DIRECT TESTIMONY
OF
BENJAMIN K SOVACOOL
ON BEHALF OF
PIEDMONT ENVIRONMENTAL COUNCIL
BEFORE THE
STATE CORPORATION COMMISSION OF VIRGINIA
CASE NOS. PUE-2007-00031 AND PUE-2007-00033

Q. PLEASE TELL ME YOUR NAME AND MAILING ADDRESS.

A. Benjamin K. Sovacool. My address is Suite #02-03J in the Oei Tiong Ham Building at the Lee Kuan Yew School of Public Policy, National University of Singapore, 469C Bukit Timah Road, Singapore, 259772.

Q. DR. SOVACOOL, WHAT IS YOU EDUCATIONAL AND PROFESSIONAL EXPERIENCE?

A. My curriculum vitae is attached as Exhibit BKS-1.

Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?

A. Counsel for the Piedmont Environmental Council asked me to address the national security implications of Dominion Virginia Power's and Tran-Allegheny Interstate Line Company's (Applicants) application to the Virginia State Corporation Commission for authorization to site and construct a 500 kilovolt (kV) transmission line between the 502 Junction Substation and the Loudoun Substation across Northern Virginia (Loudoun line). In particular, I was asked to address the Direct Testimony of Applicants' witness Col. Edward V. Badolato.

Q. DR. SOVACOOL, PLEASE EXPLAIN THE ANALYSIS THAT YOU CONDUCTED.

A. At the Consortium on Energy Restructuring, where I served as a Research Fellow for three years, we have compiled a large database of studies, research interviews, and engineering simulations related to distributed generation and the electric utility industry. I compared Col.

Badolato's comments with studies on grid stability, reliability, and energy security conducted by the Federal Energy Regulatory Commission (FERC), U.S. Department of Energy, U.S. Department of Defense (DoD), and others. The results of these studies, as well as consultations and research interviews conducted from earlier projects, contradict and refute many of Col. Badolato's claims.

Q. PLEASE SUMMARIZE THE CONCLUSIONS THAT YOU REACHED FROM YOUR ANALYSIS.

A. Few question that energy security is a vital component of national security, and that the electricity demands of Washington, DC, represent an important security concern. Loss of power in our Nation's capital can have profound and lasting effects on critical infrastructure. I agree with Col. Badolato when at page 7 of his Direct Testimony he explains that electric power systems are "highly integrated, mutually dependent and a highly utilized set of components that provide our national security programs with vitally needed services and support." It is for precisely these reasons—reliability and energy security—that the Virginia State Corporation Commission should soundly reject the proposed Loudoun line. The proposed line fails to provide reactive power needed to ensure grid stability. Such a project will not provide increased reliability and energy security — even as those concepts are defined by Dominion and Trans-Allegheny themselves. The proposed line does not meet a broader notion of reliability and energy security that includes diversification, resilience, insulation, and environmental prudence. Finally, it ignores more effective and efficient alternatives.

Q. HAVE YOU ANALYZED COL. BADOLATO'S TESTIMONY?

A. Yes, I have.

Q. DO YOU AGREE WITH HIS CONTENTION THAT MORE HIGH-VOLTAGE TRANSMISSION INTO THE NATIONAL CAPITAL AREA WILL ENHANCE SUPPLY RELIABILITY AND HOMELAND SECURITY?

A. No. I do not. The claim that additional high-voltage transmission will increase system reliability by increasing the amount of raw power available to the grid relies on a dangerously simplistic model of the Nation's electrical system. In the modern electrical power grid, catastrophic failures are rarely the result of inadequate supplies of real power. More often, outages result from, singularly or in combination, human error, inadequate diagnostics, and voltage instability caused by insufficient reactive power — the power that keeps voltage and current in phase.

Q. DR. SOVACOOL, WHAT IS YOUR EVIDENCE OF THE RELATIONSHIP BETWEEN POWER SUPPLY RELIABILITY AND THE ADEQUACY OF REACTIVE POWER SUPPLY?

A. FERC has documented in its February 4, 2005 Staff Report regarding Principles for Efficient, Reliable Reactive Power Supply and Consumption (FERC Report), Exhibit BKS-2, how inadequate reactive power leading to voltage collapse has been a causal factor in major power outages worldwide. Voltage collapse was responsible for blackouts on the West Coast on July 2, 1996 and August 10, 1996. Voltage collapse also factored into major blackouts in Paris (1978), Tokyo (1987), Quebec (1989), and London (2003), and in Sweden, Denmark, and Italy during the 2003 European heat wave.

Q. WHAT ABOUT THE EAST COAST BLACKOUT OF AUGUST 14, 2003?

A. Multiple assessments of the August 14th 2003 East Coast blackout found that the cause of the outage was not a lack of raw power or available transmission. Indeed, as documented in

Availability of Dispersed Photovoltaic Resource, Exhibit BKS-3, the Harding Chamberlain 345kV line that was wheeling some of the power lost when Cleveland's East Lake power plant tripped offline was operating at only 45 percent of its allowable limit when the cascading outage began. Instead, as the FERC Report concluded the unfortunate series of events that led to the power losses for much of the East Coast was precipitated by mounting voltage instability resulting from insufficient reactive power during the period leading up to the blackout.

While the 2003 blackout was not due to a voltage collapse (as that term has traditionally been used by power system engineers), the Task Force charged with investigating the incident said in its Final Report that "insufficient reactive power was an issue in the blackout." The FERC Report at page 20 also cites "overestimation of dynamic reactive output of system generators" as a common factor among major outages in the United States.

Q. WHAT MESSAGE SHOULD THE COMMISSION DISCERN IN THIS EMPIRICAL EVIDENCE, DR. SOVACOOL?

A. Long distance transmission is not reliable. Given the complexity of the modern electrical system, and what we know about the role reactive power has played in recent outages, relying on longer transmission lines to wheel greater amounts of real power is perhaps the *worst* strategy for ensuring system reliability. Large and long transmission lines lose reactive power the larger and longer they become, requiring the system to compensate in ways that *increase* the likelihood of systems collapse.

Q. PLEASE ELABORATE ON THE RELATIONSHIP BETWEEN REACTIVE POWER AND LONG-DISTANCE TRANSMISSION, DR. SOVACOOL.

A. It is well known that reactive power is difficult to transfer. Larger transmission lines generate greater line losses. But power lost through transmission is not equally distributed. At high loadings relative losses of reactive power on transmission lines are significantly greater than relative real power losses. Reactive power losses increase exponentially with the distance transmitted. So the difference between reactive power losses and real power losses becomes even greater the longer the line. Because long, large lines make it impossible to supply reactive power locally, it must be supplied remotely by increasing currents to compensate for the reactive power lost in transmission. But, as the FERC Report observes at page 19, large current increases also risk larger voltage drops along the path.

FERC has investigated how inadequate reactive power supplies lower voltage in long transmission lines. As voltage drops, current must increase to maintain the power supplied, causing lines to consume more reactive power and the voltage to drop further. If current increases too much, transmission lines trip, overloading other lines and potentially causing cascading failures. If voltage drops too low some generators will automatically disconnect to protect themselves. This further loss in generation causes further reduction in reactive power from capacitors and line charging, creating a positive feedback loop that results in still further voltage reductions. The result, FERC Report at page 20, is a progressive and uncontrollable collapse of voltage, all because the power system is unable to provide the reactive power required to meet the real power demand.

Q. DOES THE PROPOSED LOUDOUN LINE SATISFY RELIABILITY AND SECURITY STANDARDS, DR. SOVACOOL?

A. No, it does not. The physical vulnerabilities inherent in the proposed T&D infrastructure do not fulfill definitions of reliability and energy security provided by the Department of Defense, the National Research Council, the International Energy Agency, and Dominion’s own experts.

Q. PLEASE ELABORATE.

A. First, a comprehensive, three-year DoD and Federal Emergency Management Agency study — *Brittle Power: Energy Strategy for National Security*, which I attach in relevant part as Exhibit BKS-4 — concluded that relying on centralized plants to transmit and distribute electric power created unavoidable (and costly) vulnerabilities. The study noted that transmission and distribution systems constituted "brittle infrastructure" that could be easily disrupted, curtailed, or attacked. One of the authors of the study, physicist Amory Lovins, who is currently helping the U.S. military streamline energy-intensive sectors, has long argued that if you build an efficient, diverse, dispersed electricity system, major failures—whether by accident or malice—become impossible by design rather than inevitable by design. In Britain during the coal-miner strikes of 1976, for example, a leader of the power engineers famously told Lovins that "the miners brought the country to its knees in 8 weeks, but we could do it in 8 minutes." This is because the massive, complex, and interconnected infrastructure needed to transmit and deliver power from a centralized generation source is brittle, and subject to cascading failures easily induced by severe weather, human error, sabotage, or even the interference of small animals.

Q. HOW VULNERABLE ARE HIGH-VOLTAGE TRANSMISSION LINES TO SABOTAGE, DR. SOVACOOL?

A. They are quite vulnerable. The DoD study, Exhibit BKS-5, concludes that centralized energy facilities create tempting targets for terrorists because the terrorists would need to attack only a few, poorly guarded facilities to cause large, catastrophic power outages. In its complementary study, *Energy Security in a Dangerous World*, Exhibit BKS-6, the International Energy Agency reaches the same conclusion. In a 2002 Foreign Policy article, *The Rise of Complex Terrorism*, Exhibit BKS-7, Thomas Homer-Dixon, Chair of Peace and Conflict Studies at the University of Toronto, cautions that it would take merely a few motivated people with minivans, a limited number of mortars and few dozen standard balloons to strafe substations, disrupt transmission lines and cause a "cascade of power failures across the country," costing billions of dollars in direct and indirect damage.

As Anton Nerad documents in *Distributed Generation to Counter Grid Vulnerability*, Exhibit BKS-8, a January 2007 winter storm disrupted high-voltage transmission lines and knocked out electricity for more than 330,000 homes and businesses in Missouri, as well as 11,000 homes and businesses in New York and 122,000 electricity customers in Oklahoma. Considering that such an event was an act of nature, absent of any human malevolence, the vulnerabilities with the current centralized T&D system became painstakingly apparent.

Q. HAVE CENTRALIZED POWER SYSTEMS DEPENDENT ON LONG-DISTANCE TRANSMISSION BEEN THE SUBJECT OF ACTUAL SABOTAGE?

A. Yes. The vulnerabilities of centralized generation systems to accidental or intentional disaster has never been so apparent as in Iraq, where determined insurgents destroy critical infrastructure faster than American contractors can rebuild it. In *Security: Power to the People*, Exhibit BKS-9, James Robb, a former "black ops" agent and expert in counterterrorism, warns that a terrorist-criminal symbiosis is developing out of the situation in Iraq. There, terrorists have learned to fight nation-states strategically, without weapons of mass destruction using a new method of "systems disruption," a simple way of attacking critical networks (electricity, gas, water, communications, etc.) that require centralized coordination of complex networks.

Such disruptions are designed to erode the target state's legitimacy by keeping it from providing the services it must deliver to command the allegiance of its citizens. In the first 3 years of the U.S. occupation of Iraq, for example, relatively simple attacks on oil and electricity networks reduced, or held, delivery of these services to prewar levels, with a disastrous affect on the country's infant democracy and economy.

U.S. military bases—themselves small cities erected in the middle of the war zone — faced similar obstacles in attempting to secure fuel and supply lines to power a centralized electricity system. This led in 2006 to Al-Anbar commander and U.S. Marine Corps Major General Richard Zilmer issuing a priority 1 memo to the U.S. Joint Chiefs requesting renewable energy-powered distributed generation units to replace the diesel and gas-based generators on which his forward deployments were dependent. Zilmer's memo, as reported in the Christian Science Monitor, Exhibit BKS-10, made a persuasive case. Namely, too many staff and resources went into securing fuel and supply lines when so many points of failure are dependent on one centralized source of energy. Therefore, too few were left to assign critical, front-line security functions.

Q. DOES DOMINION OR ITS WITNESSES RECOGNIZE THE VULNERABILITY OF TRANSMISSION SYSTEMS, SUCH AS THE PROPOSED LOUDOUN LINE?

A. Apparently, they do. Dominion's own expert Col. Badolato, for example, acknowledges vulnerabilities at four points in the supply chain for electricity: the generator, the substation, the transformer, and the wires.

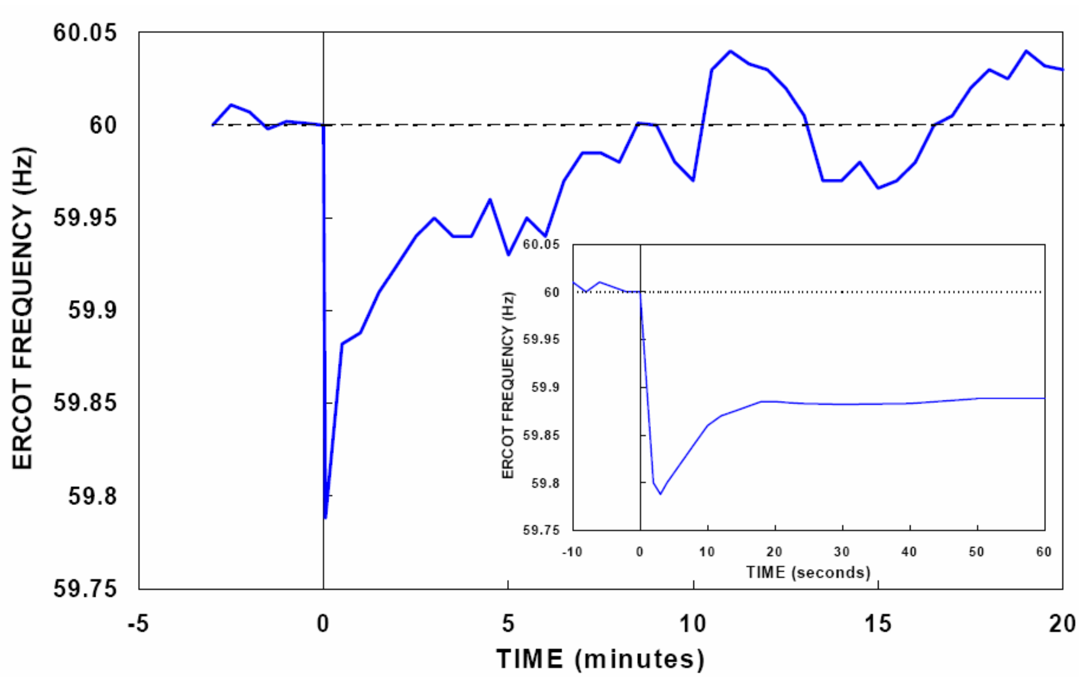
Q. WHAT IS IT ABOUT CENTRALIZED POWER PLANTS AND HIGH-VOLTAGE TRANSMISSION SYSTEMS THAT MAKE THEM SO SUSCEPTIBLE TO SABOTAGE?

A. Centralized power plants are inherently unreliable. Almost as complicated to design and construct as cathedrals, in any given hour there is a 10 percent risk that electricity from conventional power plants will be unavailable or limited due to forced outages and mechanical failures. Operator error, automobile accidents, severe weather, fuel shortages, computer glitches, fires, and even small animals can start a chain reaction that cripples an entire regional grid. When Col. Badolato states in an answer to Piedmont discovery, Exhibit BKS-11, that “in a matter of milliseconds, excessive current can damage critical infrastructure which must be replaced or repaired at significant cost, often with a corresponding service outage” he is acknowledging a risk inherent in centralized generation systems dependent on long-distance transmission.

Q. HOW WOULD THE PROPOSED LOUDOUN LINE AFFECT THE SECURITY OF THE METROPOLITAN NATIONAL CAPITAL AREA?

A. It would increase the Capital’s dependence on a centralized generation system by expanding the size of that system. For example, it is widely accepted that the larger the power plant, the larger the outage, and the more time it takes to recover. In Figure 1 Eric Hirst, a Corporate Fellow at Oak Ridge National Laboratory's Energy Division demonstrates how the standard electricity system operates when a major generating unit suddenly fails. Before the outage, overall system frequency is close to 60-Hz, yet within a second after the outage the frequency drops, and contingency reserves take more than eight minutes to restore frequency.

Figure 1: Interconnection Frequency Before and After the Loss of a 653 MW Generator



Source: Eric Hirst, *Price-Responsive Demand as Reliability Resources* (Montpelier, VT: Regulatory Assistance Project, April, 2002). The inset shows the frequency for the first minute after the outage, the outset the frequency for the first 20 minutes after the outage. Exhibit BKS-12.

480 seconds may not seem like a long time for ordinary human activity, but for a power system every *millisecond* matters. The electric power grid, unlike generators that have longer fuel cycles, has only the rotational kinetic energy of the connected synchronous generators to balance production and consumption. Many cycles happen in a single second. As reported in *Frequency Control Concerns in the North American Electric Power System*, Exhibit BKS-13, researchers at the Oak Ridge National Laboratory note that large shifts in frequency can "damage equipment, degrade load performance, and interfere with system protection schemes which may ultimately lead to system collapse." Electrical engineering studies conducted after the Italian blackout in 2003, Exhibit BKS-14, found that just a 1.0 Hz frequency drop could shed more than 50 percent of the entire load.

Q. ARE THERE TECHNOLOGICAL PROTECTIONS THAT COULD LESSEN THE VULNERABILITY OF LONG-DISTANCE TRANSMISSION SYSTEMS, SUCH AS THE LOUDOUN LINE?

A. To the contrary, several recent trends in the electric utility industry have increased the vulnerability of T&D infrastructure. To improve their operational efficiency, many utilities and system operators have increased their reliance on automation and computerization. Low margins and various competitive priorities have encouraged industry consolidation, with fewer and bigger facilities and intensive use of assets centralized in one geographical area. As the National Research Council noted in *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism*, Exhibit BKS-15, "Control is more centralized, spare parts inventories have been reduced, and subsystems are highly integrated across the entire business." Restructuring and consolidation of utilities has resulted in lower investment in security in recent years, as cash-strapped utilities seek to minimize costs and maximize revenue available for other areas.

Q. BUT DON'T THE UTILITY OWNERS OF TRANSMISSION HAVE INCENTIVES TO PREVENT DAMAGE TO THEIR TRANSMISSION SYSTEMS?

A. Load-serving entities such as Dominion also have little incentive to improve reliability since then costs of unreliable power are borne by consumers. In studies attached as Exhibit BKS-16, the US Department of Energy estimates that consumers expend an average of $150 to $400 billion every year on the cost of power outages. The Electric Power Research Institute has also noted the costs of power disturbances to industrial and digital economy companies. Exhibit BKS-17. Because many utilities do not have to absorb the excessive costs of power disruptions, they have little incentive to invest large amounts in energy security measures that would address many of the critical vulnerabilities inherent in centralized generation.

Q IS LINKING THE NATIONAL CAPITAL AREA WITH REMOTE GENERATION VIA LONG-DISTANCE TRANSMISSION, SUCH AS THE LOUDOUN LINE, CONSISTENT WITH SOUND ENERGY SECURITY, DR. SOVACOOL?

A. No. In recent years energy analysts have moved away from a narrow interpretation of energy security as the mere "availability" of domestic resources or access to fuel, and have begun to adopt and promote a more complete and holistic concept of energy security. Most modern analysts accept that true energy security is composed of several criteria, including diversification, resilience, insulation, and environmental prudence.

Q. PLEASE ELABORATE ON DIVERSIFICATION.

A. The first principle, *diversification*, entails diversifying the types of fuel, the mechanisms of power generation, and the geographical distribution of generation facilities. Multiplying one's supply sources by investing in multiple alternatives serves the interests both of consumers and producers because it ensures that the power supply chain is not dependent on any single fuel source. As well, the geographical dispersion of generators not only improves their overall reliability, it makes the entire distribution network more secure and resilient to accidental power disruption, systems failure, or intentional attack. Geographical dispersion creates multiple targets, all of which would have to be attacked at the same time to elicit total systems collapse.

Q. IS THE LOUDOUN LINE PROPOSAL CONSISTENT WITH DIVERSIFICATION?

A. No. Dominion's proposal to increase our Capital's reliance on a singular, centralized generation source served by a larger and longer transmission infrastructure satisfies none of the accepted criteria for diversification. Dominion's plan weds unreliable centralized plants to an inherently vulnerable infrastructure. Because any point of the electricity fuel cycle can be targeted for attack - from the mine to the transmission and delivery network to the generator to the waste disposal site – reliance on a centralized generation system increases the risk that any one incident will have catastrophic results that undermine our national security interests.

Q. CAN YOU ELABORATE THE KINDS OF RISK THAT ATTEND RELIANCE ON CENTRALIZED GENERATION SOURCES?

A. Certainly. My ruminations are not merely scholastic. In 1975, the New World Liberation Front bombed assets of the Pacific Gas and Electric Company more than 10 times, and members of the Ku Klux Klan and San Joaquin Militia have been convicted of attempting to attack electricity infrastructure. As the authors of *Energy Infrastructure and Security*, Exhibit BKS-18, report, organized paramilitaries such as the Farabundo-Marti National Liberation Front were able to interrupt more than 90 percent of electric service in El Salvador and even distributed manuals to its members outlining the best ways to attack power systems.

Q. PLEASE TURN TO THE SECOND PRINCIPLE OF ENERGY SECURITY.

A. *Resilience* refers to how well a system can predict, adapt to and recover from an attack, accident, or disruption. In 1973, ecological economist C.S. "Buzz" Holling wrote a seminal paper on the resilience and stability of ecological systems, in which he laid out the theory that dynamic ecological systems that are able to withstand significant perturbation survive longer than static systems, no matter how robust they are. Put simply, the ability to adapt and absorb shocks protects a system better than "hardening" a robust, but static system.

Since 1973, Holling's findings have been applied to other complex systems like economics, business, industrial computing and, more recently, the energy infrastructure. After the September 11th attacks, systems engineers began to expand the idea of infrastructure protection from the rather simplistic notion of hardening robust and redundant systems to include the ability of systems to avoid, minimize, withstand and recover from the affects of disasters, whether natural or manmade. In 2006, for example, the Department of Homeland Security's Advisory Council produced a report, Exhibit BKS-19, that calls for the adoption of critical infrastructure resilience in lieu of Critical Infrastructure Protection (CIP), as the "top-level strategic objective—the desired outcome—to drive national policy and planning."

Partly as a result of this recent shift from protection to resilience, the CIP program in February 2007 released a series of discussion papers to promote awareness of the importance of resilience among critical industries. Among them is a working paper, Exhibit BKS-20, by Lewis J. Perelman, Senior Fellow at the Homeland Security Policy Institute. In this paper, the author argues that the 2003 blackout revealed that the sheer scale and complexity of modern power grids makes periodic, disastrous failures inevitable and that measures typically undertaken by utility regulators to protect systems from repeat disasters actually tend to be ineffective or even to make future blackouts bigger and more likely. Or, as Perelman puts it: "the harder they are, the bigger they fall."

Q. IS THE PROPOSED LOUDOUN LINE CONSISTENT WITH RESILIENCE?

A. No, it continues along the older paradigm of infrastructure protection rather than infrastructure resilience. The point of a truly resilient system, such as a distributed network of solar panels or small-scale reciprocating engines, for instance, is that it can cover almost automatically from a local disruption of either generation or transmission and distribution. The DoD has noted this when integrating distributed generation into its local power grid at various military installations. In contrast, tightly-coupled and "hard" infrastructure such as T&D lines, when attacked or disrupted, bring down large components of the entire system.

Q. PLEASE TURN TO THE THIRD PRINCIPLE OF ENERGY SECURITY.

A. *Insulation* entails how well energy systems are integrated into the global energy marketplace in ways that minimize disruptions and price spikes. Dominion's proposal fails here as well. The transmission of electric power from fossil fuel sources subjects ratepayers to variable supplies and wide fluctuations in fuel prices. From 2002 to 2005, for example, operation and maintenance expenses for utilities rose by nearly $26 billion (in 2002 dollars). As shown in Exhibit BKS-21, ninety-six percent of this increase was driven by rising fossil fuel prices, not because parts or labor had gotten more expensive. In addition, aggregate fossil fuel costs nearly doubled in the four years between 2000 and 2004, from $0.023 per kWh, to $0.0437 per kWh.

The overbuilding of gas-fired peaking plants in the 1990s resulted in skyrocketing demand for natural gas, which, in turn caused prices to surge. Between 1995 and 2005, natural gas prices rose by an average of 15 percent *per year*. As a result, many electricity generators switched back to coal-fired peaking units. But the switch only increased demand for coal, driving the price up. In 2003, for example, the cost of coal in Central Appalachia was $35 per ton. The price increased nearly 7 percent *each year* until, by 2006, a ton of coal in the same region cost close to $60 a ton. In some regions of the U.S., coal prices actually doubled between 2002 and 2004. This is partly due to high demand, and also partly because most remaining coal and natural gas reserves are "stranded." That is, as recounted in the Congressional testimony in Exhibit BKS-22, the most economical reserves have already been exploited, while the remaining reserves, even though they may be quite significant, are located in areas geographically distant from major sources of consumption and thus are more costly to extract, process, and transport.

Time and again, natural gas markets have demonstrated why insulation is such a critical component of energy security. The price of natural gas, jumped from $6.20 per million BTUs (MMBtu) in 1998 to $14.50 per MMBtu in 2001, then dropped precipitously for almost a year and then rebounded steadily from around $2.10 per MMBtu in 2002 to more than $14.00 per MMBtu near the end of 2005. Exhibit BKS-23. Hurricane Katrina caused similar price spikes when it disrupted natural gas refining and reprocessing infrastructure in the Southeast. These disruptions had an especially devestating effect on the Midwest and East Coast since these areas are heavily dependent on deliveries of natural gas and refined products through a few major pipelines from the Gulf of Mexico.

Q. AND NOW PLEASE TURN TO THE ENVIRONMENTAL PRUDENCE PRINCIPLE OF ENERGY SECURITY, DR. SOVACOOL.

A. *Environmental prudence* gages how well energy systems protect human health and minimize damage to the natural environment. Researchers at the Harvard School of Public Health estimated that the air pollution from conventional energy sources kills between 50,000 and 70,000 Americans every year. In a 2001 report, *Study Details Impact of Pollution on Public Health from Nine Older Fossil Fuel Power Plants in Illinois*, Exhibit BKS-24, those researchers found that the emissions from just nine power plants in Illinois directly contributed to an annual risk of 300 premature deaths, 14,000 asthma attacks, and more than 400,000 daily incidents of upper respiratory symptoms among the 33 million people living within 250 miles of the plants.

As Michael T. Kleinman reports in his 2000 publication *The Health Effects of Air Pollution on Children*, Exhibit BKS-25, because children spend more time outside and have smaller airways that necessitate more rapid breathing, they are much more vulnerable to develop illnesses associated with air pollution. Recent follow-up epidemological and toxicological studies, Exhibit BKS-26, have shown that for some of these pollutants, such as mercury and particulate matter, no safe levels of exposure may exist. In short, by linking the National Capital Area to coal-fired generation to the west, Dominion's proposed Loudoun line will indirectly, but incontrovertibly, kill people.

To say nothing of its climate change impacts, a conventional 500 MW coal plant consumes around 7,000 gallons of water per minute, or the equivalent of 17 Olympic-sized swimming pools every day. This impact of such a plant on water resources is documented by Thomas J. Feeley in *Tutorial on Electric Utility Water Issues*, Exhibit BKS-27. Data from the Electric Power Research Institute confirms that conventional power plants use thousands of gallons of water for the condensing portion of their thermodynamic cycle. Coal plants also use water to clean and process fuel, and all traditional plants lose water through evaporative loss.

On the production side, the coal industry discharges between 70 million and 2.5 billion tons of fine coal into the nation's streams, creeks, and rivers every year. Coal extraction, processing, and transportation have a direct affect on water and land resources. Of the more than 1 billion tons of coal mined in the United States annually, roughly 70 percent comes from surface mines. Mountaintop removal—a newer technique for mining coal that uses heavy explosives to blast away the tops of mountains—in the Appalachians has destroyed streams, blighted landscapes, and diminished the water quality of rural communities. As reported in the studies, Exhibit BKS-28, show, failing coal slurry impoundments, acid mine drainage, aquifer disruption, saline pollution from coal-bed methane recovery, and occupational safety and health hazards (including mine-related deaths) are among the impacts of continued reliance on coal-fired electricity production.

Q ARE THERE ALTERNATIVES TO THE LOUDOUN LINE THAT BETTER CONFORM TO THE PRINCIPLES OF ENERGY SECURITY, DR. SOVACOOL?

A. Yes, there are many. Among these are the transmission alternatives and generation closer to eastern load centers that are discussed in the testimony of Dr. Hyde Merrill. And there are the demand-side management and energy efficiency alternatives that are discussed in the testimony of Dr. Daniel M. Violette. Consistent with the diversification principle, an optimal alternative would likely comprise some combination of these. In addition to these alternative, one that should also be considered, which has the added benefit of providing significantly to reactive power is *distributed generation*¸ or small-scale and modular generating units located closer to where their energy is consumed.

Q. HOW HAS DISTRIBUTED GENERATION BEEN APPLIED, DR. SOVACOOL?

A. By way of example, in the early 1990s, Pacific Gas and Electric (PG&E)—the largest investor-owned utility in California—faced a problem similar to Dominion's current reliability issue. PG&E planned to expand its transmission and distribution system near San Francisco, California. Using conventional planning approaches, PG&E initially proposed an estimated $355 million (in 1990 dollars) upgrade of the 230-kV and 60-kV transmission lines that served seven substations in the area. However, PG&E ultimately discovered that it would be cheaper to deploy several, distributed 500-kW photovoltaic plants connected to distribution feeders. By investing in such locally-sited projects, PG&E found that it could defer a significant number of its transmission upgrades, which ultimately saved the company $193 million (or more than 50 percent the present value of the expansion plan). The results of this investment in distributed generation are documented by C.D. Feinstein, Ren Orans and Chapel S.W. in their 1997 paper *The Distributed Utility: A New Electric Utility Planning and Pricing Paradigm*, Exhibit BKS-29.

Q. BUT ARE DISTRIBUTED GENERATION ALTERNATIVES CAPABLE OF ADDING A COMPARABLE LEVEL OF TRANSFER CAPABILITY AND DELIVERABILITY THAT A NEW TRANSMISSION LINE SUCH AS THE PROPOSED LOUDOUN LINE WOULD OFFER?

A. Not alone, but, in combination with the recommendations of Drs. Merrill and Violette, the distributed generation alternatives offer a number of benefits. In his article *Decentralizing Networks*, Exhibit BKS-30, Walt Patterson, a Senior Fellow at Chatham House, a public policy think tank in London, described how radial one-way transmission and distribution networks are completely incompatible with the way that most people consume power. His research has found that distributed generation has so much more in common, in both scale and attributes, with real electrical loads that "connecting a 500 kW microturbine has much the same effect on the system as *disconnecting* a 500 kW motor." Therefore, distributed generation systems obtain ancillary benefits associated with their scalability that centralized systems could never achieve.

Combining distributed generation with diversification of generation technologies can also realize substantial cost savings. In their 2005 *A Study of Increased Use of Renewable Energy Resources in Virginia*, Exhibit BKS-31, researchers at the Virginia Center for Coal and Energy Research (VCCER) studied *Dominion's own service territory* and concluded that distributed renewable generators fueled by wind and landfill gases offered the *cheapest* forms of electricity—2.8 and 3.0 cents per kWh, respectively—when compared to all other generators including advanced coal, natural gas, and nuclear plants: This is shown in the table below:

	LCOE, in 2005

Technology	$/kWh
Wind	$.028
MSW-Landfill Gas	$.030
Advanced Nuclear	$.035
Scrubbed Coal	$.044
Integrated Gasification Combined Cycle (IGCC)	$.044
Advanced Combined Cycle Gas/Oil	$.047
Conventional Combined Cycle (CC) Gas/Oil	$.050
Biomass	$.050
IGCC with Carbon Sequestration	$.059
Advanced Combustion Turbine	$.067
Advanced CC with Carbon Sequestration	$.069
Conventional Combustion Turbine	$.077
Solar, PV (30% capacity factor)	$.235
Solar, PV (10% capacity factor)	$.310

The U.S. government has also acknowledged the ability of renewable distributed generation to deter major power outages and provide consistent power supply. A recent assessment from the DoD, Exhibit BKS-5, found that an increased deployment of renewable energy resources significantly improved overall system reliability. The study, which focused on the deployment of wind, solar and geothermal electricity generators on and near military installations, found that:

1. Renewable energy facilities contribute to energy security by enabling military facilities to operate during simulated outages
2. Renewable energy generators enable the possibility of storing excess energy when power output is high

3. Renewable energy resources help "segregate" a service area from outside influences, creating "self-sustaining regional islands" that can provide "critical installation functions"
4. Renewable power may be more reliable during routine or prolonged power outages than conventional generators, which may have restricted hours of operation

DoD's conclusions (as well as the conclusions of two other studies on distributed generation from PG&E and the VCCER) are entirely consistent with the conclusions of Dominion's own experts. Col. Badolato in his paper *Meeting the Challenge of the Digital Age: Electric Power Shortfalls and New High Tech Solutions*, Exhibit BKS-32, has noted that, of the $10 billion spent annually on transmission and distribution infrastructure, between $800 million and $2.5 billion of these expenses could be "profitably diverted to small scale generators and improved energy efficiency given the financial benefits of avoiding power outages and spending more on grid updates." As he concludes later: "By allowing millions of customers to operate their own generators, a distributed power network … will be more capable than existing systems for meeting the need for reliable, higher quality electricity."

Q. PLEASE ADDRESS THE POTENTIAL CONTRIBUTIONS OF REACTIVE POWER ON DISTRIBUTED GENERATION.

A. Distributed generation technologies provide reactive power capability locally, often at the site of large loads, they reduce reactive power losses in transmission lines and can avoid the kinds of voltage collapse scenarios that have characterized recent major power outages. This capability is documented by John Kueck in his 2006 article *Reactive Power From Distributed Energy*, Exhibit BKS-33.

Q. DR. SOVACOOL, PLEASE REPRISE THE PRIMARY POINTS OF YOUR TESTIMONY.

A. The proposed 500 kV Loudoun line should be rejected on grounds that it fails to provide substantial reliability and security as defined by Dominion itself. Instead, the proposed line increases the vulnerability of Virginia and the National Capital Area to critical national security threats. By failing to consider cheaper and more effective alternatives, Dominion's proposal suffers substantial opportunity costs and delays investment in a safer and more practical energy system for the region.

Q. THANK YOU, DR. SOVACOOL, I HAVE NO FURTHER QUESTIONS.