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My name is Lawrence Makovich. I am Vice President and Senior Advisor for Global Power for IHS Markit; a company that provides data, analyses, and strategic insights to businesses around the world focusing on energy, automotive, chemical and defense industries. I am an energy economist specializing in the analysis of the electric power industry. My current research focuses on electric power market structures, demand and supply fundamentals, wholesale and retail power markets, emerging technologies, least cost CO_2 emission abatement pathways and asset valuations and strategies. I was a Senior Fellow at the Mossavar-Rahmani Center for Business and Government in the John F. Kennedy School of Government at Harvard University from May 2015 to June 2017. I hold a Ph.D. in Public Policy from the University of Massachusetts/Boston, an MA in Social Science from the University of Chicago, and a BA in economics from Boston College. My work address is IHS Markit, 55 Cambridge Parkway, Cambridge, MA 02142, USA.

I am appearing before you today to discuss the economic argument that supports the proposed Zero-Emissions Nuclear Resource provisions of Senate Bill 128.

The economic argument to support Ohio nuclear plants is complex because power systems engineering, economics and electric wholesale market operations are complex. I expect opposition to the Zero-emissions Credit initiative reflects a simple fear that this Zero-emission initiative is a "bailout" of nuclear power plants that cannot compete in the PJM wholesale marketplace, and that the Zero-emission credit will increase retail electricity prices for Ohio consumers. I do not think either of these perceptions is accurate.

I conclude that the cash flow shortfalls of the Ohio nuclear power plants result from PJM market distortions caused by wholesale energy market cash flow suppression due to mandates of subsidized renewable generation shares that is beyond the levels that is cost effective, as well as the failure to appropriately internalize the cost of CO_2 emissions across the PJM wholesale electricity marketplace. These market distortions are likely to remain for years to come because the probability of a political response to quickly remove these market flaws is low. Therefore, if nothing is done to address these market distortions, then the uneconomic premature retirement of cost effective baseload power plants is the predictable consequence. I believe that Ohio consumers will see lower and less variable monthly power bills by avoiding the premature closure and replacement of the Ohio nuclear power plants. I recommend taking immediate action to counter the consequences of the market distortions with the zero-emission nuclear resource policy initiative, because once these nuclear resources are lost, the probability of bringing them back in the future diminishes rapidly once the process of a premature closure gets underway.

Nuclear power plant economic viability

Let me begin with the concern that Ohio nuclear power plants are not cost competitive in the PJM electricity marketplace. In an efficient market, the profitability of the continued operation of an existing generating plant would be an indication of its economic viability. However, the profitability of operating a baseload generating resource in the PJM marketplace is not an accurate test of its economic viability because the PJM electricity market suffers from significant and increasing market distortions. PJM market distortions arise from the current lack of harmony between public policies and efficient market operations. The bottom line is that distorted markets do not produce the right price signals and without the right price signals, the market cash flows do not indicate the economic viability of a generating resource.

Getting wholesale price signals right also translates into getting the size and pace of existing power plant retirements right. Retirements in an efficient marketplace arise because existing generators are confronted by the price signals reflecting the price levels that support the cash flows of the most cost-effective replacement power supply resources when an electricity market is in a long run demand and supply balance. Under these conditions, a power plant retires when it is lower cost to replace its energy, capacity and ancillary service outputs as well as replace its resilience and environmental attributes, than the cost to keep it operating.

The Ohio nuclear plants operate in the PJM marketplace. PJM operates the world's largest competitive wholesale electricity market and coordinates the power system security constrained movement of wholesale electricity to supply the aggregate electricity demand of over 65 million consumers spread across all or part of 13 states (Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia) and the District of Columbia. PJM is also responsible for maintaining mandatory reliability standards in grid operations and network planning established by the North American Electric Reliability Corporation and approved by the Federal Energy Regulatory Commission. To do this, PJM centrally dispatches generation through a bid-based competitive market process that determines locational market prices (LMP) in day-ahead and real-time electric energy markets as well as determines zonal prices in capacity and ancillary service markets.

Getting the LMP price signals right requires the harmonization of public policies and market operations. Harmonizing public policies with market operations requires internalizing all relevant costs, including an appropriate CO_2 emission charge because an efficient market outcome does not involve externality costs. Further, an efficient electricity market outcome also requires public policies with fuel and technology neutral impacts on market operation, particularly the dispatch bidding behaviors of rival generators. When public policies and market operations are in harmony, then effective competitive forces can produce an efficient market outcome with the right wholesale price signals. The right price signals determine the economic trade-offs that shape an efficient electric supply portfolio comprised of a diverse fuel mix and a diverse technology mix involving cost-effective peaking, load following and baseload generating resources capable of providing consumers with the reliable electric services that they want, when they want them, at the lowest cost, subject to the security of supply and network constraints in the AC power system that defines the bounds of the marketplace.

Efficient market price signals shape a diverse power supply portfolio with inherent resilient supply attributes and with an appropriate balancing of the costs and benefits of CO_2 emission abatement. The resilience attributes exist because a cost-effective supply portfolio involves a diverse mix of fuels and technologies with fuel and technology specific risk factors that are weakly correlated. Quite simply, there are significant benefits to an efficient electricity market outcome that generates a power supply portfolio that does not put all of the power system's eggs in one basket. In addition, cost effective CO_2 emission levels exist when the demand and supply sides of the power sector internalize an appropriate cost for incremental CO_2 emissions.

Market distortions prevent the market from generating the right price signals. As a result, the distorted market price signals do not shape a cost-effective, resilient and environmentally efficient electric supply portfolio. Public policies at the federal and state levels that mandate and subsidize intermittent renewable technologies are neither fuel nor technology neutral policy approaches, and therefore result in inefficient market outcomes whenever mandates of subsidized intermittent renewables result in a greater wind and solar generation shares than are cost effective. In organized electricity markets like PJM, this inefficient market outcome suppresses wholesale electric energy prices. In addition, the command and control policies that mandate the greater than cost-effective shares of intermittent renewable resources require dispatchable generating resources in PJM to start up and shut down more often, and ramp output up and down more frequently than what is expected in an efficient market outcome. To make matters worse, the real-time imbalances between intermittent resources output and consumer demands creates conditions in which subsidized renewables bid their power supply at negative prices in order to preserve the volume-based subsidy payment. As a result, these resources sometimes end up setting the market-clearing energy market price at negative levels. The wholesale energy market price suppression and negative pricing episodes, along with the increased operating costs of dispatchable generators attributed to policies that mandate subsidized intermittent renewables resources cause reduced the energy market cash flows to competitive generators from the level expected in an efficient market outcome. Further, PJM does not operate with an appropriate CO_2 emission charge that internalizes the cost of CO_2 emissions, and this too results in lower wholesale energy prices than expected in an efficient market outcome.

PJM operates a capacity market alongside its energy market, and the capacity market is designed to close the gap between energy market cash flows and the revenue streams necessary to cover the costs of new entry for peaking technologies when the market demand and supply are in long-run balance. Capacity market price suppression currently exists in PJM because public policies drove more renewable capacity development than would occur in an efficient market outcome, and thereby postponed the point in time when market-driven demand and supply adjustments can bring the market into long-run balance.

Specific examples of recent PJM market distortions are included in the September 18, 2017 IHS Markit report, *Ensuring Resilient and Efficient Electricity Generation: The value of the* *current diverse US power supply portfolio*.[1] The PJM State of the Market Report 2016 notes the chronic shortfall in non-peaking power plant cash flows and shows that market-clearing cash flows sufficient to cover the costs of a typical new natural gas-fired combined cycle power plant have been the exception rather than the rule in the PJM market since it began operation. [2]

PJM recognizes the problem of market distortions. A Federal Energy Regulatory Commission (FERC) proceeding is underway to evaluate a proposal from PJM to change price formation rules in the energy and ancillary services markets to help close the shortfall between market prices and the marginal costs of production. In addition, PJM recently announced a proposal to the FERC involving a two-stage forward capacity auction to recalculate capacity market prices to eliminate the suppressive effect of subsidized capacity participation in the current single stage forward capacity market, and to accommodate state policies such as those being discussed today. The prospects and timelines for both proposals are uncertain, the proposed changes may not even impact, let alone fully mitigate the disproportionate impact of current market distortions on baseload nuclear resources in PJM, and these do not appear to be sustainable solutions.

Market distortions from a lack of harmony between public policies and market operations is not unique to PJM. For example, the cash flow suppression in California is more advanced than in PJM. Consequently, the California ISO had to implement FERC approved tariffs for flexible ramping products to provide payments supporting the generating technologies providing the necessary dispatchable, net load following generation in the power supply portfolio. These flexible resources are predominately natural gas-fired generating technologies and this market reform indicates that cash flow shortfalls for non-peaking power resources are not simply the result of low natural gas prices. Instead, the problem arises from disharmony between public policies and wholesale market operations distorting market prices, as described in the US Department of Energy Staff Report to the Secretary on Electricity markets and Reliability.[3]

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[1] Lawrence Makovich and James Richards, *Ensuring Resilient and Efficient Electricity Generation: The value of the current diverse US power supply portfolio*, IHS Markit Report, September 18, 2017. http://ihsmark.it/FezQ30feH62

[2] Monitoring Analytics, LLC, *2016 State of the Market Report for PJM*, pg. 279.

[3] US Department of Energy, Staff Report to the Secretary on Electricity Markets and Reliability, August 2017, pg.110-112.

Market distortions that suppress prices for non-peaking generating resources from the levels expected in an efficient market outcome result in greater retirements of existing non-peaking power plants than expected in an efficient market outcome. Therefore, current policy initiatives that ratchet up subsidized renewable generation shares are increasing market distortions and causing more premature baseload power plant retirements. This trend is eroding the inherent resilience characteristics of a cost effective electric supply portfolio by moving electric supply portfolios away from the diverse fuel and technology mix expected from an efficient market outcome.

Premature nuclear power plant retirements are offsetting the objectives of the renewable policy initiatives. For example, in California, renewable generation portfolio requirements have been ratcheted up five times since the first mandate was put in place in 2002. Since 2002, the CO_2 emissions from electricity generated in the state of California have not declined because the impact of the increase in renewable generation from 2 to 15 percent of the generation mix was offset by the closure of the San Onofre nuclear unit and the need to increase the natural gas-fired generation share from 50 to 60 percent of in-state generation to backup and fill-in for the intermittent renewables. This discordant outcome continues with the current mandate to reach 50 percent renewables while also prematurely closing the Diablo Canyon nuclear power plant. A similar perverse result is found in the New England power sector where the market distortions from subsidized renewable mandates caused the premature closure of the Vermont Yankee power plant and an increase in power sector CO_2 emissions of 7 percent from 2014 to 2015. This discordant outcome continues with the planned expansion of wind and solar resources and the premature closure of the Pilgrim nuclear power plant.

Therefore, the efficient market outcome provides the benchmark to evaluate market interventions designed to offset the consequences of persistent market distortions created by discordant public policies and wholesale market operations.

Analyses of efficient US power system demand and supply responses to a range of possible appropriate CO_2 emission charges in the absence of discordant public policies provide estimates of the expected outcomes from an efficient wholesale electricity marketplace.[4] The

[4] Lawrence Makovich, *Tilting at Windmills: Making a case for reframing electric sector climate policies,* Mossavar-Rahmani Center for Business and Government Associate Working Paper No. 78, June, 2017. https://www.hks.harvard.edu/centers/mrcbg/publications/awp/awp78

research indicates that, based on the typical going-forward costs of existing nuclear power plants, these non-CO_2 emitting electric supply resources would not be expected to prematurely retire in an efficient wholesale marketplace. Therefore, an economic argument exists to support public policies that provide support to these nuclear resources through compensation for the resilience and environmental attributes that these resources provide to the power supply portfolio and in doing so, move the current distorted market outcome toward the results expected in an effective competitive marketplace. Such policies improve economic efficiency in the electricity sector and avert the associated regional economic impacts.

Analysis of US efficient power system demand and supply responses to a range of possible appropriate CO_2 emission charges in the absence of discord between public policies and market operations indicates that fossil fueled generation resource generation shares decline but are not eliminated from a cost-effective electricity supply portfolio. Therefore, the problem of premature retirements of fossil-fired electric generation resource retirements is also a policy concern, as illustrated by the California flexible ramping products interventions.

As long as the lack of harmonization exists between public policies and wholesale market operations, there is an economic argument to support market interventions to offset distortions and move electricity market outcomes back toward the expected outcome of the efficient competitive market benchmark.

Consumer electric bill impacts

Turning to the question of power supply costs and consumer prices, I find no evidence that premature nuclear power plant closures are reducing power supply costs or consumer prices. If supply diversity is reduced by distorted market prices discouraging the continued operation of cost-effective existing baseload generating facilities and instead, encouraging the additions of a more expensive combination of natural gas-fired units and renewable resources, then consumers will see electric prices that are both higher and more volatile. For example, public policies are supporting the addition of wind and solar resources with unsubsidized costs of around 85 to 201 $(2015)/MWh that are integrated by flexible natural gas-fired technologies with unsubsidized costs over 64 $(2015)/MWh. In the meantime, public policies are also suppressing market cash flows to non-peaking generating resources and driving the premature closure of nuclear power plants with going-forward costs of less than 45 $(2015)/MWh.[5] The net result is that consumers incur higher electricity costs because, although mandates and subsidies suppress wholesale prices, these subsidies do not reduce overall power supply costs. Instead, mandates add out-of-market costs and subsidies shift costs among consumers or shift costs from the power bills to tax bills that consumers pay.

Concern regarding the impact of premature baseload power plant retirements led to research I directed in 2014 analyzing the impact of premature power plant retirements on the value of fuel and technology diversity in the current U.S. power supply portfolio.[6] The analysis showed that the current diversified portfolio of U.S. power supply lowers the cost of generating electricity by more than $93 billion per year compared to a less diverse portfolio with no meaningful contributions from coal-fired or nuclear power plants, a smaller contribution from hydro-electric resources (4% of generation), and significant increases in wind and solar (22% of generation) and natural gas-fired power plants accounting for the remaining power production (74% of generation). The less diverse power supply case produced monthly power bills that were 25% higher, and twice as variable, as the current power bills reflecting the costs of the current diverse power supply portfolio.

In light of the accumulating premature baseload power plant retirements and public policy initiatives to ratchet up the generation share mandates for subsidized renewable resources, I directed the September 2017 IHS Markit study entitled *Ensuring Resilient and Efficient Electricity Generation* to take a fresh look at what is at stake for US consumers if uneconomic power plant retirements continue and the US supply portfolio moves toward a less efficient and less resilient electric supply portfolio end state.[7] The research compared the recent U.S. electricity portfolio outcomes from 2014 to 2016 with analyses of the expected outcome from a less efficient diversity portfolio case that involved little or no coal, oil or nuclear generating resources, less hydroelectric resources, and involved a tripling of the current wind and solar

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[5] The National Academies of Sciences, Engineering and Medicine, *ThePower of Change: Innovation for Development and Deployment of Increasingly Clean Electric Power Technologies*. Washington, DC: The National Academies Press. Doi 10.17226/21712 and Nuclear Energy Institute, *Nuclear Energy 2016: Status and Outlook,* February 11, 2016.

[6] IHS Energy, *The Value of US Power Supply Diversity*, July 2014.

[7] Lawrence Makovich and James Richards, *Ensuring Resilient and Efficient Electricity Generation: The value of the current diverse US power supply portfolio*, IHS Markit Report, September 18, 2017. http://ihsmark.it/FezQ30feH62

generation shares with the remaining majority of electric output relying on natural gas-fired resources.

The less efficient diversity case may initially appear as an extreme change from current conditions. Yet, such a dramatic transition can unfold within a couple of decades. California is an example of a transition that began in 2002 with its first renewable mandate. Since then, California has little or no coal or oil in its generation mix, reduced nuclear generation (scheduled to be eliminated by 2025), and diminished hydroelectric resources, while intermittent wind and solar generation shares that increased from 2 to 15 percent while natural gas-fired generation increased from 50 to 60 percent of in-state electric production. Along the way, the average retail price of electricity in California increased from a 30 percent above the US average price level in 2002 to a level 50 percent above the US average in 2015 while the CO_2 emissions from in-state generation did not decline even though in-state generation was a smaller share of overall power supply.

The comparison of these alternative cases indicates the consequences of the US electricity sector following a similar path as California including:

- The current diversified U.S. electric supply portfolio **lowers the cost of electricity production by about $114 billion per year and lowers the average retail price of electricity by 27%** compared with the less efficient diversity case.
- Avoiding the consumer adjustment to the higher retail prices in the less efficient diversity case preserves current levels of electric consumption and **avoids an annual $98 billion loss in consumer net benefits** from electricity consumption.
- The resilience of the current diversified U.S. electricity portfolio to the delivered price risk profile of the fuel inputs to electric generation **reduces the variability of monthly consumer electricity bills by about 22%** compared with the less efficient diversity case.
- Preventing the erosion in reliability associated with a less resilient electric supply portfolio **mitigates an additional cost of $75 billion per hour** associated with more frequent power supply outages that add to the current US average expected outage rate of 2.33 hours per year.

Comparing the broader economic impacts of the less efficient diversity case with the IHS Markit baseline simulations of the U.S. economy indicates the following U.S. macroeconomic impacts within three years of the retail price increase:

- The 27% retail power price increase associated with the less efficient diversity case causes a **decline of real US GDP of 0.8%, equal to $158 billion** (2016 chain-weighted dollars).
- Labor market impacts of the less efficient diversity case involve a reduction of **1 million jobs**.
- A less efficient diversity case **reduces real disposable income per household by about $845 (2016 dollars) annually**, equal to 0.76% of the 2016 average household disposable income.

Conclusion

The lack of harmony between current public policies and market operations is distorting the PJM market price signals and encouraging the uneconomic retirement of baseload nuclear units. Current proposed remedies are uncertain and incomplete. Therefore, an economic argument exists to use the Zero-emission credit initiative to counter the consequences of ongoing PJM market distortions. Doing so will prevent the replacement of the energy, capacity and ancillary service outputs as well as the resilience and environmental attributes of Ohio nuclear plants with more expensive supply resources with less supply resilience and higher CO_2 emission footprints. Ohio consumers stand to benefit in the long run. Such actions will also prevent the economic impacts and direct jobs losses associated with uneconomic nuclear power plant retirements.