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## The World's First Power Plant to Produce 400 Billion Kilowatt Hours

Quo Vadis, Grid Stability? Challenges Increase as Generation Portfolio Changes

The Other End of the Rainbow: Nuclear Plant End-of-Life Strategies

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## Contents



**Cover:**
View of the Grohnde power plant site, taken by a drone.

# The Other End of the Rainbow

## Nuclear Plant End-of-Life Strategies

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This article is part II of a 3-part series on challenges, opportunities and lessons-learned related to nuclear in the circular economy. Topics:
I Nuclear New Build – How to Move Forward (atw 1/2021)
II Nuclear Plant – End-of-Life Strategies
III Circular Economy – Lessons Learned, from and for Nuclear

**Introduction** Nuclear plant "end-of-life" – and decommissioning in particular – is a topic that is changing from a practical challenge and learning experience in individual cases to a key **programmatic challenge to the nuclear industry as a whole** and, as we intend to show in this article, with high relevance for the entire new energy system.

Existing nuclear power plants are reaching the end of their operating life and preparing for final closure. Operating plants with decades of potential useful life are being closed early, especially in the U.S. and Europe for technical, political, and even financial reasons.

And while a growing number of nuclear power plants are leaving the market, the IPCC[1] and many others see a large and critical role for nuclear energy to help meet global energy decarbonization pathways. Yet although nuclear power is beneficial for decarbonization, negative public and political views of nuclear power are linked to unresolved nuclear power plant end-of-life issues. For example, the "nuclear waste question" has led to the exclusion of nuclear energy in the EU Taxonomy for Sustainable Finance & EU Green Bond Standard, at least initially:[2]

*"The Taxonomy Regulation reflects a delicate compromise on the question of whether or not to include nuclear energy …. While nuclear energy is generally acknowledged as a low-carbon energy source, opinions differ notably on the potential environmental impacts of nuclear waste. … the Commission has decided to request … a technical report on the 'do no significant harm' aspects of nuclear energy."*

The significant end-of-life issues[3] for a nuclear power plant can be put in four categories:

- Decommissioning ("D&D") of the facilities;
- Treatment and packaging of radioactive waste;
- Long term interim storage of radioactive waste;
- Disposition of radioactive waste.

The nuclear power industry, and the authors of this article, consider all but one of these end-of-life issues as resolved for commercial nuclear power plants globally, in principle: the remaining open issue is the permanent disposition of radioactive wastes[4]. This issue remains open for political, not primarily technical reasons.

However, the lack of a path for permanent disposition of radioactive waste affects the entire end-of-life strategy (including the associated financing/funding arrangements) for nuclear power plants[5]. The ultimate total cost of waste management is uncertain because the specifications for waste form and packaging and the amount of funds/financial assurance needed to meet these costs are subject to considerable uncertainty over a long period of time. Until a permanent disposition solution is agreed, long-term interim storage is needed; and without centralized off-site interim storage, nuclear power plant sites become de-facto waste storage facilities under the oversight of nuclear safety regulators.

Decommissioning is the one category that might be considered relatively self-contained, under the control and sole responsibility of the owner/operator. It has a high project complexity and cost and is the gateway to subsequent waste management and disposal as well as to re-use of the site:

- for the existing nuclear power plant owners and investors who want to understand and manage D&D responsibility including the requirements to set aside funds to meet these eventual costs;
- for the public, and government/regulators, who want assurance that nuclear power plant D&D is done properly and cost-effectively; and
- for proponents and developers of (future) nuclear new build, who require clarity on the D&D approach that will allow them to factor D&D costs into project financing considerations.

**In addition to the challenges discussed in this article, further important end-of-life issues include:**

- A nuclear power plant decommissioning is a huge logistical undertaking with constraints from limited space for lay down areas, temporary structures as well as challenging transport infrastructure.
- Reuse or disposal of non-radioactive materials, including large volumes of conventional waste which exceed normal market volumes and may face public resistance for transportation and acceptance at landfills due to their 'tainted origin'.
- Availability of qualified resources in a "dying" market.
- Different options and interests for subsequent site use and resultant requirements for the D&D process and end-state. Including questions how to replace the functional role of the former nuclear plant (site) in the electrical supply system.

**These are outside the scope of this paper but will be revisited in future analysis.**

1 E.g., see https://www.ipcc.ch/sr15/chapter/spm/spm-c/spm3b/ or https://www.ipcc.ch/sr15/chapter/chapter-2/2-4/2-4-2/2-4-2-1/figure-2-15/

2 See https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/200610-sustainable-finance-teg-taxonomy-green-bond-standard-faq_en.pdf#page=9&zoom=auto,-12,426 – Technical Reports by two EU bodies are expected in February 2021 i.e. between writing and publication of this article.

3 In this paper we shall refer to 'decommissioning' and 'D&D' interchangeably as the onsite Deactivation, Decommissioning, Decontamination and Demolition programme versus 'end-of-life' as the holistic challenge.

4 Some countries have no operational disposal sites for any waste forms (not even LLW), a small number of countries are close to complete solutions, many have some but not all. – A separate topic is legacy issues at old research, experimental, or military sites and their special, highly demanding technical and environmental challenges.

5 In reflection of this, most countries have established a public domain responsibility for disposal. Most recently, for example Germany in 2017 established a 3-pronged back-end structure, where utilities retain risk and responsibility (incl. liability) for decommissioning and waste treatment but transferred risk and responsibility for interim storage and disposal to Government, against cash payment of a fixed "price" based on the estimated cost plus a risk premium.

From a technical perspective, nuclear decommissioning has become a well-established practice. But as a large and growing business, new approaches to decommissioning must be and are being developed.

So, getting the end-of-life strategy right is a significant, immediate challenge for existing nuclear power plants. Meeting this challenge also is one precondition for nuclear power to gain public acceptance and give confidence to investors and regulators in the business case for new build projects, thereby enabling it to help secure future zero-emission energy supply.

This article is focused on the issues related to D&D for commercial nuclear power plants.[6] Looking at the magnitude of nuclear power plant closures, how the nuclear power and decommissioning industries are changing, and on best practices for funding nuclear end-of-life liabilities, we try to gain insights on where this might lead for current and future market participants.

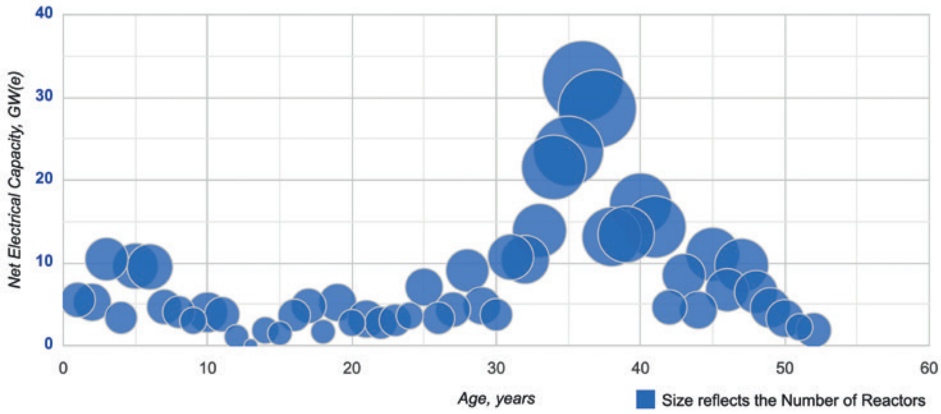


**Figure 1**
Age profile installed capacity. https://pris.iaea.org/PRIS/WorldStatistics/OperationalByAge.aspx

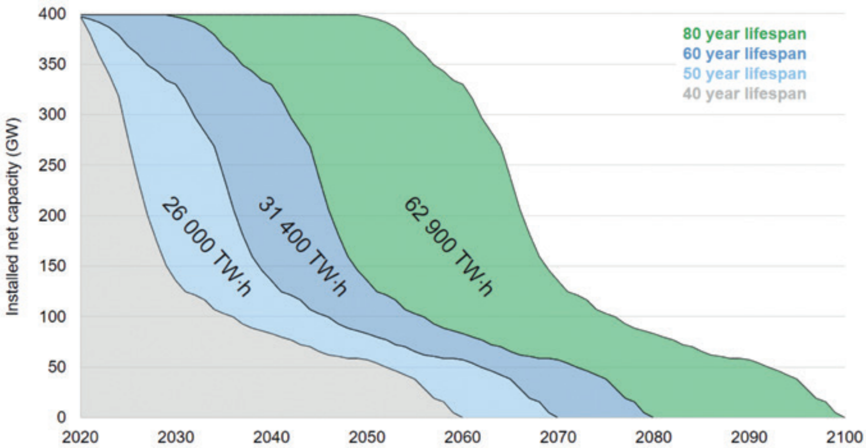


**Figure 2**
Nuclear installed capacities for different lifetime scenarios. From https://www.iaea.org/topics/nuclear-power-and-climate-change/climate-change-and-nuclear-power-2020

## Part I – Scope of the problem

### Ageing plants. Lifetime extension versus early closure

As the global nuclear power plant fleet ages, end-of-life strategies attain increasing importance for the industry overall. The life extension of existing nuclear power plants has the potential to provide large benefits from a reliable electricity supply with zero carbon emissions.

In principle, nuclear power plants are designed for long operating lifetimes and have the technical capability to substantially extend their licensed design lifetime. For example, most U.S. nuclear power plants have received approval to operate for 60 years, some have applied to operate for 80 years, and the U.S. Nuclear Regulatory Commission has started considering the issues that may arise in a 100-year operating life.

Common wisdom has it that once a plant has been fully depreciated it is highly attractive due to relatively low generating cost. Certainly, the cost and risk of extending the life of an operating reactor are lower than the cost and risk of building a new one.

The IAEA states *"… extending the operational lifetimes of existing NPPs is expected to continue to deliver significant short to medium term contributions … this can be realized with a modest investment to replace and refurbish major components to ensure plant operation in line with current expectations. … lifetime extension projects are less capital intensive, feature significantly shorter construction and payback times, and have a good track record in terms of cost control and limiting construction delays."*[7]

Yet despite offering important public goods and being financially more favorable than nuclear new build, not only is lifetime extension oftentimes not implemented but some plants are shut down early. Besides political and technical issues, reasons for this are that in the age range of 25–35 years, the plant owner may be faced with decision points related to some or several of the following factors:

- A nuclear power plant may, due to various reasons, cease to have an assured revenue source, leading to lower and riskier profits. This might be caused by privatization or divestment of government or regulated nuclear power plants. It also may be caused by the expiration of power contracts that provided revenue assurance.[8]
- A merchant generator that relies on revenue from sales into electricity markets faces significant financial risk. In new electricity markets, some combination of wind and solar generation and lower fossil fuel prices may mean that nuclear power plants face additional grid requirements (e.g., load following) and lower and uncertain offtake volumes and/or electricity market prices. In some

6 In this paper we look at decommissioning of commercial nuclear power plants (versus other nuclear facilities), and in the context of "planned" decommissioning (versus special considerations for one-off projects as in the past or situations due to unexpected economic, technical, regulatory, or political action).

7 See https://www.iaea.org/topics/nuclear-power-and-climate-change/climate-change-and-nuclear-power-2020

8 In the UK, this might happen when a limited term Contract for Difference ("CfD") ends. In the U.S. most merchant nuclear power plants had a transition power contract that expired at the end of the plant's original 40-year NRC operating license.

**Pre Shutdown**

| | | | |
|---|---|---|---|
| PPE | 800 | Equity | 200 |
| - nuclear | 0 | | |
| - other | 800 | D&D Liability | 110 |
| WC | 200 | LT/ST Debt | 850 |
| Cash | 60 | | |
| D&D fund | 100 | | |
| **Total Assets** | **1160** | **Equity & Liabilities** | **1160** |
| | | E/D Ratio | 21% |

**Post Shutdown**

| | | | |
|---|---|---|---|
| PPE | 800 | Equity | 200 |
| - nuclear | 0 | | |
| - other | 800 | D&D Liability | 0 |
| WC | 200 | LT/ST Debt | 850 |
| Cash | 50 | Loss | |
| D&D fund | 0 | | |
| **Total Assets** | **1050** | **Equity & Liabilities** | **1050** |
| | | E/D Ratio | 24% |

**Figure 3**
Financial Impact of early closure (schematic).

wholesale electricity markets, current or projected revenues may not even cover nuclear power plant generating costs.

- Continued operation, whether under current operating license or an extended license may require investments for retrofits, upgrades, or regulatory requirements. While these investments are lower than nuclear new build, they must compete for corporate commitment against other investment opportunities that may be more attractive to financial and other stakeholders.
- To the extent that D&D can be completed early and successfully, or liability and responsibility for future decommissioning activity can be transferred off balance sheet to another party, the early and immediate closure of a nuclear power plant may even serve to improve the owner's market valuation (debt/equity ratios and similar metrics, as shown in **Figure 3**).

In such cases early closure can enable reallocation of investment needs, reduce further liability accrual and perhaps even avoid financial operating losses. This would likely be viewed favorably by investors, ratings agencies and other market participants and should in turn reduce cost of capital and support other investment opportunities on better financing terms in subsidized or lower revenue risk generation.

One case study for these considerations is Kewaunee, a U.S. merchant nuclear power plant operating in a market-based electricity industry.[9]

The other reason that nuclear power plants are closing is that some countries have implemented plans to reduce or phase out nuclear power, regardless of the plants' age, performance, or of financial outcomes and effects on climate. Germany is the largest example of this; earlier examples were Italy and the closure of Soviet-era nuclear power plants in central European countries as a condition of EU accession. The recent closure of the Fessenheim nuclear power plant in France is a similar case.

## Transition to end-of-life

The global nuclear power industry has already gained significant D&D experience, with nearly 200 commercial plants having closed. This D&D experience was generally in one-off D&D projects, where a nuclear utility was engaged in D&D at one or a few units in the context of a continuing operating fleet and where speed, efficiency, and cost were not always primary considerations.

In the meantime, nuclear power D&D is developing into a major industrial prospect (see **Figure 5**): 75 % of the over 440 nuclear plants in operation are at an age above 25 years; 50 % older than 35 years. By comparison, of the app. 190 plants that have been shut down already, nearly 75 % reached an age of 40 years.

**CASE STUDY – U.S. Kewaunee nuclear power plant.**

The Kewaunee nuclear power plant is a 574 MWe PWR owned and operated by regulated utilities in Wisconsin. The plant started operation in 1973. In 2005, Kewaunee was sold to Dominion Resources as a merchant nuclear power plant. The sale included a Power-Purchase-Agreement (PPA) that expired in December 2013.

The Dominion Resources plan was to invest in the plant to reduce costs, increase reliability, increase output levels, and increase operating life. The expectation was that the value of nuclear electricity would increase over time, making this a profitable long-term investment. After the purchase, Dominion Resources applied for and received approval from the NRC to operate Kewaunee until 2033.

As the Kewaunee PPA neared the end of its term, Dominion Resources could not find a replacement PPA and would be forced to sell Kewaunee's output into short-term electricity markets at very low prices (i.e., due to low natural gas prices, low demand growth, increased penetration of subsidized renewable generation, and other factors). Faced with the prospect of operating the plant at a financial loss, Dominion Resources closed the plant on 7 May 2013.

Lessons from this early closure, and other U.S. early closures of merchant nuclear power plants, is that depending on uncertain short-term electricity markets for revenue may mean financial losses that make closing the nuclear power plant early the best option.

Because Kewaunee was closed after 40 years of operation, the plant's D&D fund was large enough. A "younger" merchant nuclear plant might impose a large financial obligation on the owner if the plant was closed early and the D&D fund was not adequate.

**Figure 4**
Kewaunee Case Study.

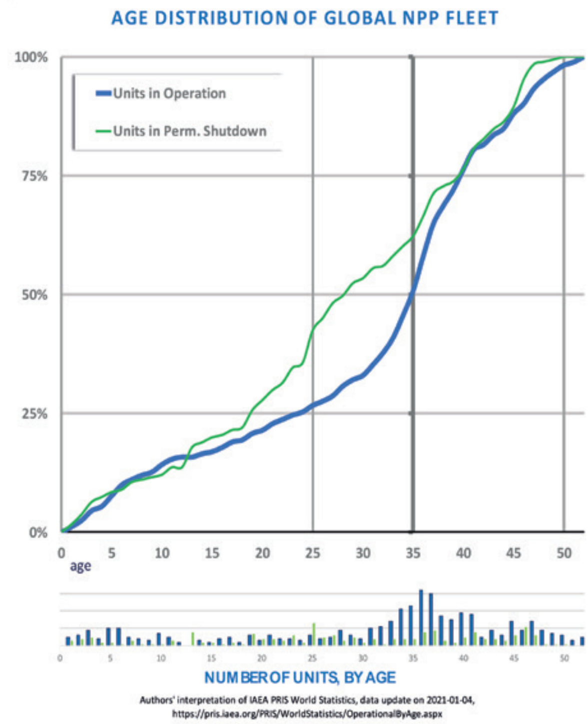


**Figure 5**
Age profiles of global nuclear fleet.

9 More on this is covered in Edward Kee's new book, "Market Failure – Market-Based Electricity is Killing Nuclear Power" available at: Market Failure.

This means that an increasing number of nuclear power plants are reaching the point where they may have a short time only left to prepare for end-of-life D&D activity. Besides the necessary technical and regulatory preparations, they reach the point where they are about to make a transition from accruing funds to pay for eventual end-of-life D&D activity to using those funds to meet actual D&D costs incurred.

Furthermore, nuclear power companies will have to either transform their organization and workforce from nuclear power plant operations to D&D activities or address the issues related to outsourcing the D&D activity to another company. It is worth noting that a nuclear power plant entity (at site and corporate level) will need to undergo at least **three** organizational transformations:

- **First,** transition from an Operation & Maintenance Organization with a strict culture of maintaining a stable system, to a Project Management Organization that is challenged to develop and prepare plans for a large, complex, and dynamic project usually in a VUCA[10] environment.
- **Then,** once the D&D project is underway, this organization needs to be skilled in "waste production factory" operations.
- **Finally,** when the D&D project nears completion, this organization will need to disperse, perhaps leaving behind a surveillance stewardship.

*Such organizational development and project skills are important for a successful D&D programme but are not usually core competencies of nuclear power plant owner/operators.*

## Part II – Industry changes

### Nuclear project structures after electricity market reforms

The reform and restructuring of the electricity industry led to new business models for nuclear power. New merchant nuclear power plants were created by the privatization of government-owned nuclear power plants (e.g., UK) and the deregulation and divestment of regulated nuclear power plants (e.g., U.S.).

Previously, regulated nuclear power plants had access to funding from the government or from ratepayers that would ensure that all commitments, including D&D, were met. This approach was generally considered "fail safe". However, merchant nuclear power plants rely on the balance sheets of owners, on current and project profits from operation, and on dedicated D&D funds. New merchant entities involved existing nuclear power plants which had accumulated funds for D&D activities, but may not have accumulated enough to meet regulatory or arms-length requirements. In some instances, the new owner of the merchant nuclear power plant was required to make funding commitments to make up the difference.

For example, when the U.S. NRC considered the transfer of nuclear power operating licenses from regulated utilities (i.e., with assured recovery of costs) to private companies, they considered the issue of financial responsibility for long-term D&D obligations and developed an approach to verify this based on detailed and regular reporting of D&D funding assurance by the nuclear power plant owner/operator prior to plant closure.

### Criteria for nuclear new build

The new electricity industry structure involves the potential for new nuclear power plants that would be merchant nuclear power plants.

Nuclear new build has generally not proven to be an attractive business proposition for (private) investors in liberalized energy markets[11], especially when there is no level playing field with large subsidized sectors and/or competition from low-priced natural gas supplies and volatility associated with renewable energy sources. The financial investment case may also be burdened by the approach to funding end-of-life D&D costs. Although the ultimate disbursements for D&D and subsequent waste management and disposal are far in the future, the advance funding contributions payable during operations have a negative impact on cash flow and need to be considered in the planning phase.

Investors in new merchant nuclear power plants will look for certainty on:

- How funds to meet eventual D&D and waste management/disposal costs will be accumulated and secured, in different scenarios, over the plant lifetime;
- What future changes in end-of-life costs influenced by Government and regulatory action (e.g., for radioactive waste disposition) should be expected and how will these be allocated; and
- How risk and responsibility for high-level waste will be transferred to Government at end-of-life; since laws can be changed, this should be secured by contract.
- How to plan and execute the future decommissioning in the most efficient way, given that a nuclear plant operator may not be best qualified to manage a complex D&D project and that after plant shutdown it may not be best suited to maintain suitable nuclear qualifications

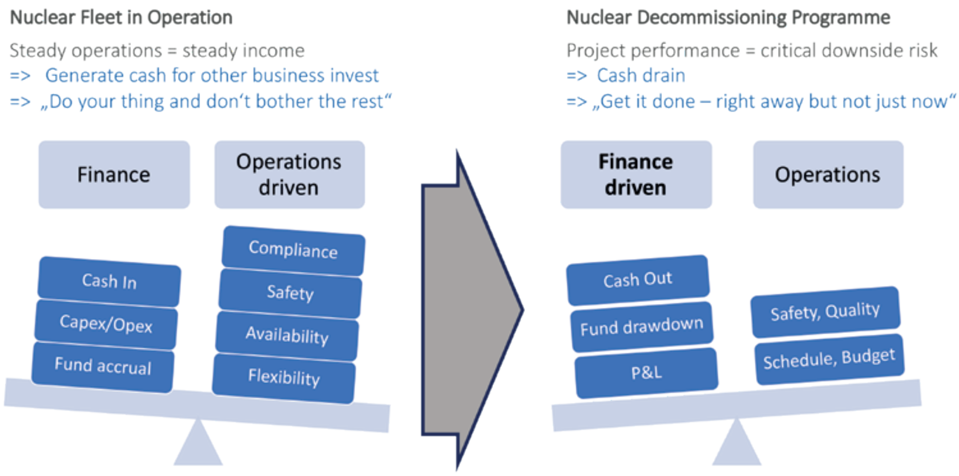


**Figure 6**
Nuclear Power D&D paradigm shift.

10 Volatile, Uncertain, Complex, Ambiguous
11 See our article in atw 01/2021 https://www.yumpu.com/en/document/read/65168156/atw-international-journal-for-nuclear-power-012021/09

The public needs certainty:

- That the owner/operator will establish technically competent operations and waste management to minimize radiological and other environmental risk and cost related to D&D activities;
- That financial and human resources will be available to complete D&D activity, as opposed to a company that will "disappear" at the end of nuclear power plant operating life; and
- That the plant owner will have the financial and human and technical resources and competencies to perform plant closure and all related responsibilities in accordance with all public good requirements: (a) those relevant to closing the relevant plant as such; (b) those relevant to the contributions the relevant plant was expected to make towards overall industry needs (e.g., funding disposal sites) during longer continued operation.[12]

Special considerations apply for both:

- What happens in case of early closure, when the plant has not earned sufficient income to fund the shutdown costs[13]
- How is D&D funding for plants that close early resolved, perhaps with different approaches based on the cause of early closure:
  - Owner's responsibility (e.g., operating error)
  - Regulatory action (e.g., new safety requirements),
  - Government action (political "exit" decision)
  - other Acts of God

Depending on the answers to these questions, or lack thereof, a positive investment decision may not be possible.

In recognition of these challenges for nuclear new build, the United Kingdom has put in place legislation and contractual arrangements that consider domestic lessons learned and international best practices. Per a Funded Decommissioning Programme the owner/operator is required to set aside some of the revenue from plant operation (i.e., under a 35-year Contract for Difference ("CfD") for Hinkley Point C) for back-end costs. The funds set aside are ringfenced in a bankruptcy remote vehicle and both their adequacy and appropriateness is subject to regular independent review. The condition, price and terms for transfer of the wastes remaining after decommissioning to Government are contractually agreed. Since the CfD strike price reflects these costs, and because there are mechanisms to re-open the CfD at defined future points, they are passed along to electricity users. It is unclear how D&D funding would be collected for a new merchant nuclear project in the U.S. or other countries.

This discussion focused on private investment in merchant plants, as the issues are most pronounced in this context. Nevertheless, similar considerations apply in case of publicly owned new build programmes, and certainly should serve as benchmarks for other models (classic rate-based or e.g., PPAs, CfD, RAB).

## New decommissioning approaches

Industry experience so far has considered three scenarios for managing end-of-life D&D liability:

- **The owner self-performs,** with suitably specialized subcontractors for various purposes. This is the traditional approach. It is certainly an efficient solution when there is a sufficiently large D&D programme, but if that is the case then it can still be a significant distraction from "core business".
- **The owner transfers responsibility to a third-party turn-key contractor but retains ultimate liability.** When this has been tried at commercial nuclear power plants, it typically resulted in contractors experiencing cost overruns, passed on to the owner, and the owner, in retrospect might have been better off self-performing. Prospects for improvement exist as industrial and regulatory experience with decommissioning grows and future risk of failure is bounded.
- **A third party steps in and takes over full responsibility and non-recourse liability from the owner.** Traditionally, this has not been accepted by regulators for fear that the third party would (perhaps even by design) not have the same financial strength, the same ability to post acceptable third-party financial assurance (e.g., letters of credit) or the ability to correct any shortfalls in ring-fenced funds[14] set aside during operations. As a result, and as noted above, owners have therefore not typically been able to fully discharge liability. However, recently efforts have been made that promise to overcome these hurdles.

As a major reference for the first of these three scenarios, this is the approach (still) being applied by the four nuclear utilities in Germany, each of which has a substantial decommissioning programme underway, spread across several sites in several federal States, and with some units still in operation. It remains to be seen whether, individually or collectively, they will consider new decommissioning business models once the entire fleet is shut down from 2022 onwards: this would be politically highly challenging, but there could be strong benefits.

The second scenario might be considered a compromise between the first and the third; it is quite common at Government owned sites. The third scenario has been gaining traction in the U.S. market, where several companies have focused on purchasing nuclear power plants as they close, with the transaction transferring the entire plant and site along with the NRC license, the D&D funds, the responsibility to complete the D&D funds:

- The old utility owner can shift the entire plant and long-term D&D responsibility to another party, with the benefits noted above.
- The new owner: where, as an engineering company or services provider they could capture only a relatively small portion of the total decommissioning budget, at competitive margins, the new "D&D company" has a captive market (its own nuclear power plant) for its D&D capabilities, controls the entire budget and funds, and has the potential for profits if the D&D activity is completed in a timely and efficient manner.

12 E.g. it may seem that in the Unites States early closures are leading to shortfalls in expected accruals for the national high-level waste disposal fund: https://www.forbes.com/sites/jamesconca/2021/12/29/premature-nuclear-reactor-retirements-could-effect-nuclear-waste-disposal/?sh=7044de5e6ab4

13 Noting precedents such as Mülheim-Kärlich (Germany) or Shoreham (USA) where plants were shut down shortly after criticality, i.e., incurring not only complete asset write-off but also full decommissioning cost: in one case at the cost to the owners in Germany, in the other as a pass-through to ratepayers in New York.

14 Typical practice in the US and Western Europe is for owners/operators to accrue funds (through cash contributions and capital market investment returns on these) in advance of decommissioning, which are then subsequently drawn upon to meet these end-of-life as and when they occur. To mitigate risks associated with operator insolvency, these funds are usually ring-fenced from the operator. More detail on this aspect is provided in Part III.

- The regulator might accept that the new owner is in a better position to perform the D&D in a safe, timely and compliant manner.

Market players specializing in this approach in the U.S. include Accelerated Decommissioning Partners (a joint venture between NorthStar and Orano), Comprehensive Decommissioning International (a joint venture between Holtec and SNC-Lavalin), and Energy Solutions.

*Whether such third-party approaches are transferable to other D&D programmes, in the U.S. or internationally; and if so, in which situations and under what conditions they would be possible and beneficial, is beyond the scope of this article. However, at least in theory an industrial offering of a sustainable "decommissioning business model", with companies with sufficient financial means (deep pockets and security) and broad technical and project specialization could prove beneficial for nuclear power plant owner/operators and for the common good. Such industrial D&D companies could bring experience and a pipeline of D&D projects that would enable:*

- *Economies of scale and learning in D&D activity;*
- *A sustainable long-term business model with employee retention and growth potential;*
- *Incentives to develop new and improved techniques and equipment for D&D activity;*
- *Better capital market allocation and lower risk, with nuclear utility assets unlinked from D&D risk and D&D specialist company risk spread across a portfolio of projects.*

*A critical enabling factor for such a business model is that decommissioning liabilities are well funded, with this funding available as and when needed: in adequate amount, liquidity, and security.*

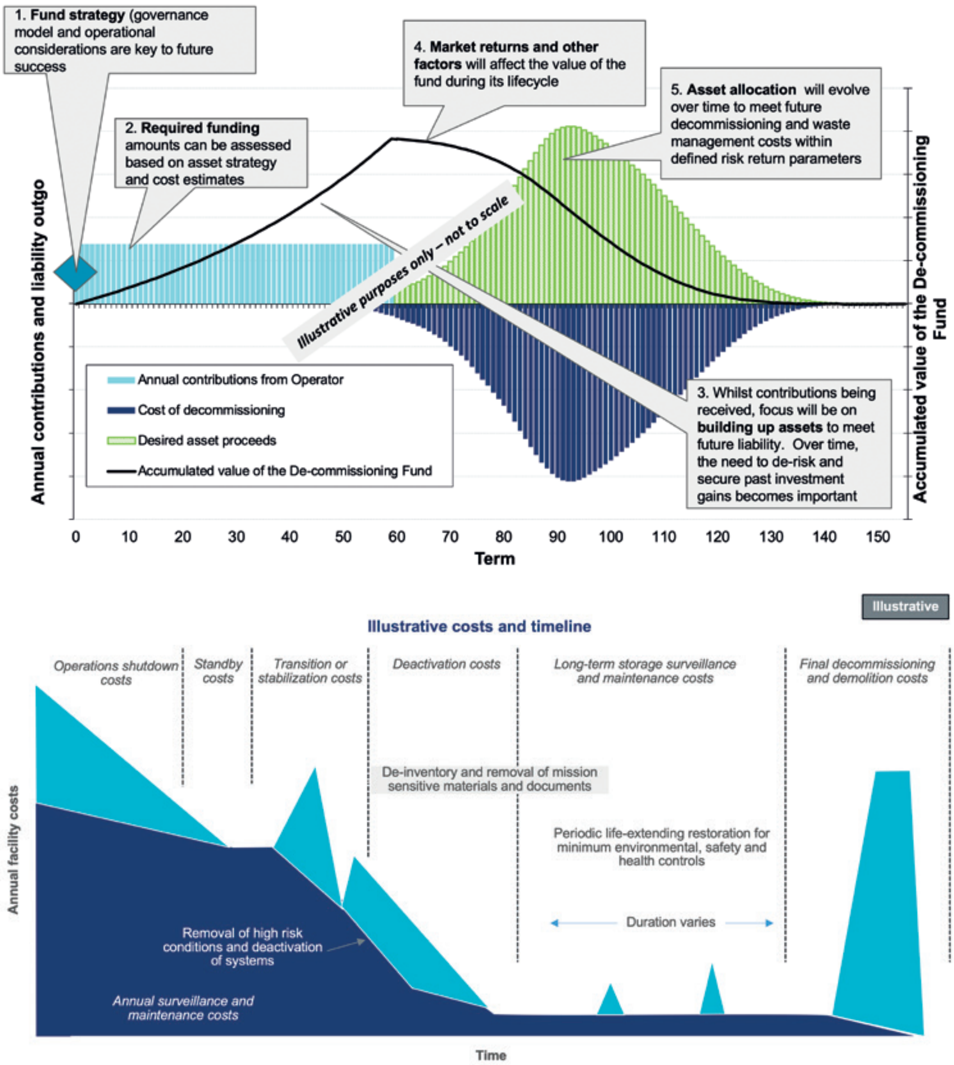


**Figure 7**
Financial profile over nuclear plant lifecycle.

## Part III – Best practice for funding end-of-life costs

As the nuclear power and D&D industry are changing, there are some lessons about how to fund and finance D&D costs.

### Historical context

There are different ways – in theory and practice – how a nuclear power plant can collect the funds to meet the eventual costs associated with long-term end-of-life activity.

Historically, many countries had the government take responsibility for meeting the future end-of-life costs, typically leaving taxpayers to fund these activities as and when they occur. This was easy when the government was also the developer and owner of nuclear power plants in the country. The problem with this approach is that it is contrary to the principle that cost should be allocated where it is caused ("polluter pays") and leaves the liability to future generations. In case of industry privatization, a further downside of this approach is that the government position may change over time and a nuclear power plant owner would want a clear way to ensure that these liabilities do not come back to them.

For these and other reasons, nowadays most countries apply some combination of the following approaches, albeit not yet generally in line with a common "gold standard":

- Government responsibility, with a D&D tax/fee charged during a nuclear power plant's operating life (e.g., like the U.S. spent nuclear fuel fee and the resulting large and unspent nuclear Waste Fund[15] held by the U.S. Government).
- Plant owner responsibility to set aside funds during the plant's operating life to be used to meet future D&D and waste management/disposal costs.
- In practice, these funds may or may not be ring-fenced, available for financing other activities, insolvency proof.
- The closest analogy are the various types of retirement or pension

15 This led to lawsuits that stopped the spent nuclear fuel fees because the US government had breached its contract to take spent nuclear fuel and had not been able to develop a viable permanent disposition approach.

funds. The main, significant difference is that the underlying obligations, funding and risks for future nuclear back-end liabilities cannot generally be effectively transferred to the insurance market.

Depending on how such a retention were structured, this might be a pass-through to ratepayers or affect the plant cash flow and return on investment (making nuclear investments electricity less attractive). Even with such approaches there is a risk that the accrued funds might not be available when needed (e.g., in the case of earlier than planned decommissioning, or due to operator insolvency, or State budget policy) or that they might not be adequate (e.g., due to cost escalation or underperformance of the investments held in the fund).

## Best practice

The best practice for meeting future end-of-life costs should be some form of advance funding arrangement during the operational phase, with appropriately ring-fenced trust funds (or similar vehicles) to mitigate the risk of operator insolvency or other fiscal diversion of funds. A best practice framework for managing end-of-life financial liabilities includes advance funding and a sound approach to investment strategy, supported by ongoing governance, monitoring and risk management[16].

In this context, it is **critical** that the interfaces between the different end-of-life liability categories and responsibilities are well defined and agreed, as outlined in Parts I and II above.

Crucially funding/investment strategies need to be cognizant of the interest rate sensitivity (i.e., the long duration) of future end-of-life costs and structured in such a way as to best mitigate this risk. Ideally this should all be captured within a well-defined national (or potentially even international) decommissioning and waste management liability framework, setting out clear requirements, methodologies, and principles for securing adequate future funding, investment of these funds, roles and responsibilities and the broader approach to governance.

Oftentimes there is a hidden or misunderstood conflict-of-interest concerning the objective that these funds should follow a conservative (low-risk) investment strategy. This is often understood to imply using "safe" instruments, i.e. government notes, for the majority of the fund's investments. However, this can inadvertently lead to a higher risk – namely, that future funds might not be sufficient, or that necessary higher future funding commitments will place too strong a burden on electricity rates – due to the often low (and potentially negative real) yield available on these government bonds. Another consideration that can complicate investment policy occurs in those cases where the funds are to be invested for other specific politically desirable benefits.

## Ring fenced end-of-life funds

In **Figure 8**, we outline the key elements of a best practice framework that might serve as a benchmark for ensuring that future end-of-life costs can be met with a high degree of confidence in a cost-effective manner.

### (a) Estimation of expected future costs

Recognising the liability-driven nature of the funds set up to meet the end-of-life costs, a robust estimate of these future costs is required before any realistic consideration of funding and investment is possible. The NEA, IAEA and EC's International Structure for Decommissioning Costing ("ISDC") has been developed to assist and its use might well be regarded as best practice.

It is crucial that cost estimates are reviewed and updated periodically in order to ensure both they and the target level of funds to be accumulated remain appropriate.

### (b) Assessment of the likely future cost inflation

Setting an assumption for future cost inflation requires an understanding of general long-term inflation expectations and nuclear specific factors. Government bond market implied inflation and long-term consensus forecasts can provide a reasonable starting point for the former but fail to capture the latter. A pragmatic approach of identifying a few major cost drivers (e.g., labour, energy and disposal costs) and determining

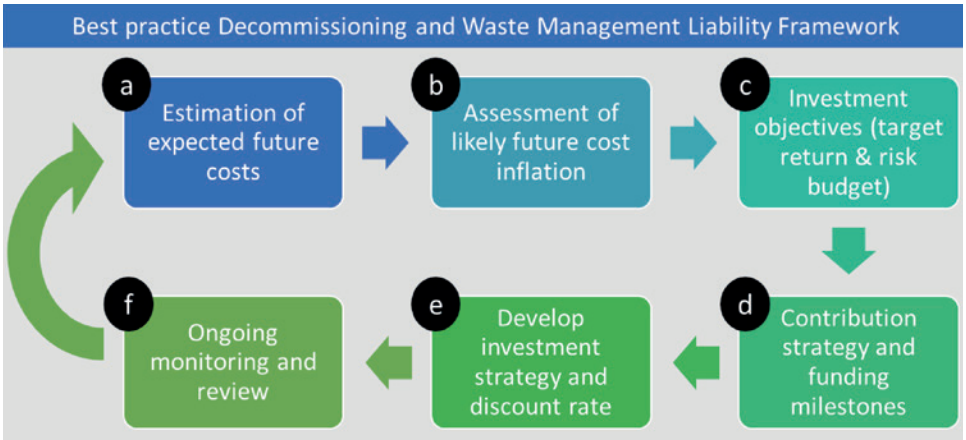


**Figure 8**
D&D Liability Framework.

| | France (operators) | UK (NLF) | Germany (FNWM) | Spain (PGRR) | Slovakia (NNF) | Hungary (CNFF) | Sweden (NWF) |
|---|---|---|---|---|---|---|---|
| Fund value (€m) | 45,300 | 10,973 | 24,148 | 5,018 | 1,399 | 910 | 6,839 |
| Operator / owner liability value (€m) | 46,600 | 38,289 | 13,946 | 10,971 | 11,537 | 2,205 | 10,522 |
| Market consistent liability value (€m) | 67,310 | 63,621 | 19,400 | 18,713 | 11,537 | 7,983 | 12,328 |
| Shortfall not covered by existing funding arrangements (€m) | 20,710 | 25,332 | - | 7,742 | - | 5,778 | 1,806 |

**Table 1**
2018 EU D&D funding situation.

16 For example, e.g. see our Report to the EU Commission: https://op.europa.eu/en/publication-detail/-/publication/3a94a52a-ec36-11e9-9c4e-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=37085&WT.ria_f=3608&WT.ria_ev=search

reasonable inflation assumptions for each of these is likely to be appropriate.

Our 2018 review of practices across the EU[16] found that although some Member States (e.g., Germany, Sweden and the UK) make allowance for expected future decommissioning and waste management specific inflation, this practice was not widespread.

### (c) Setting investment objectives, target levels of return and risk limits

An appropriate rate of expected future nuclear cost inflation should provide a minimum for the level of target investment return. This minimum level of target return can also then be used as the discount rate to place a present value on the expected future end-of-life costs. The discount rate can be thought of as the minimum return that must be achieved on a fund's investments each year in order to meet decommissioning and waste management costs at the end of the operational phase without additional (unforeseen) funding.

In the last decade, interest rates and the yields available on long-dated government bond assets (typically regarded as "risk-free") have fallen significantly. In many jurisdictions this now means that these "risk-free" rates are not likely to exceed future inflation. Funds held to meet end-of-life decommissioning/waste management costs thus need to accept risk in pursuit of higher investment returns, which of course creates the possibility for investment returns to be lower than expected. This challenge is particularly acute since 1) gross investment returns are likely to be lower in a low interest rate environment and 2) current equity market valuations are high due to economic stimulus measures (and some would argue disconnected from fundamentals).

The current low-interest rate environment (together with the elevated levels of global equity markets) is an important consideration. Lower interest rates lead to lower discount rates being used to derive the present value of long-dated future end-of-life costs. These lower discount rates reflect the expectation that capital market investment returns will be lower in future, which in turn serves to create funding shortfalls and the requirement for even greater future funding commitments. In a circular economy, the ability for operators/owners to meet end-of-life costs effectively, without placing an undue financial burden on public finances or future generations, is crucial to the future of nuclear power generation.

In the 2018 EU study referred to above[16], several Member State investment portfolios were found to be dominated by Government bonds and cash investments and, furthermore, discount rates in several Member States were not realistic in light of the future investment returns that might reasonably be expected from these investments (i.e., they had failed to make adequate allowance for the low interest rate environment). As shown below, this suggested material underfunding in several Member States which is unlikely to have been rectified.

This "forward-looking" approach based on likely future inflation and investment returns applied to plant specific future cost estimates differs fundamentally from the US NRC approach set out in 10 CFR 50. The latter is a "backward-looking" approach based on an assumed historical cost profile with cost escalation factors to inflate this cost estimate to the present time. Whilst it does provide a minimum value against which to compare the adequacy of accumulated fund investments, it is by

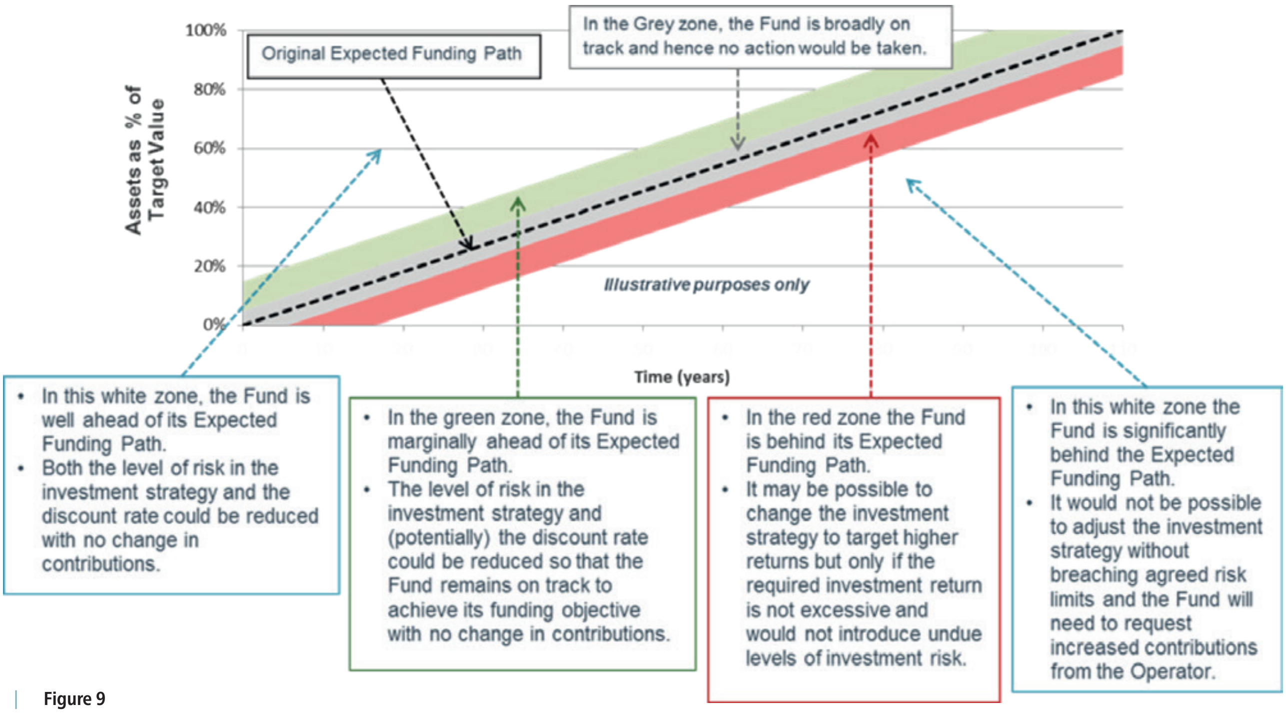


**Figure 9**
D&D Liability Framework.

no means clear that achieving this minimum value will ensure the actual sufficiency of fund investments to meet future decommissioning and waste management costs.

This is already a significant issue for the US nuclear industry, which is only likely to increase in importance (in both the US and elsewhere) as new decommissioning business approaches and models come to the fore. In particular, permanent licence transfer models (e.g., for Vermont Yankee, Oyster Creek, Pilgrim) and the adoption of accelerated decommissioning approaches can materially accelerate withdrawals from these funds, thereby calling into question previous assumptions regarding the time available for them to grow without further funding contributions.

### (d) Determining contribution strategy and funding milestones

Given realistic assumptions for future cost inflation and target levels of investment return it is possible to calculate the level of contributions that will need to be made into the fund.

Best practice would then be to develop an "intended funding path", specifying the percentage of the total liability (i.e., the funding level) that should be accumulated at different points in time, together with details on how any deviations (both upside and downside) from this intended funding path will be dealt with, as shown in **Figure 9**.

There is an important trade off in setting the date of fund maturity. On the one hand, by requiring funds to be fully accrued at the time when the plant falls out of rate base or other support schemes would go a long way to mitigating the risk of fund shortfalls in the event of earlier than planned decommissioning or where lifetime extensions are not pursued. Indeed, this is what is envisaged under the UK new nuclear build regime. On the other hand, however, a shorter funding period results in a greater impact on ROI, hence making it more difficult to attract investors.

### (e) Developing an investment strategy

The next consideration is how best to construct an investment portfolio that is expected to deliver the required level of investment return over time with no more than the acceptable level of risk. If the investment strategy cannot deliver the target level of return, then over time the fund will start to fall behind its intended funding path, creating a need for additional funding contributions or even higher target levels of return in future (which may not be commensurate with the acceptable level of risk).

Deriving a suitable investment strategy requires a detailed assessment of the investable universe and the expected cost / liability risk profile, taking full account of:

- Return and risk expectations for different asset classes;
- Correlations between different asset classes, diversification benefits and how both of these might vary in different financial market conditions;
- Underlying drivers of risk and return, including the extent to which interest rate and inflation risk can be hedged and the appropriateness of active management;
- Investment management fees, liquidity considerations and the relative complexity inherent in different asset classes;
- Restrictions or constraints on the ability to invest in certain asset classes or individual securities.

Developing an investment strategy is not a one-off exercise and will need to evolve over time, in particular:

- In the early years of operations there are many years until end-of-life costs are expected to be incurred. This should provide greater investment flexibility since there is little need for immediate liquidity and a long period of time to correct any shorter-term investment underperformance.
- Most of the cash disbursements related to decommissioning and waste management occur once the nuclear facility has stopped generating revenue. At this point, accrued funds should not only be sufficient to meet the expected future costs but steps should also have been taken to minimise asset-liability risk. There is significantly less tolerance for investment risk given the need to realise assets to

meet cost outgo and given the lack of recourse to additional cash funding.

The second bullet above is particularly relevant given that future decommissioning work may well be expected to be carried out by non-utility merchant operators or specialty decommissioning companies who may lack the financial strength typically associated with traditional regulated utilities and who are therefore less likely to be able to provide any further funding for decommissioning and waste management.

Capturing details of the strategic asset allocation, how it is to be implemented and how it is expected to evolve over time in a formal policy document should be seen as a key governance requirement.

### (f) The importance of ongoing monitoring and regular reporting/disclosure

Ongoing monitoring of and regular reporting on the development of a fund's investments relative to its liabilities (and how this compares to an intended funding path) is essential for ensuring that the investment strategy remains appropriate and that the fund is able to react quickly in light of emerging risks or opportunities.

The level of detail and frequency of monitoring/reporting updates should be based on the specific circumstances of each fund and, again, may well need to evolve over time. In early years, less frequent monitoring may be required but the frequency should be increased as the date of cessation of operations approaches. This is consistent with NRC requirements in the US and the new nuclear build regime in the UK.

A detailed update of future cost estimates might only be carried out, for example, every three to five years. However, as these cost estimates should be the primary driver of funding and investment strategy, it would be reasonable to expect the following to be reviewed in light of any material changes to the future cost estimates:

- The methodology used to determine the assumed rate of future cost inflation;
- Investment objectives, target levels of return and risk limits;
- The adequacy and appropriateness of currently agreed funding contributions;
- Strategic asset allocation (taking account of underlying market conditions); and
- A Statement of Investment Principles (or similar policy document).

### Putting 'best-practices' in context

Actual case studies show that the funding and investment approaches adopted by end-of-life funds have not always been optimal and, whilst there are examples of best practice being applied in certain areas and in certain jurisdictions,[17] there remain inconsistencies in a number of key areas. As the nuclear industry matures and the time period until large scale D&D activity draws near, it is critical that these inconsistencies are addressed.

If they are not, there is an ever-increasing risk of actual funding shortfalls. Assuming the funds are sufficiently ringfenced to exclude solvency risks over an up to appr. 100-year period, which is not always

17 Examples where this has been achieved, or at least close to that, are the UK with the FDP for the new build programme, or Germany in the 2016/17 system switch.

the case, the funds available would serve as a financial 'safety net' – but the underfunding would still result in legacy liabilities being left to future generations.

*On the other hand, with a solid funding scheme in place, compatible with best practices outlined here, this would enable some of the new, fungible D&D approaches and create an important building block for the industry to evolve most efficiently.*

## Part IV – Where does the rainbow lead?

The end-of-life D&D activities and requirements for nuclear power plants are well-understood in principle, but much room for optimization remains while big challenges for an efficient implementation are fast approaching.

As these challenges are met, and nuclear development moves further, new aspects will need to be factored in future back-end strategies:

- If future nuclear plants include a large fleet of Small Modular Reactors, and in more new markets: what back-end issues and opportunities are created (e.g., for risk sharing and learning)?
- If future nuclear plants include breeders and other types of reactors capable of re-using used fuel and even some waste types: how is the 'value' of their feed material reflected in the market model and how does this perhaps incentivize decommissioning?
- At many sites, there is a 'pot of gold' at the end of the rainbow. D&D usually considers the end state from the perspective of an environmental liability that needs to be minimized and restituted, and models its Programme accordingly (e.g. see **Figure 7**). But instead, the site may have significant value as an important asset for future purposes. Which programme achieves the integral optimum, maximum residual value over minimal D&D cost, with given external parameters?

**Strategic goals for plants end-of-life**

- Place risk where it is best managed.
- Protect the public at large and local stakeholders from incompetent or negligent, or insolvent custodians of future legacy issues.
- Transition the site to new uses. Include optimization scenarios into the D&D Programme design.
- Achieve economic optimization: Operators do what they do best: build and operate a new energy system. D&D champions perform safe efficient timely liability management.

Taking a step back, and with a forward-looking view towards future energy markets:

- Over the next 2 or so decades the world will be building an entire new, decarbonized energy infrastructure, with considerably larger share of electricity and requiring new types of energy services (such a storage, P2X conversion, smart grid functionalities, frequency control, etc.)
- In parallel it will be decommissioning the existing carbon-based global energy producing and electricity generating fleet (in the industrialized world). In addition, since the new energy system consists of many shorter-lived assets, we will also be decommissioning the first and second and next generations of wind and solar farms and other facilities.
- In other words, we will need a highly efficient industrial structure to build, operate, and decommission several trillions worth of assets in a 20-to-30-year period.

What lessons can be learned from the nuclear experience for a sustainable "circular economy" in the electricity industry and energy markets more broadly? how can nuclear participate by addressing its unique end-of-life challenges? What about the huge infrastructure building programme that will be needed to decarbonize Europe: wind, solar, CCS, hydrogen: what is the best way to protect the communities and other stakeholders against future legacy issues?

*We believe it will greatly benefit the players in the global energy industry, the governments overseeing this programme, the ratepayers financing the effort as well as the communities hosting the facilities and infrastructure if we could achieve four things:*

- *Develop the industrial skills to perform new build on the one hand and decommissioning on the other most efficiently – improving learning curves and economies of scale.*
- *Give assurance to new build investors and the public – including local communities where new facilities (whether nuclear or other) are to be developed – that funds for the future decommissioning will be adequate and safe.*
- *Develop a system to ringfence the cost and secure the funding for the future liabilities.*
- *Develop a market, with best-in-class market participants and suitably fungible products, to enable smooth, safe, regulated industrial and economic division of labor.*

We look forward to discussing these ideas further in a future opinion piece for atw. We will be happy to reflect comments which we would like to invite from readers of this and our previous article.


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