Modeling the Energy System:

Creating Evolutionary Models Useful to Evaluating a Full Range of Policies

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9 November 2006

INTRODUCTION

Because the future is contingent upon a myriad of future choices, modeling the energy future cannot be deterministic. Instead, models should seek to determine what choices, current and future, are consistent with different outcomes and to help policymakers understand how the choices they now make can enable or disable certain trajectories for future events. Ceteris parabus, holding all other things equal, is not possible for complicated social systems. Yet, with few exceptions, cetera parabus is the most fundamental assumption in energy modeling (which is probably why it has such a poor track record of accuracy). Models also leave out important factors that help determine outcomes of real systems (Ando, 1963). Worse yet, as systems change, factors that were unimportant in the past become important in the future. The failure of models to realistically portray behavior stems in part from cetera parabis assumptions, in part from leaving out factors, but mostly from our ignorance about what determines behavior. It is interesting that no person on earth can predict what they will be thinking in five minutes, yet models assume that we can predict how buyers and producers will respond to conditions decades into the future. Typically model structures assume continuity and smoothness when discontinuity and abrupt changes are common throughout natural systems, including of course human social systems (Saunders, 1980; Woodcock, 1978). The effort of energy modelers to create models that emulate physics, to create clockwork representations of reality, rather than evolutionary models that make little or no claim to be able to foretell the future, can probably be traced to the efforts of economists. more than a century ago, to create equilibrium systems that would make economics appear ‘scientific’, but which failure to correspond to the world we are in which is always out of balance.

To be of real value for policymakers, models must simulate possible futures based on a realistic assessment of ‘what it would take’ to move the current system ‘n the various directions that are possible’. Of course, those two problems, ‘determining what is possible’ and ‘what it would take’ to move the world are not small order. Even attempting to solve these problems with the help of models requires a level of disaggregation and detail lacking in models. Models must try to actually emulate a large part of the modes of behavior behind choices, not provide statistical representations of the past as a guide to an inevitable future.[1] A statistically reliable representation of the past does not assure that the statistical representation will be a good model for the future, especially since other things are *certain not to remain equal* and many of the other factors mentioned above will intervene to disrupt our view of the future In fact, if the purpose of proposed policies is to undermine the conditions that led to ‘past successes of the model as a predictor’, the procedure of using statistical representations of the past is self defeating. [2]

In developing models of the energy system that actually can assist in making better policy choices, it will be critical that actual institutions and history embedded in those institutions, as well as the actual behavior of the entities that compose the energy

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[1] Milton Friedman’s famous defense of models ‘*that do not represent the means by which people or entities actually make decisions, as long as they are good predictors*’ is logically invalid, since no one has means to see the future other than with models. Of course, Friedman offered no evidence that the models that he was defending were good predictors.

[2] Even the more sophisticated energy models, such as Dale Jorgenson’s, that econometrically fit equations from time series data so that they contain the past rate of change and then in them turn extrapolate that rate of change to the future are just more complicated ways to say nothing will change, they are still a static view of reality. But how well would such models perform in predicting nuclear energy in 1935 or computers in 1945. Not at all. But by assuming past is future, we negate our ability to use critical thinking, to use our models for altering the course of our future reality.

system, be modeled in a manner that reflects their actual and potential behavior. In this paper, I will review some of the features that describe the energy system today, some of the features that modeling the future evolution of the energy system must encompass, and propose certain policy shifts that would alter how the system behave as a whole. Current efforts to model the energy system will then be compared to what is needed to provide a more realistic understanding of the possible evolution of the system.

THE ENERGY SYSTEM [3]

There is no market for heat, coolth, light, grinding, moving air, compressing air, chopping or comfort or other services that we actually desire. Instead, we obtain *what we really want* through two co-dependent systems: the products that use energy and the system that provides energy to those products. We purchase a refrigerator freezer to store our food safely and to cool our drinks. We purchase electricity to operate the refrigerator from the grid. The two sub-systems, refrigerators and electricity supply, provide the services that we want, that is food storage and cold drinks.

These facts are often forgotten when constructing energy models, but critical to realistic assessments of the energy system. Energy consumption is means to the end, *not the end itself*. Of course, there is a chain that links services to energy. To obtain the services, devices *must perform work* and *to perform work requires energy* (Exhibit 1 on the following page). Efficiency can be defined with respect to the system that provides these services or on a component basis on the elements that make up such systems.

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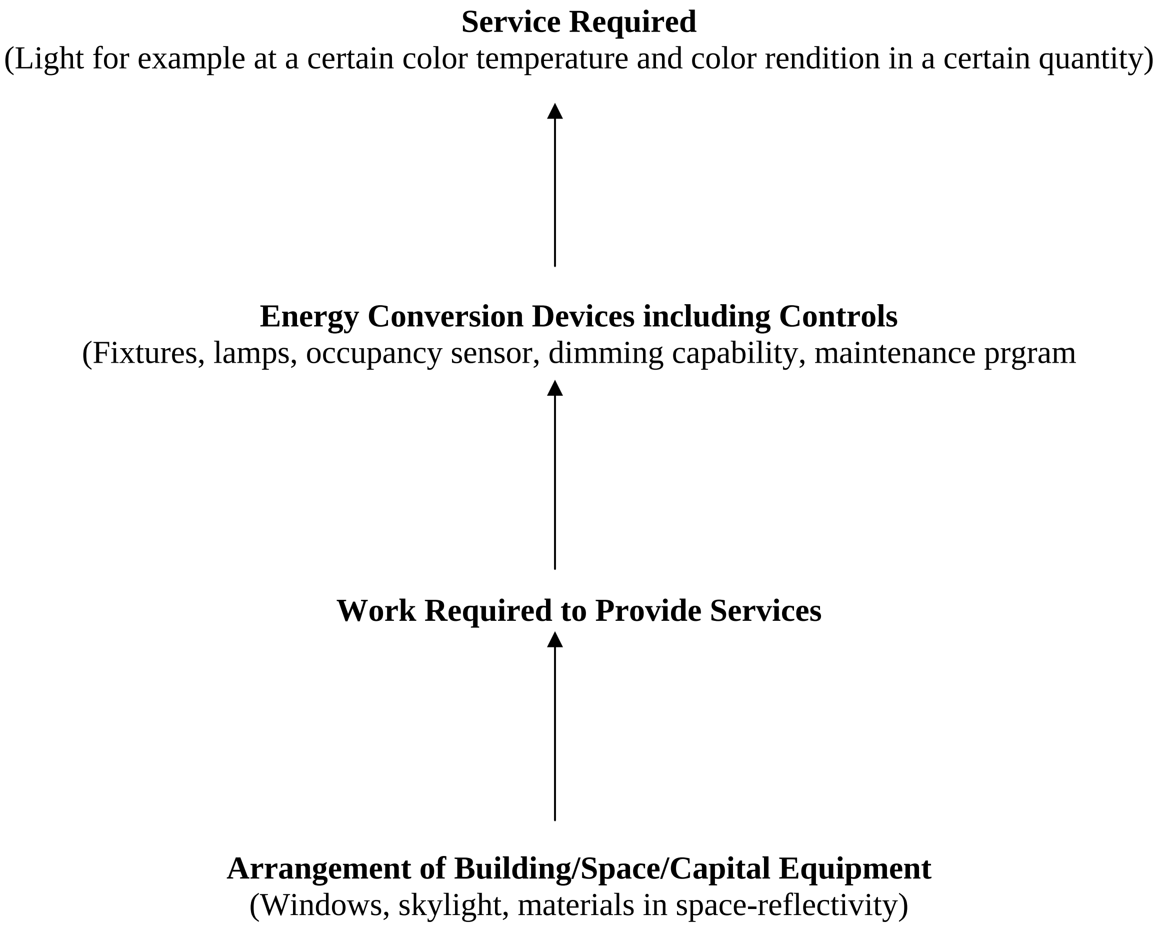
[3] The focus of this paper will be the electric power system but similar analysis could be done for the natural gas system and the transportation systems.

Exhibit 1: Relationship between Service, Work, and Energy (Lighting Example)



Service Required
(Light for example at a certain color temperature and color rendition in a certain quantity)

Energy Conversion Devices including Controls
(Fixtures, lamps, occupancy sensor, dimming capability, maintenance prgram

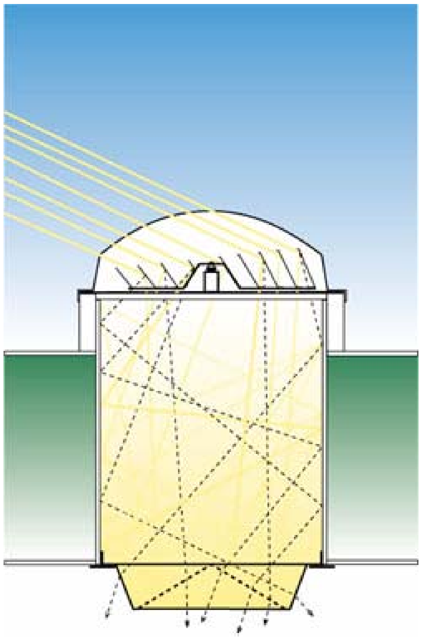
Work Required to Provide Services

Arrangement of Building/Space/Capital Equipment
(Windows, skylight, materials in space-reflectivity)

For example, light can be provided by the sun through windows or tubes that bring sunlight into buildings. These physical structures define, along with the task requirements, the amount of service that must added by artificial lighting. The only energy needed for natural light systems (see Exhibit 2) is that which is embedded in making and installing the product. When natural light is insufficient or of the wrong type for a particular application, artificial light is used to provide the illumination needed for the task at hand (whether it be ambience, reading or whatever). Thus the total energy needed for meeting a lighting service need is determined by how the space is set up, what can be done to the space and the effectiveness of the energy/lighting conversion system.

The systems viewpoint is not well understood among some energy modelers and most consumers. People often use wattage to describe the output of light bulbs and to define their lighting needs, which may have made sense when all light bulbs were incandescent and when they all produced a similar ratio of lumens per watt, typically 10 lumens per watt today. With the advent of fluorescents and other light bulbs with higher lumen to watt ratios, the use of wattage has become a misleading indicator of service, since to evaluate the service delivered one needs lumens not wattage.

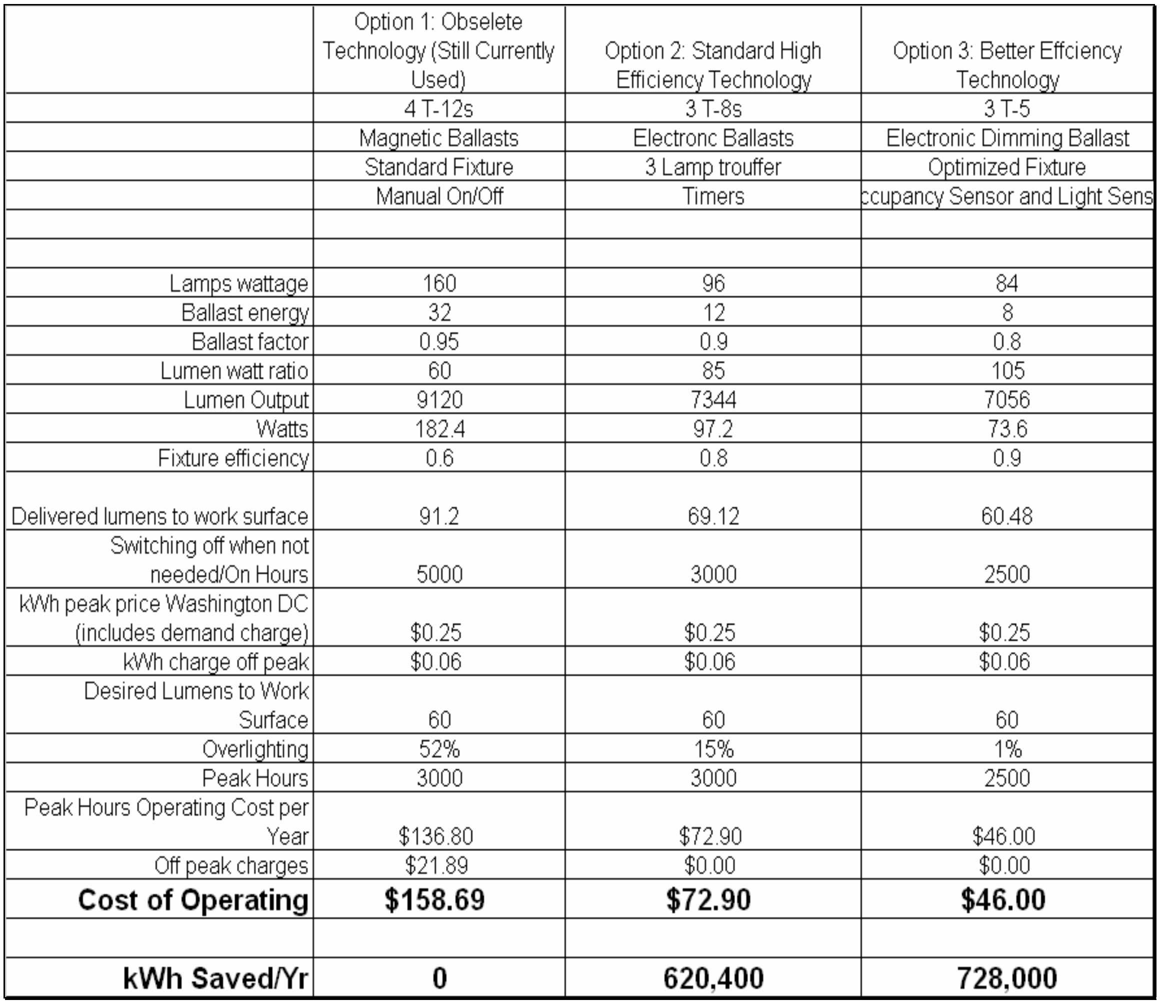
Exhibit 2: Natural Lighting Systems



Natural lighting brings sunlight into a building without using energy.

But even lumens, the light output of a lamp, in themselves, are a somewhat misleading indicator of service *since what really is desired are foot-candles at some particular* *location at some particular time(with perhaps a certain color rendering capability)*, not the output of light from a lamp (the technical term used by lighting professionals for a light bulb). Since light bulbs are always in a fixture and fixtures vary in the percent of lumen output that are directed to the task or location desired, the system efficiency depends not just on light bulb efficiency (lumens to watt ratios), but on fixture efficiency (which can vary from the 90% all the way down to 5%). Similarly, sensors now exist to assure light is only provided when needed, turning off the lamp when people are not present.

Exhibit 3: Three options for office overhead lighting



	Option 1: Obselete Technology (Still Currently Used)	Option 2: Standard High Efficiency Technology	Option 3: Better Effciency Technology
	4 T-12s	3 T-8s	3 T-5
	Magnetic Ballasts	Electronc Ballasts	Electronic Dimming Ballast
	Standard Fixture	3 Lamp trouffer	Optimized Fixture
	Manual On/Off	Timers	ccupancy Sensor and Light Sens
Lamps wattage	160	96	84
Ballast energy	32	12	8
Ballast factor	0.95	0.9	0.8
Lumen watt ratio	60	85	105
Lumen Output	9120	7344	7056
Watts	182.4	97.2	73.6
Fixture efficiency	0.6	0.8	0.9
Delivered lumens to work surface	91.2	69.12	60.48
Switching off when not needed/On Hours	5000	3000	2500
kWh peak price Washington DC (includes demand charge)	$0.25	$0.25	$0.25
kWh charge off peak	$0.06	$0.06	$0.06
Desired Lumens to Work Surface	60	60	60
Overlighting	52%	15%	1%
Peak Hours	3000	3000	2500
Peak Hours Operating Cost per Year	$136.80	$72.90	$46.00
Off peak charges	$21.89	$0.00	$0.00
Cost of Operating	**$158.69**	**$72.90**	**$46.00**
kWh Saved/Yr	**0**	**620,400**	**728,000**

Exhibit 3 shows the efficiency of three office lighting systems: lamps, lamp fixture systems, lamp-fixture-sensor systems, along with the cost of such systems per year. Clearly a systems approach allows a radical re-definition of energy requirements. Light is not alone in being a service provided by a set of intermediary products. Virtually every energy service requires a system for delivery, where components can vary in efficiency and the total work needed to meet the service need can be influenced. For example, a house's demand for heating and cooling will depend on the insulating capacities of its shell, the characteristics of its windows, and the efficiency of its system for producing and distributing heating and cooling. Doubling the insulation values of a house halves the need for heating and cooling. [4] A ground source heat pump can move six units of heat for every unit of electrical energy by capturing solar energy stored in the ground (Bernier, 2006)) and transferring it inside. Thus, a ground source heat pump, in combination with a powerplant that is 60% efficient (a combined cycle unit) and a super-insulated house can have a very high efficiency that can reduce the energy consumer for heating from a standard house about 90% (compare to a house with an 80% efficient gas furnace).

The Value Chains for Meeting Energy Service Needs

As discussed earlier, energy and energy using goods provide *services* that are delivered by *two separate systems* to customers, creating two sides to the energy system equation, demand and supply. The two sides have evolved very different organizational and institutional features.

The products and systems provided for energy using services are essentially are provided by independent businesses. Products generally pass from vendors of

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[4] Windows must also be changed out to increase insulating values and/or change shading coefficients..

components to original equipment manufacturers, that assemble final products, to distributors and then to retailers or contractors, that deliver products to end use customers. Other sorts of vendors, and occasionally banks or home financing entities, can also be part of this value chain.

On the other side of the meter lies the energy supply system, which consists of fuel suppliers, fuel transporters. power generators, transformers, transmission lines, switching stations, local power distribution lines, more transformers, and entities that operate these systems today (known as load serving entities), ratesettting commissions, Independent Service Operators (ISOs), and as well as original equipment manufacturers for these various products and a myriad of contractors that keep this system running.

Essentially, the two sides of the energy system are operated in entirely different manners. On the power provision side, *the above entities work together to alleviate the need for customers to plan, to finance, or to make intelligent investment decisions in purchasing end use products*. Entities on the supply side work to provide electricity *as a guaranteed service at specified voltages and with specificied voltage fluctuations and other power quality factors on an as needed basis.* This ‘GRID’ provides power to serve customers through normal weather and through times of weather fluctuation, sometimes dramatic, so that whether it is hot or cold power will be available (see Exhibit 4). The supply systems work to anticipate future economic and energy demand growth so that economic booms do not fizzle due to a lack of electricity. Electricity and natural gas are viewed as the life blood of the economic body and the supply system works to make economic units just as unconscious about whether there will be enough electricity available as the body is unconscious of whether it will have the requisite blood supply.

The supply system has made it easy for buyers of products that use energy to buy whatever they want.

Exhibit 4: Power Demand Fluctuates With Weather and Other Factors
(California)

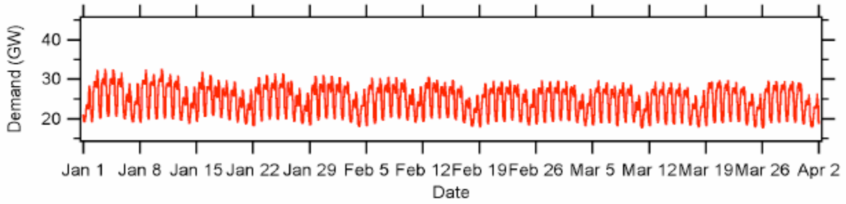

Figure 3.9 First Quarter 2001 Power Demand

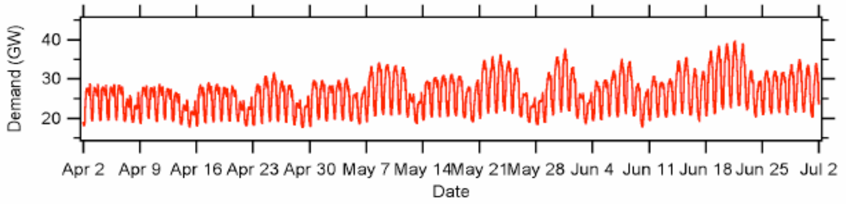

Figure 3.10 Second Quarter 2001 Power Demand

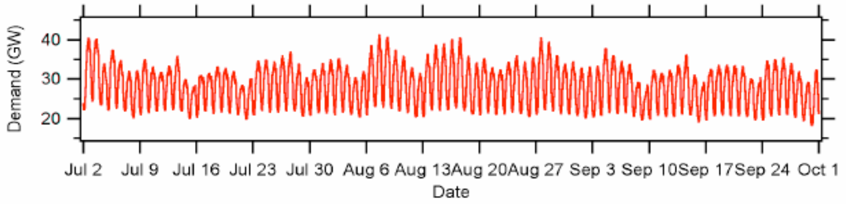

Figure 3.11 Third Quarter 2001 Power Demand

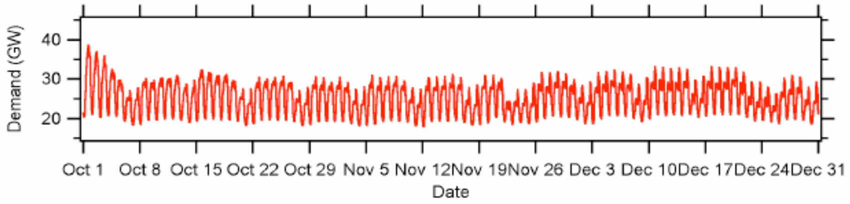

Figure 3.12 Fourth Quarter 2001 Power Demand

Power demand shows a strong diurnal variation of approximately 8 to 18 GW.

There are also strong seasonal variations. Note the high summer power demands

Thus the ‘GRID’ doesn’t just meet today’s demands for energy, but also provides future energy capacity so that users do not have to worry whether power and electricity will be available one, five or even ten years into the future. Procurement of power is assured. Financing for the system, including future needs, is provided through a complicated set of rules that assure that generators will be paid, that load serving entities will meet revenue requirements and that the grid will operate more or less smoothly even when there are plant failures (the grid bids for so called reserve margins and active spinning reserve). Operations are assured.[5]

Customers generally are billed for average costs of these services on an allocational basis. Thus, most residences just pay for kWh hours sold, based on the average cost of providing them. Many commercial and industrial customers are billed both for energy and for peak power used (in an attempt to assure that greater power users pay some of the cost for assuring peak power is available). In no cases, however, are true marginal costs used --- the allocations are based on accounting formulas that average out demand charges. Furthermore, the grid entities take care of all financing needed to purchase the upstream energy supplies. Whether a customer puts in a compact fluorescent (13 watts) or a incandescent (60 watts), the grid will finance the investment needed to serve the lamps, about $81 for the incandescent and $17.55 for the CFL (Exhibit 5). The underlying promise the GRID makes to customers is that it will be reliable and be there when needed.

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[5] The recent efforts in some regions to deregulate the power system at the generator level led to disruptions in some areas that focused attention on just how unusual disruption of supply has become in the world. Efforts to assure reliability under this new model are now moving towards planning decisions to purchase some much reserve capacity.

Exhibit 5: Supply Capital Required To Serve Two Light Bulbs Providing Same Service

			CFL at 13 watts	Incandescent at 60 watts
kW needed per lamp installed			0.013	0.06
Cost per kW total		$1,350	**$17.55**	**$81.00**
	Generation	$750		
	Transmission	$200		
	Distribution	$400		

In essence, the power supply system has been designed to form a *transactions bridge* for power users, in which the various entities that form the system perform a variety of intermediary functions for users of power, assuring that whatever they wish to ‘plug into the grid’ they can (Exhibit 6). Historically, the rationale during the evolution of the power system for this approach to creating a transactions bridge was that the power system needed economies of scale that could reduce the price of power and that to produce reliability was critical to social good[6]. Other means could have been used: for example, the buyers could have had to finance the full marginal cost of installing an item by paying a ‘full freight’ hook-up charge. But the facts are what they are: electricity has been treated as a social good available to all.

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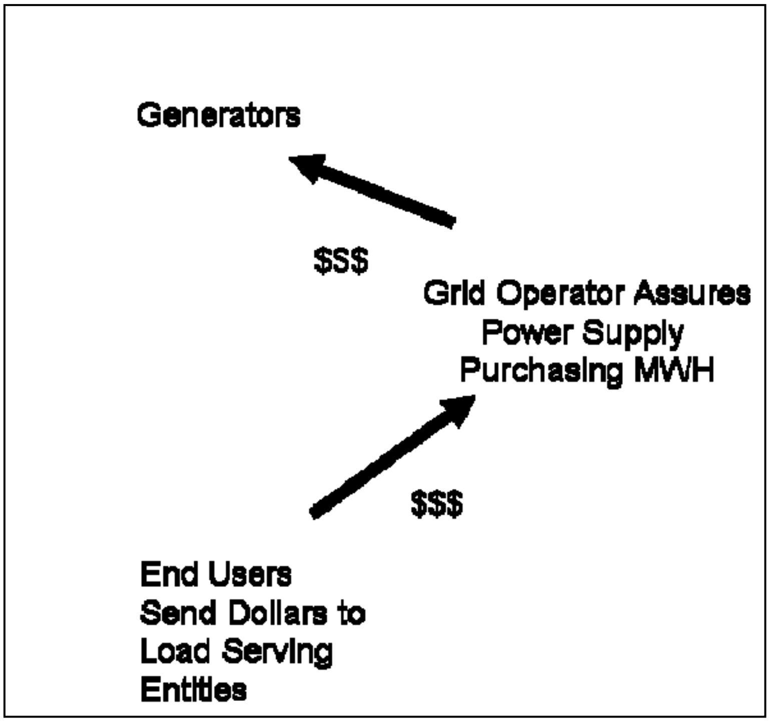
[6] The use of the terms Power and Light by many utilities was not accidental. Power companies where seen as bringing light to the world --- a light bulb is used as the symbol of a good idea for a good reason. In fact as late as the 1970s when this author moved to Chicago he received free light bulbs from the power company in the mail.

Exhibit 6: Transactions Bridge for the Supply Side



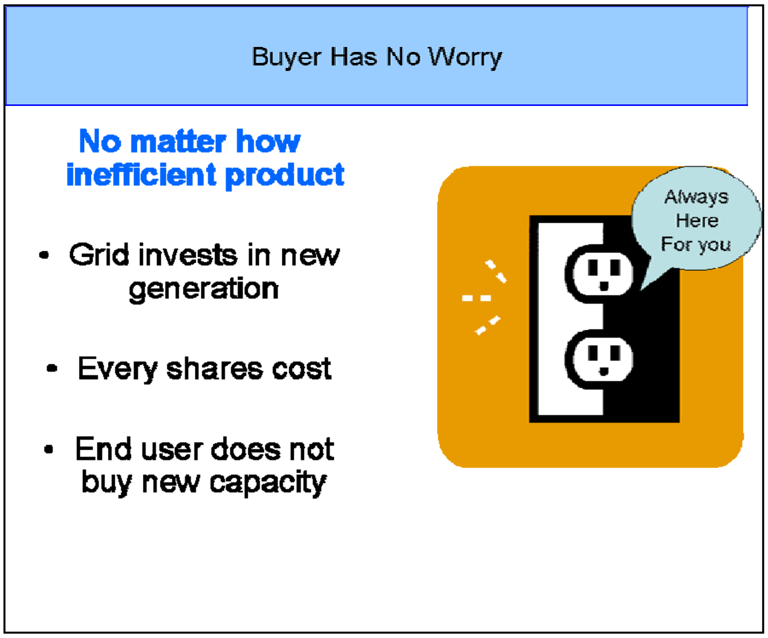
Generators

$$$

Grid Operator Assures
Power Supply
Purchasing MWH

$$$

End Users
Send Dollars to
Load Serving
Entities



Buyer Has No Worry

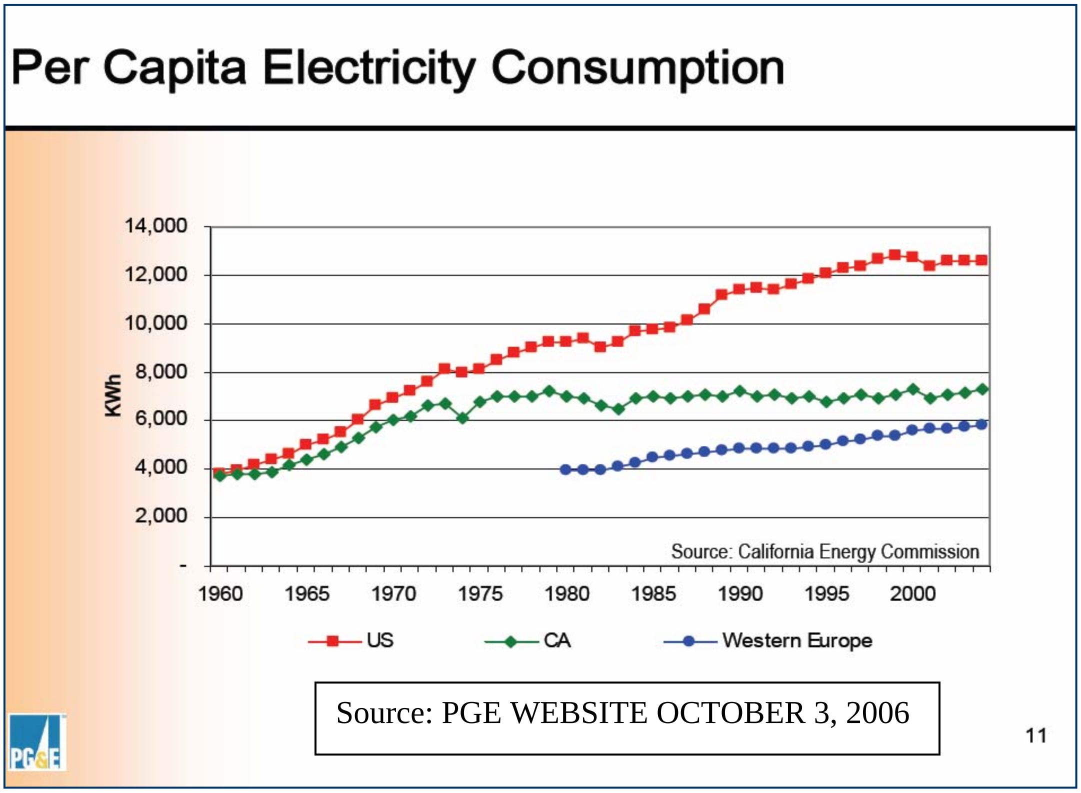
No matter how
inefficient product

- Grid invests in new generation
- Every shares cost
- End user does not buy new capacity

Buyers of electricity do not have to worry about the set of transactions required to assure reliable service. Society has created the social infrastructure to assure this (including in the ‘de-regulated markets that have emerged).

On the other side the equation, the users of power, those employing energy-dependent devices to provide services, have received little assistance from the grid. Integrated service planning (IRP) and demand side management (DSM) both attempted to provide end use customers with some help, in some locations, for acquiring more efficient products, under the correct theory that from the perspective of the energy system it makes sense to acquire the least expensive resources regardless of their nature. Such efforts, when vigorously pursued as they were in California, led to a different path of development than other regions (Exhibit 6).

Exhibit 6: California's Strong Assistance to End Use Customers Produced A Very Different Growth Pattern

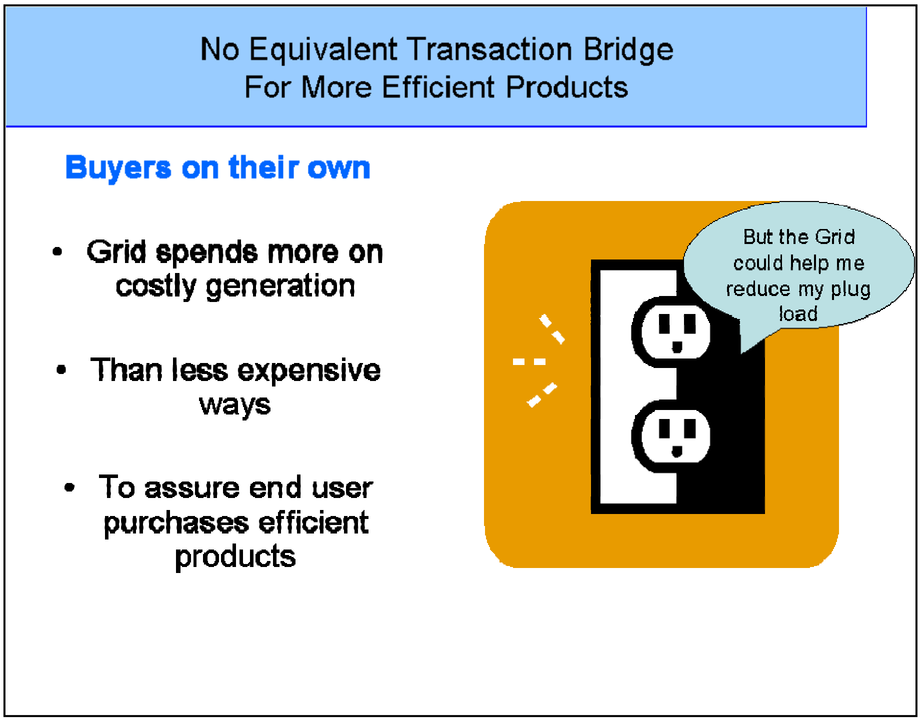


Per Capita Electricity Consumption

Source: PGE WEBSITE OCTOBER 3, 2006

But in practice, in most locations by and large, these programs have received a tiny part of utility spending, have come and gone in different years, have been subject to budgets that were limited and intermittent and, in at least many cases, received half hearted support from load serving entities.[7] The reality is that, by and large, customers have usually been on their own, with no equivalent transactions bridge to assist in the purchase of more efficient products (Exhibit 7).

Exhibit 7: One side of the energy system has lacked a transactions bridge



No Equivalent Transaction Bridge
For More Efficient Products

Buyers on their own

- Grid spends more on costly generation
- Than less expensive ways
- To assure end user purchases efficient products

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[7] There have been some important counter exceptions such as Pacific Gas and Electric, Southern California Edison, and Sempera, which in the hay day of DSM, provided significantly more resources to these DSM programs, although these too suffered budget limits and were not well integrated with supply option evaluation.

Understanding and modeling the different sides of the energy system requires understanding *that it is not a state of nature that the two sides operate so differently, with one side have a powerful transactions bridge and the other not*. The past evolution of the system was a product of social choices, *choices that can be altered in the future*.

CRITICAL FACTORS IN SIMULATING THE FUTURE BEHAVIOR OF THE ENERGY SYSTEM

Several factors must be considered carefully when seeking to realistically simulate the energy system: the purchasing behaviors of agents in the system; scale economies; innovation dynamics; the diffusion of innovation; lock out/lock in factors. Modeling the past behavior of the system that ignores the forces that created that behavior will be incapable of simulating energy futures in which the forces are altered by new policies or institutions that create new mechanisms and markets for products. Every effort must be made to create a modeling structure that realistically portrays these factors and sustain a flexible structure that allows changes to be made as knowledge grows.

Purchasing Behavior

Buyers, consumers, businesses and other organizations, are not calculating machines that estimate net present values for various decisions and choose those options which maximize profit adjusted for risk (DeCanio, 1998; DeCanio, 2006; Simon, 1972). Buyers are not all the same even within a given class such as commercial retail or single family homes. They differ in how they arrive at purchase decisions and on what influences their behavior (Kahneman, 2002). What people buy and how they buy it varies over time, as do the distribution systems that serve them. No single algorithm or modeling solution will work for all segments of a society, and no modeling solution is likely to remain static over longer periods of time.

Buyers operate on *the principles of habit, impulse and bounded rationality* (Simon, 1972). The abilities to perform calculations about the ‘True Costs’ of products varies, but is often quite limited (Kahneman, 2002). Motivations of buyers can be hard to discern and shifting. Long term trends may exist, but so do fads and erratic behavior.

The vast majority of all buyers do not use standard economic principles to choose products, estimating the ‘True Cost’ of a product (that is its operating cost, purchase price and the cost of capital) for deciding on options. The vast majority of buyers have a truncated options list, relying on purchasing what they have purchased before without undertaking even a casual survey of options. They are not investors but consumers. [8]

It would appear from anecdotal stories and experience that buyers choose products based on a perceived need or desire, usually purchasing what they have been buying in the past. For example, even if the last purchase someone made for a refrigerator was 18 years ago they will usually repeat their decisions now. Thus those who own top mounts usually buy top mounts, those who own bottom mounts or side by sides repeat those choices. The closest that buyers appear to get towards what economists believe is rationality[9] is to make a list of desired attributes/need that they check off, then choosing the least expensive product that meets those needs (EPA, 1992).

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[8] Thus even the improvements made by hyperbolic discounting, which in theory takes into account real behavior, is simply a forced application of a mathematical construct (discounting) on a behavior system most often unrelated to this arcane idea.

[9] The assertion that rational people would treat everything as an investment decision makes a strong value judgment that people want to operate in such a fashion. In fact, given the choice, most people do not want to behave as economists believe they should. Thus their behavior is not irrational as some would claim, but simply follows a different logic that the world pictured by economists.

How people define needs can vary through time and can be influenced by the behavior of others and by advertising.[10] Brand advertising works by making **THE BRAND** itself a desired attribute of the product. For example, Bayer aspirin advertises how their product helped a hard working Italian family, helping save the father's life, curing headaches for another family member, reducing shoulder pain for another. The punchline of the ad is 'what do you think I am going to choose when I choose an aspirin?'. *Bayer spends millions to create an artificial difference between their aspirin and that of competitors, to make Bayer aspirin and generic aspirin two different products.* Yet, according to medical authorities, there are no discernable differences in aspirin. [11] Here the goal of the advertising is to create an attribute 'of trust' so that the buyer will purchase a bottle of Bayer rather than a store brand such as CVS. For this 'benefit', the buyer pays about $7 per 100 versus $2 per 100 for the CVS brand (CVS, 2006). Oddly, many Bayer buyers will then revert to trying to buy the product for the least cost by going to a discount store with lower prices for Bayer. From the perspective of economics such results are impossible --- information is freely available and used by everyone.

Of course, some buyers occasionally consider tradeoffs between price, attributes and operating cost, especially for more expensive products which they perceive as having

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[10] Contrary to welfare theory as advocated by economists, most wants, desires and preferences are interdependent with those of others.

[11] Sometimes, generic versions of a drug have different colors, flavors, or combinations of inactive ingredients than the original medications. Trademark laws in the United States do not allow the generic drugs to look exactly like the brand-name preparation, but the active ingredients must be the same in both preparations, ensuring that both have the same medicinal effects. Resource: Office of Generic Drugs, Center for Drug Evaluation and Research, U.S. Food and Drug Administration (FDA), 5600 Fishers Lane, Rockville MD 20857.

high operating costs. But even in these situations their assessments are usually between pairs of attributes, one attribute against another attribute. The theory propounded by economists, that buyers use sophisticated financial analyses that project future operating costs, including future energy price rises and capital costs, future taxes, that they consider current and future investment opportunities and taxes on investment and then process all this information to estimate the net present values of various options and then choose the option with the lowest 'True Cost' simply represents a fantasy. In my twenty plus years in this field, I have never seen such an analysis done, not even at the most sophisticated companies. Of course, absence of evidence is not proof that such analyses are never done, but the evidence clearly suggests that at best it is a rare happenstance. But even complicated description of rationality would fall short of true economic rationality because to be truly comprehensive such an analysis would have to consider a range of risks and outcomes, each of which would have an 'expected value'. Furthermore to be truly rational would require assuring that the option space being investigated includes all possibilities. More often than not, important options are left out, even by those doing some kind of formal economic analysis. Pfeffer and Sutton in their book, *The Knowing-Doing Gap,* describe how companies constantly fail to do what they know is right because of a range of organizational and human failures.[12]

The hurdle rates used by companies and the implicit discount rates computed by economists attest to the fact that economic rationality (as defined by economists) is not in evidence in reality. Interestingly, although economists assert that buyers and agents act rationally, this author knows of no study by an economist in any field of endeavor that

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[12] Perhaps the oddest aspect of view that humans act rationally is that in any discussion with someone who holds this view if you asked them about the organization they were in they would not only be able to point out how irrational it was, but they would almost be certain to complain about it constantly.

actually shows that buyers are ‘rational’ as the term is defined by economics. It would appear that economists do not think such evidence needs to be developed.

Given the disparate behavior of buyers, energy models of the ‘fulfillment process’ (the term choice process is intentionally cast aside since the behaviors of the agents rarely appear to meet the conditions of ‘rational choice’) must be that the processes are:

1. **Disaggregated:** groups must be characterized in clusters of similar behaviors and segments
2. **Limited in analytic capability:** groups and sub-groups must be simulated on their actual skills in making judgments about reality and options
3. **Limited in scope of options considered:** groups must be limited in the range of options they consider, especially when systems are important in determining the amount of energy used
4. **Subject to change over time:** based on a range of factors, buyers must be modeled as shifting their needs and desires for buying
5. **Subject to discontinuous behavior:** buyers can be influenced to alter their behavior in unexpected ways under appropriate conditions.

Perhaps the most important thing that experience teaches us is *that buyers will generally do what is easiest.*[13] The greater the demands put on buyer to evaluate options, the less likely they are to buy into the process of making a purchase (Schwartz, 1992).

Scale Economics and Mark Ups

Microeconomics holds that most product areas have no scale economies, but the classical rising marginal cost curves of Economics 101. Most modeling systems in energy

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[13] This suggests that if the goal is to influence the buying behavior of real purchasers in the system, MAKE IT EASY.

assume flat cost curves, for reasons unknown. But according to Alan Blinder, in a path breaking book, *Asking About Prices*, 40.5% of the firms surveyed had falling marginal costs (Blinder, 1998). Blinder also claims that surveys done in other nations report similar results (Blinder, 2006). The results may seem shocking to microeconomists, but to businessmen they seem both intuitively obvious and experientially true. Readers of this paper should test this hypothesis by calling vendors and asking them for their quantity/pricing sheets or quotes. In the authors experience, no part or final product did not have a lower prices at larger quantity.

Declining marginal cost has serious implications for modeling energy systems. For example, for a model to be able to assess the economic implications of a energy efficiency standard, it must show the future costs declining since by definition to mass market will become the efficient product. Failure to include declining marginal costs analyses and models will overestimate the cost of the product and thus underestimate the economic value of the regulation.[14]

Declining marginal costs for volume has implications for current market prices in that high efficiency products are likely to be niche products and thus have a higher price than mass market products simply because they do not enjoy the same decline in cost per unit as the more common product. This means that the difference in the cost of the products are likely to be, in some part, caused merely by the relative sales of each, which is often just an accident of history.

For example, very few compact fluorescents (CFLs) are sold in the United States compared to incandescents light bulbs. CFLs cost about $2 per lamp while incandescents

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[14] Declining marginal costs are not the only aspect of lower costs for regulation. Dynamic innovation in response to regulation will often discover (or rediscover from the past) new means of achieving efficiency that are less expensive than those ‘on the table’.

cost $.60 per lamp. But if the quantities sold were reversed, how much less would CFLs cost and how much more would incandescents cost? [15] Perhaps if CFLs became the mass market product they would become less expensive per lamp than incandescents or at least a great narrowing of the difference in prices would occur.

Thus, if history makes a difference, as some economists claim (Hodgson, 2001), *breaking the habit that history* has may produce economically warranted outcomes. Raising prices of energy as a means of breaking habits may be one of the least effective means of gaining this outcome.

If marginal costs decline, as empirical evidence about quantity pricing for components would indicate, then prices cannot be set equal to marginal cost. In reality, as long ago as the 1920s it was disputed that businessmen even consider marginal cost pricing, but that they instead use average cost pricing with markups (Sfrarra, 19xx). [16] Typically mark-ups occur at the level of the manufacturer, the distributor, and the retailer, so that the final price of product can be four to six times the cost of making it. [17] Furthermore, niche products such as CFLs and energy efficient refrigerators often appear

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[15] Of course, the cost of an incandescent may be influenced by the fact that one company, General Electric, dominates the market with only two small competitors. How much does it cost to manufacture an incandescent? Only GE knows for sure.

[16] S http://en.wikipedia.org/wiki/Markup_(business)ome Customary Markup Percentages for Retail Businesses: Using the formula (price - cost) / price. New cars 15%; Used cars 75%: Electrical Appliances 30%; Clothing 50%; Trend Clothing 59%Cosmetics/Fragrances 75-80%; Crystal Ware 60%; Gifts and clocks 55%; Food Retailers 45%.

[17] Furniture Pricing: Wholesale and Retail Markups Editor's Rating ★★★★☆ A heated, but detailed, discussion of cost and pricing practices in the furniture trade. April 24, 2006 http://www.woodweb.com/knowledge_base/Furniture_Pricing_Wholesale_and_Retail_Markups.html; Most Googled sites show higher mark-ups for niche products, which of course means energy efficient products.

to have higher individual mark-ups. The efficiency of distribution does not appear in energy modeling. Yet if the structure of distribution can be altered, the absolute number of dollars added to products by mark ups can be reduced. The WalMart has changed the distribution system for many products, demonstrates how distribution efficiencies can influence the prices at which products reach customers.[18]

Considering declining marginal cost curves with the issue of multiple markups and it becomes clear that any modeling effort that does not model the full value chain cannot accurately determine how changes in it can alter outcomes of the system. A false picture of reality cannot be used to guide changes of reality. Later in this paper, when transaction bridges for energy dependent goods are discussed, these points become crucial with respect to properly modeling the impacts of such transaction bridges (which essentially will lead to price discounting by manufacturers and thus greatly influence the costs of products that buyers face).

Innovation (Dynamic Efficiency)

No one truly understands how innovation works, but it is clear that economic agents that are part of the economy produce it (it does not fall from the sky). Modern growth theory (Romer,1990) shows that a variety of endogenous factors help determine innovation: investment in academic and government research; patent systems; the structure of markets, etc. In *The Innovators Dilemma*, Christensen shows how the development of niche products can sometimes allow innovators to tunnel from ‘below’ to first capture a revenue stream, then gain steam to capture scale economies and disrupt markets (Christiensen, 2002). Burton Klein, in *Dynamic Efficiency*, documents how various industries did and did not create innovations that radically altered cost structures

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[18] Amazon represents another attack on conventional distribution that is reducing prices.

and markets for products, changing what is offered to customers and what is charged to customers (Klein, 1972). *Both books have a common theme: effective markets are needed for innovation to succeed*. The view that innovation depends primarily on research and development activity is simply a chimera. A corollary to these findings is that the less ‘economically rational’ or ‘motivated’ purchasers are in the market, the less innovation will be forthcoming. Conversely, the greater the purchasing of improved or better products, defined here as those products that produce equal or better service at lower energy use, the greater will be the production of innovation. *Effective markets create innovative markets*.

Modeling future energy productivity of energy-dependent products and energy supply therefore requires considering innovations that can be produced by a variety of sources and innovation that can be induced by more effective markets. Modeling here will necessarily be uncertain, but holding technology constant or assuming ‘business as usual’ improvements makes less sense. What is needed are tables of possible innovations, with variations in the timing of these innovations, increases in productivity and in their production costs. [19]

Diffusion of Innovation

A major question that simulations of the energy economy need to address is the problem of innovation and its diffusion. A large literature exists in marketing and in

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[19] Internal combustion engines have experienced steady improvements since their origins in the 1880s. However, the basic cycle still used is the Otto Cycle, which limits efficiency at peak load to less than 40% and in practice achieves 13% to 18% in cars. An example of a potential breakthrough that could increase the effective efficiency by a factor of four or more is the free piston engine: patent 6035347, Beale and Kopko, Free Piston Internal Combustion Engine (disclosure: author has financial interest in this patent). Many other such options exist and have the potential to radically alter the energy productivity of mobile vehicles and distributed generation. Another example of the potential for breakthroughs is the recent announcement in the fall of 2006 by Cree of an Light Emitting Diode (LED) that quadruples the lumen to watt ratio heretofore achieved.

technology studies about the diffusion of innovation. Generally innovation diffuses is the form of an ‘S’ curve, in which early penetration of markets is slow, followed by a steeper rise, than a trailing off of penetration. The most significant questions that must addressed for any new technology are the speed which diffusion will take and the ultimate penetration that will be achieved.

Most energy modeling efforts have ignored the diffusion modeling literature and have focused entirely on the ‘rational buyer’ model, tweaking results to reduce penetration to ‘coincide’ with actual data (DeCanio, 1997). This approach results in these models creating implicit discount rates that are significantly too high to actually represent real discount rates. By using an implicit discount rate paradigm, models like the National Energy Modeling system fixated on an early point in the diffusion curve and extrapolated it into the future. In essence, NEMS freezes an evolutionary process and makes it a prediction of the future. Because these modeling predictions are then used to evaluate policies, the modeling exercise becomes a sort of self fulfilling prophecy.

Many factors control the diffusion of a technology, some of which are subject to policy. For example, how much advertising does a product receive? How are social norms changing? The case of air bags represents an interesting case where changing social norms about safety greatly sped adaptation of this technology in mobile vehicles.[20] Relative costs are, or course, another factor, as are aspects of availability for products. WalMart’s decision to actively sell its customers compact fluorescents (CFLs) in the coming years certainly represents a social trend that will influence the penetration of that technology. While prices are likely to decrease with scale economies for the CFLs, the

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[20] Chrysler’s adverting of a head on collision in Virginia between two LeBarons with air bags in which both occupants walked away speeded acceptance of this technology greatly.

more important factor in determining penetration may be the positioning of the product by this important retailer. Constructing models in which diffusion curves can be influenced by the full panoply of factors that influence buying behavior will be critical to understanding the alternative penetration times that can occur. For example, if the Federal government decides to advertise Energy Star with the vigor that Bayer advertises aspirin, those products carrying an Energy Star label are likely to penetrate markets faster and further than otherwise would happen. The lack of a modeling structure that is responsive to shifts in society and policy and individual values has had the pernicious effect that research to understand how these processes work for energy dependent products has lagged.

The Menu of Policy Options Sets Requirements for What Models Must Do

Models must be responsive to changes in factors that policies can influence. For example, most modeling efforts have some capacity to show how raising prices for energy, by either taxes or cap and trade systems, will influence the behavior of the agents that make up the energy system. Fewer models have the capacity to consider how setting standards could alter system behavior. For example, the author knows of no model that would provide information about how a new standard for compressors would alter the evolution of the energy system by changing the costs of high efficiency compressors nor how such changes would alter the design and efficacy of products produced that use compressors.

A number of interesting policies have not been considered in energy modeling systems. One idea being developed by this author is that of transaction bridges for the demand side of the energy system. A transactions bridge for the demand side would have the GRID operators pay directly to producers of energy efficient equipment the avoided cost of energy, where avoided cost is some percent of the winning auction prices that determine power delivered to the grid. In essence, for agreeing to a fraction of the winning bid for kWh (and thereby always winning the auction), the manufacturers of efficient products who established that their products were, in fact, reducing demand on the grid, would always be ‘dispatched’ first and would receive payments for the *negakilowatts hours* produced. Exhibit 8 shows how this idea would work visually and how it differs form integrated resource planning and demand side management to which it is conceptually related. In fact, transactions bridges could be called Integrated Resource Markets that used demand reduction measures.

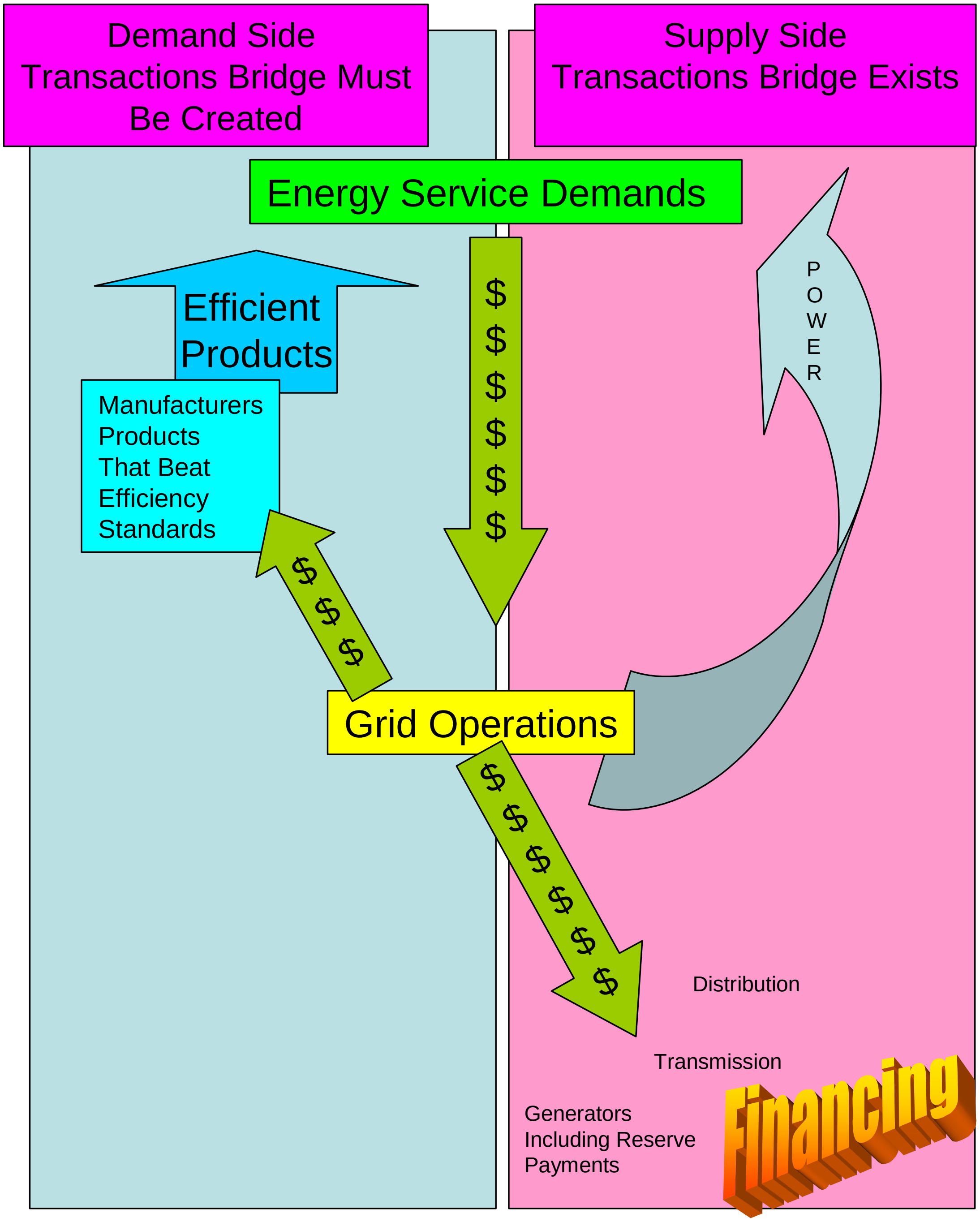
Another potential innovative policy could involve expanding the definition of infrastructure development. For example, geothermal heat pumps and their loops are a technology that can cost-effectively reduce energy used for heating, cooling and hot water by 75%. Unfortunately because of the high costs of installing ground loops and their long lifetime, the market for these systems has been reduced dramatically. The costs of installing the loops is often very high, mainly because the industry to perform such installations has not developed (due to the lack of demand because of high initial costs). By making the ground source loop part of the infrastructure that load serving entities own (as they own distribution systems and meters), a GRID could create a well functioning and effective market for the installation of loops. The price of loops would fall and their ownership would be the load serving entities that built them. Buyers would find their costs for heating, cooling and hot water equipment lower because the inside portion of these systems is actually less expensive to purchase and install than the standard equipment it would replace. Exhibit 9 shows how this would work for geothermal heat pumps.

Still another innovative policy would be to form a National Energy Purchasing Corporation that purchased power from carbon free or ultra low carbon generating systems using long term power purchase agreements (on the order of 20 years) and then resold the power. Such a policy would tend to produce scale economies for these power generating systems and create private sector incentives for technological development. A wide range of possible generating sources could be supported, including solar thermal, ocean currents, integrated gasification combined cycles with carbon sequestration and even compressed air energy storage. Energy models need to be adopted to modeling such strong attractors. Exhibit 10 shows the circulation of revenue in such a system.

Similarly, another interesting option would be to have load serving entities provide alternative financing to their customers for energy efficient systems, with a Green Credit card (Exhibit 11). Such credit might be a very effective means to increase systems efficiencies for buildings, for example. By allowing customers to use their bills to pay off long term investments, such financing cost facilitate transactions and provide tax benefits to customer (if the lines of credit were treated, for example, as home equity loads now are).

Energy model structure have been biased *to assume prices as virtually the only alternative that needs to be considered in creating energy futures and virtually nothing else*. The modeling community must move beyond such a limited if it is going to be able to effectively consider innovative options.

Exhibit 8: Transaction Bridges for the Demand Side

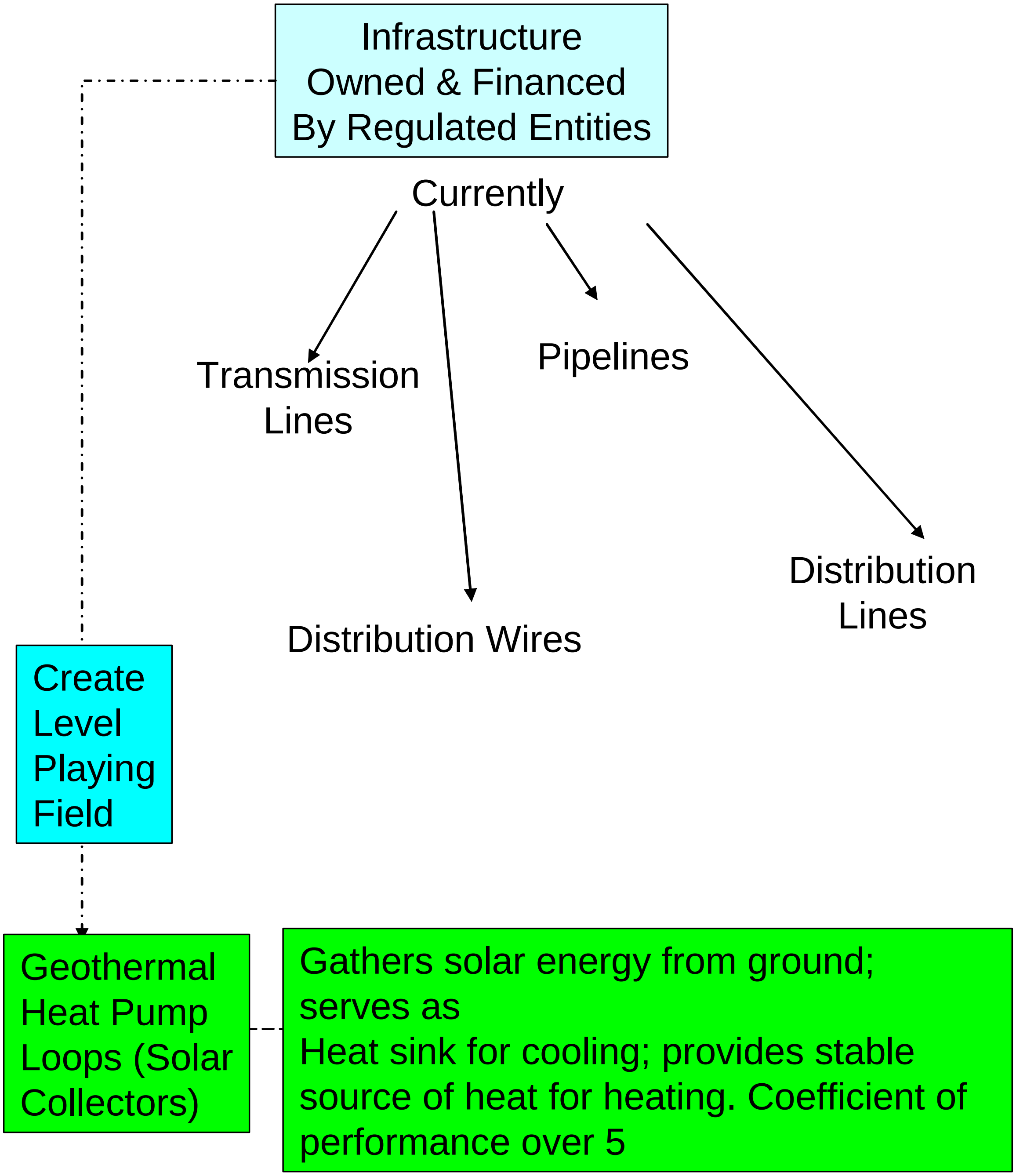


The grid currently provides power to end users, acting an transactions bridge that performs intermediary functions for generators, load serving entities and to transmission through a complicated system of rules and regulations. This guarantees financing for the providing entities through markets. By creating a transactions bridge on the demand side that provides payments directly to manufacturers of efficient products that meet service needs in the grid, overall economic efficiency can be increased as manufacturers reduce prices and take steps to make efficient products the norm,

Exhibit 8 (continued)

Differences between Transaction bridges and IRP/DSM	DSM & IRP	TRANSACTIONS BRIDGES
GOAL	Meet energy service needs at lowest resource cost to society	Same
GRID IMPLEMENTATION	Planning model Programs	Integral to grid operation
PROGRAM IMPLEMENTATION	Usually rebates with fixed budgets Starting and stopping Target usually buyers	Part of daily auction No budget limits No starting and stopping Target producers of products
BUYER MOTIVATION	Buy down Investment basis remains	Producers lower prices to sell Producers support to sell Lower prices New habit
PRODUCER ATTITUDE	Dislikes starts and stops Dislikes regulator control of rebates No direct profit	New revenue stream becomes major motivating factor in: *Marketing *Pricing *Distribution *R&D

Exhibit 9: Expanding the Infrastructure Responsibilities of Load Serving Entities to Include Geothermal Loops



Gathers solar energy from ground; serves as Heat sink for cooling; provides stable source of heat for heating. Coefficient of performance over 5

Exhibit 10: The National Energy Purchasing Corporation as a Strong Attractor to Eliminate Lock Out

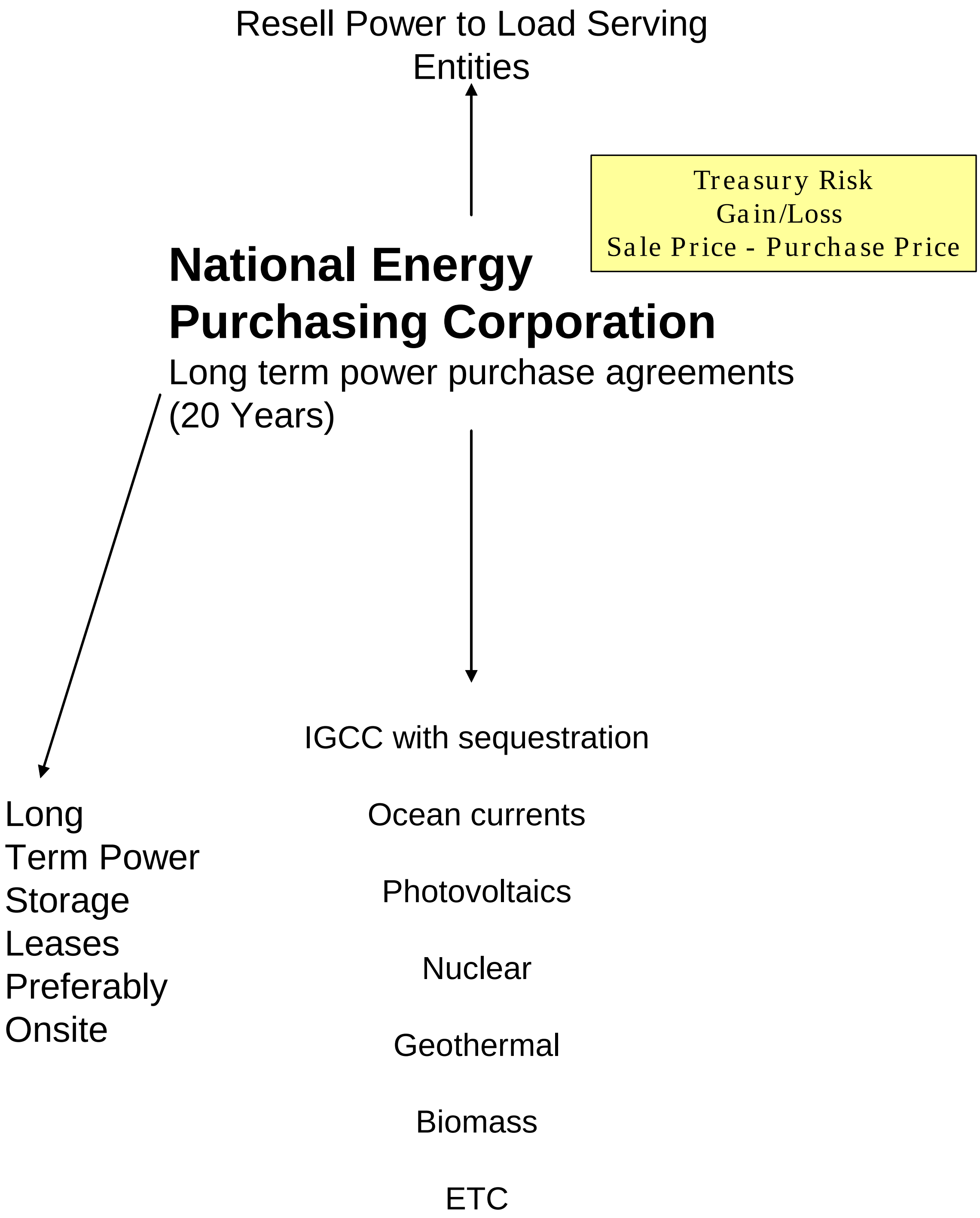


Exhibit 11: Load Serving Entities as Credit Facilitators

Finances Qualified Energy Savings Systems To Utility Bill On Favorable Terms

Modeling Must Consider All Factors in Mutually Interacting Manner

The energy system is a co-evolving system in which its past history plays an important role in the future trajectory of its evolution. The earlier discussions all point to the need for greater detail, for more attention being paid to how things work (not statistical representations of input-output), for more flexibility, and for more sensitivity to possible policy options that can change the structure of how things interact. Useful models must consider this range of critical factors, a more complete ensemble of policy options and their timing. Since the real world is in disequilibrium, care must be exercised in not assuming that what exists now is what will be tomorrow, even in the absence of policy change. Modeling should not be deterministic and modelers *need to be humble about what they can actually accomplish*. Importantly, they need to represent their results as scenarios and stories, not deterministic outcomes. Thus the outputs of modeling can, at best, be a set of self consistent inputs and relationships, which may or may not be a valid representation of what could, in fact, happen. The static world option is not the baseline (nor is projecting the past rate of change into the future). Use of models must examine various policies with various degrees of time evolving success, using uncertainty analysis as a means to develop research that sequentially reduces uncertainty. More care should be taken to create a scientific review of relationships, data and assumptions. The inability of the modeling community to agree on some ‘basics’ reveals much about the primitive state of our capacities to model and even agree on basic criteria for modeling today. When comparison between models is made, they resemble voting systems more than scientific scrutiny of reality, assumptions, and relationships. Such approaches to ‘science’ lead to everyone huddling in the middle, rejecting any new ideas that better explain the world.

Finally, when thinking about models, perhaps the goal should be to develop them so they are part of **part of a cybernetic control system,** in which they are constantly updated as part of an effort to decide how to evolve the system, rather than as a benefit-cost tool that allows ‘hard options’ to be evaluated and then chosen. The dismal record of energy modeling should caution us on taking their results too seriously. Modeling should be recast, not as a fortune telling system, but as an endogenous means to help create and think through new ideas for moving the system where society desires it to go.

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