U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Fast Reactor Fuel Cycle Cost Estimates for Advanced Fuel Cycle Studies

Technical Meeting on Fast Reactors and Related Fuel Cycle Facilities with Improved Economic Characteristics

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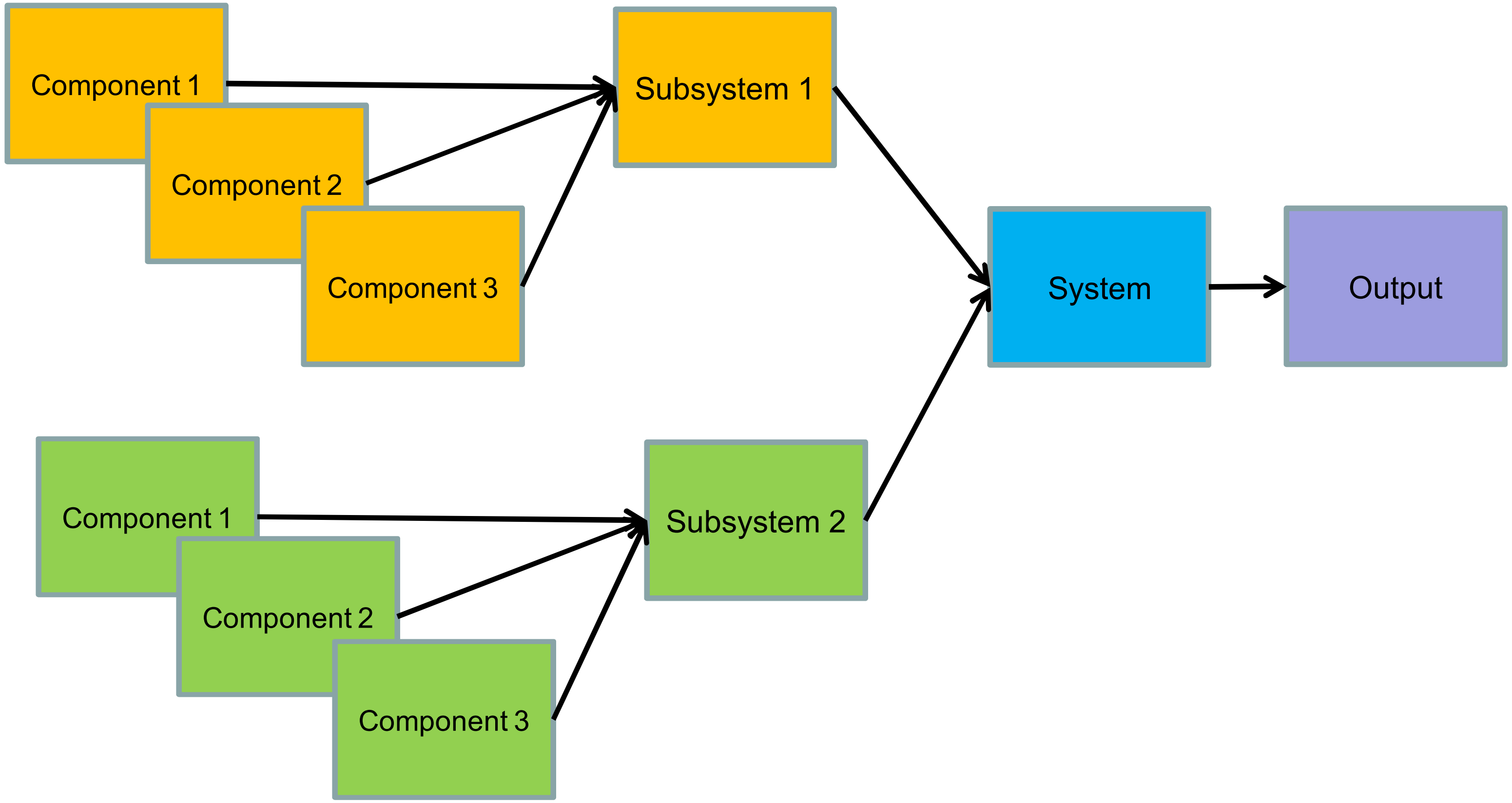
Presentation Outline

- Why Do I Need a Cost Basis?
- History of the Advanced Fuel Cycle Cost Basis
- Description of the Cost Basis
- Current Work
- Fast Reactor Fuel Cycle Applications
- Sample Fuel Cycle Cost Estimate Analysis
- Future Work

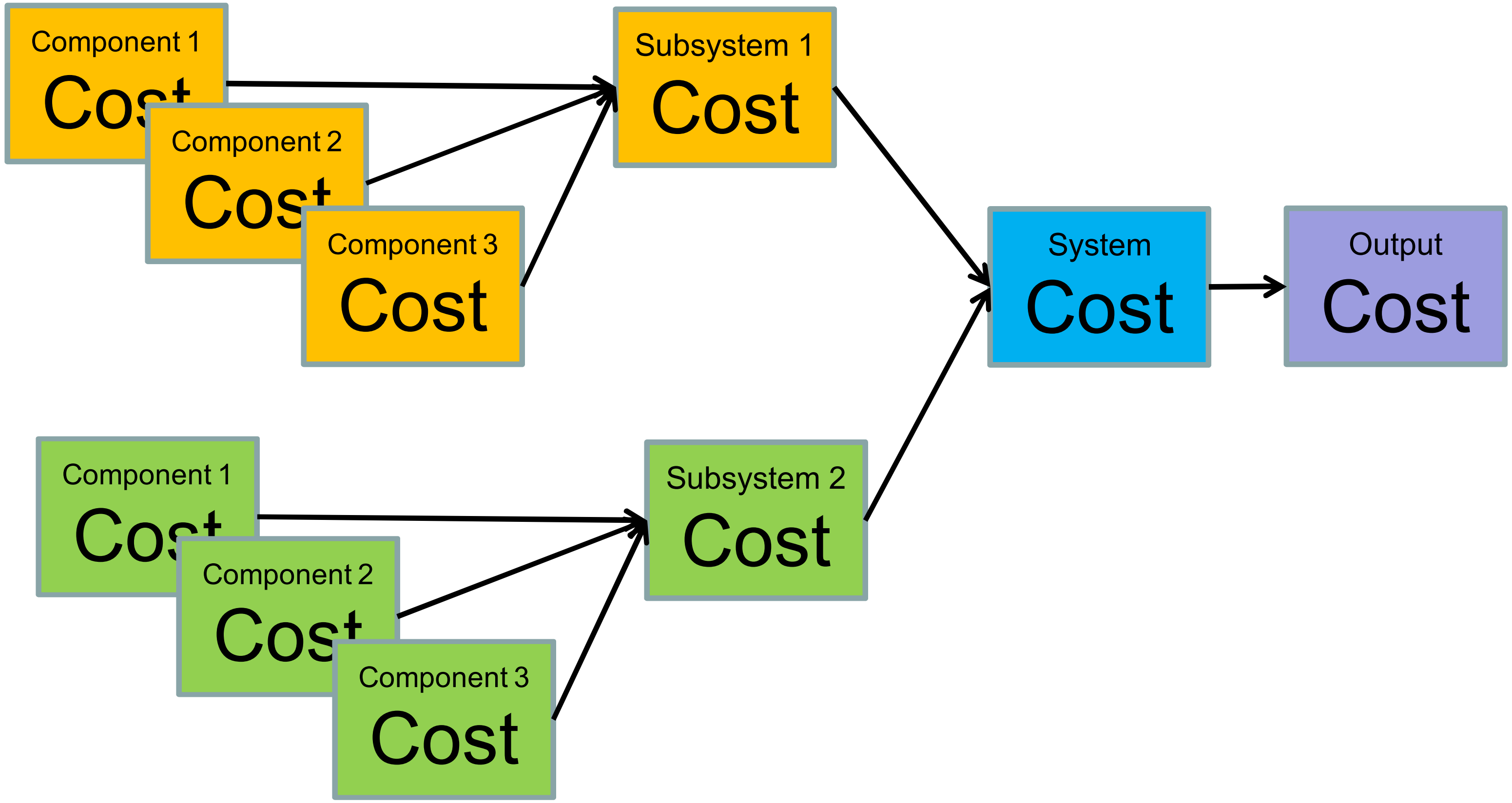
Why Do I Need a Cost Basis? Introduction

- **Components are the building blocks for systems**



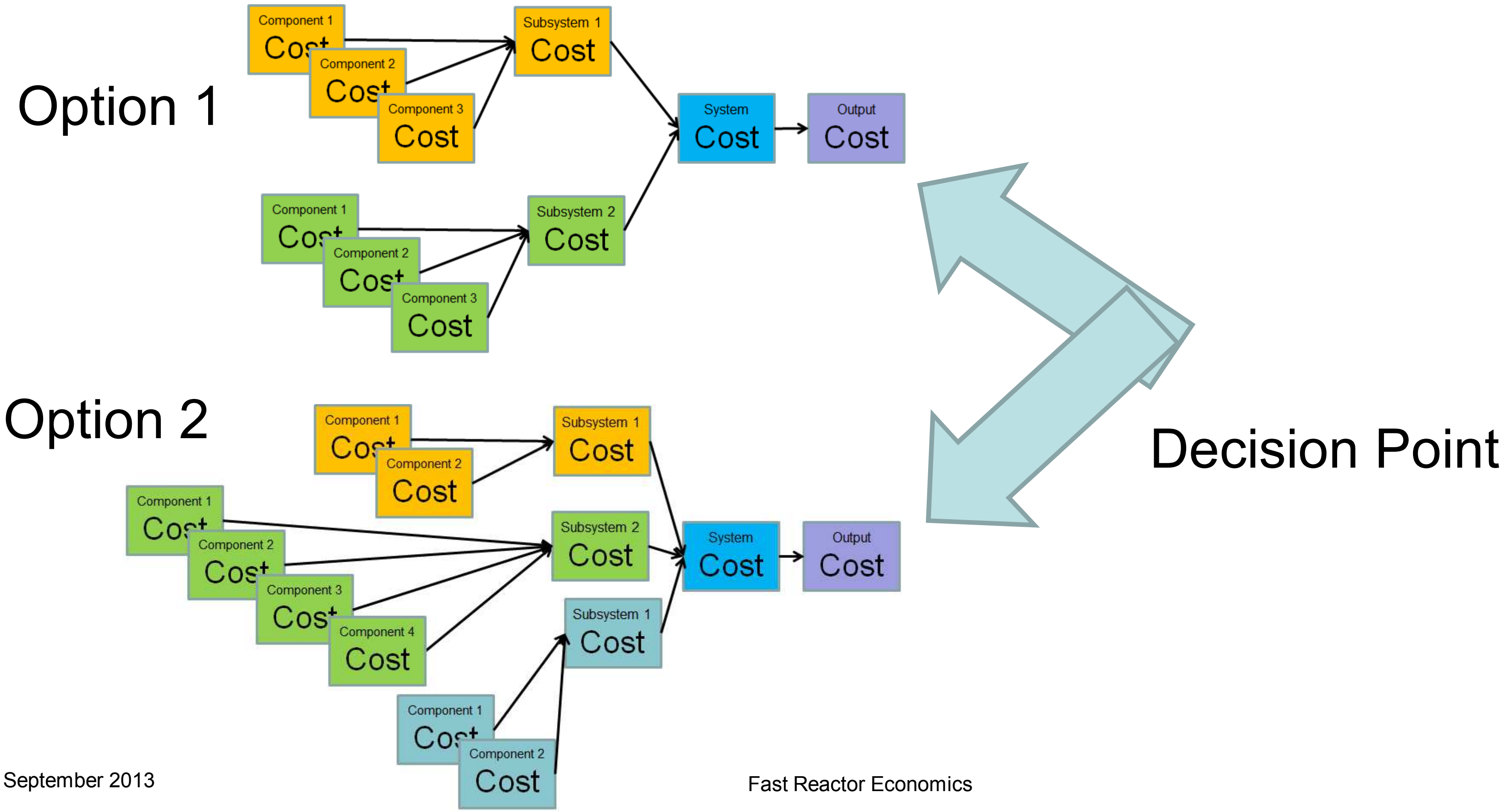
Why Do I Need a Cost Basis? System Cost Estimates

- **Component *cost estimates* are the building blocks for system *cost estimates***



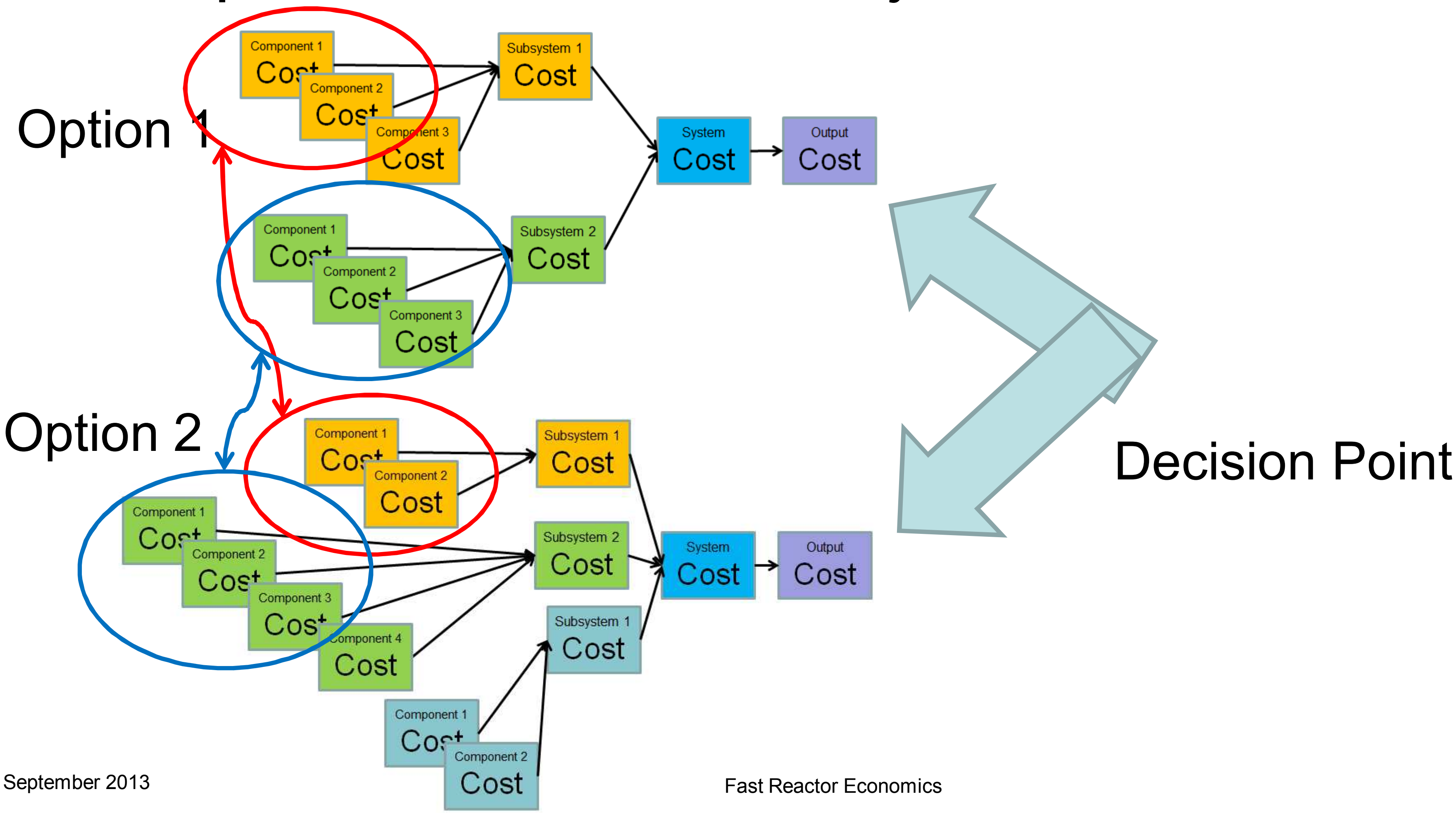
Why Do I Need a Cost Basis?
Alternative Comparisons

- **Systems analyses are used to compare alternatives**



Why Do I Need a Cost Basis? Consistent Comparisons

- **Compare the alternatives *consistently***



Why Do I Need a Cost Basis? Conclusion

- **The alternative comparisons must be on a level playing field**
  - Common assumptions
  - Common methods
- **When I want to know what something *that does not yet exist* costs, I can ask:**
  - Proponents
    - *"Very affordable!"*
  - Opponents
    - *"Too expensive!"*
- **The Advanced Fuel Cycle Cost Basis fills the knowledge gap for advanced nuclear systems**
  - Provide a range of cost estimates that are both defensible and useful

History of the Advanced Fuel Cycle Cost Basis

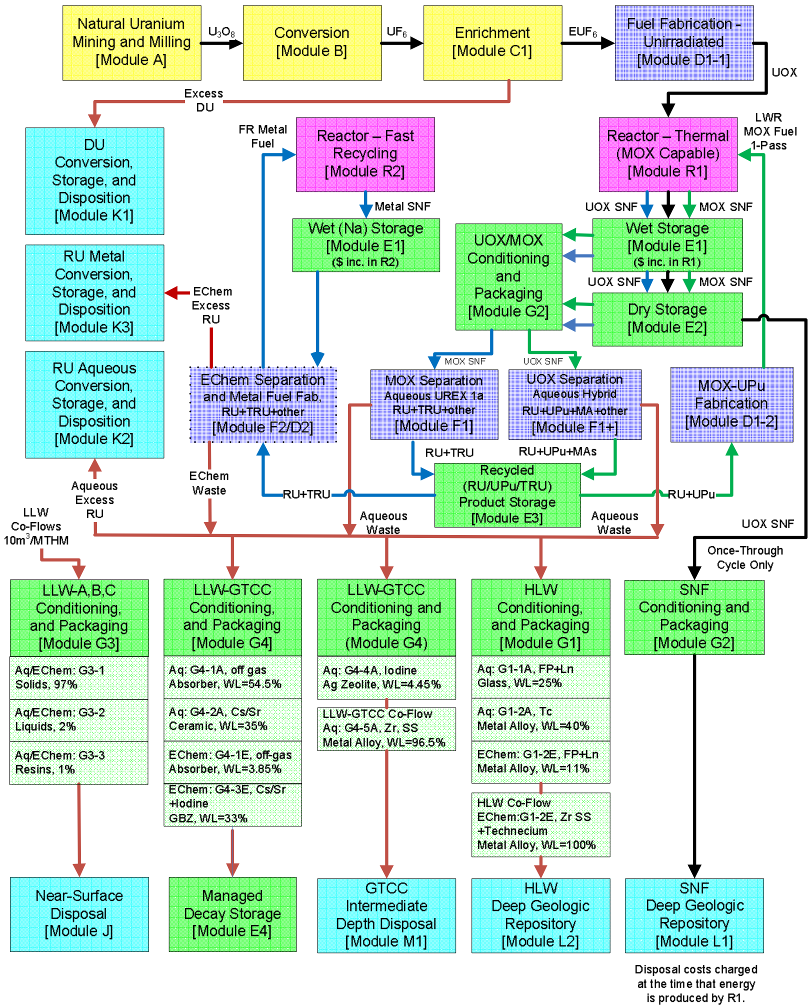
- **Economics Working Group initiated in 2003 by United States Department of Energy**
  - Tasked with assessing the projected costs of new (advanced) fuel cycles for Advanced Fuel Cycle Initiative
  - Original group membership was drawn from DOE labs and facilities
- **The Working Group**
  - Recognized that system life cycle costs were functions of component costs
  - Began the preparation of an economic data base for the components of the fuel cycle
  - Emphasis on the unit costs ($/kg, $/SWU, $/MTHM, etc.)

Description of the Cost Basis
Introduction

- **Collection of "Modules"**
- **Each module is relevant to a specific fuel cycle component**
  - For example, Module A series deals with mining
    - *A1 is uranium*
    - *A2 is thorium*
  - Module R series deals with reactors
    - *R1 is LWRs*
    - *R2 is Fast Reactors*
    - *R3 is HTGRs*
    - *Etc.*

Description of the Cost Basis Module Map

Economic Analysis Modules and Primary Flows



Description of the Cost Basis Data

- **Data sources:**
  - Public reports
  - Trade press
  - Other fuel cycle studies
  - Discussions with private industry
  - DOE-generated cost estimates

Description of the Cost Basis
Module Information

- **Data included in each module:**
  - Comprehensive description
  - Process diagrams
  - Historical information
  - Technical maturity assessment
  - Interface with other fuel cycle components
  - Existing data
  - Discussion of data limitations
  - Unit cost distribution
- **Large caveat**
  - Unit cost distribution assumes steady-state, Nth-of-a-kind deployment
  - Unit cost distribution *does not account for First-of-a-kind*
    - *Keep in mind in a few slides*

Description of the Cost Basis
Cost Distributions

- **Unit cost distributions are defined by:**
  - High (Max)
  - Low (Min)
  - Nominal (Mode)
- **The Cost Basis uses triangular and uniform distributions**
- **Analytical method samples from the distributions to generate a final levelized cost distribution**
  - Example distributions shown in backup slides

Current Work

- **The last revision was published in December 2009**
- **Work began on an update in 2012**
  - Completed in 2013
  - Available soon!
- **The 2012 update was created as an addendum, rather than a complete new revision**
  - Include new data sources and references
  - Update costs from 2009$ to 2012$
  - Add new fuel types
  - Add new reactor/transmuter types

Fast Reactor Fuel Cycle Applications Ground to Reactor

Fuel Cycle Front-End Component	Module
Natural uranium mining/milling	A1
Thorium mining/milling	A2
Natural uranium conversion	B
Enrichment	C1
HEU downblending	C2
Fuel fabrication (contact-handled)	D1
Depleted uranium disposition	K1

Fuel Cycle Reactor Component	Module
Fast reactor construction and operation	R2

Fast Reactor Fuel Cycle Applications Reactor to Ground

Fuel Cycle Back-End Component	Module
Electrochemical waste disposition	G1, G4, K3
Depleted uranium disposition	K1
Geologic waste disposal	I, J, L1, L2

Fuel Cycle Reprocessing Component	Module
Fuel fabrication (remote handled)	F2/D2
Fuel electrochemical reprocessing	F2/D2

Fast Reactor Fuel Cycle Applications
Reactor Cost

- **The capital cost is obviously the big item of interest**

	2009 $/kWe (low / nominal / high)
Fast reactor capital	3000 / 4200 / 7000
LWR capital	2300 / 3500 / 5000

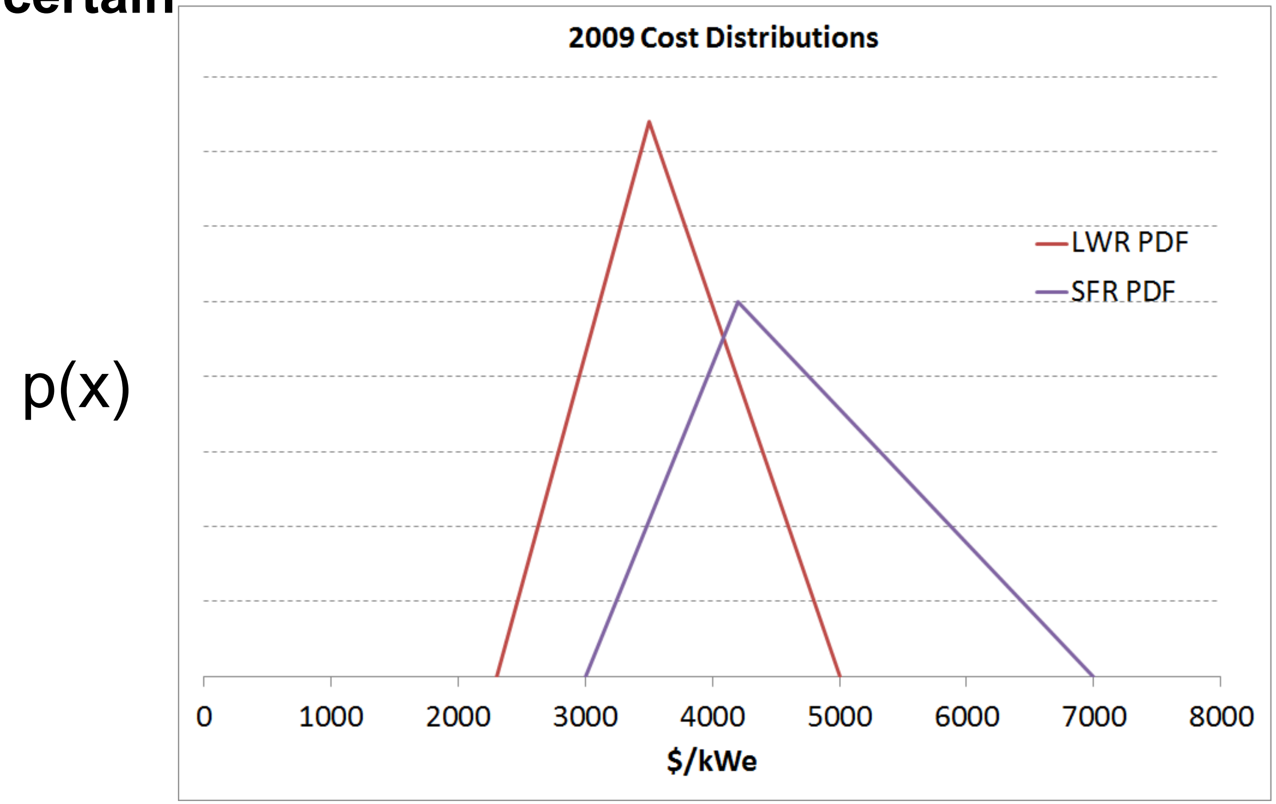
Fast Reactor Fuel Cycle Applications
Reactor Cost

- **The capital cost is obviously the big item of interest**

	2009 $/kWe (mean / median / mode)
Fast reactor capital	4733 / 4633 / 4200
LWR capital	3600 / 3577 / 3500

Fast Reactor Fuel Cycle Applications
Reactor Cost Distributions

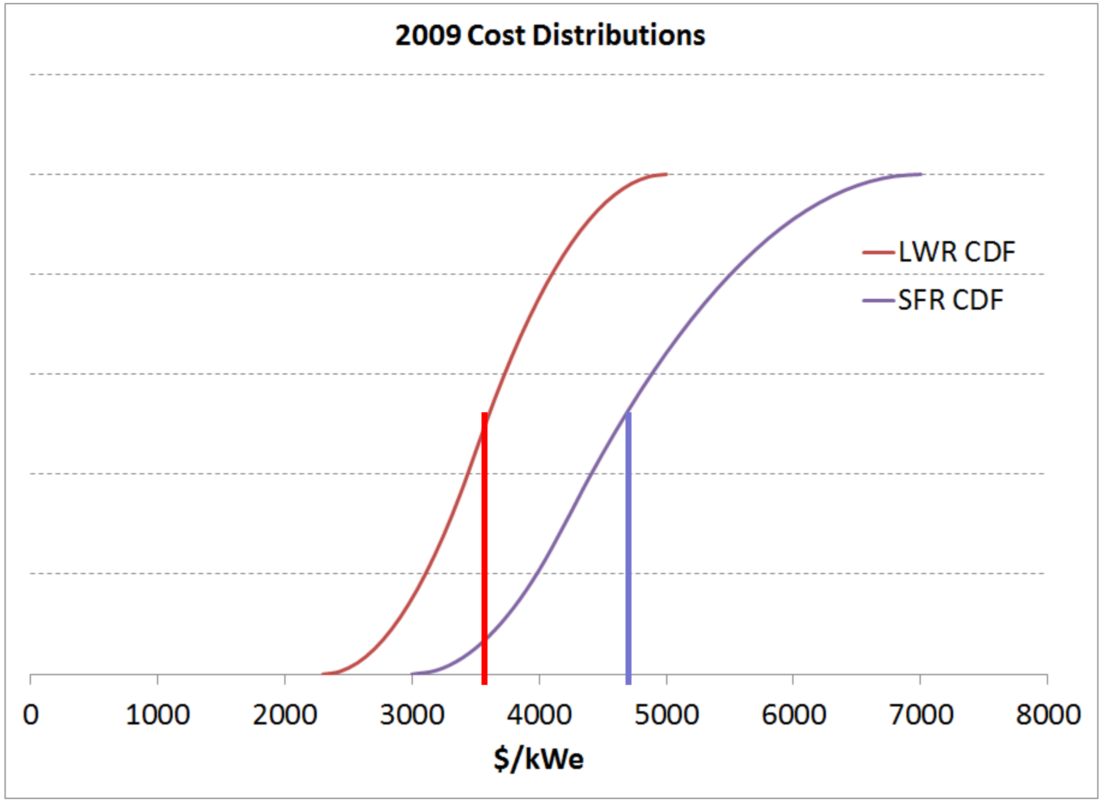
- **SFRs are shifted and right-skewed compared to LWRs—more uncertain**



Fast Reactor Fuel Cycle Applications
Cumulative Reactor Cost Distributions

- **The cumulative distributions show the effect of the higher tails**

P(x)



Fast Reactor Fuel Cycle Applications Limitation

- **This differential reflects the expected Nth-of-a-kind cost, not the First-of-a-kind cost!**
- **This is an inherent limitation of the Advanced Fuel Cycle Cost Basis**
- **How are these cost estimates used?**

Sample Fuel Cycle Cost Estimate Analysis Methodology

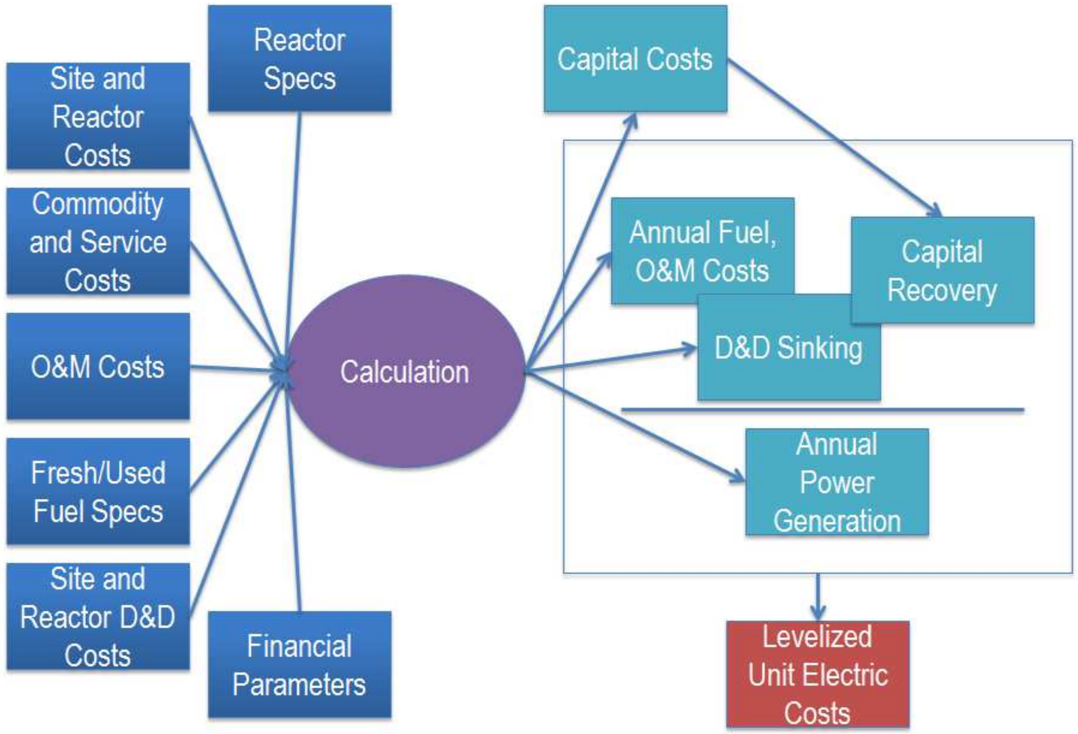
- **Step 1**
  - Calculate unit flow requirements, such as mass flows, for each step
  - Typically requires multiple physics-based calculations, especially for scenarios with reprocessing
- **Step 2**
  - Balance the mass flows for the total system—especially important for multi-tiered systems
- **Step 3**
  - Multiply all balanced units by the unit cost
- **Step 4**
  - Sum the costs
- **Step 5**
  - Divide by power

Sample Fuel Cycle Cost Estimate Analysis Methodology Engines

- **Number of ways to do the calculation ~ number of analysts doing the calculation**
- **Official calculation engine of Generation IV International Forum (GIF) is G4-ECONS**
  - Maintained at Oak Ridge National Laboratory
- **Specifically created for Gen-IV systems, such as SFRs**

Sample Fuel Cycle Cost Estimate Analysis Methodology

- **Methodology implemented in G4-ECONS**

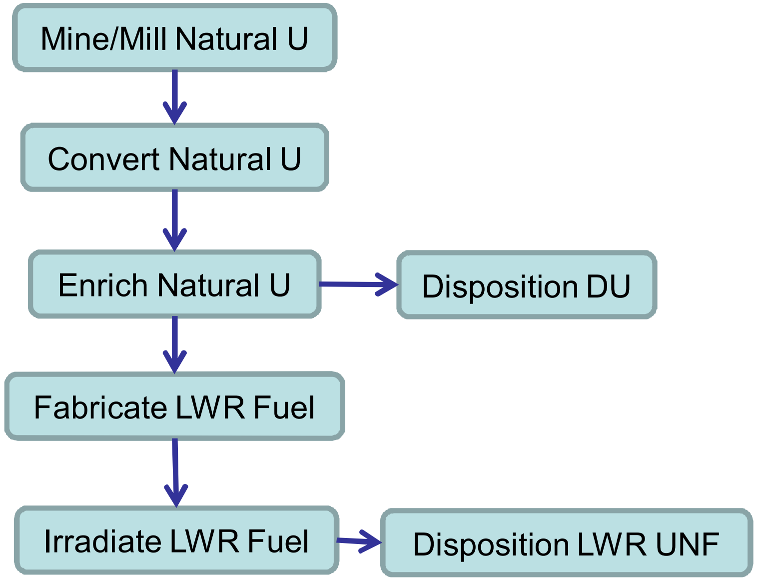


Sample Fuel Cycle Cost Estimate Results

- **A series of potential Pu-recycle schemes exist**
- **For example, compare**
  - PWR OT: Once-through low-enriched uranium light-water reactor
  - PWR CR: Continuous recycle of the Pu in an LWR with enriched uranium support
  - SFR CR: A self-sustaining Pu-recycling fast reactor
- **The Cost Basis allows us to compare them on a consistent basis and look for the major cost driver and potential differences (additions or savings) in cost between alternatives**
- **All analyses performed using G4-ECONS and the 2009 Cost Basis**

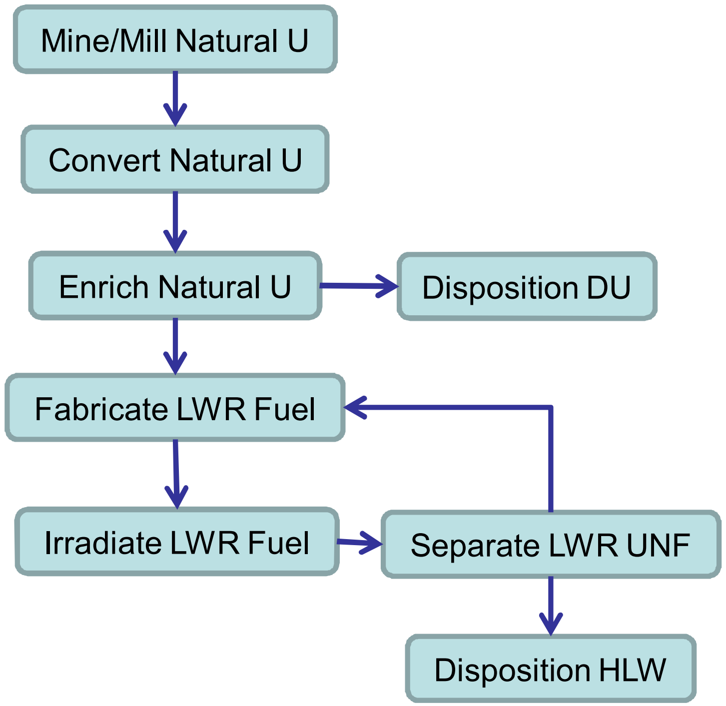
Sample Fuel Cycle Cost Estimate Results LWR Once Through

- **PWR OT: Once-through low-enriched uranium light-water reactor**



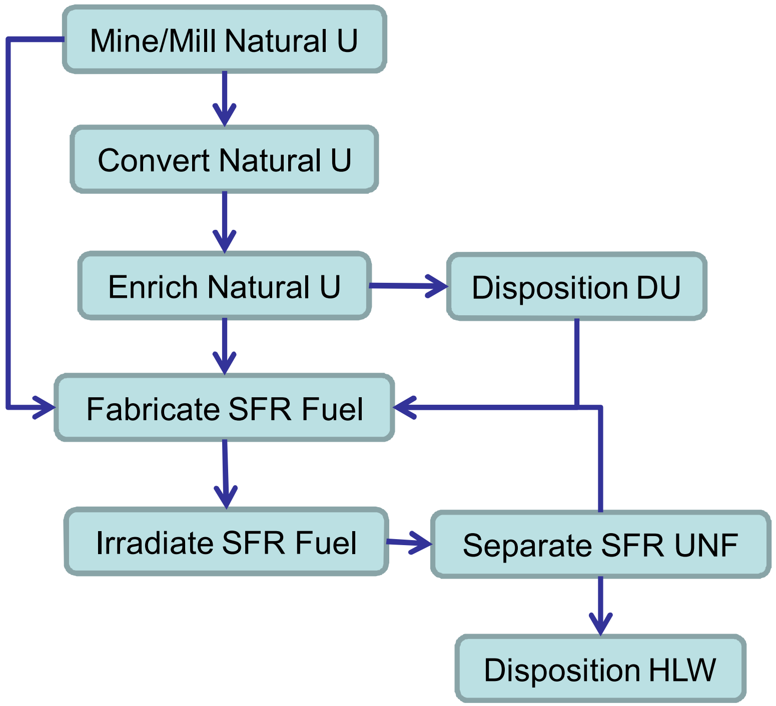
Sample Fuel Cycle Cost Estimate Results
LWR Continuous Recycle

- **PWR FR: Continuous recycle of the Pu in an LWR with enriched uranium support**



Sample Fuel Cycle Cost Estimate Results
SFR Continuous Recycle

- **SFR FR: A self-sustaining Pu-recycling fast reactor**

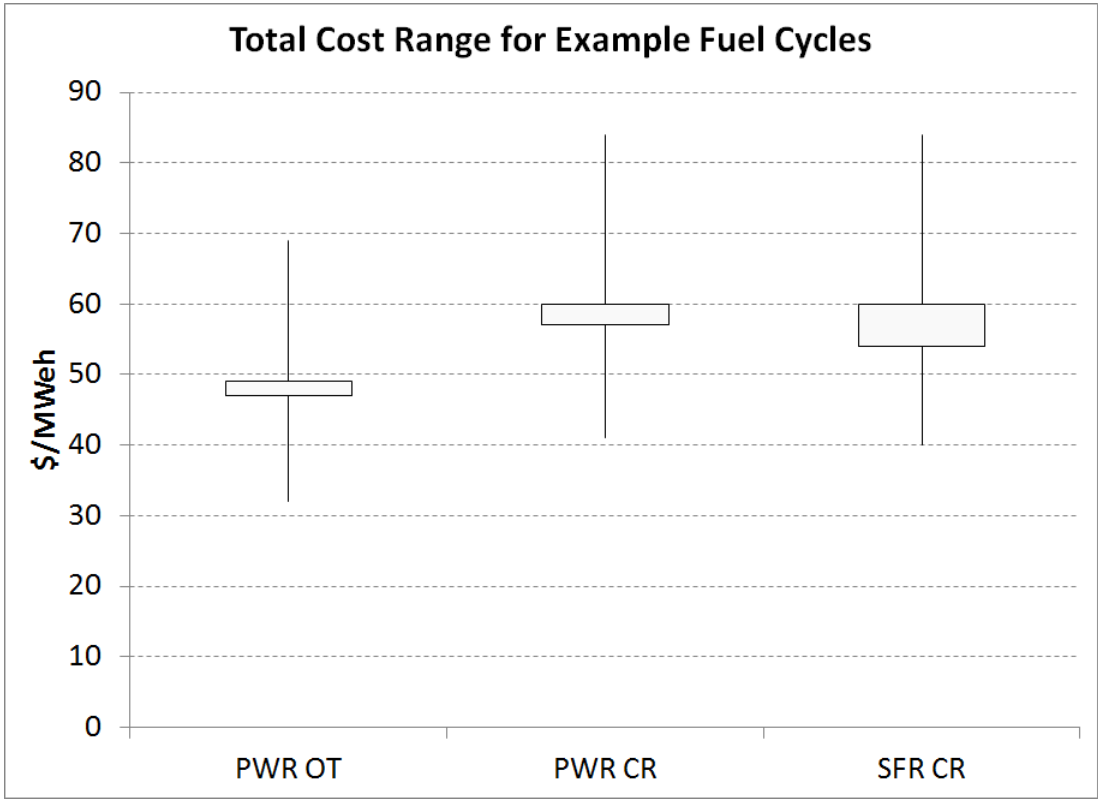


Sample Fuel Cycle Cost Estimate Results
Simple Analysis

- **Simple sample analysis**
  - All values at the low end—sets lower bound
  - All values at the mean—expected value for large number of simulations
  - All values at the nominal—point estimate using assumed values for each component
  - All values at the high end—sets upper bound

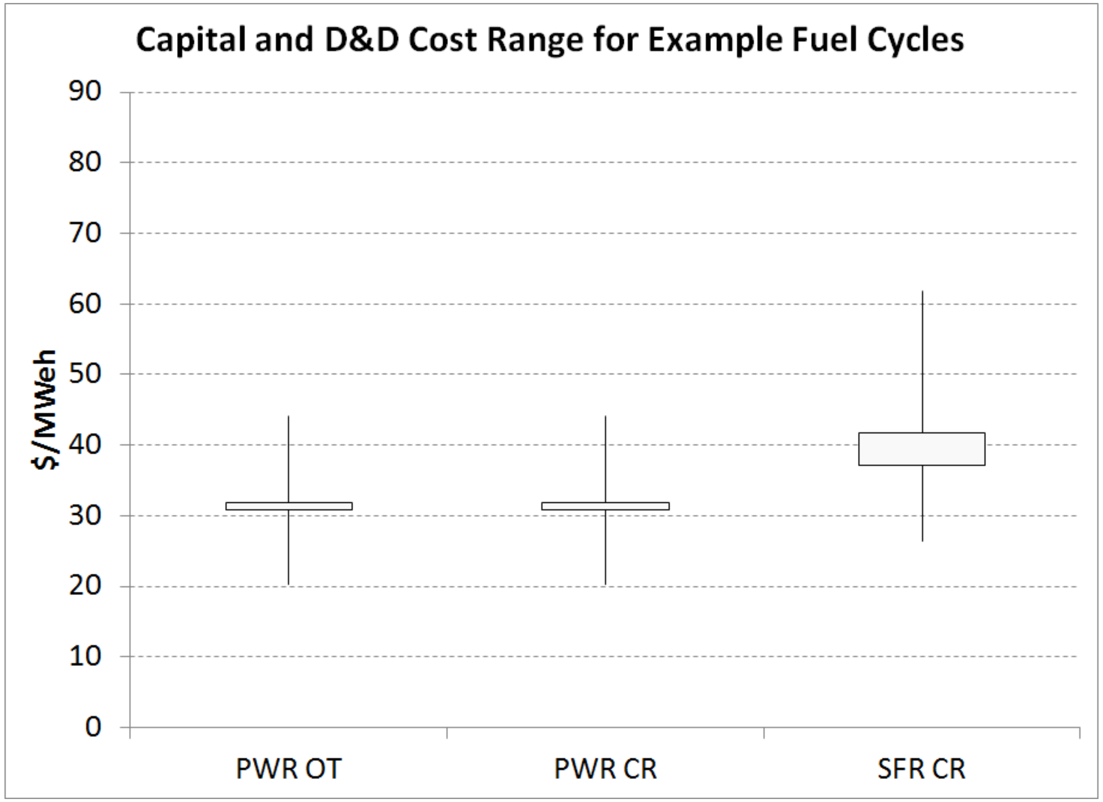
Sample Fuel Cycle Cost Estimate Results Total Levelized Cost Range

- **Plot shows Min, Mode, Mean, and Max**



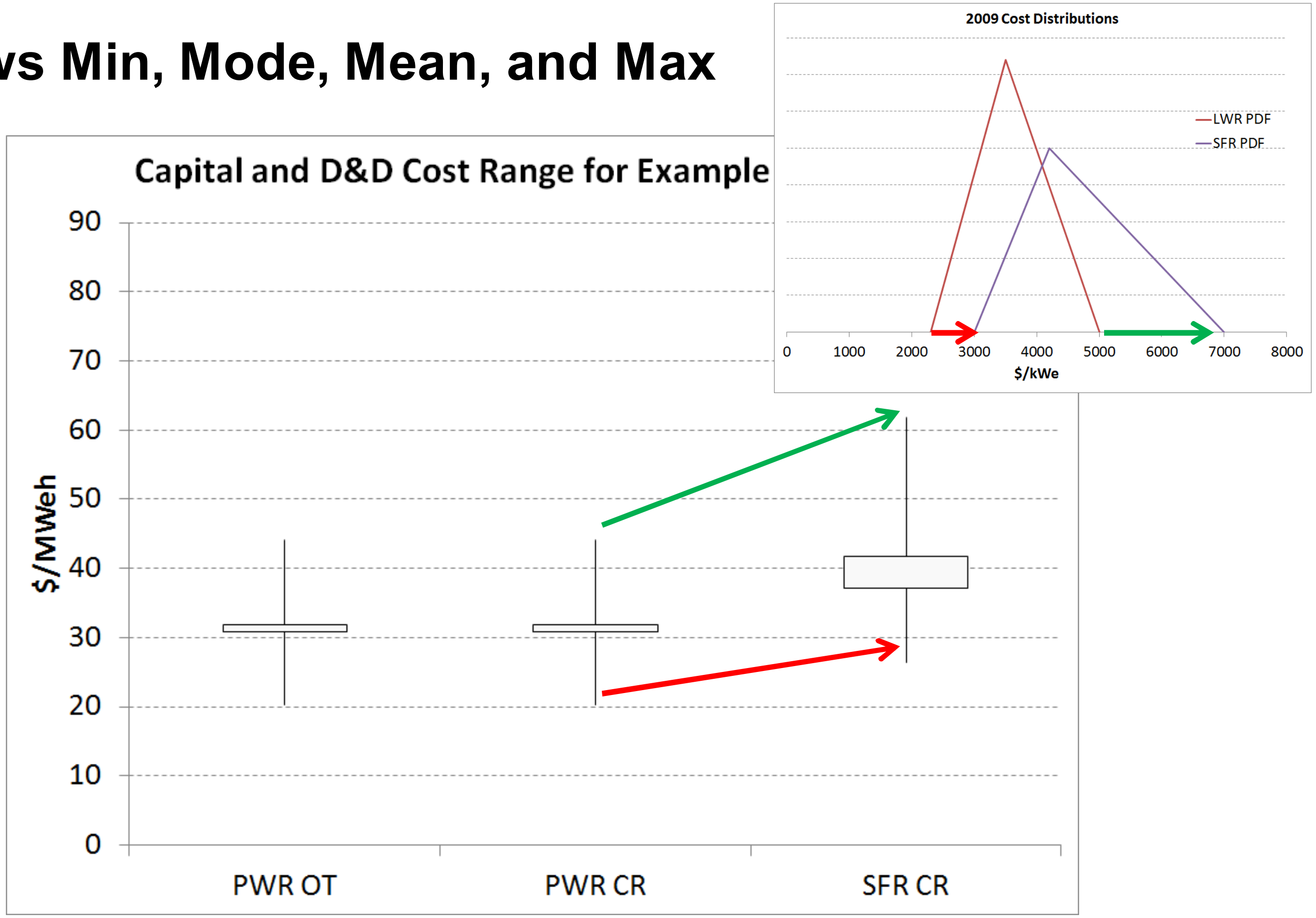
Sample Fuel Cycle Cost Estimate Results Reactor Share of Levelized Cost Range

- **Plot shows Min, Mode, Mean, and Max**



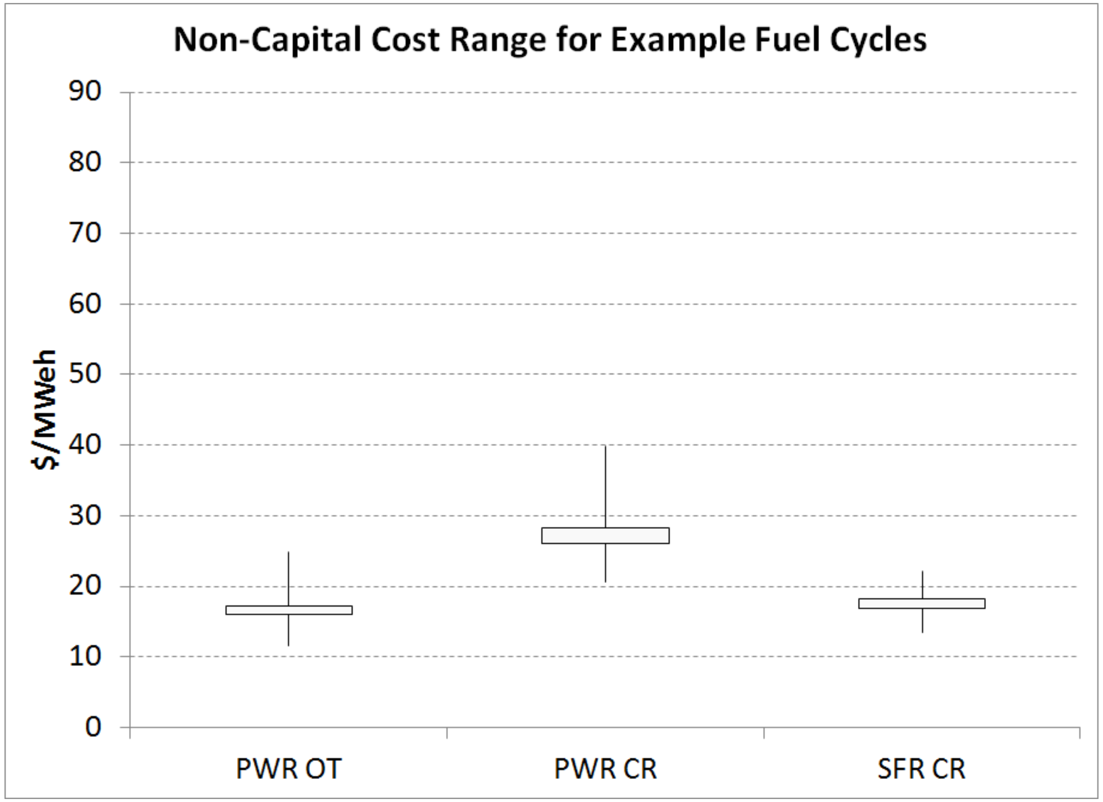
Sample Fuel Cycle Cost Estimate Results
Reactor Share of Levelized Cost Range

- **Plot shows Min, Mode, Mean, and Max**



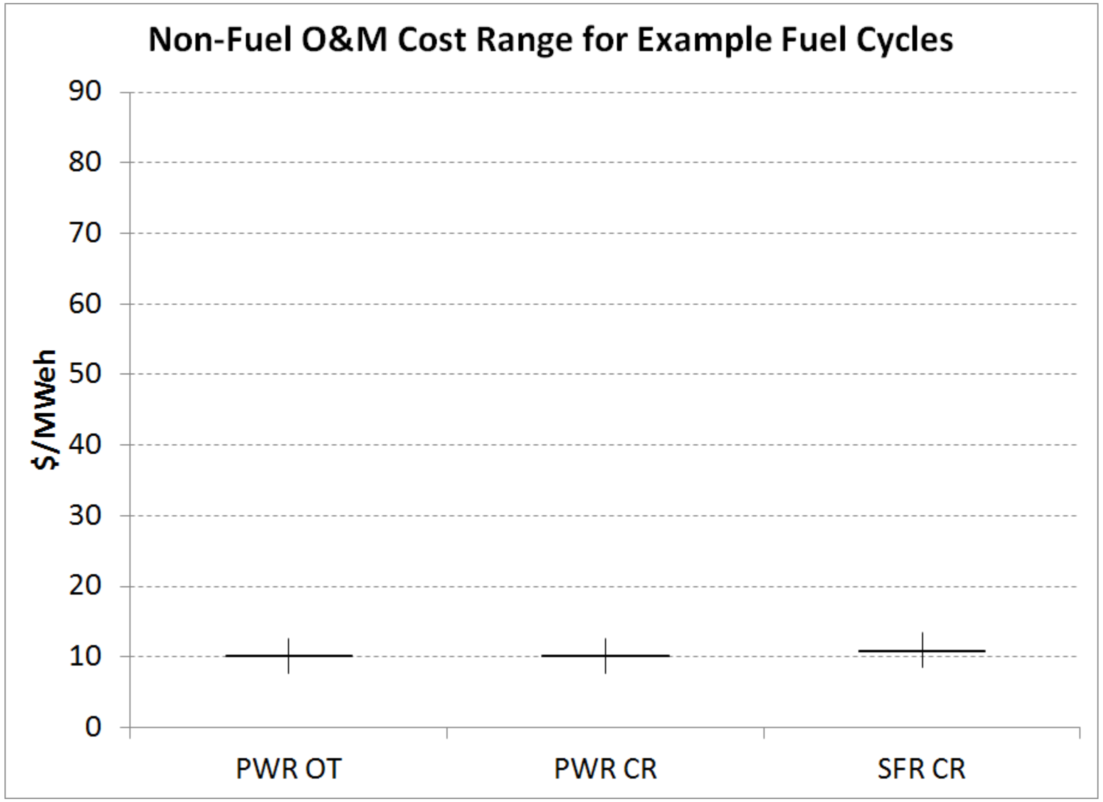
Sample Fuel Cycle Cost Estimate Results
Non-Capital Cost Range

- **Plot shows Min, Mode, Mean, and Max**



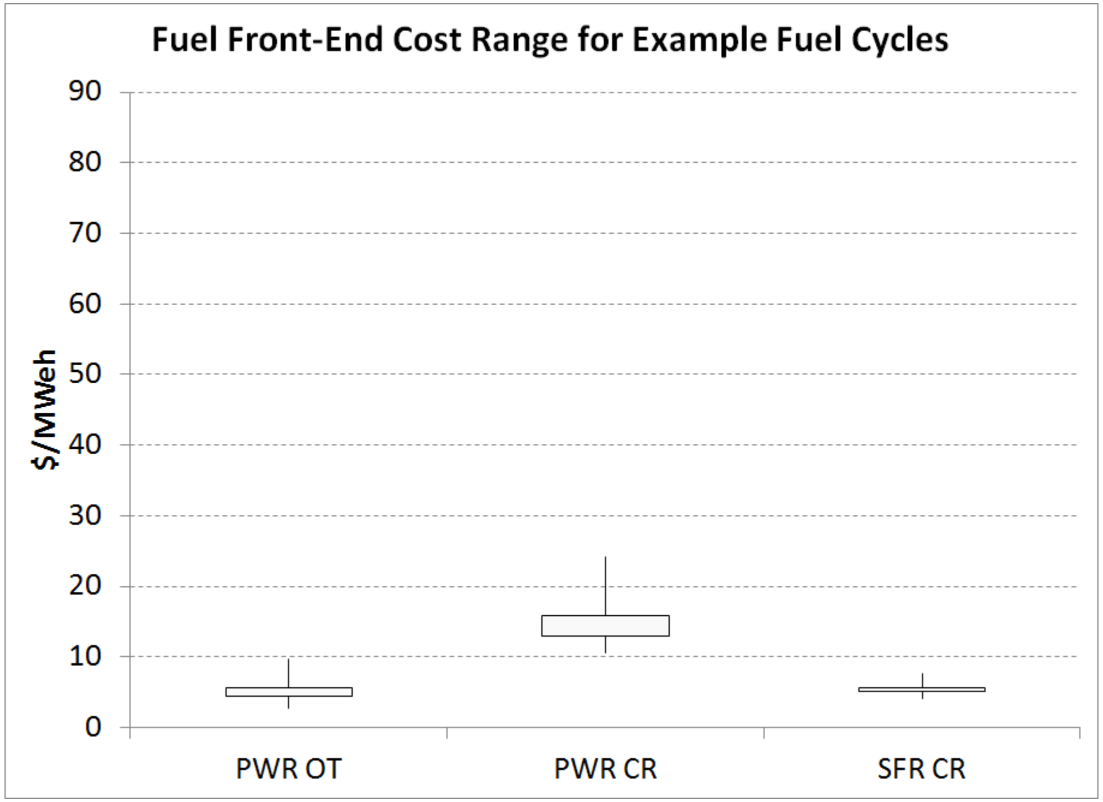
Sample Fuel Cycle Cost Estimate Results
Non-Fuel O&M Cost Range

- Plot shows Min, Mode, Mean, and Max



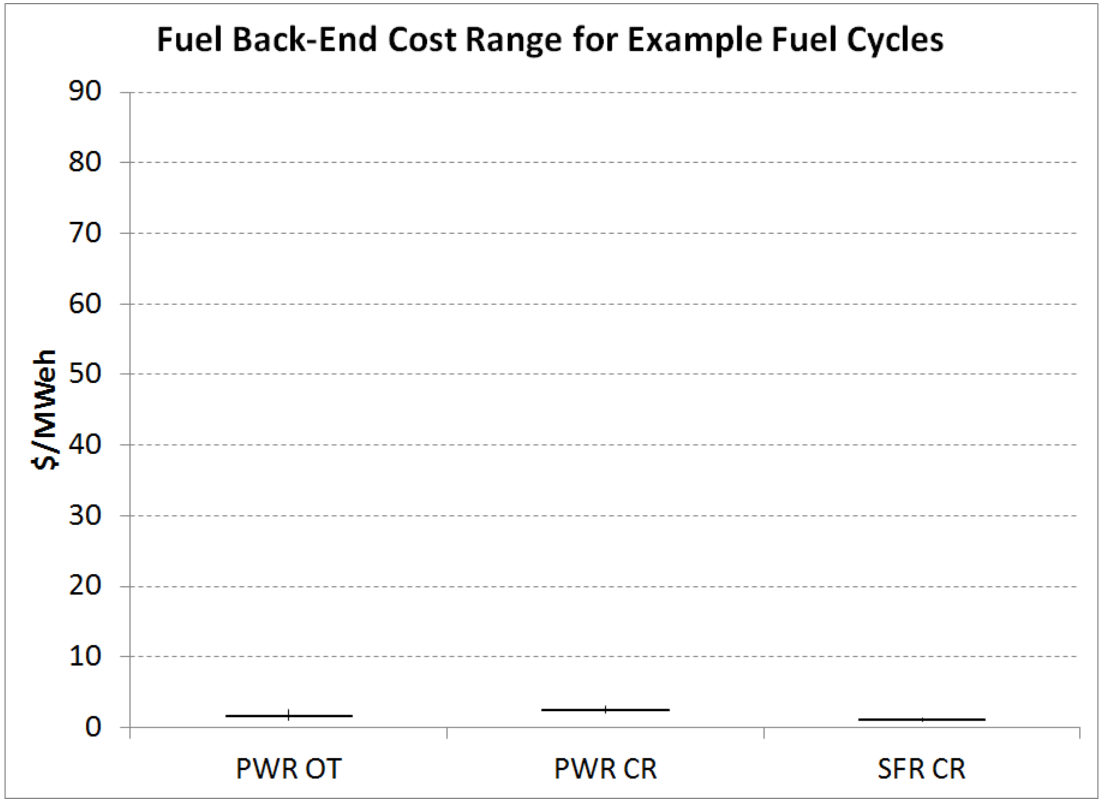
Sample Fuel Cycle Cost Estimate Results
Front-End Fuel Cost Range

- **Plot shows Min, Mode, Mean, and Max**



Sample Fuel Cycle Cost Estimate Results Back-End Fuel Cost Range

- Plot shows Min, Mode, Mean, and Max



Sample Fuel Cycle Cost Estimate Results Conclusions

- **Result conclusions—SFR systems:**
  - Have larger expected costs due to the larger expected SFR capital cost
  - Decrease the expected costs on the fuel front end, due to better resource utilization and reduced reliance on enrichment
  - The capital cost and fuel front end costs roughly balance, making the SFR continuous recycle competitive with the LWR continuous recycle
  - Compare favorably with LWR systems for O&M and the fuel back-end
- **One more conclusion—nuclear systems in general:**
  - Show large uncertainties in potential cost, mostly due to uncertainties in the capital cost

Future Work

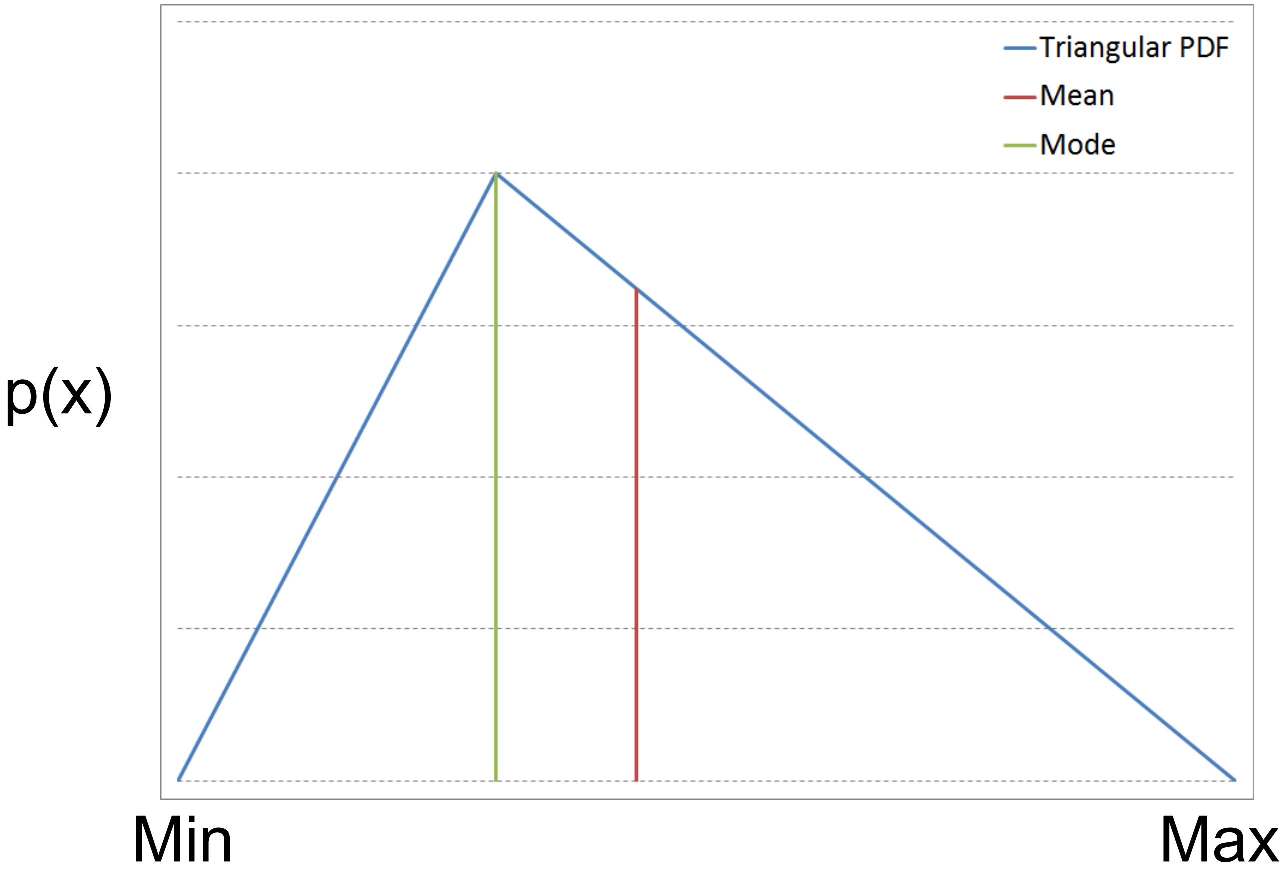
- **Work continues on correlation studies**
  - Uncorrelated cost distributions are simple to use in analysis
  - How do you handle correlated costs?

Questions?

Backup Slides

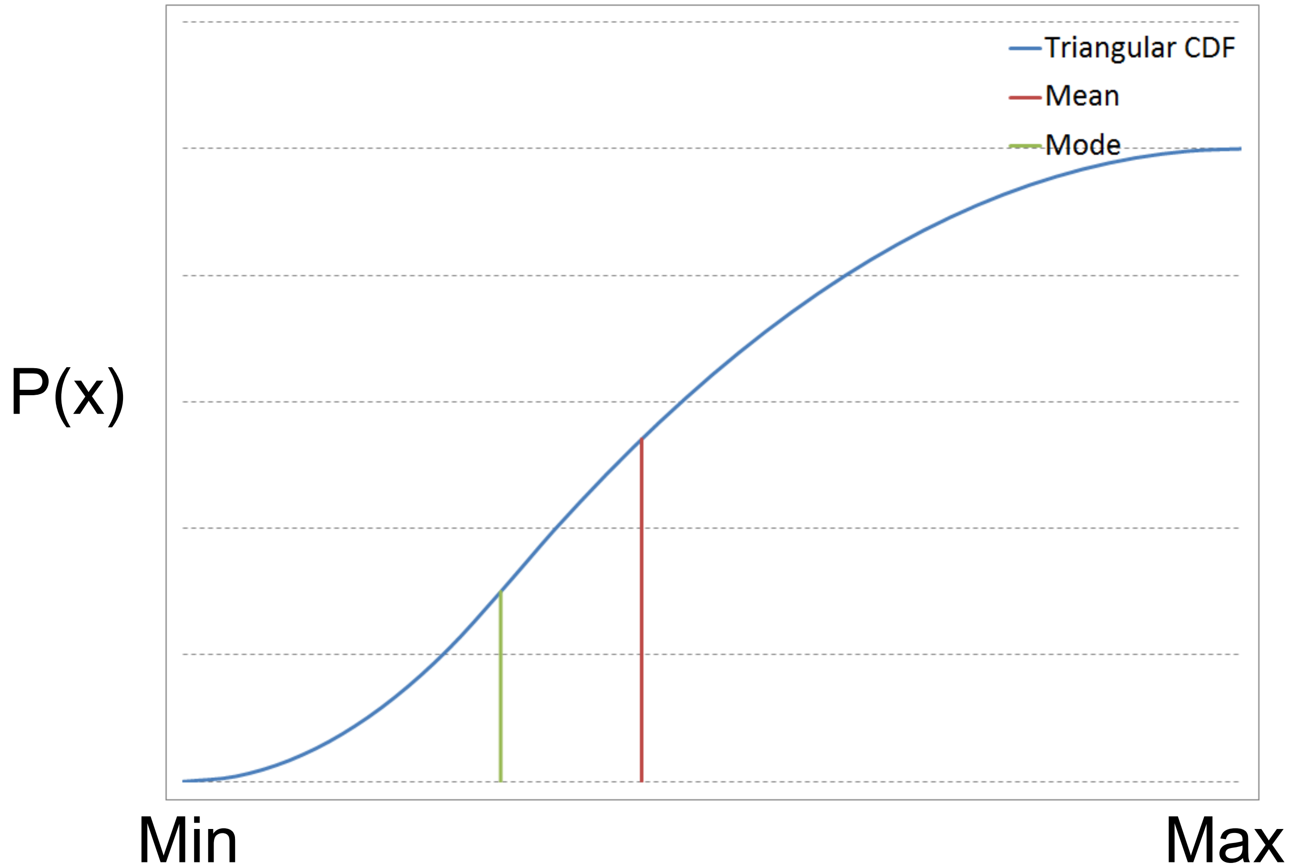
Backup Slides (cont'd)

- Unit cost triangular distribution—right skewed



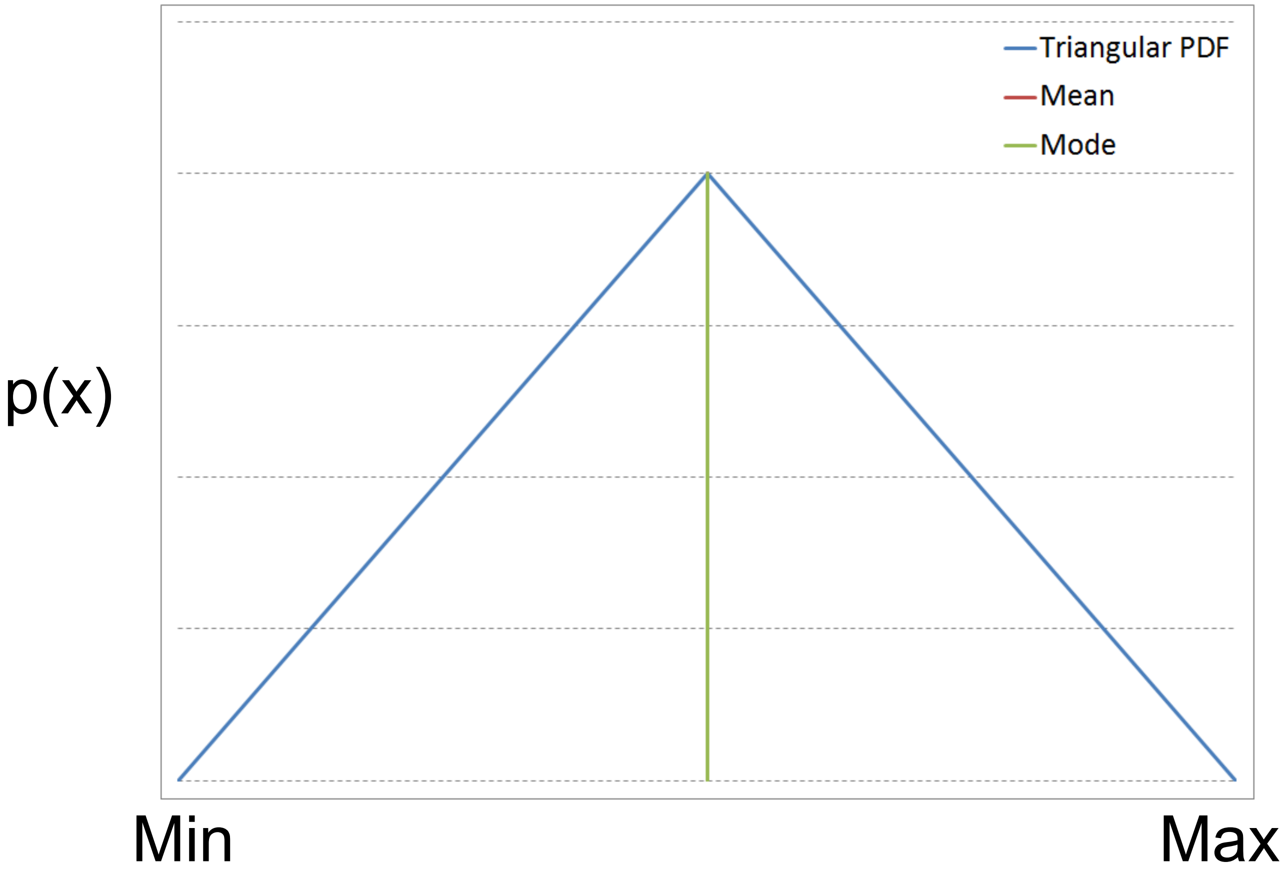
Backup Slides (cont'd)

- **Unit cost triangular distribution—right skewed**



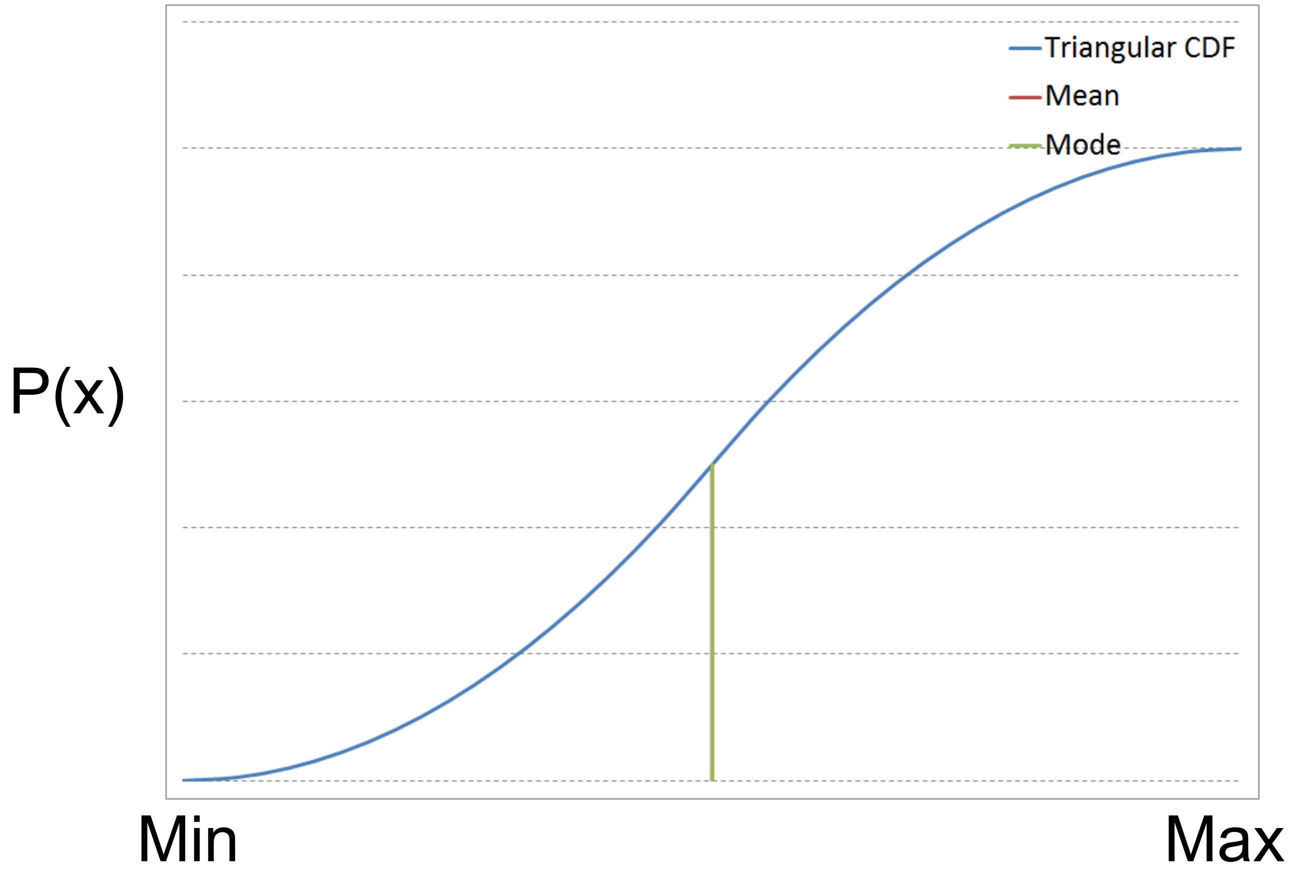
Backup Slides (cont'd)

- **Unit cost triangular distribution—symmetric**



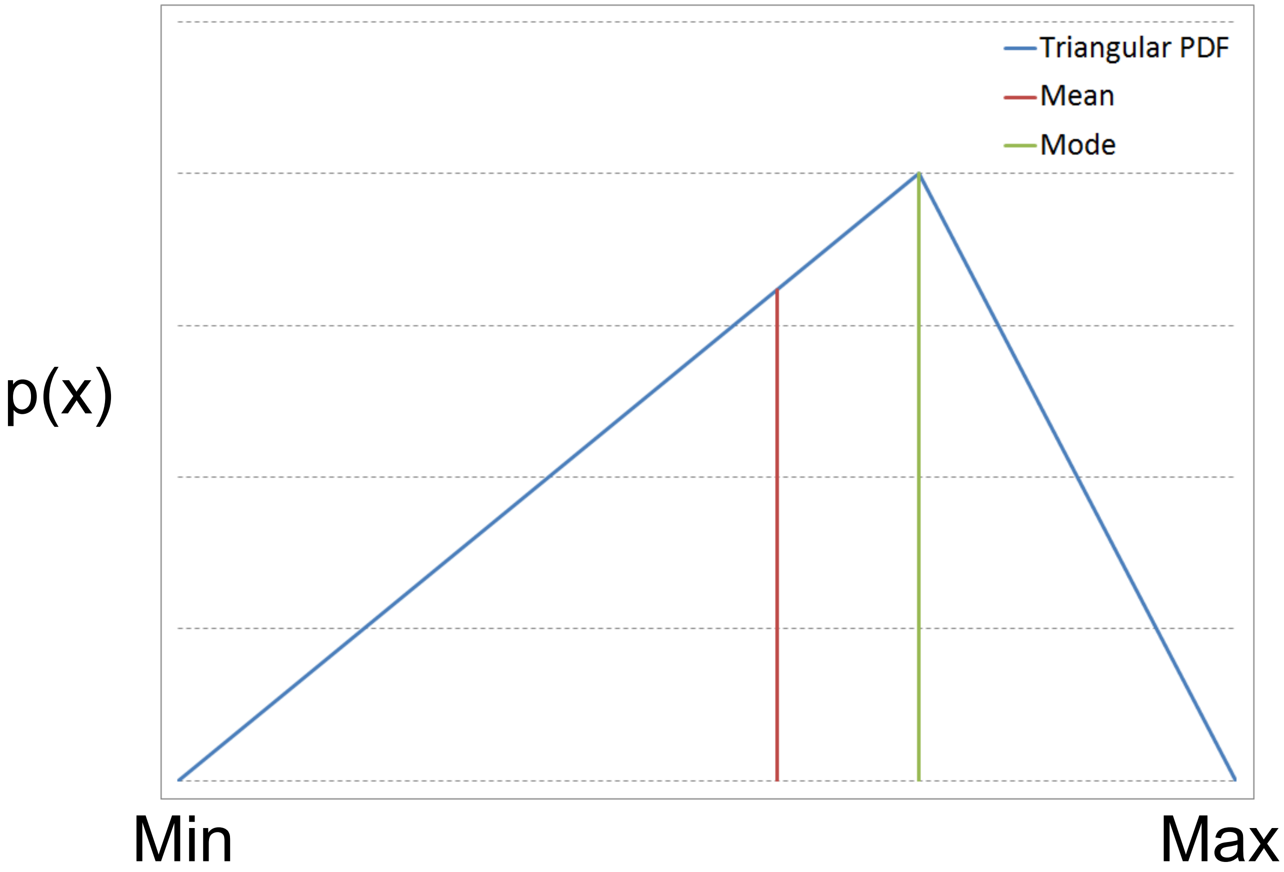
Backup Slides (cont'd)

- **Unit cost triangular distribution—symmetric**



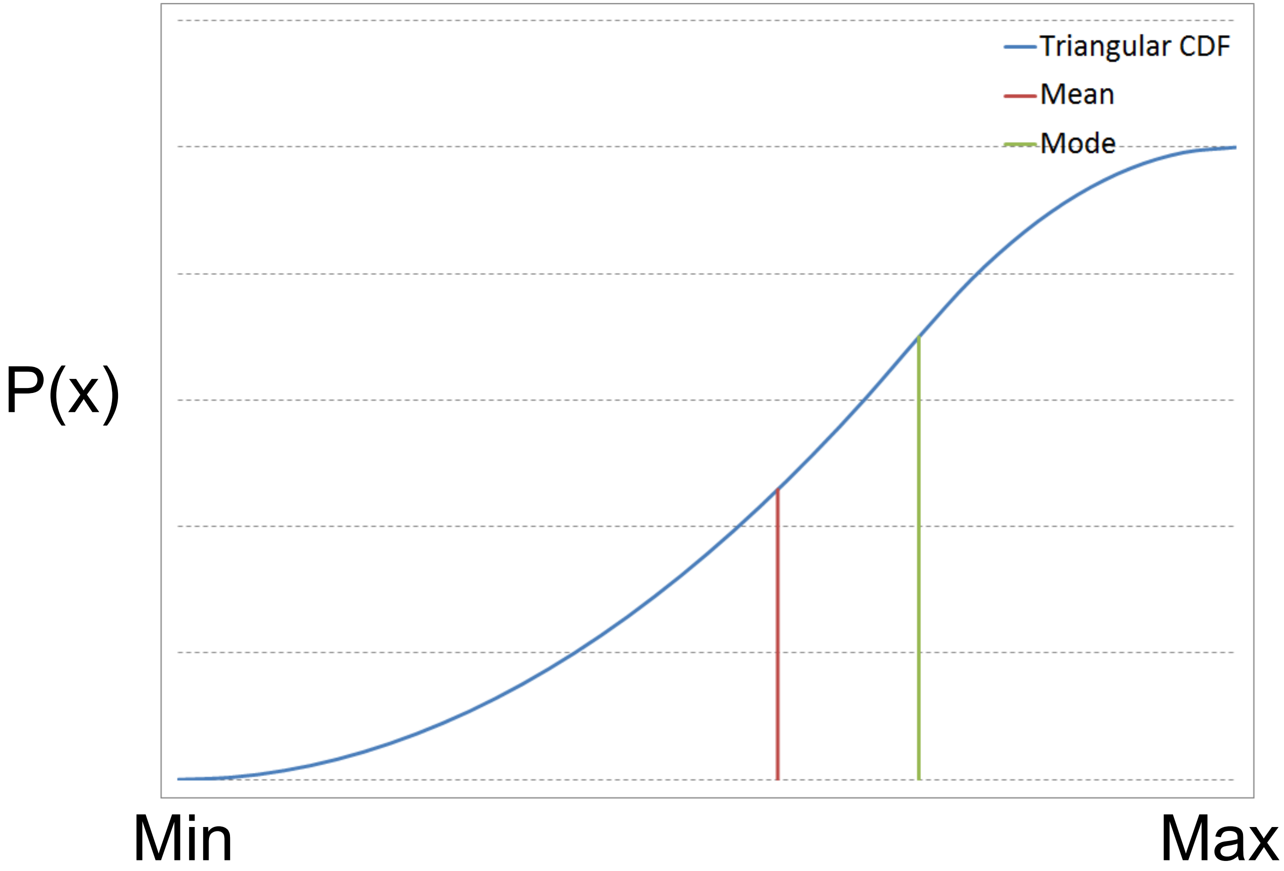
Backup Slides (cont'd)

- **Unit cost triangular distribution—left skewed**



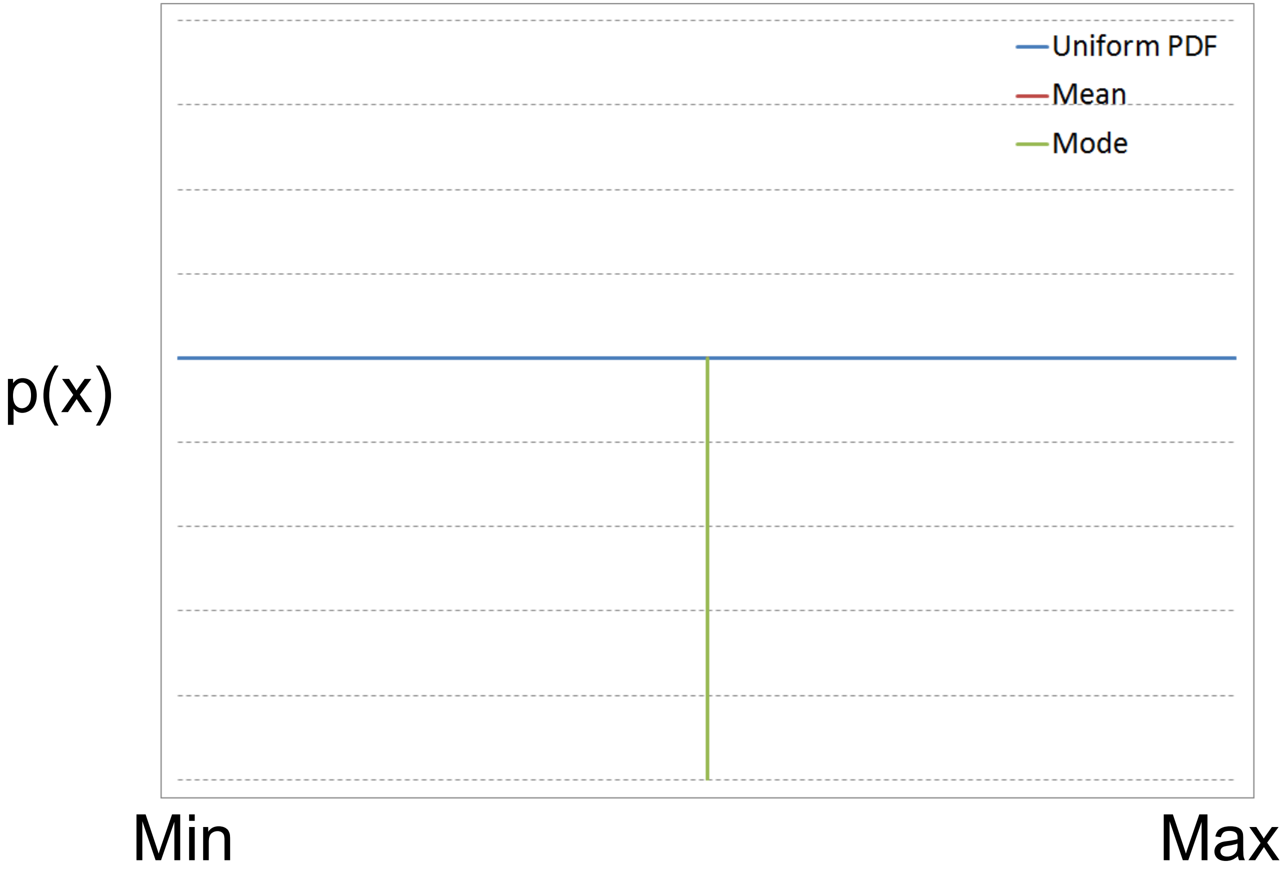
Backup Slides (cont'd)

- **Unit cost triangular distribution—left skewed**



Backup Slides (cont'd)

- **Unit cost uniform distribution**



Backup Slides (cont'd)

- **Unit cost uniform distribution**