RENAISSANCE IN REVERSE:

COMPETITION PUSHES AGING U.S. NUCLEAR REACTORS TO THE BRINK OF ECONOMIC ABANDONMENT

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EXHIBIT OF CONTENTS

LIST OF EXHIBITS

EXECUTIVE SUMMARY

Although Wall Street analysts expressed concerns about the economic viability of the aging nuclear fleet in the U.S., the recent early retirements of four nuclear reactors has sent a shock wave through the industry. One purely economic retirement (Kewaunee, 1 reactor) and three based on the excessive cost of repairs (Crystal River, 1 reactor, and San Onofre, 2 reactors), in addition to the cancellation of five large uprates (Prairie Island, 1 reactor, LaSalle, 2 reactors, and Limerick, 2 rectors), four by the nation's large nuclear utility, suggest a broad range of operational and economic problems.

These early retirements and decisions to forego uprates magnify the importance of the fact that the "nuclear renaissance" has failed to produce a new fleet of reactors in the U.S. With little chance that the cost of new reactors will become competitive with low carbon alternatives in the time frame relevant for old reactor retirement decisions, a great deal of attention will shift to the economics of keeping old reactors online, increasing their capacity and/or extending their lives.

The purpose of the paper is not to predict which reactors will be the next to retire, but explain why we should expect more early retirements. It does so by offering a systematic framework for evaluating the factors that place reactors at risk of early retirement.

- It extracts eleven risk factors from the Wall Street analysis and identifies three dozen reactors that exhibit four or more of the risk factors (see Exhibit ES-1).
- It shows that the poor performance of nuclear reactors that is resulting in early retirements today has existed throughout the history of the commercial nuclear sector in the U.S. The problems are endemic to the technology and the sector.
- It demonstrates that the key underlying economic factors -- rising costs of an aging fleet and the availability of lower cost alternatives – are likely to persist over the next couple of decades, the relevant time frame for making decisions about the fate of aging reactors.

While the purpose of the Wall Street analyses is to advise and caution investors about utilities that own the aging fleet of at-risk reactors, my purpose is to inform policymakers about and prepare them for the likelihood of early retirements. By explaining the economic causes of early retirements, the policymakers will be better equipped to make economically rational responses to those retirements (or the threat of retirement).

EXHIBIT ES-1: RETIREMENT RISK FACTORS OF THE NUCLEAR FLEET

Reactor	Economic Factors							Operational Factors			Safety Issues	
	Cost	Small	Old	Stand Alone	Merchant	20yr<w/o Ext.	25yr< w/ Ext.	Broken	Reliability	Long term Outage	Multiple Safety Issues	Fukushima Retrofit
RETIRED, 2013												
Kewaunee	X	X	X	X	X						X	
Crystal River	X		O					X		O	X	
San Onofre					X	X		X		O	X	
AT RISK												
Ft. Calhoun	X	X	X	X			O	X		O	X	
Oyster Creek	X	X	X	X	X		O			X		X
Ginna	X	X	X		X		O				X	
Point Beach	X	X	X		X		O					
Perry	X	X		X	X	X					X	
Susquehanna	X			X	X				X			X
Davis-Besse	X		O	X	X		O		X	X	X	
Nine Mile Point	X		X		X		O			X	X	X
Quad Cities	X			X	X		O					X
Dresden	X		X		X		O					X
Millstone	X		O	X	X		O				X	
Pilgrim	X	X	X		X	X	O			X	X	X
Clinton	X			X	X	X						
South Texas	X			X	X	X				X		
Commanche Peak	X			X	X	X						
Three Mile Island	X		X	X	X		O			X		
Palisades	X		X		X		O			X	X	
Fitzpatrick	X		O	X	X		O			X		X
Sequoyah	X				X	X				X		
Hope Creek	X			X	X							X
Seabrook	X				X	X			X			

Indian Point	X		X		X		O			X		
Duane Arnold	X		O		X		O				X	X
Calvert Cliff	X		O		X		O			X	X	
Vt. Yankee	X	X	X		X		O					X
Browns Ferry			X				O		X	X	X	
Monticello	X	X	X			X	O				X	
Prairie Island	X	X	X				O				X	
Turkey Point	X	X	X			X	O			X	X	
Robinson	X		X			X						
Wolf Creek	X			X					X		X	
Fermi	X		X	X		X				X		
Diablo Canyon	X			X		X					X	
Cooper	X		X	X			O				X	
Callaway	X			X		X					X	
Cook	X		O				O		X		X	
LaSalle	X				X	X						X
Limerick	X				X	X						X

Sources and Notes: Credit Suisse, *Nuclear… The Middle Age Dilemma?, Facing Declining Performance, Higher Costs, Inevitable Mortality,* February 19, 2013; UBS Investment Research*, In Search of Washington's Latest Realities (DC Field Trip Takeaways*), February 20, 2013; Platts, January 9, 2013, "Some Merchant Nuclear Reactors Could Face Early Retirement: UBS," reporting on a UBS report for shareholders; Moody's, *Low Gas Prices and Weak Demand are Masking US Nuclear Plant Reliability Issues,* Special Comment, November 8, 2012.; David Lochbaum, *Walking a Nuclear Tightrope: Unlearned Lessons of Year-Plus Reactor Outages,* September 2006, "*The NRC and Nuclear Power Plant Safety in 2011,* 2012, and UCS Tracker); NRC Reactor pages.

Operational Factors: Broken/reliability (Moody's for broken and reliability); Long Term Outages (Lochbaum, supplemented by Moody's, o-current, x=past); Near Miss (Lochbaum 2012); Fukushima Retrofit (UBS, Field Trip, 2013) .

Economic Factors: Cost, Wholesale markets (Credit Suisse) Age (Moody's and NRC reactor pages with oldest unit X=as old or older than Kewaunee, i.e. 1974 or earlier commissioning, O= Commissioned 1975-1979, i.e. other pre-TMI); Small (Moody's and NRC Reactor pages, less than 700 MW at commissioning); Stand Alone (Moody's and NRC Reactor pages); Short License (Credit Suisse and NRC Reactor pages). Some of the characteristics are site specific, some are reactor specific.

The reactors at a specific plant can differ by age, size, technology and the current safety issues they face. Historically, in some cases there were long outages at one, but not all of the reactors at a plant. Similarly, there are numerous examples of a single reactor being retired early at a multi-reactor site. Given the complexity of an analysis of individual reactors across the eleven risk factors and the fact that unique precipitating events are the primary cause of early retirements, I count only one potential reactor retirement per plant.

Thus the purpose of this paper is not to predict which reactors will be next to go. Rather it seeks to demonstrate the fundamental nature and extent of the economic challenges that old reactors face.

The analysis is primarily economic, as indicated on the left side of the table. All of the reactors have significant economic issues. If anything goes wrong, any of these reactors could be retired early. The precipitating event could be a further deterioration of the economics, or it could be mechanical or safety related problems, as indicated on the right side of the table. The market will operate faster in the case of merchant reactors, but economic pressures have become so severe that regulators have been forced to take action as well. The same factors call into question the economic value of license extensions and reactor uprates where they require significant capital outlays.

Reviewing the Wall Street analyses, it is possible to parse through the long list of reactors at risk and single out some that face particularly intense challenges, although in all cases one can site mitigating factors.

- Palisades (Repair impending, local opposition)
- Ft. Calhoun (Outage, poor performance)
- Nine Mile Point (Site size saves it, existing contract)
- Fitzpatrick (High cost but offset by high market clearing price)
- Ginna (Single unit with negative margin, existing contract)
- Oyster Creek (Already set to retire early)
- Vt. Yankee (Tax and local opposition)
- Millstone (Tax reasons)
- Clinton (Selling into tough market)
- Indian Point (License extension, local opposition)
- A couple of other reactors that are afflicted by a large number of these factors (Davis-Besse, Pilgrim) could also be particularly vulnerable.

The lesson for policy makers in the economics of old reactors is clear and it reinforces the lesson of the past decade in the economics of building new reactors. Nuclear reactors are simply not competitive. They are not competitive at the beginning of their life cycle, when the build/cancel decision is made, and they are not competitive at the end of their life cycles, when the repair/retire decision is made. They are not competitive because the U.S. has the technical ability and a rich, diverse resource base to meet the need for electricity with lower cost, less risky alternatives. Policy efforts to resist fundamental economics of nuclear reactors will be costly, ineffective and counterproductive.

I. INTRODUCTION

A. THE CHALLENGE OF AN AGING FLEET

Over the last decade, as nuclear advocates touted a "nuclear renaissance" they made extremely optimistic claims about nuclear reactor costs to convince policy-makers and regulators that new nuclear reactors would be cost competitive with other options for meeting the need for electricity. These economic analyses rested on two broad categories of claims about nuclear reactors.

(1) New nuclear reactors could be built quickly and at relatively low cost.[1]

(2) New Nuclear reactors would run at very high levels of capacity for long periods of time with very low operating costs.[2]

Dramatically escalating construction cost estimates and severe construction difficulties and delays in virtually all market economies where construction of a handful of new nuclear reactors was undertaken have proven the first set of assumptions wrong.[3] Recent decisions to retire aging reactors early remind us that the second set of assumptions was never true of the first cohort of commercial nuclear reactors[4] and call into question the extremely optimistic assumptions about the operation of future nuclear reactors.[5]

In fact, the Energy Information Administration (EIA) recently noted that in the current market, if aging reactors are in need of significant repair, it may not be worthwhile to do so. As the EIA put it, "Lower Power Prices and Higher Repair Costs Drive Nuclear Retirements."[6]

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[1] An early MIT study estimated overnight costs at $2,000/kw and contemplated factors that could lower it to $1,000/kw. Massachusetts Institute of Technology (MIT), *The Future of Nuclear Power: An Interdisciplinary MIT Study,* 2003. Over the decade since that estimate, estimates of overnight costs have increased to the $6,000 to $8,000 range (John Rowe, *Energy Policy: Above All, Do No Harm,* American Enterprise Institute, March 8, 2011, *Fixing the Carbon Problem Without Breaking the Economy*, Resources for the Future Policy Leadership Forum Lunch, May 12, 2011, Lazard, *Levelized Cost of Energy Analysis* – Version 6.0, June 2012).

[2] The standard assumptions are a 40 year life at a 90% utilization factor, although early studies like MIT (2003) and Keystone (2007, *Nuclear Power Joint Fact-Finding*, June), considered shorter reactor life and lower load factors as scenarios.

[3] Mark Cooper, "Nuclear Safety and Nuclear Economics, Fukushima Reignites the Never-ending Debate: Is Nuclear Power not worth the risk at any price?," *Symposium on the Future of Nuclear Power,* University of Pittsburgh, March 27-28, 2012; *Policy Challenges of Nuclear Reactor Construction: Cost Escalation and Crowding Out Alternatives*, September, 2010; All *Risk; No Reward*, December 2009; *The Economics of Nuclear Reactors: Renaissance of Relapse*, June 2009.

[4] Mark Cooper, "Nuclear Safety and Affordable Reactors: Can We Have Both?," *Bulletin of the Atomic Scientists,* 2012.

[5] Mark Cooper, *Report Of Dr. Mark Cooper On The Economic Feasibility, Impact On Public Welfare And Financial Prospects For New Nuclear Construction, Prepared For Heal Utah*, July 5, 2013

[6] Energy Information Administration, "Lower Power Prices and Higher Repair Costs Drive Nuclear Retirements ,*Today in Energy*, July 2, 2013.

However, the problem is more profound than that. It is not only old, broken reactors that are at risk of retirement. As old reactors become more expensive to operate, they may become uneconomic to keep online in the current market conditions. Indeed, the first reactor retired in 2013 (Kewaunee)[7] was online and had just had it licenses extended for 20 years, but its owners concluded it could not compete and would yield losses in the electricity market of the next two decades so they chose to decommission it.[8] Things have gotten so bad in the aging nuclear fleet in the U.S. that Wall Street analyst have begun to issue reports with titles like

- "Nuclear… the Middle Age Dilemma? Facing Declining Performance, Higher Costs and Inevitable Mortality,"[9]
- "Some Merchant Nuclear Reactors Could Face Early Retirement: UBS"[10] and
- "Low Gas Prices and Weak Demand are Masking US Nuclear Plant Reliability Issues."[11]

By July, 2013 the U.S. was already guaranteed to have the largest amount of early-retired capacity in a single year in the history of the U.S. commercial nuclear sector and the lowest load factor in over a decade.

B. THE IMPORTANCE OF UNDERSTANDING THE CONTEMPORARY DILEMMA OF OLD REACTORS, ITS HISTORICAL ROOTS AND FUTURE COURSE

These early retirements magnify the importance of the fact that the "nuclear renaissance" has failed to produce a new fleet of reactors in the U.S. With little chance that the cost of new reactors will become competitive with low carbon alternatives in the time frame relevant for old reactor retirement decisions, a great deal of attention will shift to the economics of keeping old reactors online, increasing their capacity and /or extending their lives.

As has been the case throughout the history of the commercial nuclear sector in the U.S., the primary obstacle to nuclear power is economic and it is critically

[7] The decision was announced in late 2012. Thomas Content, "Dominion says Kewaunee nuclear plant will shut down for good," *The Journal Sentinel*, Oct. 22, 2012

[8] Matt Wald, "As Price of Nuclear Energy Drop, a Wisconsin Plant is Shut," *New York Times,* May 7, 2013.

[9] Credit Suisse, *Nuclear… The Middle Age Dilemma?, Facing Declining Performance, Higher costs, Inevitable Mortality,* February 19, 2013, p. 11.

[10] Platts, January 9, 2013, "Some Merchant Nuclear Reactors Could Face Early Retirement: UBS," reporting on a UBS report for shareholders; UBS Investment Research*, Entergy Corp., Re-assessing Cash Flows from the Nukes,"* January 2, 2013; UBS Investment Research, *Entergy Corp. Challenging Outlook for New Team At Kickoff,* February 4, 2013; UBS Investment Research*, In Search of Washington's Latest Realities (DC Field Trip Takeaways*), February 20, 2013.

[11] Moody's, *Low Gas Prices and Weak Demand are Masking US Nuclear Plant Reliability Issues, Special Comment*, November 8, 2012.

important to cut through the hype and hyperbole on both sides of the nuclear debate to reach sound economic conclusions.[12] One way to do so is to have a clear picture of the history, contemporary reality and future prospects of nuclear economics in America.

I have examined the history of the build-cancel decision with respect to new reactor construction in a series of papers.[13] This paper provides an analysis of the repair-retire decision, which will certainly be a much bigger part of the near-term nuclear future in America. Examining the factors in the current market that have caused 2013 to witness the largest premature retirement of nuclear reactors in the history of the industry is critical to understanding the near-term future of the industry. Moreover, the issues that are combining to put pressure on old reactors reverberate through the history of the industry, with deep roots in its past and important implications for how we think about its future.

C. OUTLINE

The analysis is divided into three sections.

Section II describes the key current factors that place reactors at risk of early retirement and also undermine increases in capacity at existing reactors (uprates). It begins with a conceptualization of supply and demand factors that determine the margins aging nuclear reactors earn in the contemporary electricity market.

Section III discusses other factors that have been identified weakening the economics of aging reactors and increasing the risk of early retirement. It review reliability, capital expenditures, and safety retrofits.

Section IV views the current economic crisis from two perspectives intended to help policy makers in assessing what the prospects for future early retirements are. First it presents a review of the historical experience of the commercial nuclear sector that shows that the current crisis is consistent with the past performance of the sector. Then it evaluates the likelihood that the key drivers of the current crisis will continue over the time frame for decision making about retiring aging reactors. It concludes with a few, brief concluding observations.

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[12] Irwin C. Bupp and Jean Claude Derian, (1978, *Light Water: How the Nuclear Dream Dissolved,* New York Basic Books, 1981 *The Failed Promise of Nuclear Power,* New York: Basic Books) emphasize the role of hype in promoting the first round of commercial reactor construction.

[13] In addition to Mark Cooper, Heal Utah, 2013, and Nuclear Safety, 2012, see *Public Risk, Private Profit, Ratepayer Cost, Utility Imprudence: Advanced Cost Recovery for Reactor Construction Creates another Nuclear Fiasco, Not a Renaissance*, March 2013; *Fundamental Flaws In SCE&G's Comparative Economic Analysis*, October 1, 2012; *Policy Challenges of Nuclear Reactor Construction: Cost Escalation and Crowding Out Alternatives*, September, 2010; *All Risk; No Reward*, December 2009; *The Economics of Nuclear Reactors: Renaissance of Relapse*, June 2009.

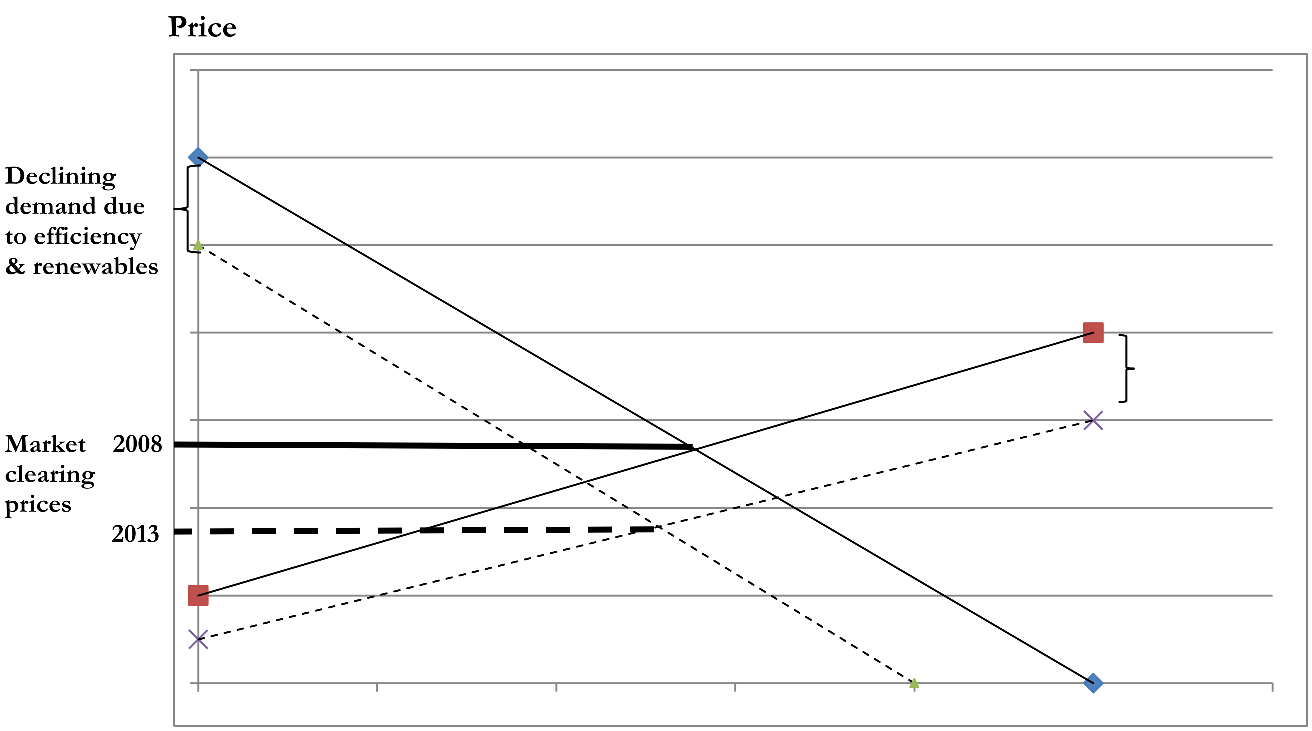
II. OLD REACTORS CONFRONT A NEW ECONOMIC REALITY

A. SUPPLY, DEMAND, QUANTITY AND PRICE

The Economics of Aging Reactors

The problem that aging nuclear reactors face can be described in basic economic terms, as depicted in Exhibit II-1. In half of the U.S. the price of electricity is set in a wholesale market. In these areas, the wholesale prices, which is what all generators earn, are driven primarily by the fuel cost of running the last plant that needs to be operated to make sure supply is adequate to meet demand (see Exhibit II-1). This is the price that "clears" the market. In most regions of the nation, the price is set by natural gas, with coal playing that role in some places. In those areas of the U.S. were the wholesale price of electricity is set by the market, prices have been declining dramatically, as conceptualized in Exhibit II-1).

EXHIBIT II-1: CONCEPTUALIZING THE SUPPLY AND DEMAND FOR MARKET CLEARING FOSSIL FUEL GENERATION



Over the past half-decade, the market clearing price has been declining. Fuel costs have been declining, driven by a dramatic decline in natural gas prices. At the same time, demand for electricity has been declining due to increasing efficiency of electricity consuming equipment and consumer durables. Moreover, the increase in renewable generation, which has the lowest (zero) cost of fuel and therefore always runs when it is available, has lowered the demand for fossil fired generation. This means that the market clears with more efficient (lower cost) plants, which lowers the market clearing price even farther. For consumers this is a very beneficial process; for producers not so much, since the prices they receive are declining.

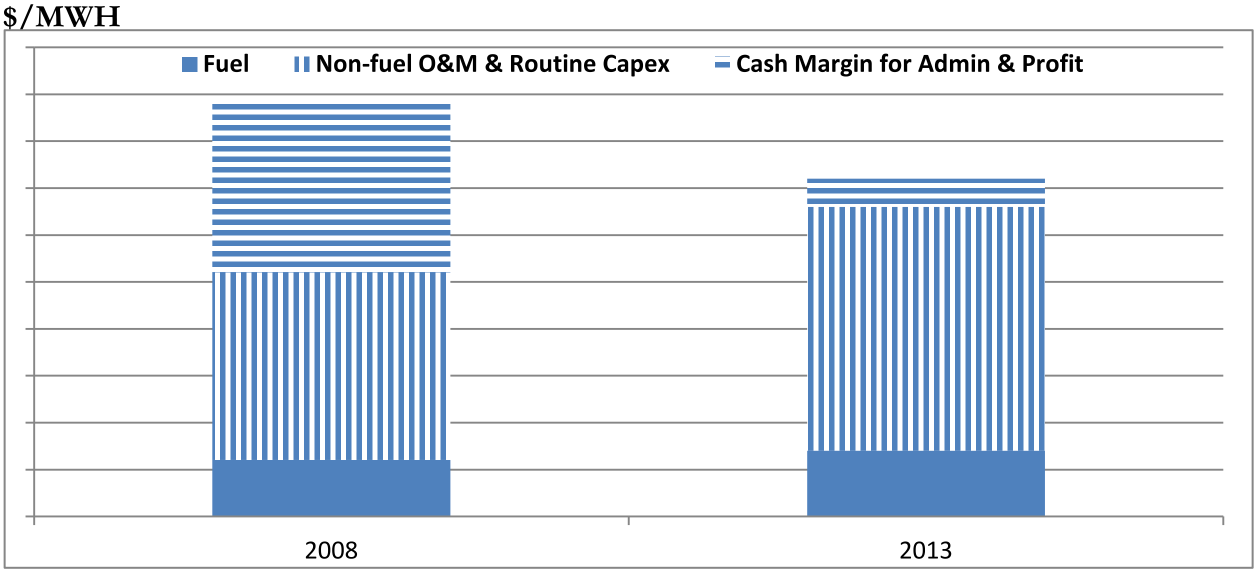
The Margin Squeeze

Old nuclear reactors are particularly hard hit by this market development. With prices set by fuel costs, all of the other costs of nuclear generation must be paid for out of the difference between the fuel costs of the reactor and the market clearing price. This is called the "quark" spread. A nuclear reactor is paid the market clearing price, which it must use to pay its own fuel costs, while the remainder must cover its other costs.

While nuclear fuel costs are low (although they have been rising), their non-fuel operation and maintenance costs and their ongoing capital costs are high. The high nonfuel operation and maintenance costs (including capital additions) are high because of the complex technology needed to control a very volatile fuel. As reactors age, these non -fuel operating and ongoing capital additions rise. As conceptualized in Exhibit II-2, with "quark" spreads falling, and operating costs rising, the funds available may no longer cover the other costs, or yield a rate of profit that satisfies the reactor owner.

EXHIBIT II-2: CONCEPTUALIZING THE MARGIN SQUEEZE ON OLD REACTORS

$/MWH



Old reactors are pushed to the edge. If a reactor is particularly inefficient (has high operating costs), needs major repairs, or a safety retrofit is required, the old reactors can be easily pushed over the edge.

Old Reactors on the Edge

The problem for old nuclear reactors has become acute. At precisely the moment that quark spreads are declining, the non-fuel operating costs of old reactors are rising. In the analysis that first sounded the alarm about early retirements of specific reactors, UBS explained the situation as follows

> Following Dominion's recent announcement to retire its Kewaunee nuclear plant in Wisconsin in October, we believe the plant may be the figurative canary in the coal mine. Despite substantially lower fuel costs than coal plants, fixed costs are approximately 4-5x times higher than coal plants of comparable size and may be higher for single-unit plants. Additionally, maintenance capex of ~$50/kW-yr, coupled with rising nuclear fuel capex, further impede their economic viability …
>
> We believe 2013 will be another challenging year for merchant nuclear operators, as NRC requirements for Fukushima-related investments become clearer in the face of substantially reduced gas prices. While the true variable cost of dispatching a nuclear plant remains exceptionally low (and as such will continue to dispatch at most hours of the day no matter what the gas price), the underlying issue is that margins garnered during dispatch are no longer able to sustain the exceptionally high fixed cost structures of operating these units. Nuclear units… have continued to see rising fuel and cost structures of late, with no anticipation for this to abate. Moreover, public policy initiatives, such as Fukushima-related retrofits and mandates to reduce once-through cooling (potentially requiring cooling towers/screens for some units) and new taxes on others (Vermont Yankee, Dominion's Millstone) have further impeded the economics of nuclear.[14]

The problem is not a figment of the imagination of Wall Street analysts or confined to a small number of individual reactors. It is widespread, as demonstrated by the behavior of Exelon, the largest nuclear utility in the U.S. with ownership of one-quarter of all U.S. reactors.

Exelon was also a big supporter of wind power, until the economics of old nuclear reactors began to deteriorate. Exelon then launched a campaign against subsidies for wind power, because the rich wind resource in the Midwest had begun to back out expensive gas.[15] Market clearing prices declined reducing the margins that its nuclear fleet enjoyed. Exelon's campaign against wind was sufficiently vigorous to get it kicked off the board of the American Wind Energy Association.[16] The economics driving Exelon's behavior was aptly described in a local business publication.

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[14] UBS, emphasis added. pp. 1-3.

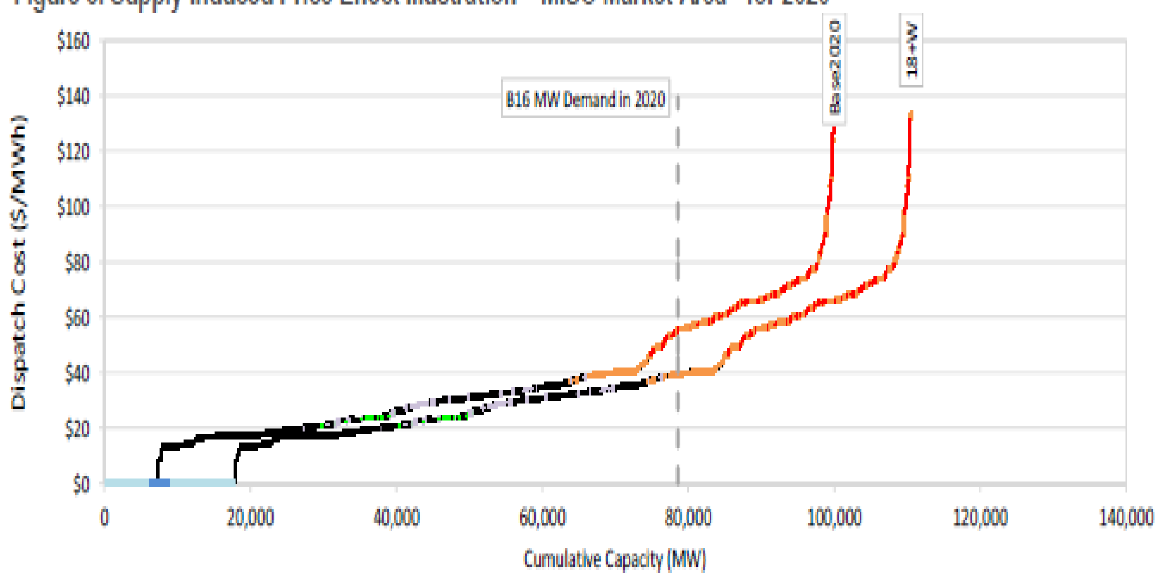
[15] Julie Wernau, "Exelon chief: Wind-power subsidies could threaten nuclear plants: CEO Christopher Crane warns plant closings could become possible; company slashes dividend," *Chicago Tribune,* February 8, 2013.

[16] Alex Guillen , "Wind group boots Exelon from board," *Politico* October, 9, 2012

> Exelon Corp., after slicing its dividend 41 percent earlier this year in the face of falling earnings, has delivered a simple message to shareholders: Be patient. Wholesale electricity prices will rise as old coal-fired plants shut down rather than make costly, federally mandated environmental upgrades, and Exelon's earnings—and stock price—will increase along with them. But a surprising turn of events is upending the Chicago-based nuclear power generator's thesis: Even though market prices for power remain low, competitors are constructing a new generation of plants fueled by cheap natural gas in New Jersey, Ohio, Pennsylvania and other key Exelon markets to take the place of those old coal facilities. And Exelon's lobbying efforts to prevent the construction of competing wind farms and some of the new gas plants haven't worked. As a result, some experts are saying it's just as likely that power prices will stay the same or fall as it is that they will rise, as Exelon forecasts.[17]

Exelon's attack on wind brought the question of the impact of zero fuel cost renewables on market clearing prices to the fore.[18] As shown in Exhibit II-3, a study by Synapse of a significant increase in the amount of wind power in the MISO region found that wholesale prices would be lowered by $0.013/kwh. A similar study for New England found a slightly higher price reduction of $0.018/kwh.[19]

Figure 8. Supply-Induced Price Effect Illustration – MISO Market Area - for 2020



Source: Synapse. Note: blue = wind, black=coal, orange/red=gas/oil.

Having failed to secure the change in policy it hoped would slow down wind development and reduce wind generation, Exelon proposed an even more drastic

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17 Steve Daniels," Exelon waiting for pricier power," *Crain's Chicago Business,* May 13, 2013

18 Richard W. Caperton, *Wind Power Helps to Lower Electricity Prices,* Center for American Progress, October 10, 2012.

19 Charles River Associates, Analysis of the Impact of Cape Wind on New England Energy Prices, February 8, 2010.

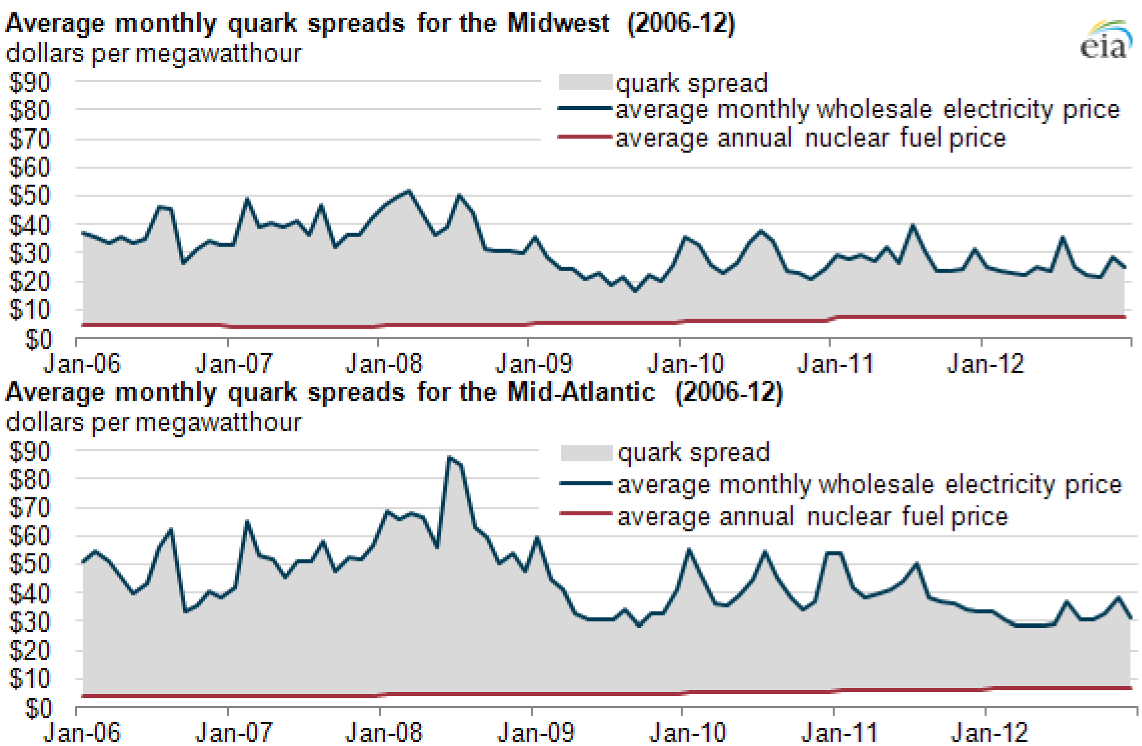
measure. After decades of arguing that nuclear is the ideal low (fuel) cost, always-on source of power and touting the benefits of free markets in electricity, Exelon is proposing to reduce its output of nuclear power to drive up the market clearing price.[20] Since withholding supply for the purpose of increasing prices is frowned upon (indeed would be a violation of the antitrust laws if they applied),[21] it has to negotiate with the Independent System Operator to reduce output.[22] These acts of desperation clearly suggest that the economics of old reactors are very dicey.

B. CONTEMPORARY ECONOMICS OF THE "QUARK" SPREAD

Declining Wholesale Prices

Most analysts focus on the Midwest (MISO) and the Mid-Atlantic (PJM) regions because they are the purest markets. They clear in gas and they do not add other costs to the wholesale price. For the past four years the wholesale prices of electricity has hovered in the range of $30-$40/MWH in these two regions, as shown in Exhibit II-4. The wholesale price has declined by about $20/MWH, with the

EXHIBIT II-4: MID-WEST AND MID-ATLANTIC FUEL COSTS AND QUARK SPREADS



Source: Energy Information Administration, "Lower Wholesale Power Prices Reduce Quark Spreads Available to Nuclear Plant Operators, *Today in Energy,* April 24, 2013, pp. 1-2.

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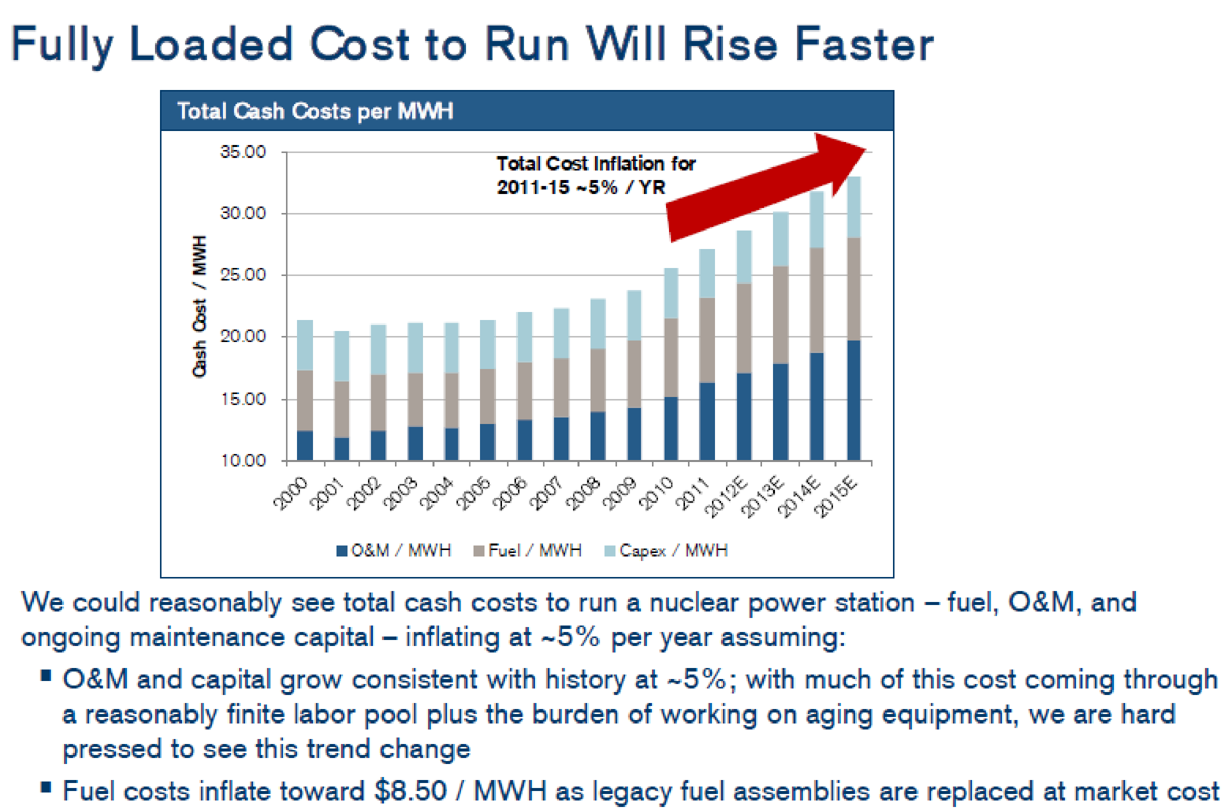
[20] Steve Daniels, "Why Exelon may cut its Illinois nuke output," *Crain's Chicago Business,* June 20, 2013
[21] Mark Cooper, Testimony of Dr. Mark Cooper on Is There Life After *Trinko* and *Credit Suisse?,* June 15, 2010.
[22] Daniels, Why Exelon, 2013.

lowest prices in the Midwest. This puts the "quark" spread in the range of $20 - $30/MWH. The prices are particularly low in the Midwest, Exelon's home region.

Rising Costs

These prices alone would put pressure on nuclear power operations, but the pressure is magnified because the cost of operating old reactors is rising, as shown in Exhibit II-5. Credit Suisse estimates that in the period when "quark" spreads were falling from $40/MWH to $20-$30/MWH, the operating costs of nuclear reactors were rising to the range of $25-$30/MWH. The resulting margins are razor thin, if not negative. The primary drivers of cost increases are non-fuel O&M and fuel costs, which have increased about $10/MWH. Thus declining wholesale prices account for about two-thirds of the shrinking margin and rising costs account for one-third.

EXHIBIT II-5: RISING OPERATING COSTS



of the reactor and the market into which it sells power. Credit Suisse points out that the merchant generators face the greatest challenges and concludes that "the challenge of upward cost inflation/weak plant profitability will likely put pressure on smaller, more marginal plants that could weigh on nuclear's market share."[23] Exhibit II-6 shows the cash margin at merchant reactors based on the wholesale price at various

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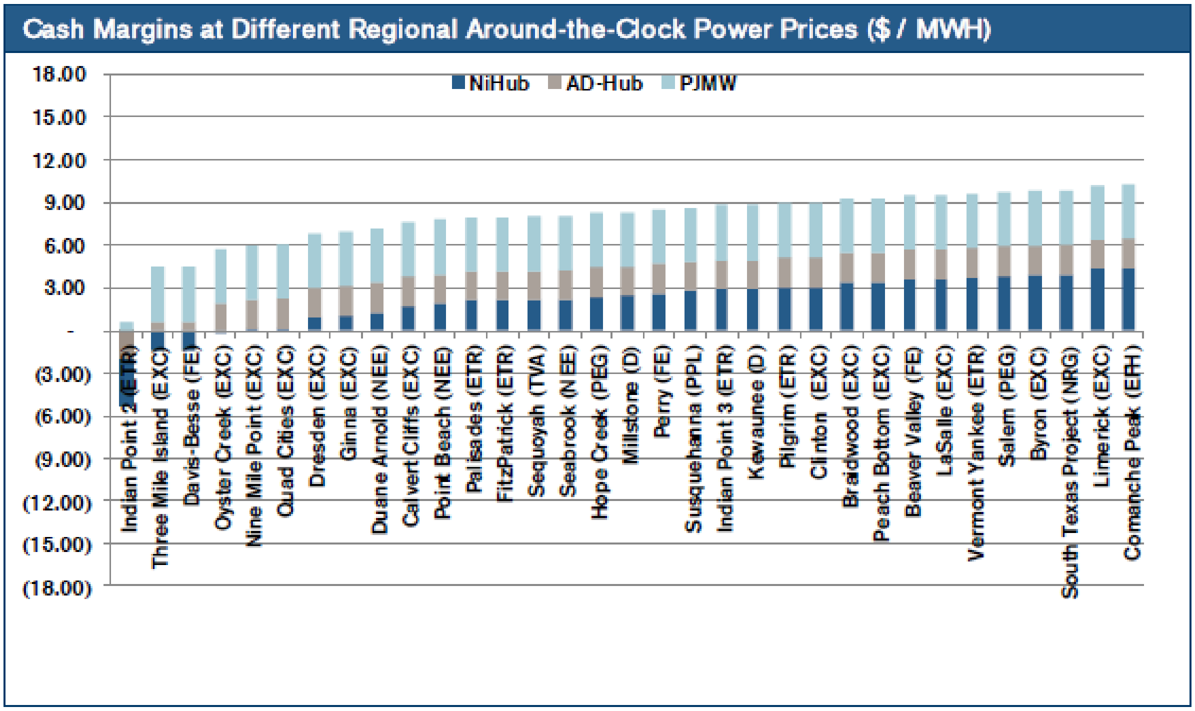
[23] Credit Suisse, 2013, p. 15.

power hubs. Credit Suisse believes that these 33 merchant nuclear reactors provide "modest cash margin expectations."[24] With "typical parent overhead of $5-7/MWH, unit economics look even worse."[25] UBS singled out four of this group as candidates for early retirement.

Merchant 'Cash Margins' at Different Power Hubs



- Using current 2014 power price forwards and unit economics, we see modest cash margin expectations even for nuclear power plants at PJM's RTO hubs AD-Hub and Ni-Hub
- Layering in typical parent overhead of $5-7 / MWH, unit economics look even worse

Source: Credit Suisse, *Nuclear… The Middle Age Dilemma?, Facing Declining Performance, Higher Costs, Inevitable Mortality,* February 19, 2013, p. 11. Platts, January 9, 2013, reporting on a UBS report for shareholders.

Three important insights can be drawn from this analysis.

- Kewaunee, retired for purely economic reasons, sits right in the middle of this group, which attests to the reality and relevance of the analysis.
- The cancellation of major uprates for reactors at the upper end of the range of margins reinforces the relevance of this approach.
- It is important to also note that not all of the reactors that are seen to be at risk are in the Mid-West and Mid-Atlantic.

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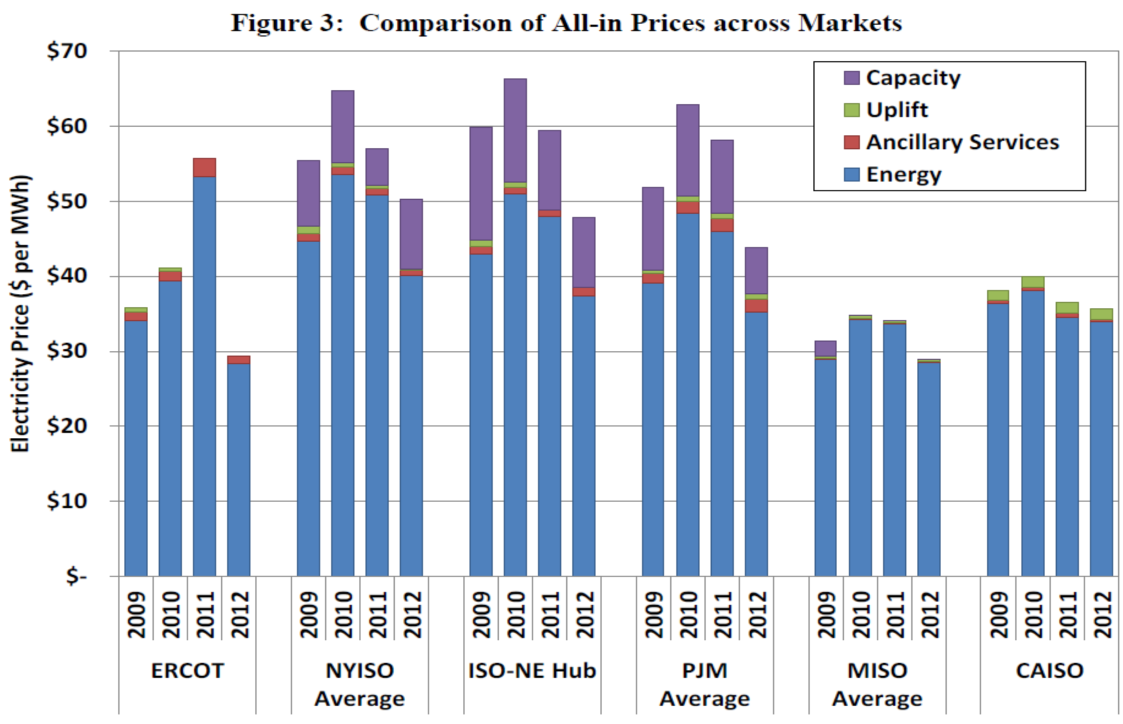
24 Credit Suisse, 2013, p. 11.

25 Credit Suisse, 2013, p. 11.

With the exception of the Northeast, the market fundamentals for existing reactors are quit challenging. The one region of the country that is not represented in this market-oriented analysis is the Southeast, where traditional utility regulation still dominates. However, as I have shown in a recent filing in South Carolina,[26] regulators are supposed to emulate the market in decision-making. Those who fail to do so are allowing the utilities to act imprudently, in violation of public utility law. The fact that markets across the country are yielding similar economic results is strong evidence about the true economics of nuclear power in today's electricity market in the U.S. today. This should influence regulatory decisions.

The recognition that the problem is not limited to the Midwest and Mid-Atlantic reflects the reality of markets in other parts of the country, as well, as shown in Exhibits II-7, which is from the annual report of the market monitor in Texas (ERCOT).[27]

EXHIBIT II-7: COMPARISON OF ALL-IN PRICES ACROSS MARKET



Source: Potomac Economics, Ltd. Independent Market Monitor for the ERCOT Wholesale Market, *2012 State Of The Market Report For The ERCOT wholesale Electricity Markets*, Exhibit 3. June 2013

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26 Cooper, Public Risk, 2013.

27 Potomac Economics, Ltd. Independent Market Monitor for the ERCOT Wholesale Market, *2012 State Of The Market Report For The ERCOT wholesale Electricity Markets*, Exhibit 3. June 2013

This analysis shows that based on the energy costs, market clearing prices in Texas (ERCOT), and California (CAISO) are close to the Midwest (MISO) and Mid-Atlantic (PJM) and in these areas there are not a lot of adders put onto the price. New York (NYISO) and New England (ISO-NE) have higher energy prices and bigger adders.

Several other factors compound the problem that aging reactor face in the current market, a discussed in the next Section

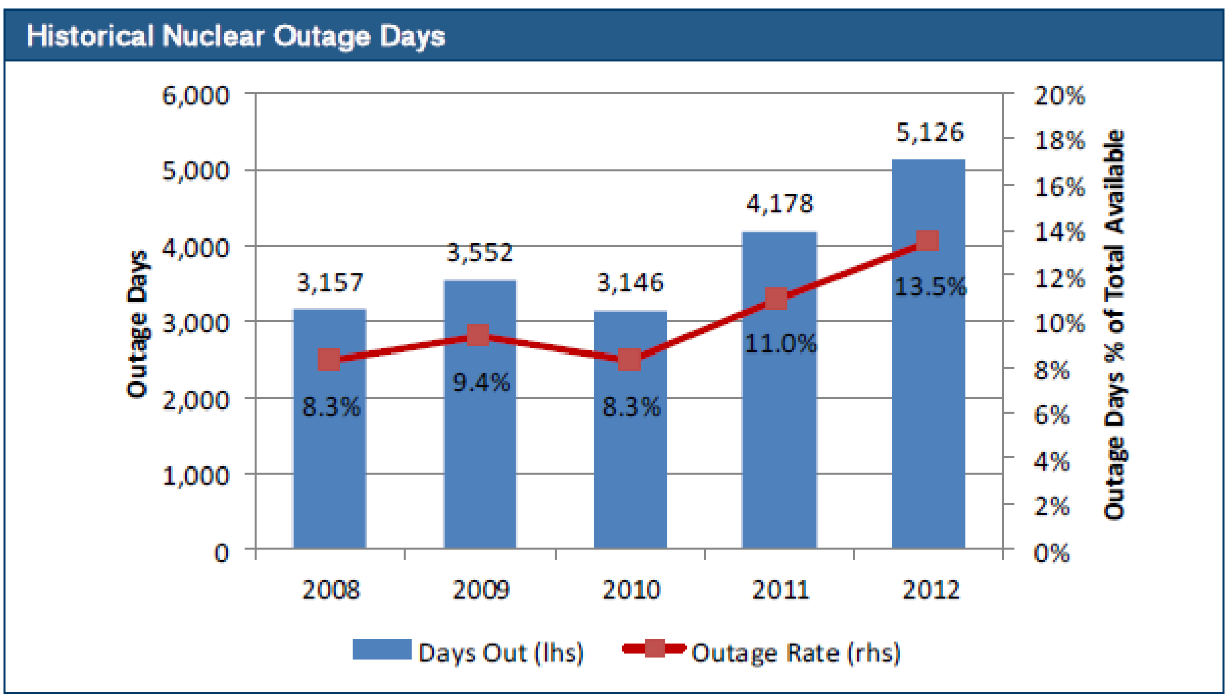
III. OPERATIONAL FACTORS THAT WEAKENED THE ECONOMIC PERFORMANCE OF AGING REACTORS

A. RELIABILITY

Outages

The Credit Suisse analysis did not stop with operating costs, but went on to identify another important characteristic that affects aging nuclear reactors, outages. A nuclear reactor only receives the wholesale prices and earns the "quark" spread if it is operating. Credit Suisse noted that 2011 and 2012 were years of heavy outage, as shown in Exhibit III-1. The largest part of the increase in outages was driven by large reactors down with operational problems (Crystal River, San Onofre, and Fort Calhoun), although extended outages for uprates also played a part (Turkey Point, St. Lucie). The reactors with the longest outages, facing substantial repair costs, Crystal River and San Onofre, have since been retired.

EXHIBIT III-1: HISTORIC NUCLEAR OUTAGE DAYS



Source: Credit Suisse, *Nuclear… The Middle Age Dilemma?, Facing Declining Performance, Higher Costs, Inevitable Mortality,* February 19, 2013, p. 4.

Moody's has also expressed concern about reliability from a different point of view. When reactors are offline, the owners not only lose whatever margin they could have earned, they must replace the power. In addition to costing the utility cash income, this will increase the demand for power in the market and push up the market clearing price. However, in the opinion of Moody's, in the current supply and demand context, the availability of low cost natural gas is "masking" the seriousness of that problem. [28] Moody's worries that if the outages continue, the cost of replacement power will rise substantially.

Moody's highlights the fact that after Crystal River and San Onofre, whose outages led to early retirements, the longest ongoing outage is Fort Calhoun, now in unplanned outage for over two years. It has been beset with multiple issues and is under close scrutiny by the NRC

Load Factor

Moody's also examines the broader issue of reactor capacity utilization. The load factor – the percentage of the year a reactor is online producing power – is an important determinant of its economic performance. Comparing the ten oldest to the ten youngest reactors for the past three years, as shown in Exhibit III-2, Moody's concludes that "it does not appear that the oldest plants in the U.S. have exhibited significantly lower capacity factors or experienced higher than average reliability issues than the newest plants."[29]

In fact, the relationship between age and capacity factor in the Moody's data set is statistically significant when the three year average is considered across time[30] or when the oldest and youngest are treated as two groups.[31] The average load factor is not only 4% lower for the oldest reactors, but the standard deviation is almost twice as high. Moody's choice of a three year period and this approach to looking at the average load factor, captures an important aspect of the aging fleet. Older reactors have shorter refueling cycles – eighteen months for older reactors versus 24 months for newer reactors. Over time they would have lower load factors. Even treating the data as single years, the relationships older reactors have lower load factors, but the statistical significance is lower, as we would expect given the refueling cycles.[32]

More importantly, in a market where margins are so thin, a four percentage point difference in load factor represents an important loss of revenue, and the much higher standard deviation represents significant uncertainty. Age and reliability matter and they go hand in hand.

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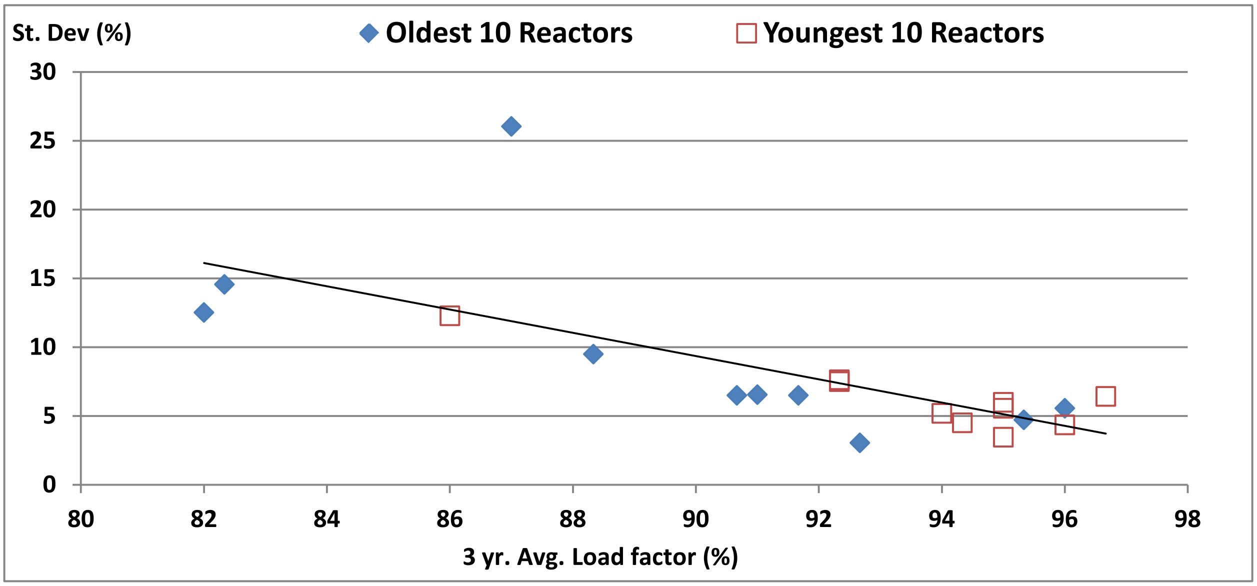
[28] Moody's, 2012, Low Gas Prices.
[29] Moody's, 2012, Low Gas Prices, p. 1.
[30] $r = .42$, p ,.06
[31] Chi Square, $p < .03$
[32] $r=.04$, $p < .12$, Chi Square $<.08$

EXHIBIT III-2: LOAD FACTORS FOR OLDEST AND YOUNGEST REACTORS (2009-2011)



Source: Moody's, *Low Gas Prices and Weak Demand are Masking US Nuclear Plant Reliability Issues,* Special Comment, November 8, 2012, p. 11.

B. ASSET CHARACTERISTICS

Asset Life

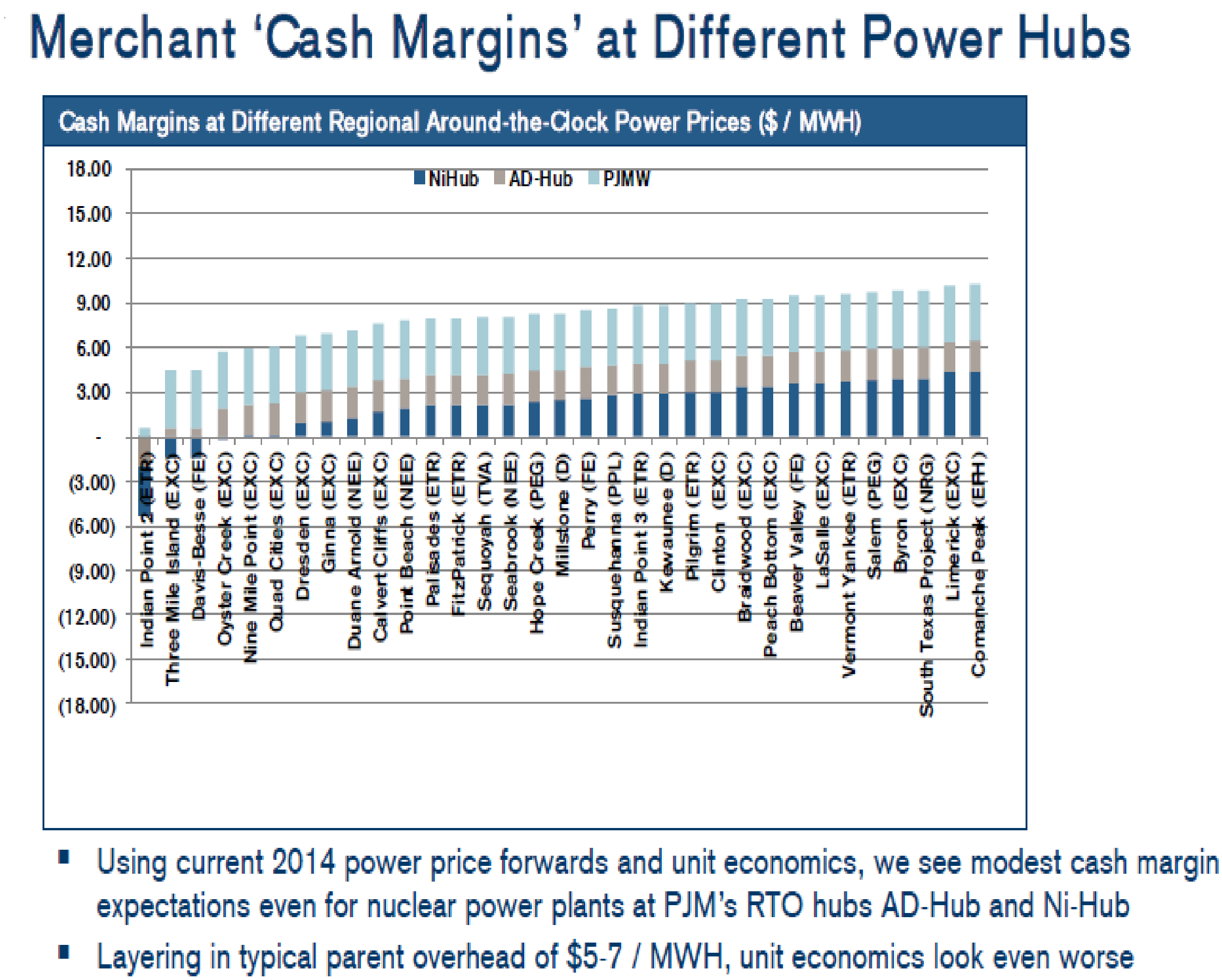
Age affects more than the level and uncertainty of the load factor. It is a primary determinant of remaining life. While many reactors have sought and received license extensions, a number of the older reactors have not. This means that any capital expenditures may have to be recovered over a shorter period of time. To the extent that there are capital costs associated with keeping these reactors online, the short life may make it difficult to recover those costs where margins are thin. "Even assuming licenses are extended, 11 merchant nuclear units have a maximum useful life of less than 20 years… We worry whether plants will see the full 60 years as thin margins and big capex are too hard to cover."[33] Exhibit III-3 identifies those units that have not had an extension of their original license and have less than 20 years remaining on their license.

Asset Size and Integration

The analysis of the economics of aging reactors identifies a number of other characteristics that appear to reduce the economic viability of aging reactors, which

[33] Credit Suisse, p. 19.

EXHIBIT III-3: REACTOR CHARACTERISTICS THAT REDUCE ECONOMIC



x = units with less than 20 remaining on license (and no extension granted)
a = alone (i.e. either single unit or not geographically and organizational integrated into a fleet)
s = small (700MW or less)

Source: Credit Suisse, *Nuclear… The Middle Age Dilemma?, Facing Declining Performance, Higher Costs, Inevitable Mortality,* February 19, 2013, p. 11, 19; Platts, January 9, 2013, "Some Merchant Nuclear Reactors Could Face Early Retirement: UBS," reporting on a UBS report for shareholders; Moody's, *Low Gas Prices and Weak Demand are Masking US Nuclear Plant Reliability Issues,* Special Comment, November 8, 2012, p. 8-9.

are also identified in Exhibit III-3. Small units that stand alone – geographically or organizationally – are believed to have higher costs and therefore are more vulnerable in the current market environment. Both of these factors generally reflect economies of scale since operating costs are spread across a smaller amount of capacity and output. Large, multi-unit sites integrated into corporate fleets of reactors can share indivisible costs. The retirement of Kewaunee underscores the fact that the economic benefits of being part of a fleet of reactors are dependent on the geographic location of the reactors as well.

Moody's described the effects of integration as follows:

> Because they operate multiple units, these companies are often better able to generate economies of scale and benefit from the breadth of experience housed in their nuclear operations. They are in a better position to share the best practices among their own fleets and to compete for talent in this highly specialized field… Because of these advantages, a number of single unit nuclear plant operator have decided to contract out all or part of the management of their nuclear operations to one of the more experienced companies in the field.[34]

The fact that single asset nuclear operators have contracted out the management of their units may solve the administrative problem, but it does not necessarily mean they enjoy lower costs. These contracts have been negotiated after long term and serious failures of management and the buyers of the services do not have a lot of options. The seller of the service may well capture the economies of scale and integration.

Exhibit II- 10 shows that the characteristics that undermine the economics of aging reactors stack up for a couple dozen aging merchant reactors.

Regulated Reactors

Credit Suisse presents a similar analysis for regulated reactors, noting that "deregulated market prices are somewhat less relevant but we think… illustrate the challenges to economics of regulated nuclear as well."[35] Market economics may not rule in these cases, but these reactors exhibit similar difficulties. Using Kewaunee economics as the dividing line (cash flow of about $9/MWH); there are almost two dozen regulated reactors with challenging economics. In this groups are retirements (San Onofre), canceled uprates (Prairie Island), and a long term outage (Fort Calhoun). We find seven standalone assets, eight reactors with less than 20 years remaining on their licenses, and half a dozen small reactors (700 MW or less). There are 14 reactors that have two or more of these characteristics. Thus, in terms of basic economics, there are three dozen reactors that are on the razor's edge.

E. CAPEX WILDCARDS

The above analysis describes the "normal" process of operating an aging fleet in the context of an energy economy in which low cost resources are available to meet

[34] Moody, 2012, p. 8.
[35] Credit Suisse, p. 12.

needs. With the economic viability of an increasing number of reactors coming into question, the possibility of the need for significant capital expenditures becomes quite ominous. The prudence of making major expenditures to meet safety concerns, repair breakage and install technologies to increase output (uprates) is called into question. While there is a tendency to treat these as extraordinary events, they are frequent enough to merit consideration as part and parcel of the nuclear economic equation.

Uprates

In analyzing the question of increasing the capacity of old reactors two important general considerations must be front and center.

- First, the characteristics of the individual reactor and the market into which it sells power are extremely important.
- Second, one must not confuse the history of past, minor changes that were relatively inexpensive and resulted in small increases in capacity and major changes that are quite costly and intended to achieve relatively large (~> 10%) increases in capacity. It was always a stretch to assume that success in executing the former guaranteed success in executing the latter and in the current market; it would be a major mistake.

The abandonment of the LaSalle and Limerick uprates sends the same strong warning signal for uprates that Kewaunee did for retirements. The earlier abandonment of the Prairie Island uprate did not attract as much attention, even though the assumed economic costs were similar.[36] Prairie Island reminds us that rate base projects can be halted, with prudence reviews and disallowance of costs possible.[37] The economics of uprates are on the economic razor's edge.

Moreover, the commercial nuclear industry has historically had difficulty executing major construction projects and that problem afflicts aging reactors. The retirement of Crystal River and San Onofre was precipitated by repairs/upgrades that failed badly, resulting in the need for major repairs. The Florida uprates had substantial cost overruns. The Monticello life extension and uprate activity have

[36] Nuclear Street, Xcel to Scrap Prairie Island Nuclear Plant Uprate, November 5, 2012. Abandonment refers to projects that were under way and involve costs that the utility seeks to recover; cancellation involves projects that were not under way.

[37] *Direct Testimony Of Nancy A. Campbell On Behalf Of The Minnesota Department Of Commerce Division Of Energy Resources,* In The Matter Of The Application Of Northern States Power Company, D/B/A Xcel Energy, For Authority To Increase Rates For Electric Service In Minnesota MPUC Docket No. E002/Gr-12-961, OAH Docket No. 68-2500-30266, February 28, 2013

experienced cost overruns of over 80 percent.[38] The response of Executives responsible for the Monticello uprate is revealing.

> "[I]t's a large complex project with many intricate components that required changes from the original plans," Xcel's chief nuclear officer, Timothy O'Connor, said in recent written testimony submitted to state regulators…O'Connor… testifies that other reactor projects – Grand Gulf in Mississippi, Turkey Point and St. Lucie in Florida and Watts Barr in Tennessee – also experienced cost overruns, in one case double the original estimate.

Defending uprate cost overruns by pointing out that everyone else is suffering the same problem is more an indictment of the industry than a defense of the utility. In fact, the severe contemporary execution risk of keeping old reactors online or increasing the output has started to look a lot like the contemporary (and historical) execution risk of building new reactors. With almost three dozen uprates approved since 2009, over half have been abandoned cancelled or put on hold. Half of those that have moved forward have suffered major cost overruns.

The costs of the uprates mention by the Xcel executive are summarized in Exhibit III-4. The estimates are based on press accounts and assume, in the case of Monticello that the uprate has caused a proportionate share of the total cost overrun. Although the cost and viability of uprates vary from reactor to reactor, some general observations can be offered. The major uprates that have been proposed, and in a number of cases cancelled or abandoned, generally have cost estimates in the range of \$1800 to \$3500 per kW. [39] Actual costs have been much higher, in the range of \$3400 to \$5800/kW.

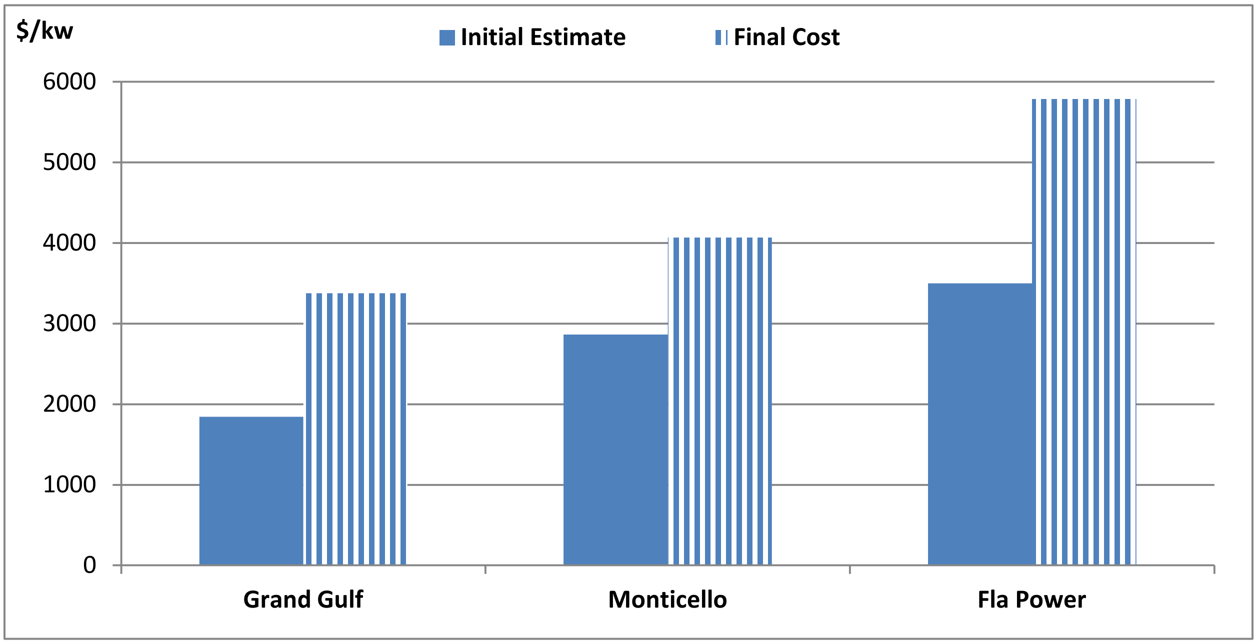
These high actual costs of the uprates are three to four times as much as new advanced combined cycle gas plant costs. Even the initial cost estimates were almost twice as high. Since the reactors being proposed for uprates are still old reactors, they are likely to have significant operating costs, although the uprates may improve their performance. With new gas plants being more efficient, as well, and having much lower capital costs and short lead times, it may well be that choosing between an uprate and a new gas plant has become a very close call. This explains the mixed record of major uprates in the past half-decade.

Since uprates represent the largest capital projects most reactors will witness and most nuclear utilities will undertake in the mid-term, the poor performance is

[38] Direct Testimony Of Nancy A. Campbell, 2013.
[39] The original estimate for Monticello is just over \$1,800/kw. The abandoned Prairie Island and cancelled LaSalle and Limerick uprates had costs of about \$1,800/kw. The implicit initial cost estimate for the Florida uprates was \$3,500.

telling. These uprates are afflicted by the same flaws as new builds, past and present, cost overruns, delays, declining demand and low cost alternatives.

EXHIBIT III-4: COST OVERRUNS OF RECENT MAJOR UPRATES



Sources: **Staff Writer, "Mississippi PSC Approves Entergy Mississippi's Plans To Upgrade Grand Gulf Nuclear Power Station,"** ***EBR,*** **December 2, 2009; New Team, $724 Million Grand Gulf Nuclear Plant Uprate Will Soon Create 4,000 Jobs,** ***Nuclear Street*** **December 13, 2011; Susan Salisbury, "Customers should not have to pay escalating costs for nuclear projects, witness,** ***Palm Beach Post*****, September 11, 2012; David Shaffer , "Monticello nuclear plant repairs surge $267 million over budget,"** ***Star Tribune,*** **July 14, 2013**

Safety, Spent Fuel and the Fukushima Effect

One factor to which UBS devotes a great deal of attention, but Credit Suisse does not mention, is safety related costs.

> Among our greatest concerns for the US nuclear portfolio into 2013 is the risk of greater Fukushima-related costs. While expectations around the need of hardened vents differ, we see cost risks of up to $30-40 Mn/per unit under a worst case scenario; while other estimates suggest costs range in the $15 Mn ballpark. Notably, PPL ests. Fukushima-related costs of $50-60 Mn, excluding vents for its 1.6 GW Susquehanna unit.[40]

[40] Platts, UBS Report of Shareholders, p. 1.

Safety concerns surrounding spent fuel are presently holding up the license extension for a dozen reactors as the NRC deals with a court challenge to its "waste confidence" finding.[41]

Fukushima and the "waste confidence" ruling remind investors that nuclear power has a unique set of risks that may weigh on economic decisions. In a major post-Fukushima analysis of the nuclear sector UBS called it a "tail risk." This is an event that may have a very low probability, but which can have a huge impact on the value of an investment.[42] It has come to be identified more popularly as a "black swan." Tokyo Electric Power Company (TEPCO), the owner of the Fukushima Reactors and the fourth largest utility in the world, experienced such an event, as described in Exhibit III-5.

In my earlier analysis of the impact of Fukushima, I cited an estimate of the potential costs that ran to a quarter of a trillion dollars.[43] Tokyo Electric Power Company is seeking public funds to help it pay for its current estimate of costs, which is $137 billion. The number has been rising steadily and there is some question about whether the victims are being fully compensated. The estimate of $137 billion, if that is the final cost, underscores several important points about nuclear safety and nuclear costs.

First, the disaster bankrupted the company. Its stock collapsed and it has been taken over by the government (as shown in Exhibit III-15). If only $137 billion can bankrupt the fourth largest utility in the world, the "tail risk" associated with nuclear reactor ownership should get the attention of investors.

Second, the economic impact of nuclear accidents does not flow from the public health effects, but from the disruption of the affected community. The most immediate impact of nuclear accidents may not be the deaths that they cause, but the disruption of the economy and social life of a large surrounding area and psychological despair that they cause.

I have shown that Fukushima deserves the attention it gets in both the historical and contemporary contexts,[44] but there is a larger lesson here. Safety is an evolving concept in nuclear power because the power source is so volatile and

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[41] UBS, In Search of Washington, 2013, p. 6, anticipates resolution by late 2014 with little disruption in decision making, although it does anticipate NRC activity in safety related matters beyond the immediate post-Fukushima recommendations. .

[42] UBS Investor Research, *Can nuclear power survive Fukushima?,* April 4, 2011.

[43] Cooper, Nuclear Safety, 2012.

[44] Cooper, Nuclear Safety, 2012, "Post-Fukushima Case for Ending Price Anderson," *Bulletin of the Atomic Scientists,* October 2011; "The Implications of Fukushima: The US Perspective," *Bulletin of the Atomic Scientists* July/August 2011 67: 8-13.

dangerous and the technology to control it becomes extremely complex. Over time, external challenges and internal weakness are revealed. The threats to public health and safety cannot be ignored. Responding to them becomes particularly costly for existing reactors, since retrofits are difficult. As older reactors become farther and farther out of sync with the evolving understanding of safety, the challenge grows.

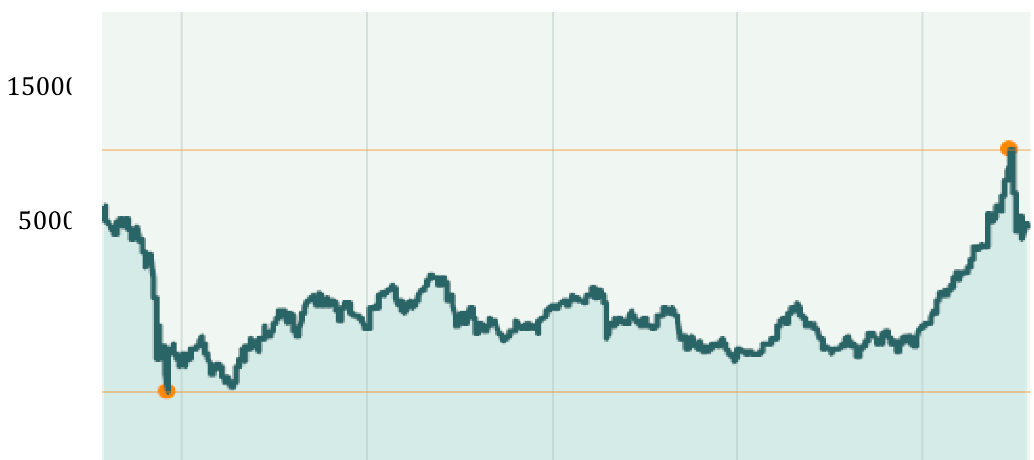
EXHIBIT III-5: THE FINANCIAL EFFECT OF FUKUSHIMA: 5-YEAR STOCK PRICE

Tokyo Electric Power Company, (in Japanese Yen)

ıes ≃ 67%

http://en.finanzen.net/stock-price/TEPCO

NIKKEI INDEX



http://www.marketwatch.com/investing/index/nik?countrycode=jp

F. REACTORS AT RISK

Turning to the future, there are a significant number of reactors, a third of the fleet that exhibits the characteristics that put reactors at risk for negative developments. Exhibit III-6 summarizes the risk factors faced by over three dozen aging reactors. The first six factors – cost, small size, old, standalone, selling into a wholesale market and short cost recovery periods – reflect the economic dimension. The next five risk actors involve Operational factors (broken, reliability and long term outage) and safety factors (Multiple safety issues and Fukushima retrofits. There reflect the operational/repair dimension of the analysis. The first three reactors evaluated have been retired early and they highlight the two different types of factors that create risk. Kewaunee epitomizes the purely economic factors. Crystal River and San Onofre epitomize the repair/outage factors. I have only included reactors that exhibit at least three of the risk factors as identified in the sources cited.

The list is long and not intended as a prediction of which reactors are "the next to go." The historical analysis shows that it is generally a combination of factors that leads to the retirement decision. However, the vulnerability of large numbers of reactors suggests that there will be future early retirements and uprates will be slow to come.

The analysis is primarily economic, as indicated on the left side of the table. All of the reactors have significant economic issues. If anything goes wrong, any of these could be retired early. The precipitating event could be a further deterioration of the economics, or it could be mechanical or safety related problems, as indicated on the right side of the table. The market will operate faster in the case of merchant reactors, but economic pressures have become so severe that regulators have been forced to take action as well. The same factors call into question the economic value of license extensions and reactor uprates where they require significant capital outlays.

Reviewing the Wall Street analyses, it is possible to parse through the long list of reactors at risk and single out some that face particularly intense challenges, although in all cases one can site mitigating factors.

- Palisades (Repair impending, local opposition)
- Ft. Calhoun (Outage, poor performance)
- Nine Mile Point (Site size saves it, existing contract))
- Fitzpatrick (High cost but offset by high market clearing price)
- Ginna (Single unit with negative margin, existing contract)
- Oyster Creek (Already set to retire early)
- Vt. Yankee (Tax and local opposition)
- Millstone (Tax reasons)

EXHIBIT III-6: RETIREMENT RISK FACTORS OF THE NUCLEAR FLEET

Reactor	Economic Factors							Operational Factors			Safety Issues	
	Cost	Small	Old	Stand Alone	Merchant	20yr<w/o Ext.	25yr< w/ Ext.	Broken	Reliability	Long term Outage	Multiple Safety Issues	Fukushima Retrofit
<u>RETIRED, 2013</u>												
Kewaunee	X	X	X	X	X						X	
Crystal River	X		O					X		O	X	
San Onofre					X	X		X		O	X	
<u>AT RISK</u>												
Ft. Calhoun	X	X	X	X			O	X		O	X	
Oyster Creek	X	X	X	X	X		O			X		X
Ginna	X	X	X		X		O				X	
Point Beach	X	X	X		X		O					
Perry	X	X		X	X	X					X	
Susquehanna	X			X	X				X			X
Davis-Besse	X		O	X	X		O		X	X	X	
Nine Mile Point	X		X		X		O			X	X	X
Quad Cities	X			X	X		O					X
Dresden	X		X		X		O					X
Millstone	X		O	X	X		O				X	
Pilgrim	X	X	X		X	X	O			X	X	X
Clinton	X			X	X	X						
South Texas	X			X	X	X				X		
Commanche Peak	X			X	X	X						
Three Mile Island	X		X	X	X		O			X		
Palisades	X		X		X		O			X	X	
Fitzpatrick	X		O	X	X		O			X		X
Sequoyah	X				X	X				X		
Hope Creek	X			X	X							X
Seabrook	X				X	X			X			

Indian Point	**X**		**X**		**X**		**O**			**X**		
Duane Arnold	**X**		**O**		**X**		**O**				**X**	**X**
Calvert Cliff	**X**		**O**		**X**		**O**			**X**	**X**	
Vt. Yankee	**X**	**X**	**X**		**X**		**O**					**X**
Browns Ferry			**X**				**O**		**X**	**X**	**X**	
Monticello	**X**	**X**	**X**			**X**	**O**				**X**	
Prairie Island	**X**	**X**	**X**				**O**				**X**	
Turkey Point	**X**	**X**	**X**			**X**	**O**			**X**	**X**	
Robinson	**X**		**X**			**X**						
Wolf Creek	**X**			**X**					**X**		**X**	
Fermi	**X**		**X**	**X**		**X**				**X**		
Diablo Canyon	**X**			**X**		**X**					**X**	
Cooper	**X**		**X**	**X**			**O**				**X**	
Callaway	**X**			**X**		**X**					**X**	
Cook	**X**		**O**				**O**		**X**		**X**	
LaSalle	**X**				**X**	**X**						**X**
Limerick	**X**				**X**	**X**						**X**

Sources and Notes: Credit Suisse, *Nuclear… The Middle Age Dilemma?, Facing Declining Performance, Higher Costs, Inevitable Mortality,* February 19, 2013; UBS Investment Research*, In Search of Washington's Latest Realities (DC Field Trip Takeaways*), February 20, 2013; Platts, January 9, 2013, "Some Merchant Nuclear Reactors Could Face Early Retirement: UBS," reporting on a UBS report for shareholders; Moody's, *Low Gas Prices and Weak Demand are Masking US Nuclear Plant Reliability Issues,* Special Comment, November 8, 2012.; David Lochbaum, *Walking a Nuclear Tightrope: Unlearned Lessons of Year-Plus Reactor Outages,* September 2006, "*The NRC and Nuclear Power Plant Safety in 2011,* 2012, and UCS Tracker); NRC Reactor pages.

Operational Factors: Broken/reliability (Moody's for broken and reliability); Long Term Outages (Lochbaum, supplemented by Moody's, o-current, x=past); Near Miss (Lochbaum 2012); Fukushima Retrofit (UBS, Field Trip, 2013) .

Economic Factors: Cost, Wholesale markets (Credit Suisse) Age (Moody's and NRC reactor pages with oldest unit X=as old or older than Kewaunee, i.e. 1974 or earlier commissioning, O= Commissioned 1975-1979, i.e. other pre-TMI); Small (Moody's and NRC Reactor pages, less than 700 MW at commissioning); Stand Alone (Moody's and NRC Reactor pages); Short License (Credit Suisse and NRC Reactor pages). Some of the characteristics are site specific, some are reactor specific.

The reactors at a specific plant can differ by age, size, technology and the current safety issues they face. Historically, in some cases there were long outages at one, but not all of the reactors at a plant. Similarly, there are numerous examples of a single reactor being retired early at a multi-reactor site. Given the complexity of an analysis of individual reactors across the eleven risk factors and the fact that unique precipitating events are the primary cause of early retirements, I count only one potential reactor retirement per plant.

- Clinton (Selling into tough market)
- Indian Point (License extension, local opposition)

A couple of other reactors appear to be afflicted by a large number of these factors (Davis-Besse, Pilgrim), so they could be particularly vulnerable. A number of the reactors on this list also face significant local opposition, which adds to the pressure.[45]

The key to the fate of these reactors is the extent to which these factors will persist over the next couple of decades when the retirement decisions will be made. The next section provides two perspectives on that issue.

- How does the current crisis fit into the historical performance of the industry?
- Will the current conditions that place old reactors at risk persist in the future?

[45] The most obvious example, based on press accounts would include at least the following: Fort Calhoun, Oyster Creek, Davis-Besse, Pilgrim, Fitzpatrick, Indian Point, Vermont Yankee, Browns Ferry, Fermi, Diablo Canyon.

IV. THE CURRENT ECONOMIC CRISIS IN PERSPECTIVE

A. THE HISTORICAL EXPERIENCE OF U.S. COMMERCIAL NUCLEAR REACTORS

The dire straits in which a significant part of the U.S. commercial nuclear fleet finds itself are not an aberration or a sudden shift in prospects. It is part and parcel of the history of the industry in the U.S. In fact, the quiet period of high performance in the late 1990s and early 2000s is the exception rather than the rule. With the memory of the huge cost overruns in the 1970s and 1980s fading, the quiet period of the 1990s played an important part in creating the misimpression that new reactors would just hum along. This contributed to the misleading economic analysis on which the "nuclear renaissance" relied during its early hype cycle.

As shown in Exhibit IV-1, the assumption that nuclear reactors hum along, once they are proposed or even online, is not consistent with the U.S. experience. About half of all reactors ordered or docketed at the Nuclear Regulatory Commission were cancelled or abandoned. Of those that were completed and brought online, 15 percent were retired early, 23 percent had extended outages of one to three years, and 6 percent had outages of more than three years.[46] In other words, more than one-third of the reactors that were brought online did not just hum along. Another 11 percent were turnkey projects, which had large cost overruns and whose economics were unknown.

Outages and Early Retirements

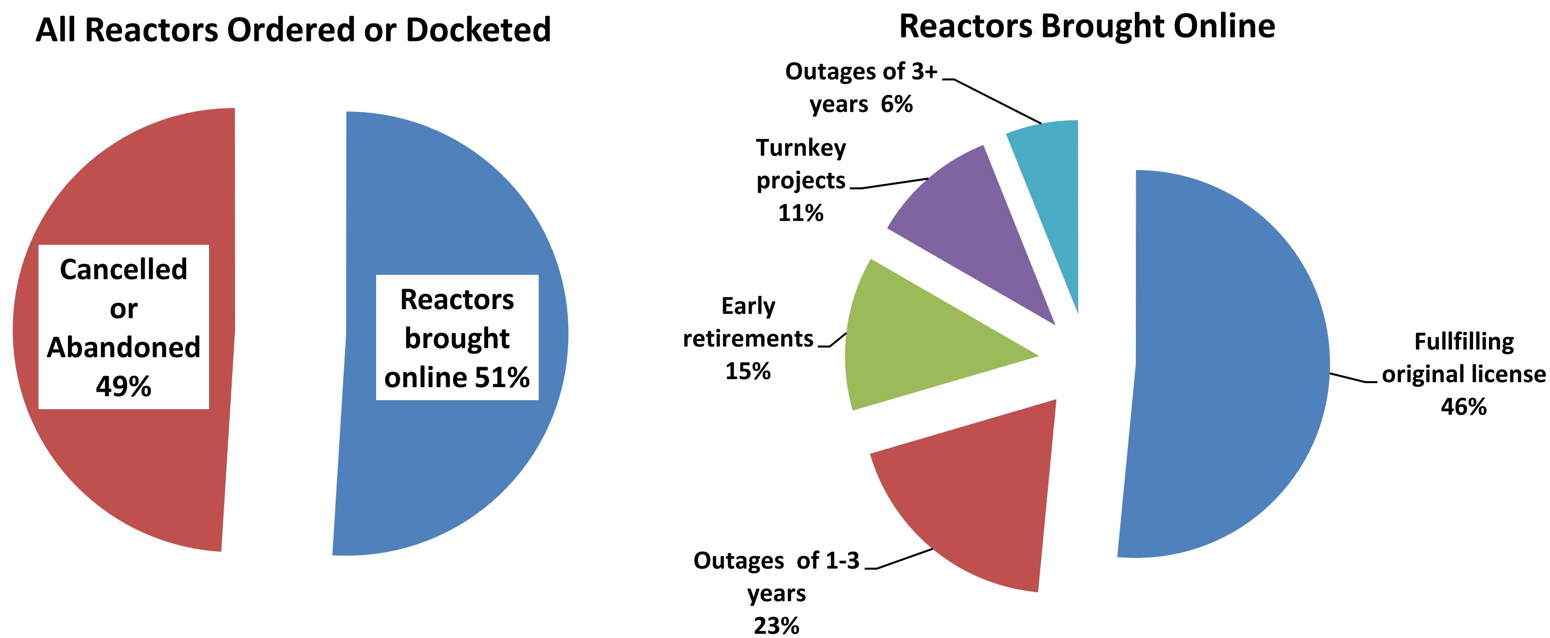
The magnitude of long outages and early retirements is sufficient to require that they be incorporated into the economic analysis of nuclear power. The pattern across time reinforces the observation that the high level of performance in the late 1990s/early 2000s were an exception rather than the rule, as shown in Exhibit IV-2. After a large number of reactors came on line there were a significant number of outages in the early 1980s. Again in the 1990s there were a significant number of outages and retirements. The lull of problems in the late 1990s and early 2000s has been followed by a sharp increase in problems.

Ultimately, since the start of the commercial industry, over one-quarter of all U.S. reactors have had outages of more than one year. There are three causes of these outages:

- Replacement—to refresh parts that have worn out

[46] Cooper, Affordable Reactors, 2012. The current numbers differ slightly from the early analysis since the recent outages and retirements have been added to the database.

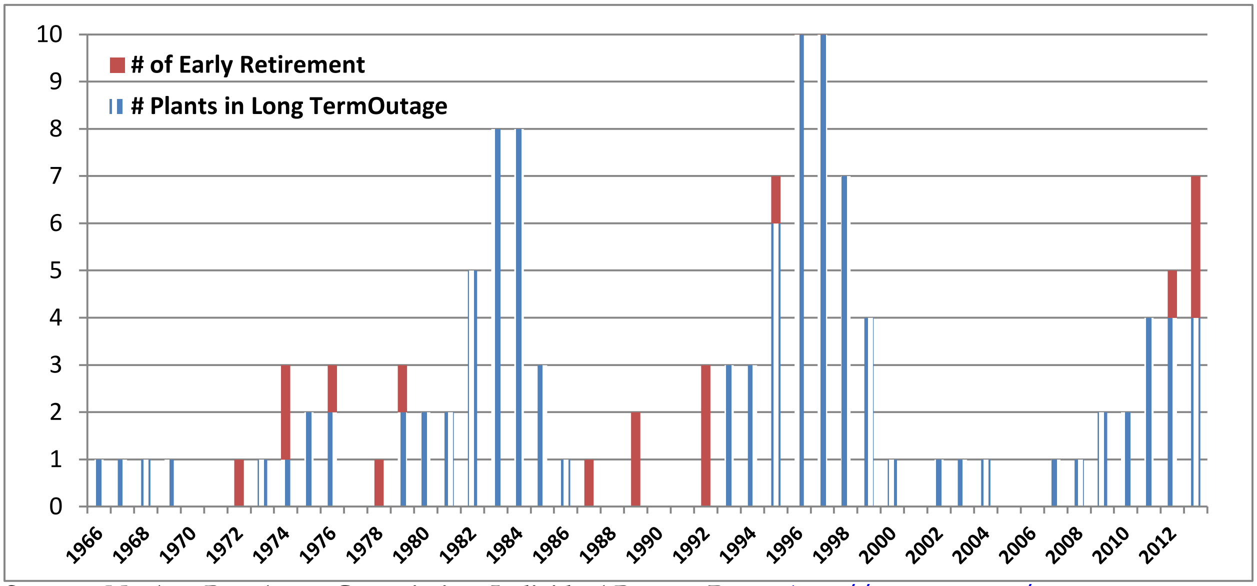
EXHIBIT VI-1: U.S. NUCLEAR REACTORS: DISPOSITION OVER 50 YEARS



Sources: Fred A. Heddleson, *Summary Data for US Commercial Nuclear Power Plants in the United States*, Nuclear Safety Information Center, April 1978; US Energy Information Administration*, Nuclear Generating Units, 1955-2009; Nuclear Power Plant Operations, 1957-2009*; David Lochbaum, *Walking a Nuclear Tightrope: Unlearned Lessons of Year-Plus Reactor Outages,* September 2006; Jonathan Koomey, *Was the Three Mile Island accident in 1979 the main cause of US nuclear power's woes?*, June 24, 2011; **Moody's, *Low Gas Prices and Weak Demand are Masking US Nuclear Plant Reliability Issues,* Special Comment, November 8, 2012,**

- Retrofit—to meet new standards that are developed as the result of new knowledge and operating experience (e.g. beyond-design events)
- Recovery—necessitated by breakage of major components

EXHIBIT IV-2: EARLY RETIREMENTS AND SERVICE OUTAGES OF MORE THAN ONE YEAR.



Sources: Nuclear Regulatory Commission, Individual Reactor Pages, http://www.nrc.gov/; David Lochbaum, *Walking a Nuclear Tightrope: Unlearned Lessons of Year-Plus Reactor Outages,* September 2006; Moody's, *Low Gas Prices and Weak Demand are Masking US Nuclear Plant Reliability Issues,* Special Comment, November 8, 2012.

The average cost of an outage (in 2005 dollars), even before the most recent outages, was more than $1.5 billion, with the highest cost topping $11 billion.[47] The costs of the recent outages that led to early retirement in Crystal River and San Onofre run into the billions.[48]

Exhibit IV-3 presents the results of pairwise correlations between key variables and outages and retirements. The database includes 122 reactors that have been in operation, but excludes the turnkey reactors. They are updated from an earlier analysis by including more reactors, the recent retirements and long-term outages, and

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[47] Lochbaum, 2006.

[48] Housley Carr, Duke Study: Crystal River Nuke Repairs Could Hit $3.4B, *ENR Energy*, October 17, 2012, Abby Sewell, "Cost of San Onofre nuclear plant outage exceeds $400 million: Operator Edison International says returning both units to full power could take five years. It has proposed restarting one unit and operating it at 70% power, *Los Angeles Times,* February 27, 2013. By the time the decision was made, the cost was close to $500 million and the utility faced years of ongoing costs which would have pushed the total to several billion dollars.

a set of variables to capture the extent of safety regulation. The Exhibit includes all of the significant variables from a list of over four dozen.[49]

EXHIBIT IV-3: SIGNIFICANT CORRELATIONS BETWEEN REACTOR CHARACTERISTICS AND OUTAGES AND RETIREMENTS

	Dependent Variable			
Independent	**Outage**		**Retirement**	
Variable	**r**	**sig.**	**r**	**sig.**
Outage			**0.8**	********
2nd Outage	**0.51**	********	**0.43**	********
Permit Year	**-0.27**	*******	**-0.28**	*******
Capacity	**-0.15**	*****	**-0.22**	******
Size	**-0.22**	******	**-0.27**	*******
Rule at Outset	**-0.19**	******	**-0.16**	*****
Change in Rules	**0.17**	*****		

Sig. * < .1, ** <.05, ***<.01, **** <.001

Quantitative and qualitative analysis of the early retirements and outages provides insight into the decision to retire reactors. The occurrence of outages has a strong correlation with retirement, as does the occurrence of a second outage. Early-retirement reactors are typically older and smaller. The early retired reactors were brought online before the agency (originally the Atomic Energy Commission) began to adopt and enforce vigorous safety regulation. They are not worth repairing or keeping online when new safety requirements are imposed, or when the reactors are in need of significant repair. Outages exhibit similar relationships.

The larger the number of rules in place when construction was initiated, the less likely there was to be an outage or an early retirements. The larger the increase in rules during construction, the greater the likelihood of an outage. While the industry interprets the existence and change of rules as an expensive nuisance, I have shown that they reflect strong concerns about safety that were triggered by the extremely poor safety record of the industry in its early years.[50] The older reactors experienced more outages and needed more retrofits to get back or stay online. They were built before performance was regulated, generally performed poorly and suffered the outage and retirement consequences.

Qualitatively, the decision to retire a reactor early usually involves a combination of factors such as major equipment failure, system deterioration,

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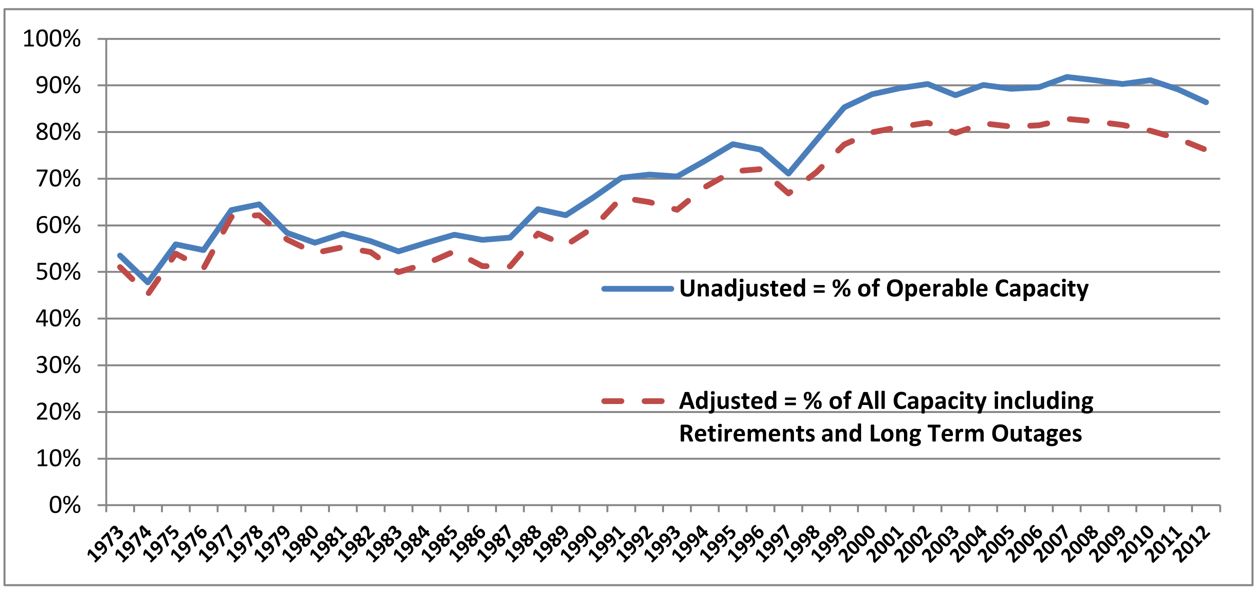
[49] Cooper, Nuclear Safety, 2012.
[50] Cooper, Nuclear Safety, 2012.

repeated accidents, and increased safety requirements. Economics is the most frequent proximate cause, and safety is the most frequent factor that triggers the economic reevaluation. Although popular opposition "caused" a couple of early retirements (a referendum in the case of Rancho Seco; state and local government in the case of Shoreham), this was far from the primary factor, and in some cases local opposition clearly failed (referenda failed to close Trojan or Maine Yankee). External economic factors, such as declining demand or more-cost-competitive resources, can render existing reactors uneconomic on a "stand-alone" basis or (more often) in conjunction with one of the other factors.

Performance: Load Factors and Operating Costs

The increasing problems faced by aging nuclear reactors are reflected in the load factor. As shown in Exhibit III-4, the average load factor for the nuclear industry throughout its history of commercial operation in the United States has been less than 75%. While it is true that over the decade from the late 1990s through the end of the 2000s the load factor was 90%, it is also true that it took twenty years to get to that level and the industry has recently fallen below it.

EXHIBIT IV- 4: U.S NUCLEAR LOAD FACTOR



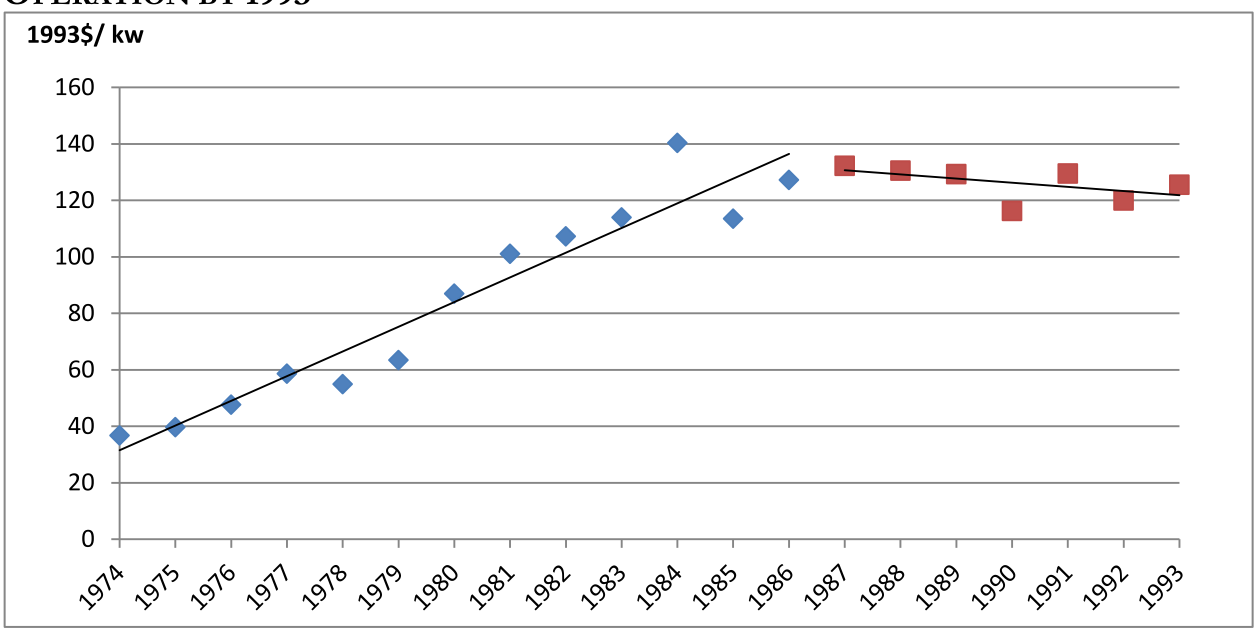
Sources and Notes: Adjusted load factor includes all capacity that would have been operable, bur for early retirements and long term outages. Outages from Lochbaum; retirements from NRC reactor profile sheets, unadjusted load factors from http://www.eia.gov/totalenergy/data/monthly/pdf/sec8.pdf

This is the source of concern expressed by the Wall Street analysts about the aging fleet, but it also raises an important point about new reactors. New technologies require shake out periods and the more complex they are, the longer the period. The assumption of a 90% load factor for new builds is highly suspect.

Moreover, the calculation of load factors in Exhibit IV-3 actually overestimates the actual load factor because the denominator includes only reactors that are operable. Reactors that have been retired early or are on long term outage (not in service for the entire year) are not included in the analysis. I show an adjusted load factor that includes in the denominator the long term outages and early retirements. I assume that all the early retirements were reactors that were expected to still be on line, but for the difficulties that shut them down. As shown in Exhibit IV-1, above, this number is substantial. When early retirements and long term outages of more than a year are taken into account, the load factor has been about 70%.

Operating costs appear to exhibit a similar long term pattern as load factors (see Exhibit IV-5). There was a long period of rising operating costs, then a period of modest decline and relative stability. However, as shown above, in the past decade costs have begun to rise again.

EXHIBIT IV-5: AVERAGE ANNUAL NONFUEL OPERATING COSTS, ALL PLANTS IN OPERATION BY 1993



Source: Energy Information Administration: An Analysis of Nuclear Power Plant Operating Costs: A 1995 Update, April 1995

B. FUTURE PROSPECTS FOR MARKET FORCES

There is always a great desire to predict the future of individual reactors but that is a perilous business. Explaining the past and evaluating its implications for the future is less risky and more informative. What we can say about the recent past is that in a short period of time the industry has experienced a full complement of the bad things that can happen to old reactors – purely economic retirement, broken reactors, an uprate that developed into a broken plant and an early retirement, large cost overruns for new builds and uprates and abandonment of uprates. We can also identify the circumstances that brought these negative events about and show that they are not only short term aberrations, but are consistent with the long-term history of the industry.

Ultimately, the future fate of old reactors will be decided by the interaction of these underlying characteristics and the conditions in the marketplace. Here I identify a couple of key factors. First and foremost, consistent with the analytic framework we have used to describe the plight of aging reactors, is the supply/demand balance in electricity markets. The key question is: will the price of alternatives keep the economic pressure on the margins of aging reactors with rising costs?

Natural Gas Cost History and Trends

Predicting long-term natural gas prices has been described as a perilous undertaking, but a consensus has emerged among most reasonable analysts that a significant period of low gas prices is upon us. Projecting price out fifty years may be very risky, but twenty years is less so and that is the relevant time frame for aging reactors.

Exelon's battle with wind, its efforts to move the market clearing prices and its decision to cancel the uprates at Limerick and LaSalle and it earlier decision to abandon its plans to build a new reactor,[51] reflect the very challenging economics that nuclear faces in today's market. Those economics are driven by a belief that gas prices are likely to remain low for the relevant economic time frame. John Rowe, CEO of Exelon has been adamant in this regard.

> Colorado School of Mines has estimated that the available reserves have increased by 60 percent between 2000 and 2008. And every consultant I can hire predicts real –- flat real prices for natural gas for at least this decade and maybe two. .. (4) I've seen an awful lot of wrong forecasts in 27 years. But the supply/demand equations on gas are very powerful and I believe they're real for a long time. And, what's more, I know better than to bet against it, because if you bet on a different fuel source and gas stays cheap, you get literally murdered… (6) But I've also seen the prevailing pattern. I can't guarantee we'll never see another spike but neither can I find a forecast from any reputable follower of the business that projects that we're going to have high prices on a consistent basis any time in the next several decades. And I work on the best facts I can find and I invest on the best facts I can find, and those facts say gas is queen, whether I love her or not. [52]

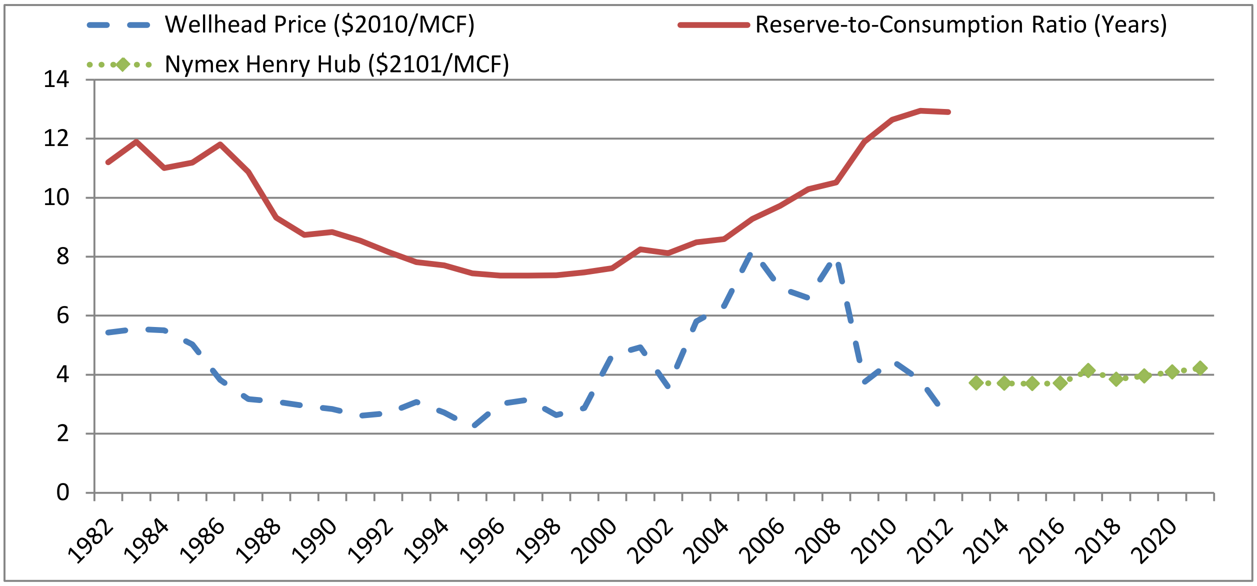
[51] Reuters, Exelon drops Texas reactor plan, cites cheap natgas, Tue Aug 28, 2012**,**

[52] John Rowe, "Energy Policy: Above All, Do No Harm," American Enterprise Institute, March 8, 2011, p. 14.

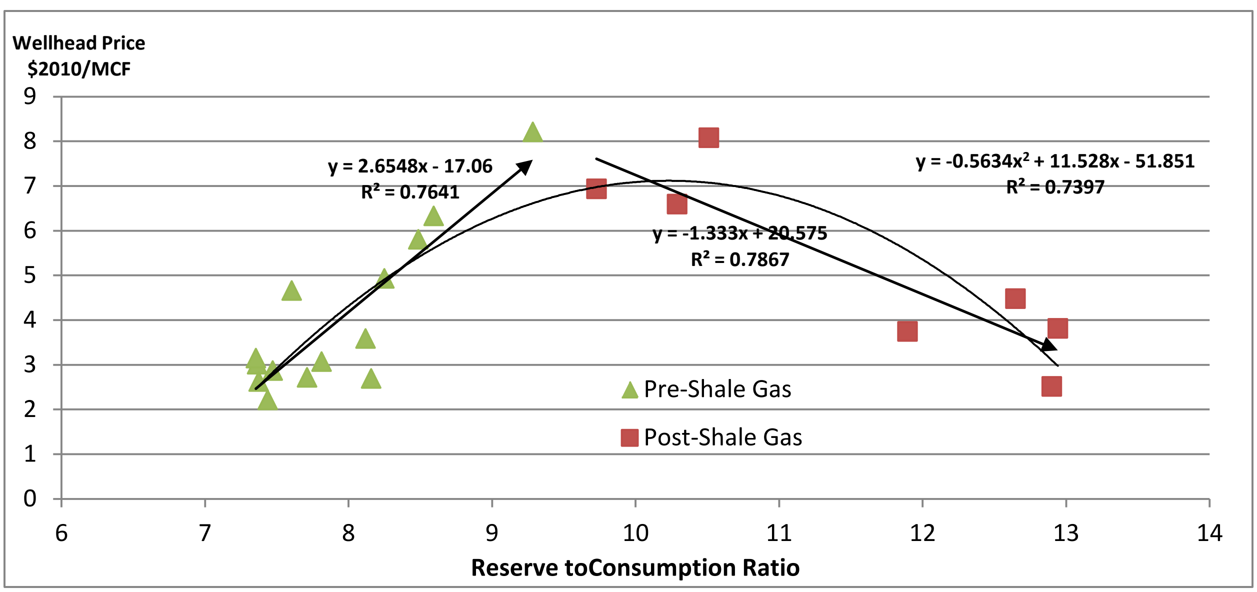
Rowe points to the technologically driven shift in the fundamentals of the natural gas supply-demand balance as calling into questions predictions of very high natural gas prices. The top graph in Exhibit III-6 shows the key variables in the

EXHIBIT III-6: THE SHALE GAS REVOLUTION TRANSFORMS NATURAL GAS SUPPLY FUNDAMENTALS

Reserves Drive Prices on a Forward Looking Basis



The Shift in the Natural Gas Supply Curve



Sources: EIA, Natural Gas Data; Nymex Henry Hub.

supply/demand equation, the reserve-to-consumptions ratio. As Rowe points out, the ratio has surged with the shale gas revolution. The upper graph also includes NYMEX natural gas futures prices out through the end of the decade. Traders on the NYMEX agree with Rowe, who notes that analysts do not see a high gas price over the several decades.

Economic theory and real world experience lead us to expect that such a dramatic improvement in the supply/demand equation would drive prices down. The lower graph shows the strong correlation between the falling and rising reserve to consumption ratio and prices with the turning point in being an R/C ratio of about 10 years.

Renewables

The mid-term prospects of natural gas prices are not the only factor that will affect the market clearing price on the supply side. As we have seen, wind power plays a role by shifting the supply-curve in such a way that it lowers the market clearing price. As wind is added to meet long-term needs, it has this short-term effect. The effect is likely to continue. Onshore wind is becoming more competitive as a long-term resource.

Rowe also notes that there are renewables that will compete with nuclear in the next decade – "But, as I look, I think wind and solar do become more economic, wind much the first. Nuclear plants may become economic again but not in the next decade."[53] Longer-term cost trends support Rowe's observation that alternatives to nuclear power beyond gas are becoming more attractive options. In contrast to nuclear reactor construction costs and cost estimates that have been rising dramatically, several of the alternatives are exhibiting reductions in cost, driven by technological innovation, learning by doing, and economies of scale.

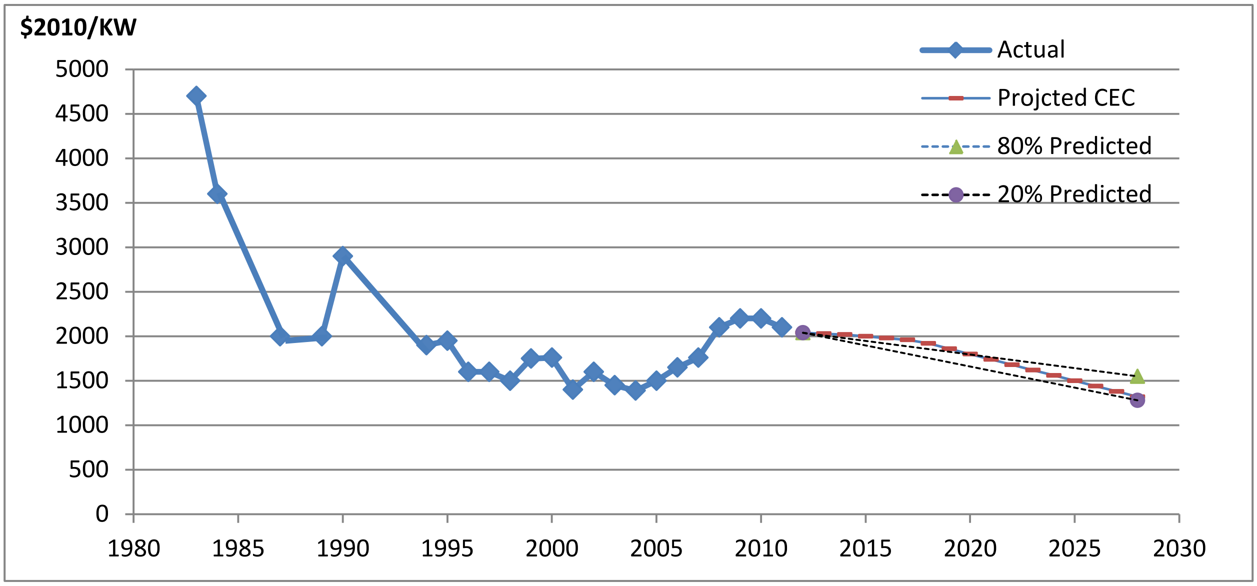
Onshore wind, the target of Exelon's enmity has exhibited a significant cost decline that is expected to continue, as shown in Exhibit IV-7. Onshore wind is cost competitive with gas in many areas today and will be more so in the future.

Some analysts believe solar will play in increasingly larger role for two reasons. In the short term, solar may already be competitive with peak load costs. If solar puts a cap on or reduces demand for fossil fuels at the peak, the wholesale price will be reduced at the key moment when the largest margins can be early. Lazard's observation on the competitiveness of solar with current peak power reminds us that the time of day a resource is available and where it enters the grid are also important

[53] Rowe, "Energy Policy, p. 6.

considerations. Lazard believes solar will be generally competitive with gas within a decade, as shown in Exhibit IV-8.

EXHIBIT IV-7: TRENDS & PROJECTIONS FOR ONSHORE OVERNIGHT WIND COSTS



Sources: Ryan Wiser, et al., ***Recent Developents in the Levelized cost of Energy From U.S. Wind Power Projects,*** **NREL, February 2012; Eric Lantz, Maureen Hand and Ryan Wiser,** ***The Past and Future cost of Wind Energy,*** **NREL, August 2012; California Energy Commission,** ***Cost of Central Station Generation,*** **January 2012.**

EXHIBIT IV-8: KEY COST TRENDS FOR SOLAR POWER: LAZARD LEVELIZED COST FOR SOLAR AND COMBINED CYCLE

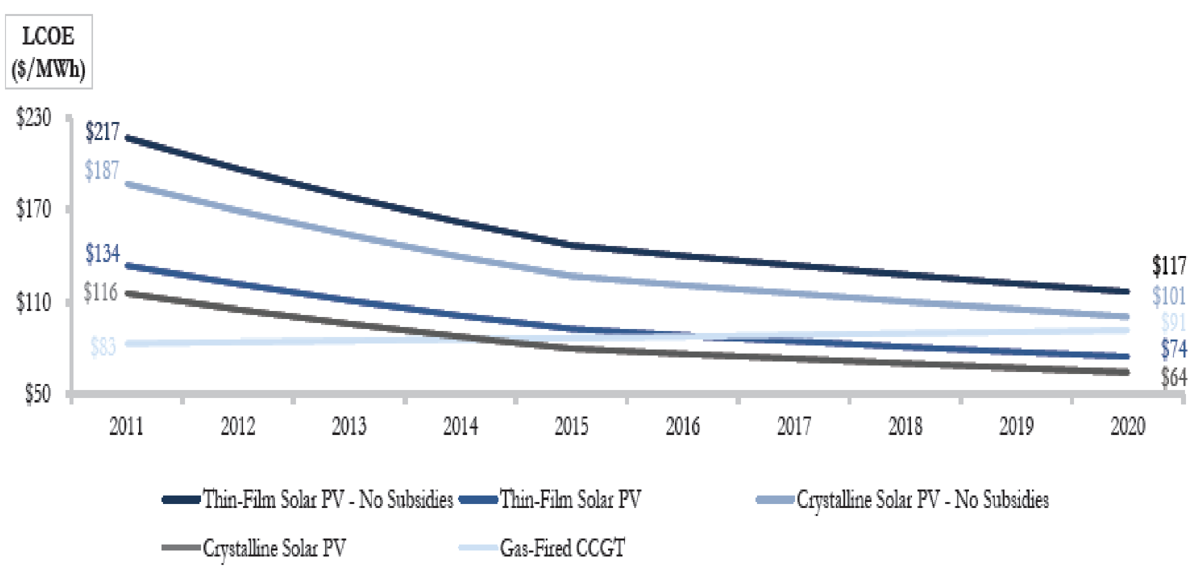
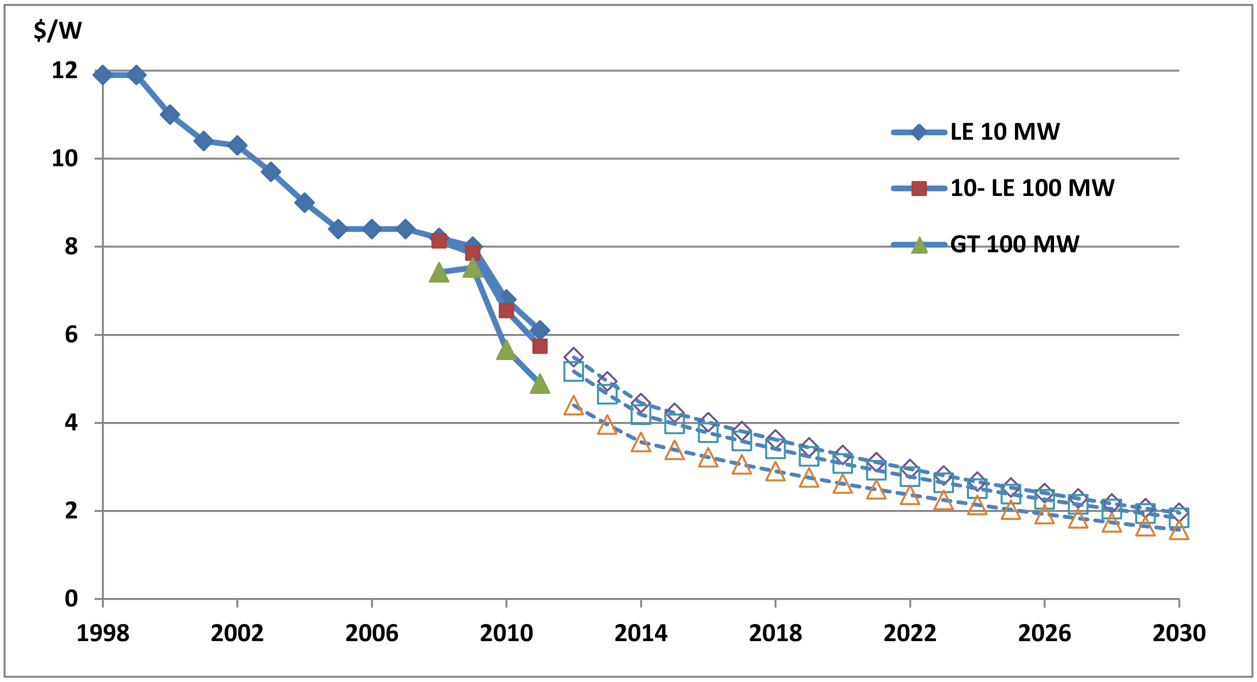


Exhibit IV-9 combines the Lazard projections with recent, past cost trends as estimated by analysts at Lawrence Berkeley Laboratory. There is no reason to believe that the pressures on the market clearing price from alternative sources of supply will ease.

EXHIBIT IV-9: TRENDS & PROJECTIONS FOR SOLAR



Source: Lazard, *Levelized Cost of Energy Analysis* – Version 5.0, June 2011; Galen Barbose, et al., *Photovoltaic (PV) Pricing Trends: Historical, Recent, and Near-Term Projections, LBL and NREL, November 2012,*

Demand

On the demand side, while there is certain to be a great debate about how much the reduction in electricity consumption reflects the recession, there is no doubt that increasing efficiency will change the trajectory of demand (see Exhibit III-10). The long term trend to declining electricity consumption per dollar of GDP has accelerated recently and the trend to less fossil fuel consumption in the utility sector per dollar of GDP has increased even more.

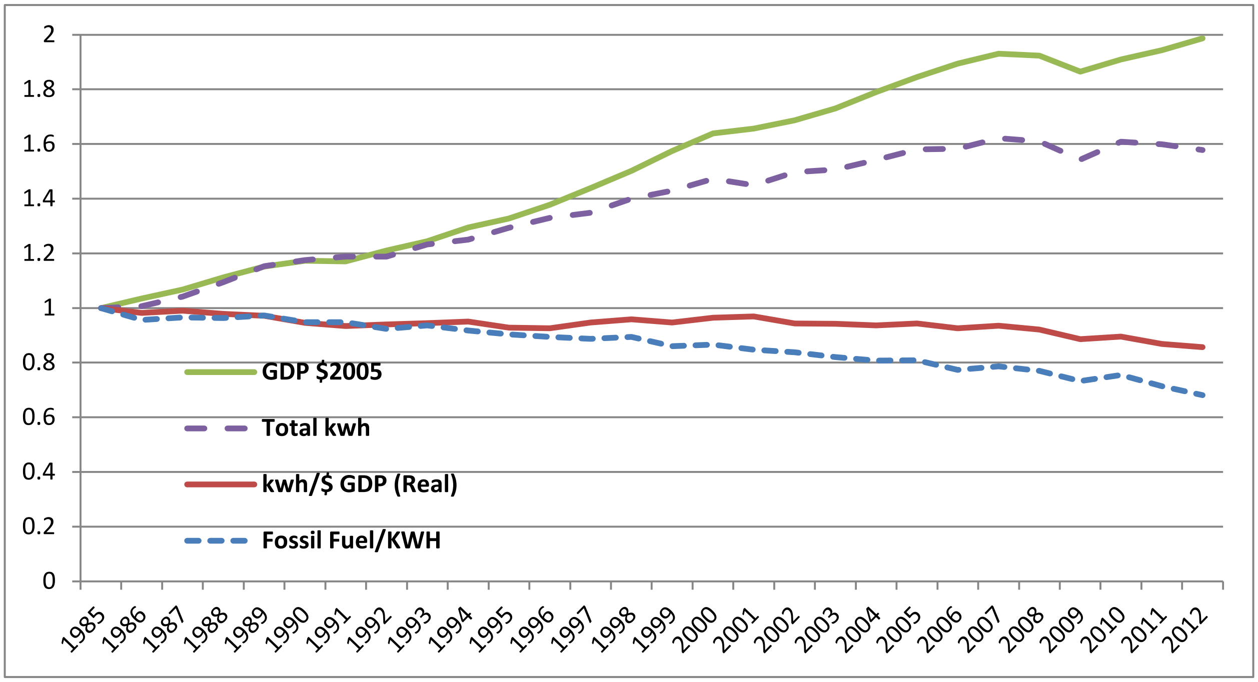
With new building codes and appliance efficiency standards, per capita energy consumption will decline significantly over the next two decades.[54] The decline will

[54] New building codes call for a 30 percent reduction in energy consumption in new building designs. Since the oldest, least efficient buildings are likely to be replaced, the effect will be larger than that. The stock changes slowly however. Appliance efficiency standards have been raised in recent years and the Obama administration has announced a program to raise standards on many appliances in the range of 20 to 30 percent. Since the life cycle of appliances is much shorter than buildings, over the course of two decade most appliances will be replaced by more efficient models. Over the next couple of decades, real GDP is projected to grow at xx percent per year, which could easily be offset by higher efficiency of electricity using consumer durables.

offset increases in population and GDP, resulting in, at best, flat aggregate demand. [55] The debate over climate change has also placed great emphasis on improving efficiency and using renewables. [56]

EXHIBIT III-10: DEMAND FOR FOSSIL FUEL GENERATING CAPACITY:

1985 = 1



Source: Energy Information Administration, *Monthly energy Review* data tables.

With aggregate demand likely to b flat, at best, and renewable costs falling and output rising, the downward pressure on market clearing prices is likely to continue. It appears likely that the pressures on the market clearing price will continue for the period in which decisions about retiring aging nuclear reactors will be made.

C. CONCLUSION

Nuclear economics have always been marginal at best. The first cohort of commercial reactors was much more costly than the available alternatives, but those reactors were forced online by a regulatory system that did not have a market to look to, or care to do so even if one existed. It can be argued that the locomotive that pulled half the nation toward restructuring and much greater reliance on market

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[55] Mark Cooper, *Building on the Success of Energy Efficiency Programs to Ensure an Affordable Energy Future*, February 2010;

[56] Mark Cooper, *A Consumer Analysis of Energy Efficiency and Renewable Energy Standards: The Cornerstone of Consumer-Friendly Energy/Environmental Policy,* May 2009;*The Impact of Maximizing Energy Efficiency on Residential Electricity and Natural Gas Utility Bills in a Carbon-Constrained Environment: Estimates of National and State-By-State Consumer Savings,* 2009;

signals was the reaction against the excessive costs of nuclear power.[57] Some advocates of restructuring loudly declared restructuring would prevent another nuclear fiasco.[58]

Ironically, it appears that an unintended consequence of the shift toward markets will be to force the early retirement of the very reactors that a market never would have allowed to be built in the first place. While half the country does not rely on markets to set the price of electricity, the presence of markets across the country sends strong signals to regulators that keeping aging reactors online, especially if they need repairs or retrofits, does not make economic sense. Thus, although the outcome is ironic in the long sweep of nuclear history in the U.S. it is perfectly consistent with the fundamental economics of nuclear power throughout that history.

While the purpose of the Wall Street analysis is to advise and caution investors about utilities that own the aging fleet of at-risk reactors, my purpose is to inform policymakers about and prepare them for the likelihood of early retirements. By explaining the economic causes of early retirements, the policymakers will be better equipped to make economically rational responses to those retirements (or the threat of retirement).

Economic reality has slammed the door on nuclear power.

- In the near-term old reactors are uneconomic because lower cost alternatives have squeezed their cash margins to the point where they no longer cover the cost of nuclear operation.
- In the mid-term, things get worse because the older reactors get, the less viable they become.
- In the long term new reactors are uneconomic because there are numerous low-carbon alternatives that are less costly and less risk.

The lesson for policy makers in the economics of old reactors is clear and it reinforces the lesson of the past decade in the economics of building new reactors. Nuclear reactors are simply not competitive. They have never been competitive at the beginning of their life cycle, when the build/cancel decision is made, and they are not competitive at the end of their life cycles, when the repair/retire decision is made. They are not competitive because the U.S. has the technical ability and a rich, diverse

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[57] Severin Borenstein and James Bushnell, "Electricity Restructuring: Deregulation Or Reregulation?," *Regulation,* 23:2, p. 47. Other states—those that had not pursued nuclear power and had been more cautious in signing long-term contracts under PURPA—retained relatively low prices. That contrast was probably the driving force behind the restructuring movement in the United States.

[58] James Cook, "Nuclear Follies," *Forbes*, February 11, 1985, uses the term "fiasco."

resource base to meet the need for electricity with lower cost, less risky alternatives. Policy efforts to resist fundamental economic reality of nuclear power will be costly, ineffective and counterproductive.