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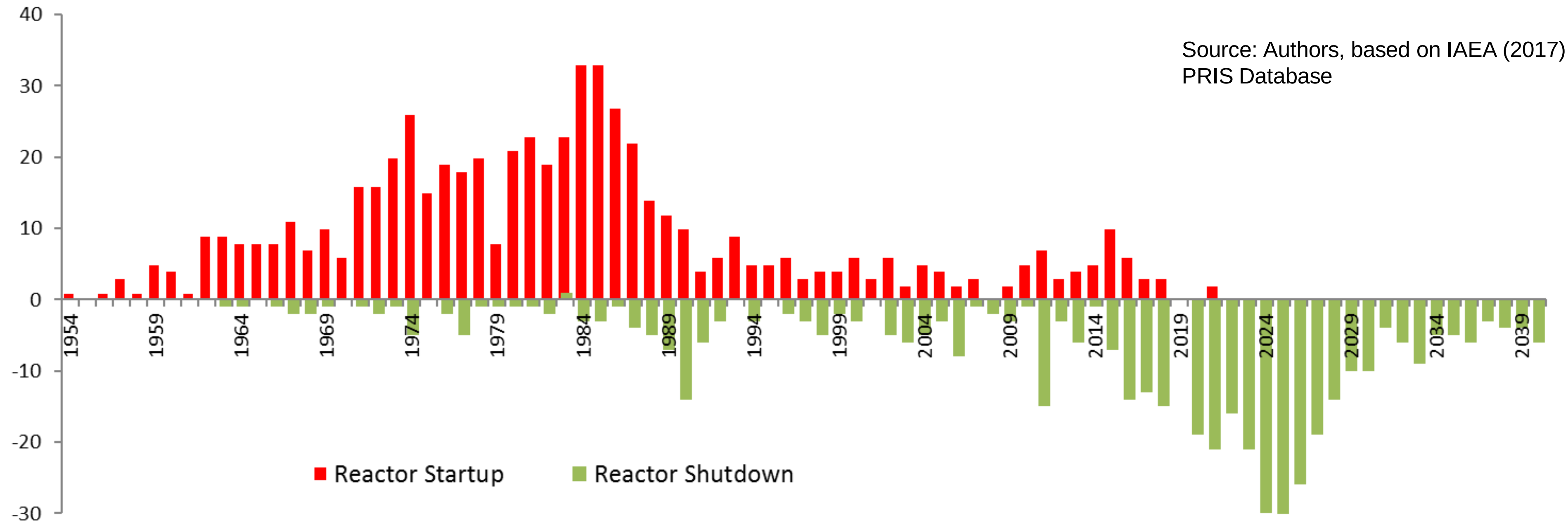
The Economics of Radioactive Waste Management: Status Quo, Lessons Learned, and Policy Perspectives

Ben Wealer (WIP/DIW)

Agenda

1) Motivation
2) Methods
3) Technological System
4) Financing schemes
5) Provision
6) Key Findings and Research Outlook

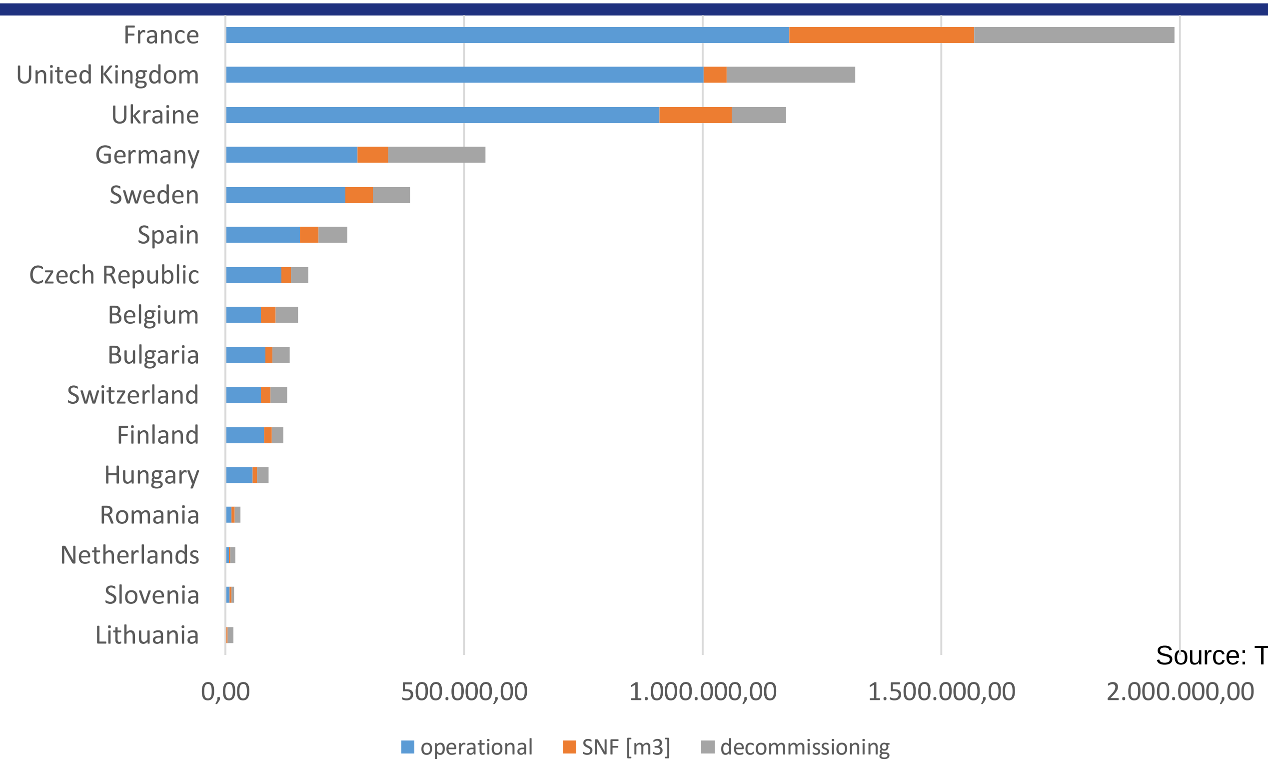
Outlook – Global Development of the Nuclear Power Plant Fleet



As of 1 July 2019, worldwide, there are 181 closed reactors totaling 77.6 GW of capacity

Assuming a 40-year average lifetime, a further 207 reactors will close by 2030 (reactors connected to the grid between 1979 and 1990); and an additional 124 will be closed by 2059; this does not even account for the 85 reactors which started operating before 1979, an additional 28 reactors in Long-term Outage (LTO) and the 47 reactors under construction as of mid-2019.

European nuclear waste increasing without disposal solutions



Source: The World Nuclear Waste Report (2019)

Using IAEA estimates, the European nuclear fleet (excluding Russia and Slovakia) is estimated to produce around 6.6 million m3 of nuclear waste over its lifetime.

With a share of 30 percent France would be Europe's greatest producer of nuclear waste, followed by the UK (20 percent), the Ukraine (18 percent), and Germany (8 percent).

If stacked in one place, all of Europe's nuclear waste would fill up a football field 919 meters high, 90 meters higher than the tallest building in the world, the Burj Khalifa in Dubai.

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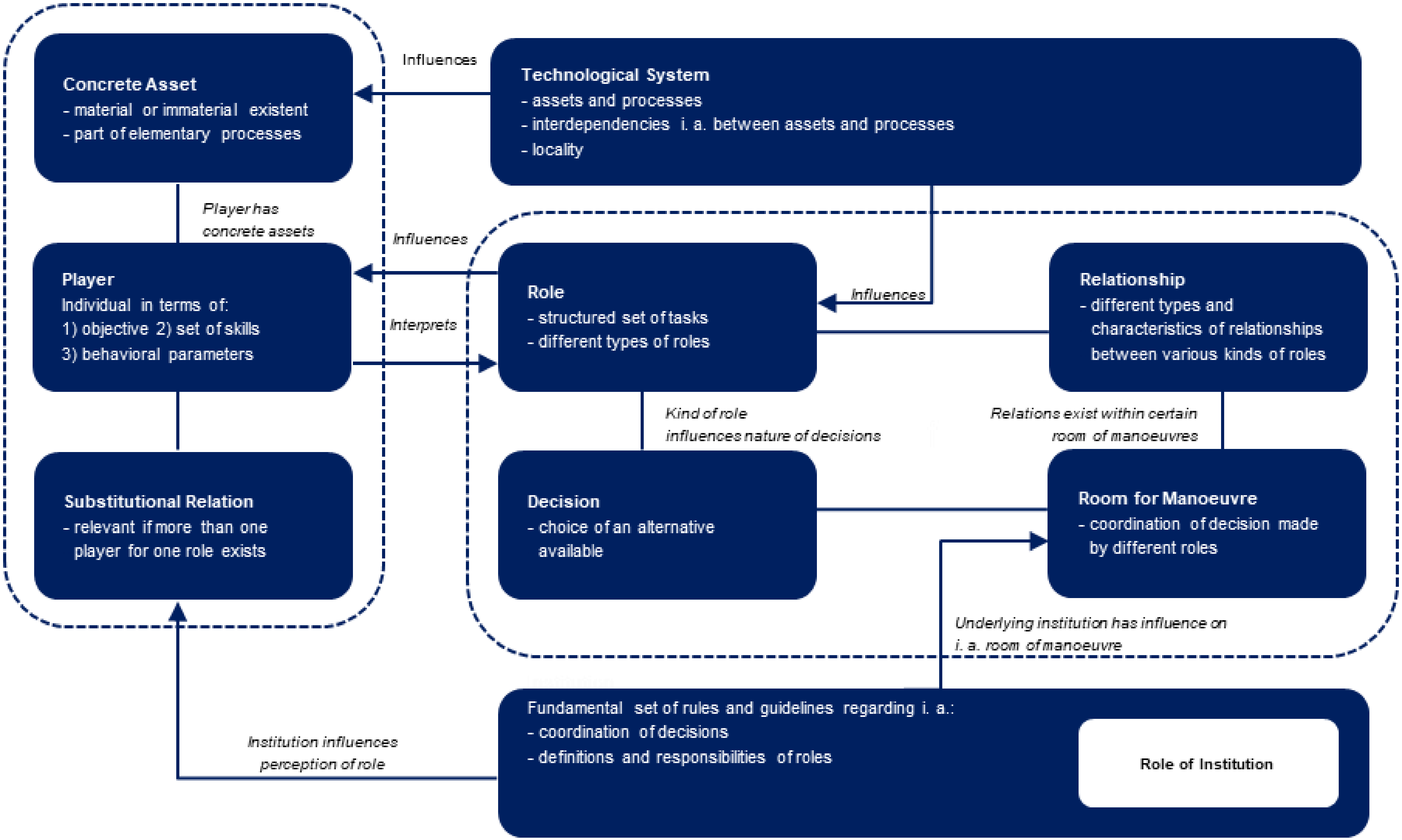
Central Elements of the Research Framework „Systemgood Economics“



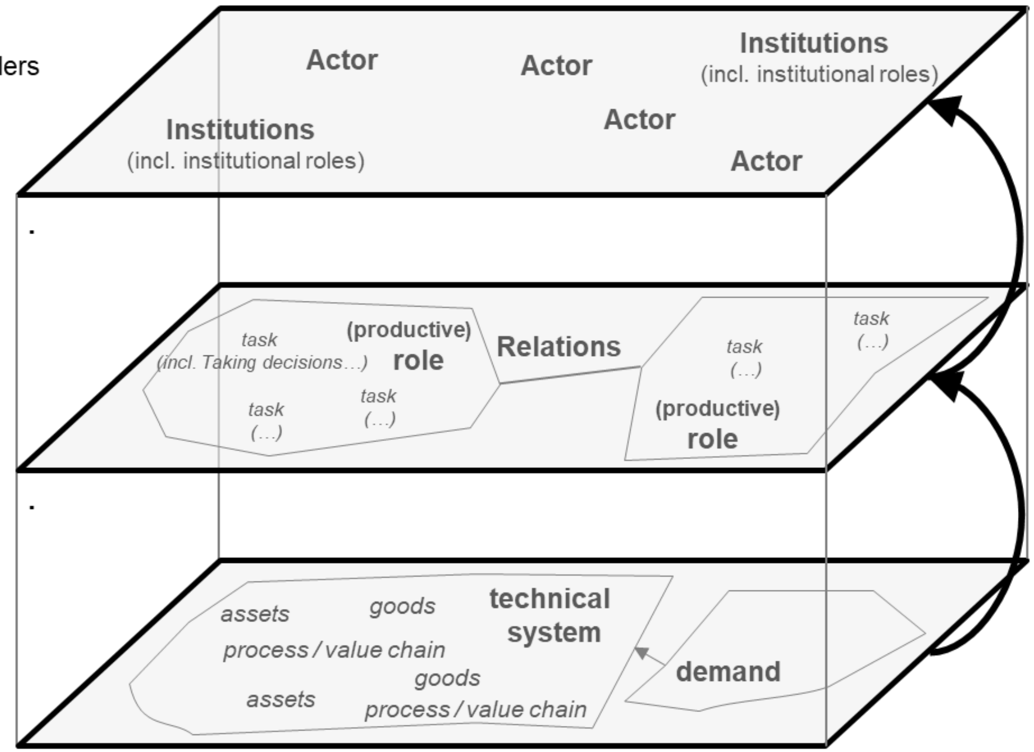
Source: Beckers et al. (2012)

Design of Organizational Models and Important Links

Organisational model: stakeholders

Tasks (decisions, roles = bundling of tasks)

Characteristics of (technical) good/asset



Some hints:

- Private companies (competition, monopoly)
- Public
- …

- Decisions: Technical interfaces, geography, pricing…

- Electric cars
- Electric charging stations
- …

Basic assumptions about key elements

Source: Beckers et al. (2012)

Organization Model consists of Production, Provision, and Financing

Production

Central technical properties of a system good are mapped in the element Technical System. The technical system contains the required processes on the one hand and the assets that are required to execute processes on the other (Gizzi 2016).

Provision

So-called roles can be derived from the technical system. These roles contain a structured bundle of tasks to be performed with regard to the offer of a defined service. If there are interdependencies between the services offered by two roles, a relationship exists between these roles. If decisions assigned to different roles are interdependent, a coordination area is created.

Roles are performed by actors who perform tasks and make decisions. Concrete actors have certain characteristics, such as a target system, and must be equipped with suitable resources in order to be able to perform a role.

Provision

To classify organizational models, Klatt (2011) and Seidel and Wealer (2016) distinguish between production and provision as well as financing of the product/service. Financing can, for example, come from the public sector, equity capital, outside capital, etc.

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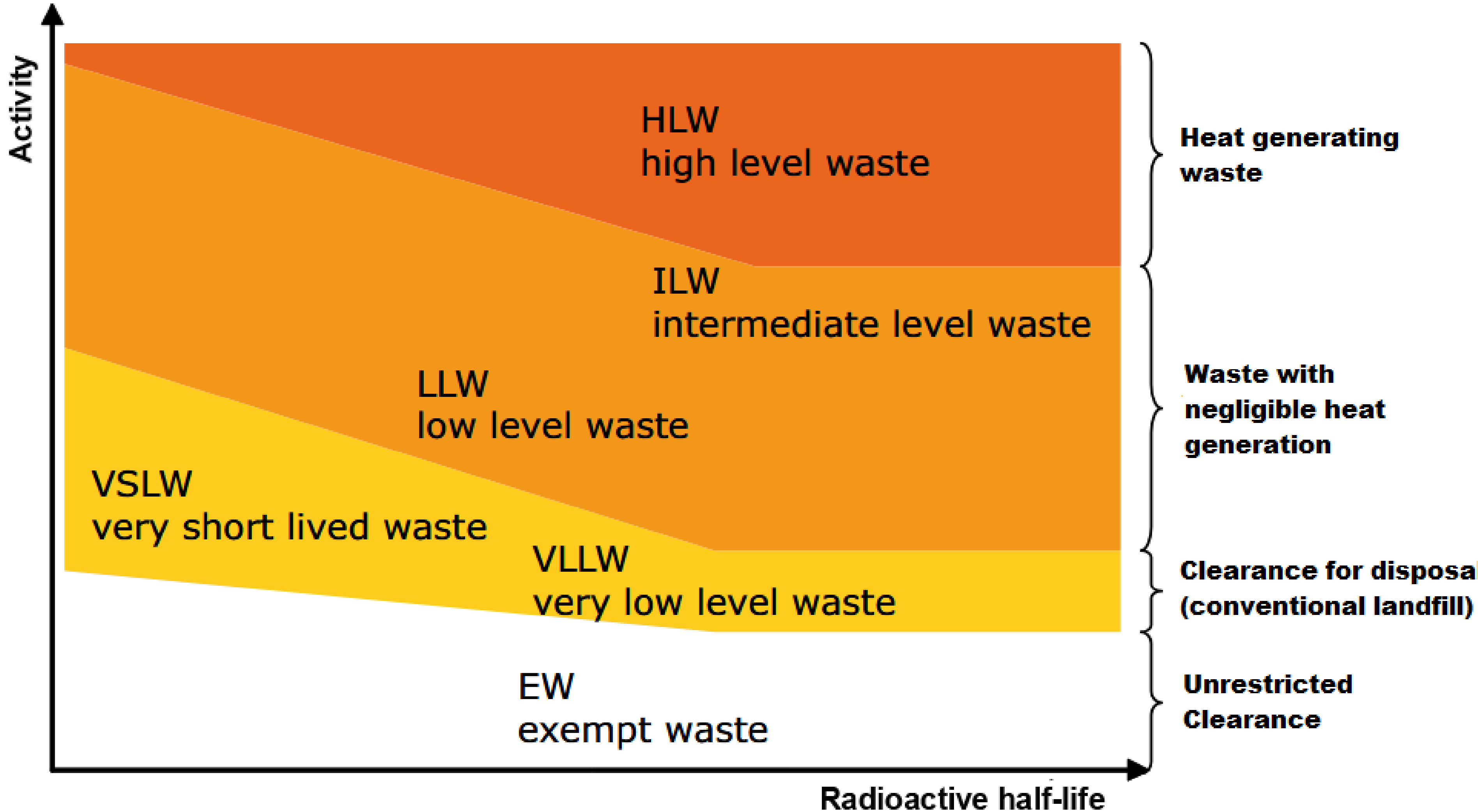
Radioactive Waste Classification (IAEA)



Technological System – Nuclear Waste along the Supply Chain

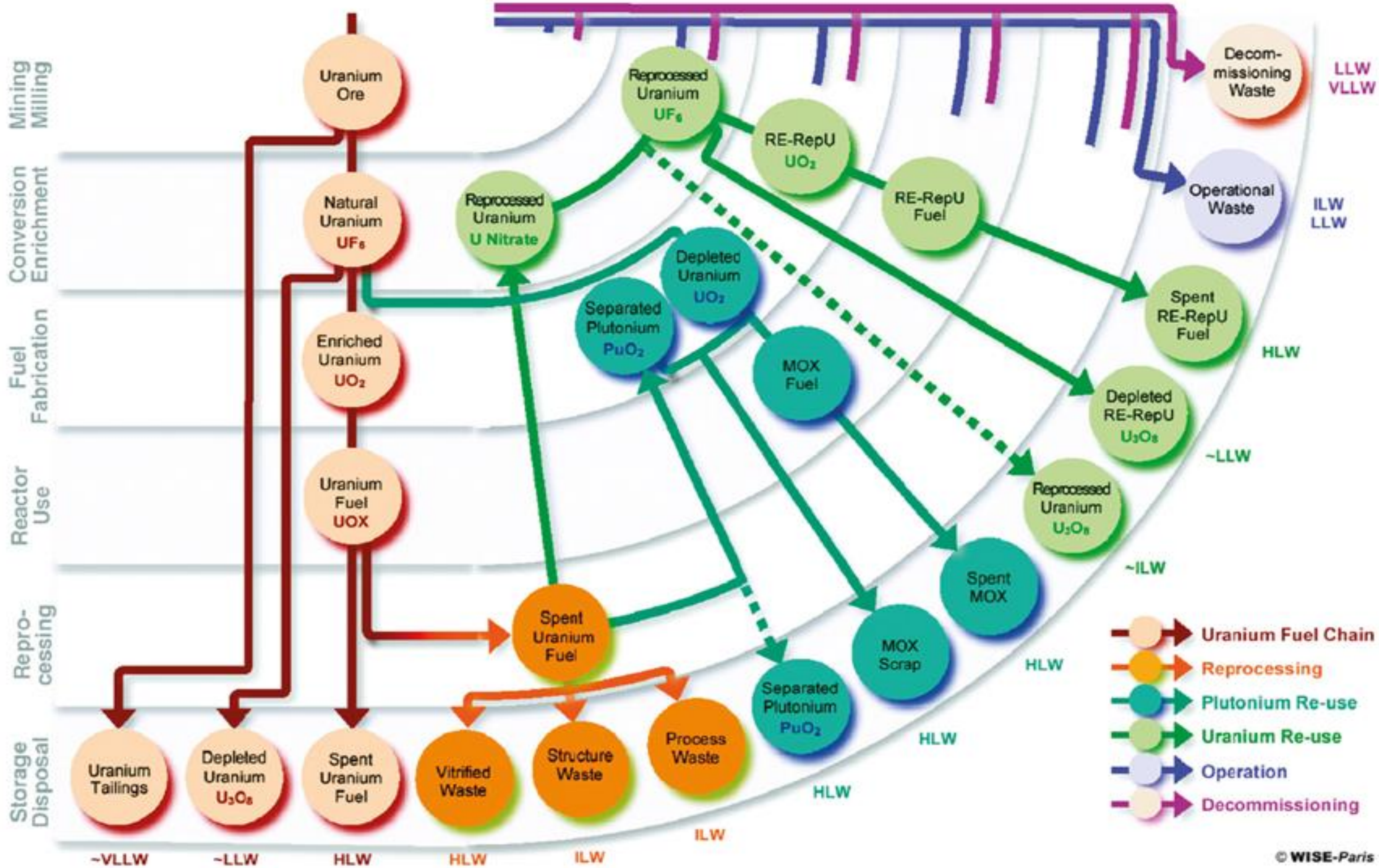


Figure 4.12 | The nuclear fuel chain. Source: WISE-Paris.

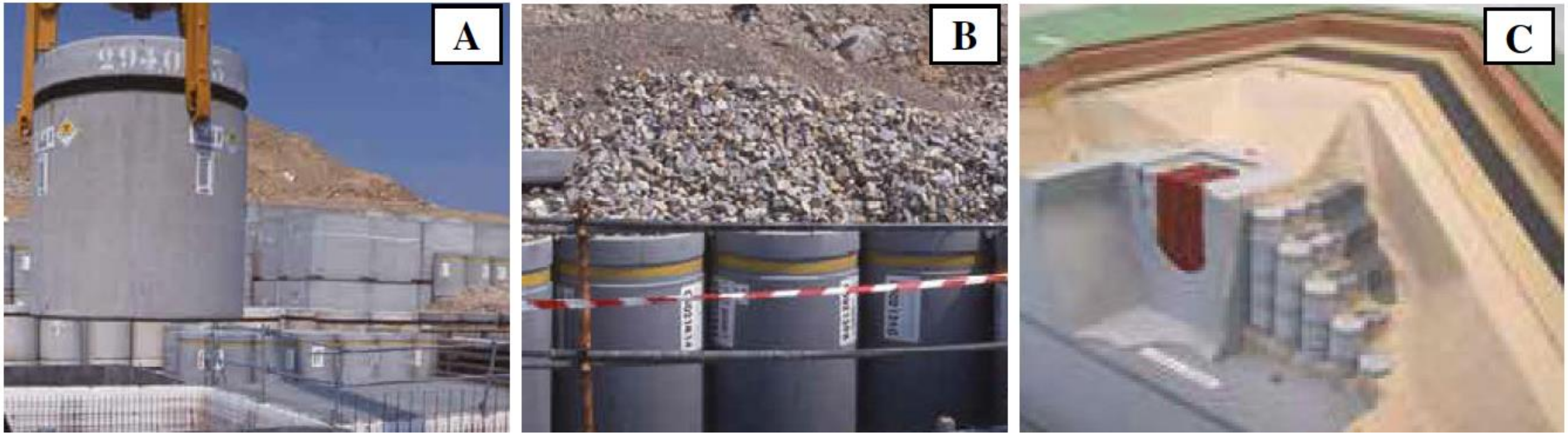
Source: WISE- Paris

Technological System – Disposal of Radioactive Waste

The IAEA (2011) differentiates in its safety requirements for radioactive waste which range between:

- **Specific landfill disposal: similar to conventional landfill for VLLW, for example from dismantling.**
- **Near-surface disposal: in engineered trenches or vaults on the ground or tens of meters below ground level for LLW.**
- **Belowground facilities: consisting of constructed caverns and vaults, or building of mines in tens of meters up to hundreds of meters below ground for ILW.**
- **Geological disposal: Siting of the facility deep underground in a stable geological setting (clay, salt, granite); Surround the containers with engineered barriers (buffer) that protect the waste packages and limit the movement of radionuclides if they are released from the waste packages such as impermeable bentonite clay.**

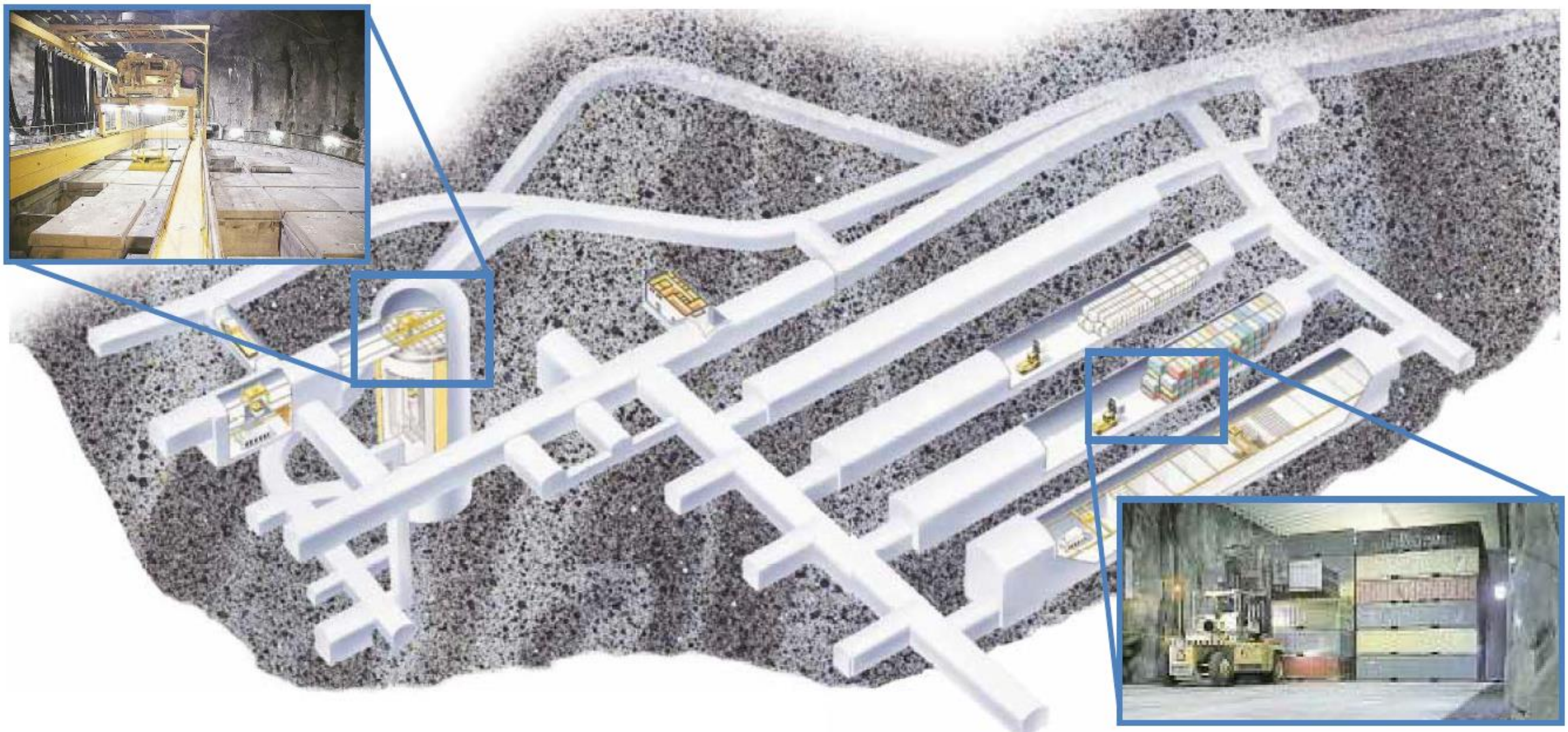
Near-Surface Disposal of LILW (Example Centre de La Manche in France)



Source: Andra

Belowground facilities for LILW

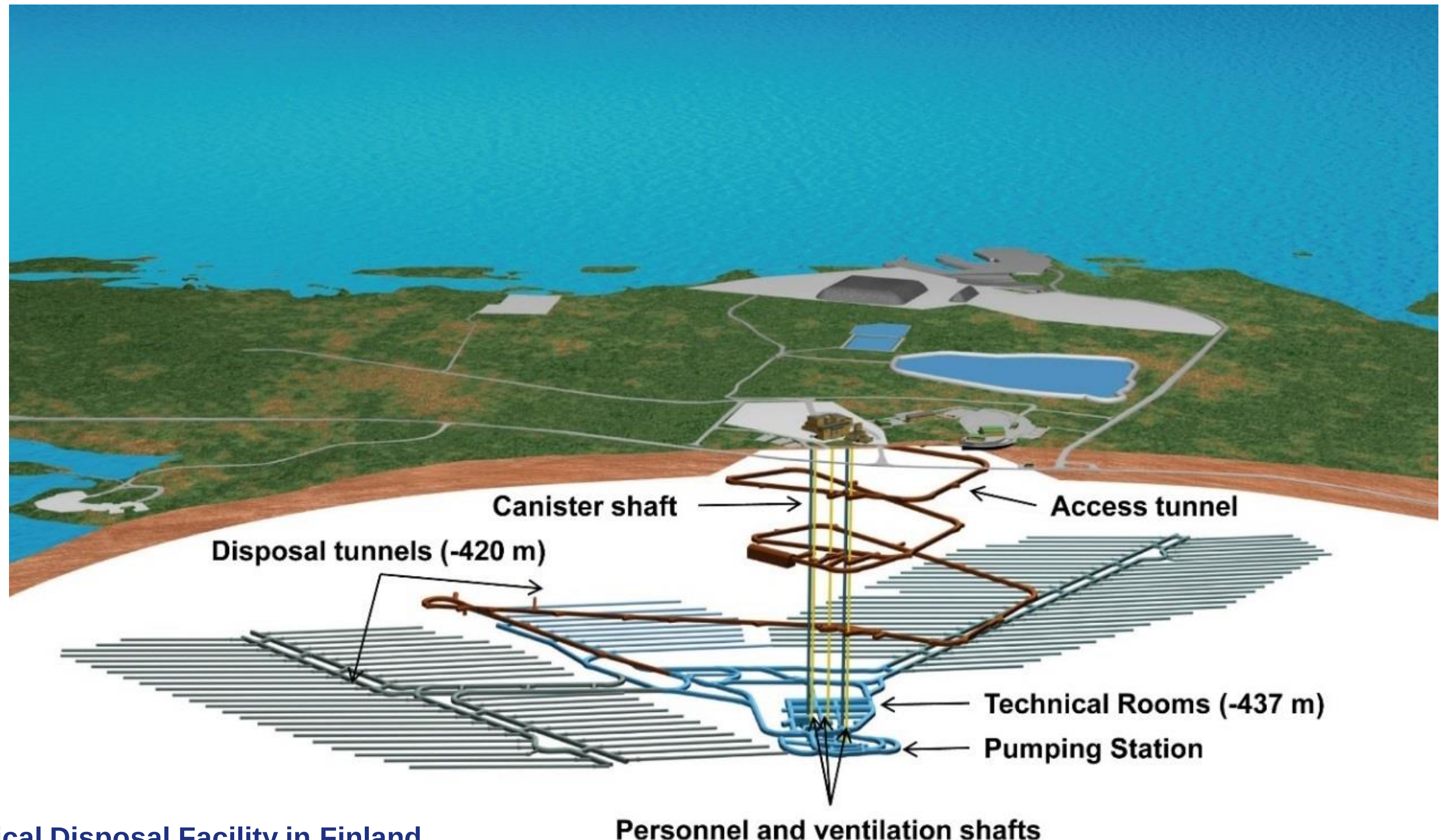
The Swedish final repository (SFR-1) for LILW



Source: SKB (2006)

Geological Disposal Facility

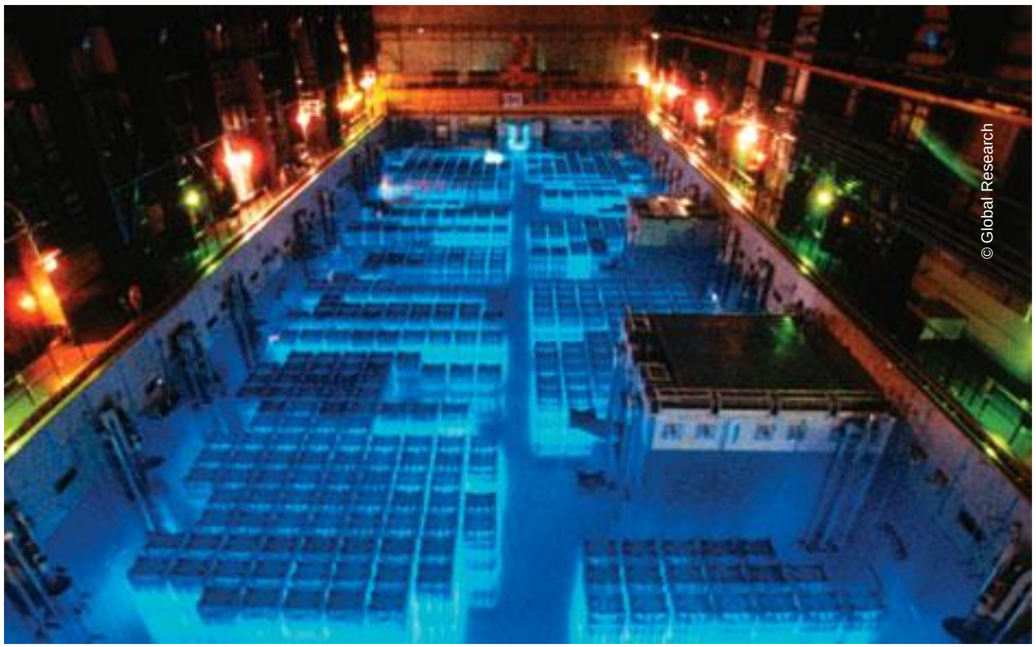
Through the use of a multibarrier system radioactive waste is isolated deep in a suitable rock formation.



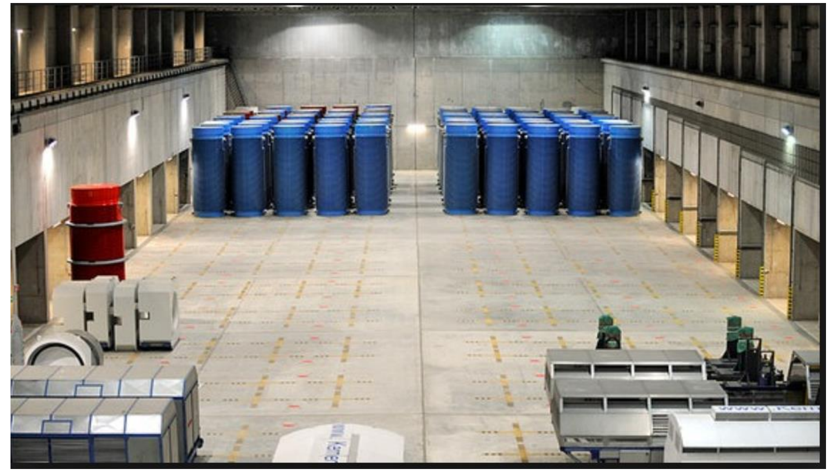
Geological Disposal Facility in Finland

Source: Posiva Oy

Interim Storage of Spent Nuclear Fuel



Source: GNS



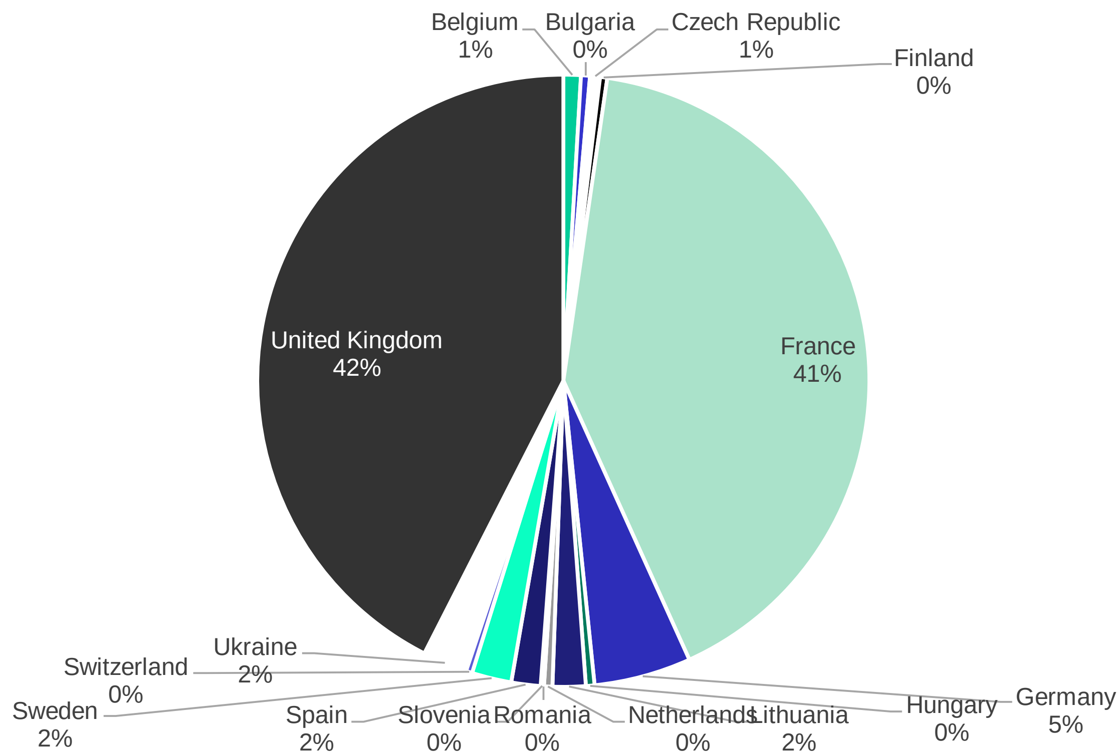
Interim Storage Facility Gorleben Source: GNS

Independent Fuel Storage Installation in the US Source: US DOE

Low- and intermediate level waste in Europe (in interim storage and disposed), as of December 31, 2016 (rounded figures)

Country	LILW in interim storage [m3]	LILW disposed [m3	Total generated LILW [3]
Belgium	23,200	No disposal facility operational.	**23,200**
Bulgaria	11,900	No disposal facility operational.	**11,900**
Czech Republic	1,750	11,500	**13,250**
Finland	1,970	7,600	**9,600**
France	180,000	853,000	**1,033,000**
Germany	45,200	84,100	**129,300**
Hungary	10,600	876	**11,500**
Lithuania	44,000	No disposal facility operational.	**44,000**
Netherlands	11,100	No disposal facility operational.	**11,100**
Romania	1,000	No disposal facility operational.	**1,000**
Slovenia	3,400	No disposal facility operational.	**3,400**
Spain	6,700	32,200	**38,900**
Sweden	13,800	39,000	**52,800.**
Switzerland	8,400	No disposal facility operational.	**8,400**
Ukraine	59,400*	No disposal facility operational.	**59,400**
United Kingdom	130,000	942,000	**1,072,000**
Total	**552,400**	**1,970,000**	**2,522,000**

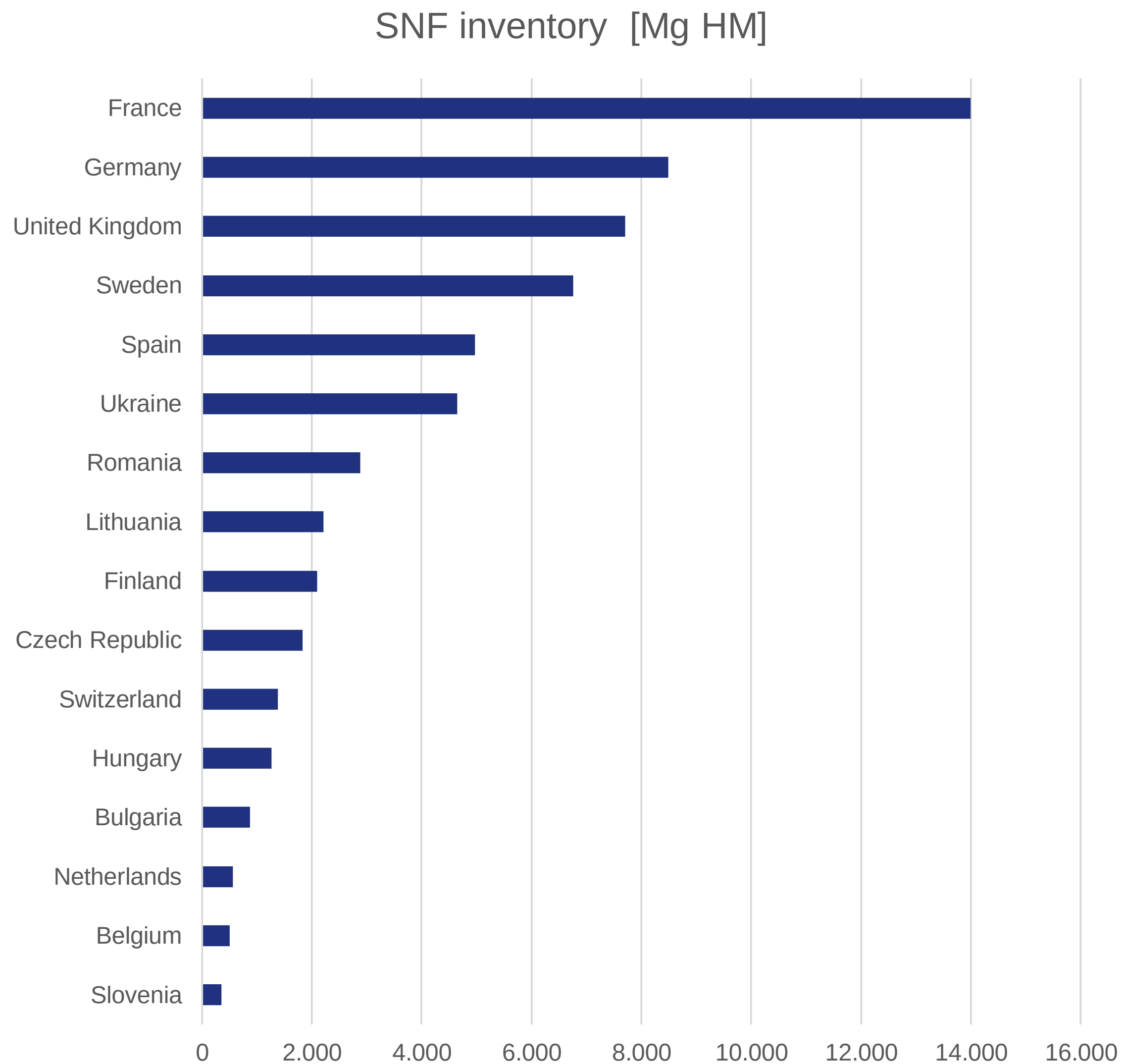
As of today, less than half of the observed countries have installed disposal facilities, mostly for LLW and not ILW: the UK, France, Spain, Hungary, Finland, Czech Republic, Sweden and Germany. But these countries have disposed of altogether close to 2 million m3 of operational waste.



Source: The World Nuclear Waste Report (2019)

Reported SNF inventories in Europe and amount in wet storage, as of December 31, 2016

Country	SNF inventory [tons]	SNF in wet storage [%]
Belgium	501**	47%
Bulgaria	876	90%
Czech Republic	1,828	36%
Finland	2,095	100%
France	13,990	100%
Germany	8,485	43%
Hungary	1,261	17%
Lithuania	2,210	64%
Netherlands	80***	100%
Romania	2,867	45%
Slovenia	350	100%
Spain	4,975	91%
Sweden	6,758	100%
Switzerland	1,377	60%
Ukraine	4,651****	94%
United Kingdom	7,700	100%
Total	**ca. 60,500**	**81%**



Source: The World Nuclear Waste Report (2019)

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Basic Liability for Decommissioning and Waste Management

In general:

- the owners or licensees of nuclear power plants are liable for the processing, conditioning, storage, and eventual disposal of the waste generated during operation and decommissioning of the reactor and for the long-term management of spent fuel.
- these obligations and liabilities arise with the start of operation
- In order “to avoid imposing undue burdens on future generations” (Article 3 of the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management Convention), one unifying concept, observed in nearly every country, is the <u>polluter-pays-principle</u>, which makes the operator liable for the costs of these activities.

But:

- sooner or later states often become directly involved at some point, including financially
- The latter principle holds especially true for waste management; the polluter-pays-principle applies in most cases only for the decommissioning and dismantling of the reactors.
- For the long-term storage of radioactive waste, a variety of organizational models has evolved in which the national authorities – not the operator of the nuclear facility – more or less assume technical and financial liability for the very long-term issues of waste management (such as in the US, Germany, and France).

Basic Liability for Decommissioning and Waste Management

Even in countries in which the polluter-pays-principle is a legal requirement, an operator of a nuclear power plant will not be held financially liable for any problems arising during the long-term storage of the waste.

For instance, at the Asse II site in Germany, LILW needs to be recovered from an abandoned salt mine at an estimated cost of €4-6 billion covered by taxpayers; while the fees collected for the disposal of radioactive waste during operation of the mine amount to only €8.25 million.

Source: Kristof (2010)

Overview and the Nature of the Funds

Internal non-segregated fund:

- operator pays into a self-administrated fund and manages the financial resources, which are held within its own assets**.**

Internal segregated fund:

- operator is obliged to form and manage funds autonomously
- assets must be segregated from other businesses or earmarked for decommissioning and waste management purposes

External segregated fund:

- operators pay their financial obligation into an external fund
- private or state-owned independent bodies manage the funds
- one fund can cover the whole industry or there can be one for each operator
- external fund can exist with or without transfer of the liabilities and with or without a short-fall guarantee by the operator

Public budget:

- State authorities take over the financial responsibility including the accumulation of financial resources (for instance via taxes and levies)

The main scenario is to build up a fund year by year over the entire expected lifetime of a nuclear power plant or facility

The accumulation of the funds can either be achieved by y a fee, a levy set on the sale of electricity, “internally” by the operators who set aside funds from the revenue obtained from the sale of electricity, or by the investment of the funds.

A crucial aspect is whether funds or future provisions are based on discounted or undiscounted costs:

- If the costs are not discounted, the operators have to set aside the full amount of the estimated costs. Only a few nuclear funding systems use undiscounted costs
- If costs are discounted, the funds are expected to grow over time. Here the provisions are determined using the inflation rate until the due date and then discounted with an interest rate, which is supposed to represent the expected rate of return
- The employed discount rates range widely (for example, 5.5 percent in Germany versus 1.5 percent in Spain).
- A cost escalation rate is not always assumed (e.g. in Germany a “nuclear-specific inflation rate” of 1.97 percent is calculated on top of the inflation rate)
- Applying only the general inflation rate could eventually lead to an underestimation of the costs and hence the amount of the funds

In Germany, for instance, the set aside funds of €24.1 billion for all waste management related activities are expected to grow nearly fourfold to €86 billion by 2099.

Cost Experiences are Scarce and Cost Estimations are Underlying High Unsecurities

In order to accumulate funds, costs need to be estimated. This is a critical aspect of funding, especially for unknown projects like a deep geological facility for high-level waste.

Different cost estimation methods are conceivable (e.g. order-of-magnitude estimate, budgetary estimate, definitive estimate).

In reality, most cost estimates are budgetary estimates based on studies and estimates from the 1970s and 1980s, which are then extrapolated.

In most cases, the waste management organization is responsible for developing cost estimates for the long-term management of radioactive waste. This organization can be state-owned (such as in the UK, Germany and Spain) or in some cases utility-owned, as in Sweden and Switzerland.

In most cases cost estimates are not publically available (e.g. in Germany, the cost of both decommissioning and long-term waste management is based on expert opinions, produced by the private companies for the utilities and not public).

Financing Schemes for (Interim) Storage

The costs and the financing schemes for interim storage depend heavily on the available waste management infrastructure and disposal paths.

As there is currently no disposal solution for HLW, all the nuclear countries are faced with both technological, organizational, and financial interim storage issues. Countries with no disposal solution for LILW increasingly face financing of storage for LILW with a growing number of reactor shutdowns.

The costs for interim storage of waste can be paid:

- from operational revenues (as at CEZ in the Czech Republic, Switzerland)
- From set aside provisions (e.g. in Germany: estimated discounted costs were around €5.8 billion in 2014, now transferred to an external segregated fund)
- From a public fund (e.g. in Sweden, the costs for the centralized interim storage facility CLAB are paid by the Nuclear Waste Fund).

In France, EDF estimates an additional €18.7 billion (US$21.1 billion) for spent fuel management (for example storage, reprocessing), and another €1.2 billion (US$1.4 billion) for waste removal and conditioning. This amounts to €51 billion (US$57.5 billion) only for handling and storing the waste generated from operation.

Financing Schemes for Longterm Storage (Disposal)

The polluters are not always financially liable for disposal (and partly waste management, too); in some cases, liability is transferred to a state-governed organization that is also responsible for radioactive waste.

	France (EDF)	**Germany**	**US**
Financing scheme	Internal segregated and restricted fund, then moved to regulator at construction start	External segregated fund	External segregated fund
Accumulated by	levy on electricity price	investment of the funds	Previously levy on electricity price but no longer collected
Total cost estimates	US$34.9 billion	US$19.8 billion*	US$96 billion
Set aside funds (in % of cost estimate)	US$11 billion (32%)	US$27.2 billion*	US$34.3 billion (36%)

* including interim storage, LILW and HLW disposal.

Source: The World Nuclear Waste Report (2019)

Integrated Financing Schemes for Decommissioning and Waste Management

Due to the great interdependences between decommissioning, storage, and disposal, an integrated, external, segregated, and restricted ("ringfenced") fund seems to be the most suitable approach to finance the future costs for these processes (Wealer, Seidel, and Hirschhausen 2019).

	Sweden	UK*	Switzerland
Financing scheme	One external segregated and restricted fund	One external segregated and restricted fund	Two external segregated funds (for waste management and for decommissioning)
Accumulation	levy on electricity price (set individually for each plant)	quarterly payment by operator	spayment by operator
Total cost estimates	US$10.7-11.8 billion	US$26.5 billion**	US$24.6 billion***
Set aside funds (in % of cost estimate)	US$7.2 billion**** (61-67%)	US$12.1 billion (46%)	US$7.39 billion (30%)

Source: The World Nuclear Waste Report (2019)

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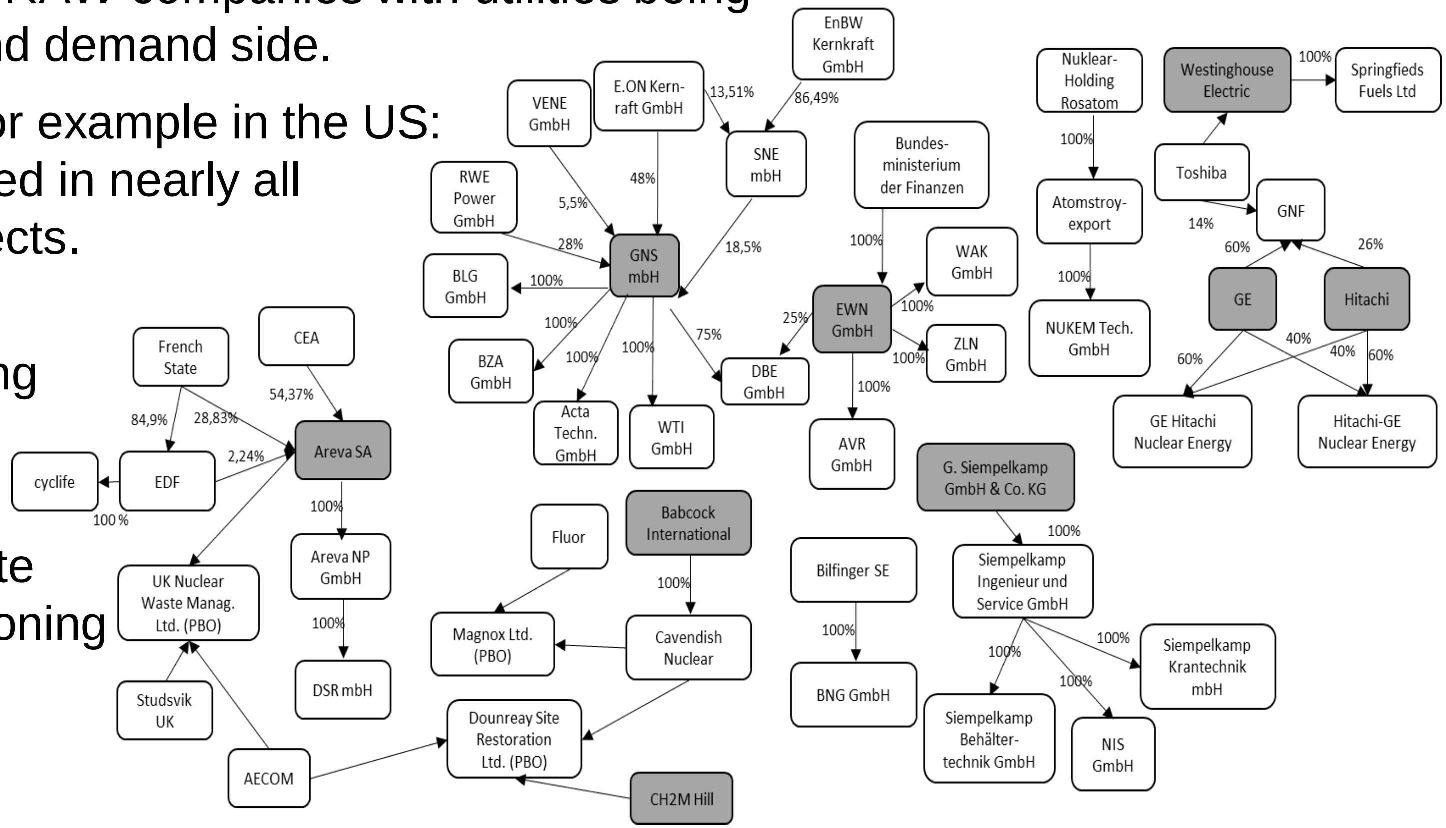
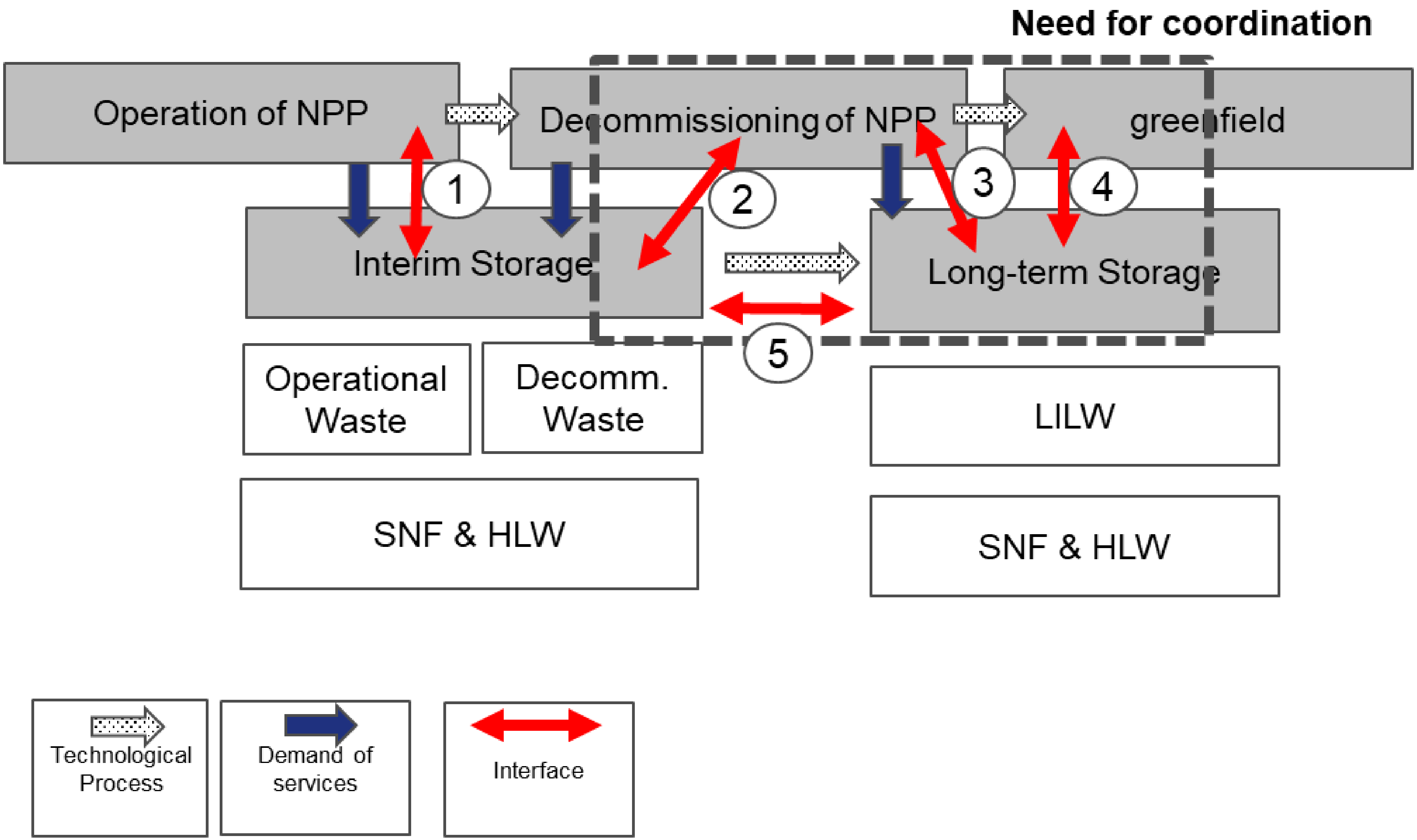
Provision of Waste Management Services

- Only a few and highly interconnected specialized decommissioning and RAW companies with utilities being active on the supply and demand side.
- Large market power, for example in the US: Energysolutions involved in nearly all decommissioning projects.
- State is in most cases responsible for providing high-level waste management services.
- In some cases, the state overtakes decommissioning too (Spain).



Source: Wealer et al. (2015)

Systemgood view on decommissioning and waste management



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Key Findings and Research Outlook

Key Findings for Production

- as of today, less than half of the European countries have installed disposal facilities for LILW
- There are currently around 60,500 tons of SNF stored across Europe, with most of it in France.
- As of 2018, 81 percent of Europe's spent nuclear fuel is in wet storage. It would be safer to transfer the spent nuclear fuel into storage casks in a separate storage facilities.
- With the ongoing generation of nuclear waste, storage facilities in Europe are running out of capacity.
- At least 1.4 million m3 of nuclear waste from decommissioning will arise in Europe.

Key Findings for Provision

- Only a few and highly interconnected specialized decommissioning and RAW companies with utilities being active on the supply and demand side; i.e. high market power
- State is in most cases responsible for providing high-level waste management disposal, while conditioning waste is the scope of the utilities

Key Findings and Research Outlook

Key Findings for Financing

- Most countries fail to properly estimate the costs for disposal (lack of experiences)
- In most cases cost estimates are drawn up the operators, industry, or state agencies and not public) and not publically available for independent energy experts
- Even small changes in the assumptions of the rates have had tangible effects on the present value of the financial resources. Lack of experience, using outdated data,
- The funds also need to be restricted, so that the liable organization is not fully free in using the accumulated money.
- Today, no country has either estimated the costs precisely or closed the gap between secured funds and cost estimates. In most cases only a fraction of the funds needed has been set aside.
- As an increasing number of reactors are shutting down ahead of schedule due to unfavorable economic conditions, the risk of insufficient funds is increasing. These early shutdowns, shortfalls in funds, and rising costs are forcing some plants to delay decommissioning in order to build up additional funds. Countries are also considering ways to enable facilities to recover their costs through higher fees, subsidized prices, and longer operation times, for instance in the US and Japan.

Key Findings and Research Outlook

Research Outlook:

- Detailed analysis on the provision of nuclear waste management services
- Look into the management of interfaces
- Evaluation and design of organization model(s) based on economic theories (e.g. transaction costs)

Thank you for your attention!

Contact:

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