Multi-Track Strategies for Risk Assessment

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Carbon Capture Challenge

- The traditional pathway from discovery to commercialization of energy technologies is long\(^1\), i.e., ~20-30 years.

- Technology innovation increases the cost growth, schedule slippage, and the probability of operational problems.\(^2\)

- President’s plan\(^3\) requires that barriers to the widespread, safe, and cost-effective deployment of CCS be overcome within 10 years.

- To help realize the President’s objectives, new approaches are needed for taking concepts from lab to power plant, quickly, at low cost and with minimal risk.

- CCSI will accelerate the development of CCS technology, from discovery through deployment, with the help of science-based simulations.

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Risk Definition

• Stated Goal of CCSI Program is removing barriers to widespread carbon capture within **10 years** at minimum cost and **low risk**

• Risk has many facets associated with negative or adverse outcomes (undesired consequence)

• Always has a flavor of relative frequency (times per year) or probability (chances in a thousand)

• Formal methods combine frequency and consequence to make choices despite uncertainty in:
  – Quality of information
  – Completeness of information
  – Details of physical complexity
Facets of Carbon Capture Risk

• Risk perspectives vary depending on goals and objectives (point of view)
• Risk of …
  – Not meeting 10-yr time compression schedule
  – Environmental impacts from new processes
  – Unacceptable COE impacts
  – Interrupting reliable electric power
  – Insufficient infrastructure to support capture/disposition
    • skilled labor, land, CO2 distribution, raw materials, design and construction services for specialty equipment

Each high-level risk measure can involve a complex system of factors and interactions
Decision Framework Architecture

- Focus on merger of Technical and Financial risk components
- Adopt risk perspectives of power producer – ultimate technology customer
  - Interpret all technical risk factors in financial business perspective
Integration Framework

UQ Framework

Risk Analysis & Decision Making Framework

Particle & Device Scale Simulation Tools and Models

Process Synthesis & Design Tools and Models

Plant Operations & Control Tools and Models

Basic Data

ROMs
MultiTrack Strategy for CCSI Risk Assessment

- Enumerate risk contributors for qualitative prioritization and tracking
- Define traditional development path using tailored Technology Readiness Levels (TRL) and chemical process maturation cycle
- Functional Analysis of capture process performance vulnerability
  – FMEA, Fault Tree, Bayesian Updating
- Interface both qualitative and quantitative performance attributes in a comparative financial lifecycle analysis
- Propagate uncertainties into formal decision metrics affecting implementation

“Multitrack Strategy” is now growing towards integrated decision analysis model
Decision Making Framework

Financial Risk Model

Sensitivity Analysis

Technical Risk Model

Functional system performance analysis

Uncertainty Analysis (E6)

Functional Analysis (E3)

Technical Readiness Level: TRL-5

0.9905 Likelihood

Did thorough testing? Initiated in a laboratory environment?

Did the broadboard have realistic interfaces?

Was the programmatic risk management plan documented?

Has a configuration management plan been documented and implemented?

Has a formal inspection of all components been completed?

Is the draft Test and Evaluation Master Plan (TEMP) documented?

Is the draft Systems Engineering (SE) plan completed?

CCSI
Carbon Capture Simulation Initiative

NETL

BEERKELEY LAB

Lawrence Livermore National Laboratory

Los Alamos National Laboratory

Pacific Northwest National Laboratory

U.S. DEPARTMENT OF
ENERGY
Technical Risk Approach: Evolves with Maturity
Carbon Capture Process System: Solid Sorbent

2 Stage, Counter-currently connected Bubbling Fluidized bed Adsorber + Moving bed Regenerator
Risk Analysis

Functional Performance

Characteristics

Attributes

Carbon Loading

Mechanical (PRA)

Sorbent (UQ)

Fatigue
Erosion
Particle Distribution
Selectivity
# Technology Maturity

## CCSI Technology Readiness Level (TRL) Questionnaire

<table>
<thead>
<tr>
<th>TRL</th>
<th>Question</th>
<th>Points</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Has a lab-scale testing of equipment (bench) been completed in simulated environment?</td>
<td>1 kW</td>
<td>Commercial operation in relevant environment</td>
</tr>
<tr>
<td>8</td>
<td>Has acceptance testing of individual components been performed?</td>
<td></td>
<td>Commercial demonstration, full scale deployment in final form</td>
</tr>
<tr>
<td>7</td>
<td>Does a draft system architecture plan exist?</td>
<td></td>
<td>System prototype in an operational environment</td>
</tr>
<tr>
<td>6</td>
<td>Does technology demonstrate basic functionality in simplified environment?</td>
<td></td>
<td>Fully integrated pilot (prototype) tested in a relevant environment</td>
</tr>
<tr>
<td>5</td>
<td>Has performance characteristics been demonstrated in a laboratory environment?</td>
<td></td>
<td>Component validation in relevant environment (coal plant)</td>
</tr>
<tr>
<td>4</td>
<td>Does a draft system architecture plan exist?</td>
<td></td>
<td>Component validation tests in laboratory environment</td>
</tr>
<tr>
<td>3</td>
<td>Have performance characteristics been demonstrated in a laboratory environment?</td>
<td></td>
<td>Analytical and experimental critical function proof-of-concept</td>
</tr>
<tr>
<td>2</td>
<td>Does a draft system architecture plan exist?</td>
<td></td>
<td>Formulation of application</td>
</tr>
<tr>
<td>1</td>
<td>Has a lab-scale testing of equipment (bench) been completed in simulated environment?</td>
<td></td>
<td>Basic principals</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MRL</th>
<th>Question</th>
<th>Points</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Are most system components available (laboratory surrogates in some cases)?</td>
<td></td>
<td>Component validation in relevant environment (coal plant)</td>
</tr>
<tr>
<td>5</td>
<td>Have designs been verified through formal inspection process?</td>
<td></td>
<td>Component validation tests in laboratory environment</td>
</tr>
<tr>
<td>4</td>
<td>Are scaling studies and architecture diagrams completed?</td>
<td></td>
<td>Analytical and experimental critical function proof-of-concept</td>
</tr>
<tr>
<td>3</td>
<td>Has a formal risk management program been initiated?</td>
<td></td>
<td>Formulation of application</td>
</tr>
<tr>
<td>2</td>
<td>Are project risk management been integrated with project management?</td>
<td></td>
<td>Basic principals</td>
</tr>
<tr>
<td>1</td>
<td>Have functional requirements been finalized?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TRL Likelihood

\[
L_i = f(k; n, p) = \binom{n}{k} p^k (1-p)^{n-k}
\]

- **TRL** is Technology Readiness Level
- **MRL** is Manufacturing Readiness Level
- **PRL** is Programmatic Readiness Level
- **S** is for software
- **H** is for hardware
- **B** is for both software and hardware
Financial Risk Model

• Risk attribute propagation through a financial balance sheet that incorporates variable lifecycle costs and other factors related to carbon capture

• Illustrates information flow from qualitative risk factor assignment and UQ from other CCSI tasks into familiar decision metrics like 30-year net present value

• Provides sensitivity measures for determining which factors are most critical for ensuring the successful adoption of carbon capture technology

• Provides means for weighing relative merits of improving carbon capture technology and determine which factors (e.g., carbon capture percentage, capital costs, operating costs, parasitic power losses, etc.) are most important contributors to financial risk

• Illustrates concepts of probabilistic decision making that are less familiar to power production industry
Preliminary Risk Analysis

Technical Risk Results

Sensitivity analysis, showing effect of each parameter on the financial risk model results (NPV)

Financial Risk Model

Comparison of marginal distributions on the financial risk model results (NPV) (line represents uniform, while the histogram represent non-uniform)
Risk Evaluation Summary

• The technical risk approach is designed to provide increasing reliability of the system as details mature
  – Identifies vulnerabilities and their relative importance
  – Suggests prioritized areas for additional R&D, functional analyses, or design improvements

• TRL provides baseline to traditional development scales and can be tailored to track independent components

• Qualitative risk factor elicitation provides perspectives on completeness and quantifies stakeholder confidence

• Financial lifecycle analysis provides monetized business context in which to evaluate the effects of complex physical systems

  Ultimate Value

• Diagnostic risk evaluation can direct further simulation and experimental studies for optimum risk reduction

• Fully integrated framework will support technology comparison
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