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DOE R&D in Support of High Burnup Spent Fuel Dry Storage and Transportation

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NWTRB Meeting
February 17, 2016
Knoxville, TN

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Nuclear Energy Research and Development: an Integrated Approach

Front End

Uranium Resources

- *Conventional production*
- *Innovative approaches*
  - *U Seawater*

Fuel Fabrication

- *Safety enhanced LWR fuel*
  - *Accident tolerance*
- *Higher performance*
  - *Improved burnup*

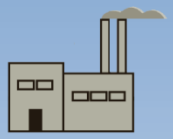
Reactors

- *Light Water Reactor Sustainability*
- *SMR support and R&D*
- *Advanced Reactors*

Back End

Interim Storage

- *Evaluating extended time frames*
- *Transport after storage*



Recycle

- *Separations*
- *Recycled fuel*
- *Secondary waste treatment*

Disposal

- *Alternative geologies*
- *Alternative waste forms*

←----------*Safeguards and Security By Design*----------→

Optimize through Systems Analysis, Engineering, and Integration

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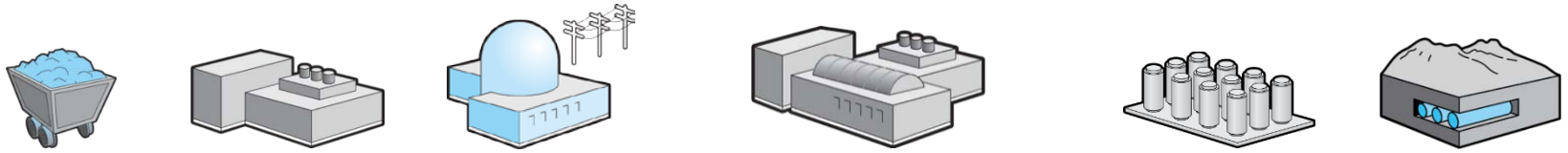
The Nuclear Fuel Cycle as a System Could Incorporate Many Components



Uranium Supply | **Enrichment & Fuel Fabrication** | **Reactors** | **Recycle** | **Interim Storage** | **Final Disposal**

"Once Through" fuel cycle - Today

Conventional Mining

Seawater Extraction

Other Advanced Techniques

Conventional LWR Fuel Fabrication

LWR Fuel with Improved Accident Tolerance

Light Water Reactors

Used LWR Fuel Recycle

Interim Storage

Geologic Repository

Product

Waste Forms

"Recycle" fuel cycle options – the Future?

Advanced Reactor Fuel

Advanced Reactors

Advanced Reactor Fuel Recycle

LLW Disposal

Safeguards and Security by Design

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Used Fuel Disposition Campaign (UFDC) Storage and Transportation R&D Objectives

1. **Support the development of the technical bases to demonstrate used fuel integrity for extended storage periods**
2. **Develop the technical bases for fuel retrievability and transportation after long term storage**
3. **Develop the technical bases for transportation of high burnup fuel**

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Performance of the Storage and Transportation Systems

Material Strength

- **Cladding Structural Integrity**
  - Hydride re-orientation
    - *Thermal profile*
    - *Internal rod pressure*
  - Drying & corrosion
  - Fatigue during transport
  - Creep
  - Oxidation
  - Annealing
  - Brittle behavior
- **Canister Structural Integrity**
  - Cracking of canister welds from
  - Aqueous corrosion (drying)
  - Fatigue in shipping
- **Cask Structural Integrity**
  - Bolted lids
  - Metallic lid seals
  - Concrete weathering
  - Lifting hardware
  - Overpack corrosion / Freeze-Thaw
  - Poison Creep

Stress Profiles

- **Storage Stresses**
  - Tipping over
  - Routine handling
  - Dropping
  - Gravity
- **Transportation Stresses**
  - Road and rail vibrations
  - Road and rail shocks

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Gap Prioritization (1) – 2014

Comprehensive technical gap analyses have been performed to identify and rank data needs

Gap[a]	Updated Prioritization	Original Prioritization	Basis for Change in Scoring/Prioritization
Thermal Profiles	1	1	N/A
Stress Profiles	1	1	N/A
Monitoring - External	2	2	N/A
Welded Canister – Atmospheric Corrosion	2	2	N/A
Drying Issues	3	6	N/A
Monitoring - Internal	4	4	No longer a pre-requisite to the HBU Confirmatory Demo
Cladding – H_2 Effects: Hydride Reorientation and Embrittlement	4	7	N/A
Neutron Poisons – Thermal Aging	4	7	N/A
Moderator Exclusion	5	8	N/A
Fuel Transfer Options	6	3	No longer a pre-requisite to the HBU Confirmatory Demo or a near-term need because DOE is pursuing a dry opening of the cask.
Welded Canister – Aqueous Corrosion	6	5	No longer a near-term need because aqueous conditions are unlikely to occur for a sufficient time to cause breach of confinement during the initial license period.
Bolted Casks - Thermomechanical Degradation of Metallic Seals and Bolts	6	5	No longer a near-term need because of the progress being made by the international community.
Bolted Casks - Atmospheric Corrosion	6	5	No longer a near-term need because of industry changes to weather cover designs, testing and maintenance.

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High Burn-up Confirmatory Data Project: Data to be Monitored

- **Fuel cladding temperature (indirect via thermocouple lances)**
- **Cavity gas monitoring is being evaluated**
  - Temperature
  - Composition
    - Fission gasses
    - Moisture
    - Hydrogen
    - Oxygen
  - Pressure
- **Active methods for sampling the gas were analyzed**
- **Use of remote sensors was evaluated to gather the needed data**
- **Gas sampling on the pad is still to be investigated**

Picture from North Anna ISFSI

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Sister Rod Testing

- **Supplement Analysis was completed December 28, 2015**
- **Rods were shipped from North Anna and received at ORNL**

LWT Cask is loaded on a truck at North Anna and impact limiter is being installed

LWT Cask is unloaded from the truck and placed on the trolley that is used to move the cask inside the lab building

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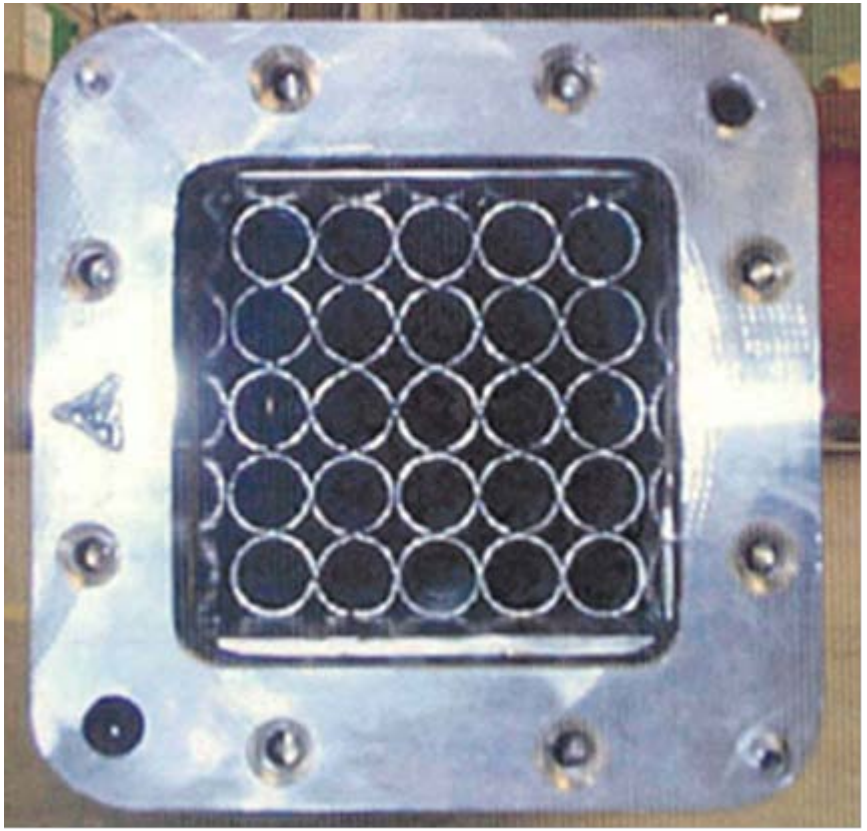
Sister Rod Selection

- **Individual rods have been pulled to perform characterization and material property tests to obtain initial cladding conditions prior to storage**
- **25 fuel rods from representative fuel assemblies**
- **These rods will form the baseline for pre- storage characterization**
  - 9 AREVA M5
  - 12 Westinghouse ZIRLO
  - 2 Westinghouse Zircaloy 4
  - 2 Westinghouse low tin Zircaloy 4



NAC LWT basket for shipping rods

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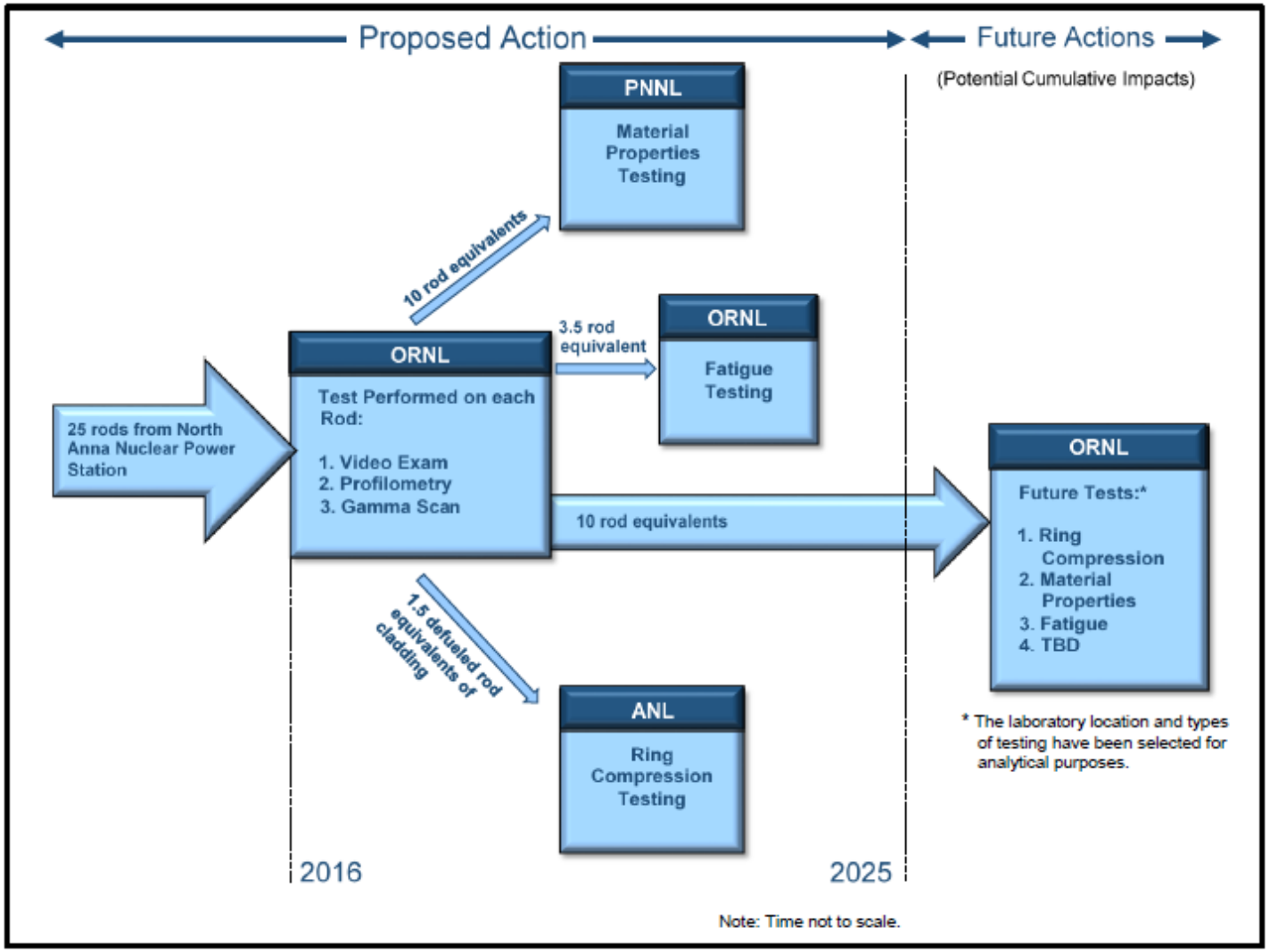
Overview of the Sister Rod Testing



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NE University Programs (NEUP) Funding for Storage and Transportation

Total Available Budget Area and Fiscal Year Award	Total
Storage & Transportation	$27,433,384
(11-2987) Anisotropic azimuthal power and temperature distribution on impact on hydride distribution - PSU	$631,957
(11-3117) Life Prediction of Spent Fuel Storage Canister Material - MIT	$899,826
(11-3278) Fuel Aging in Storage and Transportation (FAST): Accelerated Characterization and Performance - TAMU	$4,500,000
(12-3374) Validation Experiments for Spent-Fuel Dry-Cask In-Basket Convection - USU	$690,000
(12-3528) Radiation and Thermal Effects on Used Nuclear Fuel and Nuclear Waste Forms - UTK	$770,000
(12-3545) Concrete Materials with Ultra-High Damage Resistance Capacity For Extended Storage Systems - UH	$800,000
(12-3660) Simulations to Predict Used Nuclear Fuel Cladding Temperatures during Drying and Transfer Ops - UNR	$745,000
(12-3730) Probabilistic Multi-Hazard Assessment of Dry Cask Structures - UH	$865,000
(12-3736) Nonlinear Ultrasonic Diagnosis and Prognosis of ASR Damage in Dry Cask Storage - NU	$885,000
(12-3756) Seismic Performance of Dry Casks Storage for Long-Term Exposure - UU	$873,320
(13-4840) Development of a nano-modified concrete for next generation of storage systems - VU	$795,153
(13-5106) Risk Assessment of Structural Integrity of Transportation Casks - UU	$740,296
(13-5178) Structural Health Monitoring of Nuclear Spent Fuel Storage Facilities - USC	$597,832
(13-5365) Doubling the Life of Concrete Structures - UI	$640,000
(14-7356) Multi-Sensor Inspection and Robotic Systems for Dry Storage Casks - PSU	$3,000,000
(14-7730) Experimental and Modeling of Used Fuel Drying by Vacuum and Gas Circulation for Dry Storage - USC	$4,000,000
(15-9231) Multimodal Nondestructive Dry Cask Basket Structure and Spent Fuel Evaluation - UM	$3,000,000
(15-9318) Innovative Approach to SCC Inspection and Evaluation of Canister in Dry Storage - CSM	$3,000,000
Grand Total	$27,433,384

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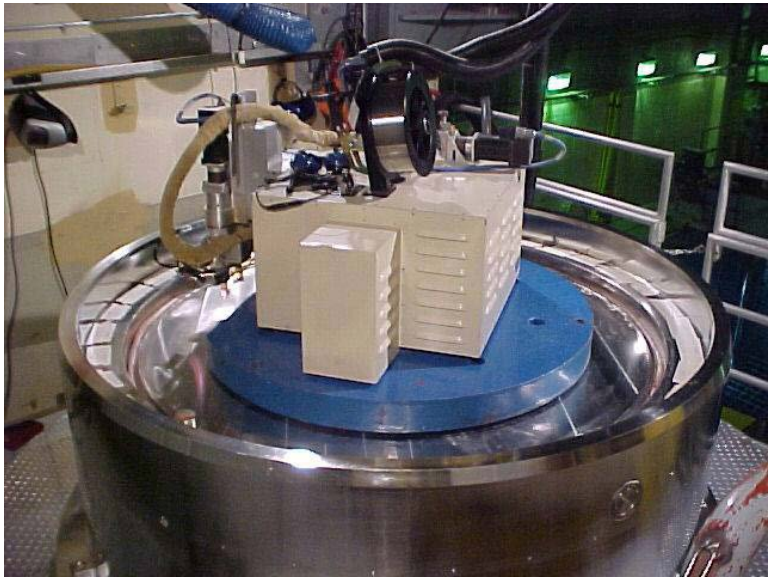
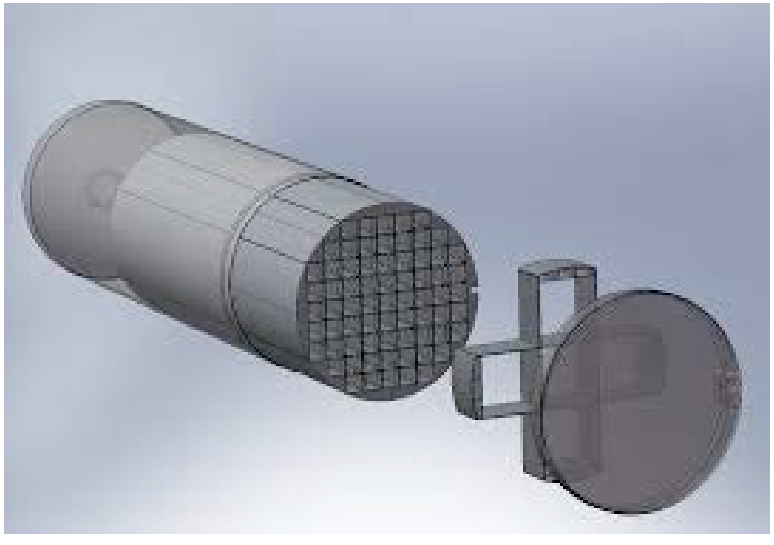
NEUP IRP
Canister Strength Drying Issues

- **HBU Demonstration cask will be sampled and analyzed for moisture**
- **A three year investigation has been awarded to investigate drying of used fuel canisters for dry storage.**
- **Objectives:**
  - This investigation will address questions surrounding the amount, form, and location of water remaining in dry casks/canisters.





UNIVERSITY OF SOUTH CAROLINA

UF UNIVERSITY of FLORIDA

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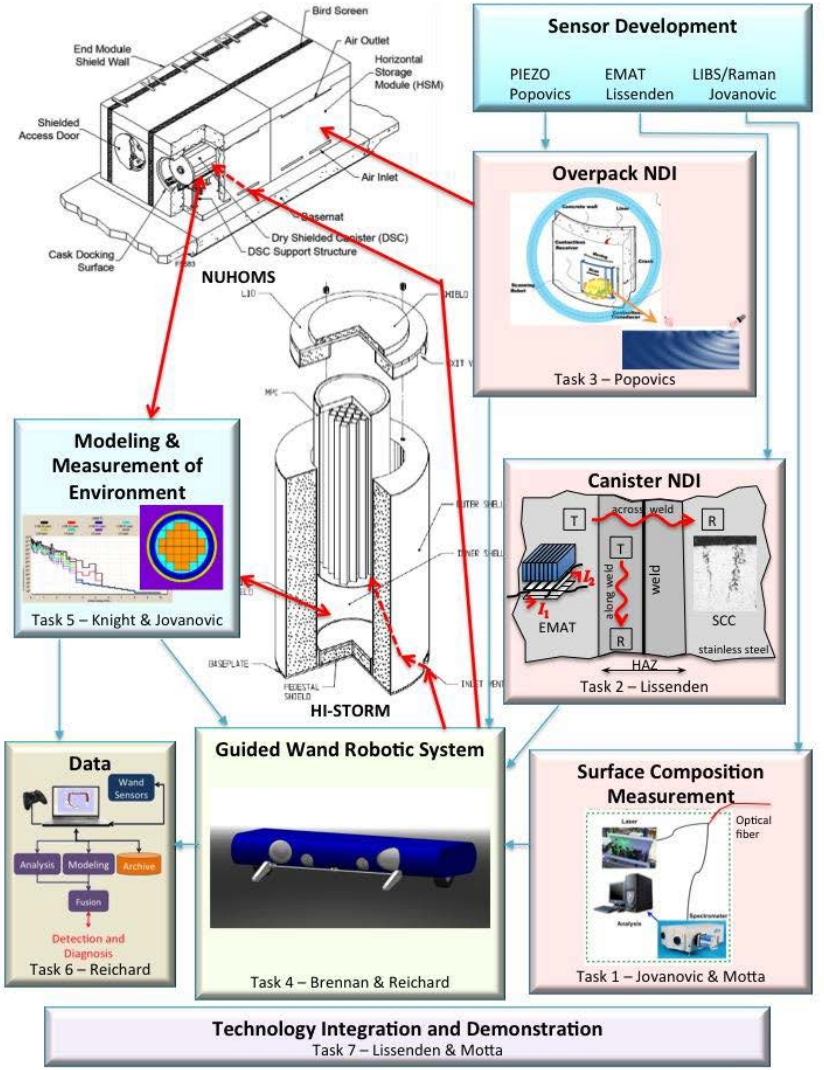
NEUP IRP
Cask Strength
Monitoring Cask System Performance

- Monitoring and observing existing welded canisters
- Stress corrosion cracking (SCC) and precursor detection
- Remaining water in a dried system
- Using remote sensors for measuring existing conditions
- Placing the sensors so they can gather needed data

PENNSTATE 1855

UNIVERSITY OF ILLINOIS LEARNING & LABOR CHARTERED 1867

UNIVERSITY OF SOUTH CAROLINA



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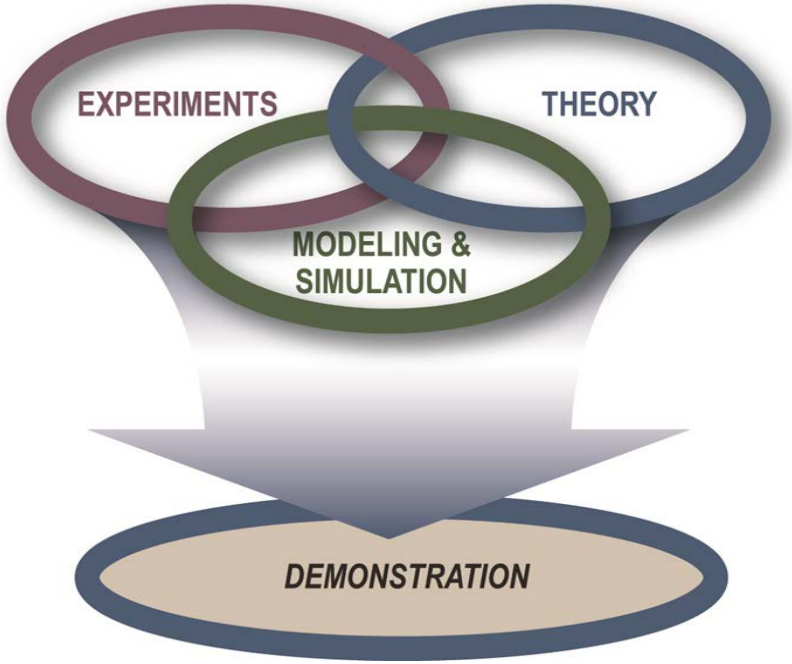
Summary

Technical Direction



Partnerships

- **Industry**
  - Utilities
  - Cask manufacturers
  - Fuel suppliers
  - Rail and trucking companies
- **National Laboratories**
  - 11 National Labs
  - Principal Investigators with needed expertise have been identified
  - Specialized facilities and equipment are available
- **Universities**
  - More than 18 universities are working with UFD
  - Numerous students and professors are involved ($27M)