

Restructuring our electricity networks to promote decarbonisation

**Decentralization, mass-customization
and intermittent renewables in the 21st Century**

Shimon Awerbuch

Tyndall Centre Visiting Fellow
SPRU - Science and Technology Policy Research
University of Sussex
Brighton, UK
Email: s.awerbuch@sussex.ac.uk

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CONTENTS

ABSTRACT	3
I. INTEGRATING DG/RE THROUGH INFORMED, DECENTRALIZED ELECTRICITY NETWORKS.....	4
OVERVIEW.....	4
THE ROLE OF THE NETWORK IN PROMOTING DG AND ECONOMIC EFFICIENCY.....	6
II. NEW WINE — OLD BOTTLES NEW TECHNOLOGIES REQUIRE NEW SUPPORTING SYSTEMS	12
III. THE VIRTUAL UTILITY CONCEPT	15
NEW ACCOUNTING MEASURES ARE NEEDED TO EVALUATE THE VU.....	17
IV. THE STRUCTURE OF DECENTRALIZED ELECTRICITY NETWORKS.....	18
<i>Responsibilities of Network Participants.....</i>	<i>20</i>
<i>Discrete Load-Matching: Back to the Future.....</i>	<i>23</i>
<i>Electricity Mass-Production.....</i>	<i>23</i>
<i>Is It Cost-Effective? Valuing DG in the context of decentralized networks and the VU</i>	<i>24</i>
<i>Options-Based Approaches.....</i>	<i>24</i>
<i>Intermittency and Efficiency.....</i>	<i>26</i>
<i>Discrete Load Matching of Dispatchable Applications.....</i>	<i>27</i>
<i>The Value of Backup power and other ancillary services in a decentralized system</i>	<i>28</i>
<i>The Role of bilateral Electricity Markets in Fostering Efficiency.....</i>	<i>29</i>
V. HOW TO EFFICIENTLY MEET EUROPEAN RET TARGETS INCENTIVE REGULATION AND THE NETWORK OPERATOR	31
<i>Attaining RET Targets with A Three-part Tariff:</i>	<i>32</i>
<i>Giving the NOs A Stake in Fostering System Improvements</i>	<i>33</i>
<i>Meeting RET Targets.....</i>	<i>34</i>
VI. THE ROLE OF NETWORK INFORMATION	34
<i>The Value of Information.....</i>	<i>37</i>
<i>Decentralized Networks: Plug ‘n play Electricity?</i>	<i>39</i>
VII. CONCLUSIONS.....	41
REFERENCES	43
ANNEX: NETWORK REVENUES UNDER A THREE-PART TARIFF.....	47
<i>Total Network operator Revenues</i>	<i>49</i>

ABSTRACT

In most EU countries *electricity market liberalization* means that generation has been deregulated and that at least *some* customers can choose from a number of suppliers, all of whom may purchase power in the same centrally-controlled market. Restructuring has ignored electricity networks, which in many countries operate under governance structures, operating protocols and pricing policies that represent an unimaginative reshuffling of former monopoly era practices. Properly organized, however, networks can help create efficient markets thereby *unlocking* the promised benefits of market restructuring.

European energy policy emphasizes energy diversity and deployment of renewable energy technologies (RET) and distributed generation (DG). While electricity networks are essential in efficiently attaining these objectives, the liberalized systems that policy makers created can only deliver centrally purchased commodity electrons. They cannot deliver desired energy efficiency or diversity, nor can they promote the deployment of RET and DG. Most European network operators have no role and no incentives to induce generators to efficiently locate and no incentives to promote the efficient delivery and use of electricity.

This paper describes a set of decentralized network operating protocols designed to enhance the efficient functioning of electricity markets in liberalized environments characterized by the diffusion of distributed technologies. The protocols rely on strict bilateral contracting for power as well as several ancillary services; they eliminate AGC dispatch, and other centrally provided services. This electricity production system incorporates the ideas of mass-customization as compared to the mass-production paradigm that currently governs electricity production and distribution.

Moreover, with effective governance and incentive regulation, *intelligent* decentralized networks can efficiently exploit intermittent renewables and enhance energy efficiency in ways that make current DSM and efficiency efforts seem feeble. This paper argues that there exists a strong and widely overlooked connection between the way we organize, regulate and operate our electricity grids and our societal objectives for decarbonization and energy sustainability. It is widely recognized that the way we run our power networks directly affects the functioning of wholesale and retail electricity markets. Much less well understood is the idea that given proper governance, regulation and tariff design, we can transform the network operator from its lackluster network-caretaker role of today, to a vital active leader and promoter of energy efficiency and the diffusion of conventionally-fired and renewables-based DG.

Today's network protocols are based on mass-produced electricity to meet an agglomerated load curve. At any moment, this load consists of millions of individual transactions with vastly different values and needs. *Informed*, decentralized networks create efficiencies by exploiting such value differences principally through their ability to support the potential matching of wind and other intermittent resources with intermittent or "dispatchable" loads. This drastically re-conceptualizes traditional network processes and changes the traditional roles and responsibilities of all network participants, which in turn leads to more efficient pricing for backup power and other services, while exploiting the unique characteristics of intermittent Rest.

Network operators are the essential market facilitators in any liberalized electricity system. With proper governance and regulation, including a three-part *balanced incentives* network tariff discussed in this paper, network operators can play a pivotal role: they can help facilitate electricity transactions, reduce transactions costs, create open, robust markets and promote energy sustainability all of which combine to enhance the value of commerce along the network. This is the contribution we should expect future network operators to make to society.

I. INTEGRATING DG/RE THROUGH INFORMATED, DECENTRALIZED ELECTRICITY NETWORKS

Overview

The term *electricity market liberalization*, over-promises. In most EU countries *liberalization* means only that generation has been deregulated and that some or possibly all customers can buy electricity from a number of suppliers, all of whom provide the same commodity electrons usually purchased in the same centrally-controlled market. Restructuring has ignored the electricity network. Properly organized power networks can help create efficient markets thereby *unlocking* the promised benefits of restructuring. Networks in many countries are owned or controlled by governments. However, even where *for-profit* investor-owned firms run them, networks operate under governance structures, operating protocols, and regulatory and pricing policies that represent an unimaginative reshuffling of former monopoly era components and practices. Day-ahead bidding may have replaced merit-order dispatch, but the system largely rests on outmoded practices including postage-stamp pricing that are centrally-controlled and administered by not-for-profit power exchanges.

European energy policy places considerable emphasis on energy diversity and the deployment of renewable energy technologies (RET) and distributed generation (DG) to help displace older, inefficient, high-emitting generators. Electricity networks are essential in efficiently attaining these objectives. The liberalized systems that policy makers created, however, can only deliver commodity electrons that are centrally purchased— pool style— under complex bidding rules. They cannot deliver energy efficiency or energy diversity and security. Neither can they promote the efficient deployment of RET and DG. Network operators have no role and worse, no incentives to induce generators to efficiently locate new supply sources and no incentives to promote the efficient delivery and use of electricity.

This paper explores a different set of the ideas for organizing and running transmission and distribution networks. It describes a set of decentralized network operating protocols and tariff-structures designed to enhance the efficient functioning of electricity markets in a liberalized environment characterized by the diffusion of distributed technologies. The protocols rely on strict bilateral contracting for power and other ancillary services. This conceptualized electricity production system creates a set of operating principles that incorporate the ideas of mass-customization as compared to the mass-production paradigm that currently governs electricity production and distribution. With effective governance and regulation, including specifically formulated *balanced incentive* tariff structures, *intelligent* decentralized networks can play an important role in accelerating the deployment of DG and RET. Such incentives enable “informed” decentralized networks to become active partners that will help us exploit intermittent renewables and enhance energy efficiency in ways that make current DSM and efficiency efforts seem feeble.

Today’s network protocols are based on mass-produced electricity to meet an agglomerated load curve. At any moment, this load consists of millions of individual transactions, all with vastly different values and needs. Clearly electricity required to run an agricultural water pumping demand is not the same product as electricity used for delicate microchip production.

Informed, decentralized networks create efficiencies by exploiting such value differences principally through their ability to support the potential matching of wind and other intermittent resources with intermittent or “dispatchable” loads. This drastically re-conceptualizes traditional network processes and changes the traditional roles and responsibilities of all network participants. For example, the decentralized network scheme requires loads— not network operators— to deal with supply-intermittence. It also requires loads to procure their own load-following and reactive power under the principle that decisions are best made by entities closest to available information. This leads to more efficient outlays and pricing for load following, backup power and other services, while exploiting the unique characteristics of intermittent renewables.

Loads have better knowledge of their moment-to moment power and back-up needs than do system operators, an idea that goes back to Richard Tabors’ seminal [1981] work. Water heating for domestic and commercial application does not need backup power in the same way, as does microchip manufacture. Yet today’s centralized network makes it virtually impossible to provide appropriately priced reliability. Reliability has the characteristics of public goods such as mosquito control— which is difficult to provide to one customer while simultaneously withholding it from its neighbor [See: S. Awerbuch, L. Hyman and A. Vesey, (hereafter A-H-V), 1999, Chap. 6].

In economic terms, this means that reliability cannot be efficiently provided through market mechanisms. This potentially creates enormous welfare losses. Half the network’s loads pay too much for spinning reserves and backup. The other half wants more. Both suffer welfare losses. Informed networks allow loads to contract and order their own electricity. Taking this idea further, it implies that individual applications such as refrigeration systems or water heating and pumping systems can “order” their own electricity at optimal times thereby creating efficiencies that are hard to conceive in today’s mass-production-based electricity delivery system.

This paper proposes a set of decentralized network protocols that serve to enhance efficiency, energy diversity and the delivery of new, customer driven products. The essential elements of this system include:

1. Establishing for-profit network operators (NO) that both own and operate the network;
2. The NO is regulated under an incentive or pure price cap ($rpi-x$) system;
3. NO revenues are produced by a three-part tariff that charges loads for access and throughput. There is also a set of (zonal) congestion charges and possibly a locational charge to suppliers, although these do not accrue to the NO;
4. The three-part tariff provides a set of *balanced incentives* that induce the NO to:
 - a. Adequately maintain the system
 - b. Provide sufficient capacity and increase access where needed;
 - c. Make technology-neutral capacity expansion decisions: e.g. it will contract for DG if this can provide voltage support or access capacity more efficiently than line extensions.
 - d. Use financial incentives to encourage new loads at appropriate network locations. This *may* require “bolt-on” or special incentives to promote RETs

- e. Efficiently utilize existing assets
 - f. Develop new market-driven products
 - g. Reduce system transactions costs
 - h. Enhance the value of commerce along the network
5. *'Informating'* the network to permit parallel information flows along with energy flows;
 6. Establishing a system of strict bilateral contracting between loads and suppliers. There is no central power exchange except as may be required for initial transition or as a provider of last resort if necessary;
 7. A given service location will likely consists of several distinct loads, which can be separately metered and served: e.g. a production plant may require high-value electricity for process and lower value electricity for water pumping/heating or for space heating. These loads can be served by different types of suppliers whose costs and other characteristics best match the needs, e.g. intermittent wind can be used to serve intermittent or "dispatchable" loads such as water heating or pumping operations.
 8. Loads procure their own base-load, load-following and reactive power. Loads also contract for backup power, under terms that suit their needs. Some loads may find it more cost-effective to have no backup.
 9. If contracted base-load and load following power is lost, the intelligent network immediately sheds the particular load (e.g. water heating at the plant) unless that load switches to its contracted backup providers. System intelligence precludes a load from "leaning on the system." The result is that generator intermittency becomes less of an issue for the NO. Costly standby and idle reserves¹ can be significantly reduced or possibly eliminated enhancing overall system efficiency
 10. This set of protocols places the burden of intermittency onto loads, which are in the best position to deal with it. This in turn relieves the NO from most traditional central AGC (automatic generation control), system balancing and related functions and allows it to focus on the strategic aspects of service provision. The NO must still perform residual system regulation functions and monitor line losses— functions that individual loads cannot effectively perform.

The Role of the Network in Promoting DG and Economic Efficiency

Policy makers view networks primarily as a means of transporting electricity. However, the network's traditional role of moving low-cost power from outlying areas to load centers has been supplanted by a significantly expanded set of requirements that now includes facilitating wholesale competition and improving reliability through resource pooling [Awerbuch, Crew and Kleindorfer, 2000]. Emerging liberalized markets increasingly rely on effective *meshed*

¹ In modern accounting parlance these are *non-value-adding* activities

power networks² with diverse capabilities and responsibilities. In an environment likely to be characterized by a large number of renewable and conventionally fired distributed generation (DG) technologies, properly “informed” networks, [A-H-V, 1999, Chapter 4] appropriately organized and regulated, become a crucial market-facilitating element in any liberalization (restructuring) policy.

New technologies enable us to consider the prospect of a reconceived electricity production and delivery system that incorporates 21st Century concepts of quality and efficiency. This transformation to an open-architecture network, with few centralized control functions cannot take place without appropriate network organization and pricing policies under incentive regulation. The decentralized network becomes an essential market-making entity that increases the *value* of power transactions and the *number* of power suppliers. This, in turn, enhances competition and benefits consumers through lower electric prices and market power mitigation.³ Decentralized networks that rely on market mechanisms as opposed to traditional centralized dispatch can serve a wide range of market needs and create the infrastructure for innovation and new services not yet conceived.

Network operating and governance policies in many countries are pretty much relics of a bygone era. They hinder innovation and do not promote efficient utilization of existing investment. For example, widely used postage-stamp rates do not induce generators to locate in such a manner as to reduce congestion, thus implicitly failing to exploit the advantages of decentralized RET and conventional sources that can locate close to loads.⁴ By contrast, properly designed access charges under price-cap regulation can recover fixed network costs more efficiently while enhancing the value of DG/RET.

Network policies and architecture directly affect the economics of RET/DG, some of whose costs have been falling sharply. Open *non-discriminatory* access is essential to help meet EU renewables targets. The European Parliament recognizes this, but relies on regulatory mandates that not-for profit network operators have little incentive to efficiently implement. The EC Directive requires Member States to ensure that network operators “guarantee” transmission and distribution of RET-based electricity, as long as this does not “exceed” grid capacity or “prejudice” grid reliability and safety.⁵

² Walt Patterson [2003] presents the concept of *meshed*, two-way network configurations, as differentiated from traditional *radial* or one-way networks.

³ Market power is an important contributing factor to the California problems; e.g. see: Harvey and Hogan [2001].

⁴ Under these tariffs, DG located close to loads receives no particular credit even though it alleviates congestion. DG output is subject to the same tariffs as a nuclear plant located hundreds of miles from load centers. See: European Union, [Oct. 2000].

⁵ Amendment 7, Article 7, paragraph 1 of the Report provides: “Without prejudice to the maintenance of the reliability and safety of the grid, [*and within the limits of the grid's capacity*], Member States shall take the necessary measures to ensure that transmission system operators and distribution system operators in their territory guarantee the transmission and distribution of electricity produced from renewable energy sources. They may also provide for priority access to the grid system of electricity produced from renewable energy sources. When dispatching generating installations transmission system operators shall give priority to generating installations, using renewable energy sources in so far as the operation of the national electricity system.

Managers of today's not-for-profit network system operators see their role as "maximizing system reliability," possibly "at the customer's expense. [A-H-V, 1999, p. 31]." Networks are administered on the basis of operating procedures designed by IEEE and other engineering committees. These procedures have never been subjected to a market test that rewards better asset utilization *and* higher kWh throughput [A-H-V, 1999, Chapter 3]. Subjecting these standards to a market test will create the framework for innovation that may produce higher throughput *and* better asset utilization. For example, engineering standards may suggest that "x transactions per hour" or "y kW of load" is "safe." A manager with no profit incentives will find a still lower limit to be even "safer" and more desirable [A-H-V, 1999, Chapter 3]. Why do otherwise in the absence of market incentives? These create the soil that will sprout innovative new processes, protocols and technologies that increase *both* safety and throughput.

The EU's implementation mechanism for open access and RE targets relies heavily on the strong European tradition of cooperation between the private sector and government. This tradition notwithstanding, appropriate incentive regulation undoubtedly provides a more efficient approach. Pricing schemes that reward network operators for increasing access and kWh throughput—the essential network services [Harvard Electricity Policy Group, April 2003]—are more likely to induce innovative ways of providing access and opening markets, all of which enhances competition among electricity producers and yields lower electric prices. Subsequent sections of this paper discuss a three-part tariff that helps efficiently recover network costs, while providing independent grid operators the inducement they need to actively pursue strategies to insure the availability of adequate transmission capacity as well as generation capacity, notwithstanding the fact they these operators do not own any generation.

The real impact of RET targets and open access requirements is not limited to increasing the share of renewable energy. In the longer run, these policies can help promote robust, competitive electricity markets and enhanced energy diversity and security. The network operator plays a pivotal role in creating these outcomes. Administrative fiat may induce network operators to increase RET deployment, although effective economic incentives will work better. Properly regulated and incentivized, for-profit NOs are undoubtedly best suited to promote effective RET deployment, to exploit the network's capabilities and to extract a wide range of efficiency benefits for consumers, while creating service options not yet conceived.

Power grids have always functioned under a highly organized and centralized set of operating protocols. In spite of the dramatic changes taking place in the industry, many observers seem to think that this must continue as a physical inevitability. Bergman, *et. al.* [CEPR, undated] explicitly promote this view, arguing that power networks "require orderly arrangements for the dispatch of generating plant," which in turn requires a *system operator* to "oversee" the process of scheduling plants. This is "technically necessary," they observe, to insure that the lowest cost generating plants are used thereby reducing total system costs.⁶

⁶ Indeed as structured today, system loads are indeed independent, connecting and disconnecting at will with no reference to how they affect the rest of the system, which must then respond accordingly to maintain stability. This paper proposes that loads be included as dynamic system participants.

Economists see the world differently. Central planning is a poor substitute for effective markets. Twenty-five years ago, Milton and Rose Friedman [1980, p. 12-13]. marveled at the ability of markets to efficiently deliver lowly lead pencils to consumers. This requires that a highly diverse set of raw materials including rubber, wood and graphite, produced by thousands of people from California, across the globe to Indonesia and Ceylon, arrive at the production facility when needed. The finished product is then shipped great distances to schools, super-markets and convenience stores, stationery shops and airport and city newsstands. Remarkably, there never seems to be either a glut or a shortage of pencils. What is even more astounding, is that no one sitting in a central office ever gives orders to the thousands of people in those many lands who produce the materials that end up in the pencil.

Friedman's ubiquitous 2-cent pencil holds important lessons for network organization: Adam Smith's *invisible hand* is probably more effective than centrally-planned and controlled economic dispatch.⁷ Many of the world's centrally planned economies collapsed in the late 20th century, replaced by the idea that freely functioning markets are more efficient. Indeed electricity market liberalization stands on the idea that markets work better than regulation. The notion of electricity markets and market efficiency is not limited to the delivery of commodity electrons. Future electricity markets will likely include markets for delivery of electricity services, not merely for commodity transactions in anonymous units of ephemeral electricity. This might include markets in contracts for use of electricity *assets*.⁸ Contracts for use and services may well be a key mechanism by which decentralization fosters decarbonization.

Ironically, in the case of the network operator, who plays a pivotal role in efficient electricity delivery, policymakers seem widely distrustful of markets and their ability to effectively deliver the needed functions.^{9,10} Today's centrally driven network operating protocols,

⁷ *Economic dispatch* is the traditional procedure by which network operators order generators to produce power in what is usually called their "merit order."

⁸ This could transform existing fledgling energy services businesses in the US and other countries into effective markets that allow load owners for example to contract with an experts to install, maintain and pay all energy charges for a lighting, refrigeration, heating and other systems.

⁹ Indeed Nobel Laureate William Vickery, demonstrated 30 years ago that with appropriate real-time pricing under a system that connects loads and suppliers, electricity supply-demand would be in constant equilibrium [** cite **].

¹⁰ Kleindorfer [2004] and others similarly exhort policy makers to abandon not for profit or cost-service regulated system operators in favour of profit making entities with a stake in the success of the grid's operation that can "promote transmission as a business."

Kleindorfer argues that current models of quasi-public, not-for-profit System Operators have led to under-investment since a not-for-profit operator lacks accountability to current and future investors, and is not focused on innovation to meet customers' needs. If this model continues so will the current trends of anemic grid investment.

This includes designing regulatory incentives for grid performance, to reward success and penalize failure. The industry must move from its current cost of service regulation to performance-based rates that recognize the central role of investments in reliability as well as congestion mitigation.

vestiges of bygone eras, cannot support an increasingly dynamic electricity production and delivery process. In addition to new operating protocols, the network of the future requires radically new regulatory regimes, as well as governance and tariff structures.¹¹

This paper describes a set of decentralized, market-driven protocols for network operation designed to enhance the efficient functioning of electricity markets in liberalized environments likely to be marked by a proliferation of DG technologies. The term *market-driven* implies a network operating regime based on market forces as opposed to engineering control of the network. In addition, the paper discusses a specifically designed three-part tariff structure that efficiently recovers network costs while it also induces grid operators to efficiently promote the diffusion of renewables. The tariff rewards the network operator for increasing the essential network services— access and peak capability. Combined with mandated EU renewables targets, this *efficiently* incentivizes grid operators to increase access for RETs along the network.

This paper proceeds as follows. The next section uses examples from manufacturing and elsewhere to illustrate that new technologies, such as RET/DG, cannot be exploited without new infra-structure and supporting systems. I revisit this idea throughout the paper to argue that current policies aimed at making RETs and other distributed (and intermittent) generators resemble centrally-dispatched gas turbines and coal plants is ineffective. Rather than new research on how to control and dispatch these new process technologies, the electricity system requires new decentralized operating protocols that accommodate them.

Next, Section III describes the Virtual Utility (VU) concept and its relation to the decentralized network. The Vu is widely and improperly interpreted as a justification for implementing unnecessary “command and control” technologies to connect disparate

The currently popular system operator model cannot endure in the long run, as it is not accountable to either capital markets or customers, i.e., it does not face the consequences of either poor investment choices or poor control and operating performance. In contrast, a fully divested transmission company has increased incentives to invest wisely. Their investment decisions directly affect their "bottom line." The profit motive driving investment ensures that investors will seize opportunities before others take advantage of the possibility to reap potential rewards. This insures that desired competition between generation, (including DG) and transmission can be better achieved.

Kleindorfer lays out four principles to guide the restructuring of governance and regulation of transmission providers. Transmission entities should face incentives that will encourage: (1) measurement and accountability for performance, (2) a focus on customers, (3) the integration of engineering and economics in operations and planning, and (4) a governance structure capable of making decisions in a timely manner concerning investment, grid management and customer needs.

Regulators should actively promote the evolution toward for-profit transmission companies with performance-based rates, and they should accommodate regulation that reinforces a focus on measurement and performance accountability. If the current model continues, with the compendium of misaligned rules, requirements and policies of the new order contributing to a lack of accountability for grid performance, then restructuring could well be a net drag on our economy, and situations such as the lack of communication and monitoring of the grid that led to the August 14th blackout may well persist in the future.

¹¹ I differentiate here between pricing (and price levels) and tariff structures, which deal with establishing the processes and services for which a charge should be made.

RET/DG facilities into dispatchable elements. Finally, the section addresses introduces the question of valuation and provides a basis for arguing that it is difficult to fully conceptualize, let alone value the benefits of radical innovations such as DG and intermittent RET under decentralized network operation, which will radically alter the electricity production and process. The section introduces the idea that decentralized networks and the VU cannot be valued using traditional accounting measures, but rather, as was the case in manufacturing two decades ago, they require new accounting concepts. This discussion also continues to subsequent sections.

Section IV lays out the informed decentralized network concept and delineates the roles of various participants. It argues that decentralized networks, with no central dispatch and little other central control, will allow markets to flourish thereby setting appropriate prices for various forms of back-up power and other ancillary services that are today likely over-priced. Decentralized networks are best suited to exploit the attributes of distributed and intermittent RETs such as wind and PV. Given bi-lateral contracting for power and services, such networks can exploit the ideas of mass-customization, first introduced in manufacturing, to provide customers the flexibility they need to best meet their complex electricity needs. One means of providing this flexibility is through discrete matching of specific load types with specific generators, a practice that represents an update of early operating procedures used by Edison.

Section V discusses the role of decentralized networks in meeting European RET targets. It lays out a three-part *balanced incentives* tariff structure that induces the NO to attain efficiency and meet access in the most cost efficient manner, which in many cases will involve renewable and conventionally fired distributed technologies. A second important element in efficient RET deployment involves empowering the NOs thereby helping them evolve from the caretaker network administrators they are today, to active, for-profit business partners, regulated under price caps and motivated to efficiently operate the network business, to meet customer demand and to make technology neutral investments. This may mean contracting for RET/DG power in lieu of line upgrades where the economics make sense.

Section VI discusses the role and value of network information and argues that the NO needs to transform itself from an asset-based manager to a firm capable of evaluating information and making rapid decisions regarding the needs of its customers. Finally, Section VII concludes.

II. NEW WINE — OLD BOTTLES: NEW TECHNOLOGIES REQUIRE NEW SUPPORTING SYSTEMS

Over the last century, the structure and operating paradigms of the electricity network, as we know it today was largely shaped by central station generating technology in the context of vertically integrated utilities. The practices that evolved are suited to this organizational arrangement. Neither the network's architecture nor its operating practices would be the same had the industry's technological evolution followed a different path. Today, the industry is undergoing its first reorganization since its beginnings a century ago with a major technological shift from central station production to DG, some of it in the form of renewables energy technologies. A fully restructured (liberalized) industry, with a proliferation of DG/RET sources will require new network operating regimes suited to *its* organizational structure. Network reorganization is an essential element of liberalization that EU policy makers have not yet fully addressed. Without a reorganized network, electricity markets cannot be truly "liberalized." Without a reorganized network, meeting EU RET targets will be considerably more difficult and costly.

New technologies enable us to conceive exciting visions about the network of the future: information rich, with FACTS capability to route power to specific loads and with flexible capability at every node [Catherine Mitchell, SUSTELNET, **]. In spite of enticing technological innovations, however, network planners and system engineers seem to visualize future networks more or less in terms of functions that mimic today's network. For example, US-DOE sponsored a series of high-level meetings that defined a technology roadmap consisting primarily of 'command and control' protocols to aggregate vast DG networks into virtual *dispatchable* generating units that fully mimic the capabilities and technical attributes of today's central station generators.¹²

DOE enunciates the collective vision of controlling DG installations through centralized dispatch, in describing its *Grid 2030* as a "Fully automated power delivery network that monitors and controls every customer and node [US-DOE, July 2003]." This is not surprising. New technologies— especially radical new process technologies such as DG— are rarely fully understood at first. New technologies are routinely conceived in terms of the previous vintage technology. For example, the word processing innovation of the 1960's was conceived simply as more advanced version of the typewriter, to be utilized in much the same manner— in the typing pool— in offices with the same organizational and hierarchical structure. Likewise, today's DG technologies are seen as a slightly different approach to injecting electricity into a grid that may have some new interconnection capabilities, but whose basic architecture and underlying operating protocols remain largely unaltered. This is naïve.

¹² NREL funded a number of studies to further these ideas. One study, [Foster and Gorokhov, 2003] defines its objectives as: "Aggregating distributed generators by adding controls to make them *dispatchable* for reduction in peak demand on the utility grid." A second [Daniels, 2003] develops "command & control algorithms for optimal dispatch," with a challenge that programming must "achieve the goal of optimal economic and operational dispatch." See also U.S. Department of Energy, Office of Distributed Energy Resources, *Communications and Control Program* <http://www.eere.energy.gov/der/>.

Experience shows that before new process technologies can be fully exploited, underlying systems and infrastructure must undergo significant change [Kleindorfer, UN Report]. The word processor is no exception. It took 25 years and important changes in office organization, cultural attitudes about typing and even the appearance of printed communications before this technology more fully came into its own. Similarly, RET/DG, a radical architectural process innovation¹³ requires equally radical changes to the network.

Incremental network enhancements—the type envisioned by US-DOE's *Electric Distribution Transformation Program*, will not serve to fully exploit the capabilities and attributes of DG. Incremental infrastructure changes in response to radical technology innovation will likely produce only incremental process improvements that may not even be cost-effective. Simply aggregating DG arrays into dispatchable units is like installing the word processors in the typing pool—like pouring new technology into old bottles. Based on the literature and the range of experience it is probably safe to conclude that fully exploiting radical new process technology generally requires, in addition to changes in underlying systems and infrastructure, changes in ancillary technologies and processes along with changes in human values and perceptions. This takes time, so people can experiment with the new technology to see how it best works.

Word processors were initially placed only in the typing pool, thus essentially continuing a decades old set of office processes, dictation followed by typing, in an essentially unchanged office organization. Recording and telecommunications technology freed stenographers from the task of manually recording live dictation. Using an intercom on the desk telephone, professionals, managers and executives could now transmit their dictation directly to a recording device in the typing pool. Technology was new—telecommunications and word processing—but its use was limited to marginal enhancements in an old process that remained essentially unchanged. Using a complex of control and communications devices to transform independent DG installations into dispatchable arrays is no different. Making new technologies look like old ones allows operators of complex systems to cope with change.

Our need to make new technologies look like old ones is evident in other ways. For example, many power systems today require wind farms to provide gas back up so they are dispatchable—so they look to the dispatcher exactly like a gas turbine. Here again the technology has changed, but the underlying process for producing and distributing electricity has not. Few people in the 1960's were thinking about how the office and its function might be reorganized to exploit new information-based technologies. Likewise, not enough people today are thinking about how to fundamentally alter network organization, governance, regulation and pricing so it exploits the new economics of decentralized generation and small, fixed-cost intermittent technologies.

Networks were originally designed to transport centrally generated power from low cost areas to urban centers. They were not designed for DG. When a new process technology—wind—is 'shoe-horned' into an existing system that evolved to support a previous vintage technology, things do not work correctly. To the network operator, it seems plain as day that the new technology needs to morph so it takes on characteristics resembling the old technology. This is wasteful and foolish. Quite the opposite must happen. If we are to

¹³ e.g. in the sense of Henderson and Clark, [1990]

effectively exploit technological progress, it is the underlying system that needs to metamorphose and adjust to accommodate the innovation. This holds whether the technology is wind or solar generation or word processors for the office.

Absent changes in underlying structures, radically new process technologies often produce only marginal gains. The Bessemer steel process, developed in the mid-1800s, illustrates the imperative of altering underlying systems and infrastructures to fully exploit innovation. Bessemer changed the way steel was made. His process reduced batch production time to 15 minutes, but existing British mills could not properly exploit his innovation because they were organized around the previous open-hearth technology, which had a production time of several days [Clark, 1987]. Fully capturing Bessemer's cost advantages had to await new American factories that were laid out around the new process [Clark, 1987]. This meant new floor plans, new job classifications and new logistics for moving high volumes of incoming raw material and high-temperature finished product. Using the identical Bessemer process, new US factories produced four-times as much steel as their British counterparts [Clark, 1987].¹⁴

Two important ideas emerge from this illustration. First, we probably do not yet understand how to fully exploit DG/RET, and second, we do not how to express their ultimate costs and benefits in a fully integrated network setting. Such full integration will require changes in networks, underlying support system and other ancillary technologies, which can enhance the value of DG just as email did for word processing. For example, the value of DC-producing PV arrays would be enhanced if computers and other electronic devices reverted to their natural DC-based state. Distribution systems capable of delivering both AC and DC power could then even further enhance the value of RETs, as well as the networks themselves.¹⁵ In all of this, there also exists an essential role for an intelligent network interface that includes reasonably priced advanced metering devices. The foregoing list is only a smattering of the possible changes in underlying networks and ancillary technologies that would help promote DG/RET. We can only vaguely envision or specify all the needed system enhancements.

Renewable technologies are viewed as ill-suited for network applications on the basis of their so-called intermittency, a "flaw" that requires backup or storage. Subsequent sections of this paper propose a *discrete-load* matching approach for dealing with intermittency that relies on informed networks and obviates the need for storage or other *non-value adding* processes and technologies.¹⁶ That said, it is important to restate Dick Tabors' observation of 20 years ago [Tabors, 1981, p. 4] that "No unit in an electric utility system is without backup" and that the backup requirement of solar technologies are "not random as would be the case with a coal or nuclear facility." All components of the electricity system are in some measure intermittent and require backup. Most loads are likewise intermittent. Intermittency is not a 'flaw' or

¹⁴ The implications for networks are more fully discussed in A-H-V (1999), Chapter 4.

¹⁵ This requires users to have the means to draw either DC for computers and other applications as well as AC as needed from the same set of residential or industrial wires. Such technologies are available.

¹⁶ The idea of a non-value adding activity is borrowed from modern Activity Based Accounting (ABC) theory and includes such activities as supervision and product inspections— which can often be minimized or eliminated without reducing quality.

shortcoming as traditional 'reliability' concepts imply. On the contrary, requiring a system to always deliver generation that matches a fleeting peak load gives rise to a set of generation and network assets that are invariably drastically over specified and underemployed, a situation long overdue for frontal attack by innovative policy.

The value of so-called *intermittent* RETs will no doubt be enhanced by more efficient storage. It will also be enhanced by innovations that allow electrically driven work to be reallocated to periods of sunshine and wind. Such innovations can be technological, but social innovations that allow us to re-conceptualize energy usage patterns will be important as well. Social innovations have historically promoted technology diffusion in important ways, for example, by empowering early 20th century women to wear appropriate clothes, social innovation allowed the bicycle to be diffused to the other half of its potential users [Pinch and Bijker, 1987]. So, while we can generally categorize *some* of the necessary network and infrastructure changes required to fully exploit DG/RET, we cannot fully anticipate or predict how these will materialize. All of this underscores the importance of information-rich, i.e.: "informed"¹⁷ networks, with open internet-like architectures and flexible, innovative regulatory and governance schemes. Such networks will effectively deliver 21st Century quality and efficiency and will support a *Virtual Utility* production and delivery paradigm that creates value-adding intangibles while eliminating *non-value adding* activities as subsequently discussed.

III. THE VIRTUAL UTILITY CONCEPT

The term *virtual utility* is widely used although it is poorly understood and often mis-conceptualized. The Virtual Utility (VU) concept seems to have been introduced by Awerbuch and Preston¹⁸ as a vision of what the future market and industrial organization for electricity might look like. The VU provides a potentially useful model for conceptualizing the network requirements to support the emerging era of customer-driven markets and demand-driven electricity based products.

The VU can be conceived as a means of organizing power generation and delivery by minimizing non-value-adding activities and providing appropriate quality energy on a *just-in-time* basis, along with high-value-adding intangibles embodied in a set of fully *mass-customized* electric services. [Awerbuch, Carayannis and Preston, 1997].

With its capabilities to deliver specialized new services and its flexible supply options facilitated by modular generating technologies, telecommunications and innovative financial instruments such as energy futures and options, the VU creates a set of benefits that may differ considerably from the traditional direct benefits usually considered in standard capital

¹⁷ This term coined by Andrew Vesey in A-H-V, 1999, Chapter 4.

¹⁸ The term, coined by A. Vesey, [1997], is ironically now widely used to describe aggregated, dispatchable DG arrays, which at best represents a simplistic adaptation of the original VU concept. Like any planning function, central dispatch is a non-value-adding activity that the VU seeks to eliminate.

budgeting and project valuation procedures. Although particular generating technologies may or may not have lower direct generating or “busbar” costs, it is the synergism of the VU organizational structure that produces cost reductions. This is similar to the way that flexible process technology reduces total costs in manufacturing, even though direct unit costs are not always lower. Facilitated by DG and other new process technologies, the VU is the electricity analogue to flexible, just-in-time production paradigm in manufacturing industries.

- Electric Utility Overhead and Transactions Costs
- Transactions costs: reflecting the exchange of material and information
 - Ordering, executing and confirming material movements;
 - Production scheduling and inventory forecasting
 - Maintenance scheduling
 - Planning & arranging purchased power
 - Inspections and conformance to safety, environmental and other standards
 - Planning and executing major capital additions
 - Inventory Costs: fuel, storage facilities, spare parts
 - Working Capital Requirements
 - Excess capacity costs
 - Standby and idle reserve capacity
 - Cost of managing personnel, facilities and
 - vehicles

What are some of the non value-adding activities inherent in today’s electricity production system? A partial list would certainly include excess transactions, excess generation and transmission capacity, stand-by and idle reserves, meter reading activities, transmission and distribution switching for maintenance work, load flow simulations, maintenance planning, maintaining fuel inventories and negotiating fuel and purchased power (see Box above). These functions are analogous to well-known non-value adding activities in the field of manufacturing. Because traditional cost accounting records costs using line item entries, it is easy for managers to ignore the cost of non-value adding activities. There is no line-item entry, for example, for “excess capacity” and nobody writes a check to directly cover its cost. Rather, excess capacity lurks out of sight, like the submerged portion of the iceberg. It is easy to forget how much damage it does to overall production costs.

The story was much the same in the manufacturing industry until the 1970s, when new activity-based costing (ABC) techniques developed at Carnegie Mellon and Harvard Universities (e.g. Kaplan, 1990; Aiyathurai, Cooper, and Sinha 1991; Kaplan, 1986; Kaplan and Atkinson, 1989; Cooper and Kaplan, 1999;) began to explicitly identify (i.e. conceptualize) and measure the cost of both value-adding and non value-adding (i.e. wasteful) activities. After almost a century of unquestioned dominance, the economics of mass-production suddenly came under more careful scrutiny. This has yet to happen in electricity production.

Manufacturing managers traditionally gauged their effectiveness with standard engineering oriented unit-cost efficiency measures: e.g. £/unit produced). And it was an apparent revelation to them to learn that unit-cost included many previously ignored cost-drivers such as machine setup times and product complexity— which is created by design activities traditionally completed before the product even hits the production line. Managers faithfully accepted the many wasteful activities involved in mass-production as necessary. Perhaps they believed the mass-production operating regime was still the best possible. Perhaps it was. The emergence of new information-based process technology in the 1970s, however, made it obsolete. The

- Non Value-Adding Activities in Manufacturing**
- Inventories and excess capacity
 - Production scheduling and batch set-up times
 - Manufacturing defective products
 - Generating of scrap material and waste
 - Over-time pay to meet end-of period production mandates
 - Unnecessarily high product throughput times

restructuring in manufacturing, which began in Japan, took nearly two decades to make its way across the world.

NEW ACCOUNTING MEASURES ARE NEEDED TO EVALUATE THE VU

Although the restructuring of the electricity sector is well underway in many parts of the world, accounting measures capable of properly supporting the new production concepts are yet to be developed as they were in manufacturing, health care and other industries. In health care, revolutionary concepts such as the DRG (diagnostic-related-group) replaced the singular centuries-old *£/patient-bed-day* cost measure and radically altered the way hospitals treated patients and perceived their costs. Electricity production and delivery is similarly dominated by a single accounting cost measure: the busbar cost.¹⁹ Busbar cost comparisons probably sufficed in a previous technological era when a single output—undifferentiated kilowatt-hours—was sold to an essentially captive market. In this environment utility resource alternatives were technologically homogeneous, consisting largely of fossil-fired options with essentially the same mix of operating, overhead, capital, transmission and distribution costs.

Today's environment, however, offers a considerable range of technological options, including PV and other capital-intensive renewables and demand side management (DSM) options. Compared to traditional central generating plants, these new resource options have fundamentally different overhead, operating, capital, and transmission and distribution costs. Given these differences, it is no longer sufficient to select resource options on the basis of their busbar or direct costs alone. The experience in the restructuring of manufacturing and health care plainly suggests the need for more innovative approaches to conceptualizing the novel and currently inexpressible benefit streams that radical new process technologies are capable of producing in a VU environment. There is an important caveat however: without radical restructuring of the network, these benefit streams will not fully materialize. Network restructuring involves new organizational, operational and governance structures for the network coupled with new regulatory regimes and tariff structures. This likely implies radically new decentralized network operational protocols in a market driven setting that are supported by advanced communications and information systems.

¹⁹ The "busbar" cost, expressed as \$ per kWh, was developed by Samuel Insull to show self-generators that Edison's power was less costly. Busbar cost represents a conceptualisation of the direct costs of generating power and delivering it to the busbar—the interface between the generating equipment and the network; see: Kahn [1988].

Busbar cost includes direct *fuel* and *operation and maintenance* (O&M) costs of the generating plant but omits all overheads and indirect costs (although the historic-based fuel-inventory cost is included in some jurisdictions) as well as the electricity delivery costs. The accounting equivalent to the busbar cost is the COGS or *cost of goods sold*. Busbar cost continues to be the predominant cost measure for planning, presumably as a proxy for the true costs of generating power. Related cost concepts e.g. \$/mw-month of capacity or \$/kWh delivered are used in network applications.

IV. THE STRUCTURE OF DECENTRALIZED ELECTRICITY NETWORKS²⁰

There is nothing sacred about today's AGC-based centralized transmission control system. Neither is it likely to be the most appropriate structure in the new environment. Indeed decentralizing network functions and, where possible allocating them to system users—loads and generators— may yield sizeable efficiency gains. A number of guiding principles can help determine how to allocate network operational control in such a manner as to:

- i. *Insure market neutrality of the network operator*: The network operator must not compete with suppliers or be perceived as having incentives to favor one supplier over another. Its position must allow it to make technology-neutral investment decisions. At the very least, this implies that the network operator will not own bulk generation.²¹
- ii. *Create a network operator with sufficient control to implement short-term operational decisions as well as long-term investment decisions*: In the US, this implies a network governance structure involving operators that have both ownership and day-to-day operational control of the network [Awerbuch, Crew and Kleindorfer, 2000]. Further, given the economic dictum that absent residual claimants— i.e. stockholders— there can be no economic efficiency, there is clear and compelling evidence that the network owner/operator must be a for-profit regulated monopoly [Awerbuch, Crew and Kleindorfer, 2000]. These governance guidelines may apply differently in countries with different regulatory and ownership traditions.
- iii. *Eliminate duplicative bureaucracies and decision-making hierarchies*: establish clearly defined rules, roles and responsibilities for the network operator.
- iv. *Align control authority with financial responsibility*: Generation owners are uniquely motivated to balance production cost minimization against maintenance cost and equipment protection. Giving them more dispatch control authority will enhance efficiency.
- iii. *Bring decision-making close to information*: Entities closest to the information are generally in the best position to make control decisions and also have the most at stake and the greatest incentives for efficiency. For example, loads have relatively precise information about their load-following needs coupled with clear incentives to minimize the total costs of power, load following, fringe control and reactive power (VARs).²²
- iv. *Exploit electrodynamic efficiencies where possible*: e.g.: minimize line losses.

²⁰ This section based on A-H-V, 1999, Chapter 5.

²¹ Although it has been suggested that network operators might own capacity for distribution augmentation (DA) functions (private communication from Mr. Albert Benson, USDOE, Boston Region; DA is more fully discussed in Awerbuch [July 2000].

²² Richard D. Tabors [1981, p. 7] succinctly laid out the basic idea 20 years ago: “It is more efficient for a customer to make the decision to shed load than an external source such as an electric utility controller.”

Table 1: Control Function Responsibilities by Sector Under Decentralized Network Operation			
	Centralized System-Specific Control Responsibilities	Decentralized, Transaction-Related Control Responsibilities	
Objectives	NETWORK OPERATOR	LOADS	GENERATORS
Economic	<ul style="list-style-type: none"> • Maintain Equipment • Efficiently utilize assets • Reduce transactions costs • Maximize the value of commerce • Provide nondiscriminatory access • Maximize transactions completion 	<ul style="list-style-type: none"> • Load Management • Power quality needs for specific applications • Backup power and other ancillary services 	<ul style="list-style-type: none"> • Energy scheduling <ul style="list-style-type: none"> – Unit Commitment • Economic Dispatch • Maintain Equipment
ELECTRO-DYNAMIC	<ul style="list-style-type: none"> • Voltage Profile Control ^{b/} <ul style="list-style-type: none"> – Reactive Capacity • Frequency Control ^{a/} <ul style="list-style-type: none"> – Transmission Loss Compensation – Default Fringe Control • Security control <ul style="list-style-type: none"> – Spinning & Ready Reserves ^{a/} – Emergency Control – Black Start ^{a/} • Network Usage Optimization 	<ul style="list-style-type: none"> • Base Load Power ^{a/} • Load Following Power ^{a/} • Fringe Load Power ^{a/} • Reactive Power ^{b/} 	<p>NOTES:</p> <p>a. Obtained through contracts with generators</p> <p>b. Contract with generators or self-provide using capacitors, SVCs or other power electronics.</p>

Based on: Awerbuch, Hyman, Vesey, *Unlocking the Benefits of Restructuring*, PUR, 1999

These criteria suggest that network *customers*— loads and generators— are likely in the best position to handle many functions previously performed by the network operator (Table 1). Such arrangements can be specified contractually and well-functioning markets may ultimately be the better arbiters of how functions and services should be allocated. The key to a properly functioning decentralized network is a set of carefully defined provisions for strict bilateral contracting for energy and ancillary services. Under this scheme the network acts as a market facilitator and common carrier subject to a set of clear *rules, roles* and *responsibilities*.

This vision of a decentralized network is quite removed from the system of today. Customers in so-called “liberalized” (restructured) markets as well as in traditional vertically integrated systems are for the most part stuck with networks based around pool-type, centrally dispatched control systems.²³ So, while production technology is radically changing, delivery processes and protocols are pretty much the same— relics of a bygone era. Rather than fostering active vitalized markets, such network organization serves to isolate suppliers from users, thereby stifling markets. Could a modern telephony market operate in such fashion? Would we have access to the mind-boggling range of products, price and service menus if customers had to ‘buy’ each and every call from a government-run dispatcher?

²³ Such systems represent the norm in Europe; 11 of 15 EU member states resort to centrally controlled power exchanges as subsequently discussed.

The system described in Table 1 has no central dispatch (AGC) function because it is unnecessary. In today's world, both the decentralized as well as centralized functions of Table 1 are centrally carried out, in part through AGC, which comprises a number of integrated economic and electrodynamic control functions. Economic AGC objectives include *economic dispatch* to minimize production costs. Electrodynamic objectives are system stability and reliability. Economic objectives are usually better met by entities whose interests are directly affected, e.g.: generation owners will strive to minimize production costs to remain competitive, thereby achieving objectives currently met through economic dispatch.

How loads function in a decentralized network system

- a. In addition to contracting for base-load and load-following power, loads provide fringe load power, their own back-up and load power-factor correction (reactive power). If its supplier fails, the load's back-up supplier must immediately support that portion of a customer's load that the primary supplier served. The system must be sufficiently informed so that it will not allow a load to "lean on the network."
- b. In this environment, individual action of a load and its suppliers does not affect system balance or does so to a much lesser extent.

Responsibilities of Network Participants

Participant in decentralized networks have new clearly defined roles and responsibilities. Loads procure their own base-load and load-following power and a number of other ancillary services. Suppliers inject power based on existing contractual agreements, under a set of priority rights or other congestion management schemes whose proceeds do not benefit the network operator. Finally, the network owner-operator, under an appropriately structured incentive regulation regime, is responsible for network security and reliability, maintaining open and non-discriminatory access and maximizing access and power throughput. The regulatory regime and tariff structure also induce the network operator to make optimal investments and develop innovative, customer driven products and services. These do not necessarily involve bolting more assets to the ground. The network owner/operator also has incentives to reduce transactions costs for network participants and to facilitate and enhance the value of commerce and transactions along the network.

Figure 1 (next page) illustrates the operation of the decentralized network, which form the basis of the Virtual Utility concept first coined by Vesey and described in Awerbuch and Preston [1997]. Network system participants include a large number of loads ($L_1 \dots L_n$), generator/suppliers ($G_1 \dots G_n$) and the network owner/operator. The network operator is responsible for enhancing commerce, and for system integrity. It carries out the latter responsibility primarily through contracts with generators and other suppliers who supply power for frequency control and for emergency and other uses.

Any particular load location in Figure 1, for example "Industrial Load-3" (yellow box) would be defined in today's world as a *single* load or "meter" in US utility parlance. In reality, the so-called single load, no doubt consists of a range of specific power applications or needs such as an industrial refrigeration system, process or process control system, space heating and water pumping and heating system. The concept of an individual power application can be carried to its limit— i.e. a single refrigerator or washing machine. Indeed given broadband internet-based communications, there is no reason to believe that matching the electricity

needs of single residential appliance would be unwieldy.²⁴ Each of these applications has some form of network interface. If the generator supplying these specific applications fails, or if the power transaction is curtailed, the application is terminated by the network operator unless backup power is available.

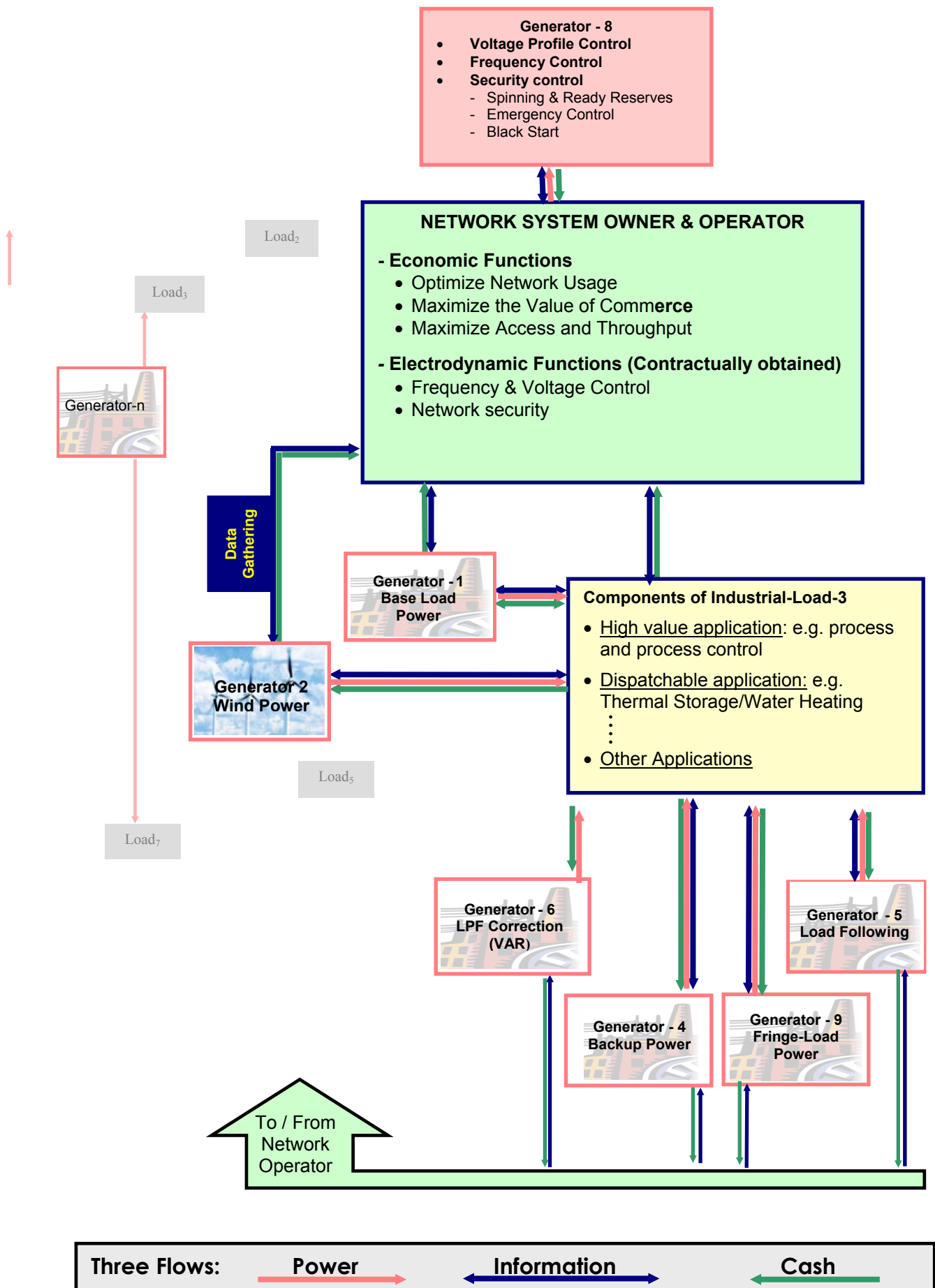
The individual applications in an industrial load can potentially be served by a number of “discretely matched” generators (see next section) or by energy service firms that intermediate between the load and effectively deal with a number of suppliers. Specific load applications are suited to specific generation types, for example, a *dispatchable* or interruptible water pumping or heating load²⁵ might be well suited to intermittent wind power. In Figure 1, Industrial Load-3 has arranged for four ancillary services: load-following, VAR power, fringe load-following and back up power, which can take a variety of forms. Some of the individual applications in Load-3, perhaps those associated with process, require immediate backup in the form of spinning reserves. Back-up for this Load’s other, more “dispatchable” applications might take the form of 1-hour standby power, or even 4- or 8-hour standby power. Segregating backup needs according to the individual application creates efficiencies that are not possible in today’s world

The individual applications of Load-3 connect to their generators along several parallel networks that carry i) power, ii) information: electrodynamic (system) information as well as accounting and financial information used in settling accounts, and iii) wealth (cash) flows. Figure 1 illustrates these three distinct flows of unbundled networks. Information flows consist of engineering system-status data as well as market information. They also present opportunities for data collection/data mining although the issue of data ownership, which is largely unresolved in the US and possibly in the EU, presents a hurdle for firms wanting to exploit this market opportunity. Finally, there may be an engineering oriented system-security need for information flows between suppliers. This is not shown, because properly structured, the economics of the system should provide sufficient security.

²⁴ Anne-Marie Borbely [2001] gives a colorful and informative description of such “transactional networks.”

²⁵ Interruptible or dispatchable loads are discussed subsequently.

Figure 1: Informed Decentralized Networks - Basis for the Virtual Utility



Discrete Load-Matching: Back to the Future

Before transformers were developed, individual generators produced the precise voltage levels required by various load devices thereby giving rise to single-purpose, custom-designed production and delivery systems.²⁶ In this nascent and somewhat chaotic pre-AC electricity industry, production/delivery was characterized by unique supply systems for each type of load: arc-lighting for streets and public buildings, incandescent-lighting for homes, transportation loads (street cars), and stationary or industrial loads. In each case, the type of generator was matched to individual peculiar load requirements. This practice continued even after the advent of AC, until it became totally unwieldy. Just before the turn of the century, for example, the City of Philadelphia had a score of independent electric companies with mutually incompatible systems: 100-Volt and 500-Volt 2-wire DC systems, 220-Volt 3-wire DC, as well as single-phase, two-phase, and three-phase AC with frequencies of 60, 66, 125, and 133 Hz. Each application dictated the design of the "system" required to serve it.

Electricity Mass-Production

The idea of discretely matching each transformer to a particular load ultimately gave way to more generalized designs that allowed loads to draw system power at specific voltages as needed. Thus emerged the *mass-production* paradigm of electricity generation and delivery. Unlike manufacturing, electricity cannot be literally "mass-produced" and inventoried like a batch of 10,000 machine parts. Yet the production process that emerged a century ago was nonetheless directed at meeting a perceived uniform, mass-market demand. The mass production paradigm in electricity prevails to this day. Moreover, it seems to dominate even proposed network concepts of the future, which usually envision some form of centralized control along with a singular, non-discriminated notion of "load."

Outmoded mass-production ideas dominate the design of modern power production and delivery systems. In manufacturing, however, the economics of mass-production have been replaced by new concepts: flexible manufacturing and mass-customization, which exploit the attributes of today's information based process technologies.²⁷ And while the benefits of a flexible, electricity system seem clear to some,²⁸ it is hard, if not impossible, to analytically estimate the full cost-benefit economics of a flexible, mass-customized electricity system relative to the current mass-production generation and delivery mode. We do not have the accounting measurement concepts

²⁶ This and the subsequent paragraph are based on personal correspondence with Lester Fink, November 2001.

²⁷ A brief overview of mass-production and how it might relate to power systems and the use of renewables is given in Awerbuch Sellers, [1994].

²⁸ For example, see the ambitious undertaking by Amory Lovins et. al. [2003], which itemizes and in some cases explicitly quantifies a full 208 benefits of DG.

we need to properly define power production/delivery costs.²⁹ Significant limitations of our accounting vocabulary invariably hamper the evaluation of new electricity production and delivery paradigms, [Awerbuch, Dillard, Mouck, and Preston, 1996; Awerbuch, February 1996; Awerbuch, Carayannis and Preston, 1997] just as they hampered the valuation of Computer Integrated Manufacturing (CIM), and other innovative manufacturing process technologies 20 years earlier [Kaplan, 1986].

Is It Cost-Effective? Valuing DG in the context of decentralized networks and the VU

The new manufacturing concepts that emerged in the 1970s failed all traditional cost-benefit tests. For example, standard cost-benefit investment models could not identify the cost superiority of flexible, computer-integrated manufacturing.³⁰ To this day, none of the “new manufacturing” ideas can be fully cost-justified using standard costing tools. Our typical conceptualization of costs and benefits is bogged down in direct-cost accounting terminology, (i.e. cost/unit, cost of goods sold, etc.) in an age when new production technologies often do not reduce such direct costs. Rather new technologies tend to produce money-saving benefits through quality improvement, enhanced product-line diversity, reduced order-processing times and the reduction or elimination of *non value-adding* overhead and indirect activities.

Most of these benefits cannot be directly observed or measured using standard cost-accounting. In fact, recognizing or conceptualizing these benefits in manufacturing required a new accounting vocabulary that was specifically developed to value the post mass-production paradigms of the early 1970’s. The new vocabulary includes benefit concepts such as *quality*, *flexibility*, *throughput*, as well as *capability* and *managerial options* [Baldwin and Clark, 1991]. When used in sophisticated option-based valuation frameworks, these concepts can indeed help justify the benefits of new manufacturing technologies— albeit with the benefit of 20 years of hindsight!

Options-Based Approaches

Options-valuation is currently in vogue and managers seem to believe that the whiz kids who practice it can solve an endless variety of valuation problems. Indeed the procedure can help us understand the benefits of CIM and other new production processes by putting a value on the flexibility they offer. This is done by mathematically treating flexibility in terms of the options it provides managers. The options are valued typically using the well-known Black-Scholes option valuation model. However options approaches are more of an art and have not yet evolved into a well-defined valuation framework.³¹ For example, although Black-Scholes was around in the late 1970s, it did not help anybody understand computer-integrated manufacturing. Why? Because until the Japanese began to preach and practice the mantra of

²⁹ Noted accountant Robert N. Anthony [1987] expressed the similar sentiment about other accounting issues.

³⁰ Thus causing Robert Kaplan [1986] to ask whether CIM would have to continue to be “justified on faith alone.”

³¹ A characterization Richard De Neufville [2003] seems to support;

flexible manufacturing lines, nobody even realized that there was such a thing as *flexibility* in manufacturing or that it could possibly have so much value!

Options models are used to value DG and RET in terms of the modularity and flexibility they provide. Though a useful beginning, these analyses do not represent a generalized valuation framework for DG/RET. They are certainly not at a point where they can value decentralized, *informed* networks since we can only wildly guess at what options might be embedded in a VU-based generation and delivery system. Options models are useful only where the nature of the embedded option is understood. We understand only the very few options that have become clear from the extensive manufacturing literature, although De Neufville [2003] reports that firms are incorporating “option-thinking” to help designers translate potential uncertainties that might affect products and system into designs for flexibility and adaptability. This will work to the extent designers can actually identify or “see” their options, which in the case of radically new process technologies may be limited if history is a guide. For such innovative undertakings, it is generally difficult to visualize the uncertainties that allow designers to create the options [De Neufville 2003, 31]. That is not to say that “options-thinking” will not improve our understanding as De Neufville [2003, 30] argues.

In electricity, option valuation is therefore also limited to evaluating modularity and other flexibility attributes of particular generation technology.³² The value of *managerial* and *capability* options [Baldwin and Clark, 1991], reasonably well understood in manufacturing and other industries, is not yet understood for electricity. Moreover, we do not yet understand the extent to which some of these values might be either additive or duplicative, either with each other or against some of the 208 DG valuation categories that Amory Lovins, et. al. [2003] outline.

For example, gas generation can be valued on the basis of the gas option (Footnote 32) but gas generation also provides managers with a useful abandonment option: because of their low initial capital costs, combustion-turbines are thought to give managers the flexibility to abandon the technology should conditions change subsequently (e.g. fuel prices rise too much). The value of this option does not seem to have been quantified in the literature.³³ Could gas-based generation be evaluated from this perspective? Is this option additive with the other gas options? These are some of the issues in the practical application of option-based valuation.

³² For example, modularity value is tied to the ability to install small incremental power addition with for example, PV modules over lumpy central station investments. e.g. see Hoff [1997, 1998] and the other extensive work of Tom Hoff (www.clean-power.com) in this area. On the economics of lumpy investment additions, see Ingo Vogelsang [1989].

In the context of fossil fuel-fired generation, the flexibility option takes a number of forms. It is valuable in the case of industrial fuel switching capability (e.g. Hobbs, 1994, Kulatilaka, 1993) or in the ability of gas-based generators to respond to high gas prices by curtailing generation and selling their contractual gas allotment at the higher spot prices (e.g. Frayer and Uludere, 2001).

³³ This value would seemingly rise the longer fuel prices stay low, because more of the originally anticipated value is returned to ratepayers and investors-- so managers have delivered on their commitment.

While options valuation focuses on two recognized option values, DG technology undoubtedly creates new options and other benefits not yet recognized. As a result, options-based valuation can only *understate* the value of fully integrated DG in a decentralized network VU setting, since these technologies have other attributes. These may come in the form of options and capabilities that enable the firm to enter new lines of business and serve new customers or by their ability to produce complementary benefits³⁴ that reduce costs elsewhere in the electricity production/delivery process.

Amory Lovins lists 208 benefits of DG, some of which take the form of options. Many of these individual benefits can probably not be quantitatively assessed at this point. Clearly new benefits attributes will be discovered over time, perhaps with hindsight as they were in manufacturing. This will give rise to new ways of understanding the benefit of VU-based production in a decentralized network environment.

The manufacturing industry reinvented itself in the 1970's. The vast literature that catalogues, analyzes and explains this revolution makes it clear that the mass-production economics underlying today's electricity generation/delivery paradigm likely no longer hold. Just as in manufacturing, health care and other industries, scale and agglomeration economies of the previous vintage of generating technologies are no doubt giving way to the new economics of quality, flexibility and rapid market response that are embodied in the new DG/RET.

The attributes of DG/RET clearly favor decentralized operation and open, information-rich networks that provide the response-flexibility required by today's dynamic markets. Small gas turbines are as efficient as large ones, and, moreover, by virtue of the microchip, these machines do not require a hierarchy of laborers, mechanics and their supervisors, inspectors and managers to keep them running on a daily basis. Passive modular RETs likewise exhibit virtually no scale economies and, because they require little or no corporate services, can function cost-effectively outside an organizational structure. Placing such technologies into the traditional, 19th Century industrial organization that produces and delivers today's electricity makes about as much sense as putting word processors in the typing pool and then patting yourself on the back for your innovativeness.³⁵ The age of declining costs in electricity is over [Hirsh, 1989] but the economics of new distributed technologies will be fully exploited only with radical changes to the network.

Intermittency and Efficiency

Decentralized networks can unleash a variety of benefits and efficiencies, especially vis-à-vis RET. In order to understand the potential, we need to stop thinking about a single "load" and daily load pattern for a region or even for a single location, whether a house or a manufacturing plant. Instead, as in manufacturing mass-customization, we need to focus on the needs of individual applications— e.g.: production equipment, space and water heating

³⁴ In the sense of Milgrom, and Roberts, [1990]

³⁵ A late 1970s *National Public Radio* program in the US interviewed Weyerhaeuser executives who were elated by their estimate that word processing doubled the productivity of the typing pool— whose members represented the lowest paid employees in the office environment of the day.

requirements, and ultimately perhaps the household refrigerator and washing machine. This focus radically alters the load picture.

For instance, a variety of industrial and residential loads are considered to be “dispatchable,” a term generally taken to mean that these applications can more readily be deferred or shifted to a different time period. Dispatchable applications, which might represent only a small fraction of the total load at a single location, include water heating and pumping or any application that depends more on the availability of a certain amount of energy over a given time period than on the amount of power supplied at any given moment. Economists would describe the electricity demand created such loads as more price-elastic— their usage can be more readily shifted. In the US it is estimated that such loads represent between 5% and 17% of total peak load [Cowart, 2001].

In decentralized networks, owners of dispatchable applications can contract with intermittent generating sources such as wind— likely to be one of the low-cost electricity sources on a risk-adjusted basis over next 15-20 years [Awerbuch, Mar-April 2003]. This in some fashion may represent a return to Edison’s practice, described earlier, of discretely matching loads and generators. Under this protocol, if the wind dies down for a few hours or perhaps even longer, the network curtails the dispatchable application. This requires information-rich networks that can monitor the activities to insure that loads do not “lean on the system.” Under this arrangement, the wind producer does not need to worry about backup power (as it does under NETA for example); neither does the system operator. This differs dramatically from today’s system and offers significant efficiency benefits.

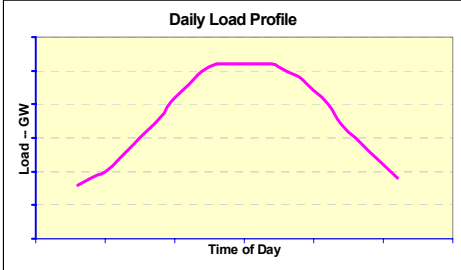
**Mass Customization in Electricity:
Creating Transactions-Based Networks**

- **Mass Production**
Henry Ford’s Model T: “Any color as long as it is black”
- **Mass Customization:**
Dell Computer (and Burger King): “Have it your way”
- **Mass customization in Electricity**
 - Abandon reliance on singular total network load figure**
 - Masks underlying dynamics of millions of transactions
 - Inhibits integration of “Intermittent” resources
 - Induces NETA to make all resources look like gas turbines
 - Decentralized decision-making— no central control of DG**
 - Real-time pricing to mitigate reserves, system overloads
 - Large information volumes and broad connectivity

Discrete Load Matching of Dispatchable Applications

Under today’s mass-production approach, the system operator obtains contracts for standby power. Faced with a mid-day rising load curve, the control room dispatcher has no time to think about tens of thousands of small individual loads and whether they actually need to be operating at that moment. He needs certainty backup. Such power is therefore invariably over-priced. An important benefit of the decentralized bi-lateral system is that back-up power is correctly priced.

Network architecture must allow loads to exploit their dispatchability. This provides



The graph, titled "Daily Load Profile", shows a bell-shaped curve representing the load in GW over the course of a day. The y-axis is labeled "Load - GW" and the x-axis is labeled "Time of Day". The curve starts at a low level, rises to a peak in the middle of the day, and then falls back to a low level. The area under the curve is shaded yellow.

The control-room dispatcher focuses on one objective— meeting his rising load curve. This is a mass-production strategy. When disaggregated, the load curve consists of millions of power transactions and uses, some of which vary drastically in type and value. As opposed to being a single market, “electricity” at any moment is no doubt a complex of dozens of products and perhaps markets.

efficiency in two ways. First, it reduces peak power costs and indeed all power costs. Second, it reduces the cost of backup power and other ancillary services that are overpriced when centrally provided. I discuss the power cost reductions first.

It is widely estimated that even small peak-load reductions can dramatically reduce peak prices. RAP's Richard Cowart, citing several noted authorities,³⁶ concludes that fairly "modest load responses to price can significantly affect reliability and price in constrained power markets."

In one instance, involving Georgia Power, peak load reductions reached 20% of load when prices spiked to \$1000/MWH.³⁷ Similarly, EPRI concluded that for California in the summer of 2000, a 1% reduction in peak load could reduce market-clearing prices by 10%, and a 5% reduction could reduce peak prices by 19%, which could have reduced total power costs for the summer season by 5–16%. Though not insignificant, this estimated result— about 10% on average— might well turn out to be feeble when compared to the efficiencies that a bi-lateral based decentralized system can create.

Awerbuch [2003] estimates the risk-adjusted post-tax cost of wind in EU at 3 US Cents/kWh. The comparable risk-adjusted cost of gas-based generation is 4 – 6 (5-7??) US cents/kWh depending on assumption [Awerbuch, 2003]. Consider the possibility of dispatchable loads effectively using intermittent low-cost wind, under long-term (20-year) contracts coupled with low-cost backup power. Interestingly, the "standby" power can potentially also be somewhat intermittent (as long as its intermittency does not correlate to that of wind). Now, ignoring the benefits of lower ancillary and backup costs, and considering only the direct power purchase costs of intermittent wind over gas-based generation, this setup might produce permanent cost reductions in the range of 20% and more. This ignores efficiencies in transmission and generation unleashed by decentralized networks. Wind farms may only want to market some of their power under long-term contracts and reserve the remainder for other arrangements.

The Value of Backup power and other ancillary services in a decentralized system

There is a second important benefit to decentralized networks: owners of dispatchable loads can contract with intermittent generating sources such as wind— likely to be among the low-cost electricity sources on a risk-adjusted basis over next 15-20 years [Awerbuch and Berger, 2003]. This in some fashion may represent a return to the elements of discrete matching between loads and generators in Edison's day. Under this protocol, if the wind dies down for a few hours or perhaps even longer, the dispatchable heating or pumping operation is curtailed. This requires an information-rich network that can monitor the activities to insure that loads

³⁶ Including Hirst and Kirby, [Cowart, 2001, p. 6.]; Renee Guild, [1999] and Levin, [1998].

³⁷ See: Cowart [2003, p. 26]. The estimated range of such price reductions of course varies. For example, the EPRI study suggests that if only 10% of customer load in the Midwest ISO had been exposed to real-time prices, customer demand reductions would have been sufficient to reduce summer price spikes by 33 to 66 percent. Finally, Robert Levin, [1998] Vice-President of the New York Mercantile Exchange testified before Congress that a 5% peak demand reduction in the Midwest in 1998 could have dropped some of the peak prices by 80% – 90%.

do not “lean on the system.” The wind producer does not need to worry about backup power (as it would under NETA); neither does the system operator. This differs dramatically from today’s system and offers significant efficiency benefits.

One of the most important benefits of the decentralized bi-lateral system is that back-up power is correctly priced. Under today’s mass-production approach, the system operator obtains contracts for standby power. Such power is invariably over priced. The system operator, faced with a rising load curve, needs certainty backup. The control room dispatcher has no time to think about tens of thousands of small individual loads and whether they actually need to be operating at the moment.

The Role of bilateral Electricity Markets in Fostering Efficiency

Markets seem to function best when individual entrepreneurs freely respond to market needs— to set prices, qualities, quantities and to schedule their services. This invariably works better than central control. OECD governments, for example, do not see the need to control the physical sale of corn or even natural gas³⁸ through a single exchange with complex regulatory rules – as they do in electricity. The inefficiencies of such an approach are widely recognized on both sides of the Atlantic as evidenced by the market liberalization in trucking, natural gas, and a host of other services and commodities.

Yet in the case of electricity generation, EU countries overwhelmingly rely on the outmoded idea of a central power exchange. This model perpetuates the perception of electricity as a commodity, which stands in the way of transforming the stodgy old network business from a low-tech *electron transporter* to an energized, market-driven entity that profits and succeed only by providing services and products its customers demand. This process can unleash powerful economic forces that can help the EU *efficiently* attain its renewable energy and energy diversity objectives. Exiting not-for-profit and government owned network operators have no such incentives to play a role in enhancing and transforming the network.

The idea of a central power exchange is strange. It resembles the reviled “company store” in the old US coal-mining towns. Does anybody believe that all those complicated rules will actually prevent gaming and the exercise of market power? Regulators may spend hours thinking about designing rules that prevent abuse. But energy traders and other system participants with market power stand to gain millions by figuring out how to best play the system. Do policy makers have any doubt about who will come out on top? Does anybody believe that a complicated centrally-run power exchange can do a better job of allocating generating resources than a system of independent bilateral contracts? Imagine if all UK homeowners wanting to do home improvements had to schedule their jobs through a central dispatcher who assigned contractors to customers. Seems ridiculous, but this is how electricity market “liberalization” actually operates in 11 out of the 15 EU member states (and 5 out of the 13 accession countries).

The power exchange puts distance between buyers and sellers, which cannot help markets while a bilateral system allows buyers to deal directly with sellers— even if they use

³⁸ The reference here is to the exchange of physical quantities, not securities and other financial instruments representing an interest in these commodities which is clearly regulated.

professional intermediaries such as brokers or energy service providers. Experience in California and elsewhere suggests that central power exchanges may not be very effective or efficient. Small, decentralized markets are probably much better at allocating resources efficiently.

Small markets, in the form of individual bilateral electricity contracts, set the stage for innovative contractual arrangements that centralized power exchanges cannot even imagine. Other markets provide us with clear evidence in support of such an expectation. For example, just look at the number of ways the same hotel room or airline seat is marketed on the Internet! As we have all experienced, price for a hotel room or airline seat is dramatically affected by the transaction's information content: its financial and non-financial characteristics including cancellation policies, assurances and guarantees. Finally, and equally important, is the instantaneous position of the particular vendor with regard to its capacity— say the number of rooms or seats it has not sold relative to its contractual commitment or allotment. This suggests what is obvious to many: market prices for the identical product are driven by a wide range of factors, including transactions characteristics and costs and the position of the seller's inventory position at any moment.

Complementing this is the idea that specialization in markets produces further efficiencies and cost reductions. Following the restructuring of the health care industry in the mid 1980s and the introduction of accounting methods based on DRGs (*diagnostic related groups*) many US hospitals became "DRG specialists," in the sense that they might provide open-heart surgery for example, at dramatically lower cost and dramatically higher quality. So significant is the difference, that insurance companies send patients to centers specializing in specific diagnostics or surgical procedures. Clearly, open-heart surgery is not the same product in Houston as it might be in Iowa or northern Maine. Similarly, the idea of electricity as a single commodity item is no longer applicable. Market-driven electricity based products will ultimately be differentiated from each other.

Given the range of observed Internet prices for airline seats and hotel rooms, a single pool-wide price for tomorrow's electricity may not make much sense. Moreover, given the specialization in health care delivery and other functions, it may not be a stretch to imagine that electricity generators, by virtue of their location and equipment, may also become specialized at marketing particular types of power. As previously suggested, electricity is not a single commodity item but might be differentiated on the basis of:³⁹

- i. Voltage⁴⁰
- ii. Transaction size: wholesale–retail
- iii. Firmness: guaranteed firm, relatively firm, intermittent
- iv. Quality: "pure" sine curve for computers versus junk for electric space heaters
- v. Inherent Load Power Factor: generators cannot readily adjust this in the short term
- vi. Long-term commitment under fixed price vs. short-term (spot) or seasonal needs

³⁹ Awerbuch, Carayannis and Preston, [1997] propose a somewhat different set of utility outputs or products that can be classified into Energy Related Service Groupings, which would be analogous to the DRG (Diagnostic Related Groupings) basis for costing in health care.

⁴⁰ Systems already differentiate for voltage or single versus multiple phases.

Decentralized networks that encourage varied and innovative bilateral contracting can probably best promote overall efficiency.

V. HOW TO EFFICIENTLY MEET EUROPEAN RET TARGETS: INCENTIVE REGULATION AND THE NETWORK OPERATOR

As already argued, network operating and governance policies in many countries hinder innovation and do not promote efficient utilization of existing investment. Widely used postage-stamp rates, under which loads pay a *kw-month* fee independent of location, do not induce generators to locate in such a manner as to reduce network congestion. Properly designed access charges can help recover fixed network costs more efficiently while inducing the NO to meet EU RET targets in a manner that is as efficient as possible. Appropriate incentive regulation can also induce strategically located DG/RE for transmission and distribution-augmentation [see: Awerbuch, July 2000].

In EU liberalized electricity markets, it is the intention to encourage new generating sources. The reality of market power however yields different results. Most anyone can enter the generation business, assuming they can get connected to a network usually owned by colossal firms that in many cases also control the vast majority of generation. Why are policy makers surprised that new sources cannot get access? Even where generation ownership has been separated from network ownership and operation, there generally exists a vast concentration of market power— huge behemoths own large portion of the generation and can easily game the complex power exchange systems that policy makers and regulators have dreamed up. This makes it even harder for small operators, let alone wind or geothermal-based generators to compete.

Electricity generation has been de-regulated presumably on the premise that the profit motive, not regulation, produces greater economic welfare. Yet in many countries regulators have established the network operator, a central economic figure in this system, as a not-for-profit or government owned entity with no stake in promoting the system's efficient performance. The not-for-profit or government owned European NO is a strange creation indeed. The NO is a regulated *not-for-profit* entity that occupies a key position in an industry being reorganized on the premise that the *profit motive*— not regulation— produces greater economic welfare [A-H-V, 1999, Chap. 2]. No one has a financial stake in the ISO's success. Its directors and employees have no financial stake other than perpetuating their salaries and the so-called TAPs (transmission asset providers) that own its assets will earn a regulated return no matter how well or badly the NO meets its objectives. Finally, the NO has only *indirect* control over investment for system expansion and— importantly— receives no real benefit from improvements that lower electricity prices. It in essence has no real stake in efficiently and effectively meeting its customers' needs. Yet this is the entity to which EC policy makers plan to entrust the enormous task of efficiently identifying, siting and inter-connecting between 60,000 and 120,000 MW of renewable energy capacity over the next 15 years.⁴¹

⁴¹ Total current capacity for "EU-15" + "13 accession countries" = 580 + 65 = 645 GW. Assumes a RET target of 10%–20%.

Open network access for renewables is essential to help meet recently revised EU renewables targets, although the EU generally relies on administrative *fiat* to require open access as previously discussed. Not-for profit network operators have little incentive to provide open access to DG/RET. Using vague language that creates significant loopholes and encourages resistance, the EC Directive requires network operators to “guarantee” open access for RET. At the same time however, the Directive gives the NO a list of acceptable excuses for not meeting the targets. All the NO has to do is claim that adding RET will cause operations to “exceed” grid capacity or will degrade reliability and safety. These are hardly objective standards. The point is that it is difficult to efficiently force the implementation of RET targets by pushing generally unwilling operators to do so. It is much easier to create monetary incentives and then let innovation loose.

A more promising and efficient approach to attaining renewables targets and network open-access is through properly designed network pricing structures that reward wires companies for increasing all types of access and kWh throughput. This is more likely to induce innovative ways of providing access and opening markets. To this can be added a system of incentives for increasing access to RET, which will induce the NO to locate such resources where they will do the most good.

Attaining RET Targets with A Three-part Tariff:

Network costs are largely fixed, and it is therefore sensible to design cost recovery using primarily fixed charges under the economic dictum that fixed costs be recovered by fixed charges, with a variable charge to induce throughput. The Balanced Incentives three-part tariff consists of:⁴²

1. Fixed access charge:⁴³ This charge, levied on loads, recovers the cost of providing access and hence depends on the system’s ability to offer access or capacity to customers. Under incentive regulation, this charge creates incentives that induce the NO to find ways to add customers or capacity in the most economical manner because these factors increase access charge revenues.
2. A usage or MWH-based throughput charge, levied on loads, that provides the NO with incentives to improve its asset utilization by devising new services that increase usage and/or minimizing congestion and reliability problems that may inhibit usage. The NO cannot collect volumetric fees for unconsummated transactions.⁴⁴

⁴² The role of the three-part tariff in providing efficient cost-recovery and promoting efficient network operation is discussed in A-H-V, 1999, Chapter 7

⁴³ In the US, FERC’s *I2-CP* Method provides a practical approach for establishing the access charge.

⁴⁴ Asset utilization in the US and elsewhere on an 8760 hours per year basis is quite low. For example, "Some 10% of the \$12 billion invested in distribution networks in New South Wales is utilised only 1% of the year." *Fair Electricity Pricing For All*, Sinclair Knight Merz and M-Co, <http://www.smh.com.au/articles/2003/07/22/1058853067003.html>

3. A Priority rights or congestion charge, levied on generators, produces fees that help manage congestion. The access and the usage charges provide cost recovery. The congestion charge by contrast, does not accrue to the NO but is used to offset access charge. Congestion management charges are not an important part of the incentive structure for attaining EU RET targets and little more will be said about them. .

Giving the NOs A Stake in Fostering System Improvements

The Three-part gives the NO in a unique position and makes it a partner in longer term planning to insure that sufficient network and generating capacity exists. It induces the NO to provide sufficient system capacity while also insuring that there are sufficient supply resources to produce the needed power. The three-part tariff rewards the NO for maximizing throughput, maintaining broad, non-discriminatory access and making system investments as needed to maintain appropriate levels of congestion. Access charges are a principal revenue source under this tariff, and may account for 50% – 60% or more of total revenues. The tariff therefore induces the NO to increase access, which requires it to enlarge the system's ability to deliver peak power. Enhancing the system in this way does not help in getting more power to loads unless the system also has access to sufficient supply capacity.

This places the NO in a key position that is radically different from the position held by today's system operators, who are powerless to affect either network or generating capacity investment decision. The three-part tariff establishes a set of performance criteria that induces the NO to insure that sufficient system capacity is available.⁴⁵ This is very different from today's setup, under which grid operators have no control over the amount of capacity available on the system and can only resort to issuing public warnings and pleadings, as they have recently done in the UK, that system capacity shortages are looming [Walsh and Hellen, 2003].

For example, Powergen recently "Urged the government to intervene" to prevent power plant closures. It is of course in Powergen's interest to keep as many plants open since this reduces its day to day operational problems. But Powergen has no stake in the cost of keeping outmoded plants operational and there has every incentive to prod policy makers in this manner. Absent a balanced set of incentives, the public and the policy makers have no way of knowing whether the plea to prop up generation is genuine – i.e. cost effective, or whether the firm is "crying wolf." Either way, this is a certainly a feeble and haphazard way to run a national electricity system. It would be far more effective and efficient for Powergen to be regulated in such a manner that it is able to provide inducements where needed to make sure sufficient generation is located at the right places, although this does certainly not advocate that it be allowed to own any generation. Moreover, this paper has argued for a system of strict bi-lateral contracting between loads and suppliers. While such a system is not without flaws, especially since generation is a long lived asset, it would clearly better serve customer needs. There should be no more reason for the government to intervene in the generation business than in the apartment house business, where the long-lived nature of the assets and the lead time involved also create cyclical surpluses and shortages. Either way Powergen's

⁴⁵ Ingo Vogelsang [2000] demonstrates that such a tariff leads to optimal capacity expansion. A numerical illustration is given in A-H-V, [1999] Chapter 8.

hat-in-hand pleas for more government intervention and support of generation are impossible to evaluate objectively.

Under the incentives of the three-part tariff, nothing precludes the NO from creating its own inducement mechanisms— not necessarily monetary— that it can use to attract appropriate resources to desired locations. The NO will do this to improve system performance, since this increases profitability under incentive or *rpi-x* price-cap regulation. For example, enhancing access and system peak capability increases the NO's access charge revenues. It may make sense for the NO to extend or increase capacity at a strategic point on the grid in order to allow a generator to locate there, if the added generator improves system performance and access and hence the NO's profitability. The three-part tariff thus aligns the interests of the NO with the interests of its customers. Meeting customer needs— delivering more electricity and enhancing peak capability improves revenues. This makes it attractive for the NO to maintain sufficient system capacity through technology-neutral system enhancements. In certain instances it will make sense for the NO to try to attract additional generating resources as opposed to enlarging the capacity of its wires. It is also in the NO's interest to reduce market power along its network so there exists a competitive priced electricity supply. This enhances demand which in turn allows the system to grow and the firm's profits to increase.

Meeting RET Targets

EU RET targets can be met in two ways. An additional set of “bolt-on” incentives can be added to the three-part tariff to further induce the NO to add RET to the system. This in a sense is analogous to the German feed-in law, and runs into the same problem: the regulator or policy maker does not know what price level to set in order to elicit the desired level of response. A second approach is to hold the NO accountable for creating a mix of resource technologies its electricity mix that by some measure⁴⁶ meets the EU RET targets. This approach builds on the inherent incentives of the three-part tariff, which already rewards the NO for increasing access— for essentially enlarging the system's ability to deliver peak power. Under the RET target mandate, the operator must now further allocate its own inducement mechanisms between conventional and RET technologies.

VI. THE ROLE OF NETWORK INFORMATION

Electric utilities stand out as an industry that traditionally has had virtually no information about how customers use its product. They viewed their role as ending when the electrons were delivered to their side of the meter. The rest was up to the customer. Firms that have no information about how their products are used can do little to improve them or to provide new products that exploit their existing technologies and capabilities. Market-leading firms therefore value information about market conditions— prices, trends, competition— and customer demands and needs. Detailed information about electricity usage, even down to the

⁴⁶ e.g. percentage capacity of different technologies on the system

level of individual appliances in residences, might ultimately form the basis for enhanced electricity products and services.

Information requirements rise as electricity markets become more dynamic and complex. Information plays an important role in the decentralized network concept as well as most other visions of future networks.⁴⁷ In decentralized networks, the network operator (NO) needs real-time system status and other information that includes such elements as:

- i. Real-time line loading (and possibly transformer loading) data;
- ii. Power injection by supplier
- iii. Power withdrawals by specific load applications
- iv. Load-following and VARs injection on behalf of particular loads and applications
- v. Accounting information required for settlements (NO can provide this thereby lowering transactions costs to all system participants)
- vi. Traditional engineering system information needed for frequency control, etc.

These information elements are critical to the proper functioning of decentralized networks. Their value is in the capabilities they provide— they enable a decentralized network to function.

Information is increasingly essential in many of today's markets. Information on customer needs, purchase and payment histories, market prices, etc. is collected and traded or sold in many markets. Internet companies routinely give away software, electronic greetings cards and other e-merchandise in return for permission to collect information on the customer's on-line habits or to send relevant advertising material to the customer's computer. This information is at least as valuable as the software or greeting card that is given away in exchange.⁴⁸

Why are manufacturers and other producers increasingly interested in acquiring market information? First, technological progress along with advanced communications creates markets that are considerably more dynamic and fluid. Without information firms cannot react to changing market needs. Second, the value-added traditionally created by manufacturing excellence—the mainstay of American and European industry for a century—is increasingly becoming a commodity that can easily be outsourced. This means that product *marketing* and *distribution*—two information-rich activities—are increasingly important.

⁴⁷ Including US-DOE's *Grid 2030* Vision for the network.

⁴⁸ Shapiro and Varian [1999] observe that in competitive markets, the price of e-based products is driven to their marginal costs. For commodity-based information this cost is ultimately zero although it is not clear whether software or electronic greeting cards are in the latter category.

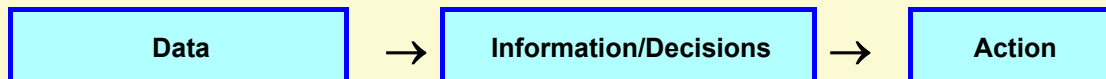
MECHANICAL VS. COGNITIVE PRODUCTION PARADIGMS

I. Traditional Mechanical Production Paradigm



– Mechanical Efficiency = Input/Output (e.g.: Btu / kWh, £ / kWh, € / km driven)

II. Cognitive Production Paradigm — The New Information Economics



- Mechanical-age measures & decision tools do not work
- Information-age firm is a decision-factory
 - Organized for quality decisions
 - Decision quality = $f(\text{data availability, processing speed, asset reconfiguration/deployment})$
 - e.g.: steel mini mills, Williams/Cat mobile turbines

Adapted from Vesey, “ _____ ” in Awerbuch and Preston , 1997

The Box illustrates. Under the previous *mechanical* production paradigm, successful competitors are distinguished in large measure on the basis of their production efficiency, as measured by traditional engineering efficiency concepts. With global manufacturing, the mechanical production aspects of many products become a commodity that is readily obtained in international markets. Now, market leadership requires other skills— e.g. product usage and design information to create products better suited to consumer needs. This requires information on consumer preferences, needs, pricing preferences, etc.

Superior manufacturing efficiency alone no longer provides competitive advantage. Rapid decision-making on the basis of processed information is key. This must be followed by the capability to re-deploy or re-configure production assets: e.g. change product lines, or in the case of electricity, re-deploy mobile generating assets to locations with the highest electricity values.

Transmission and distribution lines are increasingly more difficult to site. This is true on both sides of the Atlantic. The implication is that network operators will need other techniques for enhancing, mobilizing and redirecting the carrying capacity of their networks. They may need to apply these techniques on a diurnal, seasonal or long strategic term-basis as population and usage shift. This gives rise to the idea that NOs need to control or have access to a set of tools and equipment capable of providing rapid market response to changing conditions. It is unlikely that traditional fixed assets that are bolted to the ground can provide such capabilities. Rather, these tools will likely take the form of software, real-time monitoring equipment and mobile power, VARs and other rapid response capabilities.

Many loads have seasonal demand patterns. Traditional rate-base regulation rewards utilities simply for installing assets. This gives rise to unimaginative and inefficient solutions that ignore seasonality and simply size feeders and transformers to the peak demand, even though the equipment will be woefully underutilized over the entire 8760-hours per-year. Given more enlightened regulatory policies, the NO may find that it makes more sense to bring temporary power to meet the excess load requirements during peak seasons and times. For example, approximately every month or so, the Australian Embassy in Paris hosts an exhibition or other gala in its spacious lobby area. Special lighting and other equipment installed for these events is powered by a truck-mounted turbine parked outside the building. This turbine might supply power 50 hours per year— two or three hours on two or three successive nights every six or eight weeks— a solution that seems more cost effective than upgraded feeder and transformer capacity that would remain idle most of the time. In the traditional mechanical world, it is the KW rating of the connection to the load that determines the amount of network access available. In an information age, there exist other, possibly lower-cost ways to provide access, including mobile load-following power and perhaps even VARs power. This is one illustration of a network *plug 'n play* capability.

The *informed*, decentralized network environment requires NOs to develop new capabilities and competencies while at the same time rendering old competencies obsolete or not as important in providing value-added. At one time, manufacturing efficiency represented an important capability that distinguished market leaders. Similarly, superior transmission and distribution networks were at one time characterized principally by excellence in a single set of factors: highly effective system operation and maintenance at the lowest possible cost. Such skills will no longer suffice. They will be *necessary*, but not *sufficient* to maintain pre-eminence in administering the new information-rich network. In fact, it is highly likely that network maintenance will become a commodity item, to be acquired on an out-source basis.⁴⁹

Value-added would now be produced by a different set of skills— the ability of the network operator to respond to market demand, to produce innovative solutions that provide access and maximize throughput at the lowest cost, to reduce transactions costs and facilitate markets thereby maximizing the value of transactions throughout the network. Market leadership will be attained through excellence in these functions and through the ability of the NO to create market-driven products that efficiently use existing assets thereby enhancing profits.

The Value of Information

In developed markets, some forms of market information are easier to value: e.g. stock market quotes (and pork belly prices) are widely sold and hence have a market value, although the information is usually bundled with a variety of value-adding products and capabilities such as

⁴⁹ A relevant issue here is whether future NOs should continue the traditional separation between transmission and distribution functions. The functionality of this separation, was likely based on technological reasons, e.g. transmission voltages requires different structures, maintenance skills and operating protocols as compared to distribution systems. These distinctions will likely blur as *services* and *customers* drive decision making. For geographically small systems, e.g. the UK power system, it well make sense to create a single NO responsible for both traditional transmission and distribution services. The circumstances may differ in the US where transmission system routinely span hundreds of miles.

stock screening tools. This undoubtedly means that the commodity business of formatting and selling available information is not sufficiently profitable and is more vulnerable to competition [Shapiro and Varian, 1999].

On the other hand, *strategic* information, the type that creates new capabilities for the firm or has the potential of enabling it to enter new markets, is more difficult to value for a variety of reasons. First, the profitability of the new service or capability the information provides is hard to value. Its value likely has a Bayesian structure e.g.: profitability is conditional on success in a number of other factors. This is difficult to evaluate for new markets and new product types. So while Internet firms routinely give away software in return for the right to track customer online habits, few companies might contemplate installing advanced electricity metering in return for the right to acquire the information. Unlike stock-market prices, no one is certain how valuable electricity-usage information might ultimately be to market competitors.

Future networks will no doubt require enormous amounts of information, but it is as of yet entirely unclear what the value of this information will be and what competitive advantages will be created by technologies that provide new information. For example, the integration of RET/DG is a network modernization driver in the EU and the US. Some envision that such integration will require network operators to deploy command-control technologies that require system information.⁵⁰ This paper on the other hand argues for information that facilitates markets, reduces transactions costs, and enables mass-customization in electricity delivery. As the electricity market matures, customers will become aware of its potential and will be able to express a more sophisticated set of preferences and needs as compared to the relatively simplistic preferences for increased reliability or more frequent billing expressed by today's customers [e.g. see Hunter, Melnik, and Senni, 2003]. Future customers will want information-based capabilities that help them use electricity more efficiently, perhaps as part of an enhanced set of services and products such as heating/lighting or energy management.

While all of this sounds enticing, getting there is not simple. Technology products that merely provide new information may be hard to diffuse when ancillary processes that *use* the information are not ready. There is ample experience to support this. For example real-time line monitoring seems like a valuable capability, yet \$18,000 strain gauge devices to accomplish this have gained little acceptance, perhaps because integrated utilities cannot see the impact on profitability, or perhaps because no one knows exactly what to do with the information. Network operational decisions related to line-loading are made on the basis of day-ahead load simulations produced for expected network configurations and transactions levels. Parallel processes to exploit *real-time* information are not in place.

In other cases, the degree to which a new information-based technology alters ancillary processes is not understood. Advanced meters provide enhanced information along with other benefits, but the costs are perceived as too high, in large part because the technology's ability to provide information that reduces or eliminates non value-adding ancillary processes is not recognized.

⁵⁰ As is the case with the US-DOE Office of Electric Transmission and Distribution *Electric Distribution Transformation Program* discussed previously.

Several guidelines or considerations may be appropriate as criteria for assessing the value of innovative power technologies that produce new information:

- a. Market status and regulatory regime and their ability to accept and integrate radical innovation.
- b. Whether the new technology exploits *interdependence* with other parallel or ancillary technologies and processes; the more information the firm can gather and process the better its decisions, but the capability to process information and to act on it (e.g. make product changes, re-deploy assets, etc.,) must be in place.
- c. Does the new technology change market direction? This can create a first-mover advantage, but also open the firm to the risk of creating something no one knows how to use.

Decentralized Networks: Plug ‘n play Electricity?

The structure of today’s network has been shaped by the Rate-of-Return⁵¹ regulatory regime under which it has operated for the last century in the US and other countries.⁵² Under an ROR regime, the firm essentially recovers all of its operating costs— fuel, labor and materials and depreciation. In addition, it is entitled to a return or earnings allowance on the net book value of its assets, measured as the original asset installed cost, less accumulated depreciation.⁵³ ROR regulation provides strong incentives for firms to increase their asset base.⁵⁴ This creates an environment that favors capital-intensive solutions such as feeder and substation upgrades and line extensions and additions. This is not an environment that rewards network operators for finding innovative, low-cost ways of providing such basic necessities as access and throughput.

A regulatory regime based on price-caps (PC) and multi-part tariffs, on the other hand, provides very different incentives for the NO. Because the firm gets to keep some or all of its cost reductions over a reasonably long period (e.g. 5-years), PC regulation rewards the NO for

⁵¹ ROR regulation is also known as rate-base regulation or cost-of-service (COS) regulation.

⁵² While the intent in these other countries is to emulate a form of rate-base regulation, the reviewer properly notes that government often own these systems and in practice operate the finances as they wish.

⁵³ In jurisdictions with *historic test-years*, the utility has traditionally had relatively fair assurance that it will recover all of its operating expenses for the past year including depreciation. Such recovery is usually accomplished by adjusting rates for the forthcoming year. This system creates only modest incentives for efficiency because of the so-called regulatory-lag involved— the time between higher outlays and the utility’s ability to recover these in rates for the subsequent year. *Forward test-years*, on the other hand create some incentive for the utility to reduce cost over the coming 12 months since it gets to keep the cost savings, although the utility becomes a prisoner of its own success, since regulators will set rates for the subsequent year on the basis of these lower costs.

⁵⁴ This is the well-known Averch-Johnson [1962] effect: an ROR-regulated utility, earning its allowed rate of return, will over-invest in or “gold-plate” its assets.

producing innovative low-cost solutions that are not necessarily asset-intensive. For example, the ROR-regulated network will favor feeder upgrades while a PC-regulated network may develop lower cost solutions including contracting for mobile generators in order to enhance its profitability. This is the basis for the idea of electricity network *plug 'n play* presented by Vesey [A-H-V 1999, Chapter 4. The thrust of the idea is that network enhancement can be produced through innovative approaches that are relatively low in cost, as compared to traditional asset-intensive utility solutions. Such approaches can include software for increased real-time monitoring, mobile power, as well as pricing and technology packages that defer transactions from high-cost peak times to low-cost off-peak times.

The *plug 'n play* idea further implies an open network that allows new producers to easily connect, although appropriate tariffs and charges must be in place to induce them to locate at certain points along the network where they can produce the greatest benefit. Network externalities that accrue in communications networks are also operative in the case of power networks. Every incremental supplier increases the range of possible products and helps mitigate market power therefore benefiting all market participants.

For the foreseeable future, power networks must operate under some form of economic regulation— whether ROR or PC or some hybrid.⁵⁵ The Internet on the other hand does not. This may be one of the factors that create differences between these two networks. The second factor is the physics involved— the higher voltages and potential for system instability in power networks. Nonetheless, in order to exploit emerging generation technologies and information-based equipment, decentralized networks must have open-architectures to the extent possible. The Internet, which is fully decentralized and which enables nodes to connect with no centralized action, provides an enticing model for the power network. In the Internet, most of the required intelligence is at the nodes— in computers and servers. The rest of the network merely decodes and routes information. By being so decentralized, the net is resilient and reliable. The 9-11 World Trade Center disaster, which destroyed important telecommunications switching centers, reportedly did not significantly interrupt the flow of traffic on the net. The Internet's degree of decentralization may not be fully replicated in power networks in the foreseeable future, although Ilic for one, and others as well, envision a network architecture which enables any new device attached to the network to “announce itself and its characteristics,” which might include its power consumption or generation [Ilic, 2002].

In spite of some potential limitations, *plug 'n play* is a useful model for power networks. The concept implies innovative approaches that shatter the hitherto indestructible, century-old bond between the regulated firm's profitability and its ability to bolt new assets to the ground. *Plug 'n play* suggests that power networks must provide open, nondiscriminatory access to all network participants and that increasingly, network intelligence must migrate from its hub to its nodes. Decentralized networks, operated by *for-profit* PC-regulated firms are best suited to exploiting the new economics of distributed power generation and delivery.

⁵⁵ When self-generation or DG or other alternatives to grid-electricity become sufficiently established, market *contestability* may enable economic regulation to be greatly reduced [A-H-V, 1999, Chapter 2].

VII. CONCLUSIONS

This paper has outlined regulatory principles, pricing structures, governance forms and operating protocols for the efficient operation of the power network in an environment marked by deployment of large numbers of DG technologies and intermittent RETs. The principal elements of the proposal are:

1. A for-profit, incentive (or price-cap) regulated independent network operator that both owns and operates the network assets. To insure full independence for proper decision-making, the NO must not own any generation assets.
2. A tariff system based on charges for access, throughput and congestion, although the NO must not profit from congestion.
3. A price-cap or incentive (PBR) regulatory regime that motivates the NO to seek the lowest cost means for providing access, and for enhancing system capacity. In some cases this will mean that line extension are required. In others, system electronics, mobile generation, or DG/RET may more cost effectively meet the networks needs. The regulatory system must not bias the NO towards one type of solution with the exception that societal objectives, including RET deployment, may be additionally promoted through incentives.
4. The regulated NO can use financial incentives to induce generators to locate at appropriate nodes of the grid so as to best serve loads and enhance overall system performance.
5. A highly informed network capable of power as well as parallel information flows. The network immediately sheds loads whose suppliers have ceased generating.
6. An accounting and transactions system that enables a given service location to have multiple load types served by different suppliers.
7. A system of bilateral contract under which loads make all power purchases directly from generators without the usual centralized power exchange. This does not preclude market intermediaries who might agglomerate particular loads and negotiate power on their behalf.
8. Loads are responsible for base-load, load-following, reactive and back-up power. Some loads types may be intermittent and may benefit from low-cost long-term contracts with wind generators. Some load types may require standby or spinning reserves. Others may find that 60-minute power or even 8-hour power cost effectively meets their needs. This should create markets for various types of generation services.

The first four items are the most important. They can be summarized as: for profit incentive-regulated NOs, operating under a tariff structure that recovers fixed network costs with fixed charges and allows the NO to use financial incentives to promote optimal generator location.

The network operator is the essential market facilitator in any liberalised electricity system. With proper regulation, pricing and governance structures the network operator can become an important implementer of public policy objectives including energy diversity/security, RET integration, and the mitigation of market power. The network operator can help facilitate electricity transactions, reduce transactions costs, create open, robust markets, and enhance the value of commerce along the network.

Under the guidelines outlined in this paper, properly regulated and structured, *for-profit* network operators can enhance market efficiency in a number of ways. The NO can create new paradigms for electricity production/delivery that replace 19th-Century mass-production based generating practices with 21st century mass-customization concepts now widely used in manufacturing. Moreover, properly organized NOs can implement innovative, decentralized system operating protocols that reflect the emerging DG environment. Traditional network operating protocols, by contrast, have evolved over the last century in support of central station generating technology. Decentralized networks rely on market-driven operating protocols that reduce cost, i.e. by replacing traditional AGC with decentralized protocols that permit loads to make decisions now made by a central dispatcher. Under this approach, loads acquire their own contracts for back-up and load-following power, which greatly enhances system efficiency by allowing the establishment of proper prices for these services, consistent with the level of priority a particular load needs.

Through discrete load matching that exploits RET intermittence, decentralized networks create opportunities for energy efficiency that by contrast make today's demand-side management efforts seem feeble and, further, allow individual loads to operate with different back-up reliability levels for the different electricity uses on their site.

Finally, through appropriate tariff design NOs can be induced to efficiently use existing T&D plant and to encourage the efficient location of DG and RET, thereby enhancing competition and mitigating market power.⁵⁶ Efficiently implementing EU energy security/diversity targets requires the participation of a motivated NO. Disinterested and unmotivated not-for profit system operators NO will needlessly drive up the cost of implementing these policies.

All of this dramatically reduces overall costs as well as the central dispatcher's burden. Central planning did not work for the economies of Eastern Europe. Given today's highly dynamic electricity markets, central dispatch and planning is similarly becoming a burden that significantly degrades system capacity and efficiency.

⁵⁶ In 14 of the 15 EU member states, the largest three firms control more than 40% of the generation and wholesale market; in 12 member states, the top three firms control over 50% of the market. Further information about these figures and the methods used to calculate them can be found in: *European Commission Staff Working Paper* (2003).

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ANNEX

NETWORK REVENUES UNDER A THREE-PART TARIFF

1. Access Charge

The FERC 12-CP Method as practical basis for an access charge:

The access charge can be based on a load's share of the system's coincident peak implemented as a rolling average over the last twelve months

$$S_{i,tcp} = \frac{\sum_{t=1}^{12} L_{i,tcp}}{\sum_{t=1}^{12} TTL_{t,cp}}, \text{ with } 0 \leq S_{i,tcp} \leq 1.$$

Where:

$S_{i,tcp}$ is load i 's share of system coincident peak in month t

$L_{i,tcp}$ is the coincident peak for load i , in month t .

$TTL_{t,cp}$ is the system peak in month t .

Total revenues from this charge are equal to the access charge times the sum of the coincident peaks of all the loads. This charge provides the NO with incentives to increase capacity so it is able to serve a greater peak load for each of its customers. Since the charges are based on historic peak, they simultaneously induce loads to minimize their contribution to coincident peak thereby promoting decarbonization.

2. Usage Charges

The access charge provides the NO with incentives to increase system peaks. Efficiency considerations also dictate that NO maximize the use of its plant capacity (Now probably around 35% -- 45% -- Load-duration curves). This implies an incentive to maximize MWH throughput, especially during periods of low network utilization all of which improves efficiency and contributes to decarbonization.

MWH charge on loads for network energy usage:

This energy charge is designed to attain two objectives by providing the NO with incentives to:

1. Effectively accommodate local or zonal peaks that may not be coincident with the system peaks;
2. Use the network more efficiently by maximizing energy throughput.

3. Access Charge and Usage Charges Combined

The proportion of overall revenue requirements collected through each charge is:

$$(1-\alpha) \times RR_1 = \sum^{12} A_1 \times TTL_{t,cp}^0 \quad \text{and}$$

$$\alpha RR_1 = \sum^{12} P_1 \times TTMWh_t^0.$$

Where:

α is the proportion of overall revenues requirements to be raised through the throughput charge

P_1 is the per-MWH usage price, and

RR_1 is the revenue requirement in year 1

$TTMWh_0$ are the total MWH of transmission service used by all loads in Year 0.

Consequently,

$$A_1 = (1-\alpha) \times RR_1 / \sum^{12} TTL_{t,cp}^0, \quad \text{and}$$

$$P_1 = \alpha RR_1 / \sum^{12} TTMWh_t^0.$$

This says that in the first month of Year 1, each load i would pay

$$A_1 \times L_{i,cp}^0 + P_1 \times MWh_{i,1},$$

where $MWh_{i,1}$ is the load's energy usage in that month.

The Price Cap might look like:

$$[A_t Q_t + P_t D_t + M_t K_t] \leq (1 + X) [\text{Max}(A_{t+1}, .95 A_t) Q_t + P_{t+1} D_t + M_{t+1} K_t]$$

Where:

A_t = the access price in period t ;

Q_t = the sum of the individual coincident peak demands;

P_t = the congestion charge in period t ;

D_t = the priority capacity demanded;

M_t = the MWH based throughput charge;

K_t = the MWH throughput in period t .

Congestion Pricing Protocols -- Priority Access or Priority Insurance Charge

Priority Postage Stamp pricing or Priority Insurance: Congestion charges levied on generators guarantee either:

- i. In the case of priority postage stamp pricing: a given level of priority in the sense of a fixed place "in line." Lower priority transactions will be curtailed before higher priority ones.

- i) In the case of priority insurance: a pre-specified reimbursement in the event a transaction is curtailed.

Generally provides for some percentage of the difference between the contract price the load would have paid for electricity and the spot price it must now incur. Users can select the “deductible” the percentage reimbursement just as home owners buy insurance with different deductibles. Net priority revenues are used to offset access charge revenues in the subsequent year so that the NO does not benefit from the priority revenues.

Total Network operator Revenues

Total Year 1 revenues for the NO obtains from the three pricing components

$$TR_1 = A_1 \times \sum^{12} TTL_{tcp}^0 + P_1 \times \sum^{12} TTMWh_t^1 + PRR_1,$$

Where: PRR_1 are the priority revenues in Year 1.

A_1 and P_1 are set by previous allocation of the Revenue Requirements

Year 2 Adjustments:

Year 2 access charge: $A_2 = \tilde{A}_2 - Y_1,$

where \tilde{A}_2 is A_1 , adjusted for productivity, inflation and other items such a allowed pricing flexibility,

Y_1 is the rebate from the Year 1 priority charges, with

$$Y_1 = PRR_1 / \sum^{12} TTL_{tcp}^1$$