MITOCHONDRIA could use data from wireless sensors with IPv6 addressing to interface directly with the smart grid and the future inGrid.

iET is expected to offer dynamic control using device-specific real-time data for global optimization, for example, savings across an enterprise. iET will fall short of its potential unless its architecture allows for future integration with inGrid (Figures 1 and 2). Existing products address limited number of issues. iET calls for low cost per node (printed sensors) and systems software architecture that adapts to market demands when the Smart Grid and the future inGrid comes into play. iET must be immediately useful to help generate savings (ROI) for investors in energy efficiency projects and respond to systemic demand volatility through ad hoc curtailment measures in near-real time for utility corporations and local energy regulators.

3. CARBON SUPPLY CHAIN

Intelligent energy transparency is expected to be accessible via a web-service and serve as an user interface for multiple applications that aspires to integrate the future mitochondria which will include various versions of intelligent decision tools for ubiquitous energy efficiency. iET portals may include:

(1) Savings Optimization
(2) Carbon Footprint Audit
(3) Power Saving Automation
(4) Differential Dynamic Pricing
(5) Energy Risk Portfolio Management
(6) inGrid operating service (e.g. Globus Tool Kit)
(7) MITOCHONDRIA (sequential upgrades, versions)

A key component of iET is pricing, specifically, dynamic pricing. Applying principles of operations research to the practice of supply chain management has demonstrated that volatility of demand is reduced if an EDLP (every day low price) strategy [11] is adopted. EDLP is in contrast to practices to attract customers using promotions and discounts using variable pricing based on inventory, competition, demand variability, seasonal trends or branding, through some form of dynamic pricing. Energy markets use price per kilowatt-hour (kWh) that rarely changes. But, the pre-set rate is not reflective of EDLP. Without any incentive to conserve, the usage patterns of consumers may remain unaffected which leads to peak periods of consumption and the energy provider must build capacity. This dominant scenario of peaks and valleys clearly indicates the need to build excess capacity in order to meet ephemeral peak demand. Thus, excess electricity generation capacity is under-utilized for several hours each day. It has been proposed that an electricity quota at a base price in combination with dynamic pricing (higher rates for increasing demand) may offer incentives for users to be more efficient. Aggregated energy efficiency can reduce peak load and providers need not build capacity continuously (then pass on the cost) in order to meet projected peak demand.

It is estimated that a less variable electricity demand pattern may save about US$100 billion and a diminished need to expand capacity over the next quarter century [12]. Enabling technologies at hand can improve energy efficiency by automating the response of the consumers to dynamic pricing to substantiate the savings. Data from wireless sensor network (WSN) monitoring systems [13] integrated with savings optimization and automation portals of the proposed iET can deliver energy efficiency and savings. To maximize savings, the decision support tool cannot be manually controlled or fixed at pre-set levels irrespective of other independent variables, for example, weather. There is a need for an iterative process to perform dynamic optimization and resets, perhaps every few minutes, if necessary, depending on intelligent analysis of factors and fluctuations but without compromising the service expectation, for example, human comfort inside an airport lounge.

To extract sustainable value from the future inGrid, the diffusion of iET tools and its adoption by consumers must be accelerated to create an enabled informed society [14] that can benefit from the hypothetical intelligent mechanical mitochondria, in a manner analogous to the energy balance in cells. Combination of dynamic pricing with storage and distribution via inGrid (Figure 1) may spur buying and storage of electricity from providers at a low off-peak cost and re-selling stored power during peak demand. Weather permitting, the rooftop solar panel or the wind turbine in the backyard could add to the energy portfolio and decrease demand on the grid [15]. If the grid response time is in hours, then it limits the system because weather (for example, wind) may not be always predictable several hours in advance.

Dynamic in-the-grid analytics may use cloud computing [16] (Figure 2) to deliver business services made possible through iET. Re-routing the flow of electrons (electricity) to specific addresses may mimic the principles of DNS used by the internet protocol. It will benefit from an increased number of unique addressing capability possible in IP version 6 [17]. IPv6 enables a single or an aggregate of wireless sensors to directly upload data via the internet [17] which was not possible due to limitations of addresses in IPv4. By combining various applications and converging data layers (WiFi, ZigBee) (Figure 2) the analytical capability of iET may optimize energy use. Distributing intelligence both at the edge and core may be possible with deployment of vast number of wireless sensors and nodes that can be directly connected using existing TCP/IP suite of protocols. Ultra-low power pico-radios [18] are emerging from the lab bench to the market place and network architectures at hand (6LoWPAN) are enabling the seamless routing of data from edge to the core for bi-directional control or upgrades at the level of individual wireless sensors. Vendors are pursuing tools that may converge and strengthen the iET concept for the future inGrid energy efficiency.

4. FRAMEWORK

Integrating multiple independent variables in a repetitive and sequential decision tree may use variations of stochastic dynamic programming (SDP) and may be suitable for vanilla optimization [19]. Decisions will take into account the stages, states, transitions, policies, forecasts, conditions prevailing at the time. Approximation or accuracy of SDP will depend on or may be limited by dimensionality or state-space. In simulating or controlling a device, the input value of some of the independent variables may be selected from a distribution or to simplify, certain discrete values may be used. Classical linear regression model may suffice for some types of time-varying forecasts but other situations may benefit from application of autoregressive moving average or other advanced econometric techniques (Figure 3 and 4) [20].

The value of an iET engine relies on the ability to be modular and host a variety of algorithms that can serve general as well as specific functions which vary between verticals (industry, hotels, hospitals, domestic, public and commercial). iET may be best served by a intelligent differential decisioning engine (IDDE). Building intelligence in the tool using learning algorithms based on the principles of artificial neural networks (ANN) will be an important criterion. Over time it may evolve to an 'intelligent' mitochondrial decision support. For data driven energy efficiency and savings, consider some of the design criteria for stationary assets and apply these criteria in context of mobile assets (transport, supply chain).

iET framework may be summarized as follows:

(1) Audit : Energy Usage
- Accuracy and types of data
- Data collection, analysis and integration
- Efficiency of carbon footprint algorithm
- Savings optimization vs energy efficiency

(2) Objectives : Carbon Savings
- Calculate and compare carbon footprint
- Control automation for energy savings
- Optimize carbon credits for business units
- Reduce carbon emissions
- Increase carbon trading opportunities
- Value-add over existing technologies

(3) Parameters: Carbon Footprint
- Fuel: fossil, renewable, carbon-neutral
- Consumption in kilo-watt-hours per unit area

- Location, weather, volatility, uncertainty, TCE
- GHG emitted (tonne per kwh) vs energy cost
- Calculate carbon credits (barrels of oil saved)

(4) Recommendation : Decision Automation

- Execute actions to reduce transaction cost
- Offer choices of materials, materials origin, manufacturing process
- Compare dynamic pricing, energy use and carbon status with sector specific practices

$$y_{1t} = \beta_0 + \sum_{k=1}^{K} \sum_{i=1}^{N_{X_{kt}}} \alpha_{ki} X_{kt-i} + \varphi_{11} y_{1t-1} + \varphi_{12} y_{2t-1} + \varepsilon_{1t}$$

$$y_{2t} = \beta_0 + \sum_{k=1}^{K} \sum_{i=1}^{N_{X_{kt}}} \alpha_{ki} X_{kt-i} + \varphi_{21} y_{1t-1} + \varphi_{22} y_{2t-1} + \varepsilon_{2t}$$

$$\sigma_{1t^2} = \theta_0 + \sum_{i=1}^{q} \theta_i \varepsilon^2{}_{1t-i} + \sum_{j=1}^{p} \tau_j \sigma^2{}_{1t-j}$$

$$\sigma_{2t^2} = \theta_0 + \sum_{i=1}^{q} \theta_i \varepsilon^2{}_{2t-i} + \sum_{j=1}^{p} \tau_j \sigma^2{}_{2t-j}$$

Figure 3: Analytical Models (Datta and Granger)

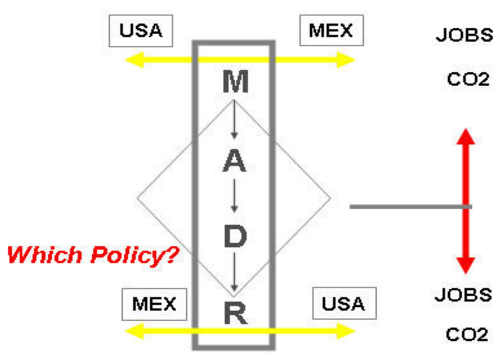

Figure 4: Analysis and Policy reflects "different strokes for different folks"

5. APPLICATION OF iET

Diffusion of the conceptual mitochondria, iET and inGrid may enable institutional and business leaders to seek appropriate combinatorial solutions. We must get acquainted with demand response and the tools necessary to implement and/or evaluate energy savings as well as carbon trading options. iET shall provide decision makers a secure mobile dashboard to deal with real-time carbon footprint reduction, energy savings and trading (as an asset or a liability). Based on the granularity of data, iET can be used in a hierarchical manner (Figure 5): business, municipality, city, state. In some countries, legislation already exists to address energy risk management. US Congress approved the Sarbanes-Oxley Act (SOX) in 2002 [21] which require businesses to assess types of risk that may be associated with its operation (SOX 409). This "risk" may now extend to include energy or carbon footprint. A form of clearance that may be required in the future may be based on the format of CDM (Clean Development Mechanism, UNFCCC). The importance of the carbon footprint was magnified by the introduction of the "polluter pays" principal in the form of financial costs for generating carbon dioxide. Carbon footprint of business and industry may not remain optional. GHG emissions, thus, emerges as a financial liability on the balance sheet. CFO's must implement measures or strategies to limit these costs. Comprehensive energy usage audit may enable carbon liabilities to be balanced against reduced energy usage by improving efficiency of use.

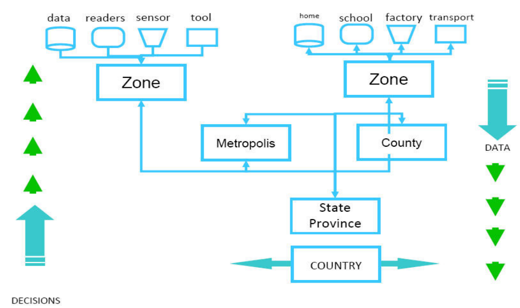

Figure 5: Flow of granular data, aggregated by operational hierarchy, may improve power systems management [22]

Rewards for saving energy may be a marketing asset as well as a financial incentive. Carbon credits have been trading for about US$30. One credit allows the owner to release one ton of carbon dioxide. The value of the carbon credits is predicted to soar. City of London predicts that current sales of £30 billion to exceed £1 trillion by 2020 [23]. Many governments are keen to increase revenue and carbon tax is no longer an idea but represents a lucrative resource in the post-recession climate to resuscitate national treasuries. Carbon tax may be a long term economic baggage rather than a solution for reducing GHG. Controlling climate change through appropriate enabling technologies may be globally sustainable.

Bi-directional secure wireless sensor (Figure 6) data communication is key to "sense and respond" triggers to execute effective secure controls. Use of WSN to monitor energy usage and optimize energy efficiency through control (Figure 7) is only one component in a portfolio of technologies that will drive the development of iET. Except for purposes of audit from a supply side, the data from monitoring energy usage is almost worthless to improve energy efficiency unless accompanied by control automation to reduce consumption without compromising the function, for example, optimum temperature in an enclosed space for human comfort. The granularity of continuous monitoring may not deliver any value unless the streaming data is able to fine tune the devices in order to optimize energy efficiency. The visualization of data and controls must offer different "views" based on the user and factors that are of importance to users: housekeeper, building manager, finance controller, energy authority, distributor, state regulator. The ability of the iET engine (IDDE) to "learn" preferences and characteristics or patterns of energy usage is key to intelligent decision support. iET may integrate hardware-associated visualization software with operational logic executing artificial neural network routines which continuously improve performance using learning algorithms in IDDE.

The strength of this granular approach for data acquisition and utilization is exemplified by the ability of a local or state electricity board to issue an online command and effect a reduction in energy consumption in buildings or premises using an iET type system integration. In this approach, it is not difficult to envision that systemic commands may be deployed with a short lag time (minutes) at multiple levels or hierarchies (Figure 5). The knowledge that this system can re-distribute power and reduce consumption on demand, may be an important tool for planning and designing, consumption prediction, power supply generation, power demand volatility, and emergency or security options. Integrating successive layers of data in local, municipal, state and country models in the framework is necessary for development of policy and planning for the future. Global organizations (UN) can use this data to better design the tools and instruments to monitor and audit carbon emissions or credits. This approach may require the following:

(1) Transparency of aggregated consumption data
(2) Granular data acquisition tools are deployed
(3) Investment necessary for adoption of tools will depend on incentives rather than goodwill
(4) Adopters seeking return on investment will seek monetary savings from reduced energy charges
(5) Standards necessary for secure installation and rapid "go live" execution
(6) Advanced modeling tools [24] and technologies [25] to profit from emissions trading schemes [26] as they evolve.

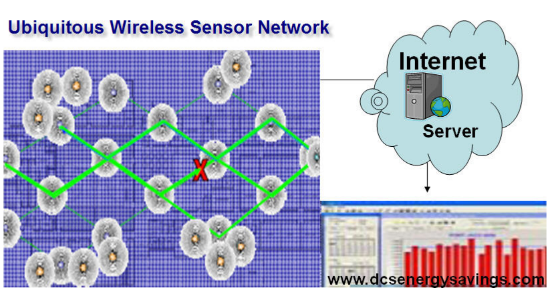

Figure 6: Illustrates a generic bi-directional secure wireless sensor network (SWSN)

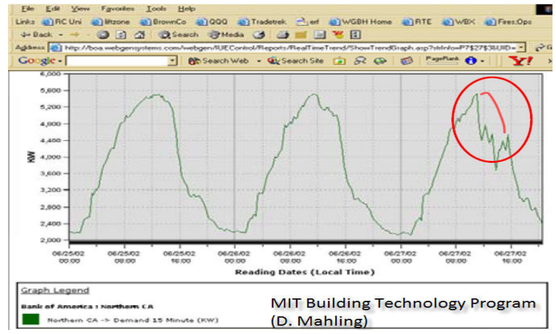

Figure 7: Example of energy usage data shows aggregated consumption and automation to reduce consumption (decrease demand by pre-set amount)

6. BIO-INSPIRED EMERGING IDEA

Most of the suggestions in this article, thus far, depends on innovation but not invention. The future of energy dynamics will also require inventions which can catalyse even more innovations. Somewhere in that undefined nexus of invention and innovation is an extension of our mitochondria concept that builds on research aimed at producing synthetic chlorophyll [27]. We opine that global energy dynamics may be sufficiently disrupted if we can change the "form" of energy, particularly from solar sources. The idea is as follows: solar energy is either (1) directed to heat water and let the steam run a turbine to generate electricity or, (2) produce electricity directly through photovoltaics. In either form, electricity generated must be transmitted (about 60% energy is lost during transmission) or used rapidly to prevent degradation since storage is still inefficient. This "physical" form of energy is at the heart of the issue of energy waste due to its perishability factor. From an energy supply chain perspective, the problem is similar to shelf-life of bananas in the produce section of a grocery store. Thus, changing the "form" or "state" of energy may be helpful for purposes of storage and transmission. Plants store energy effectively by converting carbon dioxide and water to glucose and oxygen with the help of energy from sunlight and chlorophyll, a green pigment found in plants and green algae. Research on synthetic chlorophyll is proceeding at a brisk pace. If synthetic nano-chlorophyll could be embedded on a substrate (etched on silicon wafers using photo or uv-lithography) with nano-fluidic irrigation channels (for water circulation) then these wafers (instead of mirrors) could be placed on solar-synchronized platforms. The expectation is that they will produce glucose with the help of sunlight and utilizing the carbon dioxide from the air and water from the nano-fluidic channels. The form of energy captured from solar sources is thus converted from the perishable "physical" form to the storage-capable "chemical" form in the chemical bonds of glucose molecules. Glucose may be transported and stored with ease. Vast expanses of deserts in countries like Libya and Somalia may become transformed into giant glucose factories and alleviate their economic woes. The food vs fuel debate is muted and glucose may serve as a "cash crop" for developing nations in the Equatorial belt. Using the glucose to feed bacteria (metabolically) engineered for generation of liquid fuel (butanol, pentanol) opens up a novel dimension for production of non-fossil renewable liquid bio-fuel [28]. Fusion-fission (FuFi) [29] and the hydrogen energy economy may not eliminate the need for liquid fuel in the post-2050 era when what could be left from the halcyon days of petroleum may be found only at the bottom of the barrel.

7. TEMPORARY CONCLUSION

We present a conceptual intelligent Energy Transparency to include a bio-inspired mechanical mitochondria to optimize energy efficiency. iET relies on a variety of algorithms to build intelligence in order to pursue carbon-based savings. Unlike inGrid and its long term impact, an intelligent Energy Transparency (iET) portal must be rapidly profitable. However, profits from energy efficiency may not materialize if we continue policy debates without implementing tools. Without quantitative analysis, policy provides poor guidance. With the help of analytics, some policy issues may be formalized and executed through future intelligent systems. But, it demands granular data and development of decision criteria and tools to interface with the evolution of inGrid which may in turn influence the evolution of the mitochondria. Building tools coupled with artificial neural networks based learning algorithms may evolve iET to be the intelligent mitochondrial decision support framework for energy efficiency.

Finally, we hypothesize the next generation of emerging technologies where the mitochondria may also include the synthetic chlorophyll vision. In this idea the "state" of energy is changed from physics to chemistry, enabling energy storage and transmission with minimal loss. Glucose, thus produced, when fed to metabolically bio-engineered bacteria, will result in the production of non-fossil renewable liquid fuel.

REFERENCES

1. Waltar, A., 2004, "Radiation and Modern Life", *Prometheus Books*.
2. Microsoft, "Environmental Sustainability Dashboard for Microsoft Dynamics AX," *http://www.microsoft.com/environment/business_solutions/articles/dynamics_ax.aspx*.
3. Paltsev, Sergey, et al, 2007, "Assessment of U.S. Cap-and-Trade Proposals," *MIT Joint Program on the Science and Policy of Global Change,* Report No. 146.
4. Datta, S., 2009, "Carbonomics: Trinity of Elements 6, 92 and 94 may Re-define the World Economy," *http://dspace.mit.edu/handle/1721.1/43952*.
5. Energy research Centre of the Netherlands, "Intelligent Energy Grids", *http://www.ecn.nl/units/ei/rd-program/intelligent-energy-grids/*.
6. Hepburn, C. and Stern, N, 2008, "New Global Deal on Climate Change," *Oxford Rev of Econ Policy,* Vol. 24, pp. 259-279.
7. Datta, S., et al, 2004, "Adaptive value networks," *Evolution of Supply Chain Management: Symbiosis of Adaptive Value Networks and ICT*, Kluwer, Amsterdam.
8. Schweppe, F. C. and Tabors, R.D., 1980, "Homeostatic Utility Control," *IEEE Transactions on Power Apparatus and Systems*, Vol.PAS-99, No.3, pp.1151-1163.
9. Imperial College, "Building Energy Management System Standard Controls Specification," *http://www3.imperial.ac.uk/pls/portallive/docs/1/4595924.PDF*
10. Livengood, D. and Larson, R.C., 2009, "Energy Box: Locally Automated Optimal Control of Residential Electricity Usage," *Service Science* ,Vol. 1, pp. 1-16.
11. Knowledge@Emory, 2007, "Why 'Everyday Low Prices' May Not Be Such a Deal," *http://knowledge.emory.edu/article.cfm?articleid=1047*.
12. Black, J.W. and Larson, R.C., 2007, "Strategies to Overcome Network Congestion in Infrastructure Systems," *Journal of Industrial and Systems Engineering*, Vol. 1, pp.97-115.
13. Ceriotti, M., et al , 2009, "Monitoring Heritage Buildings with Wireless Sensor Networks: The Torre Aquila Deployment, " *In Proc. of the 8th ACM/IEEE Int. Conf. on Information Processing in Sensor Networks (IPSN)*.
14. Faruqui, A. and Sergici, S. , 2008, "The Power of Experimentation: New Evidence on Residential Demand Response, " *The Brattle Group, San Francisco*.
15. Federal Energy Regulatory Commission, "FERC report marks significant progress in demand response, advanced metering," *http://www.ferc.gov/news/news-releases/2008/2008-4/12-29-08.asp*.
16. Carr, N., 2009, "The Big Switch: Rewiring the World, from Edison to Google", *W.W. Norton & Company*.
17. Datta, S., 2007, "Unified Theory of Relativistic

Identification of Information in a Systems Age: Convergence of Unique Identification with Syntax and Semantics through Internet Protocol version 6," *MIT ESD WP Series*, *http://dspace.mit.edu/handle/1721.1/41902*

18. Rabaey, J.M., et al , 2002, "Pico-radios for wireless sensor networks: the next challenge in ultra-low power design," *Digest of Technical Papers. ISSCC, IEEE International*. Vol. 2, pp 156-445.
19. Bellman, R.E. and Dreyfus, S.E., 1962, "Applied Dynamic Programming," *Princeton University Press*.
20. Datta, S. and Granger, C.W.J., 2006, "Advances in SCM Decision Support Systems: Potential to Improve Forecasting Accuracy," *MIT Engineering Systems Division WPS.* *http://dspace.mit.edu/handle/1721.1/41905*.
21. Sarbanes-Oxley, "The Sarbanes-Oxley Act", *http://www.soxlaw.com/*.
22. Kirschen, D. and Strbac, G. , 2004, "Fundamentals of Power System Economics," *John Wiley (UK)*
23. Green, R., 2008, "Carbon Tax or Carbon Permits: The Impact on Generators' Risks," *Energy Journal*, Vol. 29, pp. 67-89.
24. Daskalakis, G., Psychoyios, D. and Markellos, R.N., 2009, "Modeling CO2 Emission Allowance Prices and Derivaties : Evidence from the European Trading Scheme, " *Journal of Banking and Finance*, Vol. 33. pp1230-1241.
25. Ma, T., Grubler, A. and Nakamori, Y., 2009, "Modeling Technology Adoptions for Sustainable Development Under Increasing Returns, Uncertainty and Heterogeneous Agents," *European Journal of Operational Research*, Vol. 195, pp. 296-306.
26. Carmona, R., et al, 2008, "Market Design for Emission Trading Schemes," (submitted to *SIAM* Review)
27. Wong, W.H, et al, "A porphyrin-hexa-peri-hexabenzocoronene-porphyrin triad: synthesis, photophysical properties and performance in a photovoltaic device" *J. Mater. Chem*. (submitted 5th February, 2010)
28. Prather, KLJ and Martin, CH, 2008, "De novo biosynthetic pathways: rational design of microbial chemical factories," *Current Opinion in Biotechnology*, Vol.19, pp.468-474
29. Datta, S, 2008, "WiFi Meet Fufi: Disruptive Innovation in Logistics Catalysed by Energy," *International Journal of Electronic Business Management* , Vol. 6, pp. 117-119, *http://dspace.mit.edu/handle/1721.1/41897*