Submission to:

GenCost 2019-20: preliminary results for stakeholder review

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Table of Contents

Introduction and summary

Thank you for the opportunity to provide input into the *Draft GenCost 2019-20: preliminary results for stakeholder review* (the Draft)[1].

We provide here a review of the treatment of small modular reactor (SMR) in the Draft. We find GenCost continues to apply erroneous methodology and inputs, in turn generating an erroneous range of levelised cost of electricity (LCOE) for SMR. This is unhelpful in the national conversation.

We have carefully reviewed the input and assumptions with reference to the questions for stakeholders in the Draft. We have provided recommended changes, with transparent methodology and sources.

We re-calculated the LCOE for SMR from the Draft on the basis of the published inputs. Our calculations are to within 6 % and 5 % for the Low Price and High Price calculations respectively. Small variations in assumptions, such are investment phasing and generation phasing, might explain this small difference, however we are satisfied that we have reproduced the initial results with sufficient accuracy.

From that foundation we have progressively recalculated the LCOE with the updated inputs to demonstrate the impact of our recommended changes.

We find **the published LCOE for SMR (AU$251-$330/MWh) is an extreme overestimate** on the basis of:

- Unfounded capex;
- Unjustifiable capacity factors;
- Erroneous fixed and operational maintenance costs.

We find the costs are also erroneous on the basis of:

- Fuel cost of $0
- Thermal efficiency of 45%

Having altered these assumptions based on transparent and clearly sourced references, **including a 50% loading on the first-of-a-kind capex to account for uncertainty, we estimate LCOE for SMR (specifically light water reactor SMR) of AU$123-$128/MWh.**

These prices have the potential to fall as low as AU$60/MWh on the basis of variations in discount rate, and first-of-a-kind capex estimates without uncertainty loading.

We look forward to seeing positive changes to strengthen the robustness of GenCost on the basis of this input.

1. Do the scenarios adequately explore the plausible range of outcomes with regard to technological change of known technologies?

No, they do not.

There remains a lack of rigour in the treatment of SMR technology, indicated by

- Lack of clear technology definition;
- Absence of technology-specific literature review;
- Absence of industry consultation; and
- Continued reliance on unverifiable and erroneous figures.

In the absence of the above, misleading LCOE figures have already contributed to shaping the national discussion about energy and climate change response in Australia[2, 3].

In relation to clear technology definition, GenCost has proceeded with the inaccurate and limiting description of SMR as a Generation IV reactor of 300 MWe. As we previously submitted[4], there is no reference case offered for that reactor, the justification for limiting to Generation IV was outside the remit of a technical review, and nuclear technologies are heterogenous. As a result, references and assumptions for 'SMR' remain inconsistent, in several cases incorrect, or simply unverifiable.

It would be a simple change, and a great improvement, to re-define SMR consistent with actual global industry progress. For example, GenCost could proceed initially with a focus on light water reactor SMR as a category, SMR(LWR). This is the nearest-term commercial SMR [5]. Assumptions for that technology class will be able to be clear, consistent, and aligned with commercial deployments.

Other classifications such as molten salt reactor (SMR(MSR)), high temperature gas cooled reactors (SMR(HTGR)), or fast reactor (SMR(FR)) might be included in GenCost updates. This would be akin to the distinctions in solar technologies (PV, concentrating), coal technologies (pf, IPGG, CCS), and wind technologies (offshore, onshore).

Recommendation:

- **GenCost concludes its use of the existing definition of SMR.**
- **This iteration of GenCost proceeds with focus on SMR (LWR), using an appropriate reference case technology.**

This will permit more reliable determination of LCOE and therefore provide relevant information for Australian investors and policy makers.

Please refer to responses to further questions for examples. We provide recommendations for changes to provide transparent and robust figures for calculation of SMR(LWR) LCOE.

2. Are the updated current capital cost assumptions reflective of current project costs?

In relation to SMR(LWR), no they are not.

We note the Draft asserts there is 'no hard data' to be found on SMR costs (page 3), referring to public cost data from completed projects. We accept this basic reasoning.

Nonetheless, the Draft has chosen to assign a capital cost for SMR, retaining a capital cost published by GHD[6] which proved to be impossible to source. The citation of 'World Nuclear Association' was incorrect, as attested by World Nuclear Association itself in submission to the recent Federal Parliamentary Inquiry[7]. CSIRO/GenCost authors were unable to provide clarity on the source[8]. The figure is therefore not 'reasonable for a technology at low level of deployment'[1], it is simply unverifiable. This does not serve an informed discourse. GenCost needs to conclude its use of this figure.

In the absence of hard data from completed projects, the capital cost needs to be based on a transparent methodology using up-to-date information. That, in turn, can be tracked and updated as certainty of capital cost increases. We propose an appropriately transparent and parsimonious methodology below.

Suggested capex methodology

NuScale Power appears likely to be the first commercial vendor of SMR(LWR)[5]. Important points of reference here include:

- The design is in final stages of licencing with scheduled completion September 2020[9];
- The first project is confirmed (Utah Associated Municipal Power Systems);
- The first 150 MW of the first project have been sold[10];

This provides a reasonable basis for using NuScale data as a foundation for development of a capital cost estimate for SMR(LWR).

NuScale provided information to the Australian Parliamentary Inquiry regarding their estimated capital costs. The estimate is [5]:

- Nth of a kind;
- Generic greenfield site;
- Based on a mature design;
- Developed by bottom-up cost analysis of over 14,000 line items, 80% of which are based on catalogue costs or vendor quotes;
- Subject to independent assessment.
- Class 4 estimate based on American Association of Cost Engineers classification.

This provides a firm basis to develop an SMR(LWR) capital cost methodology.

The Nth of a kind estimate is AU$5,248/kW. NuScale states this is a 16% decline in price from the FOAK plant (therefore FOAK = $6,088/kW)[5].

The Draft states vendor estimates have proven unreliable in the past, citing costs for enhanced geothermal which began at $7,000/kW and rose to $12,000/kW (+42 %) (page 3). We accept this principle as reasonable, for the purposes of conservatism, until hard project cost data is available for SMR(LWR).

On that basis, uncertainty loading of +50% to the FOAK vendor estimate is a parsimonious and transparent methodology, and consistent with the upper bound uncertainty for a Class 4 estimate[11]. This is consistent with the cited example of enhanced geothermal (+42%) and is easily varied and updated as additional information becomes available. Table 1 below illustrates the impact of loadings varying from 50%-100%.

Table 1 NOAK vendors capital costs for SMR plus loading

Loading	Capex
0%	$6,088
50 %	$9,132
60 %	$9,740
70 %	$10,349
80 %	$10,958
90 %	$11,567
100 %	$12,175

Even with a 100% loading on the vendor estimate, the estimate remains 25% lower than the capex of $16,304/kW applied in the Draft.

Recommendation:

- ***FOAK capex for SMR(LWR) is based on available estimates with a clear and transparent methodology that can be readily updated.***
- ***We suggest $9,132/ kW based on 50% loading of recently provided FOAK costs from the leading SMR vendor might strike an appropriate balance between available vendor estimates and uncertain hard project costs.***

3. Are the inputs and assumptions for the capital cost projection model reasonable?

No. Inputs relating to first power from SMR and learning rate from SMR require attention.

Time of First Power

The Draft retains the assumption that SMR is first deployed in 2032 (on the basis of cost reduction shown in the Draft in Appendix Table B.3, page 37). No justification for this assumption is provided in terms of literature review or vendor consultation.

Current timeframes for deployment from NuScale is for first power in 2026 and power from all 12 of the first units in 2027[10].

The difference of six years is extremely material in terms of the application of learning rates to capex, and the decision-making timeframes for energy investment in Australia.

Recommendation:

- ***GenCost assumes first global power from SMR(LWR) in 2026; or***
- ***GenCost applies a transparent methodology to its assumptions for first power from SMR(LWR) on the basis of industry and vendor review and updates this methodology as certainty increases.***

Learning in Diverse technology scenario

The Draft has not provided transparent information relating to how learning rates have been applied to SMR in the Diverse technology scenario.

The SMR capex falls 53% in a single year. Capex then falls by fairly immaterial amounts for 7 more years to settle at $7,145/kW. The learning curve shown in Figure 3-8 of the Draft (page 14) is remarkable compared to all other technologies. This might relate to the unverifiable starting capex of $16,304/kW.

We have been unable to replicate the capex changes on the basis of methodological information provided by the Draft.

We have been able to precisely replicate the capex changes on the basis of the following methodology:

- Learning rate of 20% (cost reduction per doubling of installed capacity)
- 24 units installed = 4.5 doublings

This is illustrated in the Table below.

Table 2 Example methodology that replicates capex reduction shown in GenCost 2019/20

Units installed	Doublings	Cost reduction	Cost
1	0	NA	$16,304
2	1	= $16,304/1.2	$13,586
4	2	= $13,586/1.2	$11,322
8	3	= $11,322/1.2	$9,435
12	3.5	= $9,435/1.1	$8,577
24	4.5	= $8,577/1.2	$7,147

These assumptions bring us to within $2/kW of the mature cost assumed by GenCost – an excellent fit. We note our assumption of 24 units installed is consistent with an assumption of deployment of two, 12-unit NuScale plants. If this is the case, it is not disclosed.

Overall, a simple learning rate for the entirety of the SMR technology class is not appropriate. As the Draft (page 26) discusses, disaggregation of learning rate is required between, for example, the factory-built nuclear modules, and the non-nuclear on-site construction and balance of plant. Currently the Draft provides no information that any such insight is contained in the learning rates. Literature review and vendor consultation is required.

Recommendation:

- ***The Draft is updated to provide transparency on the learning assumptions for SMR, such that it can be correctly replicated and transparently updated.***

4. Are the inputs and assumptions for the levelised cost of electricity calculations reasonable?

No. The assumptions for levelised cost of electricity for SMR contains both errors and implausible assumptions.

Fuel cost

The fuel cost is assumed to be $0 (Appendix Table B.5. Data tables for LCOE assumptions, page 39). This is erroneous. While nuclear fuel is relatively lower in cost than fossil fuel plants, it is not free.

The error might have arisen from incorrect reliance on supporting work published by GHD. This source provided a 'fuel connection cost' of $0 as a component of capital cost[6].

Nuclear fuel costs are well-understood, relatively stable, and tend to decline with advanced fuel and reactor design, and better reactor operation.

A cost of $AU0.60/GJ [12] is a reasonable estimate.

Recommendation:

- ***Fuel cost is updated to $AU0.60/GJ.***

Fixed Operation and Maintenance Cost (Fixed O&M)

The Fixed O&M costs for SMR in the draft are $200/kW. This is an exceptionally high figure, being approximately double the figure published for brown coal with CCS ($101.60) (Appendix Table B.5 of the Draft, page 39).

Fixed O&M costs for nuclear in general are well known, stable, and have been estimated for Australia at $42 kW for SMR[13]. Accounting for inflation (2%), an estimate for Fixed O&M of $50/kW is appropriate.

Recommendation:

- ***Fixed O+M costs for SMR are updated to $50/kW.***

Thermal efficiency

The assigned thermal efficiency of 45% for SMR is a high figure, being second only to the thermal efficiency of combined cycle gas (51%) (Appendix Table B.5 of the Draft, page 39). We have located the reference as the 2018 report from GHD[6]. We assume the generic source of 'World Nuclear Association' refers to the SMR page of their website[14].

This page reports thermal efficiency of around 45% against several potential SMR designs. However, those designs are all specifically higher-temperature nuclear reactors. While some higher temperature SMR designs are relatively near-term commercial [15] such high thermal efficiency is not universal in SMR.

Given the nearest-term SMR with the greatest certainty and strongest available cost evidence is, at the time of this review a light water reactor design (SMR(LWR)), thermal efficiency of this reference design is more appropriate for consistency and transparency. Published technical specifications suggest thermal efficiency of approximately 30%[16].

Recommendation:

- ***Thermal efficiency of 30% tied specifically to SMR(LWR).***

Capacity Factors

The capacity factors selected for the Low and High estimates (80 % and 60 % respectively) are inappropriate and highly consequential.

Due to the relatively high capital expenditure, and relatively low fuel and variable operational costs, the LCOE for SMR is particularly sensitive to the assumed capacity factor.

The Draft states that capacity factors have been drawn from "(IRENA, 2015) (IEA, 2015) (CO2CRC, 2015)". We have reviewed these sources and an additional recent CSIRO assessment. Our findings are summarised in Table 3.

Table 3 Review of references for treatment of nuclear capacity factor

Reference	Comment
IRENA 2015[17]	Includes no references to nuclear technologies. Capacity factors for all technologies are weighted global averages.
CO2CRC 2015[18]	Offers no transparent capacity factors for nuclear technologies. Other baseload technologies (coal; combined cycle gas) have capacity factor of 80-85% (Table 79, page 225)
IEA 2015 [19]	Modelled all baseload-capable generation technologies (including nuclear) 'under assumed capacity factor of 85%)
CSIRO Electricity Generation Cost Projections 2017-2050[20]	Modelled nuclear technologies with 85% capacity factor for both the High and Low LCOE calculations – i.e. the capacity factor is a fixed technical capability of the technology.

Moving to 60% - 80% capacity factor for nuclear technologies is therefore a major departure from literature including recent CSIRO assumptions. Grouping SMR with 'flexible, 40-80% load, low emission' (Figure 4.1 – 4.4, pages 22-24 of the Draft) is an imposed constraint, limiting the permitted performance of selected technologies, as explained in the previous GenCost report[21](emphases added):

> *Over time it is **expected** that there will be fewer technologies operating in baseload mode with high capacity factors. As the share of both behind the meter and large scale variable renewables increases, it is more difficult for fossil fuel generation with positive operating costs to successfully compete to stay operating at all times of the day. As such, the cost ranges included for the fossil generators **assumes a capacity factor range of 60% to 80%.***

That methodology does not yield comparable LCOE. The analytical playing field is badly tilted against specified technologies, on the basis of an 'expected' future outcome.

These very low capacity factors should not be assumed as inputs for LCOE calculation. They might be revealed as outputs from system modelling (for all technologies, including variable technologies that might produce power at times of zero market value), but that is a separate process.

GenCost suggests it is for use as an 'input into electricity market modelling studies'[1]. These ***inputs*** therefore need to be free of market assumptions. Current capacity factors for the Australian coal sector, for example, are not a reliable guide. There is no reason to assume a 1:1 substitution of capacity from coal:nuclear in Australia's energy transition.

GenCost ought to treat all technologies even-handedly in the publication of LCOE. The technical capability of the technology needs to be the determinant of the capacity factor. Subsequent system modelling, with accompanying transparency of assumptions, might then reveal adjustments to the capacity factor on the basis of its revealed value and dispatch into markets.

From a technical specification point of view, SMR(LWR) can be assumed to offer 95% average capacity factor[16]. Across the ~100,000 MWe nuclear fleet of the United States, in the ten years to 2015 the average capacity factor was 91%[22].

Recommendation:

- ***SMR (LWR) capacity factor is amended as follows:***
  - ***Low cost = 95% capacity factor.***
  - ***High cost = 90% capacity factor.***

Summary recommendation

We recommend the Draft is updated to publish SMR(LWR) LCOE on the basis of inputs (5) and (6) in Table 4 below. These variable sets have included:

- **Corrected fuel cost = $0.60/GJ**
- **Corrected Fixed O+M cost = $50/kW**
- **Corrected thermal efficiency = 30%**
- **Capacity factor for Low Price = 95%**
- **Capacity factor for High Price = 90%**
- **Capex based on a 50% loading of the FOAK cost recently provided by the leading global SMR vendor**

Given GenCost is a global study, we recommend learning rates commence in 2026 consistent with current indications of first power, or otherwise are revised with a transparent, replicable methodology.

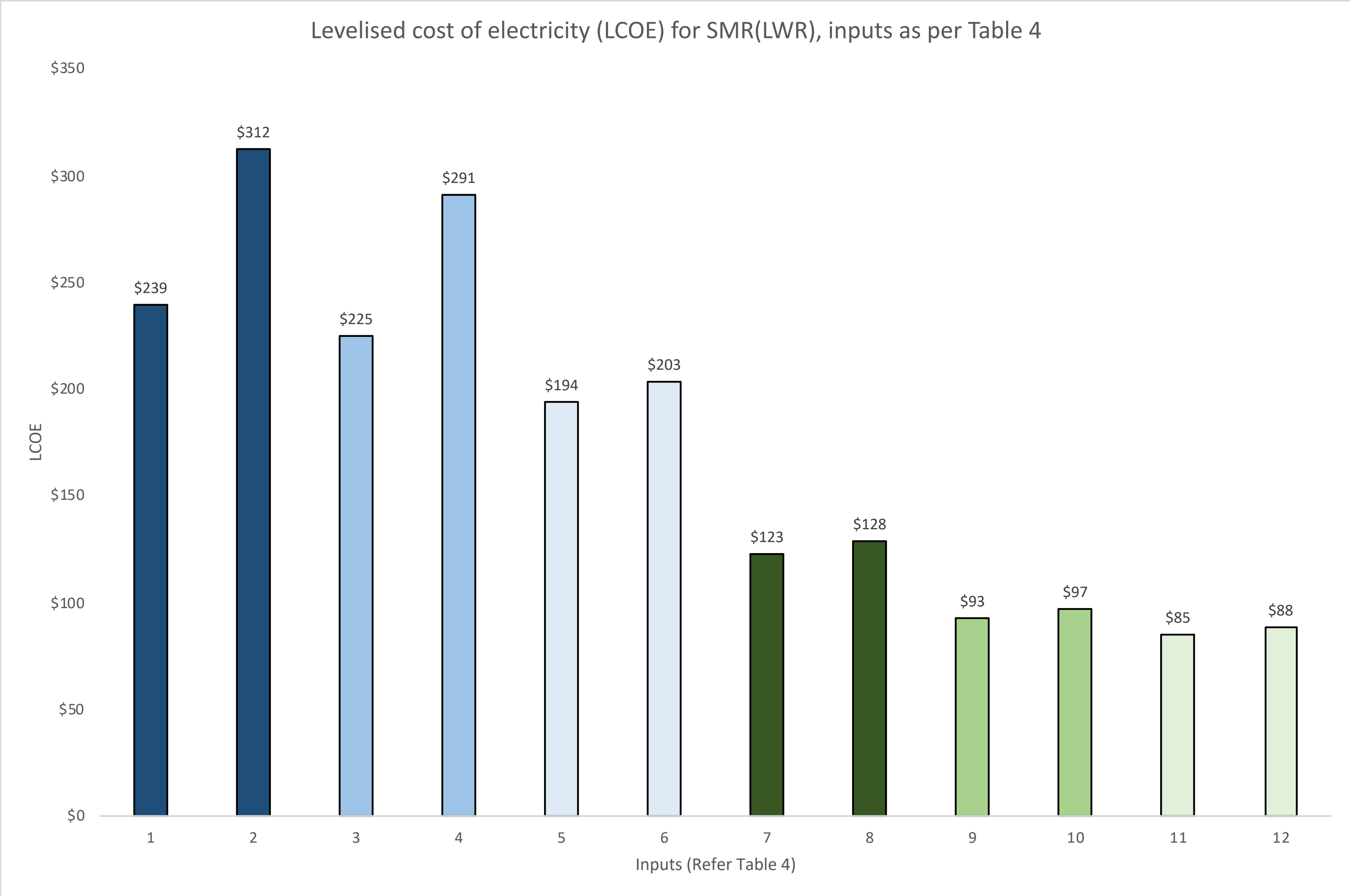
Learning needs to be based on research and assumptions that are transparent and replicable.

Our results are summarised in Table 4 and Figure 1 below.

Table 4 Inputs for calculation of SMR (LWR) with progressive corrections

	1	2	3	4	5	6	7	8	9	10	11	12
Change(s)	NA (SMR GenCost-Low)	NA (SMR GenCost-High)	Fixed O+M, Fuel, Thermal Efficiency	Fixed O+M, Fuel, Thermal Efficiency	Capacity Factor (Low Price)	Capacity Factor (High Price)	Capex = FOAK + 50% loading	Capex = FOAK + 50% loading	Capex = FOAK -	Capex = FOAK	Capex = NOAK	Capex = NOAK
CAPEX ($Mn/MW Installed)	16.304	16.304	16.304	16.304	16.304	16.304	9.132	9.132	6.088	6.088	5.248	5.248
Fuel ($/GJ HHV)	0	0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Capacity Factor (%)	80	60	80	60	95	90	95	90	95	90	95	90
Amortisation (Years)	60	60	60	60	60	60	60	60	60	60	60	60
Discount Rate (%)	7	7	7	7	7	7	7	7	7	7	7	7
Build Time (Years)	5	5	5	5	5	5	5	5	5	5	5	5
Thermal Efficiency (%)	45	45	30	30	30	30	30	30	30	30	30	30
Fixed O+M ($m/MW)	0.2	0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Variable O+M ($ MWh)	20	20	20	20	20	20	20	20	20	20	20	20
LCOE (Calculated)	**$239**	**312**	**225**	**291**	**194**	**203**	**123**	**128**	**93**	**97**	**85**	**88**

Figure 1 Levelised cost of electricity (LCOE) for SMR, inputs as per Table 4



Further considerations – Build time, amortisation, discount rate

Build time

GenCost has retained an assumption of 5-year build time for SMR. While perhaps an appropriately conservative assumption in the absence of hard project data, we also note the business model for SMR is shorter build times based on factory manufacture of the nuclear modules. The reference for the 5-year build time relates entirely to the historical build time of pressurised water reactors, normalised 'to plants with 1 GW'[23]. That is an inappropriate reference.

Using the inputs from variable set (7) we have adjusted the build time from 5 to 3 years to demonstrate the impact on LCOE.

Table 5 Comparison of LCOE of SMR(LWR) with varying build time. Reducing the build time to the basis of the SMR(LWR) commercial proposition (3 yr.) reduces the LCOE

Inputs	Table 8 (1)	Table 8 (4)
Build time	5	3
LCOE ($/MWh)	123	116

Recommendation:

- ***If an assumed 5-year build time is retained, this is on the basis of vendor estimated build time for SMR(LWR), plus a transparent loading to account for uncertainty.***
- ***The assumption is updated as more project information becomes available to remove uncertainty.***

Amortisation and discount rate

It is helpful to see a design life of 60 years reflected as the amortisation period for SMR in GenCost. This highlights an important advantage of an investment in SMR for decarbonisation - it will continue to deliver on that transition well into the future, in contrast to the shorter design lives of other technologies.

However, since levelised cost of electricity represents a ***discounted present value,*** this longevity can only be recognised in with a suitably low discount rate. If the future is treated as much less valuable than the present, then long-lived assets look like a bad investment.

This is shown in Table 6. We have applied the inputs from variable set (7) of Table 4 above, running the amortisation period down from 60 to 40 years. At 7% discount rate, an additional 20 years of operation, providing zero carbon power at 95 % capacity factor, delivers a mere $5/MWh reduction in LCOE. In other words, assuming a design life of only 40 years for LCOE will make very little difference to how people perceive the cost of SMR if the discount rate is set too high.

Table 6 Comparison of LCOE of SMR(LWR) with varying amortisation. The LCOE is insensitive to changing amortisation from 60 years to 40 years. Much of the value of the longevity of SMR(LWR) is therefore obscured.

Inputs	**Table 4 (7)**				
Amortisation (years)	60	55	50	45	40
LCOE ($/MWh)	123	124	125	126	128

By contrast, if the discount rate is reduced to, for example, 5 % or lower, low-carbon assets (irrespective of them being nuclear, renewable or fossil with CCS) with larger upfront capex and build time, and longer design lives, are appropriately recognised for delivering value several generations into the future.

Table 7 Comparison of LCOE if SMR(LWR) with varying discount rate. The LCOE is very sensitive to the discount rate, reflecting the larger up-front capex. Placing more value on the future (lower discount rate) demonstrates the value of SMR(LWR).

Inputs	**Table 8 (1)**	**Table 8 (2)**	**Table 8 (3)**
Discount rate (%)	7	5	3
LCOE ($/MWh)	123	97	75

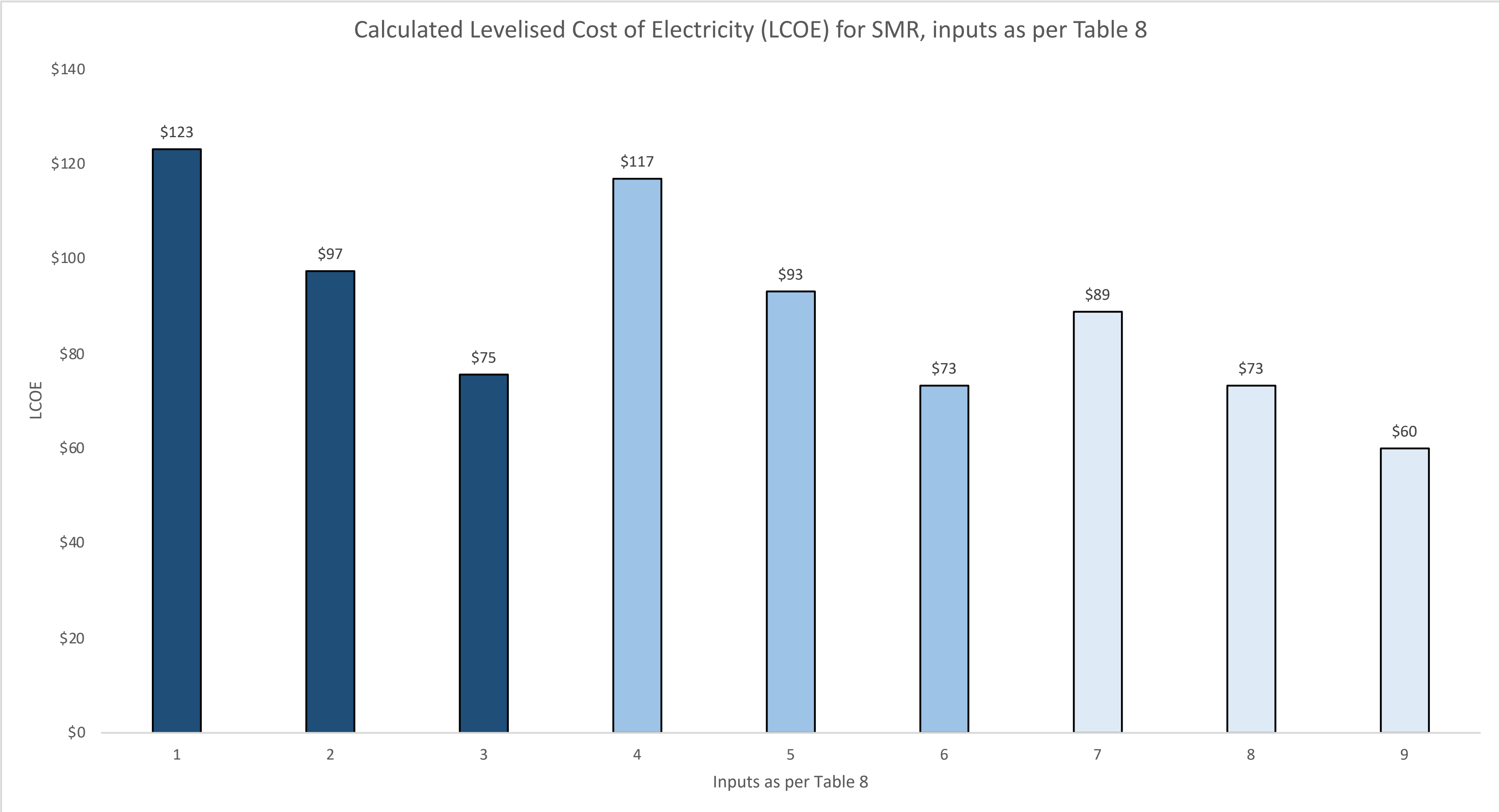
This is important for developing policy to transition entire economies to decarbonised energy sources. Even using FOAK capex with 50% loading, the LCOE of SMR(LWR) falls under $100/MWh by reducing the discount rate to 5%.

With global capital at the cheapest it has ever been[24], this is arguably a very good time for governments to provide low-cost capital for long-term, large capex infrastructure projects in support of deep decarbonisation and affordable, reliable electricity for the long-term. This is representative of the intergenerational equity that must be a key consideration of policy making in response to climate change.

Table 8 Levelised cost of SMR, with differences in discount rate build time, and capex

Inputs	1	2	3	4	5	6	7	8	9
Change(s)	NA	5% discount rate	3% discount rate	3 yr. build time	5% discount rate	3 % discount rate	Capex = FOAK	5% discount rate	3% discount rate
CAPEX ($Mn/MW Installed)	9.132	9.132	9.132	9.132	9.132	9.132	6.088	6.088	6.088
Fuel ($/GJ HHV)	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Capacity Factor (%)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Amortisation (Years)	60	60	60	60	60	60	60	60	60
Discount Rate (%)	7	5	3	7	5	3	7	5	3
Build Time (Years)	5	5	5	3	3	3	3	3	3
Thermal Efficiency (%)	30	30	30	30	30	30	30	30	30
Fixed O+M ($m/MW)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Variable O+M ($ MWh)	20	20	20	20	20	20	20	20	20
LCOE (Calculated)	**$123**	**$97**	**$75**	**$117**	**$93**	**$73**	**$89**	**$73**	**$60**

Figure 2 Levelised cost of electricity (LCOE) of SMR(LWR), showing impact of varying build time, discount rate, and capex



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