

UNITED STATES OF AMERICA  
BEFORE THE NUCLEAR REGULATORY COMMISSION

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In the Matter of	)	
	)	
Proposed Rule: Waste Confidence –	)	
Continued Storage of Spent Nuclear Fuel	)	Docket No. 2012-0246
10 C.F.R. Part 51	)	
	)	
Draft Waste Confidence Generic	)	
Environmental Impact Statement	)	
_____	)	

**DECLARATION OF MARK COOPER**

**I. INTRODUCTION AND STATEMENT OF QUALIFICATIONS**

Under penalty of perjury, I, Mark Cooper, declare as follows:

My name is Mark Cooper. I am a Senior Fellow for Economic Analysis at the Institute for Energy and the Environment at Vermont Law School. A copy of my curriculum vitae is attached. I am an expert in the field of economic and policy analysis with a focus on energy, technology, and communications issues.

For over thirty years I have analyzed the economics of energy production and consumption on behalf of consumer organizations and public interests groups, focusing in the past four years on cost of the alternative resources available to meet electricity needs for the next several decades. My analyses are presented in a series of articles,<sup>1</sup> reports,<sup>2</sup> and testimonies before state regulatory

<sup>1</sup> Cooper, Mark. “The Only Thing that is Unavoidable About Nuclear Power is its High Cost,” *Corporate Knights*, forthcoming; “Nuclear Safety and Affordable Reactors: Can We Have Both?,” *Bulletin of the Atomic Scientists*, 2012; “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; “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.

<sup>2</sup> Renaissance in Reverse: Competition Pushes Aging U.S. Nuclear Reactors to the Brink of

agencies<sup>3</sup> and state and federal legislatures.<sup>4</sup> I have served as an expert witness in several regulatory proceedings involving electricity and nuclear reactors, starting with proceedings before the Mississippi Public Service Commission almost thirty years ago regarding the proposed Grand Gulf II nuclear reactor and including proceedings before the Florida and South Carolina Commissions regarding the proposed reactors in those states.<sup>5</sup>

In the course of my economic analyses of electricity alternatives, I have developed a general framework that I refer to as a “multi-criteria portfolio analysis” for evaluating and choosing between the available alternatives in the increasingly complex and ambiguous conditions of the electricity market.<sup>6</sup> My analysis has focused on comparative economic analysis of the nuclear-gas comparison

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Economic Abandonment, July 2013; *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; *Climate Change and the Electricity Consumer: Background Analysis to Support a Policy Dialogue*, June 2008.

<sup>3</sup> “Testimony on Behalf of Utah Heal,” *Carbon County Court*; “Testimony and Surrebuttal Testimony on Behalf Of The Sierra Club,” Before the *South Carolina Public Service Commission*, Docket No. 2012-203-E; “Direct Testimony of Dr. Mark N Cooper in Re: Nuclear Plant Cost Recovery for the Southern Alliance for Clear Energy,” Before the *Florida Public Service Commission*, FPSC Docket No. 100009-EI, August 2010; “Direct Testimony of Dr. Mark N Cooper in Re: Nuclear Plant Cost Recovery for the Southern Alliance for Clear Energy,” Before the *Florida Public Service Commission*, FPSC Docket No. 090009-EI, July 15, 2009.

<sup>4</sup> *Nuclear Economics after Fukushima*, Before the *Standing Committee on Natural Resources House of Commons*, Ottawa Canada, March 24, 2011; “Testimony of Dr. Mark Cooper on House File 9,” Before the *Minnesota House of Representatives Committee on Commerce and Regulatory Reform*, February 9, 2011; “Economic Advisability of Increasing Loan Guarantees for the Construction of Nuclear Power Plants,” Before the *Domestic Policy Subcommittee, Committee on Oversight and Government Reform, U.S. House of Representatives*, April 20, 2010.

<sup>5</sup> See citations to written testimony in Note 3 above. I also provided oral testimony on the witness stand. “On Behalf of Mississippi Legal Services Coalition in the Matter of the Citation to Show Cause Why the Mississippi Power and Light Company and Middle South Energy Should Not Adhere to the Representation Relied Upon by the Mississippi Public Service Commission in Determining the Need and Economic Justification for Additional Generating Capacity in the Form of A Rehearing on Certification of the Grand Gulf Nuclear Project,” Before the *Mississippi Public Service Commission*, Docket No. U-4387, August 13, 1984.

<sup>6</sup> “Least Cost Planning for 21<sup>st</sup> Century Electricity Supply: Meeting the Challenges of Complexity and Ambiguity in Decision Making,” *MACRUC Annual Conference*, June 5, 2011; “Risk, Uncertainty and Ignorance: Analytic Tools for Least-Cost Strategies to Meet Electricity Needs in a Complex

driven by utility concentration on these two technologies, but also including efficiency<sup>7</sup> and wind.<sup>8</sup> The analysis has covered regional, national, and international levels, as well as on the impact of specific institutional arrangements on ratepayers.<sup>9</sup>

## PURPOSE AND FINDINGS

The purpose of my declaration is to evaluate whether the costs of nuclear waste management, including onsite spent nuclear reactor fuel storage and permanent disposal, are high enough to significantly affect the outcome of an analysis that compares the costs and benefits of nuclear reactors with other electricity sources. I understand that this type of analysis is generally conducted by the NRC in the course of its environmental review for new reactor license applications and applications for renewal of existing reactor licenses. In the discussion below, I analyze two of the most important costs of nuclear waste management – the cost of “temporary” storage of spent fuel at reactors and the cost of building, filling, and operating a permanent repository for that fuel. The cost of decommissioning the reactors and closing the permanent repository are also costs of nuclear waste management, but I do not include them in this analysis.

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Age,” *Variable Renewable Energy and Natural Gas: Two Great Things that Go Together, or Best Not to Mix Them*. NARUC Winter Committee Meetings, Energy Resources, Environment and Gas Committee, February 15, 2011.

<sup>7</sup> “Prudent Resource Acquisition in a Complex Decision Making Environment: Multidimensional Analysis Highlights the Superiority of Efficiency,” *Current Approaches to Integrated Resource Planning, 2011 ACEEE National Conference on Energy Efficiency as a Resource*, Denver, September 26, 2011; *Building on the Success of Energy Efficiency Programs to Ensure an Affordable Energy Future*, February 2010; *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.

<sup>8</sup> *Capturing the Value Of Offshore Wind To Promote a Secure, Affordable, Low-Carbon Electricity Future: A Multi-Criteria, Portfolio Approach to Electricity Generation Resource Acquisition in the United Kingdom*, October 2012.

<sup>9</sup> *Public Risk, Private Profit: Ratepayer Cost, Utility Imprudence: Advanced Cost Recovery for Reactor Construction Creates Another Nuclear Fiasco, Not a Renaissance*, March 2013; *Advanced Cost Recovery for Nuclear Reactors*, March, 2011; *Economic Advisability of Increasing Loan Guarantees for the Construction of Nuclear Power Plants*, Domestic Policy Subcommittee, Committee on Oversight and Government Reform, U.S. House of Representatives, April 20, 2010; “Further Nuclear Power Subsidies are Wrongheaded,” *Bulletin of the Atomic Scientists*, December 2009.

At present, the public is paying for the management of nuclear waste in three ways. Utilities pay a fee to the U.S. Department of Energy (DOE) for a Nuclear Waste Fund that is intended to pay for the repository. This fee is collected from ratepayers. The cost of temporary at-reactor storage is also being recovered by utilities from taxpayers in the form of penalties imposed on the federal government for the failure to execute its contractual commitment to take the spent fuel off reactor sites.<sup>10</sup> This penalty is paid out of the U.S. Treasury and has not decreased the Nuclear Waste Fund. Finally, utilities collect funds from ratepayers for the decommissioning of reactors. Questions about the use of the funds and whether they are adequate are not the subject of my declaration, which focuses only on the question of the magnitude of the costs relative to the cost of power from nuclear reactors and the other potential resources that could be used to meet the need for electricity. Nevertheless, as discussed below, these advance payments have a bearing on the applicability of a discount rate to nuclear waste disposal cost estimates.

My analysis shows that the costs of managing spent nuclear fuel are likely to be quite large in absolute value, running to hundreds of billions of dollars (in constant 2012 dollars). They are in the range of \$10 to \$20 per MWH (\$0.01 to \$0.02 per kWh), which is certainly large enough in relative value to affect the outcome of analyses that compare the cost of nuclear power to the alternatives available in the United States. Therefore, the cost of nuclear waste management is a significant cost that should be included in the NRC's economic comparisons of nuclear power with energy efficiency and other alternative energy sources.

## **II. ESTIMATING THE COST OF SPENT FUEL MANAGEMENT**

For the purposes of this analysis, I start with the most recent U.S. government estimates of costs of electricity generation and costs of spent fuel disposal: “Levelized Cost of New Generation Resources in the Annual Energy Outlook,” prepared by the U.S. Energy Information

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<sup>10</sup> See, e.g., *Ntl. Assoc. of Regulatory Util. Comm'rs v. United States DOE*, 680 F.3d 819 (D.C. Cir. 2013).

Administration (EIA) in 2013<sup>11</sup> and the “Nuclear Waste Fund Fee Adequacy Assessment Report” prepared by the U.S. Department of Energy (DOE) in 2013.<sup>12</sup> Each of these studies has some limitations.

I believe that the EIA has been wildly optimistic about the cost of nuclear power over the past decade, but I suspect that the NRC would be inclined to rely heavily on its estimates, and therefore I use it as my base case. I also show that the same conclusion would be reached if I were to rely on recent estimates from utility industry sources and Wall Street analysts.

The DOE’s recent analysis of the cost of a permanent nuclear waste repository is the most recent in a series of government analyses of those costs.<sup>13</sup> Because it was prepared as part of DOE’s legal obligation to assess whether current fees are adequate to fund a permanent repository, it takes a very narrow view of the costs considered. It does not consider at-reactor storage costs, and it assumes that the repository opens very quickly.<sup>14</sup> Neither of these assumptions appears consistent with the current reality of nuclear waste management or sound economic analysis of waste management costs. As I show below, this view ignores at least half of the cost associated with nuclear waste management. Nevertheless, the DOE’s analysis provides a useful starting point for estimating the cost of one component of nuclear waste management.

## **REPOSITORY COSTS**

The narrow costs of constructing and filling a permanent waste repository considered by the DOE can be a starting point for the analysis of the total cost of nuclear waste management. Exhibit MNC-1 shows a number of estimates, prepared by government agencies over the past thirty years,

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<sup>11</sup> Energy Information Administration, “Levelized Cost of New Generation Resources in the Annual Energy Outlook,” *Annual Energy Outlook*, 2013 (hereinafter EIA 2013).

<sup>12</sup> U.S. Department of Energy Nuclear Waste Fund Fee Adequacy Assessment Report, January 2013 (hereafter DOE, 2013).

<sup>13</sup> DOE, 2013.

<sup>14</sup> *Id.* p. 9, DOE 2013 assumes one pilot consolidated storage facility and one full-scale consolidated storage facility. It also assumes a time period of 34 years between the siting and opening of a repository.

of the cost of this subset of waste management activities. I have endeavored to ensure that the comparisons involve only the specific set of costs associated with the repository. While at-reactor storage costs are included in some of the later estimates, I exclude these costs in order to maintain consistency with the DOE's analysis. I exclude historic costs that are sunk and not considered in each forward looking estimate. I convert all costs to real 2012 dollars using the Producer Price Index for intermediate goods (rather than the PPI for finished goods or the Consumer Price Index, which would include many types of distribution costs not included in an activity like the construction and operation of a repository).<sup>15</sup> The cost per metric ton of uranium (used interchangeably with the term "heavy metal") is calculated based on the number of tons assumed in each of the individual studies.<sup>16</sup> The most recent DOE estimate used just over 141,000 metric tons of heavy metal (MTHM) as the total amount of spent fuel that has been produced and will be produced given present reactor licenses and reactors under construction. Studies by the Government Accountability Office (GAO) and the Blue Ribbon Commission, in comparison, used just over 153,000 MTHM, but they counted civilian and defense material not associated with civilian nuclear reactors.

The early estimates and the most recent estimate are for generic waste repositories. The others were for Yucca Mountain, which is generally assumed to be a bit more costly than a generic site. The DOE analysis of repository costs takes this into account.<sup>17</sup>

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<sup>15</sup> GAO, "Nuclear Waste Management; Key Attributes, Challenges, and Costs for the Yucca Mountain Repository and Two Potential Alternatives," Government Accountability Office, GAO-10-48, November 2010 (hereafter GAO 2009) presents analyses in discounted 2009 dollars where the discount rate reflects complex Monte Carlo simulations. Cliff W. Hamal, Julie M. Carey and Christopher L. Ring, Navigant, *Spent Nuclear Fuel Management: How Centralized Interim Storage Can Expand Options and Reduce Costs*, for the Blue Ribbon Commission on America's Nuclear Future, May 16, 2011. (Hereafter Hamal, 2011), have estimated the "best estimate," which is 1.34 times the mean from GAO. Stating that in 2012 dollars yields an adjustment factor of 1.47. I use this to restate all GAO estimates in real, 2012, undiscounted dollars.

<sup>16</sup> This is the convention adopted by Hamal, 2011.

<sup>17</sup> DOE 2013, p. 12: "To derive a cost estimate for a generic repository, rather than one located at

Exhibit MNC-1 shows the mid-point, or “best estimate” from each of the studies. Two things are clear from this history of cost estimation:

First, the estimated cost of spent fuel disposal in a repository has been escalating dramatically, which is typical of cost estimates involving nuclear power. The trend is slightly stronger for the cost estimates since the 1990s.

Second, the repository costs are very large in absolute value, reaching a hundred billion dollars. They are certainly large enough to be included in any economic analysis comparing the costs and benefits of nuclear reactor operation. As discussed below, the costs are also large enough to affect the economics of nuclear power compared to alternatives.

While using the “best estimates” is useful to demonstrate a strong and consistent pattern of rising estimated costs, it hides a great deal of uncertainty about the cost. Exhibit MNC-2 shows the range of costs in the two most recent estimates. There is a great deal of uncertainty about cost in the most recent DOE study, which is typical of estimates involving nuclear power.<sup>18</sup> I will discuss my method for addressing this uncertainty below.

### **AT-REACTOR STORAGE**

The recent GAO analysis<sup>19</sup> and the Blue Ribbon Commission study<sup>20</sup> have recognized the increasing importance that onsite storage of nuclear waste plays in the overall cost of nuclear waste management. Onsite spent fuel storage is becoming the central cost driver of nuclear waste management because very long periods of onsite storage – up to 300 years – are being considered.<sup>21</sup>

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Yucca Mountain, the TSLCC [Total System Life Cycle Cost] cost estimate was reviewed and costs that were deemed specific to the Yucca Mountain site were removed from the estimate.”

<sup>18</sup> The standard deviation of the estimate of the repository costs is large compared to the “best estimate.” The coefficient of variation (the standard deviation divided by the mean) is 0.75.

<sup>19</sup> GAO, 2009.

<sup>20</sup> Hamal, 2011.

<sup>21</sup> Dennis Vinson, Ron Kesterson, and Adrian Mendez-Torres, “Inventory and Description of Commercial Reactor Fuels within the United States,” Prepared for U.S. Department of Energy Campaign Program Savannah River National Laboratory, March 31, 2011. Which is also noted in

These costs are reflected in Exhibit MNC-3, which includes the GAO scenario in which waste remains on site for a long period of time (100 to 500 years). The GAO estimates in Exhibit MNC-3 suggest that the longer waste remains in storage on site, the higher the cost is likely to be. The Blue Ribbon Commission “best estimate” for 100 year at-reactor storage restated in 2012 dollars is just over \$100 billion.<sup>22</sup>

Given that much longer periods of time for at-reactor storage are being contemplated, even this figure is too low for three reasons:

First, when a nuclear reactor shuts down permanently, the waste at the reactor site becomes “stranded.” That is, the site must be operated solely for the purpose of attending to the waste. This means that the costs of many activities that were once attributed to operating the reactor must now be allocated to managing the waste. The Blue Ribbon Commission study suggests that the cost of managing stranded waste is five times as high as the cost of managing waste at an operating site.<sup>23</sup>

Second, over hundreds of years, storage casks will deteriorate and have to be replaced. I have assumed that cask replacement will be necessary every 100 years at a cost of \$1.6 million per cask, assuming no escalation in real costs.<sup>24</sup> Given this cost and the amount of material that will

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Eric M. Davied, *Long-Term Interim Storage for Used Nuclear Fuel: Dry Cask Storage in Centralized Storage Facilities*, Texas A& M University, 2011, identifying cask capacity at 10 to 15 MTU. (Hereafter, Davied 2011).

<sup>22</sup> Hamal, 2011, estimates just under \$72 billion for the large repository (including transportation) compared to the GAO estimate of \$53 billion. I use the difference ( $71.46/53 = 1.348$ ) to scale up to undiscounted dollars. Bringing the figure to 2012 dollars involves inflating by a factor of 1.096. The adjustment factor is 1.477. Hamal’s “best estimate” cost for the repository would \$78.3 billion in 2012 dollars compared to the DOE midpoint cost of \$88.9 billion.

<sup>23</sup> This cost difference is derived from Hamal, 2011, p. 27. GAO, 2009 shows no difference between the average at-reactor storage costs for 100 years, which would include a substantial period in which spent fuel is not stranded, and the cost of 500-years of at-reactor storage. This suggests that stranding has not been taken into account, which was the central thrust of Hamal, 2011.

<sup>24</sup> My assumption of cask replacement every 100 years is consistent with the NRC’s Draft Waste Confidence Environmental Impacts Statement, p. xxviii, 2013. Davied, 2011, identifies cask capacity at 10 to 15 MTU.



have to be stored, the GAO estimates of storage are low. Repackaging costs could be on the order to \$75 billion.<sup>25</sup>

Third, as with all nuclear costs, repackaging cost appear to be increasing dramatically.<sup>26</sup>

This analysis also excludes potentially significant costs associated with the repackaging and transportation of high burnup spent nuclear fuel over the next 30-50 years. For instance, in 2012 an expert with the National Academy of Engineering reported that “the technical basis for the spent fuel currently being discharged (high utilization, burnup fuels) is not well established... the NRC has not yet granted a license for the transport of the higher burnup fuels that are now commonly discharged from reactors. In addition, spent fuel that may have degraded after extended storage may present new obstacles to safe transport.”<sup>27</sup> Even the Nuclear Regulatory Commission (NRC) admits “there is limited data to show that the cladding of spent fuel with burnups greater than 45,000 MWd/MTU will remain undamaged during the licensing period” for dry spent fuel storage facilities.<sup>28</sup>

#### **COMBINING AT-REACTOR STORAGE AND PERMANENT REPOSITORY COSTS**

Exhibit MNC-4 adds at-reactor storage costs to the most recent DOE estimates for the cost of the repository. The stranded waste costs are based on the difference in cost estimated in the Blue Ribbon Commission report between very rapid transfer of stranded waste to central storage and no

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<sup>25</sup> GAO, 2009 uses the figure of \$1.6 million per cask. With 153,000 metric tons of waste and 10 tons per cask, the cost of repackaging all spent fuel is \$24.480 billion. Three repackaging operations would be just under \$75 billion.

<sup>26</sup> Michiel P.H. Brongers, *Appendix CC, Nuclear Waste Storage*, CC Technologies Solutions, Inc., N.D., p. cc-2, gives a figure of \$1.2 million; GAO, 2009, p. 56, puts the cost at \$1.6 million per cask, which is shown as a modification of the earlier assumption of \$1.2 million. GAO, 2009, reflects similar trends.

<sup>27</sup> National Academy of Engineering, “Managing Nuclear Waste”, Summer 2012, pp 21, 31, <http://www.nae.edu/File.aspx?id=60739>.

<sup>28</sup> U.S. Nuclear Regulatory Commission, “Standard Review Plan for Spent Fuel Dry Storage Facilities, Final Report” NUREG-1567, March 2000. p. 6-15, <http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1567/sr1567.pdf>.

transfer until 70 years later.<sup>29</sup> That difference is slightly more than \$24 billion over the first 70 years. Extrapolating to 300 years, the difference in the stranded waste cost would be \$105 billion.

Repackaging of waste is necessary as long as it is not deposited in a permanent repository.<sup>30</sup> Therefore, repackaging costs must be added. Assuming three rounds of repackaging in 300 years, repackaging adds another \$75 billion to the cost of managing spent fuel.

Combining these cost estimates for storage and disposal of spent fuel yields a cost range of approximately \$210 to \$350 billion.

### **OTHER POTENTIAL COSTS**

The estimated cost range of \$210 to \$350 billion for spent fuel management leaves out significant costs. First, it does not include an escalation in the real cost of at-reactor storage and the escalation in the real cost of construction and operation of a permanent repository. Both of these have exhibited significant historical trends of increasing real cost. Second, the estimate in Exhibit MNC-4 does not include the cost or risk of accidents that may be significant with onsite storage of waste, especially during the very long period of onsite storage that is being contemplated. Large quantities of dangerous materials stored at sites close to population centers create a risk of accidents that can impose severe economic disruption and social dislocation. While much of the discussion of nuclear accidents focuses on public health issues, the economic and social impacts are substantial. The estimated economic costs of one accident run into the hundreds of billions, equaling or exceeding the entire cost of waste management and disposal.<sup>31</sup> The fourth largest utility in the world

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<sup>29</sup> Hamal, 2011 p. 41 shows stranded waste costs of \$477 million for a central storage facility taking 6000 MTU per year starting 2020 and \$22.716 billion for a central storage facility taking 3000 MTU per year starting in 2090. The difference of \$22.239 billion in 2009 dollars equals \$24.4 billion in 2012 dollars.

<sup>30</sup> Hamal, 2011, p. 52.

<sup>31</sup> Cooper, Nuclear Safety, discusses the general magnitude of these costs. Gordon R. Thompson, "Risk-Related Impacts from Continued Operation of the Indian Point Nuclear Power Plants", November, 28, 2007 examines the potential economic cost of a severe onsite storage accident, showing it is similar in magnitude to the general accident risk.

was not thrown instantaneously into virtual bankruptcy by public health impacts, but it was destroyed by the economic cost of cleanup and compensation. While these are low probability events, keeping large quantities of nuclear waste onsite for long periods of time raises the probability of such an event.

In addition, the above analysis does not include any escalation in the cost of decommissioning reactors. Decommissioning costs theoretically are included in calculations of levelized cost. But these costs have been rising dramatically in recent years.<sup>32</sup> For the reactors that were retired in the past year, the total is approaching \$1 billion per site, significantly above the amount originally estimated.<sup>33</sup>

However, it is also important to recognize that the storage of spent fuel is included in the decommissioning cost estimates, and I have already included those costs in this discussion. In the case of Kewaunee, the spent fuel storage costs are one-third of the total decommissioning cost. At half a billion dollars per nuclear reactor, the total cost for decommissioning the entire fleet could be \$50 billion, which is quite significant, given the other costs that I have analyzed.

It appears that utilities are going to ask for rate increases to cover decommissioning costs, which means they have not been collecting enough. Given the rising costs of decommissioning, it remains to be seen if current cost estimates are adequate. For license renewals, there would be an additional question about whether extending the life of a reactor increases the decommissioning costs. In summary, I do not include decommissioning costs in this analysis, but these costs could well be another reason my estimate is low.

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<sup>32</sup> David A. Krause, “Historical NDT Fund Balances, Annual Contributions and Decommissioning Cost Estimates”, Nuclear Regulatory Commission Workshop, March 2011.

<sup>33</sup> *Decommissioning Cost Analysis for the Vermont Yankee Nuclear Power Station*, February 2012; *Kewaunee Power Station Post-Shutdown Decommissioning Activities Report*, TLG Services, Inc., 2013; *Decommissioning San Onofre Fact Sheet*, 2013; Robert McCullough, et al., *Economic Analysis of the Columbia Generating Station*, December 2013, pp. 92-101, 110-130. “Decommissioning Cost Escalation is a Global Phenomenon: Nuclear Decommissioning Authority, *Managing Risk Reduction at Sellafield*, Report by the Comptroller and Auditor General, November 7, 2012.

### **III. TRANSLATING NUCLEAR WASTE MANAGEMENT COSTS INTO THE COST OF ELECTRICITY**

In order to bring these waste management costs into the economic evaluation of nuclear power compared to other resources, I translate the aggregate estimates of costs into per kWh costs. This involves several challenges. The bottom row in Exhibit MNC-4 shows an effort to do so. There are two important issues that affect this calculation: output of nuclear reactors and a determination of the appropriate discount rate.

#### **OUTPUT OF NUCLEAR REACTORS**

The amount of power that the costs will be spread across is uncertain. The DOE's assumption is too high for several reasons. The DOE estimate shows a stream of output from nuclear reactors that start with a base in 2012 that is already 5% higher than the actual output.<sup>34</sup> The output is lower than expected because nuclear reactors were offline and have been retired early. That trend is likely to continue.

The DOE assumption of a very high load factor is inconsistent with historical experience. It took a long time to build up to a high load factor; therefore, any new reactors that come online should not be assumed to immediately jump to a high load factor. Moreover, capacity factors for existing reactors have begun to decline as reactors age. In a recent paper, I showed that including early retirements in the calculation of load factors yields a load factor that is one-sixth lower than the very high assumptions being used in much comparative economic analyses.<sup>35</sup> The output of the nuclear fleet in 2013 will have declined from the peak in 2010 to the level achieved in 2004.

DOE and many other analysts of waste management assume that reactor life will be 60 years.<sup>36</sup> While the license period might run that long, virtually all reactors that have been retired

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<sup>34</sup> DOE, 2013.

<sup>35</sup> Mark Cooper, *Renaissance in Reverse: Competition Pushes Aging U.S. Nuclear Reactors to the Brink of Economic Abandonment*, July 2013 (hereafter, *Aging Reactors*).

<sup>36</sup> DOE, 2013.

were retired before their licenses expired. The closure of Kewaunee and Vermont Yankee extend that pattern for reactors that were online when the retirement decision was made, while San Onofre and Crystal River extend the pattern of troubled reactors retiring early.

DOE assumes an increase in capacity of almost 10 percent due to large scale uprates at existing facilities,<sup>37</sup> but virtually all large scale uprates pending have been cancelled due to a severe deterioration in the comparative economics of nuclear power.<sup>38</sup>

DOE assumes early online status for new reactors under construction and an “unplanned addition” of a new reactor which would add 2 percent to nuclear capacity.<sup>39</sup> Given the historical experience of new reactor cancellations and construction delays, the “unplanned addition” should certainly be dropped.

Combining these observations, one can argue that the base case for NRC analysis should include actual 2013 output, which is 5% lower than the DOE analysis, an 80 percent load factor, without uprates and “unplanned additions.” Under these assumptions, the output of the fleet would be at least 25% lower than assumed by DOE in its analysis of disposal system costs.<sup>40</sup>

Lower output might lower the variable cost of at-reactor storage. Whether it lowers the cost of a permanent repository depends on whether one assumes that only one repository will be constructed. If adding nuclear capacity causes the construction of a second repository, fixed costs will increase substantially. The GAO analysis, adjusted for the discount rate and inflation, suggests that the cost of operating two repositories would be 32% higher than one, adding \$25 billion to the total cost.<sup>41</sup> This would offset a substantial part of the variable cost savings. Put in another way, if denying licenses or license renewals allows a second repository to be avoided, the reduction in cost

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<sup>37</sup> DOE, 2013.

<sup>38</sup> Cooper, Aging Reactors.

<sup>39</sup> DOE, 2013.

<sup>40</sup> This result is consistent with all remaining reactors plus five new ones – Vogtle, Summer, Watts Bar – running for a full 60 years at 90 percent capacity factor.

<sup>41</sup> GAO, 2009.

would be substantial including both fixed costs for the reactor and variable cost for spent waste storage.

## **THE DISCOUNT RATE**

There is a great deal of uncertainty and debate about the discount rate that should be used. In this case, as discussed below, it is my opinion that application of a discount rate is inappropriate. Therefore, the costs presented in Exhibit MNC-4 are not discounted.

For purpose of long term analysis, analysts generally believe discount rates should be quite low.<sup>42</sup> The fact that costs of waste management are incurred a long time (i.e., hundreds or thousands of years) after the useful life of the facility creates an intergenerational issue, since future generations will be incurring large costs without deriving any benefit. As GAO states:

Although the concept of discounting is an accepted and standard methodology in economics, the concept of discounting values over a very distant future—known as “intergenerational discounting”—is still subject to considerable debate. Furthermore, no consensus exists among economists regarding the exact value of the discount rate that should be used to discount values that are spread over many hundreds or thousands of years.<sup>43</sup>

Therefore the appropriate discount rate is a significant issue that should be addressed in the NRC analysis of the cost of waste management.

In my opinion, there are two additional, important reasons why application of a zero discount rate is appropriate in these circumstances. First, the real increase in the cost of at-reactor storage and the permanent repository has been increasing substantially faster than the real, discount rate. Given the long time frames being considered, the real price increase can have a very large impact. An annual real rate of increase above the discount rate of one-half of one percent would more than double the cost of waste management.

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<sup>42</sup> Hamal, 2011.

<sup>43</sup> GAO, 2009, p. 28.

The second reason stems from the unique way that the financing of the repository is being handled. To the extent that the discount rate represents the time value of money (*i.e.*, the value of the opportunity to use the money), the public is bearing the burden on the revenue side. The DOE analysis of fund adequacy takes credit for the earning of interest on the funds collected. Because those funds are being banked to make the fund whole, then the funds are not available to be used for other purposes. Much the same is true of the Treasury funds being paid to utilities because of the failure of the federal government to take the spent fuel. Because taxpayers are already being denied the opportunity to use their funds for other purposes, to discount the cost would be a double burden. Taxpayers and ratepayers would be bearing the full cost of the waste management, having been denied the opportunity to use the repository funds of penalties for storage costs for other purposes.

Given these considerations, I believe it is reasonable to estimate the combined costs of at-reactor storage and a permanent repository in the range of \$10 - \$20/MWH (\$0.01 to \$0.02/kWh). I have rounded this estimate to one significant figure, to account for the uncertainties inherent in such estimations at the present time.

In absolute value, given the EIA estimate of \$0.11/per kWh for the cost of nuclear power from new reactors, this is between 10% and 20% of the estimated cost.<sup>44</sup> That is a substantial portion of new reactor costs and therefore strongly merits consideration by the NRC in its economic analysis of the relative costs and benefits of new nuclear reactors as compared to energy efficiency and other energy sources.

For the above reasons, I believe that the bottom line in Exhibit MNC-5 provides cautiously low estimates of the cost of nuclear waste management. Therefore, in the remainder of this analysis

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<sup>44</sup> See EIA, 2013.

I use the cost range of \$10/MWh to \$20/MWh to assess the importance of including nuclear waste management costs in the NRC's economic analysis.

As discussed in more detail in Section IV, the cost of nuclear waste management is a much larger fraction of the cost of operating existing reactors than for new reactors. And it is large enough to affect the comparative cost of nuclear power from existing and new plants, relative to the available energy alternatives. Therefore, in the case of both new reactor licensing and license renewal for existing reactors, the costs of nuclear waste management could be high enough to affect decisions about which energy resources to develop.

#### **IV. IMPACT OF NUCLEAR WASTE MANAGEMENT COST ON THE COMPARATIVE ECONOMICS IN RESOURCE SELECTION**

In the previous section I showed that a very cautious estimate of waste management costs would be in the range of \$0.01 to \$0.02 per kWh. In this section I examine whether costs of that magnitude could affect the economic analysis of nuclear power compared to other resources. For the analysis of licenses for new reactors I examine the addition of waste management costs to the levelized cost of energy that are frequently used to evaluate new resources. For the analysis of the renewal of licenses for existing reactors I analyze the addition of waste management costs to the operating costs and margins of existing reactors.

##### **LEVELIZED COST ANALYSIS FOR NEW REACTOR LICENSES**

The traditional approach to comparative resource selection for new reactors relies on the calculation of the levelized cost of electricity.<sup>45</sup> For the purposes of this analysis, I start with the levelized cost of alternatives as estimated by EIA. I then add the cost of nuclear waste management

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<sup>45</sup> Levelized cost is often cited as a convenient summary measure of the overall competitiveness of different generating technologies. It represents the per-kilowatt-hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Key inputs to calculating levelized costs include overnight capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type. [http://www.eia.gov/forecasts/aeo/electricity\\_generation.cfm](http://www.eia.gov/forecasts/aeo/electricity_generation.cfm)



to those costs and observe, qualitatively, whether it would alter the evaluation of the cost of nuclear power compared to the other options available. Exhibit MNC-5 shows the results using the range of estimates in the EIA analysis.

Nuclear waste management costs of \$20/MWH would change the location of nuclear in the relation to other resources significantly.

Nuclear moves:

- Out of the range of
  - Conventional coal costs
  - Gas Combined Cycle with CCS
  - Advanced gas turbines
- Into the range of
  - Advanced coal
  - Advanced coal with CCS
- Much closer to and
  - Slightly below gas turbines
  - Slightly above Biomass

Waste disposal costs of \$10/MWH move nuclear costs in the same directions, but more modestly.

Exhibit MNC-6 shows levelized cost estimates for a similar set of resources from the Pennsylvania, Jersey, Maryland Power Pool (PJM), a major Regional Transmission Organization (RTO) in an area of the country that is not especially well endowed with renewable resources (e.g. compared to the Midwest with a great deal of wind or the Southwest with a great deal of solar, or the Northwest with a great deal of hydro). Exhibit MNC-7 shows estimates from Lazard, which is a financial analysis firm. I include these two estimates because they not only represent different institutional points of view but also because both include efficiency as a resource. Both estimates demonstrate that efficiency is the least-cost resource by far. In fact, a significant amount of efficiency could be delivered at a cost that is close to the cost of nuclear waste management alone.

Lazard also projects declining costs for solar, which I include in Exhibit MNC-7, which would make it cost competitive with even natural gas within a decade. As shown in Exhibit MNC-8,

the cost trends for solar and offshore wind are expected to make them much more competitive over the next decade and would significantly affect all of the comparisons affecting nuclear power.

Adding \$10 to \$20 per MWh to the cost of nuclear power generation would make a material difference in its attractiveness. Nuclear becomes even less attractive when one considers that other energy sources have little risk due to the short time from start of construction to finish. Looking at the cost of nuclear compared to the more costly alternatives in these analyses, the \$10 to \$20/MWh certainly can make a difference. Nuclear, which is almost the most expensive resource, could become the most costly.

### **PORTFOLIO ANALYSIS**

In the realm of electricity resource selection, I and many others have argued for an approach to analysis that deals more systematically with risk, uncertainty, vagueness, and ambiguity in the decision-making environment. I have developed a multi-criteria portfolio approach based on financial risk hedging and real option analysis, as well as a number of other efforts to deal with the challenge of ambiguity in the decision-making environment. For the purpose of incorporating the cost of nuclear waste management into the analysis, I will briefly describe the basic portfolio approach.

The top graph in Exhibit MNC-9 presents the basic approach to financial portfolio analysis, as a publication from the National Regulatory Research Institute (NRRI) attempted to introduce it to regulators.<sup>46</sup> As shown in the upper graph, investors want to be on the efficient frontier, where risk and reward are balanced. They can improve their expected returns if they can increase their reward without increasing their risk or if they can lower their risk without reducing their reward. In the financial literature, risk is measured by the standard deviation of the value of the reward.

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<sup>46</sup> Ken Costello, *Making the Most of Alternative Generation Technologies: A Perspective on Fuel Diversity*, NRRI, March 2005.

In applying this framework to the evaluation of generation options, analysts frequently measure reward as kilowatts per dollar (a measure of economic efficiency). Reward is the inverse of cost (i.e., the lower the cost the greater the reward). Indeed, they use efficiency and cost interchangeably.<sup>47</sup> The lower graph in Exhibit MNC-9 shows the cost/risk relationship. Options that would move the portfolio toward the origin should be adopted since they embody lower cost and/or risk. Movement along the risk-cost frontier is neutral. Movement away from the origin raises either the cost or the risk.

I use the array of resources to calculate a measure of the attractiveness of the reward. The distance of a resource from the origin measures the risk-cost characteristics of the resource (giving risk and cost equal weight). Resources that are farther from the origin (measured as the distance with each factor weighted equally) are less attractive. The distance from the origin can be expressed as the risk-adjusted cost or the expected cost.

Exhibit MNC-10 shows the result of applying my approach to the EIA cost estimates, assuming that waste costs increase both the point estimate and the standard deviation of the cost estimates. Exhibit MNC-10 provides quantitative estimates that support the observations in the previous section. Waste disposal costs of the magnitude I have estimated make nuclear a much “closer” call in comparison to other alternatives, and they even reverse the direction of the conclusion in several comparisons. The top graph in MNC-10 focuses on the comparisons between resource costs that would be most affected by inclusion of waste management costs in the NRC’s economic analysis. The bottom graph includes all of the resources. There are nine comparisons in which nuclear would be seen as a significantly less attractive asset to include in a resource portfolio. Including the trends for wind and solar cost and the cost of waste management, nuclear becomes almost the least attractive resource.

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<sup>47</sup> J.C. Jansen, L.W. M. Beurskens, and X. van Tilburg, *Application of Portfolio Analysis to the Dutch Generating Mix*, ECN, February 2006, p. 13 argue for a risk-cost frontier.

## ANALYSIS FOR LICENSE RENEWAL OF EXISTING REACTORS

I approach the analysis of the impact of waste management costs on the economics of aging reactors by examining these costs in relation to operating costs and margins. The economics of old reactors is already fraying and many are already on the economic "razor's edge."<sup>48</sup> Upgrades are already being abandoned because they are too costly. Old reactors are being shuttered because they are no longer economic. Proper consideration of waste disposal costs could play a part in pushing them over the edge.

In my recent analysis of aging reactors I used a Credit Suisse analysis of operating costs and operating margins as the basic data to make the point that analysis of the economics of aging reactors that are still operating is challenging. Exhibit MNC-11 contains the estimated operating costs for almost all nuclear reactors online in 2012. Exhibit MNC-12 shows the "cash margins" that the reactors would yield, given the "round-the-clock prices" at different power hubs. It shows that in all but a few cases the cash margins – revenues per MWh in excess of the offered hub price – are less than \$20 per MWh. It also shows that the cash margins are less than \$10 per MWh in many cases. Exhibit MNC-12 also identifies reactors that have been retired recently or are scheduled to retire early, even though they were online and had significant periods before their licenses would expire. Major upgrades that have recently been cancelled are also identified.

The exhibit makes the point that cash margins of about \$9/MWh put reactors on the razor's edge because the cash margins are very thin.<sup>49</sup> Exhibit MNC-12 shows that 12 of the 18

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<sup>48</sup> Cooper, Aging Reactors.

<sup>49</sup> Credit Suisse, 2013, pp. 11-17, "Using current 2014 power price forwards and unit economics, we see modest cash margin expectations... Layering in typical parent overhead of \$5-7 / MWh, unit economics look even worse... We worry that rising operating and capital costs along with operational problems at some aging plants will force owners to continuously re-evaluate the useful lives of plants independent of license extensions especially as the time to absorb ongoing capex grows shorter."

license renewals pending or expected in the near future are on this razor's edge. The waste management costs identified above are clearly material in these circumstances.

## **CONCLUSION**

In conclusion, the calculations in this declaration indicate that spent fuel storage and disposal costs could be high enough to materially affect energy choices when the costs of new reactors or extension of the operating life of existing reactors are compared with energy efficiency and alternative energy sources. Therefore, in my opinion, the NRC should consider these costs in its licensing decisions for new reactors and renewal of existing reactor licenses.

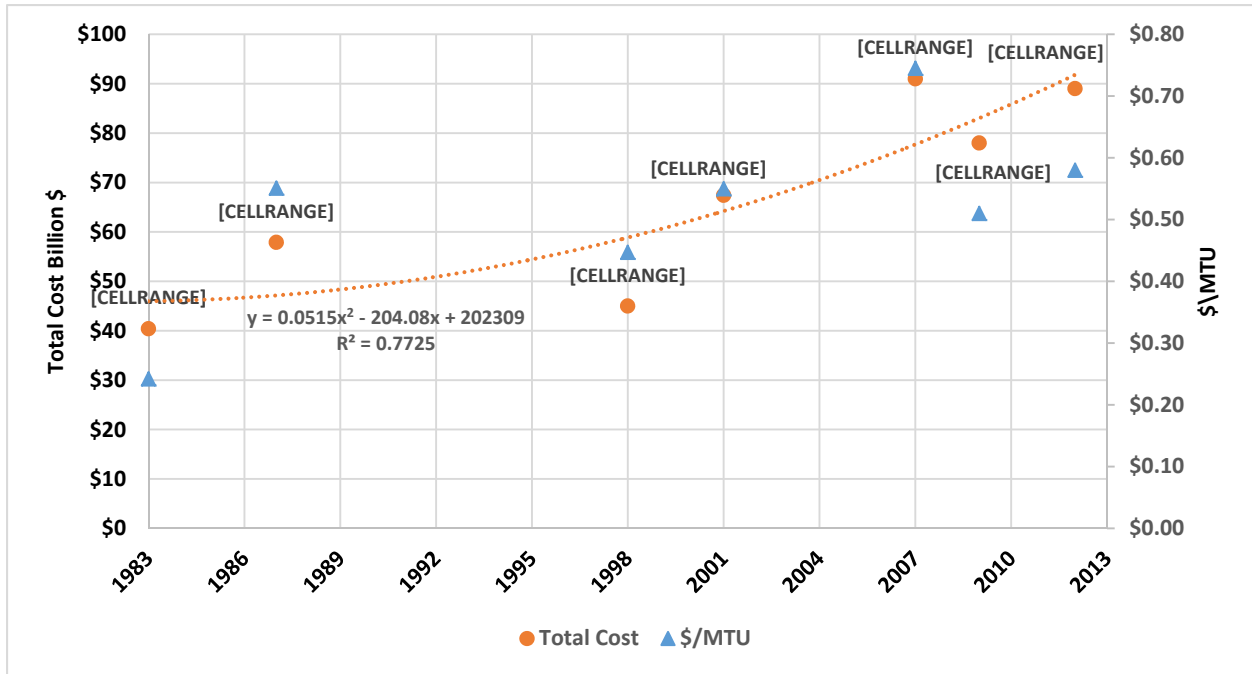
I declare that the foregoing statements of fact are true and correct to the best of my knowledge and that the statements of opinion expressed above are based on my best professional judgment.

A handwritten signature in cursive script, reading "Mark Neal Cooper", is displayed on a light blue, textured background.

Mark Cooper

Date: December 16, 2013

**EXHIBIT MNC-1, Page 1 of 1**  
**REPOSITORY COST ESTIMATES ACROSS TIME**



**Sources:**

**GAO 1998:** “Nuclear Waste: Fourth Annual Report on DOE’s Nuclear Waste Program,” United States General Accounting Office, GAO/FECD-88-131, September 1988.

**DOE 1998:** “Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program,” DOE/RW-510, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, DC-20586, December 1998.

**DOE 2008:** “Analysis of the Total System Lifecycle Cost of the Civilian Radioactive Waste Management Program,” Fiscal Year 2007, DOE/RW-0591, Washington, D.C., July 2008.

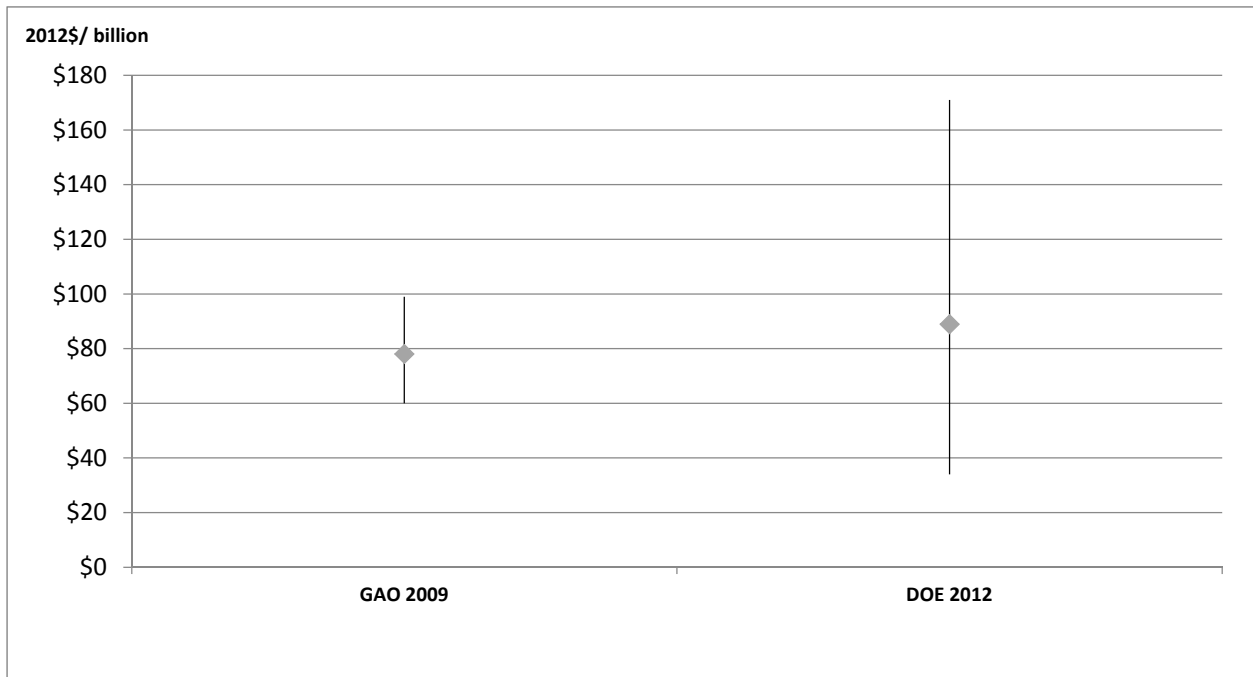
**GAO 2009:** “Nuclear Waste Management; Key Attributes, Challenges, and Costs for the Yucca Mountain Repository and Two Potential Alternatives,” Government Accountability Office, GAO-10-48, November 2010.

Using the “best estimate” identified by Cliff W. Hamal, Julie M. Carey and Christopher L. Ring, Navigant, *Spent Nuclear Fuel Management: How Centralized Interim Storage Can Expand Options and Reduce Costs*, for the Blue Ribbon Commission on America’s Nuclear Future, May 16, 2011.

**DOE 2013:** U.S. Department of Energy, “Nuclear Waste Fund Fee Adequacy Assessment Report,” January 2013.

**EXHIBIT MNC-2, Page 1 of 1**

**RANGE OF REPOSITORY COST ESTIMATES WITHIN STUDIES**



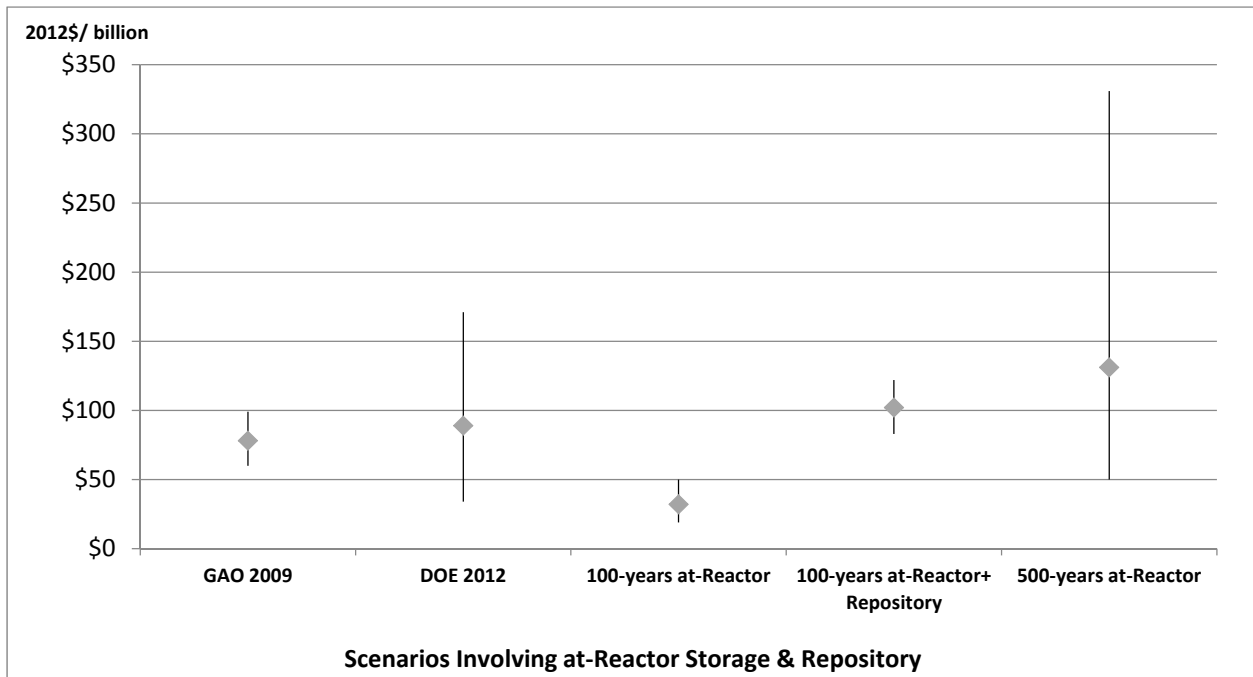
**Sources:**

**GAO 2009:** “Nuclear Waste Management; Key Attributes, Challenges, and Costs for the Yucca Mountain Repository and Two Potential Alternatives,” Government Accountability Office, GAO-10-48, November 2010 (p.71).

Using the “best estimate” identified by Cliff W. Hamal, Julie M. Carey and Christopher L. Ring, Navigant, *Spent Nuclear Fuel Management: How Centralized Interim Storage Can Expand Options and Reduce Costs*, for the Blue Ribbon Commission on America's Nuclear Future, May 16, 2011 (p.27), which is 1.34 times the GAO mean. Estimates are adjusted from 2009 to 2012 dollars using the Producer Price Index for Intermediate materials and supplies (PPI change factor = 1.096). Storage costs are excluded.

**DOE 2013:** U.S. Department of Energy, “Nuclear Waste Fund Fee Adequacy Assessment Report,” January 2013.

**EXHIBIT MNC-3, Page 1 of 1**  
**AT-REACTOR STORAGE + REPOSITORY COST SCENARIO**



**Sources:**

**GAO 2009:** “Nuclear Waste Management; Key Attributes, Challenges, and Costs for the Yucca Mountain Repository and Two Potential Alternatives,” Government Accountability Office, GAO-10-48, November 2010 (p.71).

Using the “best estimate” identified by Cliff W. Hamal, Julie M. Carey and Christopher L. Ring, Navigant, *Spent Nuclear Fuel Management: How Centralized Interim Storage Can Expand Options and Reduce Costs*, for the Blue Ribbon Commission on America's Nuclear Future, May 16, 2011 (p.27), which is 1.34 times the GAO mean. Estimates are adjusted from 2009 to 2012 dollars using the Producer Price Index for Intermediate materials and supplies (PPI change factor = 1.096).

**DOE 2013:** U.S. Department of Energy, “Nuclear Waste Fund Fee Adequacy Assessment Report,” January 2013.



**EXHIBIT MNC-4, Page 1 of 1**  
**NUCLEAR WASTE MANAGEMENT COST ESTIMATES**

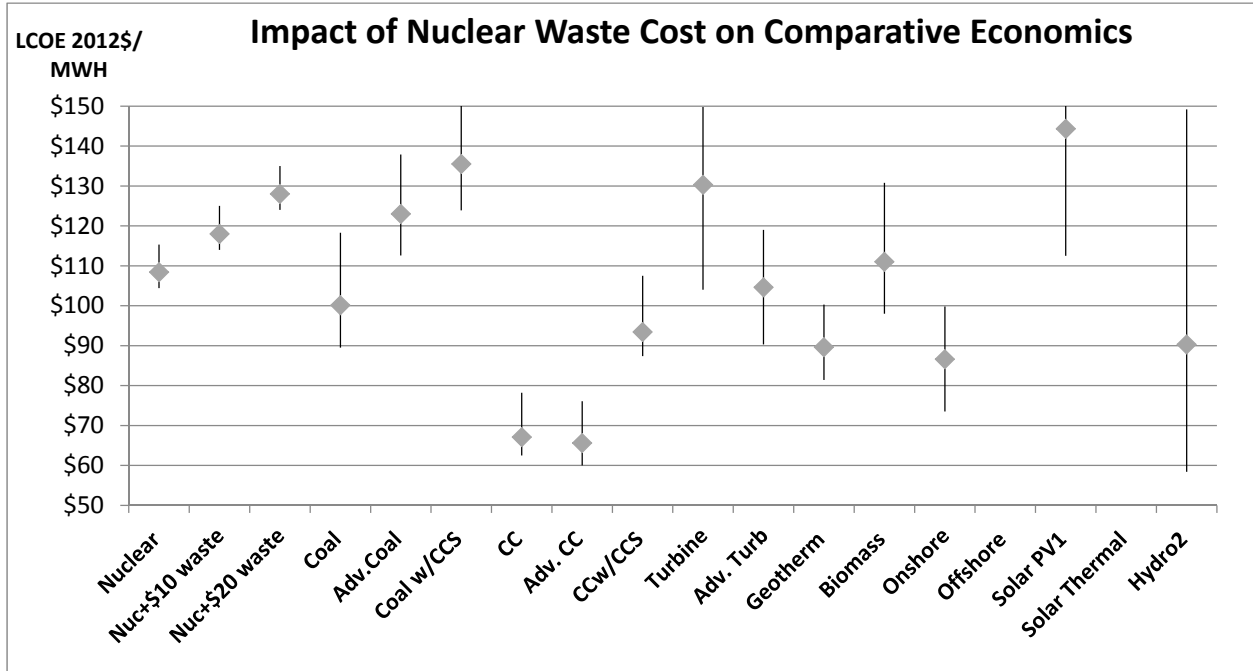
Cost Category	DOE Repository + At-Reactor Storage Cost in Billions of 2012 Dollars	
	Low	High
Repository	\$34	\$171
Stranded Waste 300 years	\$105	\$105
3 repacks over 300 years	\$75	\$75
<b>Total</b>	<b>\$214</b>	<b>\$351</b>

Cost in \$/KWH		
DOE Assumption (29,000 TWH)	\$0.0074	\$0.012
DOE Corrected (22,000 TWH)	\$0.0097	\$0.016

Source: see text for discussion. Repository costs are the most recent DOE estimates. Stranded waste costs are based on the Hamal, 2011, estimate that shows stranding adds \$22 billion over the first 70 years. Repackaging costs are estimated by multiplying the cost per cask (\$1.6 million) times the number of casks (15,000). The output of the nuclear fleet is assumed to be 25% lower than estimated by DOE based on declining load factors, early retirements, and abandoned uprates not considered by DOE. This is also consistent with all remaining reactors plus five new ones – Vogtle, Summer, Watts Bar – running for a full 60 years at 90 percent capacity factor.

EXHIBIT MNC-5, Page 1 of 1

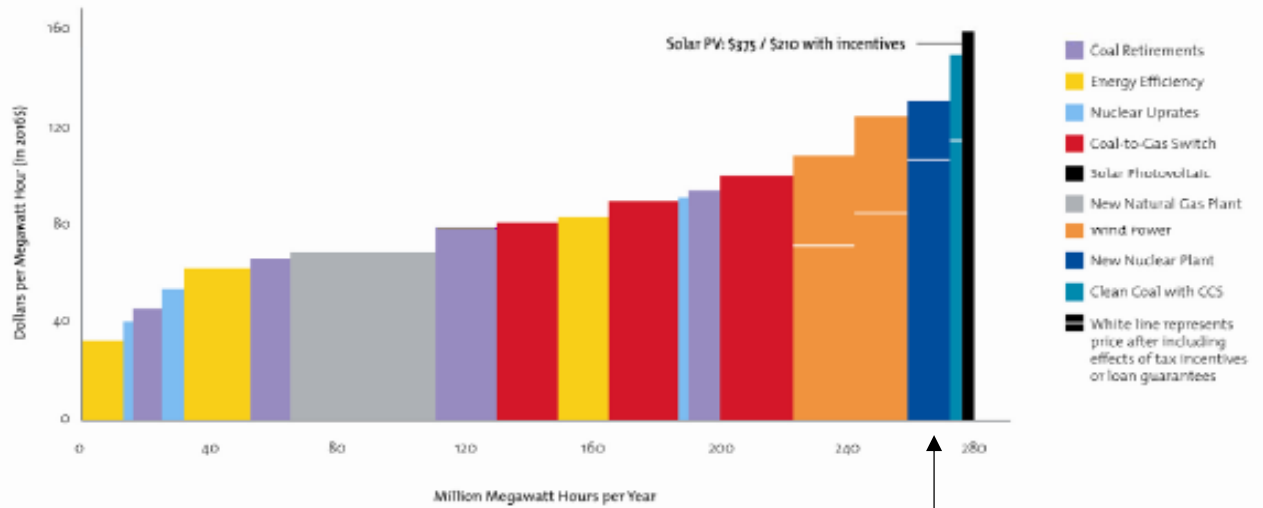
**IMPACT OF WASTE MANAGEMENT COSTS ON RESOURCE COST COMPARISONS**



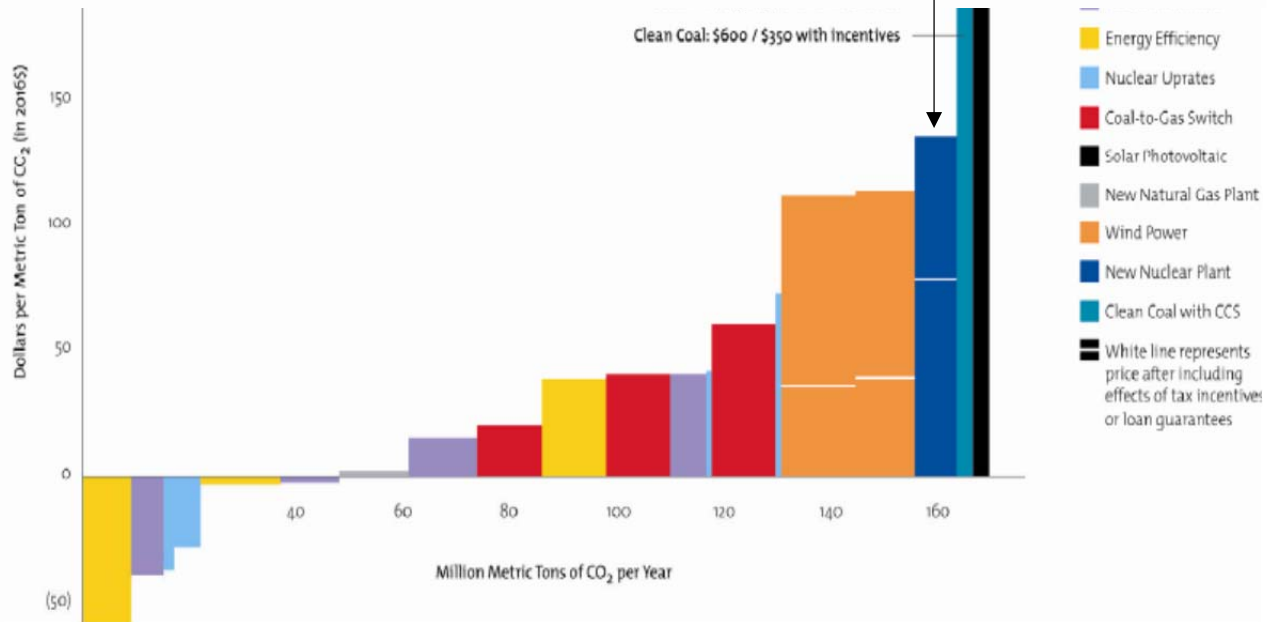
Source: Energy Information Administration, “Levelized Cost of New Generation Resources in the Annual Energy Outlook,” *Annual Energy Outlook*, 2013.

There are Cheap Ways and Costly Ways to Clean the Generation Fleet

Levelized Cost of Clean Energy Options in PJM

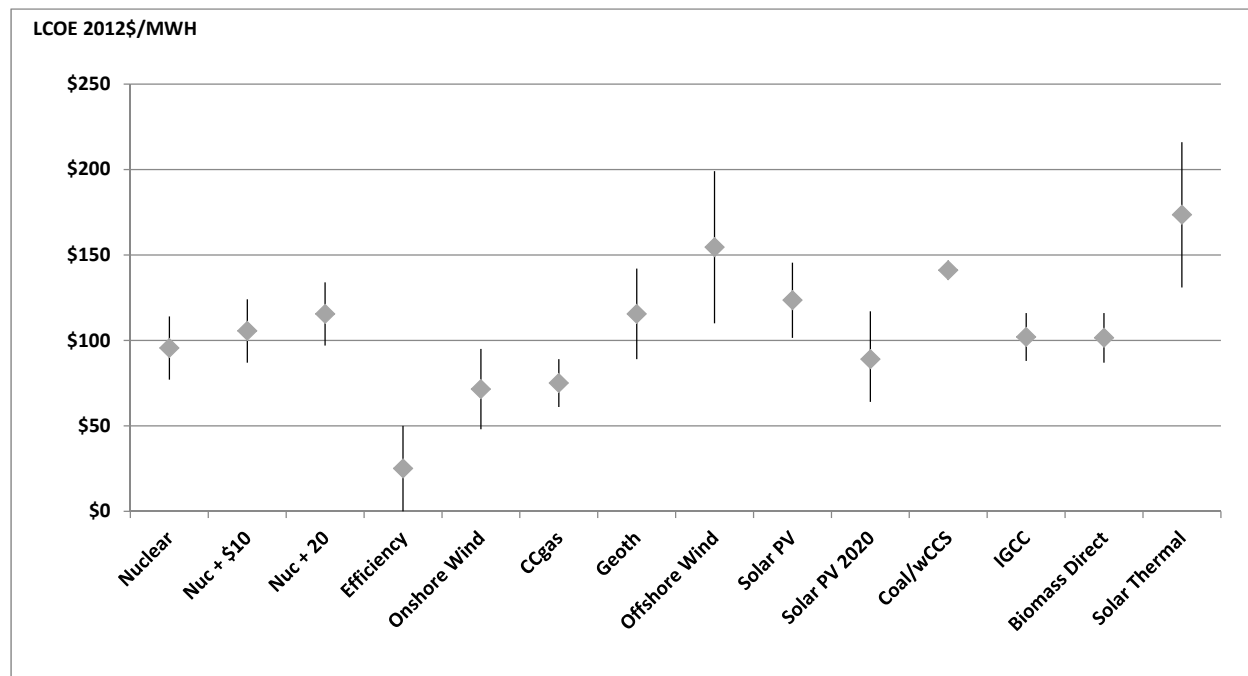


Note: Adjusts for the market value of the generation's reliability and production profile.  
 Technology cost assumptions (in 2016 \$/kwh)  
 Combined-cycle-gas turbine: \$1,500 - \$1,200  
 Wind: \$5,000 - \$3,500  
 Nuclear: \$5,000 - \$6,000  
 Clean coal with CCS: \$5,500 - \$6,500  
 Solar photovoltaic: \$5,000 - \$4,000



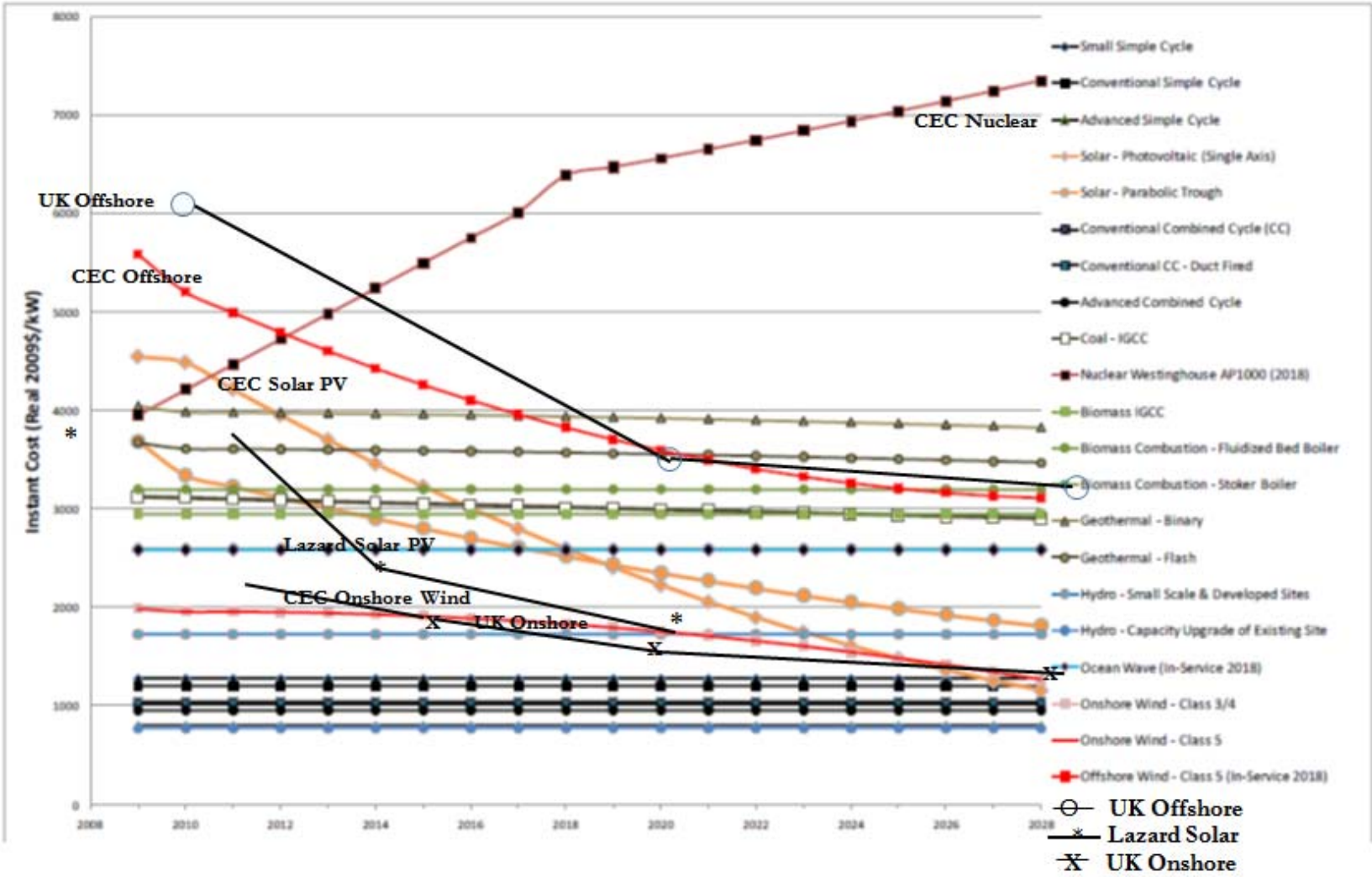
Source: John Rowe, *Energy Policy: Above All, Do No Harm*, American Enterprise Institute, March 8, 2011.

**EXHIBIT MNC-7, PAGE 1 OF 1  
LAZARD, LEVELIZED COST OF ELECTRICITY**



Sources: Lazard, Levelized Cost of Electricity 6.0 for all except solar PV 202, which is Lazard, Levelized Cost of Electricity 5.0.

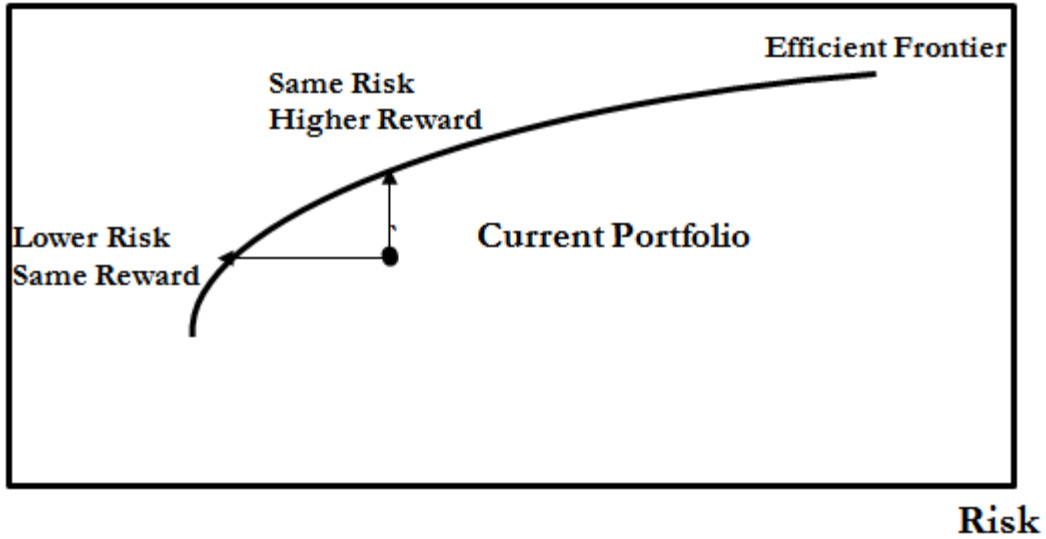
EXHIBIT MNC-8, PAGE 1 OF 1  
 OVERNIGHT COST TRENDS IN THE U.S. AND UK



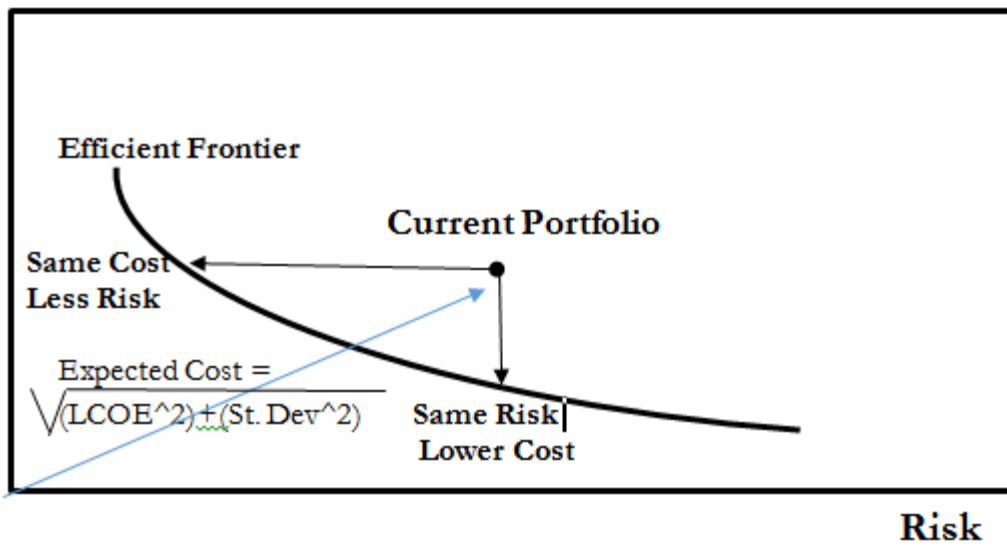
Source: California Energy Commission, *Cost of Central Station Generation*, January 2010; Mott MacDonald, *Cost of Low-carbon Generation Technologies: 2011*; Lazard, *Levelized Cost of Energy Analysis - Version 5.0*, June 2011.

EXHIBIT MNC-9, PAGE 1 OF 1  
 PORTFOLIO ANALYSIS OF RISK/COST REWARD ANALYSIS

Reward

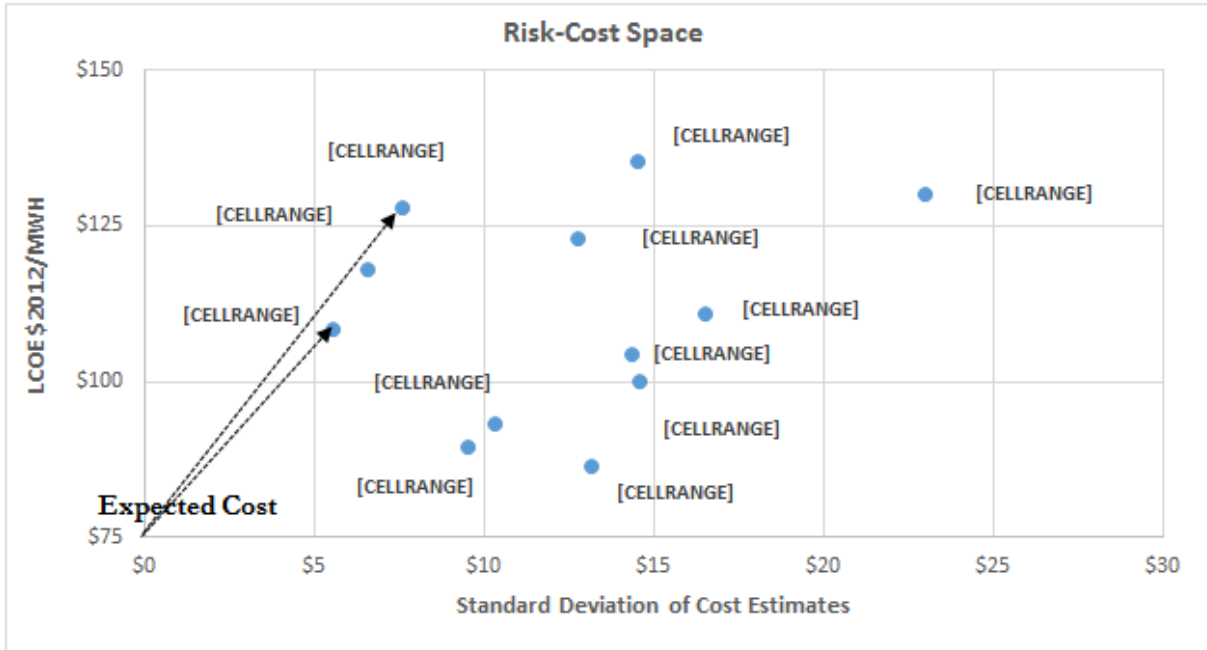


Cost

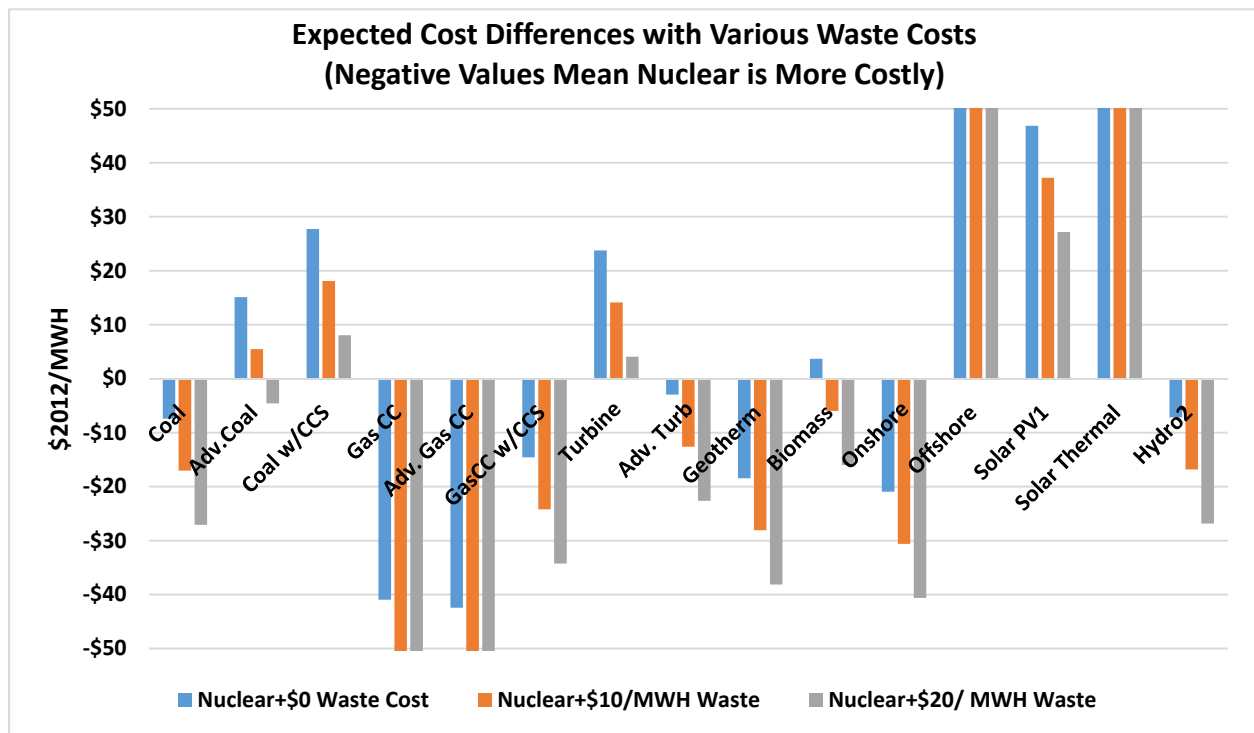


Source: Ken Costello, *Making the Most of Alternative Generation Technologies: A Perspective on Fuel Diversity*, NRRI, March 2005), p. 12, upper graph

**EXHIBIT MNC-10, Page 1 of 1**  
**RISK FRAMEWORK EXPECTED COST WHERE WASTE COSTS AFFECT**  
**PERCEIVED ATTRACTIVENESS OF RESOURCES**



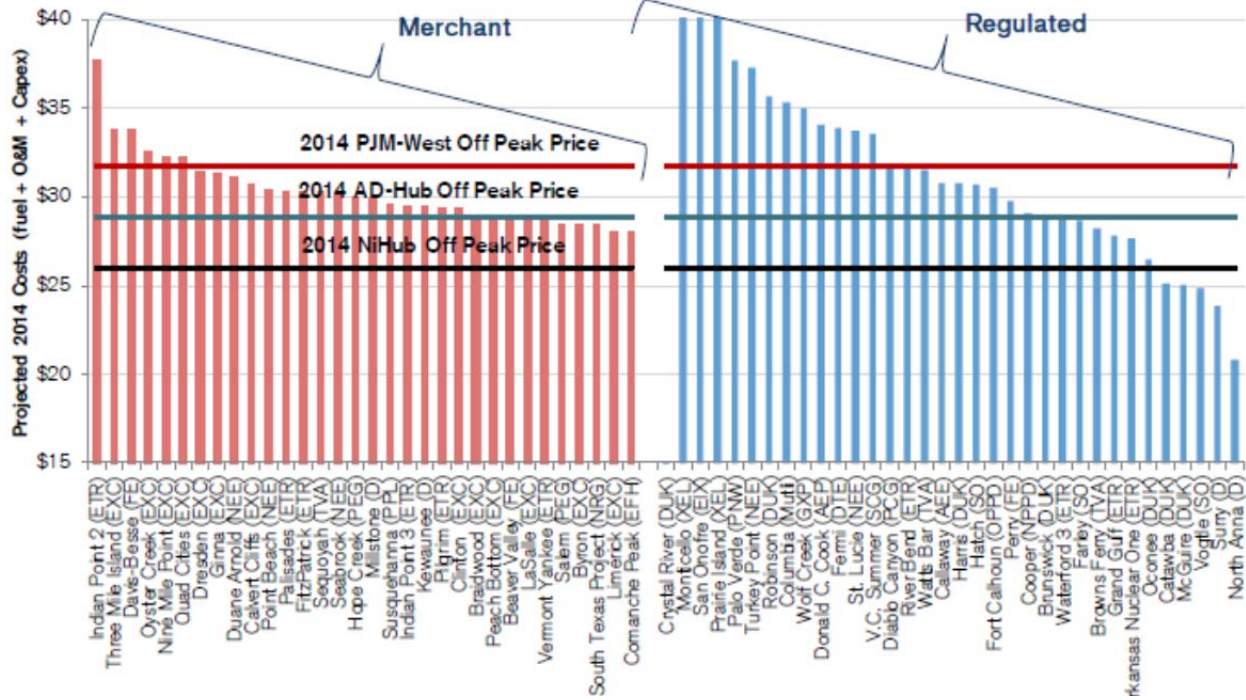
Source: Expected cost is distance from the origin. See text for discussion.



Source: Expected cost is distance from the origin. See text for discussion.

EXHIBIT MNC-11, PAGE 1 OF 1  
 CREDIT SUISSE ANALYSIS OF AGING REACTOR ECONOMICS

All-in Nuclear Plant Economics are Thin in Off-Peak

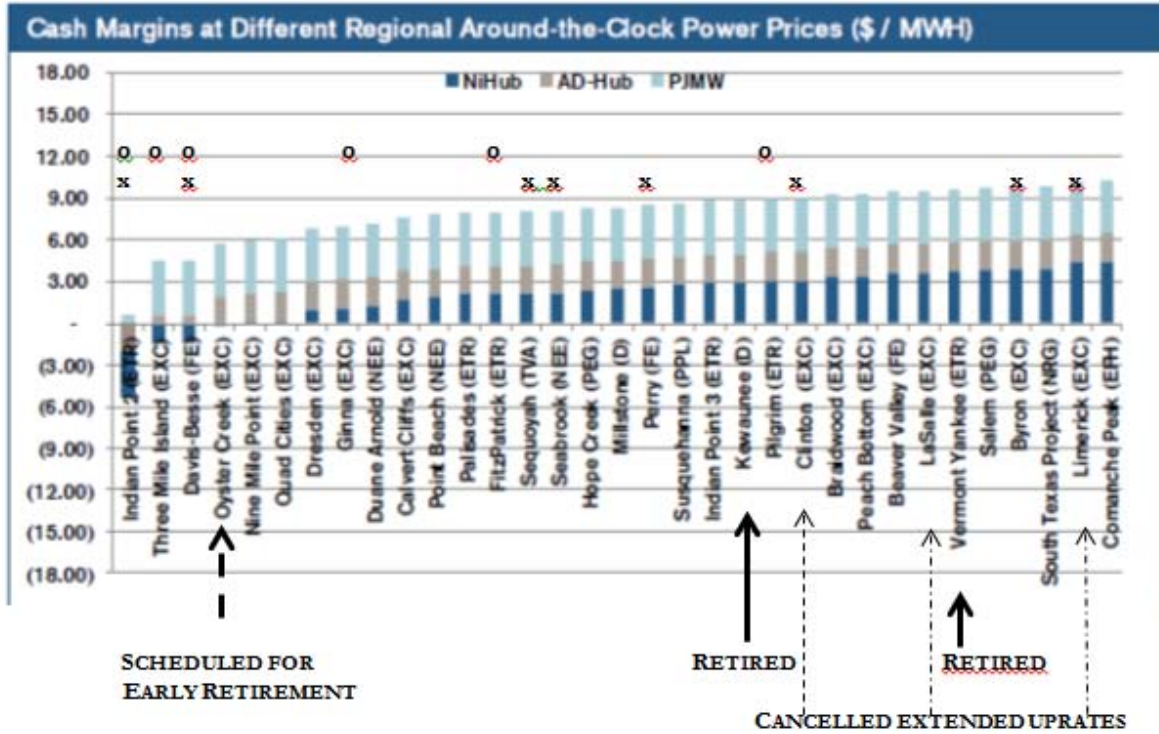


Source: Credit Suisse, *Nuclear... The Middle Age Dilemma?, Facing Declining Performance, Higher Costs, Inevitable Mortality*, February 19, 2013, p. 10.

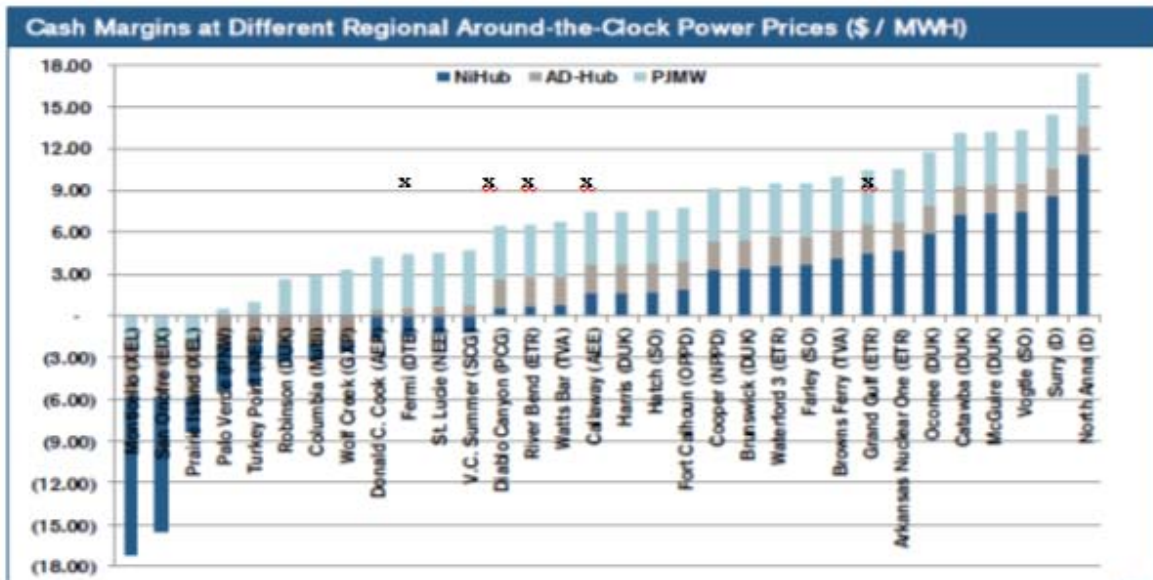


# EXHIBIT MNC-12, PAGE 1 OF 1 AGING REACTOR CASH MARGINS

## MERCHANT 'CASH MARGINS' AT DIFFERENT POWER HUBS



## REGULATED 'CASH MARGINS' AT DIFFERENT POWER HUBS



Legend: o= reactors that are being considered for early shut down  
x= license renewals pending or expected in the near future.

Source: Credit Suisse, *Nuclear... The Middle Age Dilemma?, Facing Declining Performance, Higher Costs, Inevitable Mortality*, February 19, 2013, p. 11.