Opportunities and Barriers for Optimizing Costs across the back end of the Advanced Nuclear Industry– 25376

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ABSTRACT

There is increasing global interest in new nuclear reactor designs, such as Small Modular Reactors (SMRs) and Advanced Reactors (ARs). These offer the potential to improve the safety, economics, and sustainability of nuclear energy, with more flexible construction and generation options at lower costs. However, the innovative features of these reactors also bring new fuel types and hence challenges for waste management. Innovation at the back end of the nuclear fuel cycle can support safe and cost-effective storage, transportation, and disposal of SMR and AR waste in a geologic repository – enabling an integrated waste management strategy that, in many countries, is currently missing with respect to the current inventory of spent nuclear fuel (SNF) and high-level radioactive waste (HLW).

This paper provides an evidence-based view of the opportunities and barriers for integrated waste management strategies, informed by qualitative and quantitative research involving government and industry stakeholders. Key findings include:

- **The back end of advanced nuclear would benefit from increased focus in policy-making:** more than nine out of ten research participants agree that consent for new nuclear seems to be growing faster than consent for waste disposal facilities, and agree that most funding and focus for new nuclear is on the development of the reactors, with less priority on the back end of the system.
- **Considerable back-end uncertainty exists:** three-quarters of participants agree that uncertainty on the future disposal path means that organizations planning to own and/or operate an SMR or AR face significant risks and additional costs.
- **Key barriers associated with this uncertainty by the majority of respondents** include: the current ***policy and regulatory framework*** (72%); lack of ***commercial incentives*** to optimize costs across the back-end system as a whole (68%); uncertainty about ***waste characteristics*** of spent fuel from SMRs and ARs (64%); and ***lack of muti-functional containers*** approved by regulators for storage, transport and eventual disposal of this material without future repacking (56%).

The paper draws preliminary conclusions on measures that the nuclear community can take to address high priority areas for action identified by stakeholders in this research, in particular within the Joint Project on Waste Integration for Small and Advanced Reactor Designs (WISARD) being launched by the OECD Nuclear Energy Agency in 2025 [1]. Greater engagement by policy makers with respect to the risks and uncertainties surrounding the back end of the fuel cycle is recommended. Preliminary conclusions from this stakeholder research suggest three key opportunities for the WISARD initiative to support such engagement:

1. Supporting the development of clear **policy, regulatory, and commercial frameworks** that incentivize individual organizations to optimize safety and cost across the whole back-end system.
2. Establishing greater certainty about the generic **Waste Acceptance Criteria** that geologic facilities will apply when accepting SMR and AR spent fuel and high-level waste.
3. Establishing clear **regulatory standards for multi-functional canisters** able to manage storage, transport and disposal of spent fuel and high-level waste from SMRs and ARs.

INTRODUCTION

A three-year project is being launched in 2025 by the OECD Nuclear Energy Agency to address Waste Integration for Small and Advanced Reactor Designs (WISARD) [1]. The WISARD Joint Project aims to identify and address these issues through collective public-sector and private-sector collaboration on an international basis. Scoping of this Joint Project was supported in 2024 by a group of industry stakeholders, including the Electric Power Research Institute (EPRI), the Nuclear Energy Institute (NEI), and Deep Isolation. As part of this support, these three organizations are collaborating on a phased research program to establish an evidence-based view about the opportunities and barriers for optimizing costs across the back end of the advanced nuclear industry. The program uses a combination of quantitative and qualitative research methodologies to establish views and priorities from industry, government, and regulatory stakeholders working on storage, transportation, and eventual disposal of SNF and HLW from SMRs and ARs. The phased, iterative research methodology uses in-depth, semi-structured interviews to shape the development of a web survey, and then uses further in-depth interviews with a sub-set of the survey participants to provide additional qualitative insights on the quantitative results from the survey.

This paper describes the target audience, and the methodology used to engage with that audience, followed by an analysis of results. Common themes are drawn out across domains that include market uncertainty, policy and regulation, commercial incentives, and technology and products.

METHODS

The target research group included senior-level stakeholders from both the public and private sectors whose professional and organizational roles involve specific responsibility for helping to manage the safe storage, transport, and eventual disposal of spent fuel from nuclear reactors. Sub-segments include:

— From the public sector:
- Policy makers in national governments
- Nuclear and environmental regulators
- Researchers from universities, national laboratories and other research institutions

— From the private sector:
- Organizations that produce and have subsequent custodianship of spent nuclear fuel as a by-product of electricity generation or other industrial uses
- Organizations that provide services to:
  - store spent nuclear fuel
  - transport spent nuclear fuel
  - recycle, reprocess, or recondition spent nuclear fuel
  - dispose of spent nuclear fuel
- Industry representative bodies.

Table 1 summarizes the seven-step research process. This combined qualitative and quantitative analysis, and was informed by methodologies recommended in the Handbook of Practical Program Evaluation (in particular, with respect to using the internet, conducting semi-structured interviews and qualitative data analysis) [2].

Table 1. Seven-step research process

Step	Method Description
1. Initial hypotheses	— Work within the project team to develop a set of initial Working Hypotheses about the Opportunities for and Barriers to optimization of safety and costs across the back-end of advanced nuclear fuel cycles.
2. Test these in in-depth interviews	— Undertake in-depth interviews to explore Opportunities and Barriers with 2-3 members of target population, using a semi-structured interview format.

	— Use the results of these to develop and refine a) our Working Hypotheses, and b) the survey questionnaire to be used in quantitative research.
3. Quantitative validation	— Use a web-based survey to seek quantified and comparable views from a broader set of people in each target population.
4. Preliminary analysis	— Initial assessment of quantitative results, to develop understanding of views and priorities - and how these may vary across population sub-segments. — Use this to identify issues to explore and understand in more detail during the second phase of in-depth interviews.
5. Qualitative validation	— Ongoing in-depth interviews, exploring issues raised by preliminary analysis of the web survey results. — In parallel, continue to expand numbers of people undertaking the web survey (including interviewees).
6. Analysis and conclusions	— Analysis of qualitative research results, to identify key themes and undertake role analysis. — Iterative documentation of findings, referring back to both qualitative and quantitative data and using both to test, substantiate, and evidence the key themes.
7. Quality assurance	— Review of draft and final report.

SURVEY PARTICIPATION

In the initial research phase, around 250 people from 21 countries were approached to participate in the project, with a broadly equal split between the public and private sectors. A total of 25 respondents participated in the research. Respondents were from five different countries, with 84% of respondents located in the US – suggesting that the issues dealt with in this research are of particular interest in the US context. As shown in Figure 1, 14% of respondents came from the public sector, and 86% came from industry. Of these industry organizations, two-thirds are owners and custodians of spent nuclear fuel, with over half of these waste owners also providing waste management services. The remaining third of industry organizations were providers of waste management services but without direct ownership of waste.

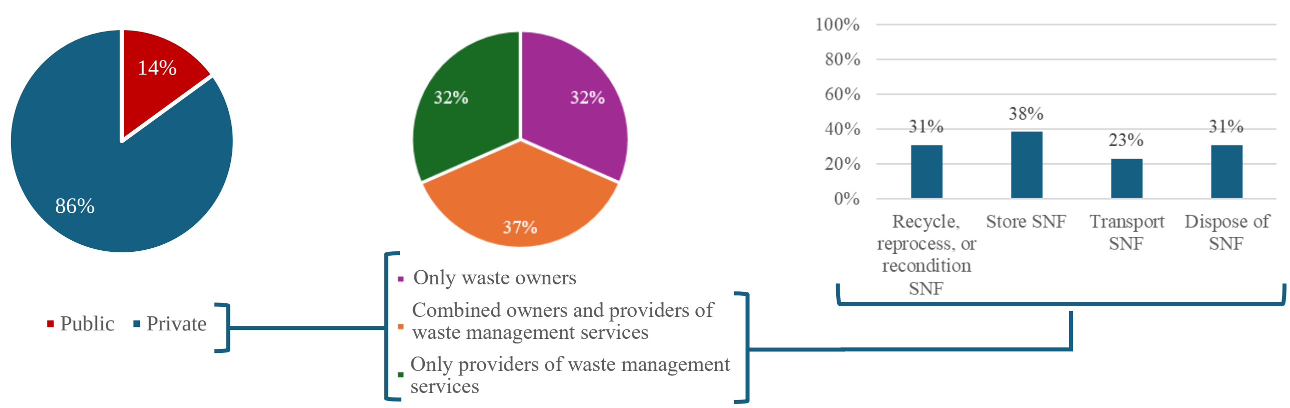

Figure 1. Split of respondents by Sector and Services Provided.

RESULTS: BARRIERS TO INTEGRATED WASTE MANAGEMENT

Research participants were asked to review nine statements and state the extent to which they agreed or disagreed with them. The results of this are summarized in Figure 2 below, with the statements ranked from highest to lowest in terms of the level of agreement (i.e. ranked by the sum of respondents saying they "tended to agree" and "strongly agree", with the highest level of agreement listed at #1 below).

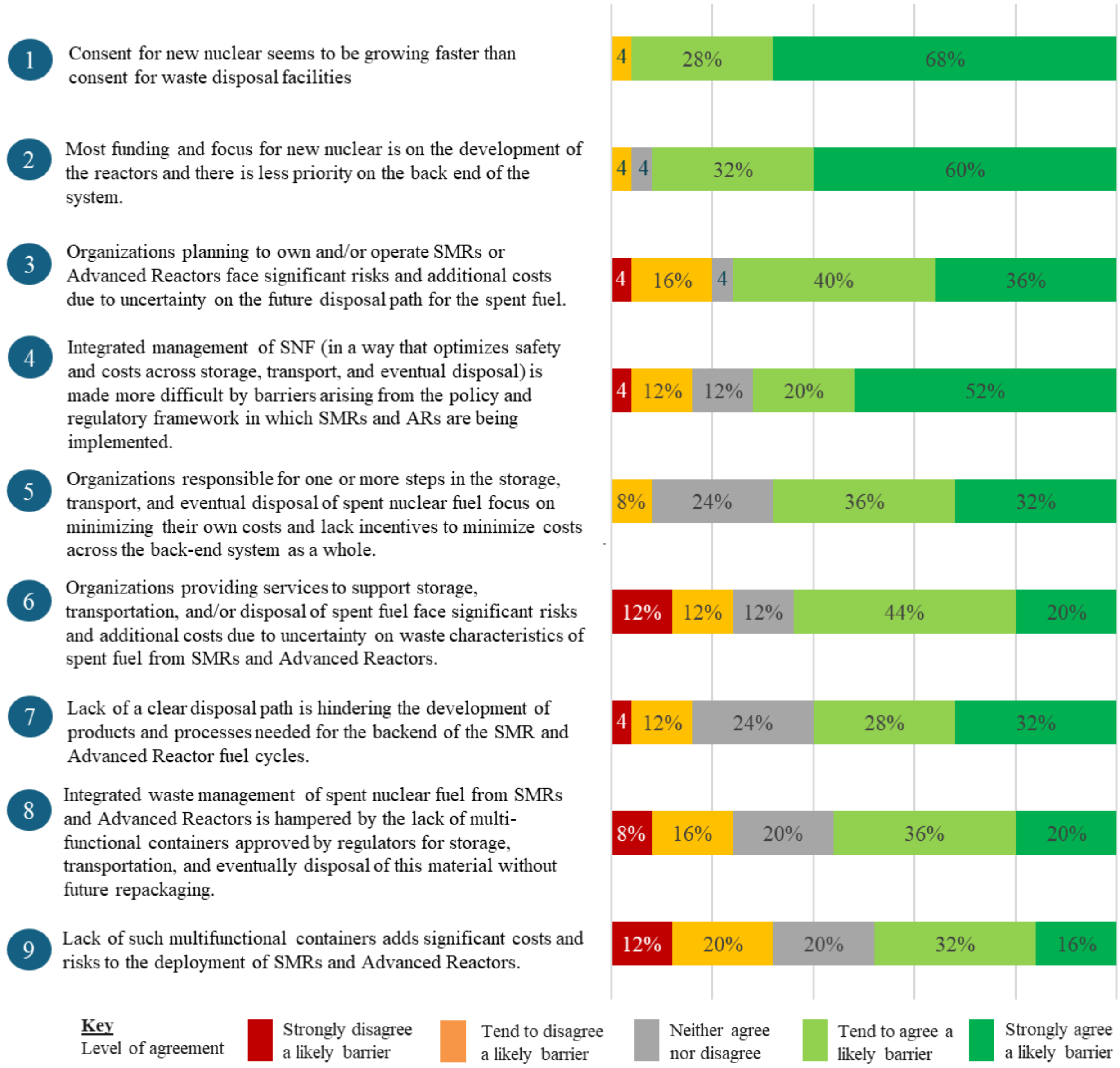

Figure 2. Extent to which Respondents Agreed with Potential Barriers.

As shown in Figure 2, there seems strong consensus that the back end of advanced nuclear would benefit from greater policy-making focus:

- 96% of research participants (all but one) agree that consent for new nuclear seems to be growing faster than consent for waste disposal facilities.
- 92% agree that most funding and focus for new nuclear is on the development of the reactors and there is less priority on the back end of the system.

This relative lack of focus on back-end issues is associated with lack of consensus on the way forward, leading to significant uncertainty in SMR/AR markets - uncertainty that is a source of additional risk and cost for the industry. In particular, the lack of a clear path in relation to final disposal of spent nuclear fuel and high-level waste is widely seen as creating significant problems for the nuclear industry:

- 76% agree that uncertainty on the future disposal path means that organizations planning to own and/or operate an SMR or AR face significant risks and additional costs.
- 60% agree this lack of a disposal path hinders the development of products and processes needed for the back end of the SMR and AR fuel cycles.

Some of the more specific barriers associated with this uncertainty by the majority of respondents include:

- **The policy and regulatory framework in which SMRs and ARs are being implemented:** 72% agree that this makes integrated management of SNF (in a way that optimizes safety and costs across storage, transport and eventual disposal) more difficult.
- **Commercial incentives:** 68% agree that incentives on individual organizations engaged in storage, transport and eventual disposal are not sufficient to minimize costs across the back-end system as a whole.
- **Uncertainty about the waste characteristics of spent fuel from SMRs and ARs:** 64% agree that is a source of significant risk and additional costs.

In addition, around half of respondents saw problems caused by **a lack of technology and products for integrated waste management** of spent nuclear fuel from SMRs and ARs:

- 56% agree that integrated waste management of SMR/AR spent fuel is hampered by the lack of muti-functional containers approved by regulators for storage, transport and eventual disposal of this material without future repackaging.
- 48% agree that lack of such multi-functional containers adds significant cost and risks to the deployment of SMRs and ARs.

The qualitative insights from the study give a similar but more richly textured picture, suggesting that key barriers to integrated waste management fall into six main areas: regulatory uncertainty; siting uncertainty; limited commercial incentives; lack of stakeholder engagement on back-end issues; data uncertainty for advanced fuels; and lack of muti-functional waste canisters. These six key themes of the research are summarized at Table 2 below, and illustrated by relevant comments shared by research participants.

Table 2. Barriers to integrated waste management – key themes from qualitative research

a) Regulatory uncertainty Many respondents highlighted that SMRs and ARs face uncertain regulatory landscapes, with concerns about the agility of regulators to adapt to new reactor designs and waste management challenges. In particular, the regulatory frameworks around waste disposal and interim storage are underdeveloped in many regions, with long delays in implementing solutions (e.g., in the US and the UK). The lack of clear requirements for waste disposal (e.g., waste acceptance criteria, waste form specifications) is perceived as making planning difficult: − *“Advanced reactors currently have no approved options for the management of their spent nuclear fuel. There is no guidance, and no path forward that would minimize risk to our company.”* − *“...I strongly fear that if the industry cannot align with the Government (Federal, State, Local) regarding handling, transportation and storage of spent nuclear fuel canisters this will become a problem for the industry advancements.”* − *“Policy uncertainty increases risk and cost. It also helps fuel negative impressions of a wonderful, safe and proven clean technology.”*

− *"It will be hard to license any new reactors of any size or type without a compliant national program which can sign a standard contract. Either move forward with existing law or amend it to allow alternative solutions including those in the private sector."*
− *"More work is needed that can really only be completed with regulatory certainty - e.g. what will the WAC [Waste Acceptance Criteria] be, what packages will be acceptable, how adaptable will those packages be to new reactor facilities…"*
− *"Key barriers arising from the policy and regulatory framework for Small Modular Reactors (SMRs) and Advanced Reactors include: lengthy and complex licensing processes, lack of established regulatory frameworks for new designs, high costs associated with permitting, uncertainty around waste disposal, and potential public perception issues regarding safety, which can hinder project development and investment decisions; all of which can significantly impact the timeline and economics of implementing these new nuclear technologies."*

The above issues seem particularly acute in the US. In the US, the lack of a national policy on waste disposal is creating planning uncertainties for SMR and AR projects, as reactor operators have to plan without clarity on waste management and long-term disposal routes:

− *"The failure to either enforce or revise the Nuclear Waste Policy Act, as amended, the approval of the NRC's Waste Confidence Rule, and the suspension of the Nuclear Waste Fund collection of fees are all barriers and challenges to the integrated management of spent fuel from SMRs and Advanced Reactors. The ability of the NRC to grant AR licenses based on "good faith negotiations" rather than signed 10 CFR 961 dis-incentivizes the development of an integrated waste management system."*
− *"The primary barriers in the US are the same as the barriers for current reactors, i.e., (i) failure of the federal government to carry out the established waste management policy and (ii) failure of the federal government to establish a new policy that it is willing to carry out."*
− *"The possible re-start of the nuclear waste fee further complicates our thinking. Is my company going to have to start paying 0.1 cent per kWh, or not? Is there a fund I could pay into that would be more likely to actually cover the cost of waste disposal? And what of the cost of storage? This is very unclear, and makes it difficult to know if we should include the cost of waste management and disposal in the amount we charge customers for electricity, I have no official guidance or estimate on how much we should charge if we want to be responsible."*

b) Siting uncertainty

For many respondents, the above regulatory uncertainty is exacerbated by complex and lengthy siting processes for disposal facilities:

− *"Balancing a sense of urgency with a consent-based approach to select an informed and willing host community with suitable geology will be the greatest challenge of all."*
− *"RWM [radioactive waste management] business is well known, most of the technical issues are solved, probably the biggest concern is siting of disposal facilities."*
− *"It also makes it hard to answer the question "what are we going to do with the waste" when this comes up in siting conversations."*
− *"Lack of clarity on spent fuel management and disposal is a very significant barrier to our siting activities."*
− *"We must have a repository certified so that pathways to that repository can be developed."*
− *"It is difficult to plan for the final disposition of waste when you don't know the requirements that the final disposition facility will impose."*

c) Limited commercial incentives

There is a strong sense that there are few commercial incentives for advanced reactor companies to focus on spent fuel management. Companies face significant risk if they commit to waste management plans (with no clear regulatory or financial benefits), and there is little incentive to think about long-term disposal issues at the early stages of reactor development.

− *"SMRs and ARs have largely focused on development of reactor and fuel systems, front-end has been deemed critical because of HALEU procurement, but back-end has taken a back seat to other priorities."*
− *"Spent fuel storage for the new nuclear designs does not seem to be something of real consideration."*
− *"What kills us in the U.S. is that we have large numbers of utilities, but DOE is responsible for disposal. So the utilities are not incentivized to re-process their waste - or take any other action to optimize their waste for disposal - because the benefits will all fall to the Government. And the Government isn't prepared to invest now to reduce its huge lifecycle disposal liability."*
− *"In the United States, there is a strong incentive for Advanced Reactor companies not to think about the back end of the system. There is only downside for having a plan - no upside. It would be extremely helpful if the DOE had a framework for thinking about this that considered total cost and total risk - not just the immediate costs."*
− *"The issue in the US is a legislative issue. There is uncertainty surrounding the liability of the spent fuel for new SMR operators."*
− *"The US lacks a policy to keep life-cycle waste management costs as low as reasonably achievable. Each waste producer is incentivized to use the cheapest near-term solutions without regard for the impacts on the life-cycle costs."*
− *"Storage, transport, and disposal regulations are not integrated, so a commercial solution for all can't be made. Especially without disposal requirements."*

Several respondents pointed out that policy makers and regulators are not considering total lifecycle costs and risks in their frameworks, highlighting a need for incentives like government-backed contracts or financial benefits for developing innovative waste management technologies, as well as integrated policies for waste storage, transportation, and disposal:

− *"I'd like to be able to package our spent fuel once, in a container that would then never need to be unpacked whatever options in future that the US Government might decide about how it wants eventually to dispose of it. That would be the right thing for the US taxpayer. But currently I am incentivized just to focus on minimizing my own immediate costs for interim storage, not to collaborate with DOE to minimize costs across the whole back end of the fuel cycle."*
− *"Some commercial incentives that should be considered include government contracts with guaranteed fees for storage and transportation services, financial benefits for developing innovative waste treatment technologies, incentives for siting a repository in a willing community through economic development opportunities, and potential cost reductions through streamlined regulatory processes."*
− *"In the United States, the organization responsible for the transportation and eventual disposal of spent fuel does not focus on costs at all. The DOE has not been required to perform a fee adequacy evaluation since collection of waste fund fees were halted about a decade ago."*
− *"In the US, the amended standard contract and the long timeframes for opening a repository will create financial risk for all new reactors built. For AR's, the regulatory framework is unproven, and the regulator has not shown agility to adapt. Although, congressional pressure may help the regulator move in a positive direction for the industry, it has yet to be seen."*
− *"There is little incentive for finding solutions to the nuclear waste problems facing the USA today. Even worse is that there seems to be no penalty for the government not fulfilling its obligation. Incentives should be offered to the private sector as the government seems to get a pass without consequence for doing nothing."*

d) Lack of engagement on back-end issues

Many respondents identified a lack of engagement in dialogue on waste management issues:

− *"There is certainly a significant step change in acceptance of nuclear and SMR technology. These dialogues are currently widespread and almost continuous. It is interesting, however, that these discussions rarely if ever deal with the back end of the fuel cycle. It is almost as if, as an industry, we are about to repeat the same mistakes we made 50 years ago."*
− *"I'm not sure how much the SMR developers are focused on the back end; I just don't see that being discussed. It needs to be part of their plan.*
− *"As an advanced reactor company, there is little context in which to talk about the waste. All of my competitors are completely avoiding the issue - which creates an incentive for my company to do the same. But I am aware that this creates significant risks - including liability, cost, and stakeholder engagement risk. It also makes it hard to answer the question "what are we going to do with the waste" when this comes up in siting conversations…"*
− *"The discussion around storage and disposal of spent nuclear fuel does not seem to be a "hot" topic within the public perspective of SMR and Advanced Reactors, not sure if this is because the current industry has found a solution to manage it, even if temporary, and the public doesn't necessarily realize the challenge. This viewpoint currently appears like it will carryover into the industry expansion with the philosophy of kicking the can down the road."*

e) Data uncertainty about advanced fuels

There is considerable perceived uncertainty around the final disposition of spent nuclear fuel (SNF) from SMRs and ARs. While some reactor types (like Light Water Small Modular Reactors, LW-SMRs) may face fewer concerns, other reactor designs, particularly those using new fuels (e.g., TRISO, fluoride salts), complicate predictions and create risks related to waste storage and disposal:
− *"There is still too much uncertainty on which, if any, ARs will be built, leaving great uncertainty in the final waste forms that will be generated. This dilutes investment in optimal solutions at all levels of the value chain."*
− *"There is quite a bit of uncertainty when working to finalize spent fuel characterization data that will be used to determine whether a certain waste falls into a given waste classification or is suitable for a particular treatment or disposition route."*
− *"The wide variety of advanced reactors makes it difficult to assess the risks and uncertainties, as clearly UO2 fuels little to no risk whereas fluoride/chloride salt fuels are likely much greater risk at this time based on ORNL salt reactor experience."*
− *"Each advanced reactor SNF type potentially poses unique management challenges. New planning efforts will be necessary to anticipate how the management requirements of advanced reactor SNF will affect the deployment of an integrated waste management system."*
− *"Some of the fuel types for SMRs and ARx are less dense than LWR fuels and may require additional costs for disposal. Being able to reduce the life-cycle costs will make them more cost competitive with other alternatives for electric generation."*

However, a significant minority (26% of respondents) disagreed that lack of clarity on waste characteristics is a potential cause for concern - with one commenting:
− *"Advanced reactor spent fuel characteristics do not pose a challenge for disposal. Updating disposal standards (to being more geology neutral) and addressing policy/political issues are more challenging."*

f) Lack of multi-functional canisters for SMR/AR waste

There are mixed views on whether appropriate technologies and products exist or can be developed for integrated management of waste from SMRs and ARs.

As shown at Figure 2, just over half of respondents agree that integrated waste management of SMR/AR spent fuel is hampered by the lack of muti-functional containers approved by regulators for storage, transport and eventual disposal of this material without future repack, and that this lack adds significant cost and risks to the deployment of SMRs and ARs. Doubts are raised in particular around advanced, non-light water reactor fuels. Some stakeholders believe that the existing waste management infrastructure (such as dry cask storage) could be adapted for SMR/AR fuels. However, there is concern that not all new fuels will fit into this framework, and custom solutions may be required, which could drive up costs:

− *"Preliminary studies seem to show that existing cask/containers could be suited to host SMR and AR fuels; however, 1) this might not be the case for all new fuel forms, and 2) some of these fuel forms (e.g., TRISO) could potentially benefit from their own design and require simpler and/or less costly cask/containers."*

− *"Utilities or organizations required to store SNF have incentive to utilize the largest possible containers licensed for safe long-term storage based on cost and effective resource utilization. Technology or products developed as multi-functional containers will need to optimize cost and efficiency to overcome the incentive currently in place to use available licensed maximum storage systems."*

A significant proportion of respondents, however, argue that the necessary products will follow easily once commercial incentives are aligned and clear Waste Acceptance Criteria are defined:

− *"Multi-functional containers can easily be designed. What the containers will hold inside and how they control criticality must be defined, before a package can be designed."*

− "*Most advanced reactor vendors are creating their own waste management systems and containers. There are no barriers for storage and transportation (except those inherent in particular fuel types). The issue is that it has nowhere to go."*

− *"I personally don't view this as a challenge being managed at this time because the SMR / Advanced Reactor industry will get to a point where there has to be a solution, similar to the current industry when Spent Nuclear Fuel Storage started over 20 years ago."*

− *"Once we have SMR used fuel the transport packages will be available. It is not rocket science."*

− *"Containers can be developed, licensed and delivered by the time spent fuel exists. It is an issue, but not a show stopper at this point."*

One product development was cited as an example of how the technology issues for multi-functional canisters can be resolved:

− *"My personal belief is that integration is where things need to be looked at….. We talk about the big picture items: transportation; interim storage; maybe generic types of repository. But we don't talk about how we integrate these all together. The Universal Canister System being developed by Deep Isolation and NAC is being posed as the integrator. It allows you to do interim storage; it allows you to do transportation; it allows you to do disposal, in deep boreholes and other disposal media. I think if we have something like this that looks at the integration and interfaces between these steps, that's an important activity that we haven't really thought about much."*

− "*Deep Isolation's Universal Canister System shows that we can join up across storage, transport and disposal without needing to repack at each step. So the technical issues can be solved if we get the commercial incentives aligned."*

RESULTS: ENABLERS FOR INTEGRATED WASTE MANAGEMENT

This section explores the potential enablers that might support development of a more integrated strategy for managing spent nuclear fuel from SMRs and Advanced Reactors.

Research participants were asked to identify, from a list of ten potential enablers, the top five in order of importance to them (awarding five points to first choice, four points to second choice and so on). Figure 3 on the following page ranks each of these enablers based on the responses received in the online survey, converting their score to a percentage of the total available points. (In other words, if 100% of respondents were to identify the same enabler as their highest priority choice, that enabler would score 100% on the scale shown at Figure 3.)

With an overall score of 69%, the highest priority for respondents is for **clear policy, regulatory, and commercial frameworks that incentivize individual organizations to optimize safety and cost across the whole back-end system**. Three-quarters of respondents listed this as one of their top three enablers, and it was the single most important enabler for the majority of respondents. The next highest priority is **greater certainty about generic Waste Acceptance Criteria** that facilities will apply when accepting waste, with an overall score of 48%.

Two of the next three priority enablers relate to waste containers, ensuring clear regulatory standards and commercial availability of multi-functional storage and disposal containers (with overall scores of 39% and 34% respectively). The respondents also rated having options for consent-based geologic disposal of waste fairly highly (with a score of 35%).

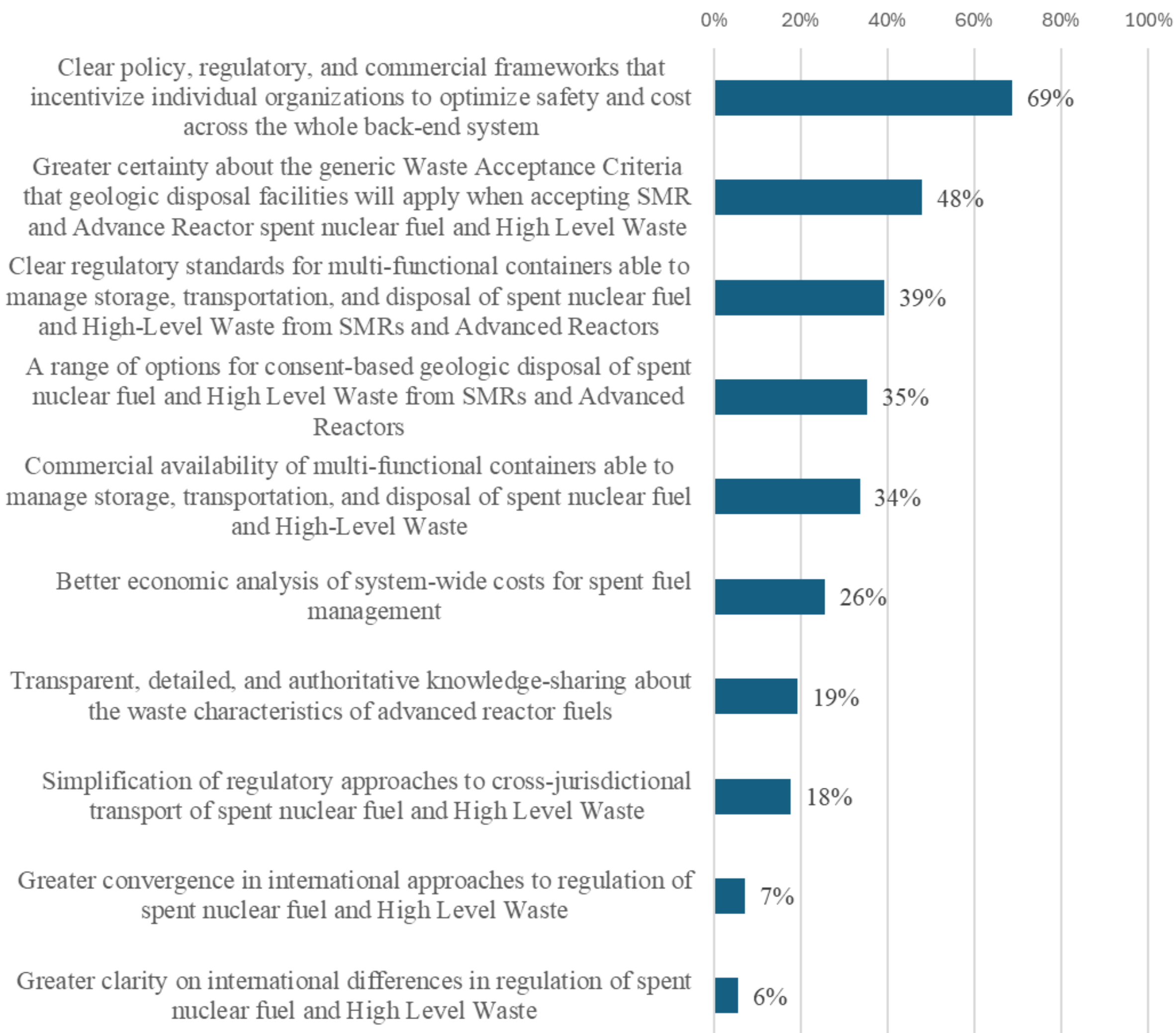

Figure 3. Prioritized List of Potential Enablers.

Interestingly, the two lowest rated enablers relate to greater coordination of international approaches, with greater convergence on approaches to regulation and greater clarity on differences in regulation.

Other potential enablers of a more integrated approach raised by participants include:

- **Financial innovation:**
  - *"Greater certainty about who is paying for the various back-end components (e.g. storage, transport, disposal canisters, repackaging, disposal) and how the funds will be obtained."*
  - *"Have nuclear waste fee be based on mass disposed, not amount of electricity generated. Current fee approach penalizes good practice to get the most kilowatts out of set amount of fuel."*
- **Collaboration across the public and private sectors:**
  - *"We need a public-private partnership. Government has failed to solve the disposal problem, so we need utility-led implementation. But to retain public trust, the Government still needs to retain overarching ownership for the long term."*
  - *"Early design considerations for the fuel cycle, collaborative research and development between reactor developers and waste management experts, standardized regulations, robust international partnerships, policy frameworks that incentivize innovative waste management, advanced reprocessing technologies, and public engagement to build trust in the waste management process; all aimed at optimizing spent fuel management from the outset of reactor design, minimizing waste volume, and ensuring safe and efficient disposal options."*
  - *"An Industry /Government agency should be in charge very similar to TVA."*

CONCLUSIONS

84% of participants in this research came from the US. With over a fifth of the world's stockpile of spent nuclear fuel and high-level waste [3] (and many of the leading global companies in waste management) being located in the US, views from this market are instructive in informing wider global approaches. Nevertheless, care must be taken when applying the findings of this report to a global audience, and further research in other markets would be beneficial. With that caveat, the research enables the following preliminary conclusions.

The key barriers to optimizing costs across the back end of the nuclear industry for SMRs and ARs revolve around market and policy uncertainties, lack of incentives for long-term waste management, and the absence of clear regulatory and technological pathways for spent fuel disposal. There is a pressing need for more integrated solutions that address both policy (clear, actionable waste disposal and storage policies) and technology (developing cost-effective, adaptable waste management systems) to support the deployment of advanced nuclear technologies.

Greater engagement by policy makers with respect to the risks and uncertainties surrounding the back end of the fuel cycle is recommended. Preliminary conclusions from this stakeholder research suggest three key opportunities for OECD NEA's WISARD initiative to support such engagement:

1. Supporting the development of clear policy, regulatory, and commercial frameworks that incentivize individual organizations to optimize safety and cost across the whole back-end system.
2. Establishing greater certainty about the generic Waste Acceptance Criteria that geologic facilities will apply when accepting SMR and AR spent fuel and high-level waste.
3. Establishing clear regulatory standards for multi-functional canisters able to manage storage, transport and disposal of spent fuel and high-level waste from SMRs and ARs.

REFERENCES

[1] 'Nuclear Energy Agency (NEA) - Joint Project on Waste Integration for Small and Advanced Reactor Designs (WISARD)'. [Online]. Available: https://www.oecd-nea.org/jcms/pl_86832/joint-project-on-waste-integration-for-small-and-advanced-reactor-designs-wisard)

[2] K. Newcomer, H. P. Hatry, and Wholey J S, *Handbook of Practical Program Evaluation*, Fourth Edition. 2015.

[3] *Status and Trends in Spent Fuel and Radioactive Waste Management*. in Nuclear Energy Series, no. NW-T-1.14 (Rev. 1). Vienna: INTERNATIONAL ATOMIC ENERGY AGENCY, 2022. [Online]. Available: https://www.iaea.org/publications/14739/status-and-trends-in-spent-fuel-and-radioactive-waste-management