ANALYSIS OF GW-SCALE OVERNIGHT CAPITAL COSTS*

Introduction
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INTRODUCTION

by Robert Rosner and Stephen Goldberg

This paper is the second of a series of papers published by the Institute discussing the economic issues pertaining to future nuclear energy deployments This paper focuses on the overnight capital costs for gigawatt-scale (GW-scale) nuclear plants over the last decade.

Nuclear power occupies a unique position in the public policy debate as the only carbon-free energy source that (1) is already contributing to world energy supplies on a large scale, (2) has potential to be expanded significantly if the challenges of safety, nonproliferation, waste management, and economic competitiveness are addressed, and (3) is technologically fully mature. In this paper, we conclude that any alternative nuclear development pathway (as defined by, for example, additional flexibility in technology approaches and deployment strategies) would need to be an evolutionary, rather than a disruptive radical shift. In the absence of significant progress on large-scale energy consumption reduction, the urgency of scale-up is such that only technologies that have either already been tested in the marketplace or at least are close to commercial demonstration should be eligible for consideration. Because of the high capital intensity of nuclear energy projects, the cost of nuclear electricity is particularly sensitive to the availability of financing at competitive rates. In the report *Nuclear Reactors: Generation to Generation*,[1] the authors described the evolution of nuclear reactor designs from Generation I technology to Generation IV designs and concluded that the determining factor in establishing the future nuclear marketplace will likely be based on "who wants to invest and where."

We believe that more detailed information on overnight cost behavior will be one of the key factors impacting investment for new nuclear plants in the U.S. Since publication of the original economic study performed at the University of Chicago ("2004 Chicago Study"), significant capital cost increases in GW-scale light water reactors (GW-LWRs) have been widely reported in other studies, industry trade press reports, and the general media. This part of the report presents the assessment of the major cost drivers contributing to the overnight cost increases by our two key collaborators, Mr. Joseph S. Hezir and Mr. Edward M. Davis. One of their key findings, which we endorse, is that the learning rates for GW-scale reactors are expected to be significantly smaller than those for small modular reactors.

The contributors used analyses by MIT, Stanford University, the Electric Power Research Institute (EPRI), and the Energy Information Administration (EIA) as benchmarks. They surveyed and assessed estimates provided in public filings by nuclear utilities, some of which were supported by the Department of Energy (DOE) Nuclear Power 2010 Program, or were developed to support applications to the Nuclear Regulatory Commission (NRC) for combined operating licenses (COLs). Finally, the contributors performed an independent expert survey that assisted in the identification and assessment of the most significant cost drivers.

The analysis presented in this paper was largely completed prior to the March 11, 2011 Tohoku earthquake that severely damaged the Fukushima Dai-ichi nuclear power plant complex. The analysis of the events at Fukushima is still unfolding, and the process of assessing the implications for new U.S. nuclear power generation has just begun. On July 12, 2011, the

[1] American Academy of Arts and Sciences, http://www.amacad.org/publications/nuclearReactors.aspx.

U.S. NRC Near-Term Task Force issued its 90-day report to the Commission.[2] As stated by Chairman Jaczko in Senate testimony, "Overall, the Task Force found that continued operation and continued licensing activities do not pose an imminent risk to public health and safety. The Task Force concluded that a sequence of events like the Fukushima Dai-ichi accident is unlikely to occur in the United States, and that some appropriate mitigation measures have been implemented, reducing the likelihood of core damage and radiological releases."[3] Nonetheless, the Task Force report and Chairman Jaczko's testimony point out a number of issues that may result in new NRC requirements. We will need to await the follow-on technical and regulatory assessments of these issues to determine the scope of possible backfit requirements for both existing and newly licensed plants. We believe that there may be additional perturbations to the overnight cost estimates for new plants as more information becomes available on the lessons learned from the events at Fukushima, as well as implementation of the NRC Task Force recommendations proceeds.[4] In addition, the NRC recently issued an information notice, as a result of the 2011 Virginia earthquake, that may have implications of increasing the safety hardening of both equipment and structures of operating reactors as well as reactors that are being designed for future deployment.[5] Designs with passive safety features will be least impacted by these likely seismic upgrades.

Many people have made generous and valuable contributions to this study. Professor Geoff Rothwell, Stanford University, provided the study team the supplemental analyses and very timely and pragmatic advice. Dr. J'Tia Taylor, Argonne National Laboratory, supported Dr. Rothwell in these analyses. Deserving special mention is Allen Sanderson of the Economics Department at the University of Chicago, who provided insightful comments and suggested improvements to the study. Constructive suggestions have been received from Dr. Pete Lyons, DOE Assistant Secretary of Nuclear Energy; Dr. Pete Miller, former DOE Assistant Secretary of Nuclear Energy; John Kelly, DOE Deputy Assistant Secretary for Nuclear Reactor Technologies; Matt Crozat, DOE Special Assistant to the Assistant Secretary for Nuclear Energy; Vic Reis, DOE Senior Advisor to the Under Secretary for Science; Craig Welling, Deputy Director, DOE Office of Advanced Reactor Concepts; Rebecca Smith-Kevern, Director, DOE Office of Light Water Reactor Deployment; and Tom Miller, Deputy Director, DOE Office of Light Water Reactor Deployment, as well as Chuck Wade and Tim Beville along with members of the staff of DOE's Office of Nuclear Energy. We also would like to acknowledge the comments and useful suggestions we received during the peer review process from the nuclear industry, the utility sector, and the financial sector. Reviewers included the following: Michael G. Anness, Small

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[2] Nuclear Regulatory Commission, http://pbadupws.nrc.gov/docs/ML1118/ML111861807.pdf.

[3] Written Statement by Gregory B. Jaczko, Chairman, United States Nuclear Regulatory Commission to the Environment and Public Works Committee and the Clean Air and Nuclear Safety Subcommittee, United States Senate, August 2, 2011.

[4] The NRC Near Term Task Force report developed a set of 12 high level recommendations. The Appendix to the report contains 34 specific actions for Commission consideration. A detailed discussion of these recommendations and the possible implications for overnight capital cost estimates would be speculative at this time.

[5] "Based on results of a safety/risk assessment, the NRC staff determined that the issue should continue to the regulatory assessment stage of the Generic Issues Program for further investigation to assess whether candidate backfits should be considered for plant improvements to reduce seismic risk and to evaluate their potential cost-justified imposition" (NRC Information Notice 2010-18, Generic Issue 199, "Implications of Updated Probabilistic Seismic Hazard Estimates in Central and Eastern United States on Existing Plants," September 2, 2011).

Modular Reactor Product Manager, Research & Technology, Westinghouse Electric Co.; Matthew H. Kelley and Clark Mykoff, Decision Analysis, Research & Technology, Westinghouse Electric Co.; George A. Davis, Westinghouse Electric Co.; Stephen A. Byrne, Executive Vice President, Generation & Transmission Chief Operating Officer, South Carolina Electric & Gas Company; and Robin Bedilion, Electric Power Research Institute. The authors especially would like to acknowledge the discerning comments from Marilyn Kray, Vice-President at Exelon, throughout the course of the study.

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1.0 OVERALL FINDINGS

Based on public service filings, this study estimated the overnight unit capital cost (defined in Section 2.1) for GW-LWRs to be $4,210 per kW. This estimate is about $2,210 per kW higher than the early stage estimates developed in the 2004 Chicago Study (see Figure 1). The study team learned that changes in commodity prices would add almost $500 per kW[6] to the earlier estimate from the Chicago Study. The study team also learned that improved definition of the scope of owner's costs could add up to $350 per kW to the earlier estimate from the Chicago Study. Current estimates, reflecting a more detailed scope, indicate that owner's costs are 15-20% of total overnight capital costs.[7] The Chicago Study assumed that an advanced boiling water reactor and evolutionary power reactor could be built in the U.S. without the need for extensive additional detailed engineering since they were being built in Asia and Europe, respectively. However, the study team found that extensive additional engineering work was performed on both designs. Outside experts consulted by the study team indicated that that these overnight costs may be conservative because of the possibility of "pancaking" of contingencies. Figure 1 identifies the categories that have caused the average overnight cost estimates to increase from about $2,000 per kW to $4,210 per kW.

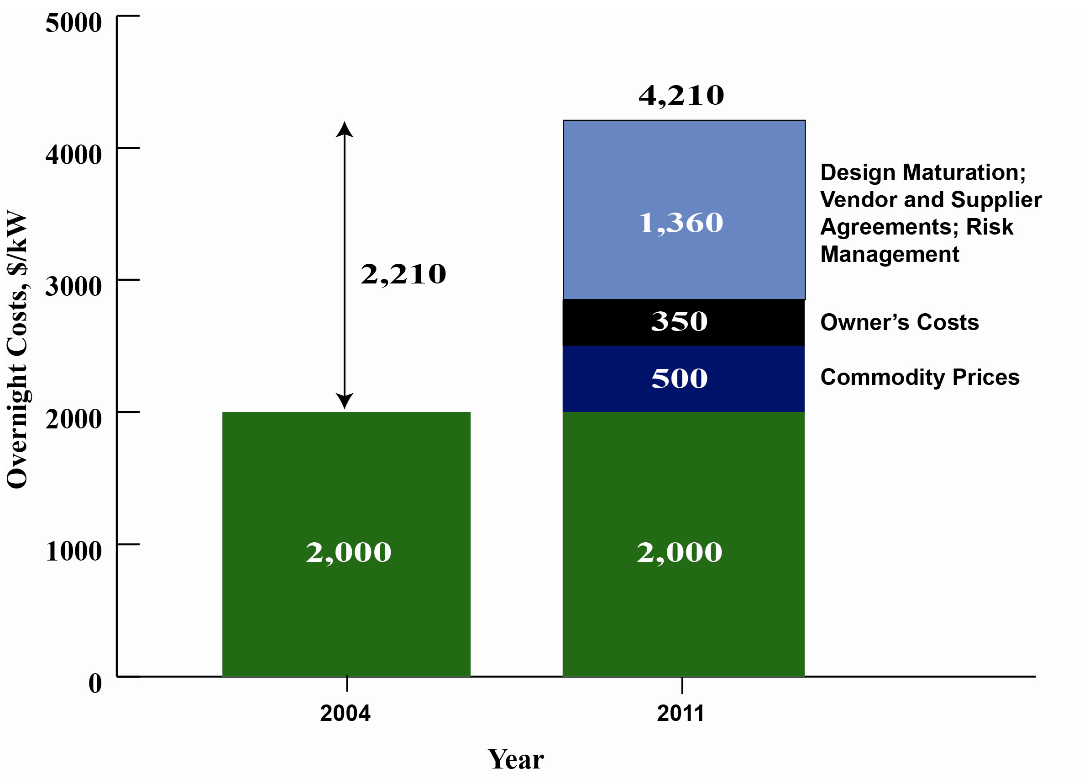

FIGURE 1 Overnight Cost Change (2011$) for GW-LWRs

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6 It should be noted that commodity prices have softened recently, and the dollar has strengthened.

7 Owner's costs are largely reflective of site-specific project development costs, including utility interconnections, transmission upgrades, spare parts, first nuclear core, and project development costs as well as land, taxes/insurance/advisory fees, and legal expenses, and they are, thus, liable to fluctuate from project to project. It is very difficult to draw any generalizations regarding "average" owner's costs.

Our estimates of overnight capital costs are for the first-of-a-kind (FOAK) deployments. Subsequent deployments should have reduced costs reflecting the benefits of learning. For purposes of this study, the study team did not estimate the overnight capital cost of a fully mature nth-of-a-kind (NOAK) plant.

2.0 BACKGROUND

The 2004 Chicago Study assessed the economics of new nuclear power, providing initial estimates of the potential range of overnight capital costs for new nuclear power plants. The 2004 Chicago Study also compared the overnight nuclear power plant cost estimates with coal and natural gas. The final report concluded that absent federal financial policies targeted at the nuclear energy industry, (e.g., loan guarantees, accelerated depreciation, investment tax credits, and production tax credits), new nuclear plants would not be able to compete with coal- and gas-fired plants. This assessment, combined with a parallel study by MIT (2003), was influential in encouraging Congress to provide financial incentives for the first movers of new commercial nuclear power plants.

Since the 2004 Chicago Study, significant capital cost increases have been widely reported in other studies, industry trade press reports, and the general media. Nuclear power plant costs have been quoted from a wide range of sources, including academia, environmental groups, state utility commissions, industry, government, and the press. Frequently, these costs are not determined on a consistent basis, which makes direct comparisons difficult at best. Current publicly quoted estimates of overnight capital costs range from $3,500 kW to $5,000 kW, and total "all-in" project costs are up to $6,000 kW and above.

This study examines the changes in overnight capital cost estimates and analyzes the underlying factors affecting the cost estimates. It does not address the issue of the economic competitiveness of new nuclear power plants relative to alternatives for power demand management or power generation technologies. These comparisons are best made on a case-by-case basis, taking into account projected power needs, cost and availability of alternative fuel sources in the region, financing costs, construction schedules, and various local and site-specific factors. The optimum cost-effective solution will not be the same in all cases.

This study was organized into two categories:

- ***Literature Review***: This part of the study consisted of researching available trade, industry, and government information sources for nuclear plant capital cost estimates. The EIA and the EPRI have published a series of cost estimates over time, which facilitated a degree of uniformity and consistency in assessing changes over time. Other sources reported cost estimates on a one-time basis. The estimates were then formatted into standard cost account classifications based on the DOE Energy Economic Data Base (EEDB) Program.[8] Once placed into a standard cost format, the various nuclear capital cost estimates were converted to a common 2010 dollar basis using data from the GDP Deflator (quarterly index, seasonally adjusted) from the Department of Commerce, Bureau of Economic Analysis.

- ***Survey of Outside Experts***: This part of the study evaluated various estimates to identify sources of cost increases over time and any other significant factors influencing the

[8] The DOE cost breakdown structure is based on the Code of Accounts developed in EMWG 2007.

estimates. Industry subject matter experts were then asked to comment on the results of estimate comparisons to provide further insights into the significant contributors to nuclear capital cost increases. A Delphi survey technique was used to identify the major factors affecting project costs.

2.1 DEFINITIONS OF CAPITAL COST CATEGORIES

One of the major problems with comparisons of cost estimates drawn from public reports is that the estimates are not generally reported on a consistent basis. Press reports can refer to engineering, procurement, and construction (EPC) costs, plant overnight costs, or all-in capital costs. Even when the estimates are properly labeled, the definition of what is included in each labeled category can differ. Moreover, capital costs estimates can be presented in constant dollars or in current dollars to account for escalation and assumed future commercial plant operation dates. Appendix A provides a comparison between overnight capital costs and all-in capital costs.

All estimates in this report are presented as overnight capital costs. The estimate of overnight capital costs is not fully inclusive, since it excludes by definition escalation and financing costs. However, it does represent a reasonable and consistent metric for comparison purposes. The final all-in capital cost of a nuclear power plant would include escalation costs, which are dependent upon project construction schedules and expectations of future inflation, and financing costs, which are dependent upon financing structures. The differences between using overnight capital cost estimates and all-in capital cost estimates are illustrated by an example in Appendix A.

Figure 2 illustrates the major components of a pressurized water reactor (PWR) used for estimating overnight capital costs, with the three major capital cost groupings for the nuclear steam supply system (NSSS), the turbine/generator, and the balance of plant (BOP).

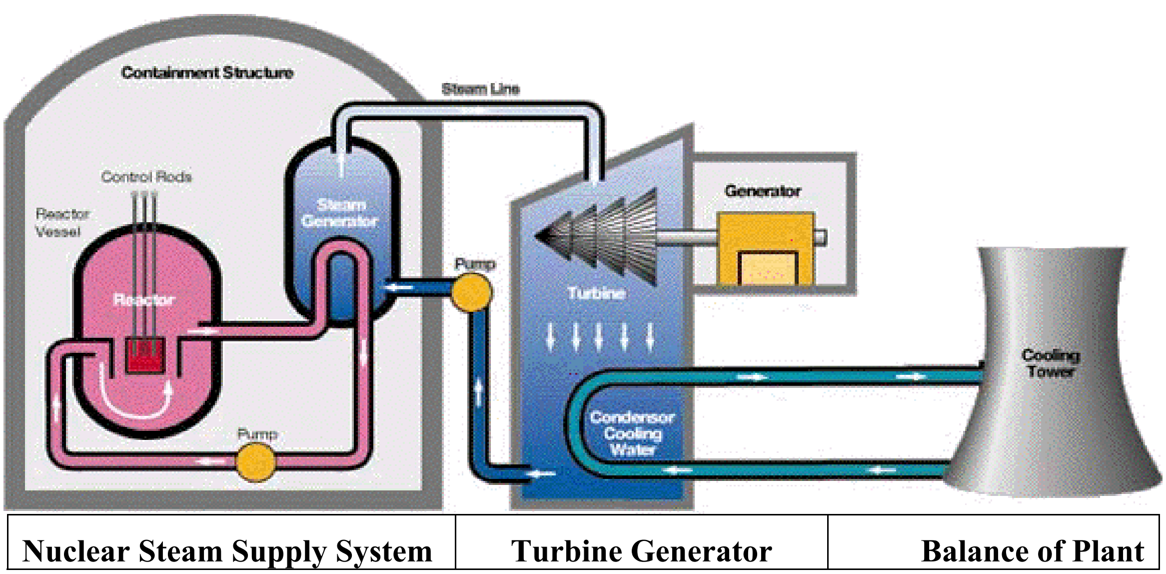


FIGURE 2 Schematic Diagram of a Pressurized Water Reactor

2.2 EARLY-STAGE OVERNIGHT CAPITAL COST ESTIMATES

The 2004 Chicago Study presented a broad range of estimates of overnight capital costs. The report considered three reactor designs in different stages of development (mature design, new design, and advanced new design) and developed a lower-range, mid-point, and upper-range estimate for each design. The cost estimate for the mature reactor design was based on the advanced boiling water reactor (ABWR) design and excluded any amortization of first-of-a-kind engineering (FOAKE) costs, because the reactor design was considered mature. The cost estimate for the new reactor design was based on an AP1000 reactor, and that for the advanced reactor design was based on the then Framatome Siede Wasser Reacktor (SWR). The cost estimates for the latter two reactors assumed full recovery of FOAKE costs in the estimate.

Updating the 2004 Chicago Study cost estimate to 2010 dollars yielded a midpoint range of overnight cost estimates of $1,413-2,120 per kW. The upper-range overnight cost estimates are $1,554-2,331 per kW in 2010$, with a mid-point of $1,943 per kW. The 2004 Chicago Study assumed that the contingency for the "mature" ABWR design was 12% of total direct and indirect costs, and the owner's cost was 5% of total direct and indirect costs. No detail was provided for the "new" and "advanced new" designs. Based on the limited level of knowledge of these topics at this time, these costs were probably understated significantly. For example, in current estimates, owner's costs are about 17% of total direct and indirect costs. Adjusting the 2004 Chicago Study for current information on the scope of owner's costs could add on the order of $500 per kW to the 2004 estimates.[9] This adjustment brings the 2004 Chicago Study upper range estimate to $2,100-2,800 per kW.

The 2004 Chicago Study relied heavily on a study of the ABWR by the Tennessee Valley Authority (TVA), funded under the Nuclear Power (NP) 2010 program. The TVA study reported a total cost estimate (direct and indirect costs) of $1,842 per kW, adjusted to 2010 dollars. The TVA study did not report contingency or owner's costs, and so it is not directly comparable with the 2004 Chicago Study costs. Based on current estimates for other projects, contingency and owner's costs could add an additional $1,000 per kW. This would place the overnight cost estimate at about $2,800 per kW. In addition, based on personal communications with several of the participants in the TVA study, the cost estimate was believed to be low because the costs were taken directly from Japanese experience in building the ABWR, and not adjusted fully for an "Americanized" project.

Additional detailed information from the 2004 Chicago Study and the TVA cost estimates is provided in Appendix B.

[9] This does not imply that the 2004 Chicago Study costs were underestimated, but rather it highlights the relatively early stage nature of the 2004 Chicago Study estimate, and the degree of maturity that has since occurred in the identification and estimation of plant costs.

2.3 CURRENT OVERNIGHT CAPITAL COST ESTIMATES REPORTED IN REGULATORY FILINGS

We reviewed current cost estimates reported in filings made with state utility rate commissions by investor-owned utilities subject to rate regulation. The study team reviewed the regulatory filings for four AP1000 projects: Vogtle, Summer, Levy County, and Turkey Point. Key project milestones and highlights for each of the four projects are summarized below.

Vogtle Units 3 and 4: Georgia Power, an operating unit of the Southern Company, is 45.7% owner and the lead developer of Vogtle Units 3 and 4. The cost estimate for the Georgia Power share of the Vogtle project was certified at $6.113 billion by the Georgia Public Service Commission (PSC) on March 17, 2009 (Georgia Power 2011, Table 1.1). Following certification, Georgia Power commenced site construction activities in April 2009.

The breakdown of the certified cost estimate is shown in Table 1.

The construction and capital cost component of the certified cost estimate for Vogtle includes cost escalation, which is not separately identified in the filings to the Georgia Public Service Commission (PSC). Also, the filings do not address the issue of whether the estimate includes an allowance for contingencies, and if so, the magnitude of the allowance.

TABLE 1 Certified Total Cost for Georgia Power Share of Vogtle Units 3 and 4

($ in millions, including escalation)	
Construction & Capital	$4,418
Financing	$1,695
Total (with escalation)	$6,113

The certified total cost was set as a cost ceiling rather than as a current best estimate. Semi-annual reports filed by Georgia Power with the PSC show that the estimated cost has been less than the certified total cost and has been relatively steady (Georgia Power 2011, Table 1.1a). The trend is shown in Table 2.

TABLE 2 Trend in Estimated Costs for Georgia Power Share of Vogtle 3 and 4

($ in millions, with escalation)

	Jun. 2009	Jun. 2010	Dec. 2009	Dec. 2010
Construction and Capital Cost	$4,418	$4,414	$4,395	$4,408
Financing Cost	$1,636	$1,678	$1,637	$1,675
Total Project Cost	$6,054	$6,092	$6,032	$6,083

The December 2010 estimate shows a construction cost of $4.4 billion, plus financing costs of $1.7 billion, for a total of $6.1 billion. This estimate has been remarkably stable over the last reporting period beginning in June 2009. The "construction and capital cost" category also includes the cost of the EPC contract, escalation for the EPC, owner's costs, and transmission interconnection costs.

To determine the total cost for the project, the Georgia Power costs was divided by its share of the ownership (45.7%) to yield a cost estimate for the total project, shown in Table 3. The estimated total cost for the project assumes that the owners of the 54.3% share (Oglethorpe Power Corporation, the Municipal Electric Authority of Georgia, and the City of Dalton, Georgia) have the same proportion of indirect and owner's costs as Georgia Power.

TABLE 3 Total Project Costs for Vogtle 3 and 4 (Based on December 2010 Estimates)

($ in millions, with escalation)

	Total Cost ($M)	Unit Cost ($/kW)
Construction and Capital Cost	$9,646	$4,318
Escalation	Included above	
Financing	$3,665	$1,641
Total Project Cost	$13,311	$5,958

To generate an overnight cost of construction, escalation must be removed to produce a constant dollar estimate. Though the report does not specify the amounts, the inclusion of escalation in the "construction and capital cost" category[10] indicates that these are year-spent dollars that include escalation. The Georgia Power filings do not indicate the assumed escalation rate. A conservative assumption is that 10% of the construction and capital cost would reflect the escalation rates and allow the overnight construction costs to be reported in terms of 2010 dollars. Note that the financing and total project costs are unchanged by this adjustment. The estimated overnight cost of the Vogtle plant is $3,886/kW, shown in Table 4.

TABLE 4 Revised Total Project Costs for Vogtle 3 and 4 (Based on December 2010 Estimates)

($ in millions)

	Total Cost ($M)	Unit Cost ($/kW)
Overnight Cost	$8,681	$3,886
Escalation (est.)	*$965*	*$432*
Financing	$3,665	$1,641
Total Project Cost	$13,311	$5,958

[10] The Georgia Power filing (Georgia Power 2011, Table 2-3) includes escalation in the "Construction and Capital Cost" item. The study team also assumes that the subcategories contributing to the construction and capital cost item include escalation . There was not a means to verify this because the following cost categories were redacted – fixed semiannual escalation, other fixed escalation, and EPC base.

The February 2011 *Semi-annual Construction Monitoring Report* (Georgia Power 2011) indicated that:

> While the Project continues to track under the $6.113 billion Certified Amount, as with any project of this magnitude, it is now apparent that the cost of several individual items will be greater than budgeted while the cost of others will be less than budgeted; however, the overall net change in the projected cost of the Project is favorable.

The report also noted that the Georgia PSC approved Amendment No. 3 to the EPC contract. This amendment replaced "...certain index-based adjustments to the purchase price with fixed escalation amounts," thus increasing cost certainty. The report also noted a shift in certain costs from the category of owner's costs to EPC costs. This also indicates the fact that definition and allocation of costs among categories can change with the maturation of the project. Although the allocation of some costs has changed, the report states that "…the Company is not requesting any changes to the overall Project schedule or budget for this Reporting Period." However, the current forecasted schedule for commercial operation date (COD) of Unit 3 is June 7, 2016, two months later than the approved schedule of April 1, 2016, in the PSC Certification Order. The report notes that the Westinghouse and Stone & Webster consortium are "…developing a plan to return the forecast to meet the original COD."

V.C. Summer Units 2 and 3: SCANA Corporation, the parent corporation of South Carolina Electric and Gas, owns 55% of the Summer project and is the lead developer. The cost estimate for the Summer project was initially certified by the South Carolina PSC in Order No. 2009-104 (A) on March 2, 2009 (SCE&G 2010). The capital cost and schedule milestones for the project are shown in Table 5.

TABLE 5 Approved Total Cost for SCANA Share of Summer Units 2 and 3

($ millions)

Capital Cost	$4,096
Contingency	$438
Total Overnight cost (2007$)	$4,534

The inclusion of a contingency in the approved estimate was challenged in court. On August 9, 2010, the South Carolina Supreme Court ruled that capital cost contingencies were not permitted as a part of approved capital cost forecasts under the South Carolina Base Load Review Act. The contingency has been dropped from the official PSC tracking process. However, for purposes of this study, contingency (but not escalation or financing costs) was included in the reported estimate to maintain consistency with the other estimates.

SCANA initiated site clearing activities for the project on January 26, 2009. SCANA has reported no changes to the approved cost estimate in its quarterly reports to the Commission's Office of Regulatory Staff. Further, in the report for the quarter ending September 30, 2010, SCANA reported that engineering design of the Summer facility was 83.1% compete, and that an August 10, 2010, amendment to the EPC contract resulted in approximately two-thirds of total EPC costs shifted to either "fixed cost" or "firm cost with escalation" categories.

The most recent quarterly report provided by SCANA to the South Carolina PSC provides a breakdown for its expected expenses in each year of the project (SCE&G 2010).[11] The first column of that chart is the total for the SCANA construction costs and is reproduced in the first column of data in Table 6. The total project costs can be estimated by dividing the SCANA costs by it ownership stake of 55%. This assumes that the indirect and owner's costs for the 44% owner (currently Santee Cooper) are in the same proportion to EPC costs as the SCANA estimates.[12] These two adjustments produce a base project cost (2007 dollars) slightly above the April estimate and a total project cost slightly below that in April owing to a reduced escalation rate used in the forecast.

TABLE 6 Summer 2 and 3 Cost Estimates – SCANA Share and Total Project Cost

($ millions, with escalation)

	SCANA Share of Costs ($M)	Total Project Cost ($M)
Base Project Cost (2007 $)	$4,270	$7,764
Project Escalation	$1,261	$2,293
AFUDC (Capitalized Interest)	$256	$465
Total	$5,787	$10,522

The "base project cost" appears to be the equivalent of an overnight cost estimate, as it does not include financing or escalation.[13] The remaining adjustment to be made is to convert the estimate into 2010 dollars for consistency. Multiplying the total project overnight cost calculated in Table 2-4 by this factor yields a total overnight cost of over $8.6 billion in 2010 dollars. Dividing that total by the installed capacity of the plant returns an overnight cost of $3,617 per kW in 2010 dollars, derived as shown in Table 7.

[11] This update should be available on the South Carolina PSC website in the near future.

[12] Informal communications from SCANA indicate that the owner's costs for the Santee Cooper ownership share of the project may, in fact, be a higher proportion than SCANA's portion. If so, the overnight capital cost estimate for the project total may be slightly higher than estimated in Table 6.

[13] In September, 2011 , SCANA's Chief Operating Officer, Stephen Byrne, told the S.C. Public Service Commission that it was reducing its so-called "all-in" cost estimate by $1 billion. The reduction was attributed to lower escalation rates than initially assumed. The announcement did not provide any information as to a lowering of the overnight capital cost estimate (which excludes escalation).

TABLE 7 Estimated Overnight Capital Costs for Summer 2 and 3

($ in millions)

	Total Cost ($M)	Unit Cost ($/kW)
Overnight Cost (2007 $)	$7,764	$3,475
Electric Power Industry Deflator: 2007 - 2010	1.041	1.041
Overnight Cost (2010 $)	$8,082	$3,617

Levy County Units 1 and 2: On March 11, 2008, Progress Energy Florida filed with the Florida PSC a "need determination" study and a plan to construct two AP1000 units at a new site in Levy County, Florida (Progress Energy Florida 2008a). The PSC approved the project in July 2008 (Reuters 2008) and allowed Progress Energy to recover costs in rates beginning in 2009 (World Nuclear News 2008). As of the end of 2010, Progress incurred about $850 million in licensing and design costs (Progress Energy Florida 2008b, p. 34).

Florida PSC Order No. PSC-09-07683-FOF-EI requires an annual feasibility update of life-cycle net present worth (also referred to as the cumulative present value of revenue requirements) of the Levy Nuclear Project. The April 2010 filing estimated the total all-in capital cost of constructing Levy Units 1 and 2 at about $22 billion, assuming a COD for Unit 1 in 2021 rather than the initial plan for 2016 (Progress Energy Florida 2008b, p. 4). This result compares with the initial all-in capital cost estimate of nearly $17 billion provided in the 2008 need determination (Progress Energy Florida 2008b, p. 4). Unlike other commercial nuclear power plant projects, the Levy Nuclear Project estimate included a large investment in new transmission—about $3 billion in the initial estimate, comprising about 18% of the total.

The detailed filing was presented as an annual spending profile (Progress Energy Florida 2010). Costs are broken down to include categories for "site selection," "preconstruction," and "construction" with subcategories of "additions," "carrying costs on additions," and "carrying cost on deferred tax asset." Additional categories are "allocated or assigned O&M amounts" and "other adjustments," which do not have subcategories. Table 8 reproduces the project total for this breakdown, indicating a total all-in capital cost of $22 billion.

This total project estimate can be adjusted to an overnight capital cost estimate by eliminating escalation and financing costs from the estimate.

- The as-spent cost estimate was based on the assumption of a 2% inflation rate and an additional 2% escalation rate (p. 140 of the filing). Using this information and the yearly spending projections, an estimate of annual expenses, in 2010 dollars, can be derived. This estimate is $16,226 million, a reduction of $5,805 million from the total as-spent estimate.

- The financing cost component can be estimated by adding the various carrying costs listed in Table 8. Adjusting the financing costs to remove escalation, following the same process as for the total costs shown, yields an estimate of total financing charges of

$4,881 million in 2010 dollars. Removing financing costs, along with escalation, yields an estimated overnight capital cost of $11,345 million.

TABLE 8 Estimated Total Project Costs for Levy Units 1 and 2

(Total as-spent $ in millions, with escalation and financing)

	($M)
Site Selection Category	
Additions	$32
Carrying Costs on Additions	$4
Carrying Costs on Deferred Tax Asset	$1
Total Site Selection Amount	**$37**
Preconstruction Category	
Additions	$1,282
Carrying Costs on Additions	$127
Carrying Costs on Deferred Tax Asset	$113
Total Preconstruction Amount	**$1,522**
Construction Category	
Additions	$13,809
Carrying Costs on Additions	$6,214
Carrying Costs on Deferred Tax Asset	$382
Total Construction Amount	**$20,405**
Allocated or Assigned O&M Amounts	**$68**
Other Adjustments	**$0**
Total	**$22,031**

As mentioned earlier, the Levy County project has a large transmission component. In order to allow for an apples-to-apples comparison of the overnight capital costs for the Levy nuclear generation plant with other nuclear generation projects, it may not be appropriate to include transmission costs that would apply to any technology that would be producing an equivalent amount of power. Early reports indicated that the cost of transmission grid expansion would be about $3 billion. The assumptions provided on page 132 of the filing indicate that the financial projections were developed by using an assumed total cost of $1,980 million. The study team's analysis uses the latter estimate of transmission expenses. This estimate also includes escalation and financing costs, and was adjusted to yield an overnight capital cost for transmission by allocating total transmission costs among the overnight, escalation, and financing categories on a proportional basis. Excluding transmission, the overnight capital cost estimate (for generation only) is $4,668/kW.

Table 9 presents the total and unit costs for the Levy project. The table summarizes the adjustments made to decompose the total project cost into overnight capital costs, escalation, and financing, with and without transmission costs.

TABLE 9 Estimated Total and Overnight Capital Costs for Levy 1 and 2

(2010$ in millions)

	Including Transmission Costs		**Excluding Transmission Costs**	
	Total Cost ($M)	**Unit Cost ($/kW)**	**Total Cost ($M)**	**Unit Cost ($/kW)**
Overnight Cost*	**$11,345**	**$5,129**	**$10,325**	**$4,668**
Escalation	$5,805	$2,624	$5,283	$2,388
Financing*	$4,881	$2,207	$4,442	$2,008
Total	$22,031	$9,960	$20,050	$9,064

Turkey Point Units 6 and 7: Florida Power and Light (FPL) is the owner and developer of proposed new nuclear units Turkey Point 6 and 7. On April 11, 2008, the Florida PSC made an affirmative determination of the need for Turkey Point 6 and 7. Since that time, FPL has pursued the necessary licenses and permits but has not commenced any construction activity. Recovery of pre-construction costs is permitted under the Capital Cost Recovery Rule authorized by Florida statute. Pursuant to a PSC request, FPL updated its non-binding capital cost estimates, which were submitted to the NRC on May 3, 2010 (FPL 2010).[14] The updated cost estimate showed an overnight capital cost of $4,991/kW in 2010 dollars, including transmission and excluding escalation and financing costs.

Table 10 reproduces the relevant information. The overnight cost for the plant without transmission investments is $4,669/kW. Elsewhere FPL has reported a total project cost of $12 to $18 billion. The accompanying documents do not appear to indicate how escalation and financing are combined to move from overnight to total costs.

[14] Note the estimate range was modified to be consistent with the report's inflation assumptions.

TABLE 10 Estimated Unit Overnight Capital Cost for Turkey Point 6 and 7

(2010$ in millions)

Category	Unit Cost ($/kW)
Standard Plant	$2,118
Balance of Plant	$342
Site Development	$225
Construction Labor	$951
Owner's Cost	$381
Contingency	$651
Overnight Cost without Transmission	**$4,669**
Transmission	$322
Overnight Cost with Transmission	$4,991

The filing (FPL 2010) stated that:

> An overnight cost is developed using the most current information available. An overnight cost provides an estimate of the total project costs assuming all costs occur at one point in time ("overnight") and time-related costs (escalation, interest during construction) are not included. Further, recognizing many things influence the overnight cost, a sensitivity analysis is conducted on each component of the overnight cost, resulting in a cost estimate range. The overnight cost provides an indication of the cost per kilowatt ($/kW) for the project in a given year reference. The 2008 cost estimate range was $3,108/kW to $4,540/kW for the 1,370 MW sized unit in 2007 dollars. Updating the cost estimate range to 2010 dollars, adjusting for the 1,100 MW sized units and using a net 2.5% escalation rate, results in a cost estimate range of $3,398/kW to $4,940/kW.

In a December 21, 2010 filing with the NRC, FPL provided an updated cost estimate range, from a low end of $3,347 per kW to $4,889 per kW (both in 2010$). The estimate is for overnight capital costs only, excluding escalation and financing, which were reported separately. This information was initially posted on the NRC web site, but subsequently withdrawn. However, it conforms with the estimate contained in the public report to the Florida PSC.

Summary Results: The results of the analysis of regulatory filings for the four AP1000 projects are shown in Table 11. The average of the four plant estimates is $4,210 per kW (in 2010 dollars).

TABLE 11 Overnight Capital Cost Estimates for AP1000 Units

Project	In-service Year	Overnight Cost ($/kW)
Vogtle 3 & 4	2016 – 2017	$3,886
Summer 2 & 3	2016 – 2019	$3,617
Levy 1 & 2	2021 – 2022	$4,668
Turkey Point 6 & 7	2022 – 2023	$4,669
Average AP1000	**2016 – 2023**	**$4,210**

The estimates in Table 11 show close correspondence between the first two projects in Georgia and South Carolina, which are scheduled to begin operation in 2016, and between the two Florida projects, which are ten years from startup, but there is a sizable gap between them.

The differences created by the different implementation timelines should have been eliminated in the derivation of the overnight costs exclusive of escalation and financing. Assuming that the proper escalation and financing factors were used to adjust the estimates to a common basis of overnight capital costs in 2010 dollars, other factors are at play in accounting for the differences in costs.

The regulatory filings contain insufficient detail to conduct further analysis of the differences in cost assumptions among the four AP1000 projects. There could be differences in site preparation costs (e.g., more site preparation needed for the Florida sites); differences in owner's costs; and differences in contingencies (e.g., the Florida projects may have higher embedded contingencies because of later construction schedules). More analysis is required to understand these effects.

2.4 COMPARISON WITH GENERIC OVERNIGHT CAPITAL COST ESTIMATES

Both the DOE EIA and the EPRI have reported generic overnight cost estimates for new nuclear power plants. The EIA estimates are for a twin AP1000 unit plant for a generic site. The EPRI estimate is generic with respect to both reactor technology and site. Both organizations also have reported estimates over time, enabling an analysis of trends in cost estimates.

The EIA estimates are performed to support the EIA Annual Energy Outlook (AEO) modeling activity. The EIA contracts for the completion of cost estimates for the full suite of new electricity-generating technologies, using common assumptions and methodologies, for purposes of comparing the cost of electricity from new generating technologies and the potential market shares of various fuels and technologies. Because this effort is designed to support the EIA National Energy Modeling System (NEMS), the assumptions and methodologies are set according to model requirements, including the need for internal consistency among generating options. As such, the EIA estimates of overnight capital costs for new nuclear plants are not necessarily consistent with reported regulatory filings, but provide a point of comparison.
The cost estimates in EPRI's Technical Assessment Guide (TAG) are performed as part of its Program on Technology Innovation. Similar to EIA, the driving factor in the EPRI cost estimates

is the need for uniformity and consistency across various new electricity generation technologies. As noted in the 2011 TAG Report (EPRI 2011, p.1-3), TAG cost estimates "…are conceptual estimates that differ from site-specific project estimates for a number of reasons…" including level of detail, owner's costs, site-specific requirements, transmission system improvements and financing costs. Nonetheless, similar to the EIA series of cost estimates, the process of annual updates to the TAG estimates provides a useful indicator of changes over time.

Recognizing the limitations of comparing project specific cost estimates with generic estimates developed by EIA and EPRI for other purposes, the study team developed a side-by-side comparison of the three sources of cost estimates. Table 12 provides a detailed comparison of the weighted average generic overnight cost estimates from the regulatory filings with the most recent EPRI and EIA publicly available cost estimates. Appendix C provides additional details regarding the EPRI and EIA estimates.

TABLE 12 Comparison of Overnight Capital Cost Estimates

(2010$ per kW)

	AP1000 Regulatory Filings	**EPRI (2009 TAG)**	**EIA (2011 AEO)**
Total Direct Costs		2,513	2,577
Total Indirect Costs		416	1,218
Contingency		569	581
Total Direct & Indirect Costs (EPC)		3,498	4,376
Owner's cost		502	963
Total Overnight Unit Capital Cost ($/kW)	4,210	4,000	5,339

Notes:
1. Cost breakdowns are based on the Code of Accounts developed in EMWG 2007.
2. The EPRI generic capital cost estimate is taken from the TAG study (EPRI 2009).
3. The EIA capital cost estimate is based on an advanced nuclear facility consisting of two 1,117 MW Westinghouse AP1000 units built in a Brownfield facility (EIA 2010).

Additional detailed backup information on the derivation of the EIA and EPRI cost estimates can be found in Appendix C. Note that the table includes the EPRI 2009 TAG estimate, the last year for which detailed data were available. The EPRI 2010 TAG report provides only a total cost estimate, which is defined on a different basis; direct comparison with prior years is not readily possible.[15]

Table 12 shows good agreement between the estimates for direct costs, but wide divergence on estimates of indirect costs, contingencies, and owner's costs. The following observations were made:

[15] The trend analysis, presented in Section 3.1 of this report, provides a further description of the change in the EPRI 2010 TAG cost definition.

- The table shows that the ***total overnight capital cost*** from the regulatory filings is between the EPRI and EIA estimate, with the EPRI estimate being about 5% lower than the average of the AP1000 regulatory filings and the EIA estimate being 27% higher than the AP1000 estimates from regulatory filings.

- There appears to be a good convergence around the estimates of ***direct costs***, with a 2.5% difference between the EPRI and the EIA estimates.

- The estimates of ***indirect costs*** vary by a factor of three due to the EIA estimate being significantly higher than the EPRI estimate. The relationship of indirect to direct costs in the EIA estimate is significantly at variance with other estimates and appears to be overstated. Follow-up communications between the study team and the EIA contractor determined that some portion of the EIA indirect costs is attributable to costs such as cranes, scaffolding, etc., which could be reclassified as direct costs.

- There is a range of almost two in the estimates of ***owner's costs***. Because these costs are sensitive to site-specific factors, such as site development and transmission costs, there is no "right" or "wrong" answer here.

Our estimates of overnight capital costs for U.S. GW-LWRs are comparable to the average cost surveyed in other Organization for Economic Co-operation and Development (OECD) countries (except Korea). Data from an international survey (IEA/NEA 2010) show an average overnight capital cost of $4,177 per kW for 12 projects in 10 OECD countries other than the U.S. The OECD average is significantly impacted by very low costs reported for two nuclear projects in South Korea, each of which is less than $2,000 per kW. Removing these two projects from the OECD group yields an average overnight capital cost of $4,669 per kW. Cost estimates for projects in non-OECD countries average $2,521 per kW, or about 54% of the OECD average (excluding Korea). Additional details on the overnight capital costs for new commercial nuclear deployments in other countries, based on the IEA study, are provided in Appendix D.

3.0 ANALYSIS OF MAJOR FACTORS AFFECTING OVERNIGHT CAPITAL COST ESTIMATES

3.1 TRENDS IN OVERNIGHT CAPITAL COST ESTIMATES

Section 2.0 describes the reported cost estimates from various sources, including the annual EIA estimates, EPRI estimates, estimates from independent studies, and estimates from the AP1000 regulatory filings. These cost estimates are consolidated into a single graph (Figure 3), showing how the cost estimates have varied over time. This section discusses the factors that have caused the estimates to vary over time.

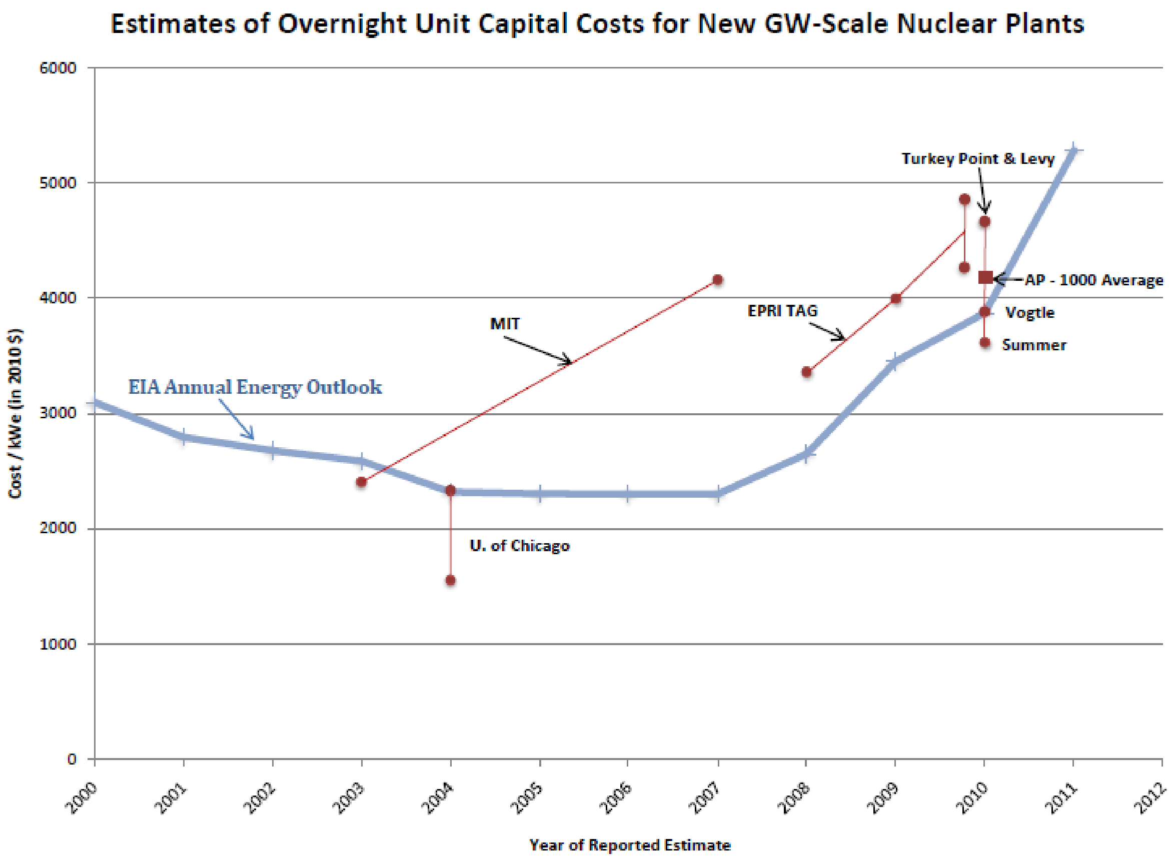


FIGURE 3 Changes over Time in Overnight Unit Capital Cost Estimates

The overall pattern shows a period of relatively little change in overnight unit capital costs up to about 2007, with sharply rising costs thereafter. This timing coincides with the period of intensified engineering design activity for early mover projects seeking to qualify for tax credits and loan guarantees authorized in the EPACT of 2005. This period also coincides with a period of significant cost increases across all technologies in the power generation sector.

While the overall pattern shows rising costs in recent years, the rate of change and current estimates vary significantly. he high end is represented by the EIA generic cost estimates. The most recent EIA cost estimate, developed in support of the AEO 2011, is significantly higher than all other estimates. As discussed earlier, the estimate of indirect costs contained in the EIA estimate may have methodological or estimating issues. So it may represent an outlier.

The EPRI TAG generic cost estimates also show increasing costs, but a lower rate than the EIA estimates. For purposes of trend analysis, a modified range of estimates was used for the EPRI 2010 TAG. The TAG estimate reported by EPRI was adjusted for consistency of scope with the other estimates presented in Figure 3.[16]

The current project-specific cost estimates drawn from the regulatory filings are significantly higher than the early stage estimate developed in the 2004 Chicago Study, but less than the EIA and EPRI generic estimates. Updated to 2010$, the 2004 Chicago Study presented an upper range estimate of $1,554-2,331 per kW (with a mid-point of $1,943 per kW, or approximately $2,000 per kW), depending upon the choice of reactor technology. On the basis of the average cost of $4,210 per kW from the AP1000 regulatory filings, the current estimate is about $2,200 per kW higher than the mid-point estimated from the upper range from the 2004 Chicago Study. The study team's estimate of the increase is similar to the increase of about $2,000 per kW estimated by MIT in its 2009 update of the 2003 *MIT Report on the Future of Nuclear Power* (Du and Parsons 2009).

3.2 FACTORS AFFECTING CHANGES IN OVERNIGHT COST ESTIMATES

The study team identified and analyzed the factors affecting the change in cost estimates. Five factors were identified for further analysis:

1. General maturation of the cost estimates with increasing technical maturity of the engineering design;
2. Improved accounting for the owner's costs, which are site specific and primarily driven by site-specific development requirements;
3. Changes in commodity costs;
4. Amortization of FOAKE costs; and
5. Influence of the DOE Title XVII Loan Guarantee Program requirements.

Each of these factors is discussed in further detail in the subsections that follow.

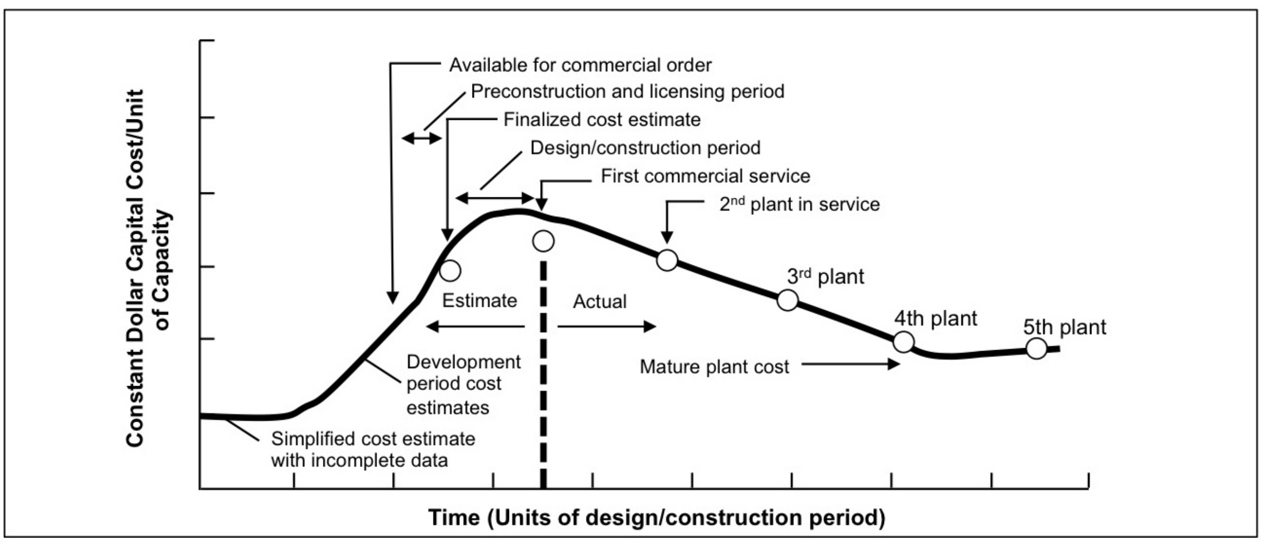
[16] The 2010 EPRI TAG Report provides two estimates: a total plant cost and a total capital requirement. Neither is an overnight capitial cost estimate. The study team derived a modified EPRI TAG overnight capital cost estimate by adding an estimate of owner's costs to the EPRI total plant cost estimate. Based on informal communications with EPRI personnel, the adjustment for owner's cost added 10-11% to total plant cost estimate. The TAG Report (EPRI 2011, p. 8-8) notes that owner's costs typically add 3-11% to the total plant cost estimate.

3.2.1 Relationship of Cost Estimates to Project Maturity

In comparing the early stage to current cost estimates, a major factor that has to be taken into account is the maturity of project planning and design. Over the past five years, over 10 million hours of engineering design effort is estimated to have gone into maturation of the ABWR, AP1000, and European Pressurized Reactor (EPR) designs. Thus, current cost estimates reflect much greater technical detail.

A framework for relating changes in cost estimates to technological maturity can be found in the EPRI Capital Cost Learning Curve. This generalized model is for new electricity generating technologies. The model indicates that cost estimates generally will increase significantly as detailed engineering and other development work proceeds to the point of initial commercial deployment. Once a new technology is deployed, the subsequent commercialization process will "bend the curve" so that cost savings will be achieved in subsequent deployments. This concept is illustrated in Figure 4.

The EPRI cost model displays two distinguishing features. The first is that the cost estimate for power generation technologies tends to increase rather significantly at first, reflecting advances in completion of design and engineering as well as the firming of equipment, material, and labor costs and financing costs. A second feature of the EPRI maturity model is that project costs tend to decline gradually after the first plant is built followed by the construction of additional units of identical or similar design, resulting from the learning process.



Source: *EPRI Program on Technology Innovation: Integrated Generation Technology Options*, June 2011.

FIGURE 4 EPRI Capital Cost Learning Curve. (Reproduced with permission.)

While the EPRI model provides a good conceptual framework for consideration of cost estimates, it is not often possible to pinpoint precisely where any particular cost estimate is on the curve at any particular time. The study team believes that the 2004 Chicago Study represented a "development period cost estimate," while the EPRI estimates are more representative of cost estimates that were current in the 2008 time frame.

3.2.2 Site-Specific Owner's Costs

There is a wide variation in the level of site-specific project development costs that are included in cost estimates. Examples include owner's agent/engineer costs; licensing and project development costs, including project management and oversight; owner's contingency; administration building and security; site facility transportation upgrades and site improvements; interconnect and switch yard upgrades; spare parts; the initial nuclear fuel core; banking and legal fees; state permitting; property tax; sales tax; and working capital. Owner's costs also include site-specific development costs, such as transmission costs, which can vary widely from site to site. Also, owner's costs can vary due to the relative magnitude of development costs that are capitalized (in which case they are included in owner's cost) or expensed (in which case they are excluded). Owner's costs have increased to a much greater extent than other cost factors, increasing from about 5% of total overnight capital costs in the 2004 Chicago Study estimate to 15-20% in the present study team's estimate. This increase is due to the better definition of scope rather than escalation in particular cost items.

3.2.3 Bulk Commodity Price Increases

The run-up in commodity prices and its concomitant effect on nuclear capital costs have been much discussed. Material and equipment prices increased dramatically in the late 2000s, though they have declined recently with the onset of the global recession. However, given that material prices account for only a fraction of the overall total overnight costs, their impact on a percentage basis is significantly less than the overall increase in commodity prices. A rough estimate of the major components of overnight capital cost for a GW-LWR is 25% labor, 15% materials, and 60% equipment.

Combining the cost distribution data from the 2004 Chicago Study with data from the EPRI studies, the study team estimated that a 100% increase in bulk commodities and a 30% increase in equipment costs would have contributed an increase of $495 per kW (approximately $500 per kW) or almost 25% to the overnight capital costs reported in the 2004 Chicago Study. This estimate, based on Bureau of Labor Statistics indexes, appears generally consistent with the IHS CERA Power Capital Cost Index (PCCI). The PCCI, which tracks the costs of all new generation technologies, showed an increase of 93% from 2004 through early 2008, followed by a decrease of 8% into 2009. Appendix C provides additional detailed information on the allocation of plant costs by labor and materials.

3.2.4 Amortization of FOAKE Costs

While not explicitly identified, FOAKE costs could be a significant factor in comparison of cost estimates. The 2004 Chicago Study estimated that the full amount of FOAKE could be as high as 35% of the total overnight capital costs. The amortization of FOAKE could have a significant impact on the cost of the early plants.

We considered estimates of the FOAKE cost and the methods by which they might be amortized among commercial deployments. Information on FOAKE costs and amortization is generally considered to be business proprietary; the study team was able to obtain only limited information from informal communications.

Regarding the estimate of FOAKE costs, the information gathering found that:

- Both the ABWR and the EPR were originally fully designed for commercial deployments outside the U.S. and thus have no FOAKE costs. However, communications with the vendors revealed that both reactor designs required significant additional engineering design work for U.S. deployment, i.e., "Americanization" of the designs. The study team estimated that the process of "Americanization" could have required about five million work-years of effort.

- The AP1000 represents a significant re-design of the previously certified AP600 reactor, but a significant portion of the design certification effort was cost shared by DOE under the NP2010 program. Based on informal communications with industry executives who participated in the NP2010 program, the study team estimated that the FOAKE cost for the AP100 was about $800 million, of which $600 million was incurred as part of the NP2010 program and cost-shared by DOE. If so, that would leave a vendor share for FOAKE cost of about $500 million to be amortized in the cost of initial commercial deployments.

The manner in which the three reactor vendors will amortize these costs over planned reactor deployments is proprietary information. Westinghouse is in the process of deploying 4 two-unit AP1000 commercial plants, two in China (Sanmen and Haiyang) and two in the U.S. (Vogtle and Summer). Nuclear Innovation North America, the sponsor of the ABWR reactor technology, initially announced its intention to deploy 6 units (3 two-unit plants) in the U.S., beginning with a two-unit plant at South Texas.[17] UniStar Nuclear, LLC, announced plans for 6 EPRs, each of which would be a single-unit 1,400 MW plant, beginning with Calvert Cliffs 3 (and possible Nine Mile Point, Belle Bend, and Callaway).[18] It is not known how each venture plans to amortize its FOAKE costs among the planned sale of reactors.

Based on an extrapolation of the information from the NP2010 experience of the AP1000 and the costs for "Americanization" of the ABWR and EPR, the study team estimated that the total

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[17] NRG, the lead partner in the South Texas Project Nuclear Operating Co., announced in April 2011 that it would no longer be investing in the project.

[18] In April 2011, NRC stated that UniStar is not eligible to build a third reactor, as it is not a U.S.-owned company, since Constellation left the partnership in 2010.

FOAKE cost for GW-scale reactors is on the order of $800 million per design. If fully amortized in the cost of an initial plant of about 2,000 MW (i.e., a two-unit plant deploying either ABWR or AP1000 reactor technology), this FOAKE cost represents about 11% of the total overnight capital cost estimate presented in this study.[19] If amortized over 4 plants (i.e., 8 two-unit facilities), FOAKE costs would represent only about 1.5% of the total overnight capital cost. The study team viewed these as the bounding estimates of the effect of FOAKE costs on the total overnight cost estimates.

The degree of completion of detailed engineering design, including FOAKE, significantly affects not only the quality of the cost estimate but also the ease of regulatory approvals. The general view within the industry was that detailed engineering design needed to reach a level of 25-30% completion in order to support submission of the proposed design certification documentation to the NRC for review. This level is generally sufficient to document the safety basis of the plant design, which is the basis for NRC design certification. However, the experience in the NP2010 program indicates that substantially greater engineering design completion prior to submission of design certification documentation to the NRC is important in facilitating NRC review. For example, as design work on the AP1000 advanced, changes in the design caused the AP1000 team to revise design certification filings with the NRC, causing delays in the NRC review process. Thus, significant progress toward completion of detailed engineering design, including FOAKE, appears to be a critical step in expediting design certification and licensing approvals.

3.2.5 Influence of the Title XVII Loan Guarantee Program on Cost Estimates

The requirements of the DOE Title XVII Loan Guarantee Program played an important role in the maturation of the overnight capital cost estimates. In particular:

- The Loan Guarantee Program sets a cap on the guarantee amount at the time the guarantee is issued, which is before the start of construction. This step can result in additional conservatism in the development of cost estimates so as to ensure that no future cost growth falls outside of the guarantee.

- The Loan Guarantee Program also encourages project sponsors to reach fixed/firmed cost agreements for much if not all of the EPC costs. This step, in turn, requires the EPC contractor to negotiate fixed price contracts with suppliers well in advance of placing the order. Vendors may price a premium into their contracts to minimize price risk. This step can lead to "pancaking" of cost contingency estimates, adding to conservatism in the total overnight capital cost estimate.

- The ability to finance costs on a leveraged basis may have encouraged sponsors to capitalize certain owner's costs that would otherwise be expensed. This may be particularly true for the merchant nuclear power plants, which do not have the ability to recover ongoing project development costs in rates. Regulated nuclear utilities have

[19] This assumes a FOAKE cost of $1,000 million embedded in an overnight capital cost estimate totaling $8.84 billion for a two-unit plant (or approximately $4,200 per kW).

> generally sought and received approvals from their respective state utility commissions to recover costs in current rates as construction work in progress.

While these requirements are beneficial to minimizing taxpayer risk associated with the loan guarantee, they represent a different business model that was not anticipated at the time when the early cost estimates were prepared. Moreover, they suggest that current overnight capital cost estimates may be conservative, and cost savings may be possible once the projects are under construction.

3.3 EFFECT OF LEARNING BY DOING ON OVERNIGHT CAPITAL COST ESTIMATES

The 2004 Chicago Study (p. 4-3) identified "learning by doing" as a factor that could reduce the overnight capital cost estimates for new nuclear power plants. The 2004 Chicago Study defined learning by doing as the process "… when human beings involved in a production process gain experience performing their tasks and, over time, find more efficient ways to do them." Learning by doing is separate from the effects of economies of scale or decreases in input prices.

The 2004 Chicago Study described the learning-by-doing process as the learning rate, defined as the percentage of decrease in cost each time the cumulative output doubles. The 2004 Chicago Study performed a critical analysis of prior studies of learning rates during the first generation of new nuclear plant builds in both the U.S. and other countries. The results of these studies were mixed and inconclusive. However, the 2004 Chicago Study (p. 4-24) drew several key conclusions:

> The evidence from international nuclear construction implies that standardization increases learning effects. The evidence from U.S. nuclear construction history, especially when compared with overseas construction, implies that unpredictable regulation reduces potential for learning. Moreover, the literature on knowledge deprecation implies that construction stoppages impair learning by doing.

The 2004 Chicago Study recommended a "reasonable range for future learning rates for the United States nuclear industry is 3 to 10 percent." The achievement of this rate would depend upon the degree of standardization of new nuclear plants and the rate of new plant builds. Higher learning rates would be achieved through greater standardization of plants, construction of multiple units at single sites, an order book that resulted in continuous construction, and a significant degree of competition among firms.

The estimates of overnight capital costs presented in this report represent a "pioneer" plant, and thus do not reflect any cost reductions due to learning by doing. However, both the 2004 Chicago Study results and the EPRI Technology Maturity curve indicate that subsequent new plants should be able to capture the benefits of learning by doing.[20] If the benefits of standardization in engineering, construction techniques, and procurement were implemented across a large-scale business enterprise platform, the reduction in capital costs could be significant. For example, NERA reported that "…some data show that the 5th or 6th unit can be 40% less expensive than the first unit" (Kee 2010).

Our estimates of overnight capital costs are for the early deployments. Subsequent deployments should have reduced costs reflecting the benefits of learning. For purposes of this study, the overnight capital cost was not estimated for a fully mature NOAK plant.

3.4 OUTSIDE EXPERTS' PERSPECTIVES ON THE FACTORS AFFECTING COST ESTIMATES

As a means of better identifying and understanding the specific factors that accounted for this increase, outside experts, including industry executives and subject matter experts, were interviewed to solicit their views as to what factors have been the most significant contributors to this capital cost increase.

3.4.1 Methodology and Approach

Over a dozen senior industry executives and subject matter experts were initially contacted to solicit their interest in participating in one-on-one interviews regarding nuclear capital cost increases during the period 2004-2010. Eight nuclear industry executives and subject matter experts agreed to participate in the interviews, which were conducted either in person or by telephone. To structure and focus the interview, each participant was emailed a comparison chart of the individual capital cost estimates as well as a "straw man" listing and description of potential causes for the observed capital cost increases. The table compared a series of cost estimates, beginning chronologically with the TVA ABWR cost estimate from 2003 and continuing through current present estimates.

Arrangements were then made for an in-depth interview, typically lasting for about an hour, with each participant. Insights, comments, and observations on the factors influencing capital cost increases were noted and were then used to synthesize a set of consensus findings.

3.4.2 Outside Experts' Findings

Based on the results of the individual interviews, the study team developed a summary assessment of the consensus views of the participants. The input from the expert reviewers was generally consistent with the analysis and conclusions of the study team in the areas of the

[20] The EIA estimates reported in this report also are for pioneering plants, EIA does reflect the effects of learning by doing, but in the form of a negative adjustment factor. Rothwell (2010) reports that the EIA National Energy Modeling System includes a technological optimism factor of 5% added to the overnight capital cost estimates for the first four units of a new, unproven design.

project maturation process, expanded definition of the scope of owner's costs, increases in commodity prices, and uncertainty regarding amortization of FOAKE costs.

More important, the outside experts provided additional technical insights into the reasons for observed changes in the overnight capital cost estimates. The results of the expert interviews can be summarized in six specific topical areas:

1. **EPC Contract Risk Allocation:** The recent movement to fixed or firm price EPC contracts, with full plant cost, schedule, and performance risks and penalty clauses, as the contracting vehicle of preference has had a major influence on the capital cost of nuclear plants. This fact was repeated often in discussions with industry subject matter experts and accordingly is cited as the "number one" reason why nuclear capital costs have increased so dramatically in recent years. Fixed or firm price EPC contracts provide certainty to the owner's price, but it comes at a significant premium due to conservatism on the part of EPC contractors.

2. **Supply Chain Pricing:** To manage their EPC contract risk, the prime contractors negotiate similar contracts with the same terms and conditions for their sub-tier suppliers/contractors. The result tends to be multiple companies on the EPC team managing their own scope/risk trying to avoid losses or penalties. The contract tends to drive them into silos and increase costs with duplicated efforts and double accounting for contingencies. Industry subject matter experts often cited the "pancaking of cost contingencies" and "margin on margin" to describe this effect.

3. **Potential for Cost Reduction:** The outside experts generally agreed with the concept that cost estimates increased with project maturation. However, some experts opined that since current estimates have priced in a significant risk allocation, the actual as-built costs for the first units might be lower than current estimates.

4. **Incomplete Scope of Owner's Costs:** Some earlier estimates did not include full scope for the entire plant, particularly the balance-of-plant and site-specific owner's costs. Many of the early estimates were more applicable for the "power block" only, i.e., the nuclear island and turbine building, and did not include all required site-specific work. The site-specific work, such as cooling water systems, warehouses, roads, or security, can lead to a significant add-on charge to the estimates for the power block alone.

5. **Real Supplier Prices:** As the project engineering design advances and the plant and equipment specifications are firmed up, the capital cost estimates tend to increase significantly. Later stage estimates are based upon real supplier price information, including terms and conditions and warranty provisions. This pricing information is often quite different and higher than earlier "budgetary" pricing that the vendors of the nuclear steam supply system had received from suppliers and that had formed the basis for the earlier cost estimates. Budgetary pricing is generally not binding and generally not compliant with specific terms and conditions, i.e., specifications typically represent off-the-shelf parameters.

6. **Unwillingness to Fully Credit Construction Advances until Proven in the U.S.:** Experience has shown that many of the construction advances implemented in recent nuclear power plants constructed in foreign countries (such as open top construction, modularization, and improved construction planning) will reduce costs, and the U.S. projects will benefit from these advances. However, since these techniques are new and not fully demonstrated to most U.S. constructors, the outside experts were of the view that constructors were unwilling to fully credit them in their cost estimates and prices at this time. In addition, the estimated project construction schedules for the first nuclear plants to be built in U.S. are conservative when compared with international experience.

4.0 CONCLUSIONS AND RECOMMENDATIONS

This report examines estimates of overnight capital costs for new commercial nuclear plants in the U.S. Overnight capital cost definitions and methodologies are reviewed and presented in a systematic framework so as to facilitate comparisons.

The principal objective of this report was to examine trends in overnight capital cost estimates for GW-LWRs. The study team assembled cost information from public sources and analyzed it on a comparable basis, with all estimates adjusted to current (2010) dollars.

All estimates are presented as overnight capital costs. The study team did not seek to account for escalation costs, which are dependent upon project-specific construction schedules, or financing costs, which are dependent upon financing structures. Thus, any conclusion with respect to the final cost to consumers of nuclear electricity, or how the cost may compare to that for natural gas or other electricity generation sources, is beyond the scope of this study.

4.1 CURRENT OVERNIGHT CAPITAL COST ESTIMATES

We estimated current overnight capital costs for FOAK commercial deployments of GW-scale commercial nuclear power plants to be about $4,210 per kW (in 2010$), based on an analysis of regulatory filings for four AP1000 projects. This estimate falls between the range set by the 2009 EPRI TAG estimate (which is based on a generic plant at a generic site) and the EIA 2011 Annual Energy Outlook estimate (which is based on the AP1000 reactor at a generic site). The EPRI estimate is 5% lower and the EIA estimate is 27% higher.

The range is not necessarily due to uncertainty in the estimate, but rather to choice of reactor technology, site-specific costs, and specific owner's costs, which are variable. Depending upon the combinations of these factors, the overnight capital cost could range from about $4,000 per kW to about $5,000 per kW.

- The differences in the direct costs for a GW-LWR—the nuclear steam supply system, the turbine generator, and the balance of plant—are relatively small, within 2.5%.

- The differences in indirect costs vary by a factor of three and appear to be largely driven by differences in the methodological approach to allocating costs between the direct and indirect categories. This appears to be an issue with the EIA cost estimate, which is much higher than any other reference.

- The differences in owner's costs vary by a factor of about two and reflect differences in the scope of owner's cost elements included in the category of owner's costs. For example, even among the AP1000 projects, the variance among the estimates for Levy County, Summer, and Vogtle is about 15%, from a low estimate of $3,786 per kW to a high estimate of $4,333 per kW. Since the EPC costs for Summer and Vogtle are relatively fixed or firm estimates, the study team attributed the variance to differences in owner's costs.

Our analysis of the current overnight capital costs represents the cost for the FOAK plants. The 2004 Chicago Study, as well as other analyses, suggests that costs should begin to decline with learning as deployment approaches the NOAK plant. For example, U.S. sponsors of AP1000 units report that their construction planning has benefited from the experience with the construction of the AP1000 units in China. *However, because of the larger component of stick-built costs, the learning rates for GW-scale LWRs are expected to be significantly smaller than the learning rates for small modular reactors.*

4.2 REASONS FOR CHANGES IN OVERNIGHT CAPITAL COST ESTIMATES

Current estimates for overnight capital cost are $2,210 per kW higher than the mid-point estimate from the upper range of the early stage estimates developed in the 2004 Chicago Study. Updated to 2010$, the 2004 Chicago Study yields an upper range estimate of $1,554-2,331 per kW, depending upon the choice of reactor technology. Other analyses, including the MIT reports and EIA estimates, show similar patterns of increase. The study team identified four factors that appear to account for the increase: inflation in commodity prices, detailed scoping of owner's costs, maturation of the engineering design, including site specific engineering costs, and finalization of supplier contractual agreements.

- We estimate that changes in commodity prices would add almost $500 per kW to the earlier estimate from the Chicago Study. The analysis of this change is provided in Appendix E. This analysis, based on Bureau of Labor Statistics indexes, appears consistent with historical trends reported in the proprietary PCCI.

- We estimate that better definition of the scope of owner's costs could add up to $350 per kW to the earlier estimate from the 2004 Chicago Study. This estimate does not reflect an increase in cost but rather a better definition of scope. The 2004 Chicago Study appears to have assumed owner's costs of 5% of the total overnight capital cost. Current estimates, reflecting a more detailed scope, indicate that owner's costs are 15-20% of total overnight capital costs. Owner's costs are largely reflective of site-specific project development costs, including utility interconnections, transmission upgrades, spare parts, first nuclear core, project development costs as well as land, taxes/insurance/advisory fees and legal expenses, etc., and are thus liable to fluctuate from project to project. Thus, it is very difficult to draw any generalizations regarding "average" owner's costs.

- Maturation of the engineering design also added significant cost, but the study team was unable to quantify its contribution. The Chicago 2004 Study assumed that the ABWR and EPR designs could be built in the U.S. without the need for extensive additional detailed engineering, since they were being built in Asia and Europe, respectively. However, the study team found that extensive additional engineering work needed to be performed on both designs in order to "Americanize" the designs.

- Finally, the study team found that overnight capital cost estimates increased as project sponsors moved from vendor “budget” estimates to contractual agreements containing fixed or firm pricing together with warranty provisions. Outside experts consulted by the study team indicated that that these prices may be conservative because of the possibility of “pancaking” of contingencies.

Because of business proprietary data limitations, the study team was not able to undertake a detailed analysis of FOAKE costs and determine how the amortization of these costs affected the estimates of total overnight capital costs. The DOE NP2010 program cost shared a large portion of the AP1000 FOAKE costs. The FOAKE costs for the ABWR and EPR had the benefit of previous design and construction activity outside the U.S., although there may be significant FOAKE costs associated with “Americanizing” the designs. The study team estimated that FOAKE costs could total about $800 million for each of the GW-LWR designs, accounting for 2-11% of total overnight capital costs, depending upon the amortization employed by the reactor vendor. While only about 25-30% engineering design completion is generally required for NRC design certification, the experience with the NP2010 program indicates that achieving a higher level of engineering design completion prior to filing for design certification facilitates NRC review and approval.

Our assessment of the factors affecting changes in the cost estimates was greatly aided by input from an outside group of experts, who reviewed the cost estimates and provided expert advice using a Delphi technique. The outside experts identified many of the same issues as the study team. The experts also pointed out several areas that may cause current estimates to be conservative, such as:

- Additive risk allocations among the owner, EPC contractor, and first- and second-tier suppliers affecting conservatism in cost estimates, including the potential for “pancaking” of cost contingencies; and

- Reluctance to fully credit potential cost savings along with shorter construction schedules from new construction advances (e.g., open top construction and modularization) until these techniques have been proven in the U.S.

4.3 CONCLUSIONS REGARDING ROLE OF DOE IN COST ESTIMATES

We found that DOE programs contributed significantly to the maturation of the overnight capital cost estimates. DOE programs have laid the groundwork that could yield significant future benefits as new commercial power projects are deployed.

The NP2010 program supported detailed engineering for several advanced nuclear technologies, thereby enabling detailed specifications for systems, equipment, and components upon which actual supplier pricing could be based. The reduction in uncertainty surrounding the cost estimates and the potential cost avoidance due to unnecessary project cost escalation during the construction process would more than offset the cost of the program.

The due diligence process for the DOE Loan Guarantee Program required project applicants to move toward fixed-priced EPC contracts. This requirement, in turn, necessitated fixed and/or firm pricing from suppliers. In addition, the loan guarantee conditional commitments set ceilings on the government's liability, which encouraged greater scrutiny of cost estimates. The DOE Loan Guarantee Program is essential to the initial round of new nuclear deployments, by reducing the "risk premium" that otherwise would be associated with such projects. The loan guarantee fees that will be paid by nuclear utilities on the initial $18.5 billion in loan guarantee likely will yield receipts to the U.S. Treasury in excess of $1 billion.

4.4 RECOMMENDATIONS

1. The DOE Office of Nuclear Energy (DOE-NE) should develop a database to monitor nuclear plant capital costs so as to provide accuracy and consistency to the public dialogue involving alternatives for electricity power generation.

2. DOE-NE should develop a systematic approach to capturing the lessons learned from both domestic and international construction projects for nuclear power plants. As part of this effort, DOE-NE should examine changes and variations in nuclear plant construction costs, including the lessons learned and benefits from modular construction techniques and other advanced processes that have the potential of reducing nuclear plant capital costs.

APPENDIX A: COMPARISON BETWEEN OVERNIGHT CAPITAL COSTS AND ALL-IN CAPITAL COSTS

The wide differences between an overnight capital cost estimate and an all-in capital cost estimate can be illustrated by an example taken from EPRI (2009) and reproduced in Table A-1. The table illustrates that for a single project, the all-in capital cost estimate can vary greatly depending upon the schedule assumptions, prevailing interest rates during construction, and escalation rates. (*Note that this table is shown as an example and is not intended as current cost data.*)

TABLE A-1 EPRI Comparison of Utility, TAG 2008$, and TAG 2015$ Capital Cost Estimates. (Reproduced with permission.)

Key Cost Elements	**Utility site specific project (2015$)**	**TAG 2008$**	**TAG 2015$**
Process Capital Cost (Equipment & Construction Labor)	2152[(A)]	2479	2479
General Facilities & Site Specific Costs	315[(B)]	111	111
Engineering & Construction Management	340	410	410
Contingency	470	561	561
Owners Cost	323	384	384
Total Overnight Cost	*3600*	3945	3945
AFUDS (Allowance for Funds Used During Construction) – Short term Project Financing	1837[(C)]	915	1490
Escalation	892[(D)]	0	1144
Total	6329	4860	6579

A. Reflects utility's design specification for reliability and other preferences.
B. Includes site specific requirement for transmission, security, raw water, etc.
C. Short term Project Financing at 11.4%.
D. Escalation at 2.5% per year.

As can be seen from Table A-1 (the reproduction of EPRI Table 1-4), the all-in capital cost can be as much as 67% higher than the total overnight cost. Several key differences are noted below.

Overnight cost comparison: Comparing the TAG 2008$ versus the TAG 2015$, the overnight costs are unchanged, as expected given the definition for "overnight costs". The overnight "utility site specific" cost differs from the other two estimates since the overnight estimate for the category “general facilities and site specific costs” is higher than that for both the TAG 2008$ and TAG 2015$ estimates.

Escalation costs: The TAG 2008$ estimate implies an “overnight” operation date in 2008 and thus no allowance for escalation costs during the construction period, whereas the “utility site specific” and the TAG 2015$ estimates imply an operation date of 2015 and, therefore, include estimated escalation costs during the construction period through the commencement of operations in 2015.

Constant vs. nominal dollars: The TAG 2008$ estimate reports interest costs during construction in constant 2008$, while the “utility site specific” and TAG 2015$ estimates report interest costs in the actual amounts paid in each year during the construction period. This significantly increases (i.e., inflates) the estimate.

APPENDIX B: ADDITIONAL DETAILS FOR EARLY STAGE OVERNIGHT CAPITAL COST ESTIMATES

The 2004 Chicago Study reported overnight capital costs of $1,200, $1,500, and $1,800 per kW in 2003 dollars, representing the low, mid, and upper cost cases. This study noted the wide range of variability and uncertainty associated with nuclear plant capital cost estimates. In fact, it noted that overnight cost estimates from different sources ranged from less than $1,000 per kW to as much as $2,300 kW.

In an effort to establish a point of departure for comparing nuclear capital cost estimates, the present study team performed a review of Chapter 3, "Capital Costs," of the 2004 Chicago Study, including the methodology, assumptions, and references.

From this review, it was clear that much of the cost basis for the 2004 Chicago Study was derived from earlier estimates that centered on the ABWR as contained in the 2001 DOE report, *A Roadmap to Deploy New Nuclear Power Plants in the U.S. by 2010*, Volume II. This report was used as the basis for providing cost breakdown detail of the ABWR into a series of accounts displaying the buildup of the ABWR costs in terms of equipment, materials, and labor as well as indirect costs, including administrative overhead.

The Chicago Study reported that the ABWR was considered a mature nuclear technology given that the NRC approved the ABWR standardized design in 1997, and that the ABWR had been constructed and was operating successfully in Japan. The Chicago Study authors believed that no FOAKE costs were required to be allocated to the estimate for ABWR overnight capital cost.

To narrow the range of capital costs estimates to be used in the study of the levelized cost of electricity (LCOE), the authors chose a set of current reactor designs that they considered having the best prospects for being commercialized in the U.S. These reactor designs were then sorted into general cost range categories to develop a low range, midpoint, and upper range.

- For the *lower capital cost case*, the 2004 Chicago Study grouped the ABWR along with the CANDU ACR-700, describing both as mature designs with no need of FOAKE and also as sharing similar cost characteristics despite the ACR-700's smaller size. This low capital cost category was assigned an overnight capital cost midpoint of $1,200 per kW in 2003 prices.

- For the *mid capital cost case*, the 2004 Chicago Study chose the AP1000, which they noted had not yet been built. The Chicago Study estimate was derived, in part, from publically available Westinghouse estimates at the time of $1,100 to $1,200 per kW and an assessment of business prospects for the advanced light water reactor (ALWR) by Scully Capital, which included a representative capital cost model for the advanced pressurized water reactor (APWR) similar to that of the AP1000. Since the AP1000 had not yet been built, the Chicago Study assigned a FOAKE cost of roughly 30% and assigned the entire FOAKE to the first AP1000 plant to arrive at a representative midrange overnight cost estimate of $1,500 kW.

- For the *upper range capital cost estimate*, the Chicago Study looked to the Framatome SWR 1000, a boiling water reactor (BWR) that had seriously been considered for construction in Finland. The SWR features had been proven in the European market, and Framatome had expressed interest at the time to submit the SWR for NRC certification. The cost of the SWR was thought to be similar to that of the Framatome EPR, which had been selected for construction in Finland. The EPR overnight capital cost had been estimated at the time in the range of $1,600 to $1,900 per kW.[21] Based on these estimates, the 2004 Chicago Study adopted an overnight cost estimate of $1,800/kW to represent the upper overnight capital cost range.

The 2004 Chicago Study adopted an overnight capital cost range of $1,200, $1,500, and $1,800 per kW in 2003 dollars and represented the lower, mid, and upper cost range estimates for reactor designs that had a potential for near-term deployment in the U.S. To account further for the uncertainty in the overnight capital cost estimates, the Chicago Study derived a proxy for variability of costs by examining the variation in capital cost accounts from a previous study and arrived at a variability of 21.5% of total overnight capital costs. The Chicago Study then applied 10% variability in either direction from the midpoint to arrive at a spread for each capital cost case, including the lower, mid, and upper ranges. The result, presented in the Chicago Study as Table 3-7, is incorporated below as Table B-1.

TABLE B-1 Range of Overnight Capital Cost Estimates from 2004 Chicago Study, Table 3-7 ($ per kW, 2003$)

Characterization of Reactor	Lower Range	Midpoint	Upper Range
Mature Design (no FOAKE)	1,080	1,200	1,320
New Designs (includes FOAKE)	1,350	1,500	1,650
Advanced New Design (inc. FOAKE)	1,620	1,800	1,980

These numerical estimates in the above table were then adjusted for inflation to convert the overnight capital costs for each range from their original 2003 dollar values to 2010 dollars (Table B-2).

[21] The Olkiluoto, Finland project, which utilized the EPR reactor design, received regulatory approval in March 2005 and site construction commenced in August 2005, about 1 year after the publication of the Chicago study. Some reports (Thomas 2010) indicate that the cost estimates for the Olkiluoto EPR project subsequently increased by nearly 100 percent by 2010. Subsequent reviews identified a variety of construction management issues. The study team observed that the EPR design was relatively immature (approximately 15 percent engineering complete) at the time of initiation of construction, which likely was a significant factor in the subsequent cost increase.

TABLE B-2 Range of Overnight Capital Cost Estimates Adjusted from 2004 Chicago Study, Table 3-7 ($ per kW, 2010$)

Characterization of Reactor	Lower Range	Midpoint	Upper Range
Mature Design (no FOAKE)	1,272	1,413	1,554
New Designs (includes FOAKE)	1,590	1,763	1,943
Advanced New Design (inc. FOAKE)	1,908	2,120	2,331

Expressed in current 2010 dollars, the 2004 Chicago Study's overnight capital cost estimate can be rounded as $1,400, $1,800, and $2,200 for the lower, mid, and upper range cases, respectively.

In addition to developing an estimate for overnight capital costs of new reactor designs, the Chicago Study explored the cost contribution of various capital costs accounts as a percentage of the total project capital cost, exclusive of escalation and interest.

Table B-3 (reported as Table 3-2 in the 2004 Chicago Study) is useful in comparing the relative cost contribution of certain capital accounts such as equipment, labor, and materials with the total project estimate, as well as for comparing such relative cost contributions with different capital costs estimates over time to perform trending analysis.

For example, using the data from Table B-3, the study team found that equipment costs represent approximately 62%, site labor represents approximately 26%, and site material costs represent 12% of direct capital costs. In addition, indirect costs represent approximately 25% of the overnight capital cost estimate, and finally owner's cost and contingency represent approximately 15%.

The direct equipment and material cost components were based on capital costs estimates prior to the run-up in commodities prices in the period 2004-2008, i.e., before the recession and credit freeze in 2008. In Appendix D, current data from EPRI are used and compared with the 2004 Chicago Study data to determine if the run-up in commodity prices had a significant impact in altering the cost distribution of direct costs among material-related costs, including equipment as compared to labor costs.

TABLE B-3 Breakdown of Overnight Capital Cost Estimate Taken from 2004 Chicago Study, Table 3-2

Percentage distribution of overnight capital costs are divided by account for mature design of ABWR (1,144 MWe).

Account	Description	Factory Equipment Cost	Site Labor Cost	Site Material Cost	Account Costs Percent of Total Costs
21	Structures & Improvements	1.6	7.7	4.5	13.9
22	Reactor plant equip	17.0	2.5	0.9	20.4
23	Turbine plant equip	12.5	1.7	0.5	14.7
24	Electric plant equip	2.5	1.3	0.6	4.4
25	Misc. plant equip	1.5	1.3	0.4	3.1
26	Main condenser heat rejection	2.2	1.0	0.2	3.4
	Total Direct Costs	**37.3**	**15.4**	**7.0**	**59.8**
91	Construction services	3.5	5.0	4.5	13.0
92	Engineering Services	6.4			6.4
93	Field supervision	**4.3**	0.6	0.6	5.6
	Total Indirect Costs	**14.2**	**5.6**	**5.2**	**24.9**
94	Owner's cost	**-**	**-**	**-**	5.1
96	Contingency	**-**	**-**	**-**	10.2
95	FOAKE				**Already Paid**
	Total	**51.5**	**21.0**	**12.2**	**100.0**

APPENDIX C: ADDITIONAL DETAILS FOR CURRENT OVERNIGHT CAPITAL COST ESTIMATES

This Appendix provides additional detailed backup for the EPRI 2009 estimate and the EIA estimate (from the R.W. Beck study).

C.1 EPRI ESTIMATE

EPRI has conducted a series of cost estimation studies of new nuclear plants. The most recent estimate is summarized in Table C-1.

TABLE C-1 EPRI Estimate from *Program on Technology Innovation: Integrated Generation Technology Options*, November 2009

Advanced Nuclear Plant, 1400 MWe Unit

Account	Description	$/kW(2008)	$/kW(2010)
21	Structures & Improvements	620	628
22	Reactor plant equip.	793	804
23	Turbine plant equip.	570	578
24	Electric plant equip.	198	201
25	Misc. plant equip.	124	126
26	Main condenser, heat rejection	174	176
	Total Direct Costs	**2479**	**2513**
91	Construction services	410	416
92	Engineering services	-	-
93	Field supervision	**-**	-
	Total Indirect Costs	**410**	**416**
	Total Direct & Indirect Costs	**2,889**	**2929**
94	Owner's cost	495	502
95	FOAKE		
96	Contingency	561	569
	Total Overnight Cost	**3,945**	**4,000**

From the EPRI Technical Assessment Guide (TAG) and other information, the direct labor cost was estimated to be approximately $645 million ($2008), which is equivalent to approximately $461/kW or 26% of the total direct costs.

C.2 EIA ESTIMATE

EIA updates its cost and performance assumptions related to electric generating technologies annually as part of the development cycle for its Annual Energy Outlook (AEO) report. For the AEO 2011 cycle, EIA commissioned an external consultant to develop current cost estimates for utility-scale electric generating plants. The estimate presented in Table C-2 is taken from Appendix A of *EIA Updated Capital Cost Estimates for Electricity Generation Plants*, November 2010.

TABLE C-2 EIA Cost Estimate from R.W. Beck Report for AP1000, Twin Units, 2,236 MWe

Account	Description	$MM/2010	$/kW(2010)
21	Structures & improvements	1,732	
22	Reactor plant equip.	3,400	
23	Turbine plant equip.	-	
24	Electric plant equip.	630	
25	Misc. plant equip.	-	
26	Main condenser heat rejection	-	
	Total Direct Costs	**5,762**	**2,577**
91	Construction services	2,723	1,218
92	Engineering services	-	
93	Field supervision	-	-
	Total Indirect Costs	**2,723**	**1,218**
	Total Direct & Indirect Costs	**8,485**	**3,795**
94	Owner's cost	2,131	963
95	FOAKE		
96	Contingency	1,200	581
	Total Overnight Cost	**11,815**	**5,339**

APPENDIX D: INTERNATIONAL COMPARISON OF OVERNIGHT CAPITAL COST ESTIMATES

The International Energy Agency (IEA) compiled current estimates for commercial nuclear projects around the world. The estimates include 12 projects reported by 10 OECD countries (other than the U.S.) and five projects in three non-OECD countries. The survey included several reactor designs than are not under development in the U.S. The results of the IEA survey are shown in Figure D-1.

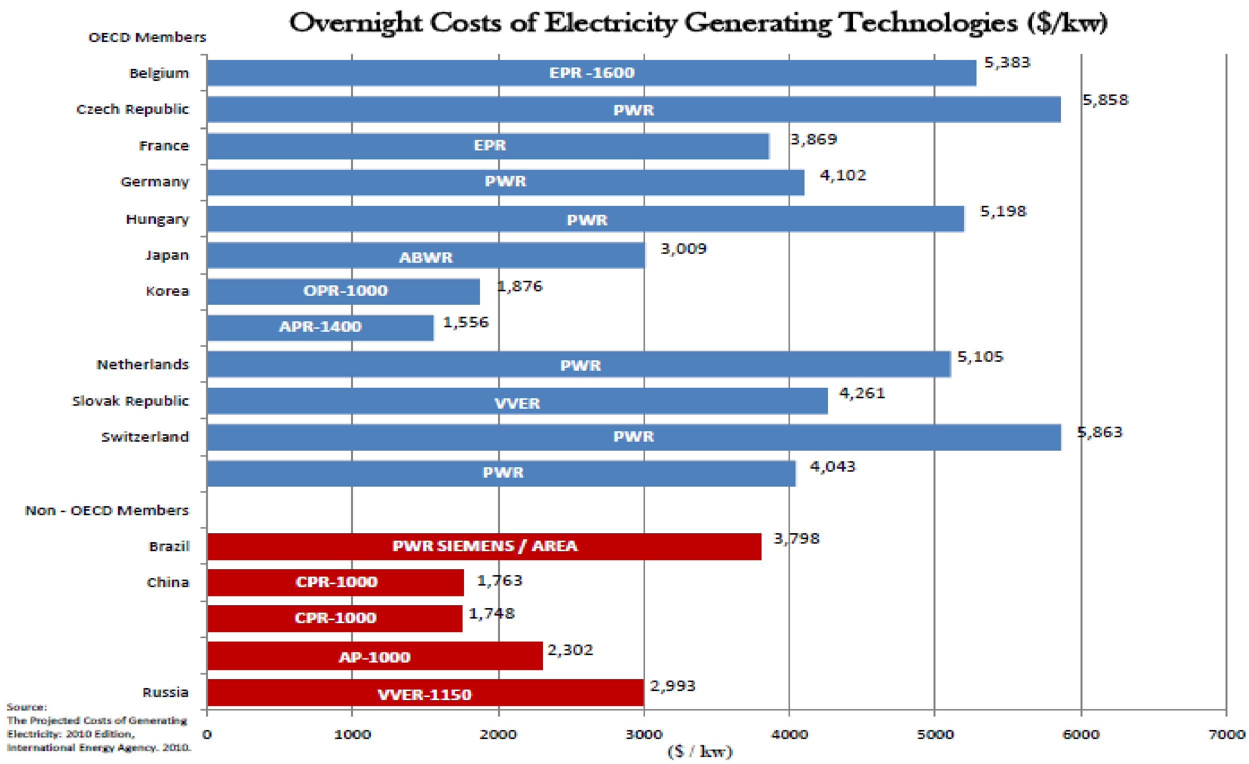

Figure D-1 Overnight Costs of Electricity Generating Technologies ($/kW). (Reproduced with permission.)

The data show an average overnight capital cost of $4,177 per kW for the OECD countries (other than the U.S.) and an average of $2,521 per kW for the three non-OECD countries. The OECD average is significantly affected by the low costs reported for two nuclear projects in South Korea, each of which is less than $2,000 per kW. Removing these two projects from the OECD group yields an average overnight capital cost of $4,669 per kW.

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APPENDIX E: ADDITIONAL DETAILS ON THE CONTRIBUTION OF INCREASED COMMODITY PRICES TO OVERNIGHT CAPITAL COST ESTIMATES

It has been speculated that the increase in nuclear power plant capital costs was largely due to a run-up in commodity prices. Costs for commodities prices and power generation equipment increased significantly prior to the global recession in 2008 and have hence subsided significantly.

The study team estimated the contribution of commodity price changes to the overnight capital cost in several steps. First, the team developed estimates of the breakdown of overnight capital costs between labor and materials. Then, the team examined the changes in prices for various commodities and equipment. Finally, the team estimated the extent of the contribution of commodity price increases on estimates for overnight capital cost.

E.1 BREAKDOWN OF LABOR AND MATERIALS COSTS

The breakout of direct equipment, materials, and labor as a percentage of the total direct costs is shown in Table E-1, taken from Table 1-5 of the EPRI report, *Program on Technology Innovation: Integrated Generation Technology Options*, November 2009. (*Note that this table is shown as an example and is not intended as current cost data*.)

TABLE E-1 Breakdown of Labor and Materials Costs (from EPRI). (Reproduced with permission.)

A generic example of ABWR Process Capital cost estimate breakdown for low and high cost scenarios

		Cost $/kW			% of total costs	
		2008	2015, low	2015, high	2008	2015
Structures & Improvement	Labor	$278	$343	$391	13%	14.4%
	Materials	$256	$274	$305	12%	11.5%
Electrical	Labor	$43	$53	$60	2%	2.2%
	Materials	$128	$137	$152	6%	5.8%
Reactor Plant Equipment	Labor	$85	$105	$120	4%	4.4%
	Materials	$598	$638	$711	28%	26.9%
Turbine Plant Equipment	Labor	$64	$79	$90	3%	3.3%
	Materials	$427	$456	$508	20%	19.2%
Main Heat Reject System	Labor	$43	$53	$60	2%	2.2%
	Materials	$107	$114	$127	5%	4.8%
Miscellaneous Plant Equipment	Labor	$43	$53	$60	2%	2.2%
	Materials	$64	$68	$76	3%	2.9%
TOTAL		$2,137	$2,372	$2,662	100%	100%

The data in Table E-1 indicate that equipment and material costs account for approximately 74% of the total direct costs, and labor related costs represent the balance, or 26%.

From Table B-3, the 2004 Chicago Study reported equipment costs at approximately 62%, site labor at approximately 26%, and site material costs at 12% of direct capital costs. Because the EPRI estimate was reported in 2008, it should include the effects of the run-up in commodity costs. Although the EPRI cost information did not break out equipment costs separately from site material costs, the distribution can be inferred from a 2004 Chicago Study table that showed equipment costs at 84% of total material related costs. The distribution of direct costs is shown graphically in Figure E-1, taken from the EPRI report.

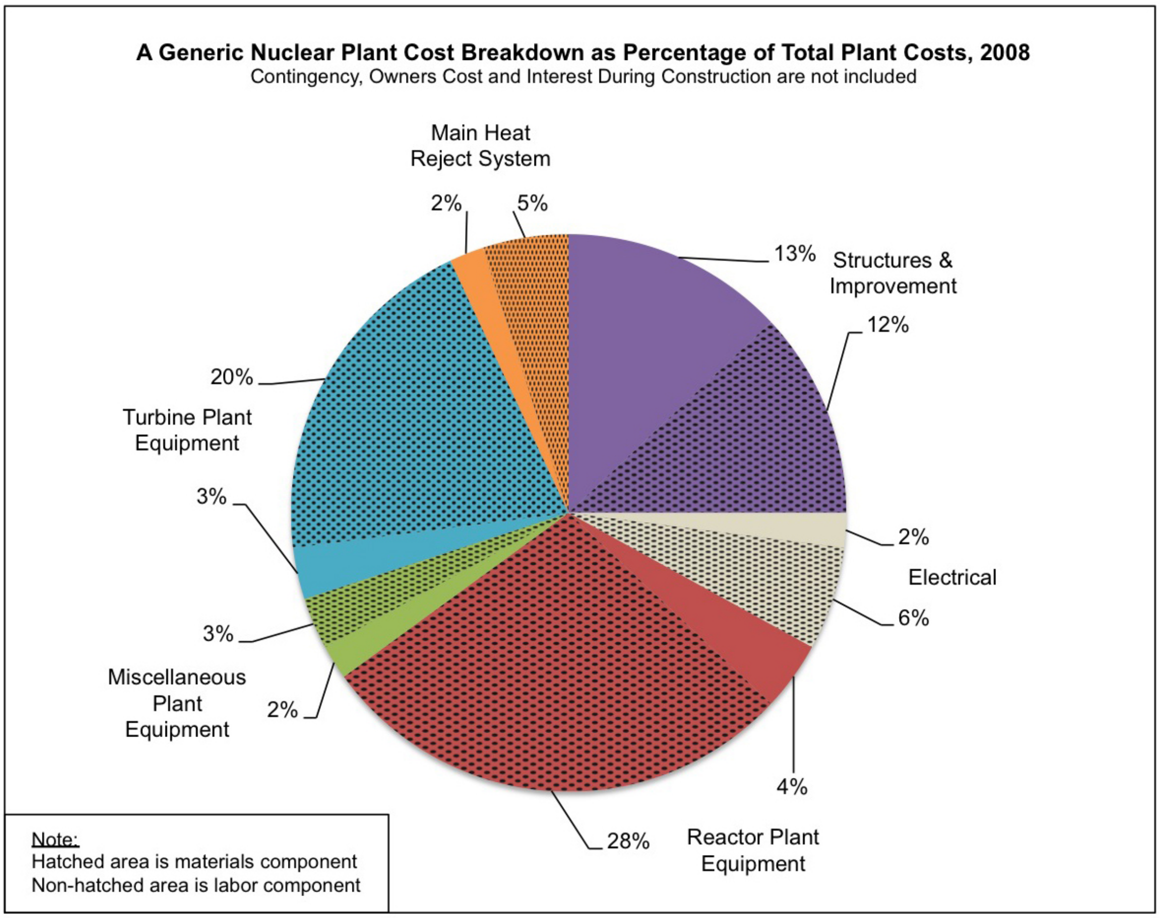

FIGURE E-1 Breakdown of Nuclear Power Plant Costs by Major Components (from EPRI). (Reproduced with permission.)

E.2 CHANGES IN COMMODITY AND EQUIPMENT PRICES

The run-up in prices during the period 2004-2008 for commodities used in the construction of power plants, both fossil and nuclear, is well established. Figures E-2 and E-3 illustrate the Bureau of Labor Statistics (BLS) indexes for commodities and equipment important in nuclear power plant construction.

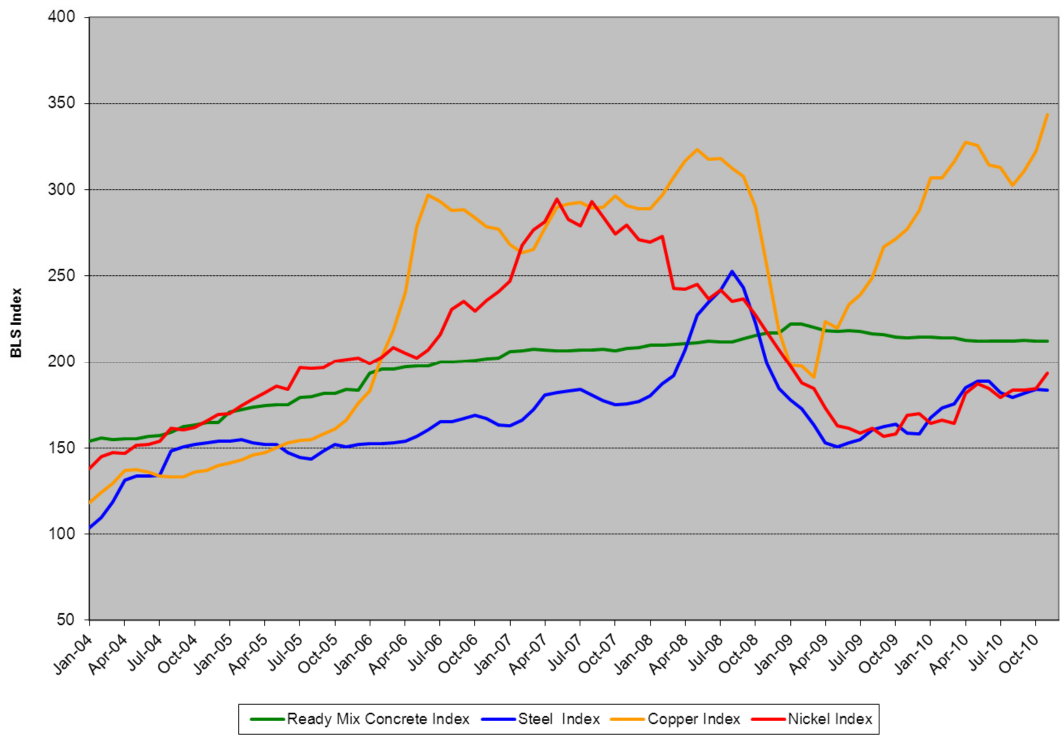

FIGURE E-2 BLS Indexes for Select Commodities

For commodities, the prices increased dramatically between October 2005 and October 2008. Following this period, these prices dramatically dropped off to their 2005 price levels, with the exception of copper, the price for which has continued to increase. For power plant equipment, the prices associated with turbine generators and pumps rose significantly from January 2005 and only began leveling off in the beginning of January 2010.

For commodities, the BLS index for copper appears to have increased from approximately an index of 150 in October 2004 to approximately 300 by October 2008, or a 100% price increase.

For other related construction commodities, the increase was somewhat less. For equipment, the BLS indexes indicate an approximately 30% price increase, from 170 to just over 220, for turbine equipment, and a 25% increase, from 180 to 225, for pumps.

These increases in prices are well corroborated with a proprietary index developed by IHS CERA, an energy consulting firm, for tracking capital cost increases for building coal, gas, wind, and nuclear plants. The PCCI, derived from data reported in IHS CERA press releases,[22] is shown in Figure E-4.

[22] The HIS CERA press releases can be found at http://press.ihs.com.

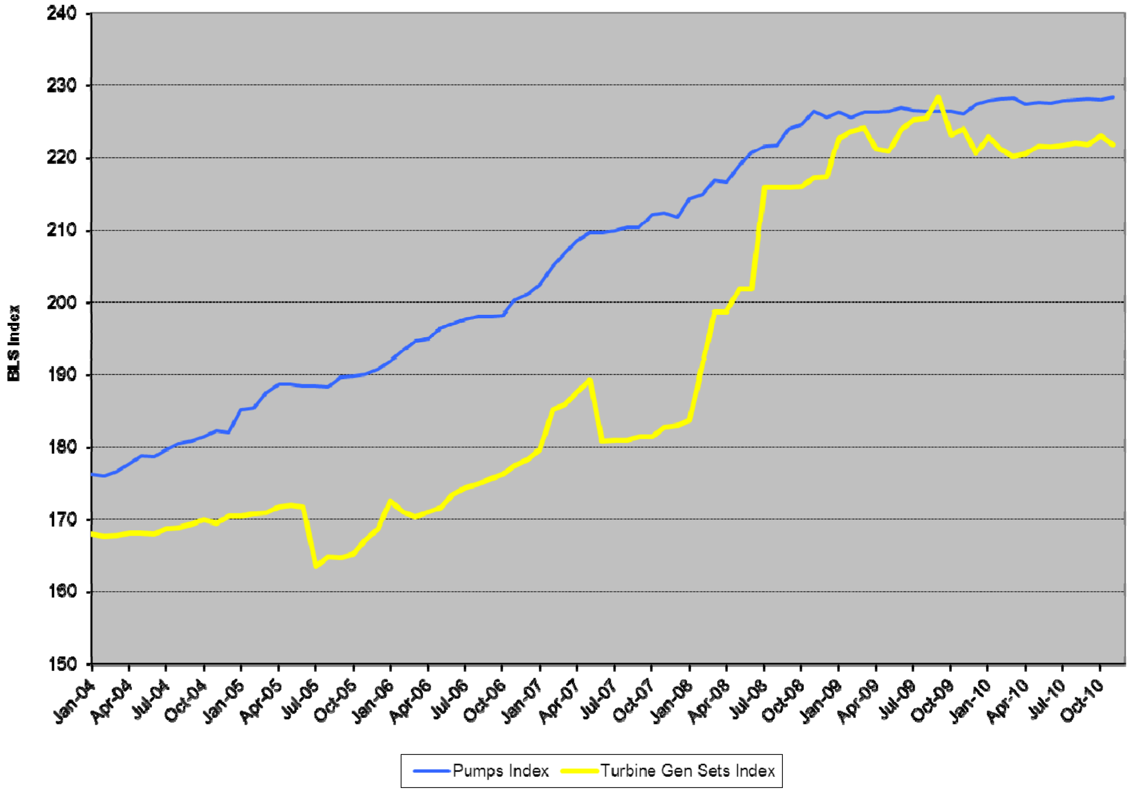

FIGURE E-3 BLS Indexes for Select Equipment

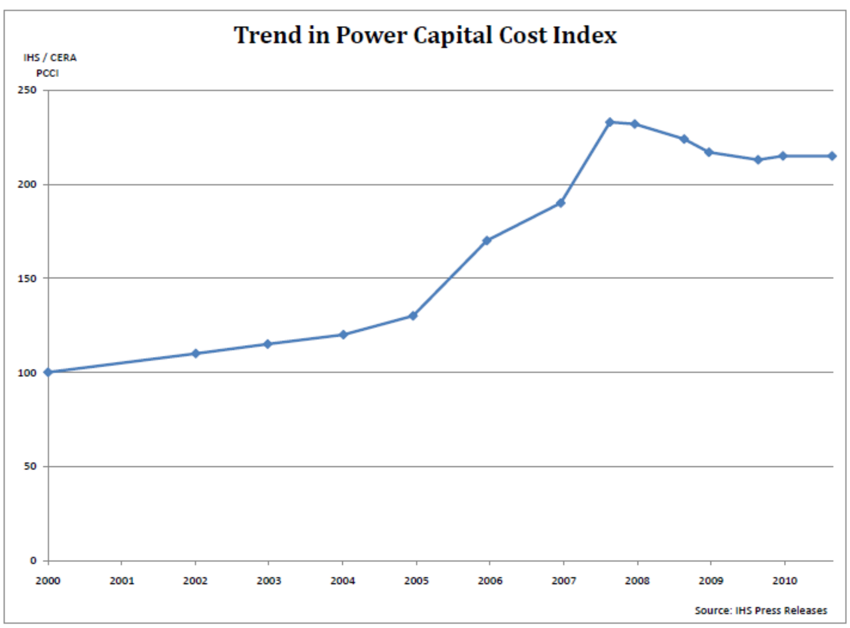

FIGURE E-4 Trend in Power Capital Cost Index

The PCCI index has increased from around 120 in 2004 to a peak of 233 for the third quarter of 2007, representing a 93% increase over the period. The index declined by 8% in 2009 and has been level for most of 2010. The PCCI index covers all generation technologies, including nuclear, coal, gas, and wind. The IHS CERA noted that the decrease in the PCCI in 2009 was primarily driven by nuclear; in fact, other generation technologies showed little or no decline, partly offsetting the large decline in nuclear as they were included in the index (IHS CERA 2009).

In a December 21, 2010, press release, IHS CERA reported that “the costs of building new power plants flattened during the Q1 2010–Q3 2010 period after rising six months ago for the first time since 2008.” IHS CERA went on to report that its PCCI index registered a flat 215, down from its peak of 234 in the third quarter of 2007.

E.3 CONTRIBUTION OF COMMODITY PRICE INCREASES TO CHANGES IN OVERNIGHT CAPITAL COST ESTIMATES

Using the breakdown of materials-related costs from both the 2004 Chicago Study and the EPRI report, combined with the changes in price indexes, one can derive a first-order approximation of the relative impact of the commodity price run-up between 2004 and 2008.

For the purposes of estimating the effect of commodity prices on the overnight capital cost, the study team assumed that material costs increased by 100%, and equipment costs increased by 30%, since the time of the 2004 Chicago Study. For the purposes of this approximation, the team further assumed that the 2004 Chicago Study assumed a 75/25 direct-to-indirect cost distribution, and used the upper-range, midpoint value of $2,000 per kW overnight capital cost for the example. Based on the 2004 Chicago Study and the EPRI data, the team assumed that material-related costs of equipment and site materials represent 75% of the direct costs, and labor accounts for 25%. Further, the team assumed, based on the same data, that equipment costs are 80% and materials, 20%.

Decomposing the direct costs into their respective components and then applying the escalation factors (100% for materials and 30% for equipment) yielded an increase of approximately $495/kW. This represents an increase of approximately 25% in the overnight capital cost estimates of the Chicago Study.

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APPENDIX F: LIST OF ACRONYMS

ABWR	Advanced Boiling Water Reactor
AEO	Annual Energy Outlook
ALWR	Advanced Light Water Reactor
AFUDC	Allowance for Funds Used During Construction
APWR	Advanced Pressurized Water Reactor
BLS	Bureau of Labor Statistics
BOP	Balance of Plant
BWR	Boiling Water Reactor
COD	Commercial Operation Date
COL	Combined Construction Operating Licenses
DOE	U.S. Department of Energy
EIA	Energy Information Administration
EEDB	DOE's Energy Economic Data Base Program
EPACT	Energy Policy Act
EPC	Engineering, Procurement and Construction
EPR	European Pressurized Reactor
EPRI	Electric Power Research Institute
FOAK	First of a Kind
FOAKE	First-of-a-Kind-Engineering
FPL	Florida Power & Light
GW-LWR	Gigawatt-scale Light Water Reactor
IEA	International Energy Agency
LCOE	Levelized Cost of Electricity
NE	DOE Office of Nuclear Energy
NEA	The OECD Nuclear Energy Agency
NEMS	National Energy Modeling System
NOAK	Nth of a Kind
NP	Nuclear Power
NRC	Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System
OECD	Organization for Economic Co-operation and Development
OMB	Office of Management and Budget
PCCI	Power Capital Cost Index
PSC	Public Service Commission
PWR	Pressurized Water Reactor
SWR	Siede Wasser Reacktor
TAG	EPRI's Technical Assessment Guide
TVA	Tennessee Valley Authority

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