Cost Comparison of Spent Fuel Storage and Deep Geological Disposal

A paper prepared for the Nonproliferation Policy Education Center

by

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Overview

This paper considers two assertions, that spent nuclear fuel storage at the surface is cheaper than deep geological disposal; and that the which utilities produce spent nuclear fuel should have a direct role in the implementation of spent fuel management so as to lead to better cost control. Assumptions and constraints to the analysis are first defined, and brief information presented on costing methodologies. Evidence for costs is drawn from various sources, including the discussions of uncertainties. Account is also taken of the necessary time-scales for spent fuel management. Illustrations of how different organisations control costs are provided. Finally conclusions are drawn on the original assertions and the robustness of those conclusions to alternative assumptions.

Introduction, Objectives and Scope

Part of the debate about continued or extended use of nuclear reactors to generate power concerns the management of spent nuclear fuel. Questions arise concerning the ability to deliver on any necessarily long term strategy, bearing in mind a range of safety, environmental and human health protection issues. Another long term issue is the financial cost of successful delivery of any such strategy. Such matters are addressed in the International Atomic Energy Agency's (IAEA) 'Fundamental Safety Principles'[2] which in the current context suggests that: 'Where effects could span generations, subsequent generations have to be adequately protected without any need for them to take significant protective actions.'. Decisions, however, have to be taken in the short term, if only for the spent fuel which has been produced already.

The objective of this paper is to consider two assertions:

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[2] Fundamental Safety Principles. IAEA Safety Standards No SF-1. Vienna (2006) http://www-ns.iaea.org/standards/documents/default.asp?sub=100

1. That the costs of storing spent fuel above ground in dry casks a. at the reactor site or b. at an agreed remote location, cost much less than deep geological disposal of the sort associated with a. Yucca Mountain b. a proposed European site.

2. That there would be merit in giving the utilities which produce the spent fuel some financial stake in the management of the spent fuel, if only to discipline the process from becoming unhinged from cost constraints.

The costs considered here are defined in a strictly financial sense, dollars net present value to achieve the goal of storage or deep geological disposal. This is not to set aside important social and political considerations, only to say that they are addressed elsewhere. However, it has to be acknowledged that financial costs will be affected by how the intended goal is achieved. The Nuclear Energy Agency (NEA) highlights[3] the role of stakeholders in achieving better decisions, but also suggests that site-specific ***discussions*** *(my emphasis)* are increasingly the norm in identifying the optimum protection solution. Without care, such discussions can confuse the arguments used to justify cost estimates, not least because they tend to be unclear about the intended goals. The IAEA maintains[4] that 'storage of radioactive waste has been demonstrated to be safe over some decades, and can be relied upon to provide safety as long as active surveillance and maintenance is ensured. In contrast, geological disposal **promises** *(my emphasis)* long term safety without surveillance and maintenance'. Consideration of the meaning of that promise is critical; although, from a technical perspective, deep disposal has been considered a sound and safe option for many years[5]. However, if there is no agreement among stakeholders on the definition of adequate protection, there can hardly be an easy consensus on how to balance costs against safety to determine the most optimum option.

Accordingly the paper first sets out some assumptions and constraints to the subsequent cost analyses. These are intended not to limit the relevance of the paper, but to allow consideration of the robustness of any conclusions to alternative assumptions and constraints, and to ensure that the reader can determine the claimed robustness for himself. Some brief information is provided on costing methods adopted in this context, taking into account the time-frames over which costs occur. This is followed by presentation and discussion of some cost estimates made in particular circumstances, and comparisons are drawn between costs estimates for storage and those for deep geological disposal. The history of waste management costs is then discussed in relation to the progress made. Finally conclusions are

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[3] 'Radiation Protection in Today's World: Towards Sustainability.' NEA-OECD Paris, www.nea.fr (2007).
[4] 'The Long Term Storage of Radioactive Waste: Safety and Sustainability.' A position paper of international experts. IAEA, Vienna (2003).
[5] 'PAGIS: Performance Assessment of Geological Isolation Systems for Radioactive Waste. Summary. Commission of the European Communities, EUR-11775.

drawn on the assertions mentioned above, and the robustness of those conclusions is considered in relation to the assumptions and constraints adopted in the first place.

Assumptions and Constraints

1. The first assumption is that any storage or disposal option is assumed to be built, operated and decommissioned according to plan, within the law, and meeting internationally recognised protection objectives. This means that insurance costs against failure are included, since they would be planned for, but not any costs arising from any actual failures to meet budgets, schedules or protection objectives. That being said, there could be a cost attributed to the health or other impacts expected to arise from the planned implementation of an option, albeit the individuals impacted may not be readily identified in advance and all would be exposed to only very low individual risk. The basis for determining such costs is discussed and options provided in Jackson et al (2004)[6,7]. Such costs are not included in the analysis, and are considered likely to be comparatively small given the assumption made above that radiation protection and other safety objectives are met.

2. Experience suggests that a spent fuel storage facility could be operated safely for several decades and possibly for somewhat longer, but is it assumed that there is an intention to eventually retrieve[8] the waste and do something more with it. For example, such additional actions could involve eventual deep geological disposal of the spent fuel, with or without further treatment to enhance containment of radioactivity; or reprocessing and use of product, with later treatment and disposal of residual radioactive waste. Rather than hypothesize further on these possibilities, the actions assumed here are those adopted within the cost studies referenced. In general, such studies do set a time-table for the storage option, since not to do so would appear to be negligent of the continuing hazard associated with the spent fuel. Spent fuel will continue to be significantly hazardous for times beyond the time over which safety in storage could be assured from today. Note, however, that the period of storage and the intentions after the storage period will materially affect storage costs.

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[6] 'Understanding and using a risk related value of spend for saving a statistical life'. Jackson D, Stone D, Butler G and McGlynn G. Proc. 11th International Congress of the International Radiation Protection Association, Madrid (2004).

[7] 'The derivation and application of a risk related value of the spend for saving a statistical life.' Jackson D, Stone D, Butler G and McGlynn G. Journal of Radiological Protection, Vol. 24, p41-59 (2004).

[8] The widely recognised definition of storage is specifically that it involves an intention to take further action at the end of the storage period; whereas disposal is an action following which no further action is intended or planned. See for example, the IAEA's Radioactive Waste Management Glossary, 2003 edition.

3. Storage for more than a generation or two would appear to conflict with the IAEA's fundamental safety principle about not placing burdens on future generations to take {continuing} protective actions. This factor is not accounted for in the analysis.

4. In the comparison of costs of storage and deep geological disposal, the costs of managing the spent fuel at the end of the storage period are not included. However, it is generally the case that the cost studies allow for disposal costs after a period of storage.

Costing methodologies

Securing the long-term financing of decommissioning and the management (including disposal) of spent fuel has become an important issue in many countries. One of the reasons for this is that waste management programmes are taking longer to implement than originally anticipated, and this means that some of the associated costs only arise several decades after power has been generated from the stored spent fuel.

However, in accordance with the principle of polluter pays, the necessary financial resources already have to be produced today and secured in a manner that is both socially and politically acceptable. The range of options here includes government funding, formation of reserves, the establishments of special funds, insurance solutions, etc., as well as various combined models. The choice depends to some extent on whether a nuclear power station is operated as a private or state enterprise.

Whichever way it is decided to manage the spent fuel, it is essential to define a coherent and transparent management programme, and determine the necessary financial resource for subsequent implementation. In case of a solution involving special funds, the annual contributions to be paid in have to be specified, for example up to the assumed time at which a given objective is planned to be achieved, and the resulting assets could be invested on the financial markets while taking due account of the optimal balance between risk and return. If government is taking responsibility for the programme, then the funding might be based on assumptions for future tax revenues, based on government sponsored infrastructure projects which support the general growth of the economy. Either way, it is necessary to define a suitable investment strategy, which includes making assumptions regarding the long-term interest rate and economic growth trends. One can be cynical and simply note that the time-frames for such investment to support a spent fuel management programme are rather longer than our historic ability to forecast those trends with any useful degree of accuracy[9]. This does not mean we can escape consideration of the problem.

Different countries approach the nuclear decommissioning problem in different ways[10]. The fundamental differences in approach concern whether future costs are discounted or not, and when the funds have to be provided. In Sweden and Finland, the full undiscounted decommissioning costs have to be provided for or guaranteed from the beginning of facility operation. In France, undiscounted funds have to be provided within a five year transition period. Those countries which do allow for discounting at a non-zero rate adopt rates from 1.5% up to 5.5% on different plants. In the UK, funds are provided by a so-called on budget scheme, with annual funding decided annually from the annual overall government budget. The latter appears to be the scheme for funding of spent fuel management in the USA, albeit, the utilities have to directly pay into a spent fuel management fund from generation revenues.

Example cost estimates

Cost estimates comparing storage v disposal costs for the US situation and Yucca Mountain are available from the Licensing Support Network at http://www.lsnnet.gov/.

A series of reports[11] presents a range of costs for a set of scenarios for storage, for discount rates ranging from 3% to 7%. The scenarios include disposal assuming construction at Yucca Mountain begins in 2016 and disposal operations commence by 2026; deferral for 100y; and deferral for 200y. The current cost of the disposal facility is taken as $58 billion, an obsolete but reasonable lower bound US DOE estimate, including storage cask costs which are common to stall options. In costing each scenario, the relevant scheduling of interim storage requirements and construction is taken into account, but the repository operational costs, including a period of ‘retrievability’ before final backfilling and closure, have been neglected.

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[9] “The only way to make decisions is to pull numbers out of the air, call them 'assumptions' and calculate the net present value. Of course, you have to use the right discount rate, otherwise it's meaningless.” Dilbert Gives You the Business. Scott Adams 1999, Boxtree.

[10] ‘Comparison among different decommissioning funds methodologies for nuclear installations.’ Report prepared for the European Commission under service contract TREN/05/NUCL/S07.55436. Wuppertal (2007).

[11] Document LSN #: NEV000004074, Document LSN #: NEV000004546, Document LSN #: NEV000004309, Document LSN #: NEV000004300, Document LSN #: NEV000004347, Document LSN #: NEV000004282, Document LSN #: NEV000004380, Document LSN #: NEV000004386, Document LSN #: NEV000004337

Component	**Present Day Cost (billions of dollars)**		
	Construct Facility by 2026	**Construct Facility by 2126**	**Construct Facility by 2226**
Storage to 2025	5.79	5.79	**5.79**
Storage 2026 to 2125	not applicable	7.16	**7.16**
Storage 2126 to 2225	not applicable	not applicable	**0.36**
Construction	38.3	1.90	**0.09**
Total	**44.09**	**14.85**	**13.40**

Breakdown of Costs for Different Options Based on a 3% Discount Rate

Taking storage to 2025, 2125 or 2225 into account and assuming correspondingly that the facility is available to receive spent fuel in 2026, 2126 or 2226, using a 3% discount rate, the total cost of storage plus construction is $44.09 billion for operation in 2026, $14.85 billion for operation in 2126 and $13.40 billion for operation in 2226. Thus, deferring construction and operation by 100 to 200 years reduces the overall present-day cost of storage plus disposal to about one third of that associated with commencing disposal operations in 2026.

Costs of storage for 200 years are not much larger than costs of storage for 100 years, because only a small investment is required now to fund the second period of 100 years. Overall, the cost savings for deferring construction by 100 years are $29.2 billion at a discount rate of 3%, $25.8 billion at a discount rate of 5% and $20.7 billion at a discount rate of 7%. The corresponding cost savings for deferring construction for 200 years are $30.7 billion at a discount rate of 3%, $26.0 billion at a discount rate of 5% and $20.7 billion at a discount rate of 7%. The savings decrease with increasing discount rate because the current investment needed to construct the repository in the period 2015 to 2025 decreases with increasing discount rate.

These results are clear enough, but raise two observations. Firstly, if one adopts a zero discount rate assumption (broadly consistent with policy of sustainability) then the financial savings disappear. Secondly, while safe storage for 50 years or so may be a realistic target, as regards ability and desire to maintain institutional control and hence safety, safe storage until the hazard has decayed to very low values is arguably not a sound ethical proposition as regards the burden of responsibility, nor likely to be achieved given the scope for social and political change over the period of interest, i.e. 1000 years or more.

The limit for disposal at Yucca Mountain has been set at 70,000 metric tonnes of heavy metal. This would not be sufficient for all spent fuel arisings, especially if new plant were constructed. However, this limitation is not technically derived. EPRI has considered[12] a range of alternative packing and layering configurations which suggest that up to 570,000 metric tonnes could be accommodated.

Chapman and McCombie have completed a study for BNFL of spent fuel disposal costs for new build reactors in the UK[13]. Their scenarios include assumptions for a period of interim storage and then disposal, based on actual costs seen within waste management programmes in Sweden, Switzerland and Belgium. These programmes each have their own advantages and disadvantages, technically and in relation to cost, but each of them assumes that eventual disposal is an absolute pre-requisite for any strategy which is not reckless. Considerable cost experience with spent fuel storage exists in the various conditions. While no disposal of spent fuel has taken place, the repository plans are considered well enough developed to be useful. A key assumption is that immediate disposal is in all cases not viable, with some interim storage required in any event (e.g. corresponding to Yucca Mountain operation not possible until say 2025). Scenarios allow for co-disposal of other wastes from the historic nuclear legacy, which in those cases, reduces the marginal cost of new build spent fuel disposal. The study takes advantage of different assumptions from the different countries. It also takes account of the marginal effects of the size of the generation programme. The key conclusions as regards the interests of this paper are as follows:

- The range of current costs for stand-alone direct disposal of new build spent fuel for a UK programme of 10 APRs, generating 14,000 tonnes of spent fuel operating for 60 years is from \$6.5 billion to \$7.2 billion[14].
- In the UK, it is likely that the unit cost would be lower if legacy HLW were co-disposed. Chapman and McCombie present data collated by the IAEA, which combined with the UK conditions, suggest that from this new build starting point, doubling the mass of spent fuel to be disposed would only increase costs by 50%.

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[12] 'Analysis of the Maximum Disposal Capacity for Commercial Spent Nuclear Fuel in a Yucca Mountain Repository.' J Kessler. EPRI Technical Report 1015046. (2007).
[13] 'Cost estimates for disposal of spent fuel from new build reactors in the UK'. Chapman N and McCombie C. MCM Consulting, MCM-TR-06-01 (2006).
[14] Assuming 2 \$ per GBP

- Approximately 0.2 cents per kWh would generate $10 billion after 60 years, not allowing for interest accrued in the interim. Sufficient funds for the entire disposal programme would be generated after 30 years (c.f. the 60 year programme) assuming a 2.5% interest rate on deposits.

- The interim storage programme over 60 years represents only a small fraction of the total spent fuel management programme, i.e. 22% on the Swedish model; 9% on the Swiss model.

The UK Nuclear Decommissioning Authority (NDA) has commissioned an economic analysis of spent fuel management[15]. In this case the scenarios take detailed account of the complications of the UK historic nuclear legacy, including, in a related study[16] management of U and Pu. Three bounding scenarios are considered:

- *Waste scenario*: in which there is no further development of nuclear power in the UK, uranium prices are low and all the materials are disposed of as soon as a repository can be constructed.

- *Store scenario*: places all materials into long-term storage on the assumption that they may have value in the future, but after 300 years this has not been the case and the materials are then disposed of.

- *Use scenario*: assumes that the materials have value now, with uranium stocks used in new fuel, Pu used in MOX fuel, and spent fuel is reprocessed, with all product used in an extended UK programme of 12 GW, running for 60 years, followed by a fast reactor programme on the same scale, with disposal of all wastes at 300 years.

Basic results for the three scenarios are illustrated below, with the additional (green columns) representing costs for intermediate scenarios where some of the materials are treated as waste now, some are used and some are disposed after storage. The conclusions are:

- *Waste* is low risk, and if the uranium price is low, it is either the lowest undiscounted cost option, or close to it;

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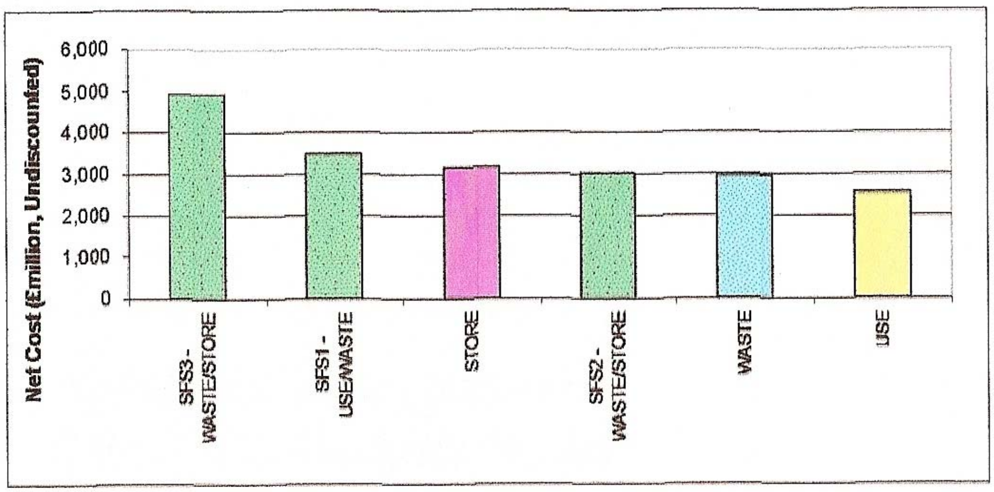
[15] 'Spent Fuel Management: Life Cycle Analysis Model'. Wooders P, Butler G and McGlynn G. Nuclear Decommissioning Authority, NDA Ref: KP000068 (2007).

[16] 'Uranium and plutonium: Macro-Economic Study'. Wooders P, Butler G and McGlynn G. Nuclear Decommissioning Authority, NDA Ref: KP000068 (2007).

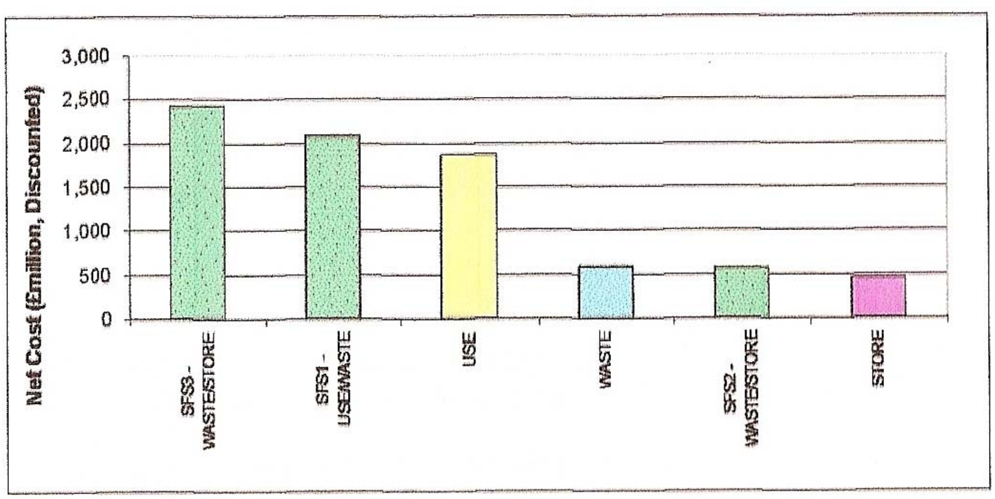
- *Store* keeps options open, making future use of materials an option, which will reduce costs of the uranium price is high; and it also delays costs significantly reducing net present costs after discounting and making it the cheapest option;

- *Use* may release significant value, especially if the uranium price is high, but is subject to downside risks.

Net Costs by Scenario, Uranium Price $75/lbU$_3O_8$, Undiscounted



Net Costs by Scenario, Uranium Price $50/lbU$_3O_8$, Discounted



None of the numerical results is regarded as precise, as many uncertainties are recognised, but the trends in costs for the different strategies is considered reliable.

Who is best to manage civilian spent fuel management?

Responsibility for radioactive waste management, and especially to manage spent fuel, is arguably best given to a central national agency rather than being left to a set of disparate waste producers who may not have the same long-term goals or capacities to ensure delivery. However this still leaves a range of options for financial control. To illustrate the point, McCullum[17], in discussing the development of single fuel canisters for transporting, aging and disposal (TADs), noted that the TAD programme was abandoned in 1997 due to:

- Uncertainties in final repository design
- Uncertainties in program funding
- Bureaucratic impediments
- Lack of market diversity

The pricing situation had improved in a renewed programme (circa 2005) under which competitive tendering was introduced and by which time confidence in a repository design was reasonable. In a similar vein, Moore[18] made a strong case in the context of remediation of US DOE nuclear legacy site management for independent review of technical programmes to better ensure effectiveness and efficiency.

Conclusions

This brief review suggests that:

- Storage v Disposal is the wrong contest! It should be *Disposal As Soon As Possible (ASAP) v Planned Storage and Disposal Later.*

- Since Disposal ASAP still needs interim storage, the real questions are how long to store for and what cost, logistical or other advantage can be taken from an extended storage period.

- Storage is not one thing. There are different or multiple objectives:

    - Radioactive decay and heat rate reduction, to simplify disposal

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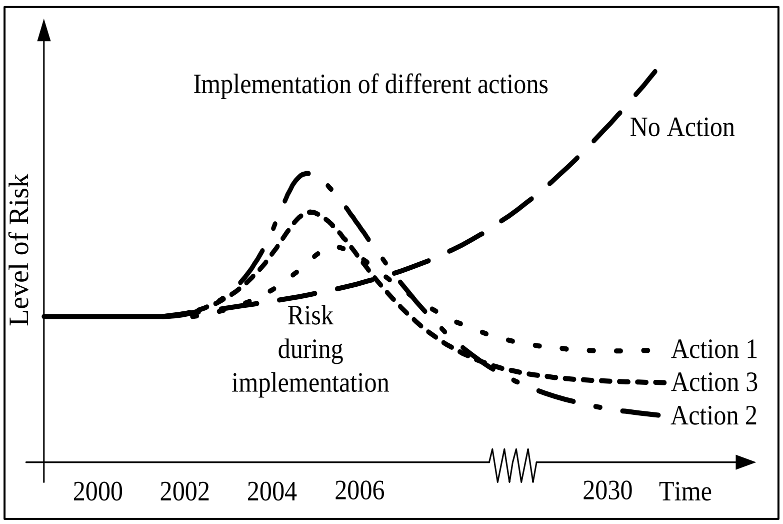
[17] 'Transportation, Aging, and Disposal (TAD) Canisters for Used Nuclear Fuel: Getting from here to there and beyond'. McCullum R, Nuclear Energy Institute paper to Waste Management 08, WM Symposia Inc. (2008).
[18] 'Improving remedial effectiveness at US DOE through optimisation review and performance basis.' Moore B, paper to Waste Management 08, WM Symposia Inc. (2008).

- Logistical buffer within an on-going disposal programme
- Interim storage until deep disposal facility is available
- Interim storage awaiting strategic decision on use of materials

- Whichever, the conditions of storage and hence costs will be dependent on the objective.

- New technology will not make things massively safer – at least according to designs, all realistic options are already reasonably safe. Early action introduces some risks in solving the problem, but indefinite storage will introduce long term risks, as well as shifting responsibility, see the illustrative figure below [19]. Whether there is a serious risk that something could go badly wrong within 30 years or later on is less the point than that if nothing is done to isolate the waste, then it eventually will.



- All strategies present costs which are small compared with the overall cost to the power user.

- Assuming discount rates commonly used in financial planning, storage is cheaper than disposal.

[19] 'Regulatory Perspectives on Risk Management for Lepse De-fuelling Operations'. Sneve M K, Gordon B, Smith G M and Egan M J. In Proc, VALDOR 2004, International Conference on Values in Decisions on Risks. Swedish Nuclear Power Inspectorate, Stockholm.

- There are important continuing uncertainties which need to be explored, but they only present possible ranges in costs which are still only marginal to the power user.
- These uncertainties arise from socio-economic and political factors, such as the appropriate choice of discount rate, as well as technical factors.
- Planning long term operations with hazardous material such as spent nuclear fuel needs a central and strong authority. However, management models should be adopted which allow for transparent technical and financial oversite, involving waste producers and independent technical expertise.

Given the above, the overall conclusions are that both the assertions raised in the introduction are true, subject to the assumptions and constraints also set out. Furthermore, these assertions are robust to the many technical and other uncertainties.