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# ARPA-E MEITNER Program

Modeling-Enhanced Innovations Trailblazing Nuclear Energy Reinvigoration  
DE-FOA-0001798

## Webinar on Technoeconomic Analysis (TEA) Workbook

February 2, 2018

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Webinar Link: <https://youtu.be/znTkeoY2JaE>

Webinar led by workbook developers at Lucid Strategy, Inc.

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With Introduction by Dr. Rachel Slaybaugh, ARPA-E Program Director

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# Agenda

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- Introduction by Dr. Rachel Slaybaugh
- Nuclear Power Plant Capital Cost Components
- TEA Workbook Overview
- User Instructions
- Additional Notes
- Additional Q&A

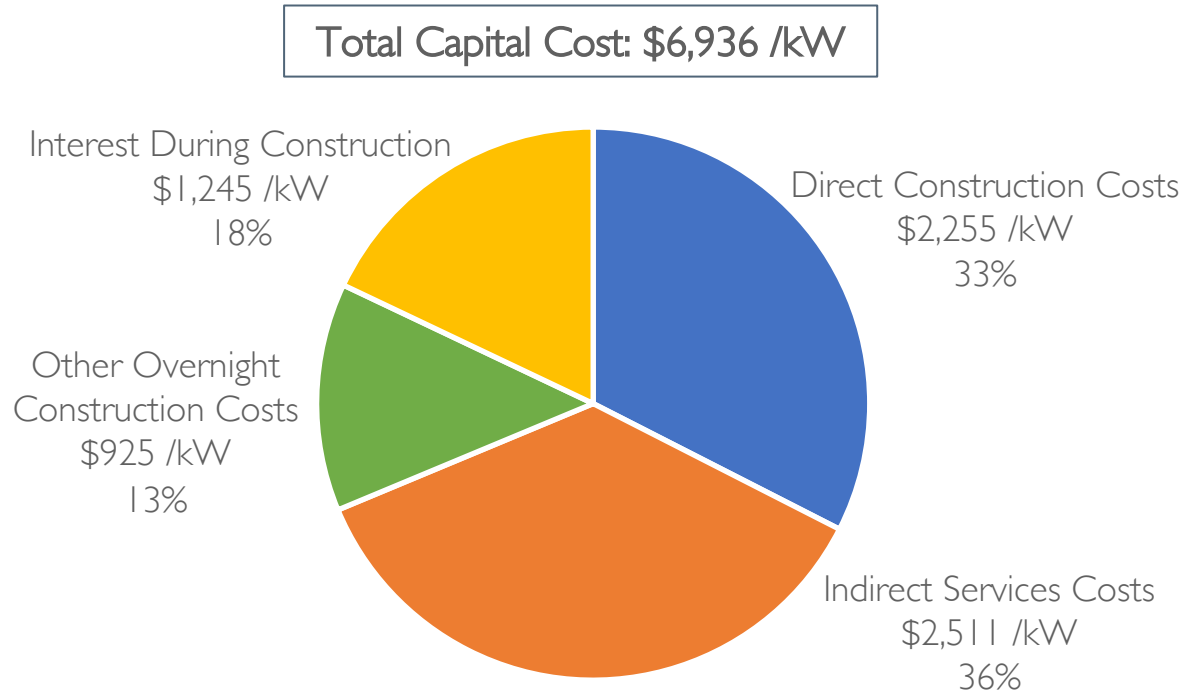
# Introduction by Dr. Rachel Slaybaugh

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- The MEITNER Program's objectives include moving advanced nuclear concepts toward cost-competitive and commercially-viable products.
- It is essential to think in detail about plant costs early in the process, because much of the cost is “baked in” to the initial designs.
- The Technoeconomic Analysis (TEA) Workbook helps Applicants estimate their overnight construction cost (Item 1 in the table of target areas)...
  - ...and think about additional aspects of cost competitiveness and commercial viability.
- Applicants are not expected to be experts in plant cost components or technoeconomic analysis.
- However, Applicants are expected to have thought carefully about how their innovative ideas would affect plant costs...
  - ...and clearly articulate their thought processes behind cost impact estimates in their applications.

# Nuclear Power Plant Capital Costs

Estimated Capital Costs for Generic PWR Reference Plant from National Lab Reports  
("should cost" - not actual cost for recent US projects)



Note: Overnight construction cost excludes interest during construction.

Details on reference cost components and values are discussed further in this webinar and in the TEA Workbook.

# Capital Cost Components and Drivers (1 of 2)

Capital Cost Component	Description	Key Cost Drivers
Direct Construction Costs (20s)	<p>Equipment, labor, and materials costs for each plant system, such as:</p> <ul style="list-style-type: none"> <li>- Nuclear steam supply system</li> <li>- Reactor safeguards system</li> <li>- Instrumentation and controls system</li> <li>- Turbine system</li> <li>- Etc.</li> </ul>	<p>For each plant system...</p> <ul style="list-style-type: none"> <li>- Equipment: Scope, types, prices</li> <li>- Labor: Onsite vs. offsite (prefabrication / manufacturing), necessary tasks, worker types, wage rates</li> <li>- Materials: Quantities, types (“nuclear grade” or not), prices</li> </ul>
Indirect Services Costs (30s)	<p>Engineering and other technical support costs for:</p> <ul style="list-style-type: none"> <li>- Site-specific design services (after reactor design and licensing)</li> <li>- Project management services</li> <li>- Other indirect services</li> </ul>	<ul style="list-style-type: none"> <li>- Standard plant design vs. customization</li> <li>- Design completion before constr. start</li> <li>- Design simplicity and project risk mitigation strategies</li> <li>- Engineering scope (home office vs. field)</li> <li>- Project management scope</li> <li>- Q/A scope</li> </ul>

Note: Nuclear power plant cost codes refer to the Generation IV International Forum’s cost accounting framework.

# Capital Cost Components and Drivers (2 of 2)

Capital Cost Component	Description	Key Cost Drivers
Other Overnight Construction Costs (10s, 40s, 50s)	Costs for: <ul style="list-style-type: none"> <li>- Land, studies, permits (preconstr.)</li> <li>- Staff recruitment, training, housing</li> <li>- Supplementary costs</li> </ul>	<ul style="list-style-type: none"> <li>- Potential economies of scale (large plants could have low \$/kW in these categories)</li> <li>- Streamlining of studies and permits from safety features and plant standardization</li> <li>- Headcount impacts on general staff costs</li> </ul>
Interest During Construction (60s)	Costs to repay debt and equity capital with interest over time <ul style="list-style-type: none"> <li>- Not included in overnight construction cost</li> <li>- But included in LCOE (part of cost recovery)</li> </ul>	<ul style="list-style-type: none"> <li>- Construction duration</li> <li>- Capital structure (debt vs. equity)</li> <li>- Interest rate and equity rate of return based on financial risks (reflecting contract terms) and capital market conditions</li> </ul>

- Capital costs per kW also depend on plant efficiency (based on heat supply temp, heat sink temp, and power conversion cycle parameters)
- TEA Workbook incorporates the major cost components that could be affected by innovative cost-reduction concepts...
  - ...but even with better designs and plans, cost containment for actual nuclear power plants is a complex challenge with additional important factors

# TEA Workbook Overview

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- Model calculates the overnight construction cost, total capital cost, and levelized cost of electricity (LCOE) for nuclear power plants based on user inputs reflecting innovative cost-reduction concepts.
- Applicants in the MEITNER Program specify cost reductions for the nuclear power plant systems affected by their concept.
- Cost reductions are relative to generic cost values for a PWR with conventional project delivery, as estimated by Lucid Strategy based on national lab sources.
- Model applies the comprehensive and standardized cost accounting framework used by the Generation IV International Forum.

# User Instructions: Single Tab for User Inputs

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- Applicants should make changes to only one tab in the spreadsheet: User Inputs and Cost Calcs.
  - The input cells on this tab are blue.
- Other tabs are locked.



# Applicant's Organization and Concept

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- Please enter the requested information about your organization and concept in the blue cells near the top of the User Inputs and Cost Calcs tab.
  - Use drop-down menus for Applicable Reactor Type and Technical Category.

## User Inputs and Cost Calcs

<b>Applicant Organization:</b>	
<b>Application Control Number:</b>	
<b>Principal Investigator Name:</b>	
<b>Concept Title:</b>	
<b>Applicable Reactor Type:</b>	
<b>Technical Category:</b>	

# Plant Systems in Cost Table

- The main table on the User Inputs and Cost Calcs tab lists nuclear power plant systems and their cost codes from the Generation IV International Forum's cost accounting framework.
  - Interest During Construction (60s) is calculated separately with summary results above the table.

Direct Construction Costs (20s)	
220	Nuclear Steam Supply System
223	Reactor Safeguards System
227	Reactor Instrumentation and Controls
Other 22s	Other Reactor Systems
23s	Turbine System
24s	Electric System
25s	Heat Rejection System
26s	Other Plant Systems
21s	Plant Buildings
Indirect Services Costs (30s)	
35, 37	Site-Specific Design Services
32, 36, 38	Project Management Services
31, 33	Other Indirect Services
Other Overnight Construction Costs	
10s	Land, Studies, Permits
40s	Staff Recruitment, Training, Housing
58	Decommissioning
Other 50s	Other Supplementary Costs
Operating Costs	
81, 84	Fuel Purchases
86, 87	Spent Fuel Storage and Reproc
71, 72	Staff
Other 70s	Other O&M Costs
90s	Operating Fees

Note: Some cost codes in the Gen IV framework have been excluded from the cost table because they are outside the scope of this analysis.

# Reference Plant Cost Estimates by System

- Reference costs for each plant system have been estimated by Lucid Strategy based on reports by national labs and other sources for PWRs.
  - All Applicants have a common benchmark for cost reductions (though the national labs have also estimated costs for advanced reactor types).
  - Sources and calculations for the reference cost estimates are shown on the black tabs at the right of the spreadsheet (no user inputs or changes on the black tabs)...hyperlinks at the left of the table

		Ref. Cost
<b>Direct Construction Costs (20s)</b>		
220	Nuclear Steam Supply System	\$344 /kW
223	Reactor Safeguards System	\$48 /kW
227	Reactor Instrumentation and Controls	\$45 /kW
Other 22s	Other Reactor Systems	\$274 /kW
23s	Turbine System	\$498 /kW
24s	Electric System	\$223 /kW
25s	Heat Rejection System	\$105 /kW
26s	Other Plant Systems	\$130 /kW
21s	Plant Buildings	\$588 /kW
<b>Indirect Services Costs (30s)</b>		
35, 37	Site-Specific Design Services	\$912 /kW
32, 36, 38	Project Management Services	\$809 /kW
31, 33	Other Indirect Services	\$791 /kW
<b>Other Overnight Construction Costs</b>		
10s	Land, Studies, Permits	\$132 /kW
40s	Staff Recruitment, Training, Housing	\$715 /kW
58	Decommissioning	\$38 /kW
Other 50s	Other Supplementary Costs	\$40 /kW
<b>Operating Costs</b>		
81, 84	Fuel Purchases	\$5 /MWh
86, 87	Spent Fuel Storage and Reproc	\$3 /MWh
71, 72	Staff	\$7 /MWh
Other 70s	Other O&M Costs	\$15 /MWh
90s	Operating Fees	\$0.3 /MWh

# Summary of Reference Plant Costs

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- Gray box above main table of User Inputs and Cost Calcs tab summarizes cost estimates for reference plant.

	Reference Costs	
<b>Overnight Construction Cost --&gt;</b>	\$5,691 /kW	\$59 /MWh
<b>Interest During Construction --&gt;</b>	<u>\$1,245 /kW</u>	\$13 /MWh
<b>Operating Costs --&gt;</b>		<u>\$30 /MWh</u>
<b>Total Capital Cost and Levelized Cost of Elec --&gt;</b>	\$6,936 /kW	\$101 /MWh

- Overnight Construction Cost is the sum of costs per kW in the main table.
- Interest During Construction is calculated separately on the LCOE Parameters and Interest tab based on assumed construction duration and interest rate.
- Total Capital Cost is the sum of Overnight Construction Cost and Interest During Construction.
- Levelized Cost of Electricity (LCOE) is the sum of capital costs converted to \$/MWh (based on capitalization period / plant lifetime, discount rate, and capacity factor parameters) and operating costs in \$/MWh.

# User Inputs for Relevant Plant Systems

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- In the main cost table of the User Inputs and Cost Calcs tab, indicate whether each plant system's costs would be affected by your concept (TRUE or FALSE).
- For each system affected by your concept (TRUE in first column), enter brief notes about your concept's technology and cost impacts.
  - If necessary, provide additional details in your main application document.
- Enter your estimated cost reduction percentage for the relevant system relative to the reference cost values.
  - The model will then calculate the updated cost for the relevant system based on your reduction percentage.

# Example User Inputs and Cost Calcs

Nuclear Power Plant Systems	System Affected by Concept?	Brief Summary Notes on Concept Innovation for System (Additional Details in Application Document)	Brief Summary Notes on Concept Cost Impact Notes for System (Additional Details in Application Document)	Reference Costs		Applicant's Cost Reductions		
				\$/kW	\$/MWh	% Cost Reduction	\$/kW Cost Reduction	\$/MWh Cost
<b>Direct Construction Costs (20s)</b>								
Nuclear Steam Supply System	TRUE	Our concept affects the NSSS by ...	Our concept would significantly reduce NSSS costs because...	\$344 /kW	\$4 /MWh	50%	\$172 /kW	\$2 /MWh
Reactor Safeguards System	FALSE			\$48 /kW	\$0.5 /MWh		-	-
Reactor Instrumentation and Controls	TRUE	Our concept affects I&C by ...	Our concept would somewhat reduce I&C costs because ...	\$45 /kW	\$0.5 /MWh	25%	\$11 /kW	\$0.1 /MWh

- ... and likewise for other plant system rows in the table

# User Inputs for Construction Duration

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- Below the main cost table on the User Inputs and Cost Calcs tab, enter your construction duration if different from reference plant.
  - Construction duration automatically affects Interest During Construction.
  - Concepts that shorten construction duration would also likely reduce Indirect Services Costs (30s), but this is not calculated automatically by the model because it should be estimated by the user.
  - Construction duration excludes preconstruction activities (land acquisition, studies, permits)...it aligns with Item 2 in the table of target areas.

# User Inputs for Plant Lifetime

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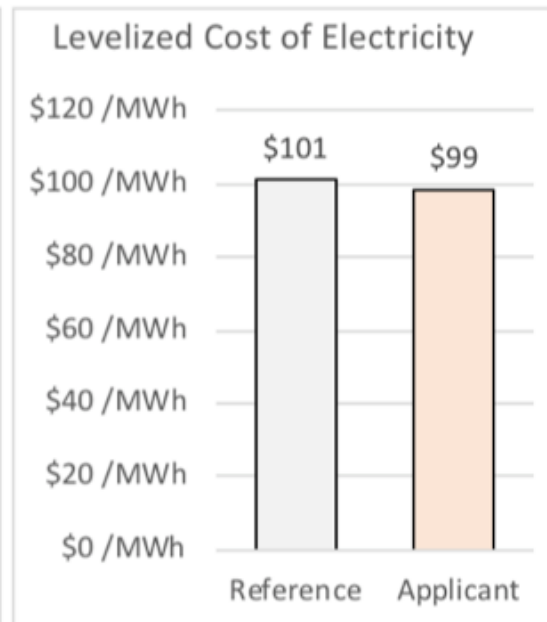
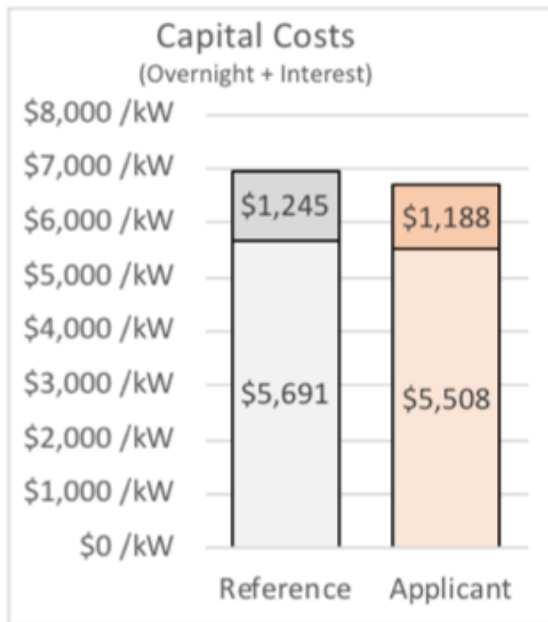
- Below the main cost table on the User Inputs and Cost Calcs tab, enter your plant lifetime if less than reference plant.
  - Plant lifetime affects conversion of capital costs from \$/kW to \$/MWh for LCOE, so it should be interpreted as financing period for capital costs.
  - Although reference plant and perhaps your plant could operate for longer than 25 years, the model uses this value as the maximum financing period.
  - You can account for different component lifetimes from your concept by adjusting annual O&M costs (Other 70s) to reflect more frequent or less frequent parts replacement...and discuss in your application.

Note: Plant lifetime does not affect overnight construction cost.



# Example Summary of Applicant's Total Costs Relative to Reference Plant

	Reference Costs		Applicant's Costs	
Overnight Construction Cost -->	\$5,691 /kW	\$59 /MWh	\$5,508 /kW	\$57 /MWh
Interest During Construction -->	<u>\$1,245 /kW</u>	\$13 /MWh	<u>\$1,188 /kW</u>	\$12 /MWh
Operating Costs -->		<u>\$30 /MWh</u>		<u>\$30 /MWh</u>
Total Capital Cost and Levelized Cost of Elec -->	\$6,936 /kW	\$101 /MWh	\$6,695 /kW	\$99 /MWh
Applicant's Reductions from Reference Total Capital Cost and Levelized Cost of Elec -->			\$240 /kW	\$2 /MWh
Applicant's Reduction Percentages -->			4%	3%



- Overnight construction cost aligns with Item 1 in the table of target areas, after conversion from \$/kW to \$/W.

# Additional Notes

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- Cost impact estimates should reflect Nth-of-a-kind plants.
- If any aspect of your concept would increase costs for a power plant system, enter a negative value for the system's cost reduction percentage.
- All capacity labels (kW and MW) refer to electric power.
  - The model does not account for other potential nuclear plant outputs (such as heat production).
  - The model does not calculate impacts on power revenue or grid value from load following or other grid integration concepts.
- Emergency Planning Zone (EPZ) and emergency response time can affect staff levels and other operating costs.
- Cost estimates do not include contingency factors, contractor markups, or development costs (such as reactor design or licensing costs).
- Costs are expressed in 2017 dollars, and source tabs show inflation factors for bringing older cost values to this level.

# Additional Q&A

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- Any other questions from Applicants attending webinar?
- Later questions may be submitted to [ARPA-E-CO@hq.doe.gov](mailto:ARPA-E-CO@hq.doe.gov).
  - Include MEITNER DE-FOA-0001798 in subject line.
  - Deadline: March 5