Technology: Current & Future Subcommittee

FINAL REPORT & RECOMMENDATIONS

October 19, 2012

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Tasks

1. Identify current and/or future technologies that will likely determine the direction of nuclear energy in the nation.

2. Summarize those technologies and their potential influence on the nuclear energy industry, their potential role in the industry and the expected timing for their development.

3. Identify the strategic opportunities for Idaho to participate in, influence, and/or benefit from those technologies.

4. Identify potential opportunities for Idaho to lead the development or implementation of the technologies in a national and global environment.

5. Recommend steps Idaho could take to influence, promote and effectively participate in these developments in a manner that promotes the mission and competitive position of the INL and Idaho's future economic opportunities.

Recommendations

Nuclear Technology

The INL is a national resource for advanced technology in support of nuclear power. This is especially true when addressing nuclear fuel management. Maintaining and enhancing the nuclear expertise at the INL is important nationally for the US if it is to continue to have influence internationally and important locally to ensure that the best available technologies are applied to management of nuclear materials in Idaho. There are several components to this capability, each of which should be supported by joint state and DOE initiatives. As shown in the table below, they involve 1) advanced capability to investigate and characterize the condition and performance of nuclear fuel, 2) safety testing to ensure that newly developed fuels are safe and reliable, 3) a test reactor to develop advanced, accident tolerant fuels, and 4) demonstration of the ability to safely store used fuel safely over extended timescales while the country addresses permanent fuel disposal issues.

The State should endorse the following facilities, capabilities and programs coming to INL. The State should provide the necessary and appropriate enablers and advocacy for these investments.

Facility/Capability /Program	Benefits to Idaho	Enablers
Advanced Post-Irradiation and Characterization Facility	• Additional ~20 good paying jobs at INL (scientist and technicians) • User facility concept will bring visitors (users) to town continuously benefiting local economy (hotels, restaurants) • Construction jobs for the facility • Spinoffs commercializing innovative technologies	• Continued operations of ATR • Ability to bring commercial used fuel at research quantities for examination • Specialized INL workforce and infrastructure
Transient Testing Reactor (TREAT) Restart	• Additional ~40 - 50 good paying jobs at INL (scientist, reactor operators and technicians) • User facility concept will bring visitors (users) to town continuously benefiting local economy (hotels, restaurants) • Reactor refurbishment jobs during restart • Spinoffs commercializing innovative technologies	• Continued operations of ATR • Ability to bring commercial used fuel at research quantities for examination • Specialized INL workforce and infrastructure
New Test Reactor (Fast Test Reactor)	• Additional ~100 good paying jobs at INL (scientist, reactor operators and technicians) • User facility concept will bring visitors (users) to town continuously benefiting local economy (hotels, restaurants) • Construction jobs for the facility • Spinoffs commercializing innovative technologies	• Specialized INL workforce and infrastructure

Facility/Capability /Program	Benefits to Idaho	Enablers
Used Fuel Storage Demonstration	• Additional ~20 good paying jobs at INL (scientist and technicians) • Additional investments for characterization capabilities at the site	• Requires permission to bring larger than research quantities of used fuel to the site
Pilot US Regional Interim Storage Facility	• As the lead US Regional Interim Storage facility, demonstrate full scale technology, licensing, and operations for the nation's regional used fuel storage facilities. • Considerable investments (100s of million dollar) into RD&D infrastructure at the site with additional jobs • Investments into fuel cycle options demonstrations at engineering scale (100s of jobs) • Spinoffs commercializing innovative technologies	• Requires support and a revised consensus based partnership with the state to bring used fuel to the site from regional reactors for storage until disposal
Nuclear Hybrid Energy Demonstration at the Site or Hybrid Demo Using a Non-nuclear Heat Source	Hundreds of new permanent jobs at the site • Temporary construction jobs • Additional clean energy for Idaho (≤100 MW) • Spin-off small businesses for component manufacturing and maintenance	• Construction of a commercially funded advanced SMR at the site • Land • Site infrastructure (including the local grid)
High Performance Computing Center	Additional jobs • Competitive advantage to state universities • Spin-off small businesses with specialized software development for multiple applications	• INL workforce specializing on flexible HPC software platform development • State support through partnership with state universities

- Develop proposal for state to commit – at least startup investment/expedited permitting – to joint industry/federal/state-funded "national reactor testbed" to meet needs of regulators and industry to conduct at-scale "hot" testing of developmental/pre-commercial reactor components and systems (individual SMRs & multiple-SMR modules, HTGR, SFR, TWR, etc.[1]). This capability should address dynamics and controls for reactor load following process heat applications and use in hybrid energy systems.

[1] SMR = small modular reactor; HTGR = high temperature gas reactor; SFR = sodium fast reactor; TWR = traveling wave reactor

- Pursue DOE designation of and funding for establishment of a formal Nuclear Materials Treatment, Packaging and Aging Assessment Center to meet industry and regulatory agency "back-end" process/technology development and validation needs and to fully leverage distinctive Idaho capabilities resident at INTEC.

- Create – through HERC/EPSCoR [2]– an Idaho Energy Storage Center of Excellence to lead research into more efficient/cost-effective solutions (e.g. Na/S, REDOX flow[3], 2-way fuel cells, etc.) for back-up nuclear station power & renewable energy load-leveling. This could and should leverage assets associated with INL's new Energy Systems Laboratory.

- Establish streamlined mechanism to facilitate stronger/more fluid working relationships between INL/Idaho universities and Utah universities/Utah industries with established strengths and interests in high-performance ceramics (e.g. Ceramatec) and temperature-sensitive industrial processes (e.g. Huntsman Chemical) to build greater awareness of Intermountain West's leading capabilities in support of High Temperature Steam Electrolysis, Thermo-chemical Hydrogen Production, Biomass Hydrothermal Gasification and related industrial applications of process heat from High Temperature Gas Reactors. This approach should be expanded to include an Idaho led regional energy technology leadership council.

- Leverage one or more existing State Board of Education "Funded Research Centers" or create Idaho's 8th "Funded Research Center" to focus on ways for the state to take advantage of substantial thorium/rare earth element deposits at Diamond Creek, Hall Mountain and Lemhi Pass to enable continued/accelerated Idaho, national and international R&D on thorium power systems (e.g. the Gates-supported TWR, and the liquid fluoride thorium reactor) as well as electric vehicles, renewable energy systems, energy-efficient lighting, and national defense systems that are reliant on rare earth elements.

- Develop a "positioning letter" carrying the signatures of the Governor, legislative leaders, all members of the delegation, Butte/Bingham/Bonneville/Bannock commission chairs and Idaho Falls mayor supporting the addition of new and renewal of existing national nuclear capability facilities at INL, including – but not limited to – the Advanced Post-irradiation Examination (APEX) facility and the Transient Reactor Experiment and Test (TREAT) facility and other previously identified facilities, capabilities and programs.

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[2] HERC = Higher Education Research Council; EPSCoR = Experimental Program to Stimulate Competitive Research

[3] Na/S = sodium sulfur storage battery; REDOX = reduction/oxidation flow battery

- Through CAES, develop a partnership with Lab / Dept of Commerce / University to identify areas where nuclear energy RDD capability can be leveraged to non-nuclear global energy markets from Idaho-based corporations. This should include a council (could be part of the regional energy leadership council mentioned above) that develops a sound process to identify and prioritize these targets of leverage. The council should provide recommendations on incentives (tax credits, etc) and associated value propositions to target the most promising areas of opportunity (e.g. leverage separations expertise to rare-earth industry; leverage nuclear fuel modeling and simulation to unconventional fossil energy extraction needs, etc.).

- The Subcommittee strongly supports the work being done at the Naval Reactors Facility (NRF) and their approach to dry storage of used fuel. Given the important national security dimension of their work and the high standards of safety and environmental stewardship we observed, the state should strongly endorse and advocate for the continuation of NRF's mission at the INL site. The state should also endorse and advocate for the proposed recapitalization of NRF facilities.

- The Subcommittee was impressed by the capability demonstrated at the Advanced Mixed Waste Treatment Project (AMWTP). The AMWTP facility could continue processing waste after the cleanup in Idaho has been completed. The Subcommittee recommends the state consider such a proposal favorably as long as waste brought into Idaho is processed and shipped out within a reasonable timeframe (such as six months).

- The technical issues of the Integrated Waste Treatment Unit that resulted in its aborted start up and the consequent delay in processing the remaining radioactive liquid waste stored in Idaho is of concern. These technical issues do not at this stage seem insurmountable and the liquid waste is safely stored in tanks that will contain it and protect the environment for a considerable period of time. Recommend the state closely monitor progress at the IWTU and take firm action under the appropriate agreements and orders if start up and liquid waste processing does not proceed in a 2013 – 2015 timeframe.

- The Subcommittee supports the Radioactive Waste Management Complex (RWMC) and the approach being taken to exhume, sort, categorize and ship buried waste out of the state. The Subcommittee recommends that the state continue to endorse this approach and advocate for continued DOE funding to complete this work and install a cap over the area promptly as has been planned and committed to. In addition, the state should require a formal follow up on monitoring and appropriate research effort, conducted in Idaho, to ensure that the cap and other remediation techniques that have been employed remain effective in protecting public health and safety.

National & Homeland Security, Energy and Environmental Technologies

- The state should endorse and advocate for INL's wireless test bed designation as an official DOE National User Facility. This designation will support national missions in smart grid and spectrum allocation research, and increase federal/commercial funding in INL's research. The state of Idaho will benefit economically from industry collaboration as major carriers access the INL as well as small business incubation in a newly evolving technological area.

- Pacific Northwest Cyber Center (PNCC) is a new Idaho-centered concept intended to address the national challenge of sharing national security information between the U.S. government and infrastructure asset owners. Fundamentally, PNCC would be an INL-located, Idaho-led initiative to provide surrounding states and their infrastructure asset owners (utilities) access to actionable intelligence on industrial control system cyber security threats. The immediate and tangible benefit to Idaho would be protection of Idaho's critical infrastructure leveraging INL assets as well as assuming a regional leadership role. The surrounding state CIOs have shown a high level of interest, as well as has the DOE CIO in pursuing this leadership opportunity. The state should endorse and advocate for establishment of the PNCC.

- The INL grid and grid testing expertise represents a national asset for grid reliability and security research. The state should endorse designation of the INL grid as a national user facility and advocate for its designation.

- First Responder Training is important to ensure cities and states are protected against radiological threats and that responders are proficient in threat mitigation. The state should advocate for INL to provide first responder training regionally to hospitals, medical facilities and industrial sites.

- INL, in collaboration with the state universities and the Idaho Regional Optical Network (*IRON), has formed the Idaho Computing Consortium intended to share research level supercomputing across all institutions for collaborative research and to gain economy of scale on these very large investments. The INL computing center is now at capacity. An additional $6-10M will more than double INL's and the Idaho Computing Consortium's capacity enabling the next 10 years of simulation, modeling, and general research. The state should endorse this expansion and seek the resources to make this investment in the ICC. The state should also consider expanding the ICC regionally.

**IRON is a not for profit 501 (c) 3 entirely focused on enabling Idaho's education, research, health care, and state government with very high speed, low cost bandwidth. IRON's charter associates are ISU, UofI, BSU, BYU-Idaho, WSU, INL, Idaho Hospital Association, and Idaho State Government. IRON currently has over 275 connectors.*

- Broadband infrastructure is provided at INL today through INL's own 72-mile fiber loop for internal communication and association with the Idaho Regional Optical Network (IRON) for external worldwide very high speed access. The state of Idaho should consider partnering with IRON and INL for nonprofit, education, virtual rural health care, and statewide research to expand high speed bandwidth to all communities in central and southern Idaho. This would leverage all related bandwidth investments into a coordinated and highly leveraged research, economic, and educational engine for Idaho.

- The state should consider expanding the role of the LINE Commission in the future to more broadly address "Leadership In Energy Technologies" (LIET) as opposed to just nuclear. All parties should use this broader energy technology mission to build upon the assets already in place and offered through state colleges, universities, ESTEC, CAES, and vocational training centers.

- The state and INL should pursue increased collaboration and funding for R&D from foreign governments and overseas commercial businesses in those countries that have active nuclear power expansion initiatives. This will both ensure that the U.S remains engaged in development of cutting edge nuclear technologies regardless of the lack of nuclear expansion in the U.S., and it will provide further diversification of INL funding sources.

- Most of the INL work in nuclear technology seems to be focused upon fuels and materials since that has been the areas of historical expertise. INL should consider taking a broader look at the nuclear industry and address other R&D opportunities in areas such as uranium in situ recovery, uranium conversion technologies, engineering design of plant equipment, and interim fuel storage to name just a few.

- The state should assist INL in recruiting government agencies such as NRC, DOT, EPA, and FAA to consolidate their research, testing, training, and inspection program work at the INL. The state should advocate for INL to support regional regulators.

- In the LINE Commission's June 29 meeting, both former Governors Andrus and Batt indicated it is unlikely the country is going to have a permanent repository by the 2035 deadline which means Idaho's dry used nuclear fuel and calcined high-level waste has nowhere to go. The Obama Administration's decision to terminate the Yucca Mountain project creates a strategic decision that this subcommittee and the full Commission grappled with. The state may want to evaluate the 2035 deadlines for removal of dry stored used nuclear fuel and the processing of calcine into a "repository ready" form. The calcine presents very little risk and processing the material to change it into a different form suitable for a yet-to-be identified and characterized repository may not be the best use of taxpayer's dollars.

Report

Preceding any discussion of the present and the future of nuclear energy, it is useful to review the positive and negative attributes of that energy source. This value proposition for nuclear energy should be considered in terms of: Economics, Energy Security, National Security, and Environmental Impact.

Table 1 summarizes this review.

	Pros	**Cons**
Economics	• Cheap electricity production by existing already amortized nuclear plants • Low operational costs and stable market prices (low volatility in the price of nuclear generated electricity) • High tech, high paying domestic jobs (at the plants and the service sector) • Production cost immune to potential carbon taxes • Growing international market for new nuclear plants that can create a strong industry in the U.S.	• Very high capital cost of new plants • Economic uncertainty associated with the regulatory process • Relatively inexpensive domestic alternative energy sources (e.g. natural gas) • Competitive international market for reactor vendors (France, Russia and South Korea) • Uncertainty in long-term storage and disposal of used nuclear fuel (UNF)
Energy Security	• Reliance on primarily domestic resources (uranium) • A very good safety, reliability and operational availability record by domestic industry	• Increasing domestic fossil fuel resources • Negative public perception of safety post-Fukushima • Public concern about increasing volume of used fuel (stored at operating reactor sites)
National Security	• Maintaining U.S. leadership in technologies and applications during an increasing international demand on nuclear energy • U.S. leadership in non-proliferation and nuclear safety • Reduced reliance on non-domestic energy sources	• Concerns about the vulnerability of nuclear plants and fuel facilities to terrorism • Risks of the misuse of civilian technologies for proliferation of nuclear weapons
Environmental Impact	• High density clean energy with nearly zero green house gas emissions • Small plant footprints per unit energy	• Environmental impact of uranium mining • Water usage equivalent to any large thermal plant • Uncertainty in long-term disposal of used nuclear fuel

Table 1 – Attributes of Nuclear Energy

Current Nuclear Technologies That Are Likely to Determine the Direction of Nuclear Energy in the Nation

The current technologies that define the nuclear energy landscape in the nation rely on light water reactors fueled by uranium oxide –zircalloy fuel. There are 2 types of reactors deployed in the U.S., pressurized water reactors (PWR) and boiling water reactors (BWR). The fuel is enriched to less than 5%. The fuel is burned in the reactors up to ~50 MWd/kgU. After discharge from the reactor, the fuel is stored in the storage pools and then transferred to storage canister for extended dry storage above ground. Ultimately, the used fuel is expected to be disposed in a geologic repository but with the termination of the Yucca Mountain project, this disposition option is uncertain. Evolutionary advances are being made on the reactor designs for both the BWRs and PWRs and will likely constitute the beginning of a new U.S. fleet. The advances are primarily in the areas of passive safety features.

The major RD&D activities associated with the current technologies are as follows:

- Non-destructive examination techniques (NDE) for the irreplaceable reactor components
- Advanced materials for enhanced reliability of the balance of plant components
- Digital instrumentation and control technology
- Accident tolerant instrumentation and/or instruments that can be remotely deployed after an accident when parts of the plant are not readily accessible
- Nuclear fuels with
    - enhanced accident tolerance,
    - increased performance (higher power density for power uprates),
    - increased reliability (reduced number of fuel failures), and
    - reduced waste volume (increased burnup)
- Multi-scale, multi-physics modeling and simulation with a strong verification and validation program for the implementation of risk informed safety margin characterization
- Human factors, man-machine interface improvements
- Enhanced safety features with reduced reliance on operator action. This is particularly important for export markets where the nuclear safety culture is not as mature as in nations that have operated and maintained nuclear reactors for many decades

- Extended dry storage of UNF and associated monitoring technologies

- Ultimate UNF disposal (geologic repository)

A natural extension of LWR technology in the near-term is expected to be in the form of water-cooled small modular reactors (SMRs), if economies of scale can be overcome by economics of modularity. Such reactors will satisfy the needs of some markets domestically and internationally and could be used as the base-load provider in hybrid energy systems.

Anticipated Technologies That Will Influence the Future of Nuclear Energy, Their Anticipated Role in Industry and the Expected Timing for Their Deployment

It is expected that LWR technology will dominate the nuclear energy landscape domestically and internationally for the next 30 to 40 years. In addition to the large giga-watt size plants planned and being built, SMRs may be part of the portfolio. In the next 30 to 40 years, we also expect the introduction of new technologies into the market place. In the U.S. it is not likely that any more than a handful of these advanced reactors will be built in the next 30 years. The most likely are:

- High-temperature reactors (gas or molten-salt cooled) for process heat applications where nuclear energy is utilized for more than just electricity production (synthetic fuel production, chemical processes, desalination, etc…)

- Liquid metal cooled fast reactors for better resource utilization and waste management (e.g. continuous recycle of actinides)

The deployment of these systems is beyond the investment horizon of the industry. The large fraction of the development cost is expected to be carried by the federal government. An exception to this is liquid metal cooled SMRs where the industry is currently making serious investments for a pilot demonstration within the next 10-15 years.

In addition to the new reactor technologies, advances in energy production and fuels cycle technologies also will form the major portion of the RD&D portfolio:

- Instrumentation and control with higher reliability and lesser reliance on human interventions, including radiation hardened in-situ instrumentation

- Advanced materials (e.g. high temperature materials) for high temperature reactors

- Advanced fuels (TRISO, TRU bearing fast reactor fuels)

- Reprocessing and recycling technologies

- Waste forms engineered for geologic repository

- NDE techniques

- Advanced modeling and simulation with rigorous verification and validation at multiple scales in order to
    - Accelerate the development and deployment of new technologies with reduced number of prototyping
    - Enhance passive safety of the reactors and supporting nuclear facilities

- Process heat transport and utilization related technologies

- Energy storage technologies

- Dynamic control systems for hybrid energy deployment

Strategic Opportunities for Idaho to Participate In, Influence, Benefit From, and Potentially Lead the Development and Implementation of Current and New Technologies in a Global Environment

At present, INL is leading or participating in almost all the current and future technologies previously discussed in close collaboration with industry. The existing and continuously improving infrastructure and expertise at INL enables that leadership and participation. Particularly noteworthy and unique capabilities are the large and flexible test reactor, the facilities where large quantities of nuclear materials can be handled safely and securely, the characterization and examination capabilities for irradiated materials, and the State support that allows research quantities of irradiated fuels to be brought to the laboratory. Appropriate test reactors, fuel storage research, recycling research, component development and testing capabilities that can be added to INL will not only provide a competitive edge for U.S. vendors but will also influence the safety standards in international markets. These additional capabilities are important for developing future technologies.

Globally, Idaho can lead the development of an international nuclear safety infrastructure, helping nuclear energy newcomers to establish a robust safety basis and preventing nuclear accidents. The facilities at INL can be used as a test bed for training the international nuclear safety professional.

In addition, the technologies developed and demonstrated in INL can be used for reducing the proliferation risk associated with the expanded use of nuclear energy globally. The facilities at INL can be used as a test bed for training the international nuclear security professional.

Steps Idaho Could Take to Influence, Promote and Actively Participate in these Developments in a Manner that Promotes the State's Competitive Position and Economic Opportunities

Summarized in our Subcommittee recommendations.