MERIDIAN ECONOMICS
NAVIGATING COMPLEXITY

# COMPARATIVE ANALYSIS OF IRP 2023 COST ASSUMPTIONS

2 FEBRUARY 2024
VERSION 20240205.1

# INTRODUCTION

## TECHNOLOGY COST ASSUMPTIONS - A CRITICAL INPUT TO POWER SYSTEM PLANNING

- This report documents the technology cost assumptions disclosed in the Integrated Resource Plan 2023 (IRP 2023) and compares them to assumptions used in other recent studies of the RSA power system, as well as several independent sources.
- The reasons for this publication are three-fold:
  1. To assist stakeholders in making informed comment into the IRP 2023 public participation process.
  2. To elicit views from sector experts as to the reasonableness of the assumptions, and particularly the likely path for future cost development in each technology over the short, medium and long term.
  3. To clarify that our understanding of the assumptions used in the IRP 2023 analysis is correct.
- Meridian Economics also plans to publish an independent power system capacity expansion analysis to further assist stakeholder review of the IRP 2023
  - constructive, critical views on reasonable technology costs will be used to guide the input assumptions for our analysis.
- Considering the exceptionally short timeframe for comments (currently all stakeholder comments on IRP 2023 are due by 23 Feb 2024) we request feedback on the technology cost assumptions as soon as possible.
- The accompanying spreadsheet with associated LCOE calculations, graphs and data supporting this slide deck can be found here
- Feedback can be sent to ndivhuwo.segakweng@meridianeconomics.co.za

# CONTENTS


1. Comparative data sources
2. Methodology
3. General comments and preliminary observations
4. Notes on the charts
5. Cost comparison by technology

| | Wind | Solar PV | Concentrating solar thermal | | Battery storage | | Pumped hydro | Coal | Combustion turbines – gas fired | | Internal combustion engines – gas fired | Nuclear | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Onshore wind | Single axis tracking | Parabolic trough | Central receiver | 4h | 1h | | Coal without CCS | Combined cycle gas turbine | Open cycle gas turbine | Internal combustion Engines | Pressurised Water Reactor | Small Modular Reactors |
| Slide refs | 9-11 | 12-14 | 15-17 | 15, 18-19 | 20-22 | 20, 23-24 | 25-26 | 27-29 | 30-32 | 30, 33-37 | | 38-40 | 38, 41-42 |

# COMPARATIVE DATA SOURCES

## IRP 2023 ASSUMPTIONS ARE COMPARED TO THREE RECENT POWER SYSTEM STUDIES, AND FOUR OTHER SOURCES

- IRP 2023 data:
  - **IRP 2023** (IRP 2023 technology costs sourced from here. Technology descriptions and cost data are provided under "New Tech Assumptions IRP 2023").
  - **EPRI 2021** ("EPRI Report: Supply-Side Cost and Performance Data for Eskom Integrated Resource Planning" sourced from here) – this is the source document for IRP 2023 assumptions, but IRP 2023 assumes no future cost learning. We have applied cost learning from EPRI 2021 to the IRP 2023 values for comparison.
- Power system studies:
  - **Meridian 2020** (Meridian Economics 2020 report A Vital Ambition in collaboration with the CSIR Energy Centre sourced from here).
  - **PCC 2022** (Presidential Climate Commission South Africa's Just Energy Transition Investment Plan (JET IP) for the initial period 2023-2027 sourced from here).
  - **NBI 2021** (National Business Institute, Climate Pathways sourced from here).
- Technology cost assumption sources:
  - **AEMO 2023** (Australian Energy Market Operator 2023, Draft Integrated System Plan sourced from here) – includes comprehensive technology input assumptions to the Australian Integrated System Plan ISP 2024.
  - **ATB 2023** (National Renewable Energy Laboratory Annual Technology Baseline 2023 sourced from here) – this is focused mainly on the USA market, with Conservative, Moderate and Advanced cost learning estimates.
  - **IEA 2023** (International Energy Agency, World Energy Outlook 2023 sourced from here) – includes estimates for 4 jurisdictions (USA, EU, China, India) and 3 scenarios (Stated Policies, Announced pledges, Net Zero emissions by 2050). For brevity only India (Stated Policies) is included in charts. The spreadsheet includes all scenarios for India and EU.
  - **REIPPPP** (Renewable Energy Independent Power Producer Procurement Programme) – where applicable we have included data from previous rounds of the REIPPPP for comparison.
  - **DNV 2023** (Energy Transition Outlook 2023 sourced from here) – includes capital cost estimations for 10 different geographical regions. Costs from DNV 2023 are not currently included in the graphing as the currency reference (nominal or real and year) is unclear.
  - These data sources are based on publications from reputable international organizations and cover wide range of regions (not only limited to North America/EU). These sources also include technology cost projections. The LCOE costs from Lazard do not include cost projections and are not currently plotted in this work.

# METHODOLOGY

- The general approach is to maintain comparability to the IRP reference frame (Cost of Capital, Exchange rate, Inflation, Real April 2023 Rands)
  - International cost sources are first expressed in Real April 2023 home currency before converting to Rands at the April 2023 exchange rate (economic assumption sources can be found in the accompanying spreadsheet under Assumptions tab).
- Technology costs per technology are broken down into Overnight Capital, Fixed O&M, Variable O&M, and Fuel. Overnight capital costs are converted into Total Capital Costs by adding the cost of financing during construction.
- Comparison between sources for each technology is complicated by differing non-cost assumptions.
  - In order to facilitate comparison, we have calculated a Levelised Cost of Energy (LCOE R/kWh) for all generation sources, and Levelised Annual Cost (R/kW/year) for storage technologies.
  - The LCOE calculation uses Capacity Factor and Economic Lifetime specific to each source, but fuel cost for each technology is standardised using IRP 2023 and EPRI assumptions.
    - An exception is the IEA 2023 data which does not separate O&M and fuel costs. The LCOE plotted is sourced directly from the publication.
    - Where Capacity Factor or Economic Lifetime is not specified in a source, we have used the EPRI 2021 assumptions.
  - Due to the differing roles of technologies in the power system the LCOE comparisons are most relevant within each technology category.
- The costs for each technology are determined and presented according to the Commercial Operation Date (COD). When a data source does not explicitly state the reference for the year it is assumed to be COD.

All costs are expressed in Real April 2023 Rands (aligned to IRP 2023)

# GENERAL COMMENTS AND PRELIMINARY OBSERVATIONS

- The IRP 2023 relies on cost assumptions provided in the EPRI report.
  - Most notable is the fact that the IRP 2023 did not consider any future cost changes in real terms (cost learning) for any technology to 2050, despite the EPRI report including cost learning assumptions.
  - Ignoring cost learning significantly overstates the cost of new technologies (Wind, Solar, Batteries in particular) relative to more mature technologies (Coal, Nuclear, Flexible) especially for medium to long term horizon planning.
- In the stakeholder engagement workshop on 31 January 2024, DMRE confirmed that the costs presented in the IRP 2023 input assumptions spreadsheet were applied to the PLEXOS model, without further modification.
  - Although DMRE mentioned that the costs for Wind and Solar PV have been modified to align with REIPPPP, the costs provided in the DMRE spreadsheet for Wind and Solar PV remain based on the EPRI report.
  - These costs appear to be much higher than other estimates and higher even than prices bid into the REIPPPP as far back as 2016.
- The IRP 2023 input assumptions spreadsheet includes multiple generator/storage options for several technology categories. For example, in the case of nuclear there are widely varying capital cost assumptions between the different generator options (overnight CAPEX R67,288/kW for PWR-CP vs R141,397/kW for SMR-CP 3).
  - In the stakeholder engagement workshop on 31 January 2024, DMRE confirmed that all generator options outlined in the input assumptions spreadsheet were used in the model. This essentially results in the optimisation selecting only the lowest cost option within each technology category as the representative generator.

# GENERAL COMMENTS AND PRELIMINARY OBSERVATIONS

- In general, the IRP 2023 levelized cost assumptions for Wind, Solar PV, CSP and Batteries are significantly higher than other studies and sources, with the exception of the ATB 2023 Solar PV estimates. However, the latter are strongly influenced by USA import tariff protection in the short/medium term – not applicable to Solar PV in RSA.
- Assuming equivalent fuel costs and capacity factors for dispatchable, fossil fuel fired, generators (coal and gas), the resulting LCOE from IRP 2023 falls broadly inline with other sources, although on the lower end for gas fired generation.
- No detail is given in the IRP 2023 around the contracting realities of gas and how this is linked to the gas price based on offtake volumes. Further insight in this regard is required.
- The IRP analysis has not made diesel-fired peaking generation available as a competing alternative to lower capacity factor gas fired generation.
- An assumed overnight capital cost of $3,651/kW for nuclear is on the lower bound of the datasets reviewed, with the exception of the IEA WEO data for India, which assumes an “nth generation reactor” that has already had substantial cost reductions from a first-of-its kind construction.
- Given recent cost over-runs and delays of international nuclear projects in the UK and US, and local cost overruns with respect to building mega-projects such as Kusile, Medupi and Ingula, the nuclear cost assumptions appear exceptionally optimistic.

# NOTES ON THE CHARTS

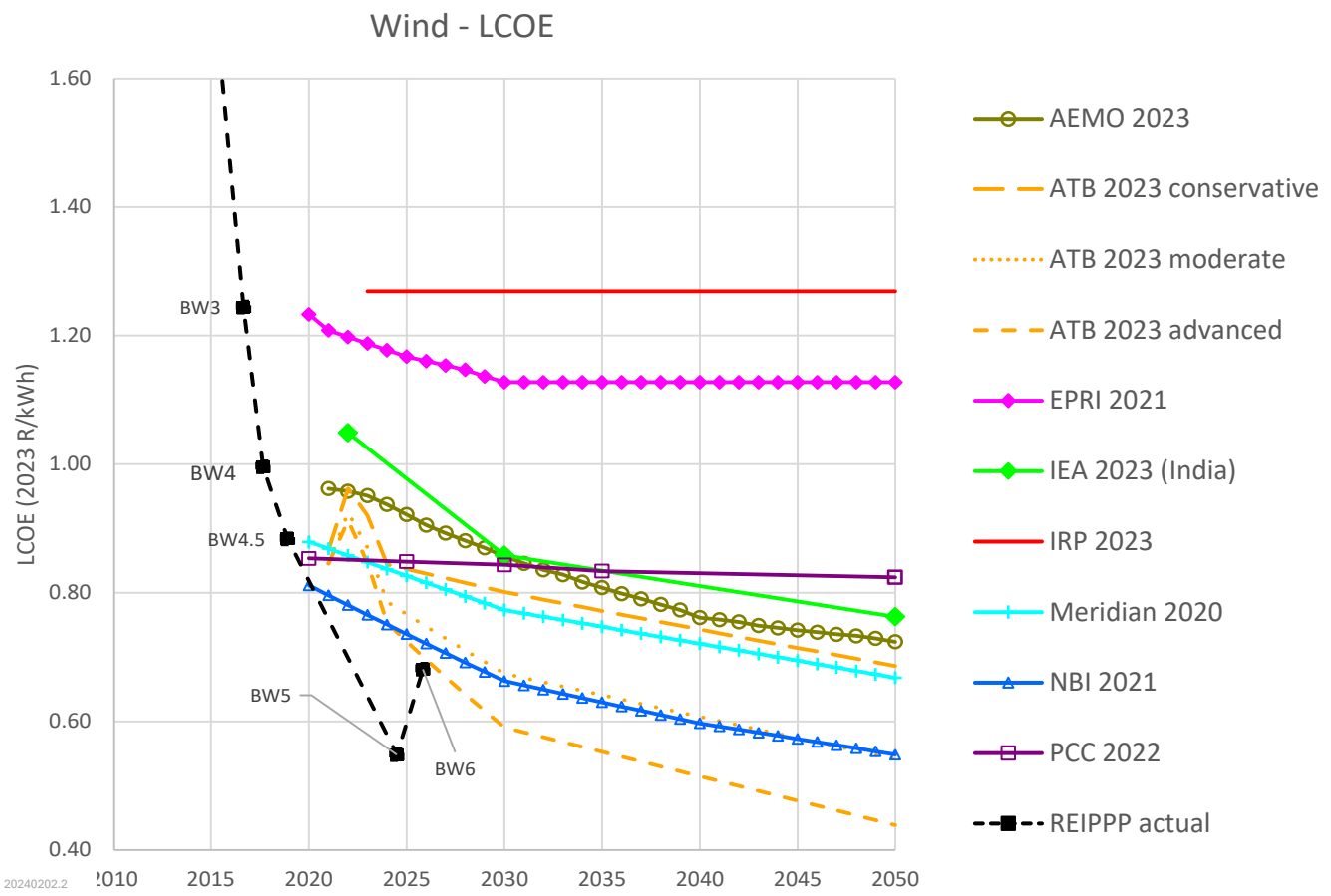
- The primary metric of comparing the cost datasets within a single technology type is the LCOE for generation and Levelised Annual Cost for storage.
- For each technology there are two slides, the first compares the LCOE (or Levelised Annual Cost in the case of storage) and the Total Capital Cost. The second slide compares the Fixed O&M and Variable O&M (or Capacity Factor in the case of renewable technologies).
- Each data source is associated with a single colour for all technologies as depicted in the legend to the right.
- The IRP 2023 data is represented by a red solid line for instances where a single technology option has been provided. For instances where there are multiple technology options red dashed lines with markers are used.
- Where multiple IRP 2023 lines are presented the lowest LCOE/Levelised Annual Cost is considered to be the reference technology that is deployed in the PLEXOS model used in compiling the IRP 2023.

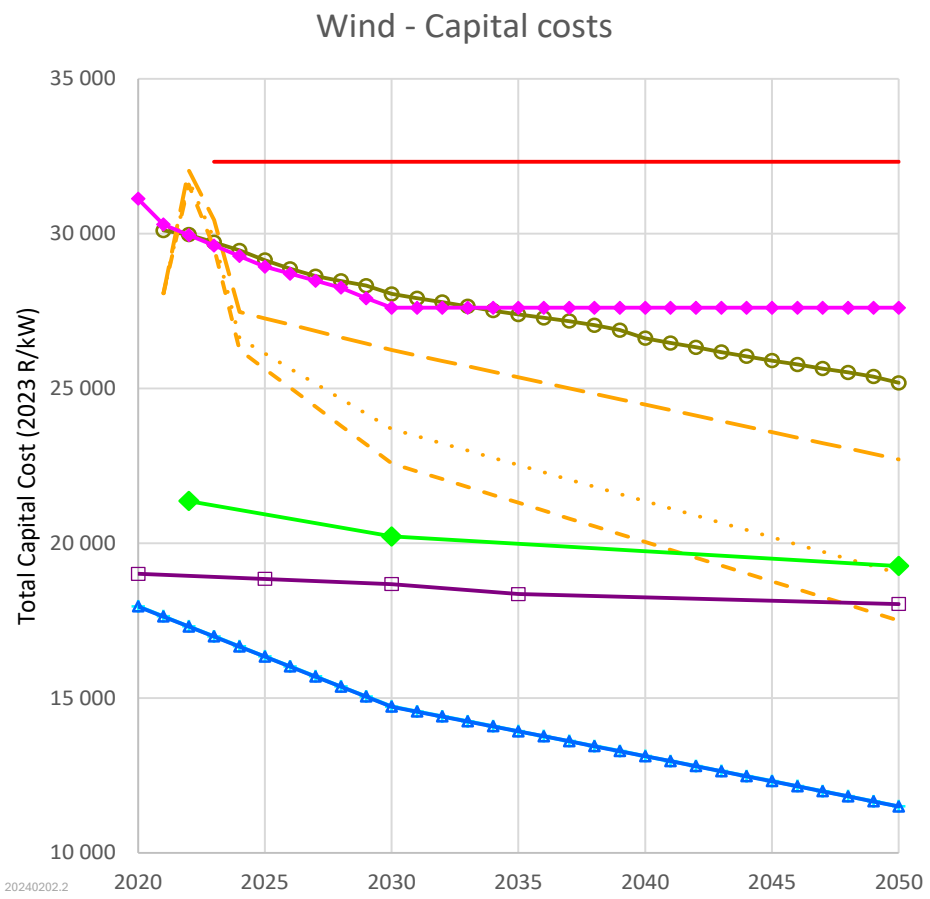
# WIND

- IRP 2023 input assumptions spreadsheet uses the EPRI reference 2.8MW turbine size. This is a significantly outdated assumption with cost implications - new turbines are in >5MW size with consequent lower CAPEX and Fixed O&M costs.
- CAPEX for wind is on upper bound of all data sources (only ATB initially in same range but this likely for USA specific reasons).
  - Fixed O&M is significantly higher than international sources (Meridian 2020 also used high Fixed O&M based on IRP 2019, but LCOE aligned with REIPPPP 4.5).
  - Combination of CAPEX and Fixed O&M assumptions results in LCOE that is 82% higher than average of lowest 15 BW6 unsuccessful wind project bidders.
    - Wind generators will need to be placed in sub-optimal resource areas or in higher resource areas with curtailment in the short/medium term due to grid constraints, increasing the cost per kWh. However, even considering generous cost increases associated with this, the IRP 2023 assumptions appear to be unreasonably high.
    - Even if maximum curtailment at 10% is assumed, the IRP 2023 costs remain 70% higher than BW6 bids that are accordingly adjusted.
- In the stakeholder engagement workshop on 31 January 2024, DMRE confirmed that the CSIR/Fraunhofer study was used for hourly Wind and Solar PV capacity factors. The combined spatially averaged capacity factor from this study is 38.1%, which is reasonable.

# WIND

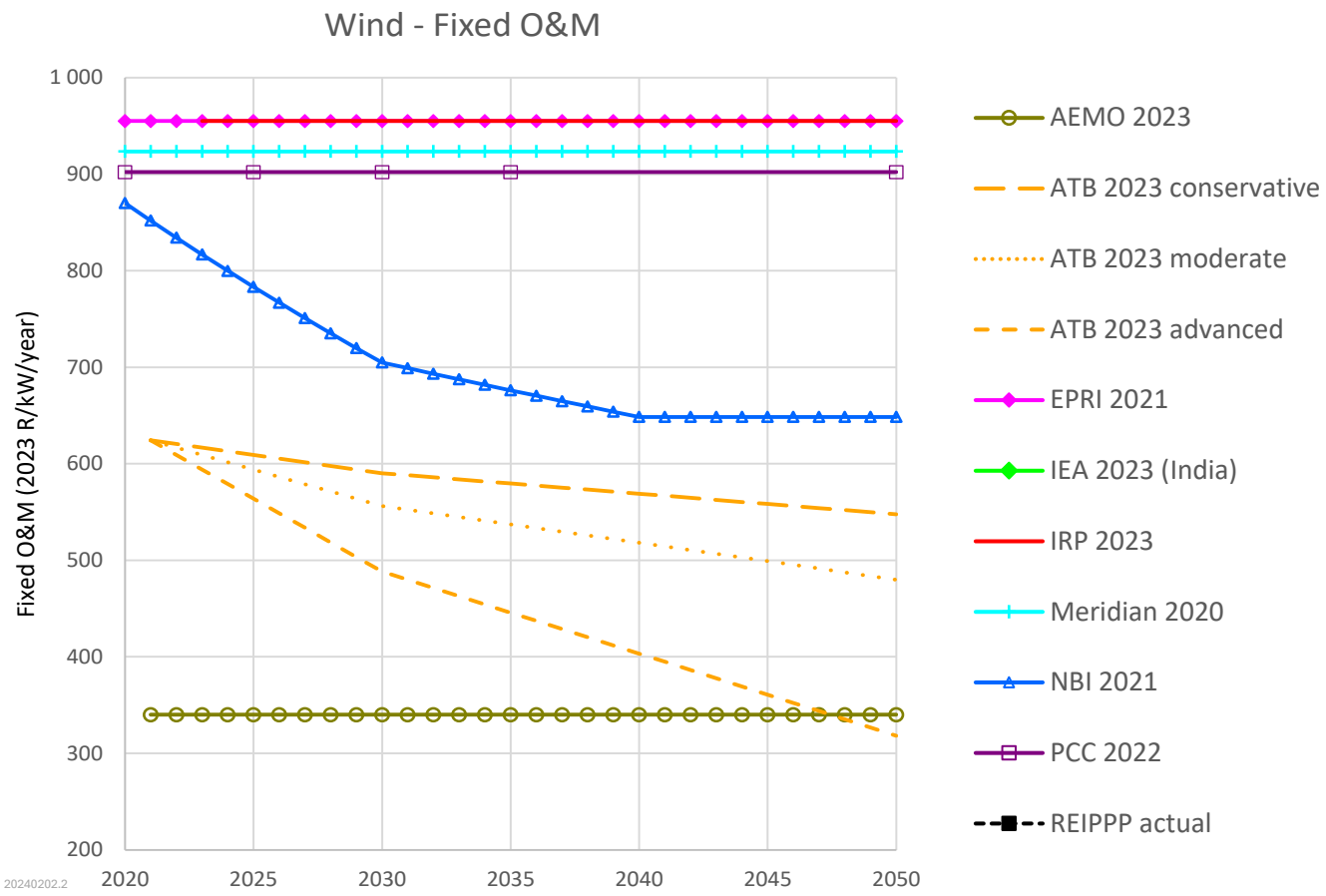
## LCOE AND CAPITAL COST

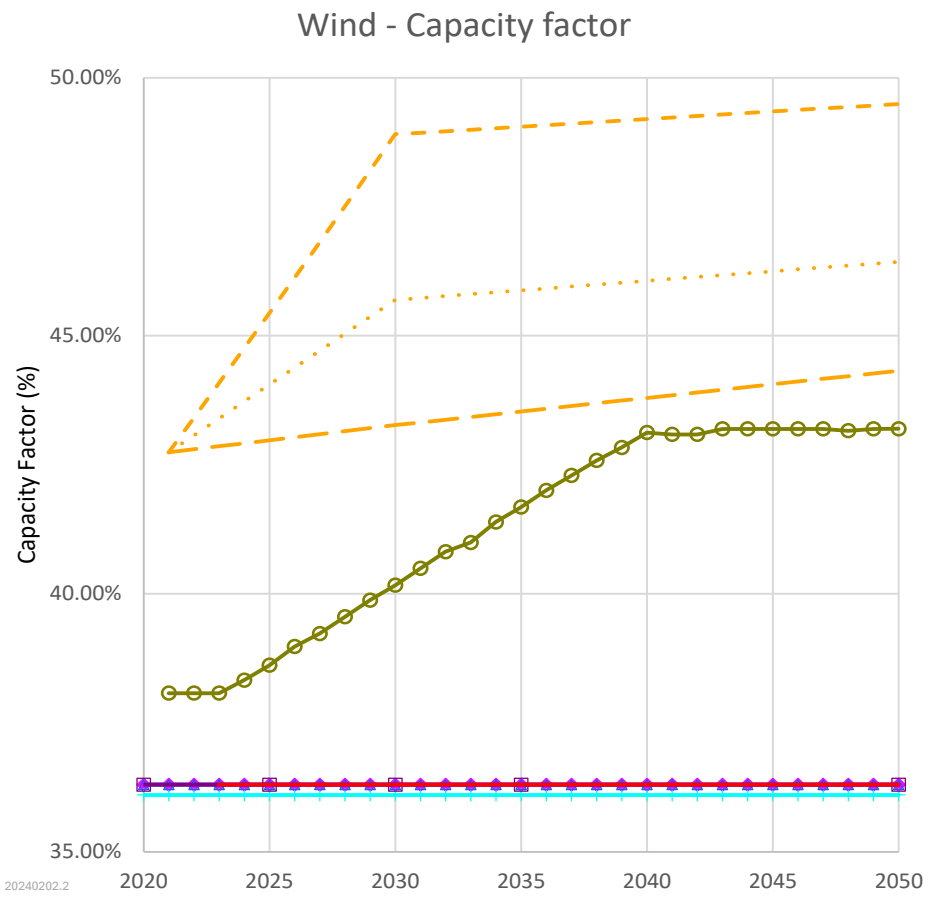


# WIND

## FIXED O&M AND CAPACITY FACTOR




We have used the EPRI capacity factor of 36.3% for the IRP 2023 Wind LCOE calculations.

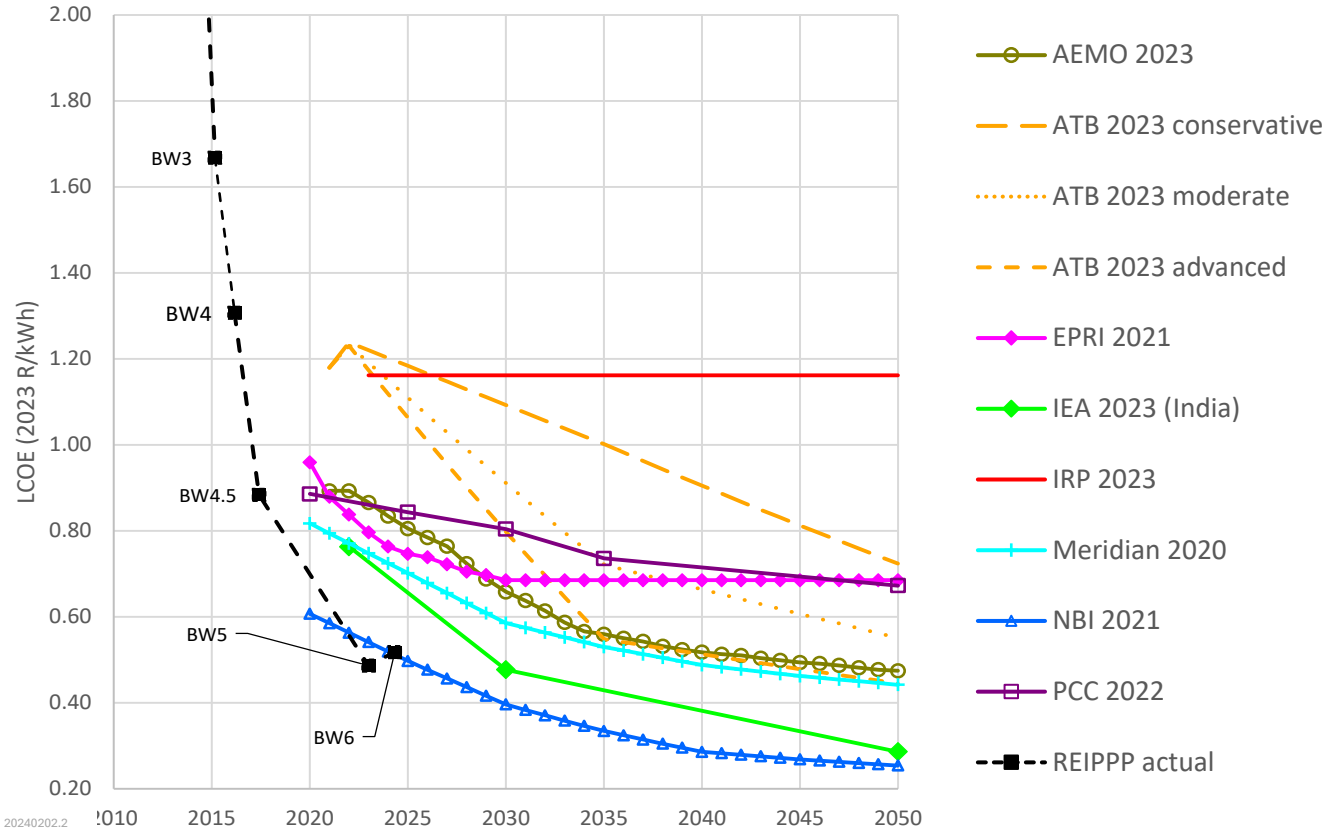
# SOLAR PV

- EPRI report presents a number of Solar technologies. IRP 2023 input assumptions spreadsheet includes cost only for thin film CdTe technology. This has a much lower capacity factor than the now-ubiquitous bi-facial crystalline SI (c-SI) technology.
  - IRP 2023 Capacity factor assumption is not specified but EPRI report shows CdTe with CF of 26.5% (vs 29% for c-SI)
  - We assume IRP 2023 has used thin film CdTe cost and CF, for single axis tracking.
- CAPEX is on upper bound of all data sources (only ATB 2023 is initially in same range but this likely relates to USA specific reasons).
- Fixed O&M from IRP 2023 for solar PV is significantly higher than other sources (except ATB 2023 initially).
- Combination of CAPEX and Fixed O&M assumptions result in LCOE that is double the average of BW6 successful bidder prices.
  - Solar PV is less affected by grid constraints, could be built where grid is available without incurring as much of a premium as wind.
- Solar PV cost assumption appears unreasonably high.
- IRP 2023 assumes Solar PV costs for a Single Axis Tracking plant, which will yield typical capacity factors of between 25-32% depending on location. However, the DMRE stated that the hourly generation profiles used in the IRP 2023 model are based on the CSIR/Fraunhofer study, which assumes a Fixed Tilt system with a mix of ground mounted and rooftop Solar PV. The spatially averaged capacity factor from that CSIR/Fraunhofer study is 19.6% (with regional ranges between 16.8% and 22.6%). This is too low to be applied to a Single Axis Tracking technology in the IRP 2023 model.

# SOLAR PV

## LCOE AND CAPITAL COST

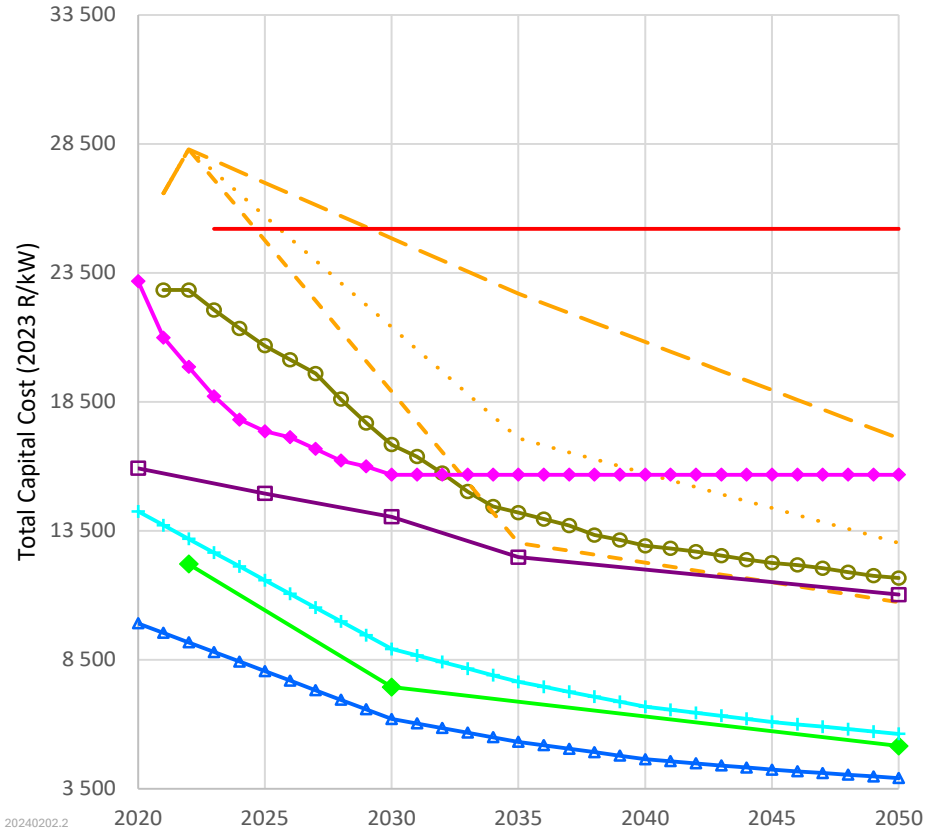
Solar PV - LCOE







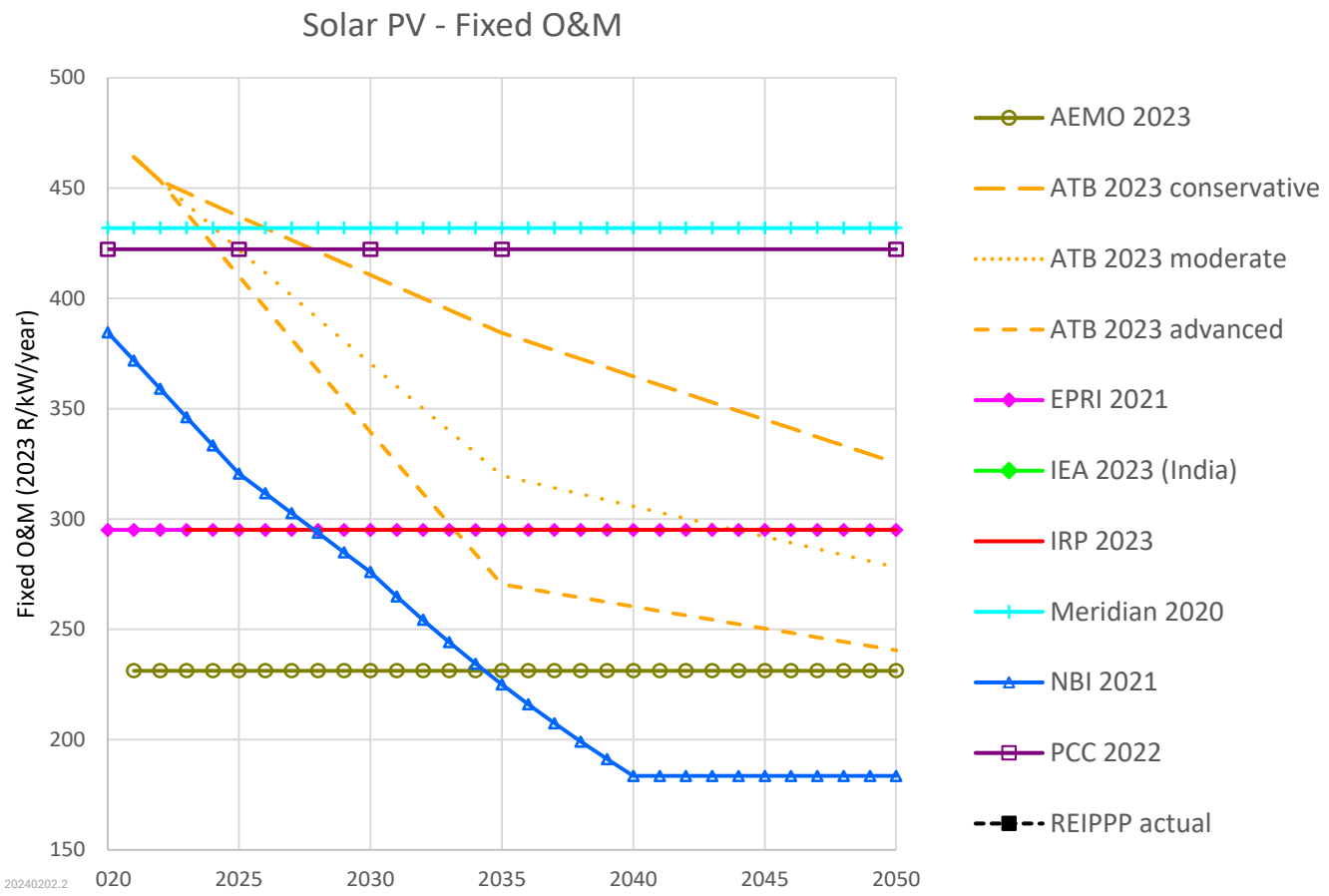
Solar PV - Capital costs

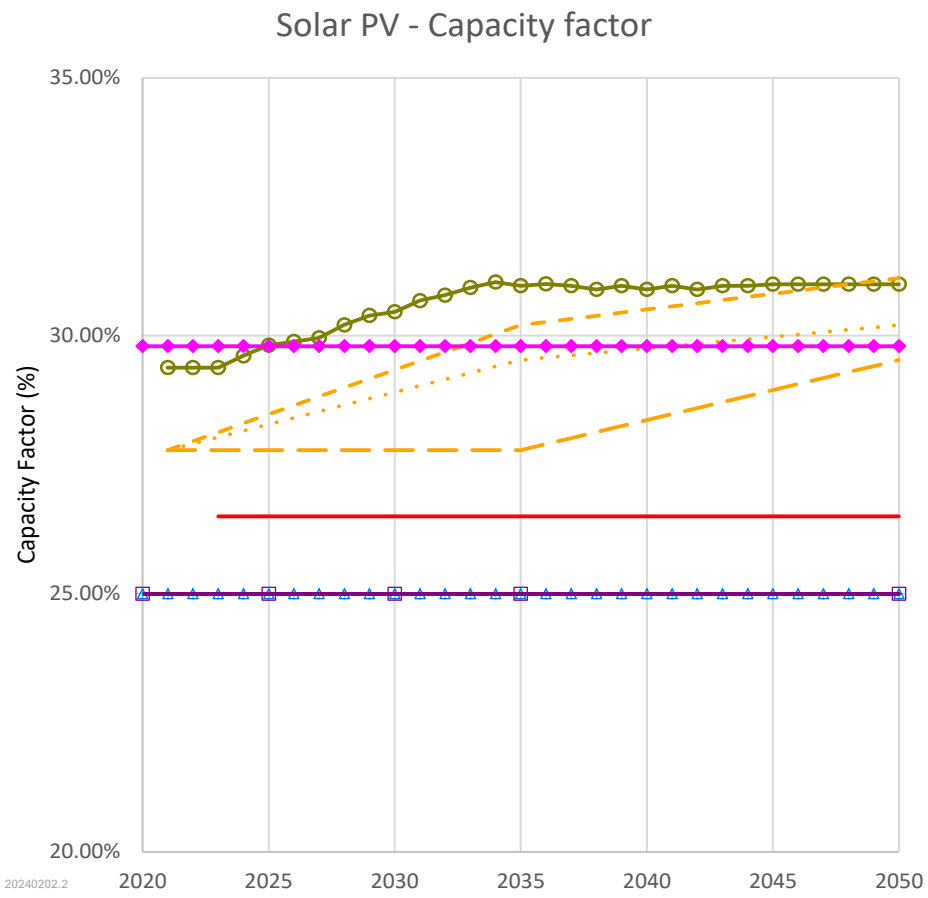



We have used the EPRI capacity factor of 25% for the IRP 2023 Solar PV. However, the actual profiles used in the model are closer to 20%, which further increases LCOE.

# SOLAR PV

## FIXED O&M AND CAPACITY FACTOR



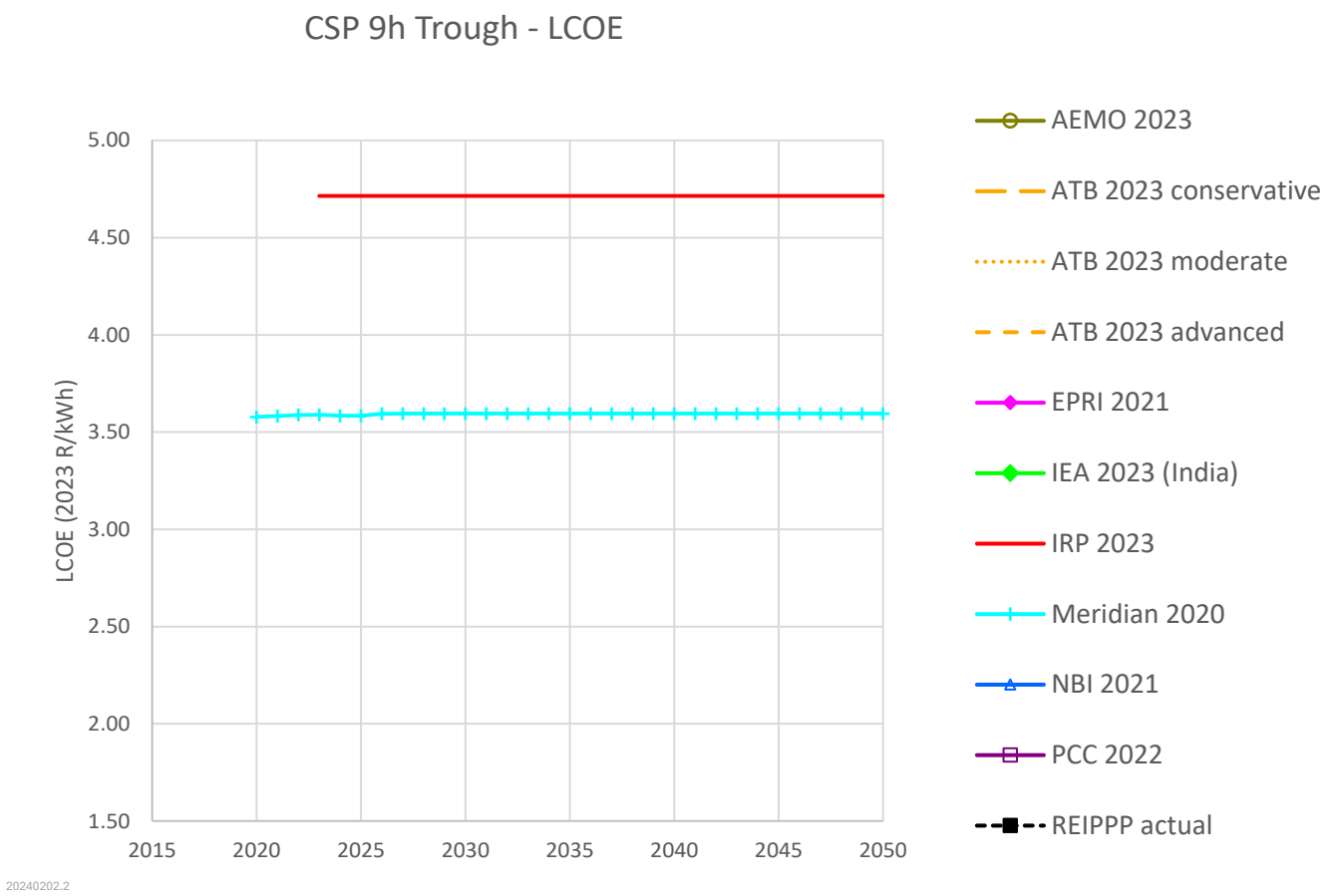
# CONCENTRATING SOLAR POWER (CSP)

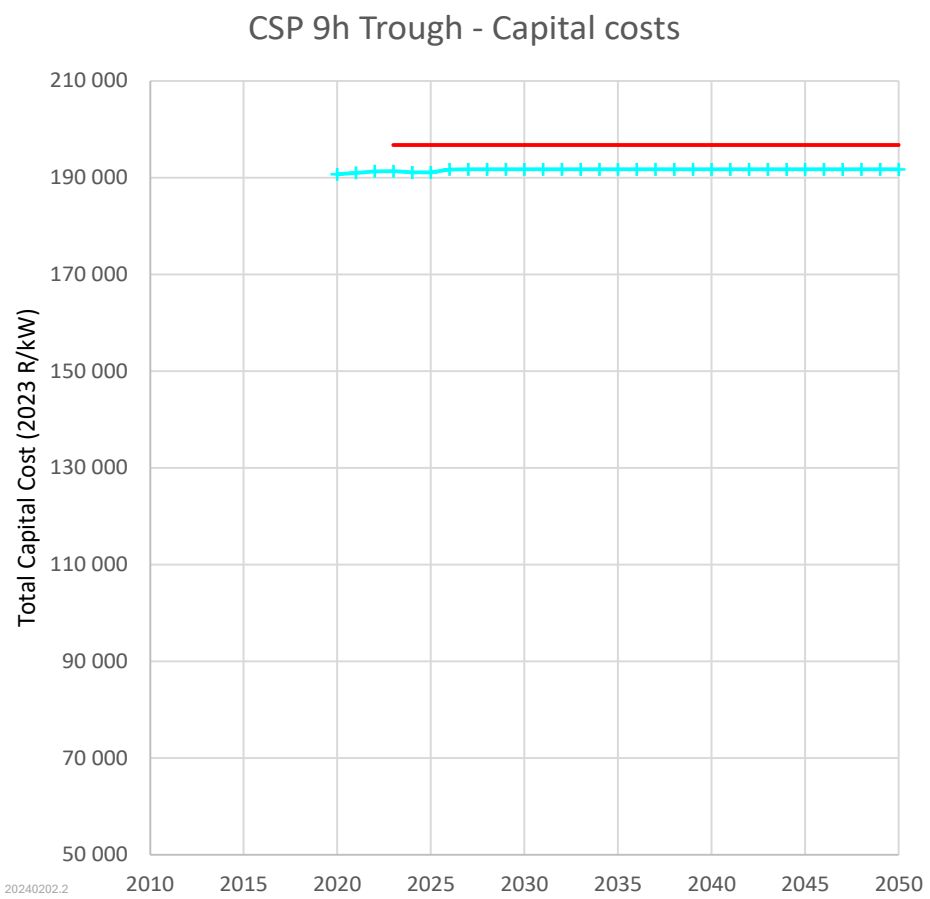
- CSP includes technology options for both parabolic trough and central receivers (power tower), with varying degrees of thermal energy storage (3h, 6h, 9h, 12h).
- Here we focus on tower technology, which has the lowest cost potential.
- A comparison of the data sources shows a wide range of capital cost and O&M assumptions.
- IRP 2023 capital cost assumptions are notably higher than all other data sources, whilst O&M assumptions are on the lower bound.
- By ignoring future costs reductions, the IRP 2023 assumptions result in LCOE that is higher than other data sources post 2025.
- It has not been stated what hourly profiles for CSP have been applied to the model.

RSA specific data on the declining costs of CSP is limited to earlier REIPPPP bid windows. Stakeholder comment would be useful regarding potential cost reductions of CSP for local conditions.

# CSP PARABOLIC TROUGH WITH 9HR OF THERMAL STORAGE

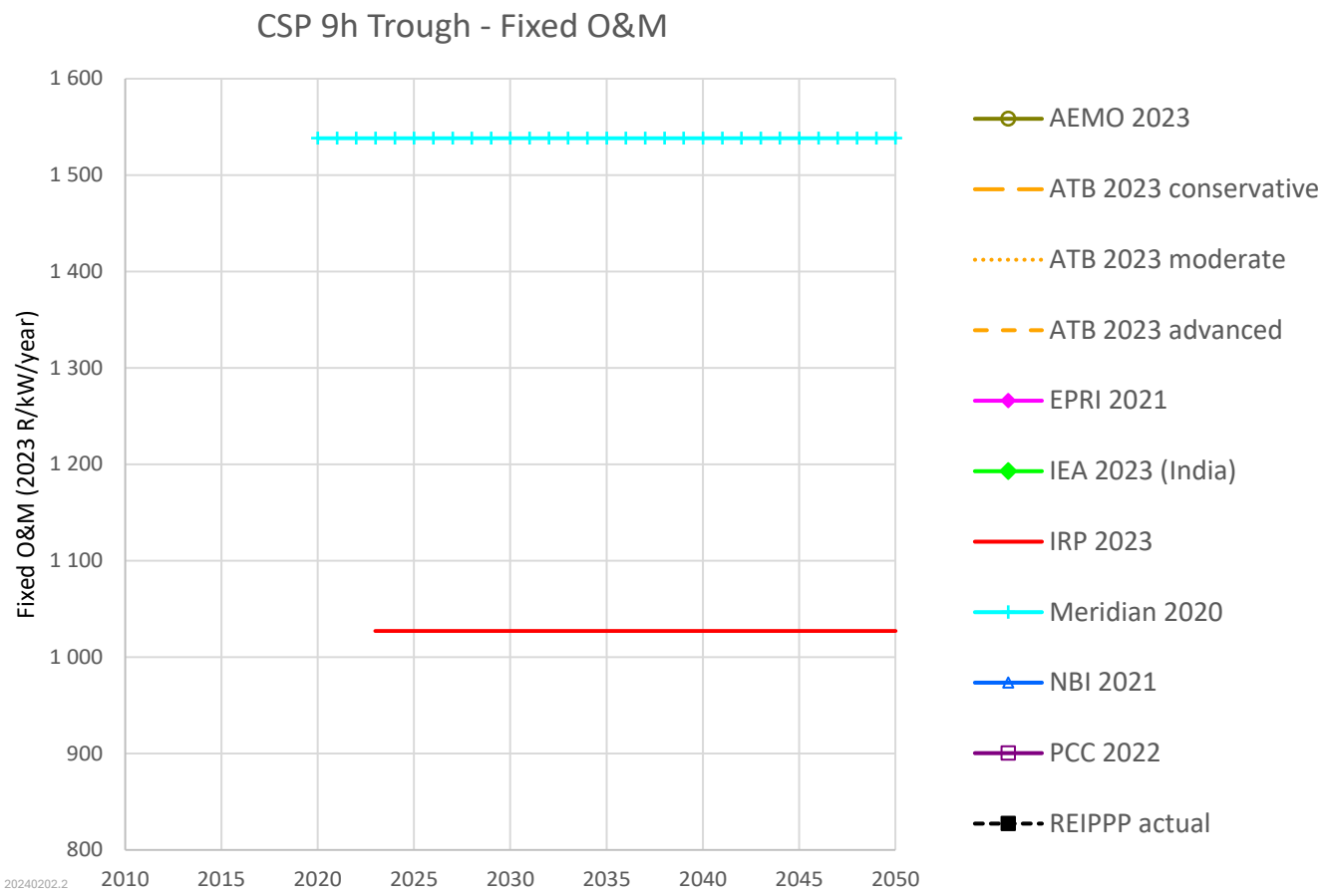
## LCOE AND CAPITAL COST

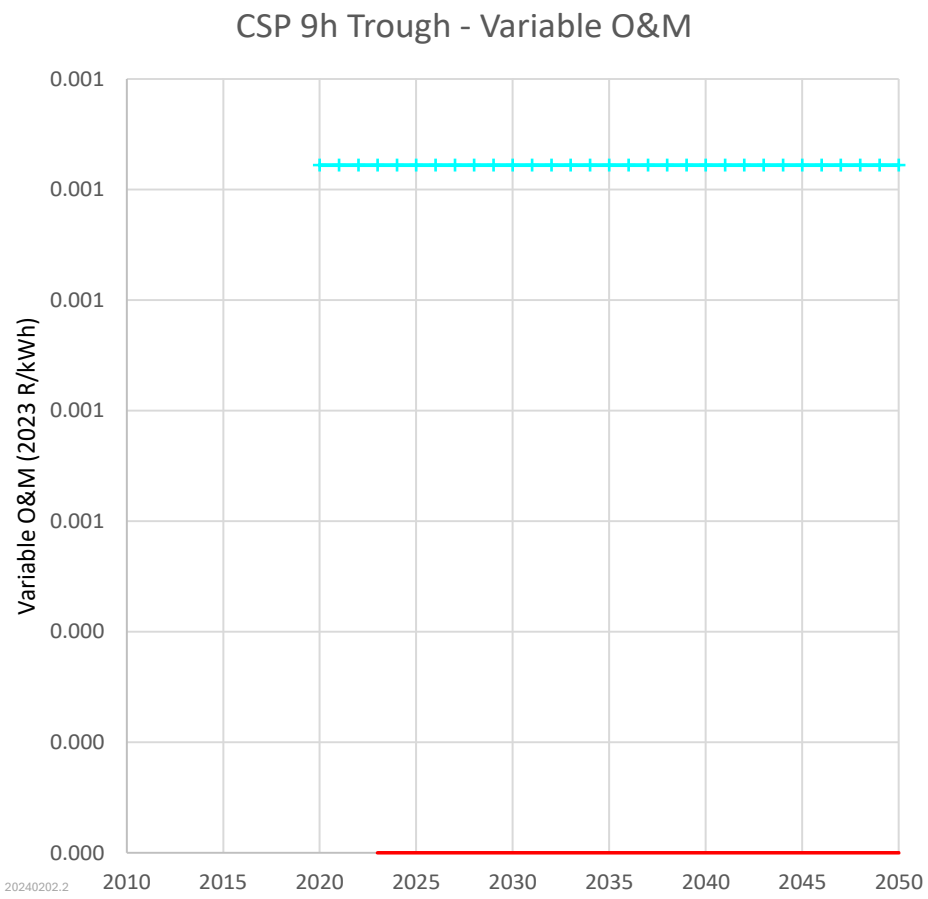


# CSP PARABOLIC TROUGH WITH 9HR OF THERMAL STORAGE

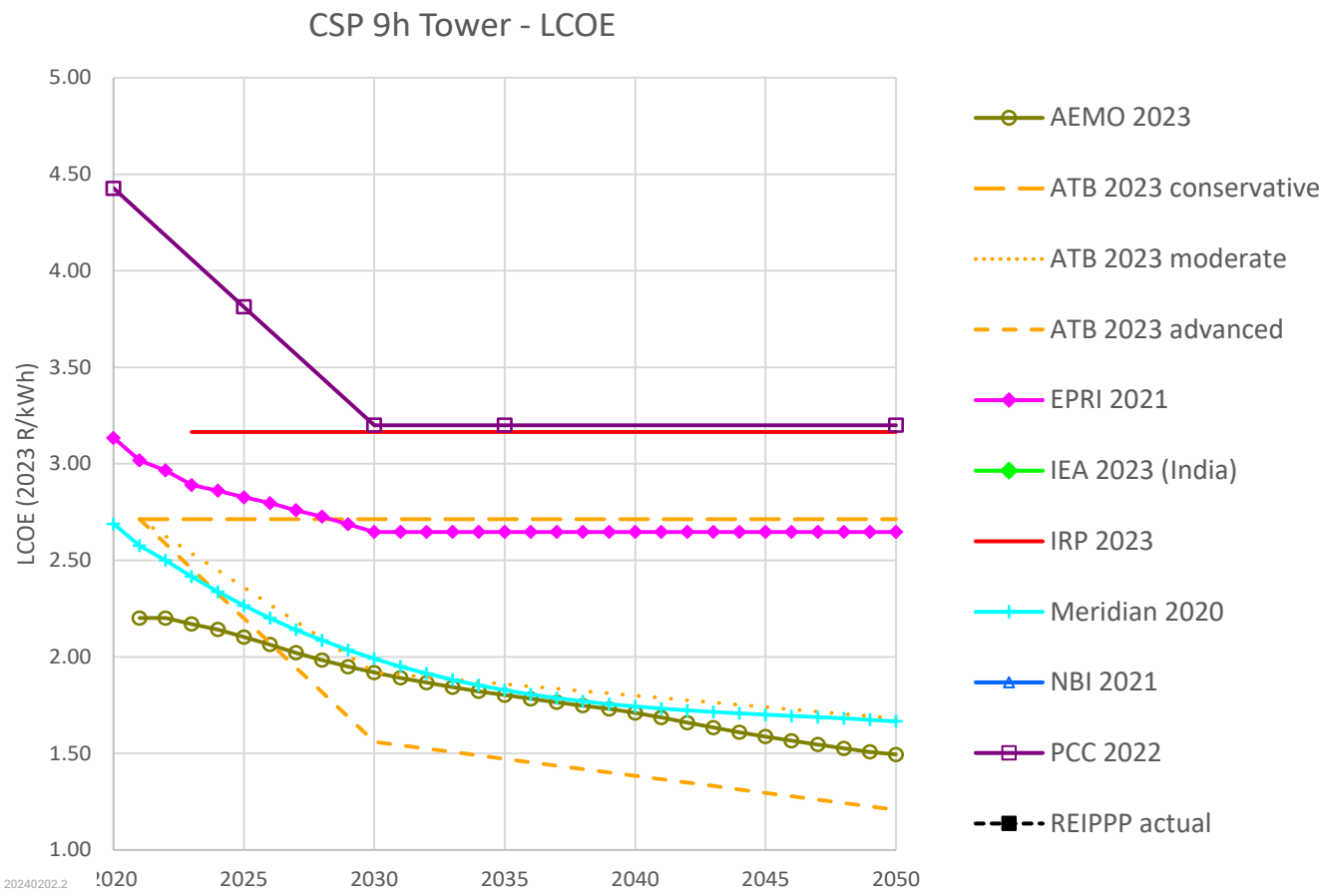
## FIXED O&M AND VARIABLE O&M

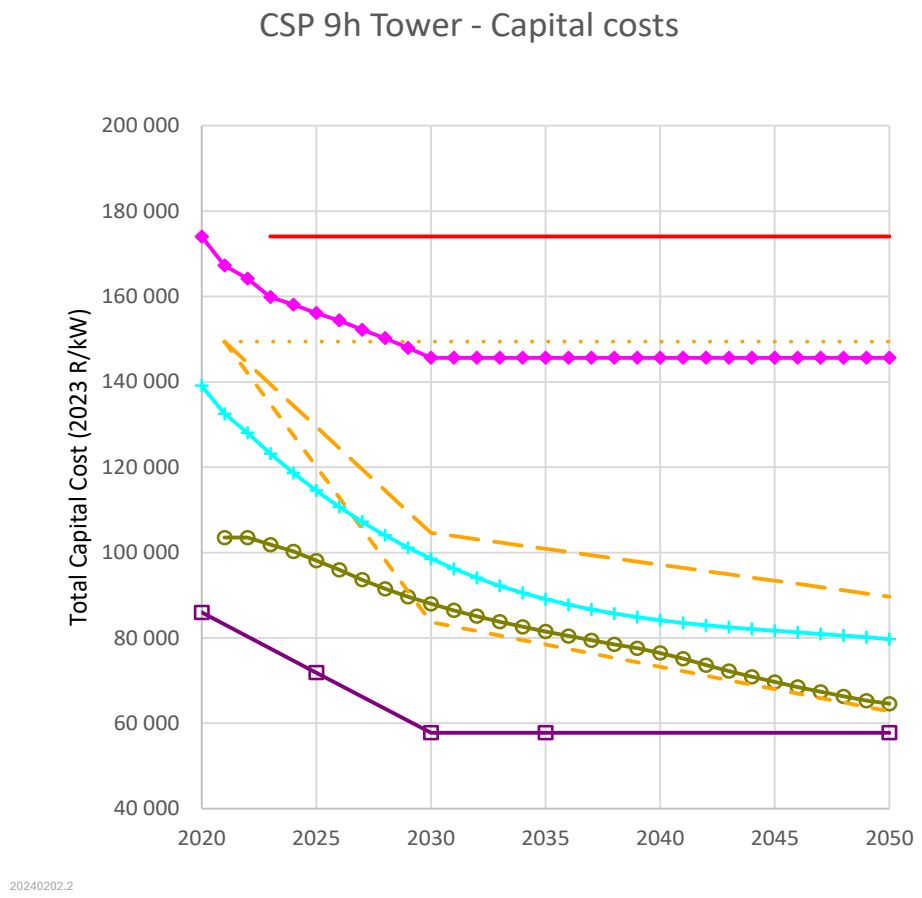


# CSP CENTRAL RECEIVER WITH 9HR OF THERMAL STORAGE

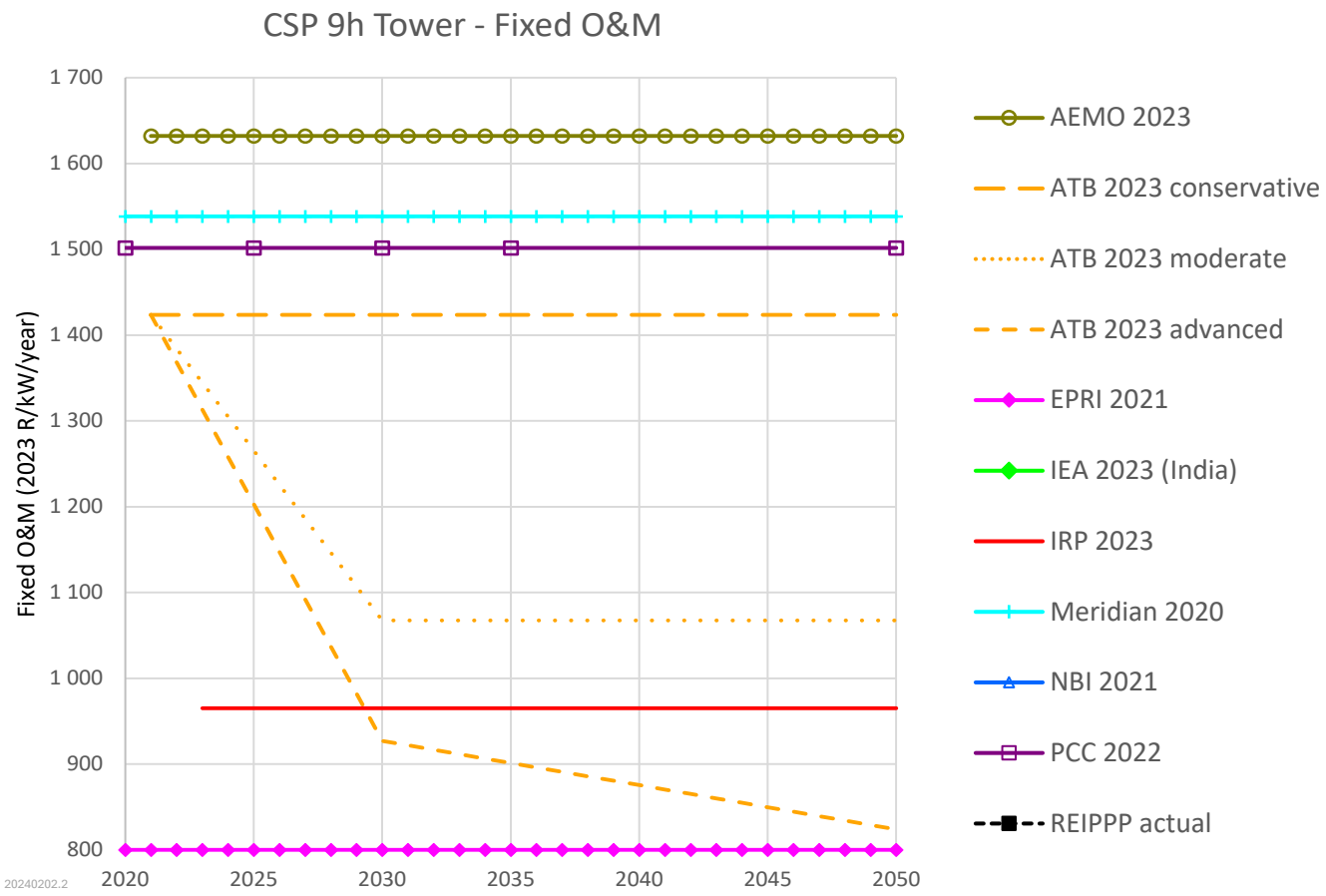
## LCOE AND CAPITAL COST

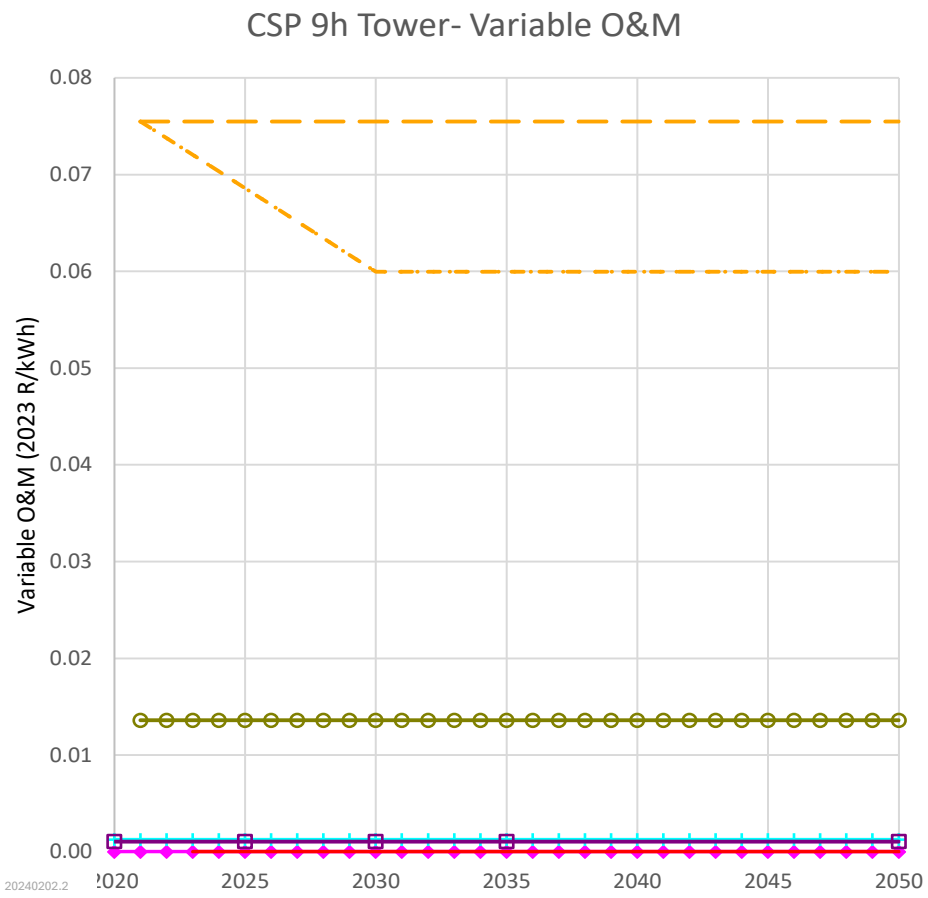


# CSP CENTRAL RECEIVER WITH 9HR OF THERMAL STORAGE

## FIXED O&M AND VARIABLE O&M



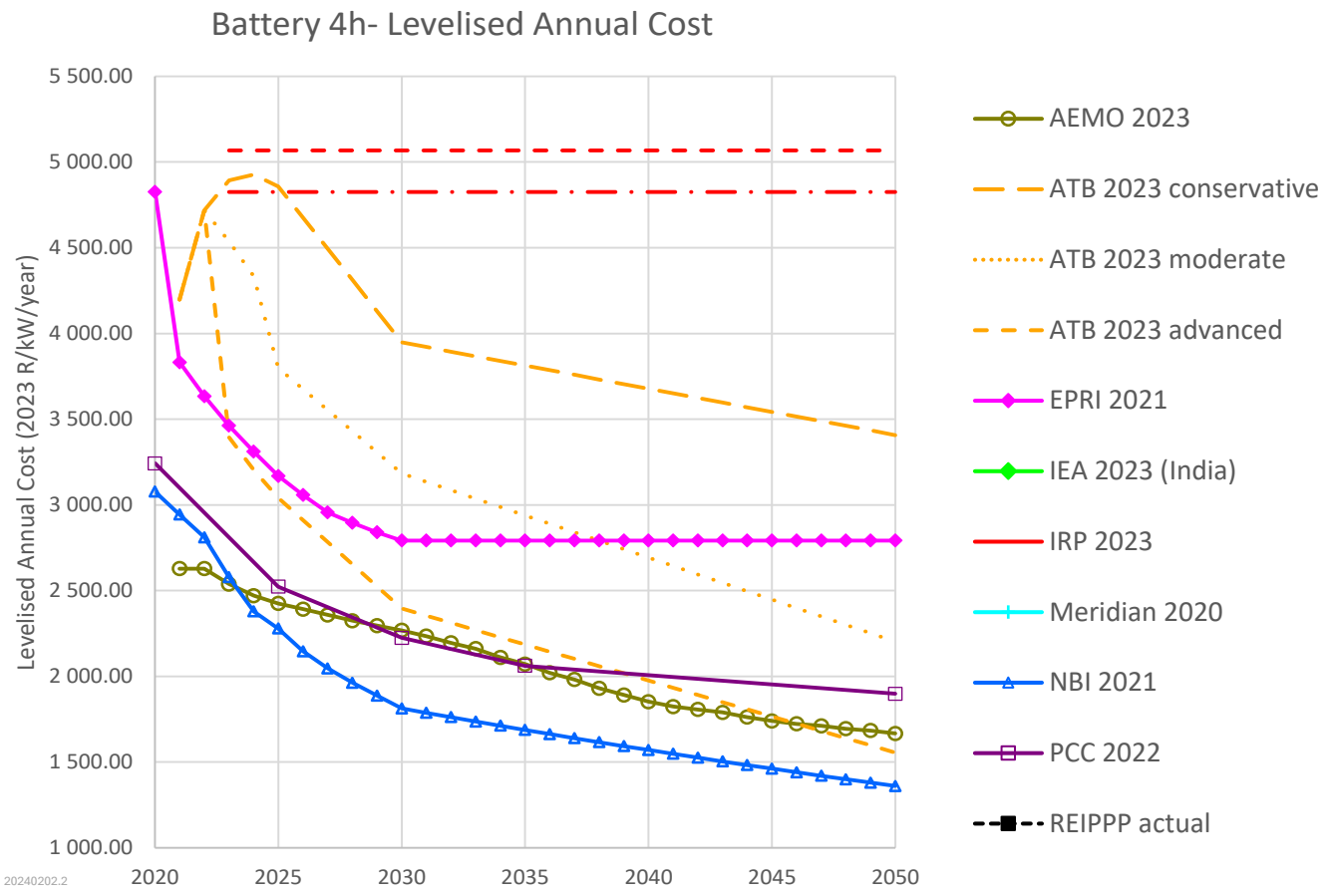
# BATTERY STORAGE

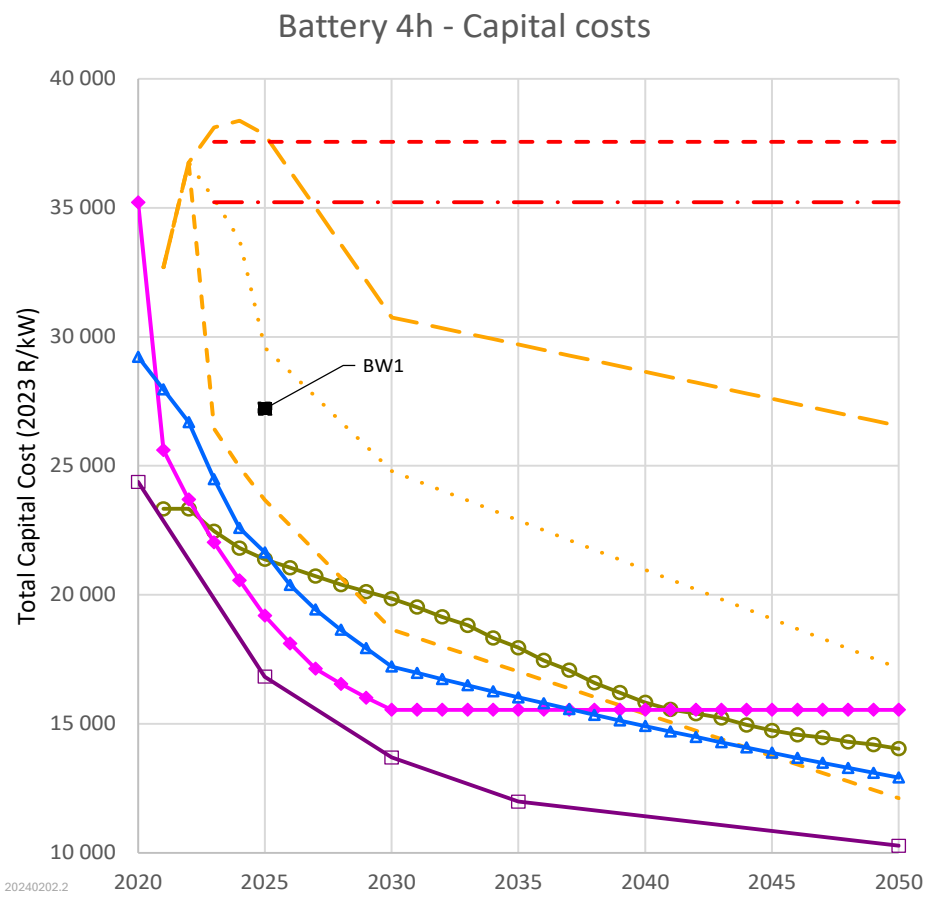
- IRP 2023 input assumptions spreadsheet has 2 battery storage options provided for each of 1h and 4h capacities.
- The IPPO states that the total project cost for the successful bidders in the first round of the BESIPPPP was R10.09bn for 360MW of capacity of 4h batteries. Assuming this refers to capital costs this equates to R28,028/kW for a 4h battery.
- The overnight CAPEX assumption in the IRP for a 4h battery ranges between R35,216-37,557/kW which is notably higher than the BESIPPPP result.
- Fixed O&M from IRP 2023 is significantly higher than all other data sources. Especially so if not considering ATB 2023 data specific to USA.
- All sources indicate a strong predicted reduction in costs for battery energy storage, including the EPRI report.
  - IRP 2023 assumption of no learning results in unreasonably high cost of batteries maintained across the simulation horizon.

It appears Li-ion is used as a proxy for all battery storage technologies in the IRP model. Alternative technologies such as flow batteries can be included in our modelling if stakeholders are able to provide reasonable cost and performance data.

# BATTERY STORAGE WITH 4 HOUR CAPACITY

## LEVELISED ANNUAL COST AND CAPITAL COST

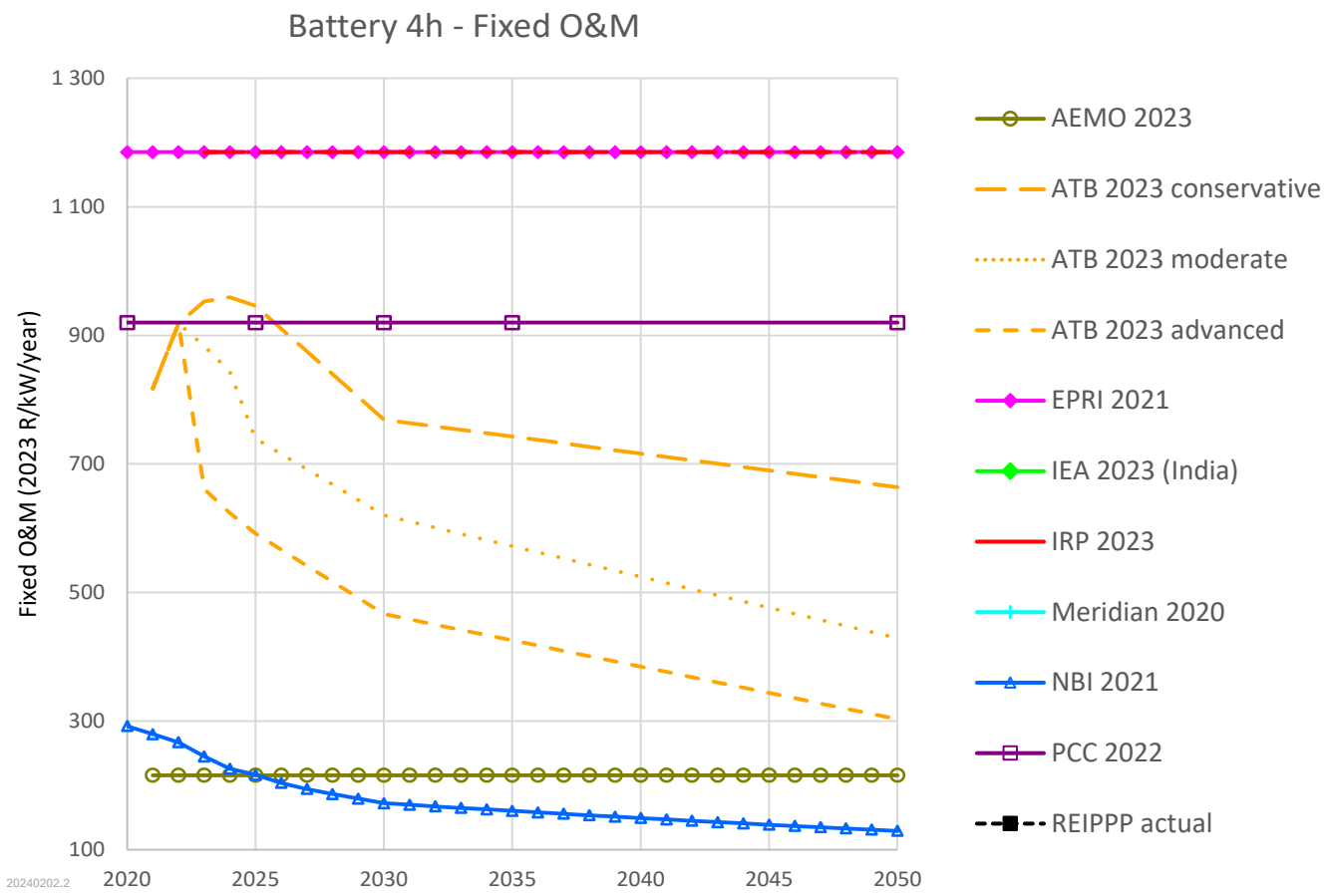



Refer to Excel spreadsheet for more information on datasets with multiple technology options.

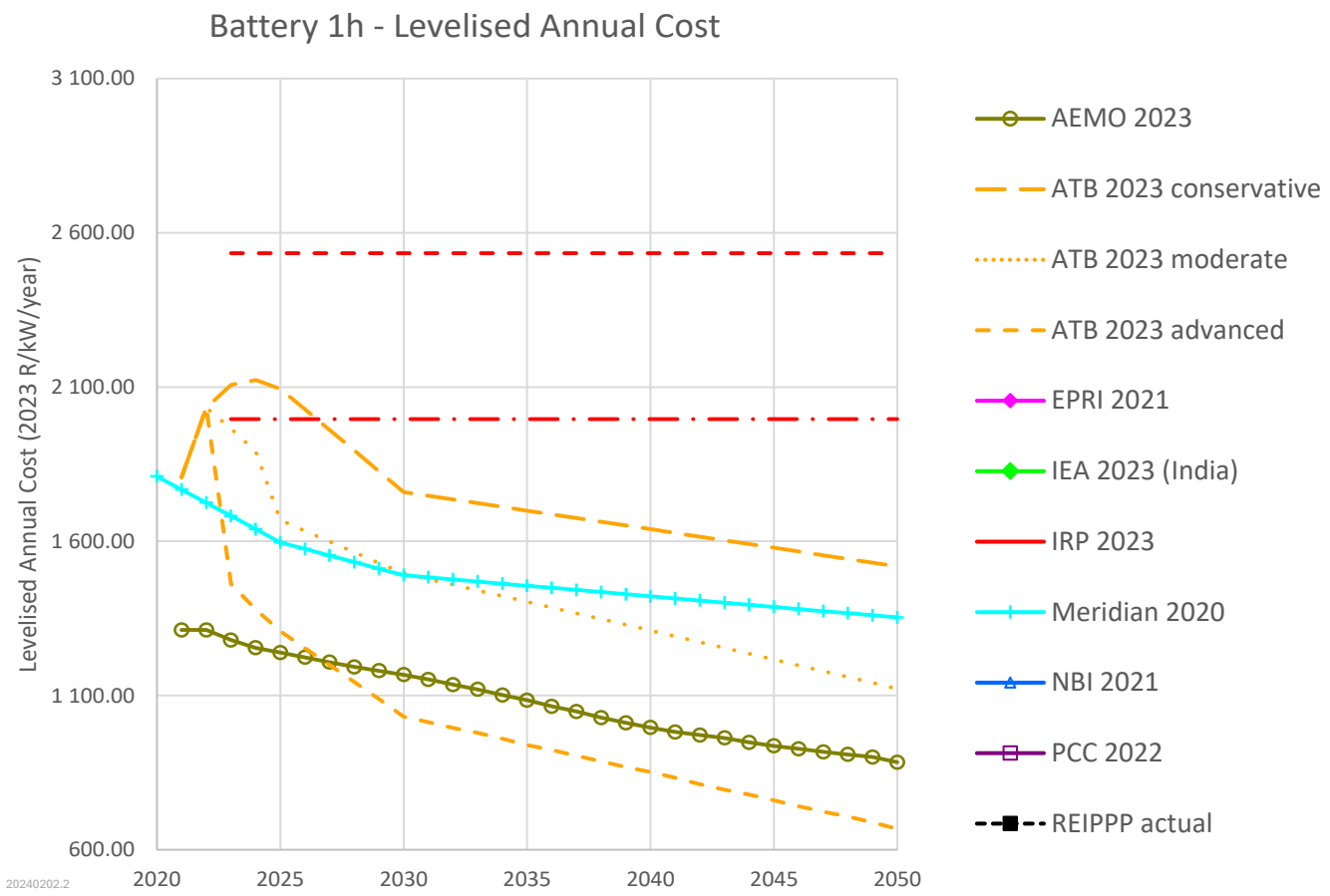
# BATTERY STORAGE WITH 4 HOUR CAPACITY

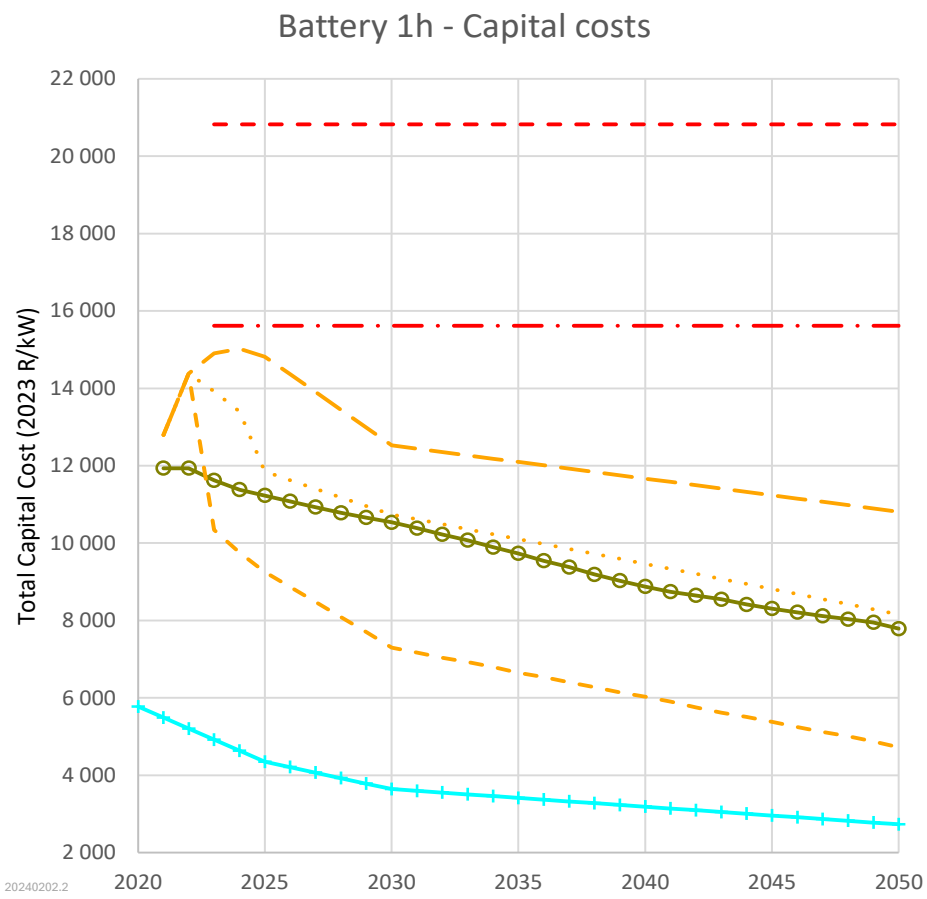
## FIXED O&M



# BATTERY STORAGE WITH 1 HOUR CAPACITY

## LEVELISED ANNUAL COST AND CAPITAL COST

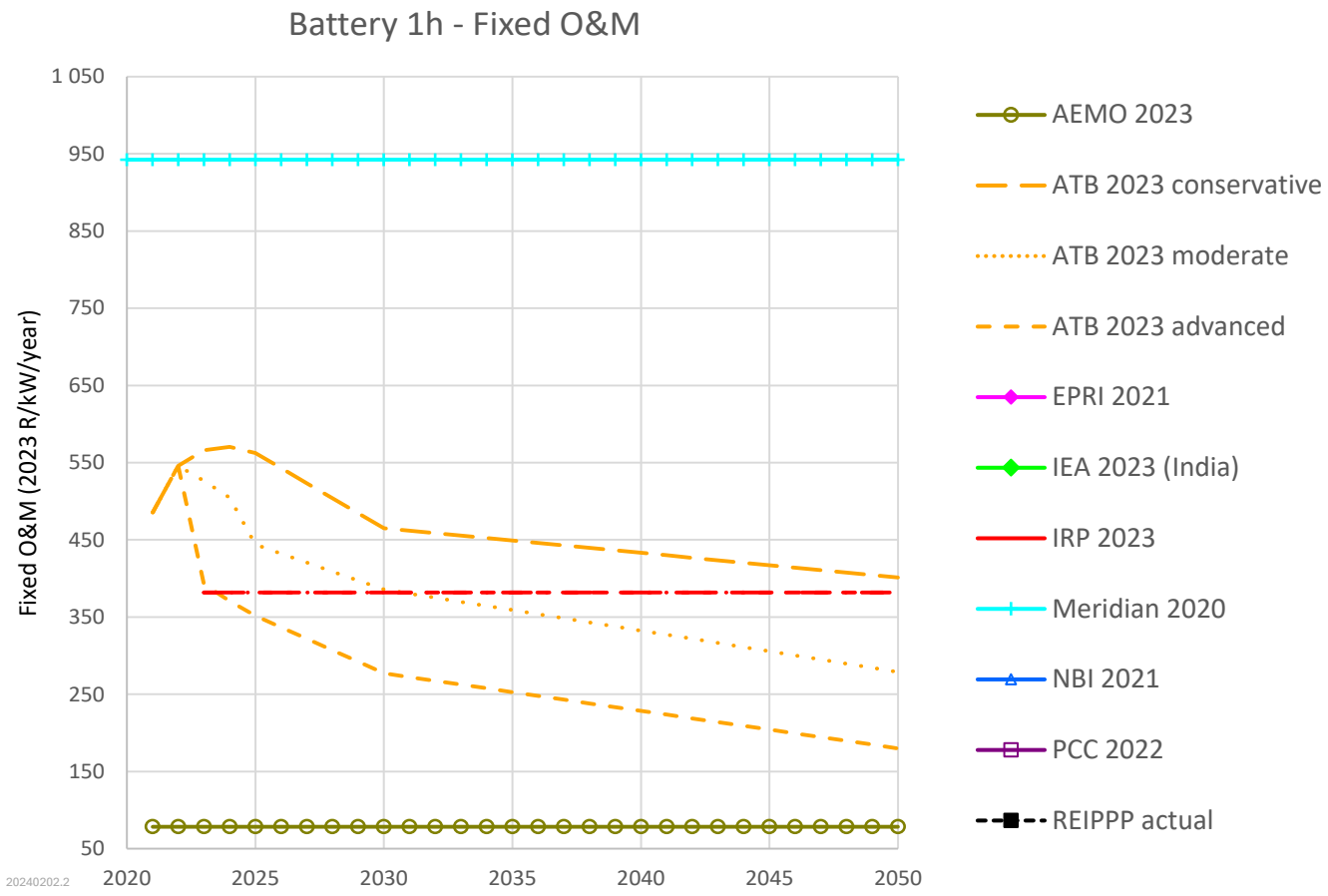



Refer to Excel spreadsheet for more information on datasets with multiple technology options.

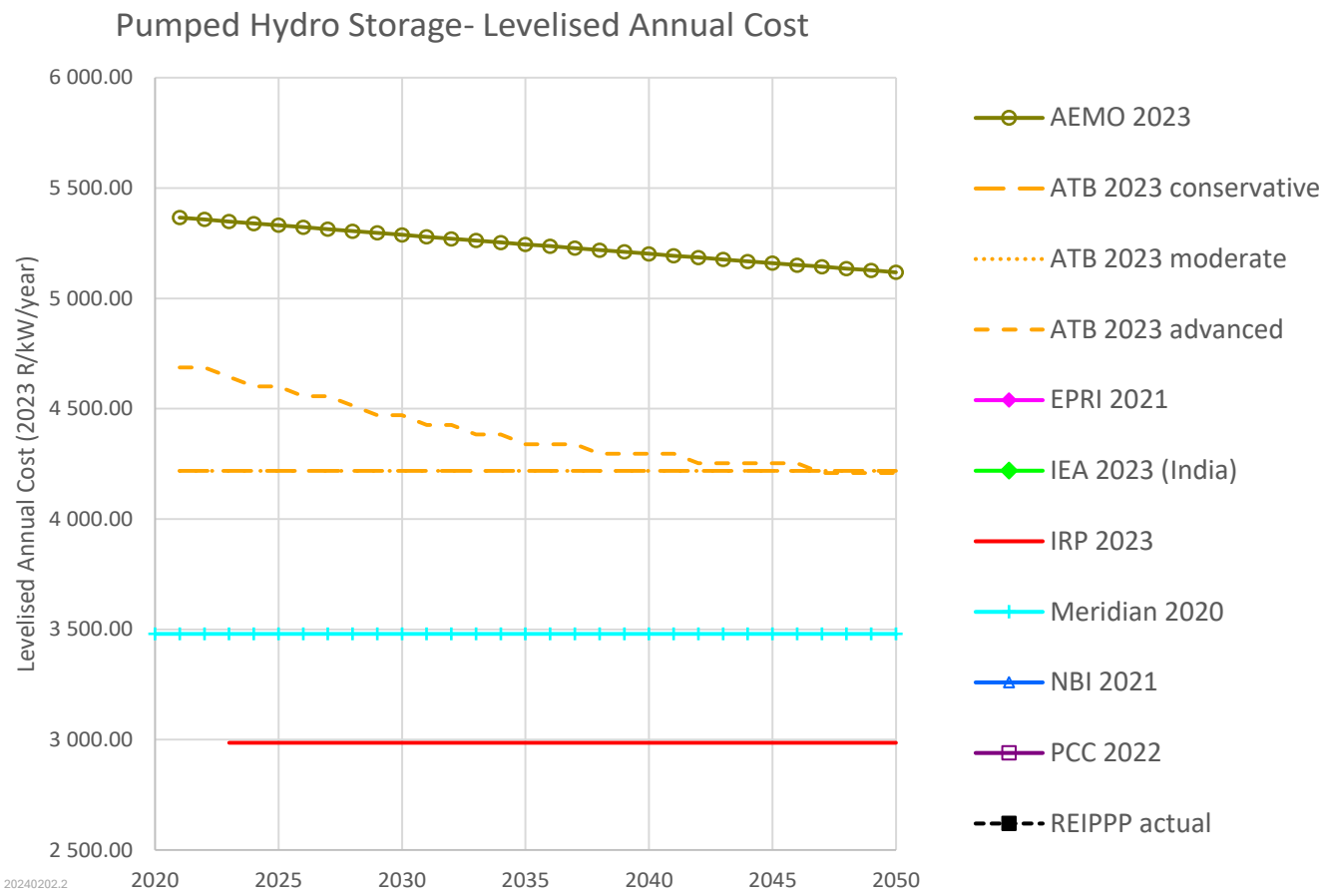
# BATTERY STORAGE WITH 1 HOUR CAPACITY

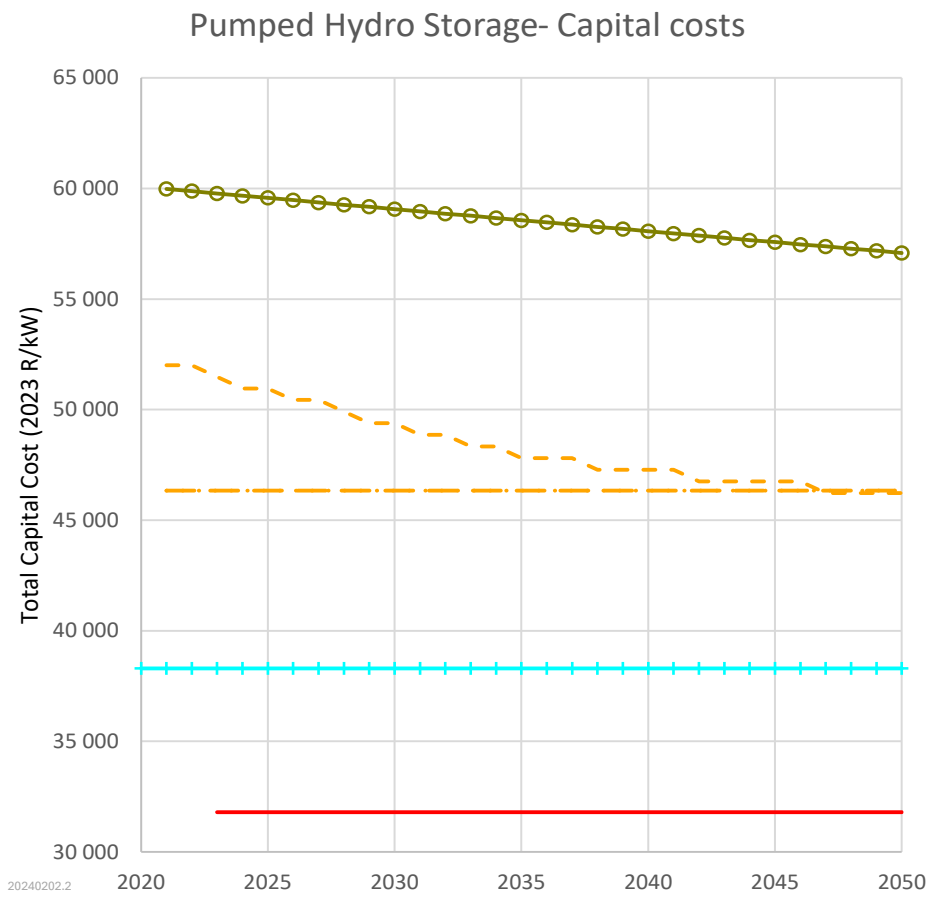
## FIXED O&M



# PUMPED HYDRO STORAGE

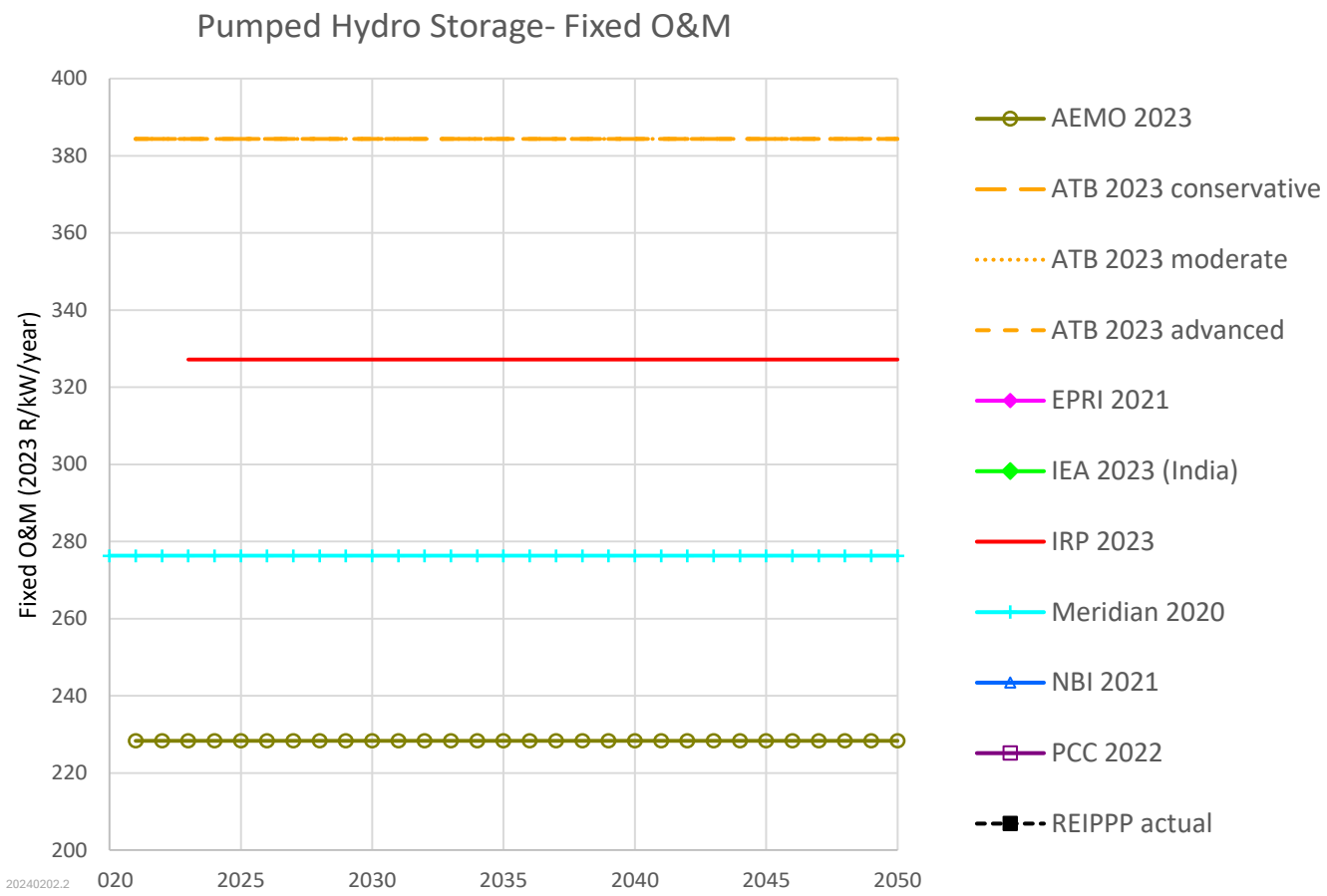
## LEVELISED ANNUAL COST AND CAPITAL COST

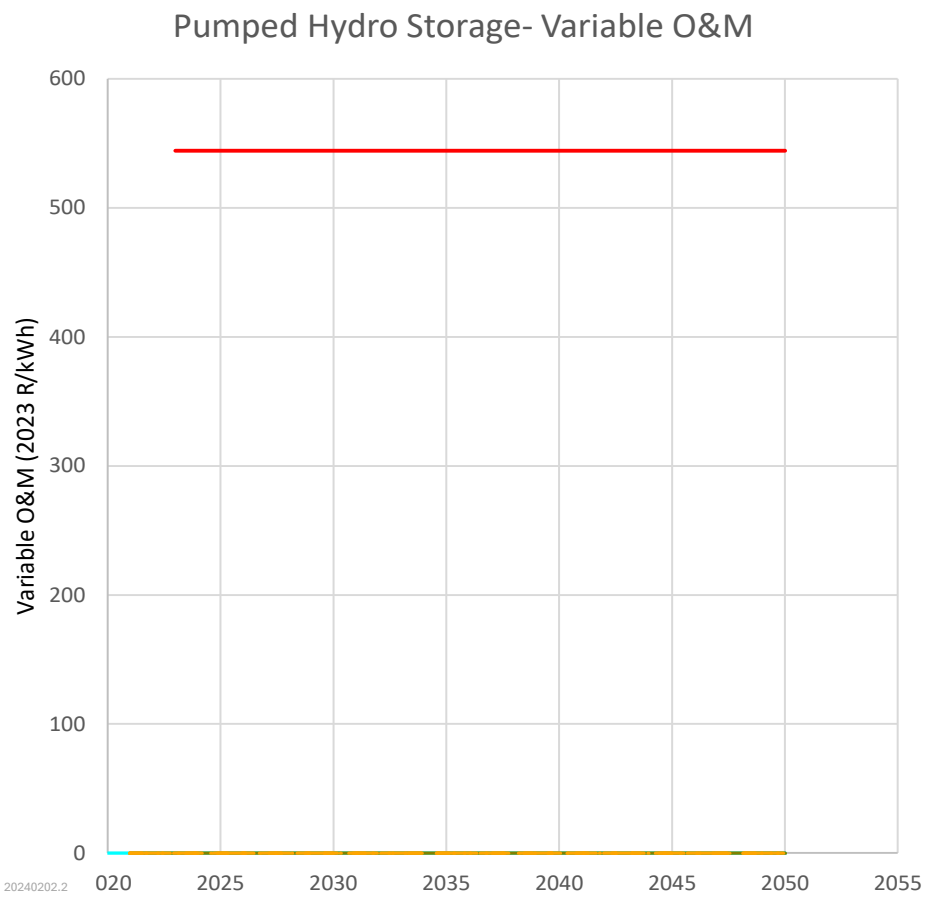


# PUMPED HYDRO STORAGE

## FIXED O&M AND VARIABLE O&M



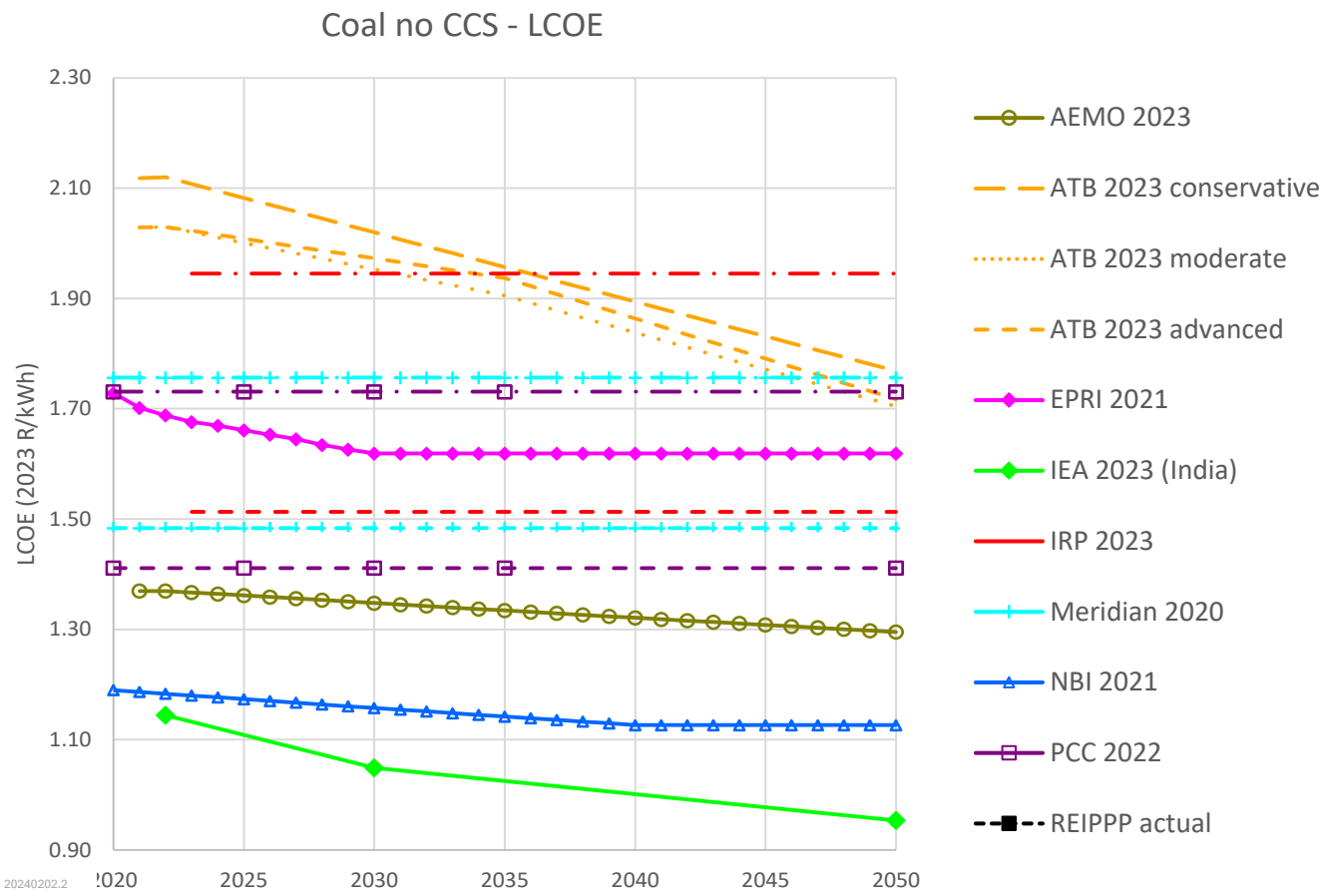
# COAL

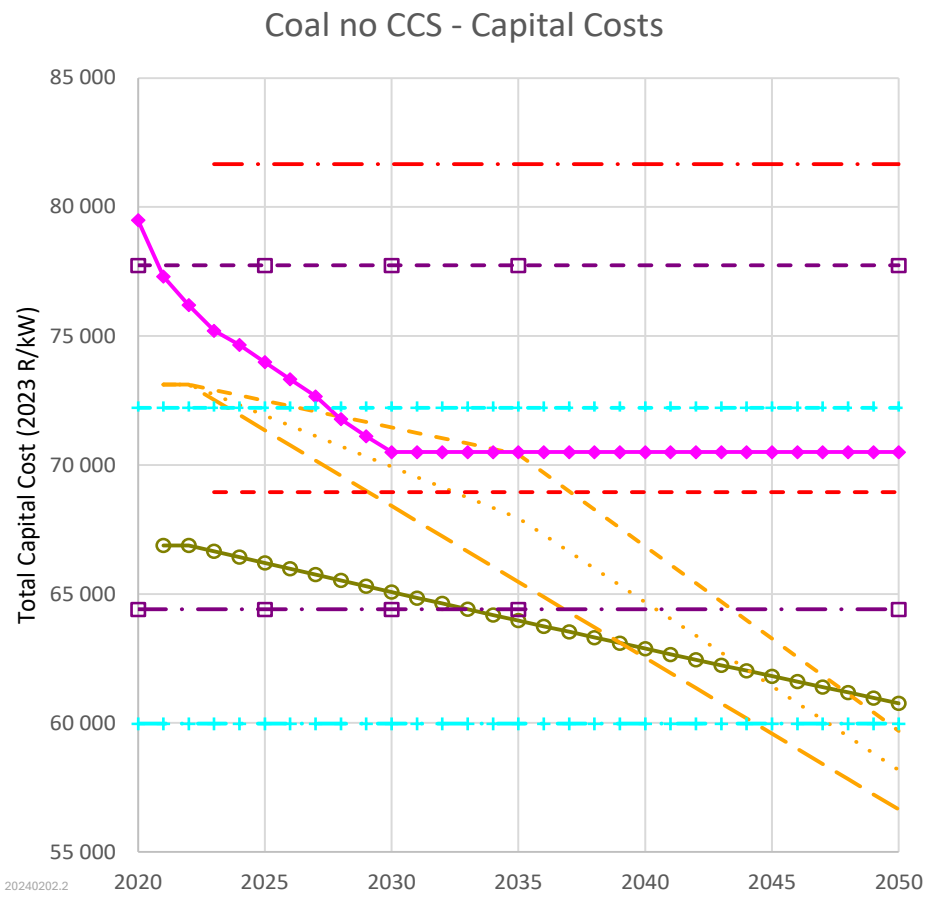
- IRP 2023 provides cost estimates for 2 types of coal plants. As all options are provided to the model, with similar operating characteristics, the unit with the lowest LCOE becomes the default reference.
- There are a wide range of assumptions on capital costs and Fixed O&M for a new build coal plant based on either Pulverised Coal (PC), or Fluidised Bed Combustion (FBC) technology, without Carbon Capture and Storage (CCS).
- For all dispatchable generators, our LCOE calculations assume a common fuel cost and capacity factor that is based on IRP 2023 and EPRI 2021.
- The LCOE across the various data sources ranges between R1.1-2.1/kWh, with the lower bound from the IRP 2023 placed in the middle of the range at R1.5/kWh.
- No operating parameter assumptions are given in the IRP input assumption spreadsheet (heat rates, ramp rates, min stable level, min annual capacity factor, etc). We assume the values from the EPRI report are applicable per technology option.
- It does not appear that coal + CCS was considered in the model optimisation.

The coal price assumption is R45/GJ – stakeholder comment would be useful regarding the level, and possible adjustments that could be made across the different existing Eskom coal fired power stations.

# COAL (BOTH PC AND FBC) WITHOUT CCS

## LCOE AND CAPITAL COST

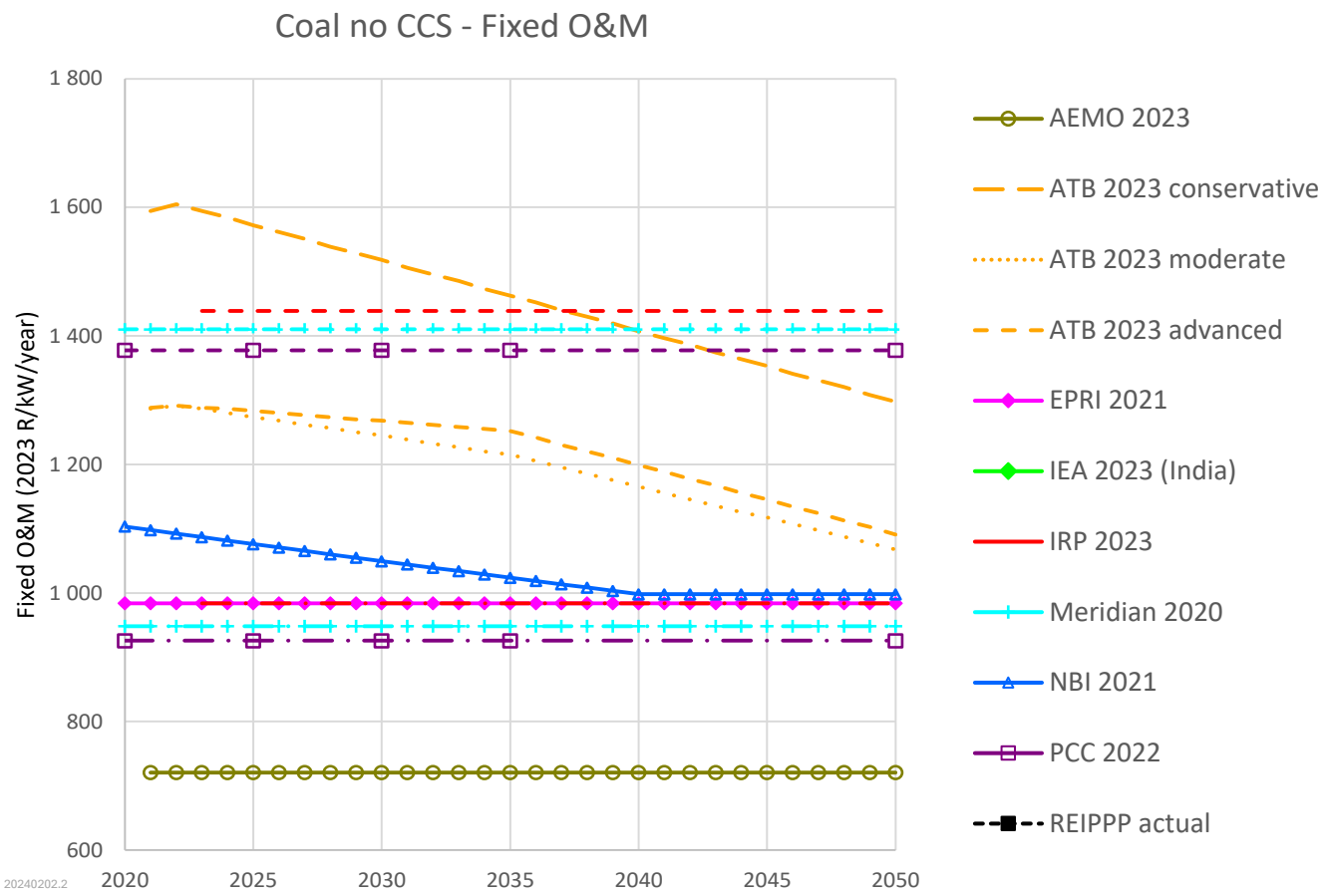


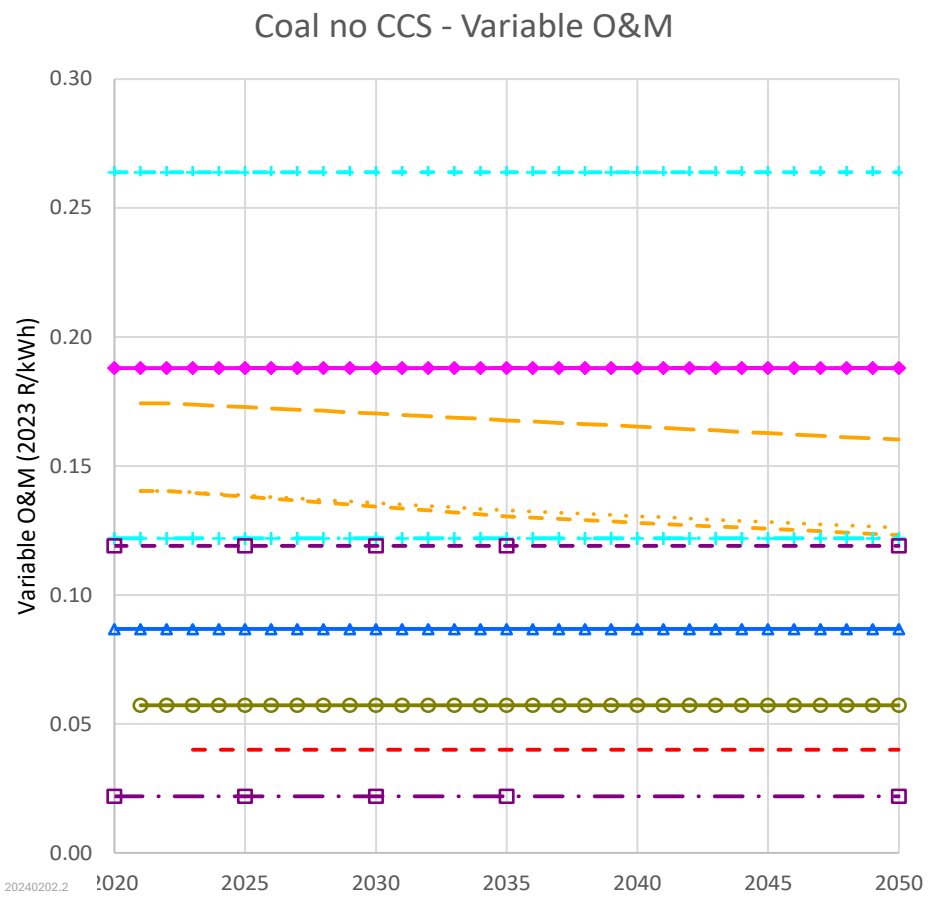




Duplicate lines for Meridian 2020 and PCC 2022 are due to multiple technology options in the datasets (PC and FBC).
Refer to Excel spreadsheet for more information on datasets with multiple technology options.

# COAL (BOTH PC AND FBC) WITHOUT CCS

## FIXED O&M AND VARIABLE O&M






Duplicate lines for Meridian 2020 and PCC 2022 are due to multiple technology options in the datasets (PC and FBC).
Refer to Excel spreadsheet for more information on datasets with multiple technology options.

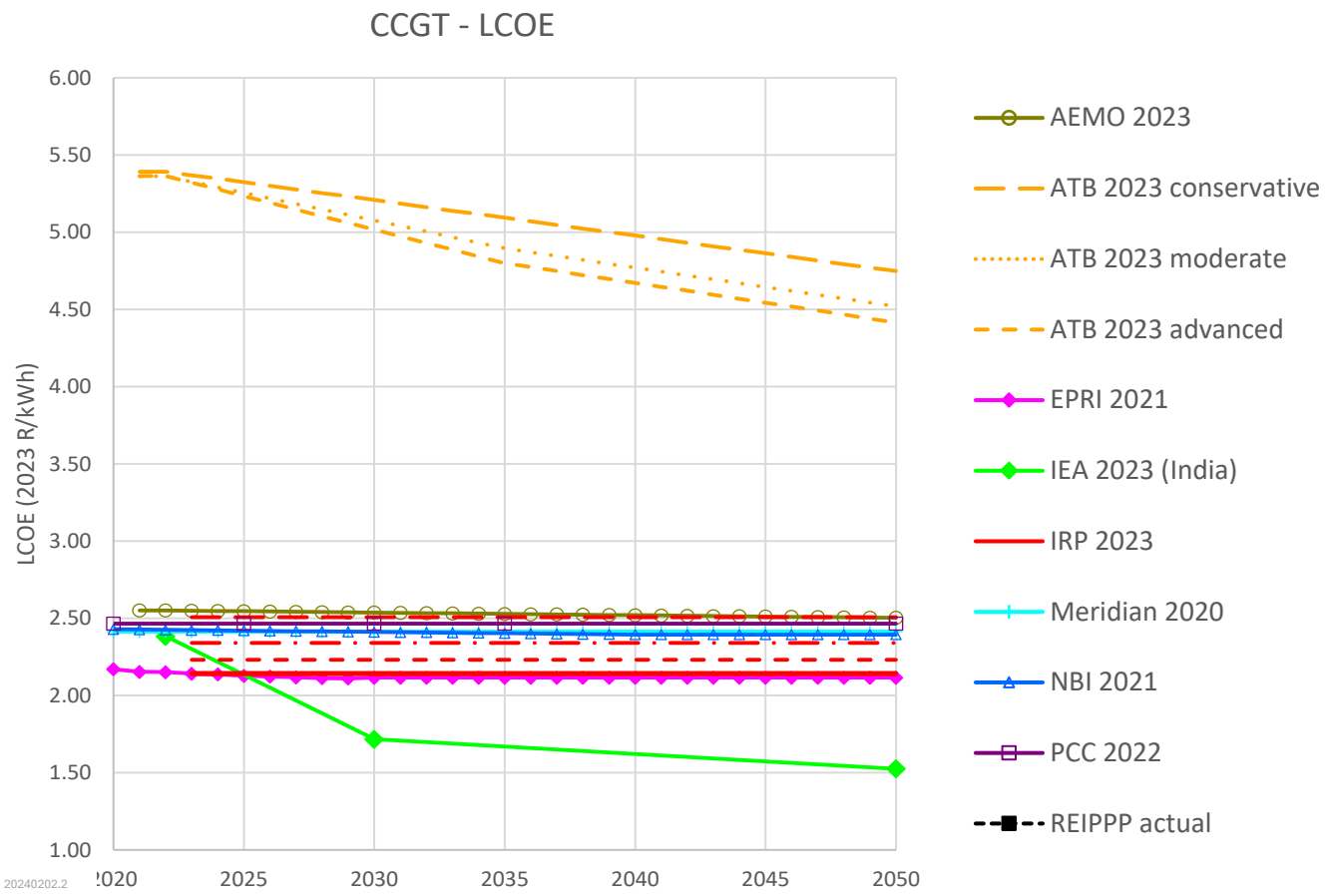
# COMBINED CYCLE GAS TURBINES

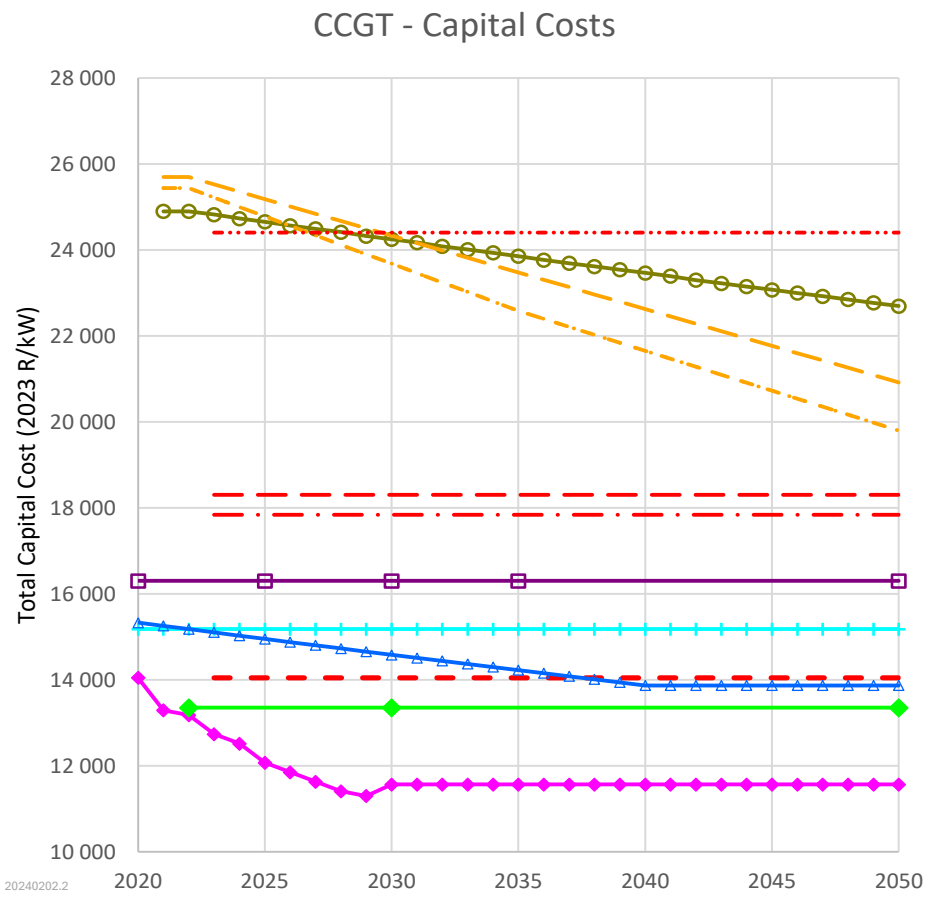
- IRP 2023 provides cost estimates for 4 types of CCGT plants and 1 ICE combined cycle. As all options are provided to the model, with similar operating characteristics, the unit with the lowest LCOE becomes the default reference.
- There are a wide range of assumptions on capital costs on the CCGT plants ranging between R12,000-25,000/kW, with the EPRI assumption on the lower bound, and the NREL and AEMO assumptions on the upper bound.
- In terms of Fixed O&M the NREL data is significantly higher than other datasets, leading to an estimated LCOE above R4.5/kWh. It is not clear if additional upstream costs are included in the NREL data (possible double counting if already included in gas price).
- For the common fuel price assumption of R272/GJ and capacity factor of 50%, the LCOE across the various data sources ranges between R2.1-2.6/kWh, with the IRP 2023 and EPRI 2021 values for CCGT plants on the lower bound of the dataset ranges. However, the following issues are not considered, which makes the LCOE subject to future uncertainty vs other options:
  - Price volatility associated with gas is not considered in the IRP model, which is a key risk.
  - The gas price vs offtake volume is not considered. The gas price is driven by both fixed costs for infrastructure and variable fuel costs. By modelling as a single variable cost the optimisation does not consider any sunk costs associated with fuel supplies if volumes are decreased.
- No operating parameter assumptions are given in the IRP input assumption spreadsheet (heat rates, ramp rates, min stable level, min annual capacity factor, etc). We assume the values from the EPRI report are applicable per technology option.

The gas price assumption is R272/GJ – stakeholder comment would be useful regarding gas source, contract term, offtake location(s), offtake volume that would support this assumption or any better assumptions basis.

# COMBINED CYCLE GAS TURBINE

## LCOE AND CAPITAL COST

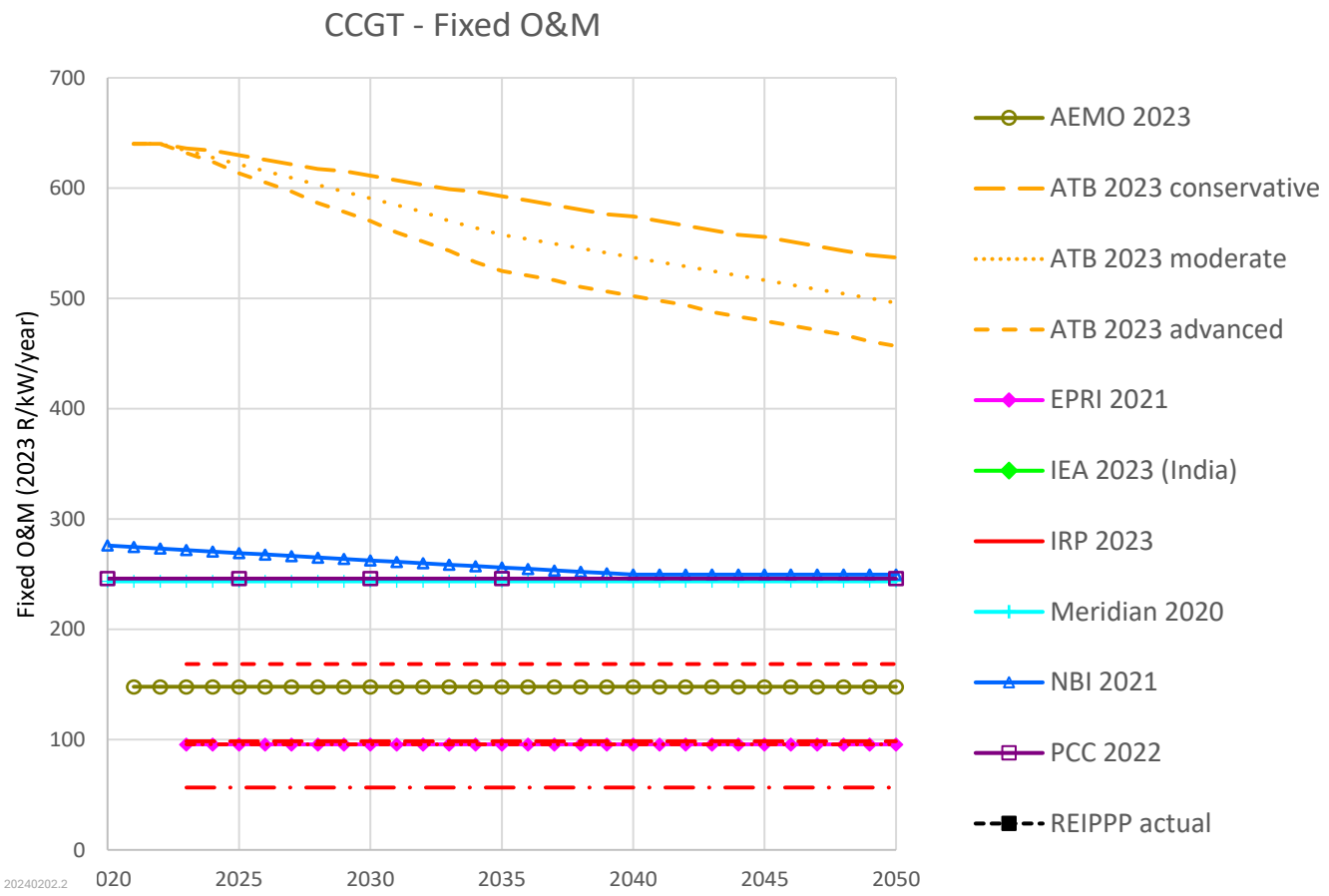


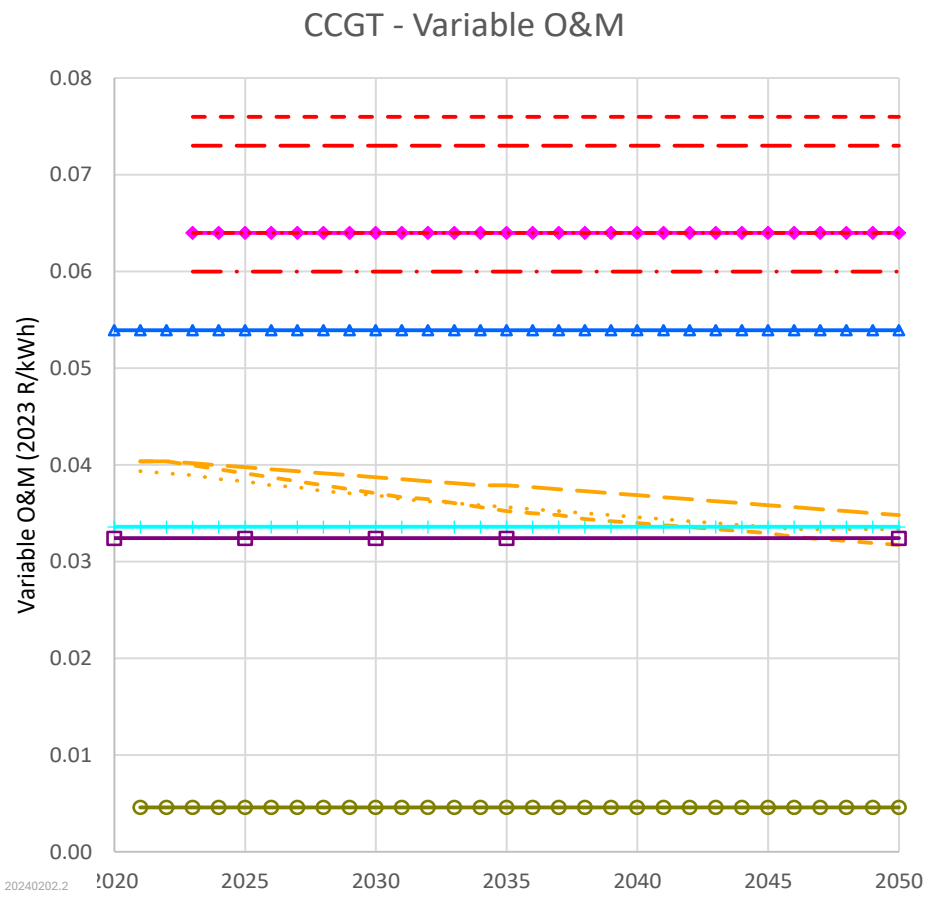




Refer to Excel spreadsheet for more information on datasets with multiple technology options.

# COMBINED CYCLE - GAS TURBINE

## FIXED O&M AND VARIABLE O&M




Refer to Excel spreadsheet for more information on datasets with multiple technology options.

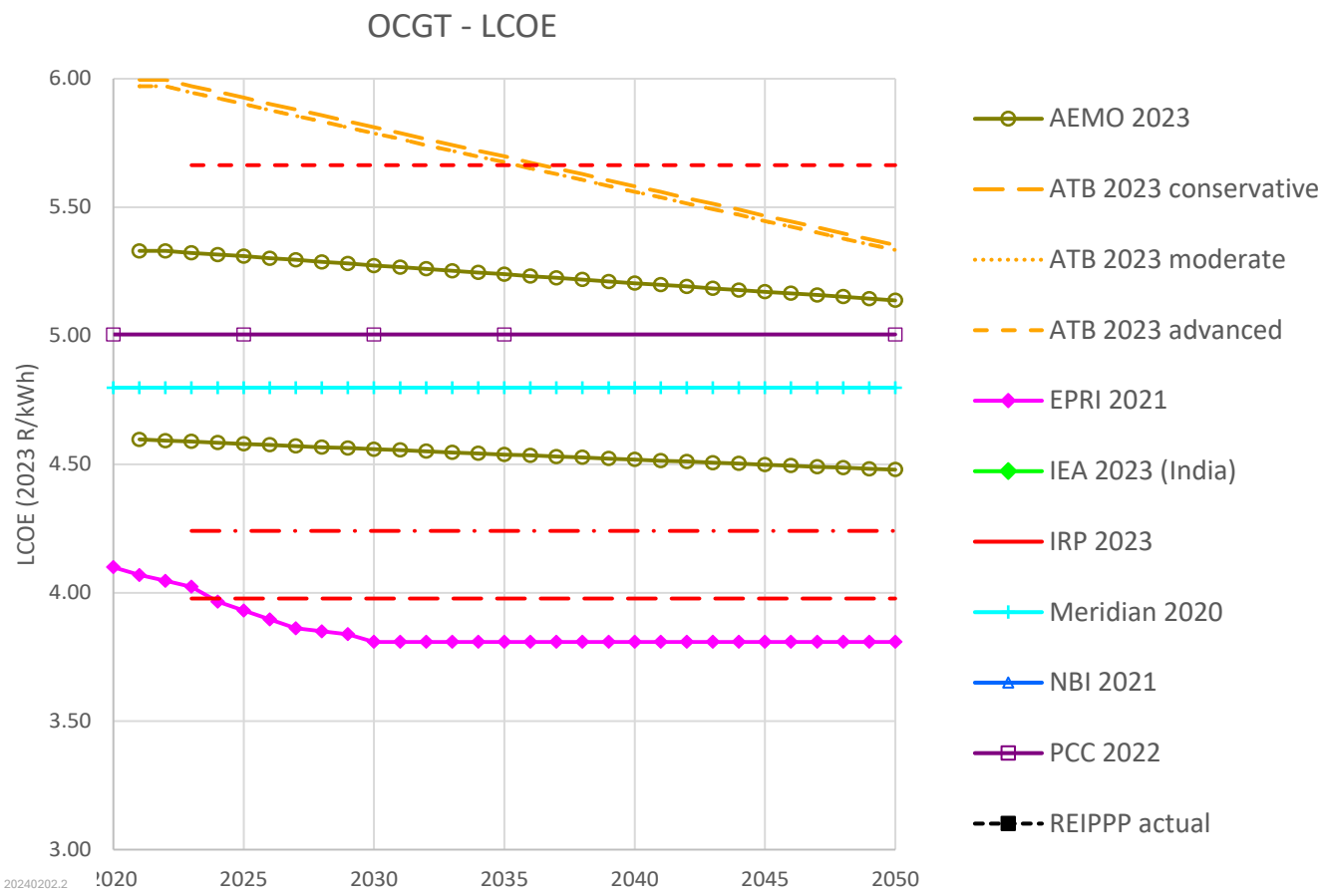
# PEAKING PLANTS – OCGT AND ICE

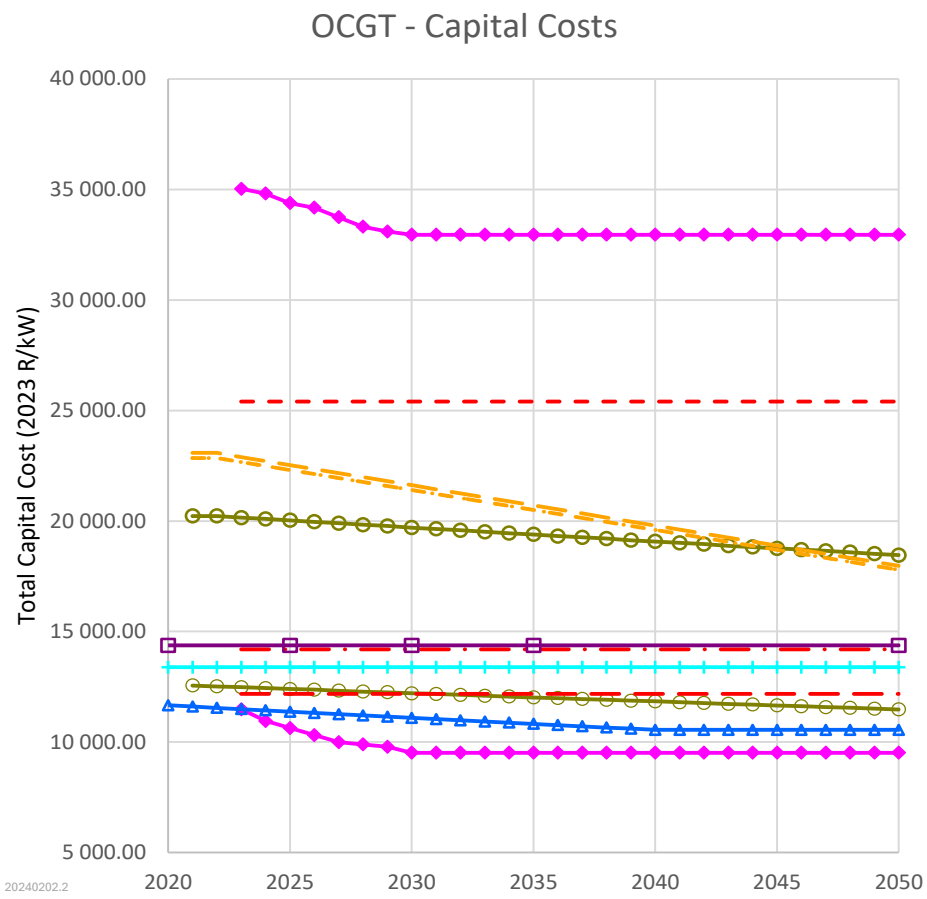
- Peaking plants are typically designed for usage at capacity factors below 10%. Given the lower capacity factor the LCOE of the plants are significantly higher. From a system perspective the Total Capital Cost of peaking generation is a more useful metric for comparison.
  - There appears to be agreement of the Total Capital Cost of large non-aeroderivative turbines in the range of R10,000-R15,000/kW, with smaller or aeroderivative turbines significantly more expensive.
  - The EPRI and IRP Total Capital Cost numbers for ICE exceed R55,000/kW and are significantly higher than other references. A recent study released by Wartsila (a leading ICE manufacturer) indicated capital costs in the order of $750/kW (R13,900/kW).
- No operating parameter assumptions are given in the IRP input assumption spreadsheet (heat rates, ramp rates, min stable level, min annual capacity factor, etc). We assume the values from the EPRI report are applicable per technology option.

It is assumed that peaking plants will be gas-fired, and at the same gas cost as mid-merit CCGT plants. Stakeholder comment regarding the feasibility/cost of using gas for peaking power would be valuable.

# OPEN CYCLE GAS TURBINE

## LCOE AND CAPITAL COST

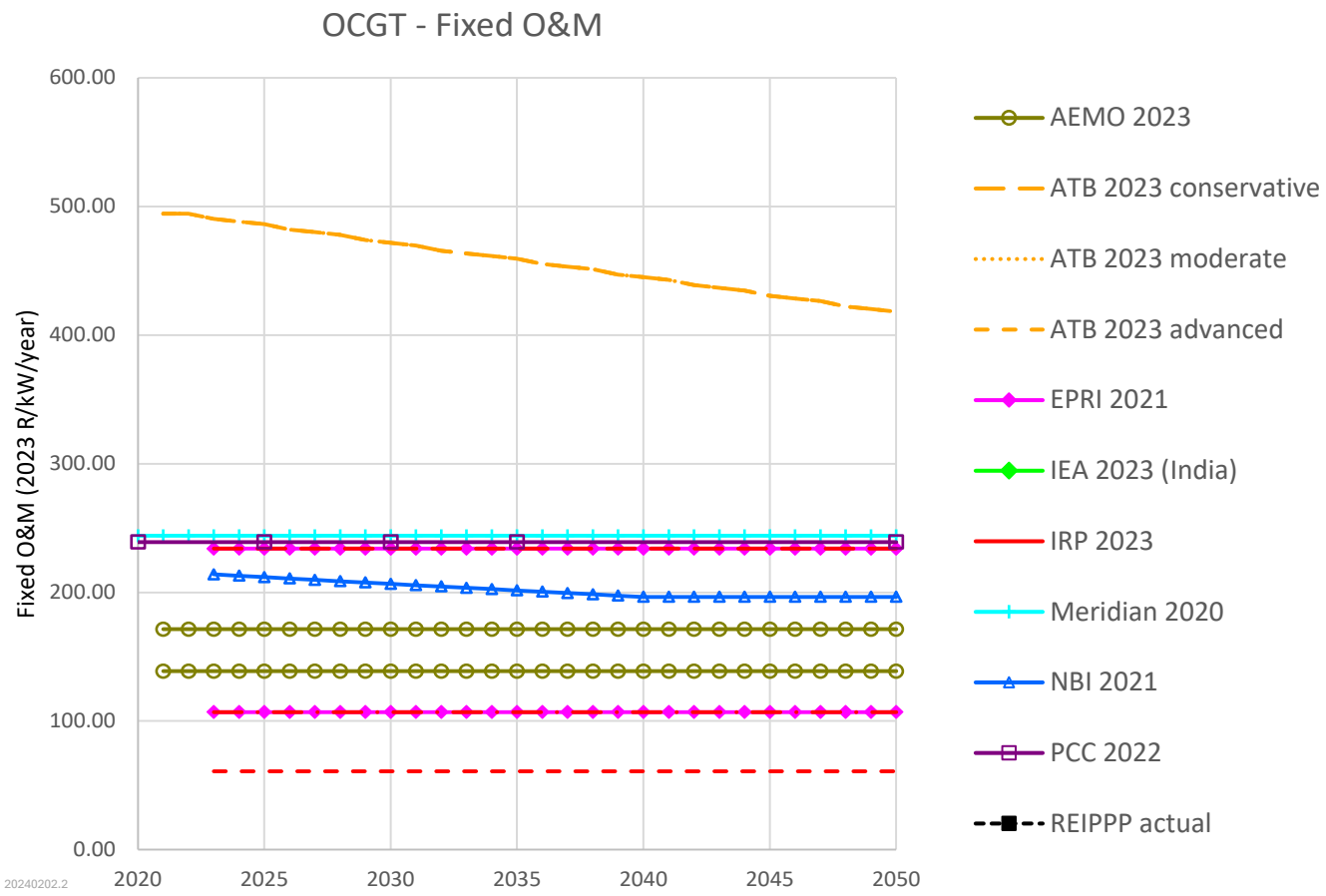


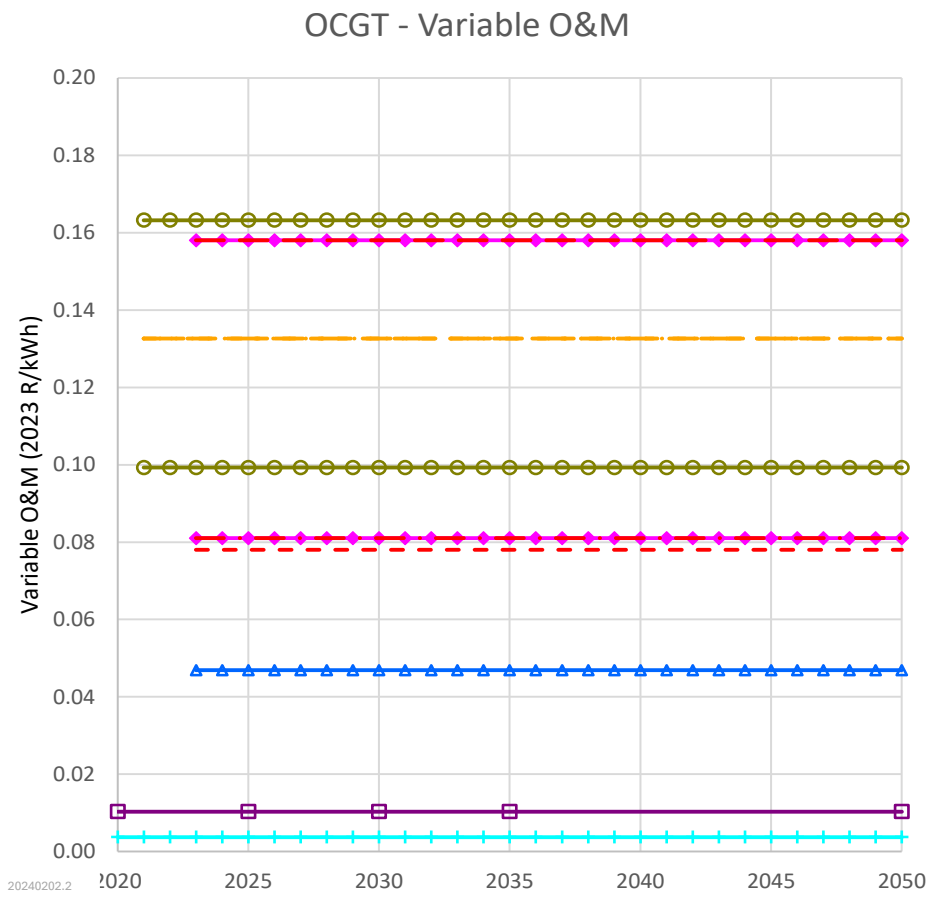




Refer to Excel spreadsheet for more information on datasets with multiple technology options.

# OPEN CYCLE GAS TURBINE

## FIXED O&M AND VARIABLE O&M

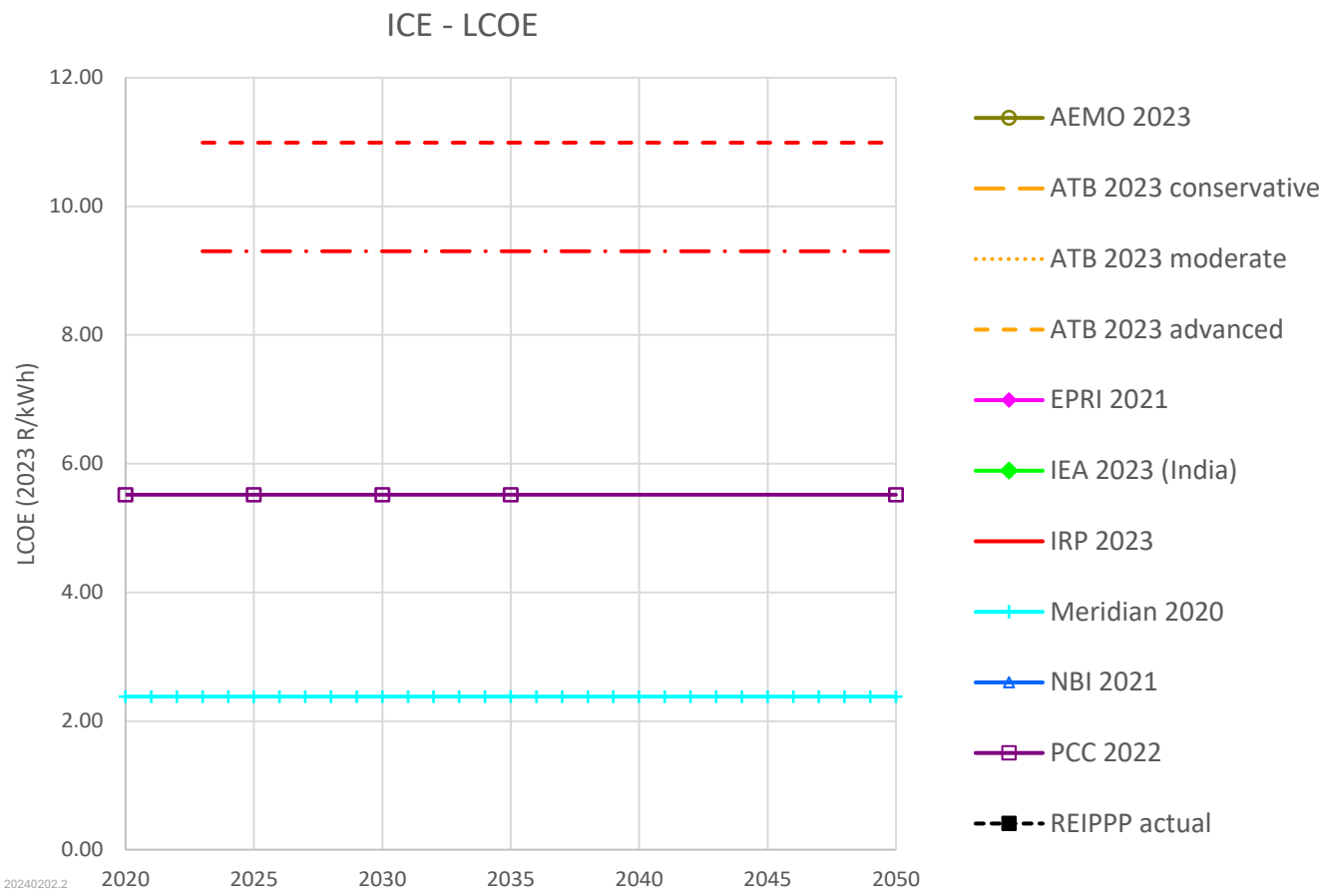


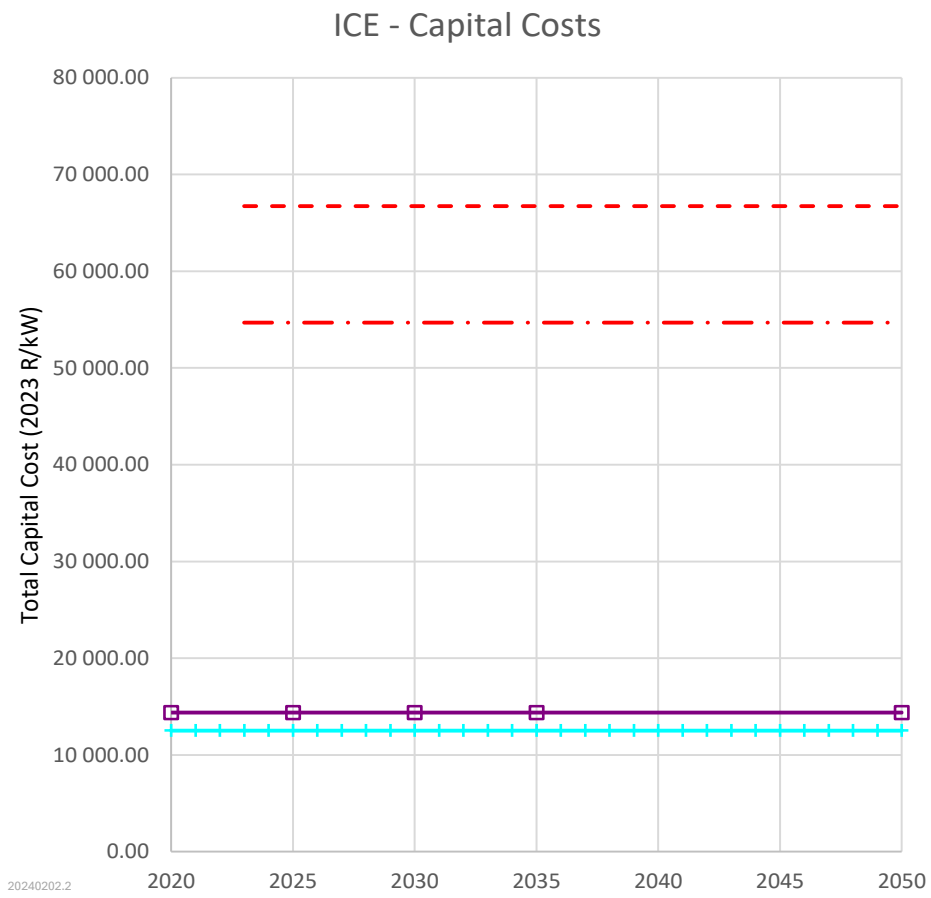




Refer to Excel spreadsheet for more information on datasets with multiple technology options.

# INTERNAL COMBUSTION ENGINE

## LCOE AND CAPITAL COST

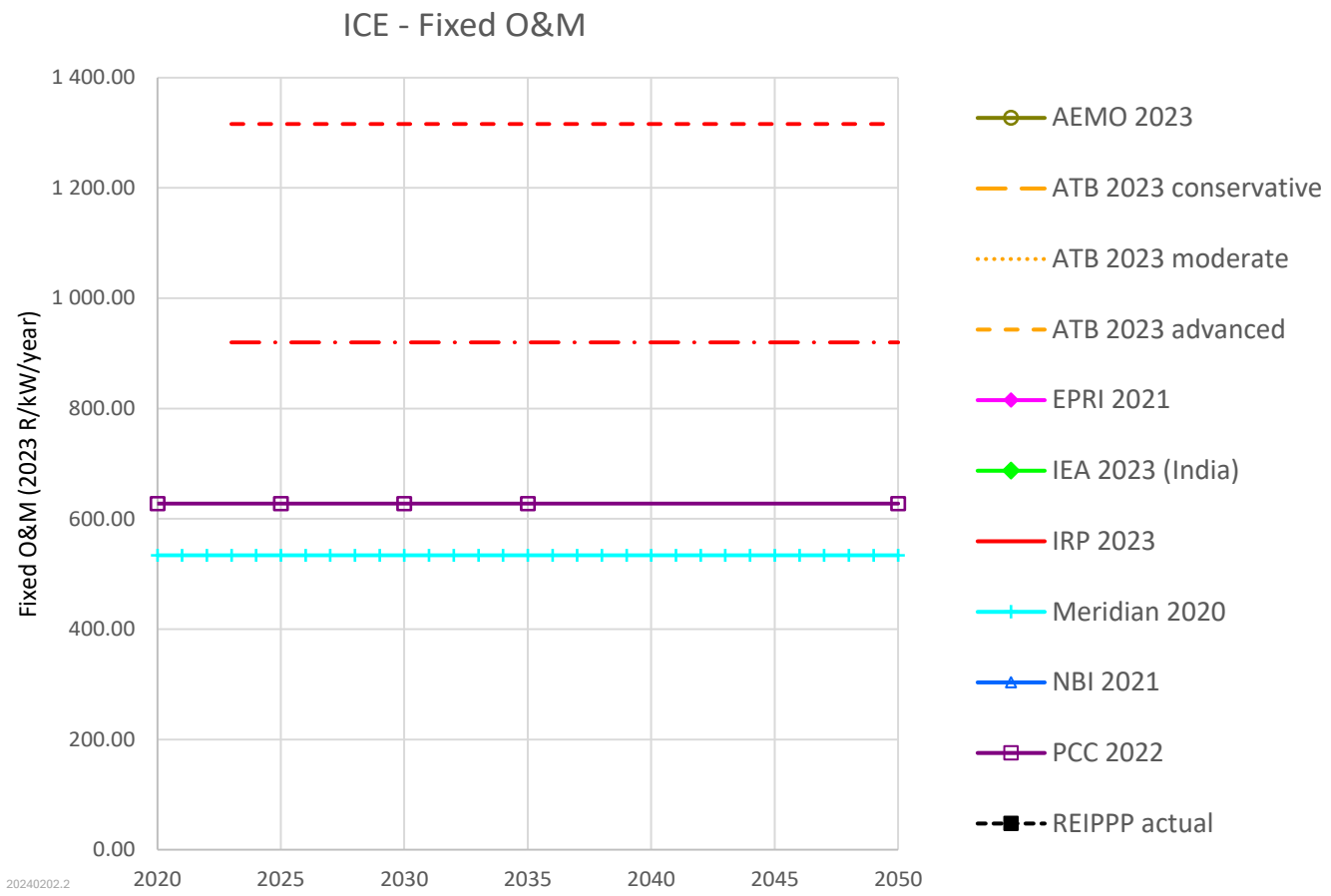


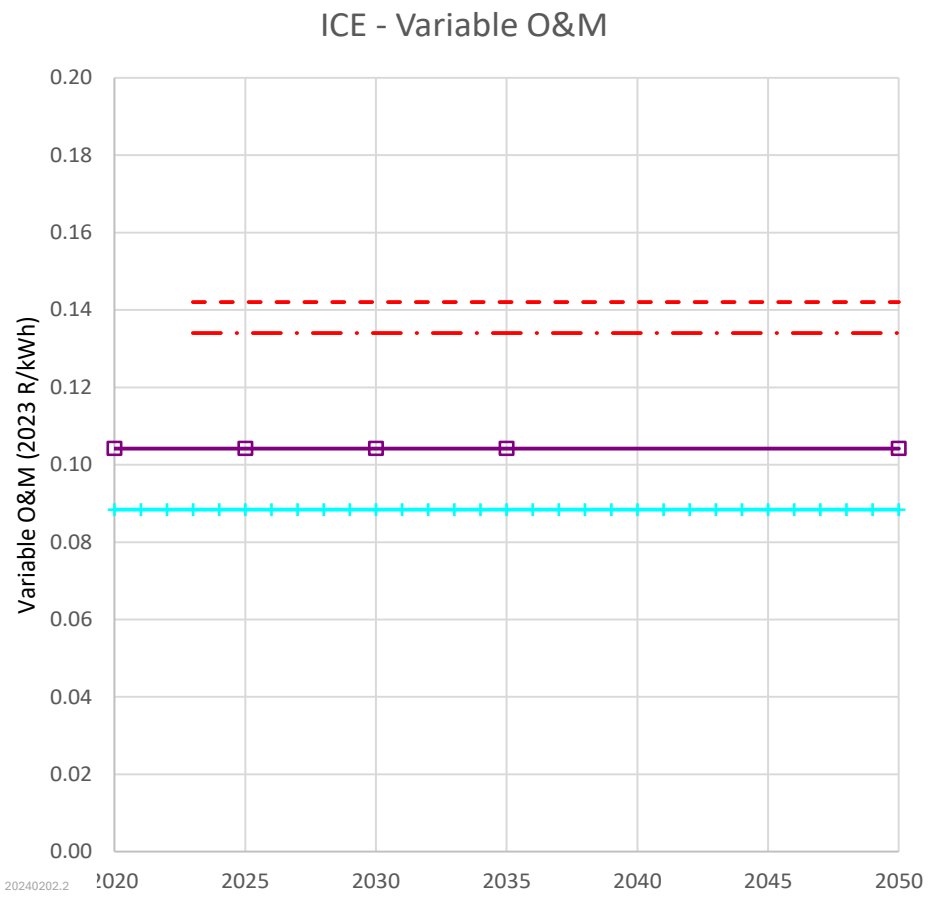




Refer to Excel spreadsheet for more information on datasets with multiple technology options.

# INTERNAL COMBUSTION ENGINE

## FIXED O&M AND VARIABLE O&M




Refer to Excel spreadsheet for more information on datasets with multiple technology options.

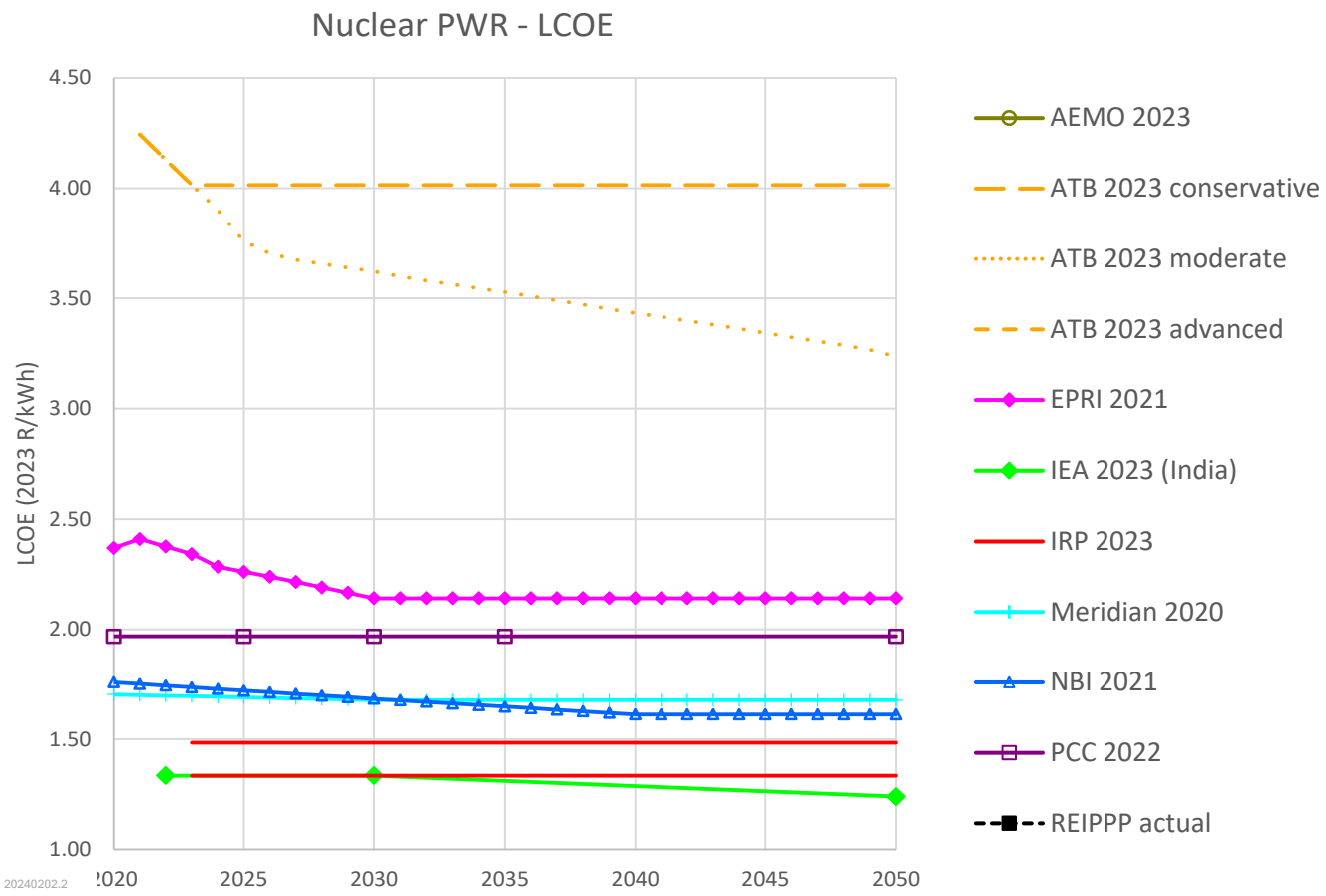
# NUCLEAR

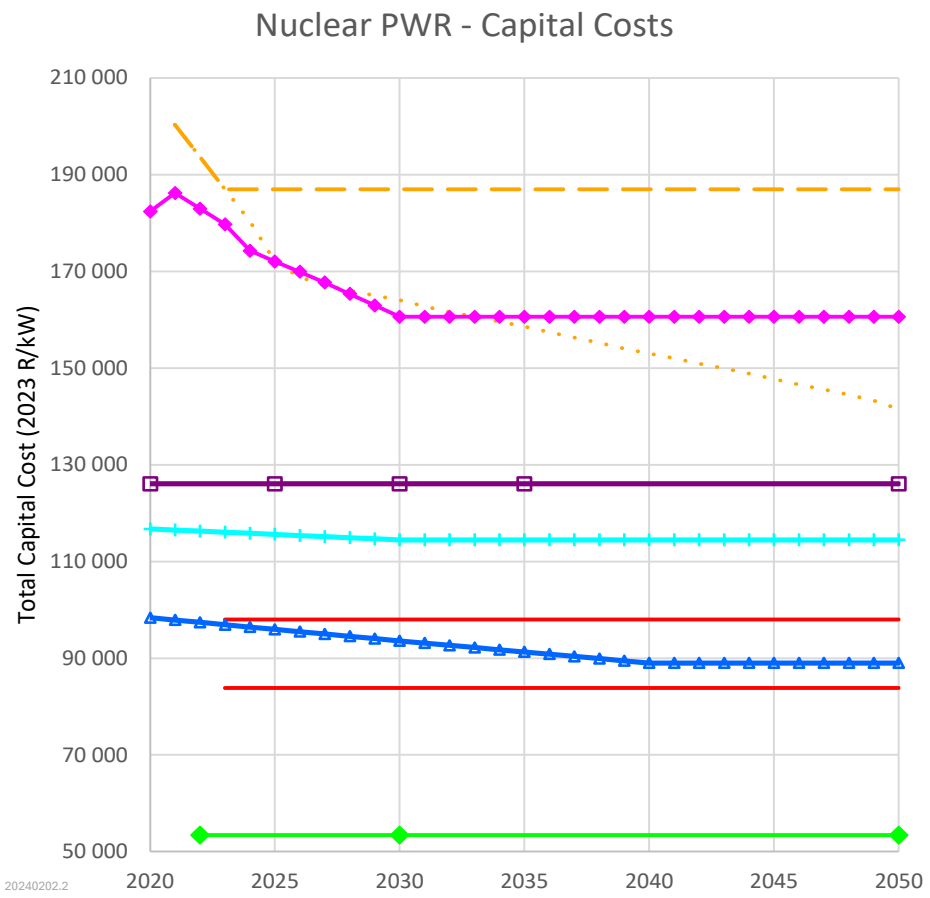
- It appears both pressurised water reactor (PWR) and small modular reactor (SMR) options were provided to the IRP 2023 model. Given the LCOE of the PWR are lower than SMR this is assumed the default technology in the model for nuclear.
- According to the DMRE the assumed cost of the PWR plants is based on information received from vendors through an RFI process. The assumed Total Capital Cost range between R83,814-98,029/kW.
- Given recent cost over-runs and delays of international nuclear projects in the UK and US, and local cost overruns with respect to building mega-projects such as Kusile, Medupi and Ingula, the nuclear cost assumptions appear exceptionally optimistic.
- These assumed IRP costs, result in an LCOE below R1.5/kWh, which is lower than all other data sources but closest to the IEA data for India. However, it should be noted:
  - The IEA data for nuclear builds in China and India is significantly lower than in the EU and North America.
  - The IEA data assumes an “nth of its kind” reactor that has already undergone significant cost reductions. This refers to costs of reactors that are replicated from previous projects with cost reductions associated with previous construction and design experience. Therefore, this would not be representative for the cost of the first series of new nuclear plants built in South Africa.
- SMRs have not yet been fully commercialised. This technology is included in the IRP as the only non-commercialised technology and therefore any cost information is subject to high uncertainty.

Given the sensitivity of the nuclear LCOE to capital cost assumptions – further stakeholder input on the costs would be valuable.

# NUCLEAR PRESSURISED WATER REACTOR

## LCOE AND CAPITAL COST

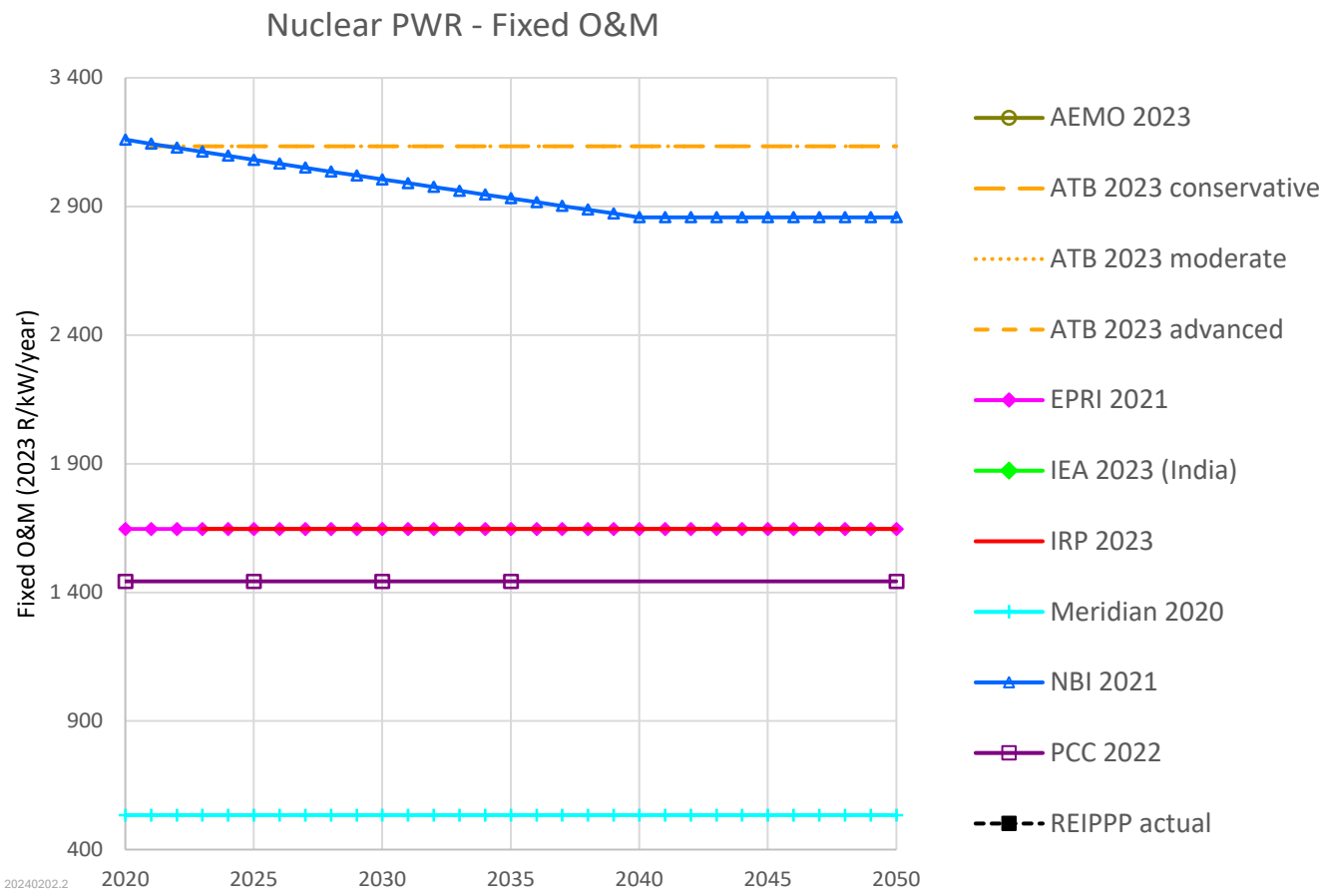


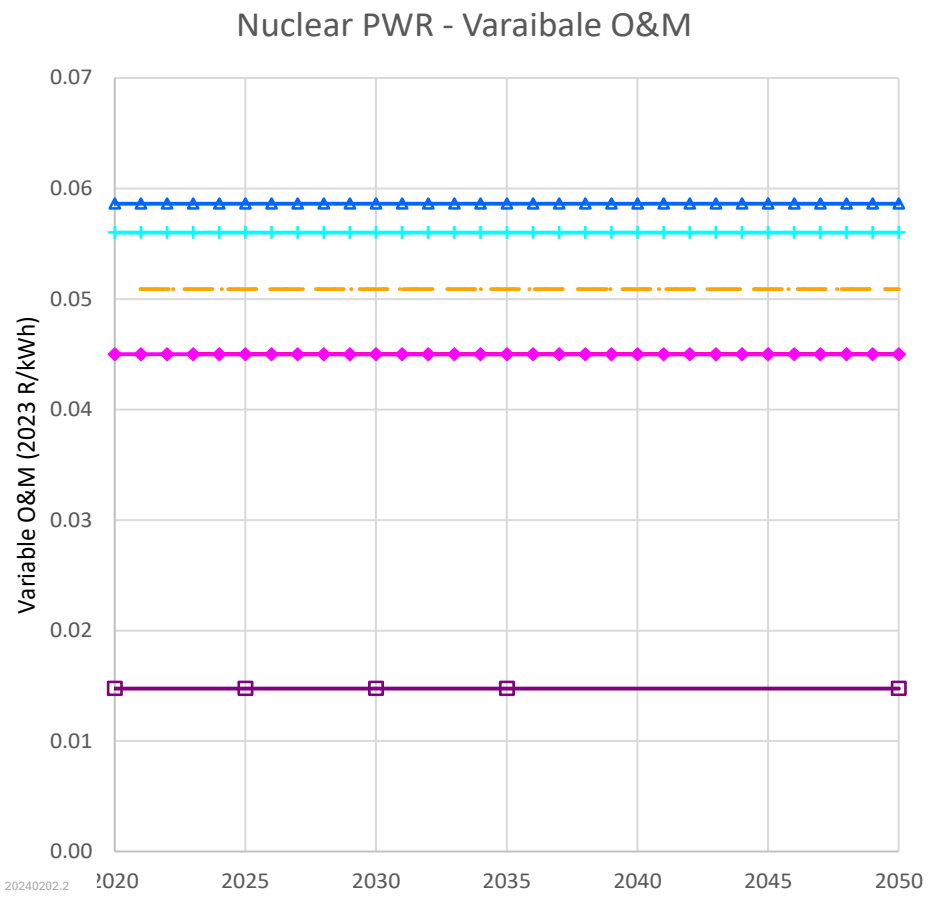




Refer to Excel spreadsheet for more information on datasets with multiple technology options.

# NUCLEAR PRESSURISED WATER REACTOR

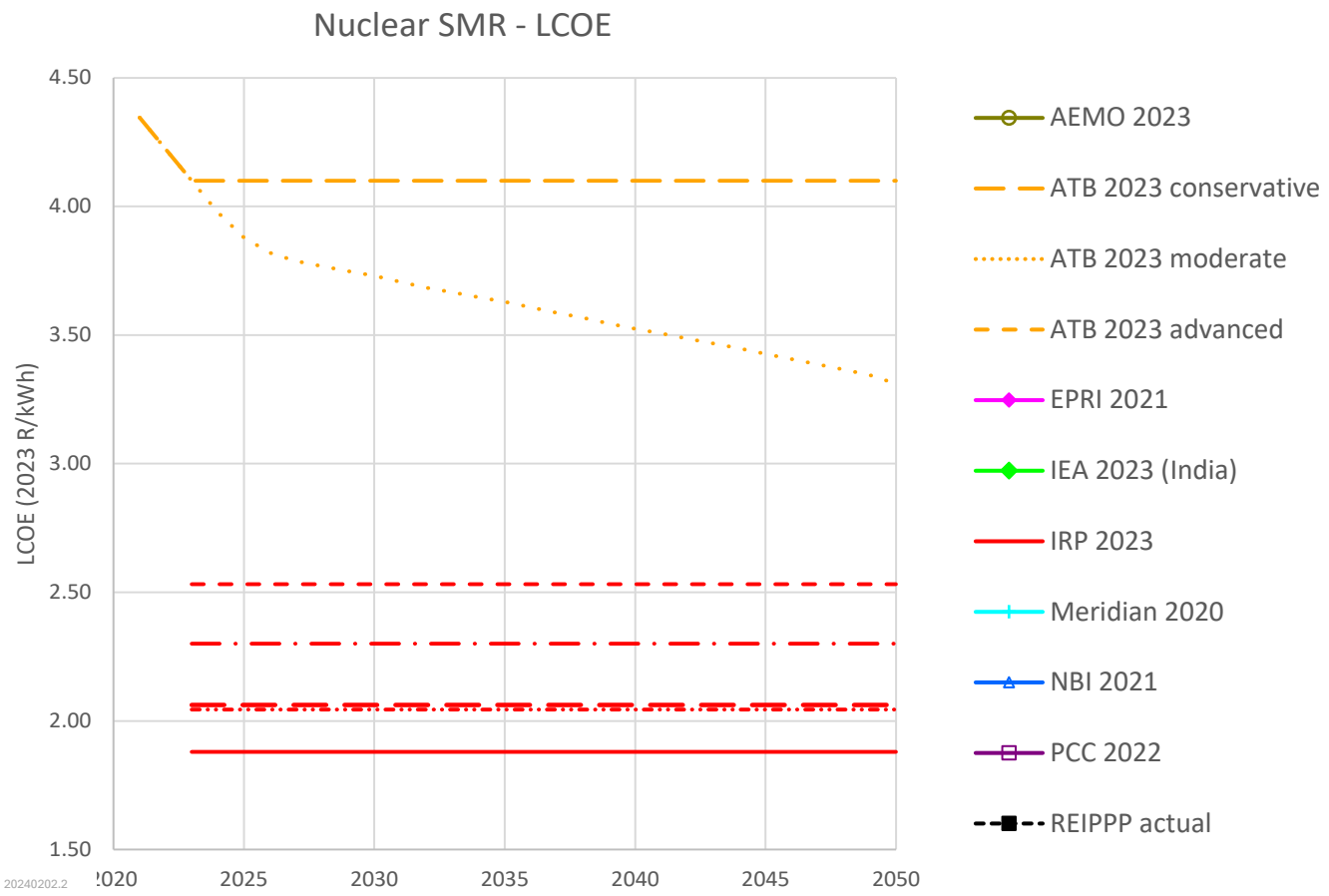
## FIXED O&M AND VARIABLE O&M

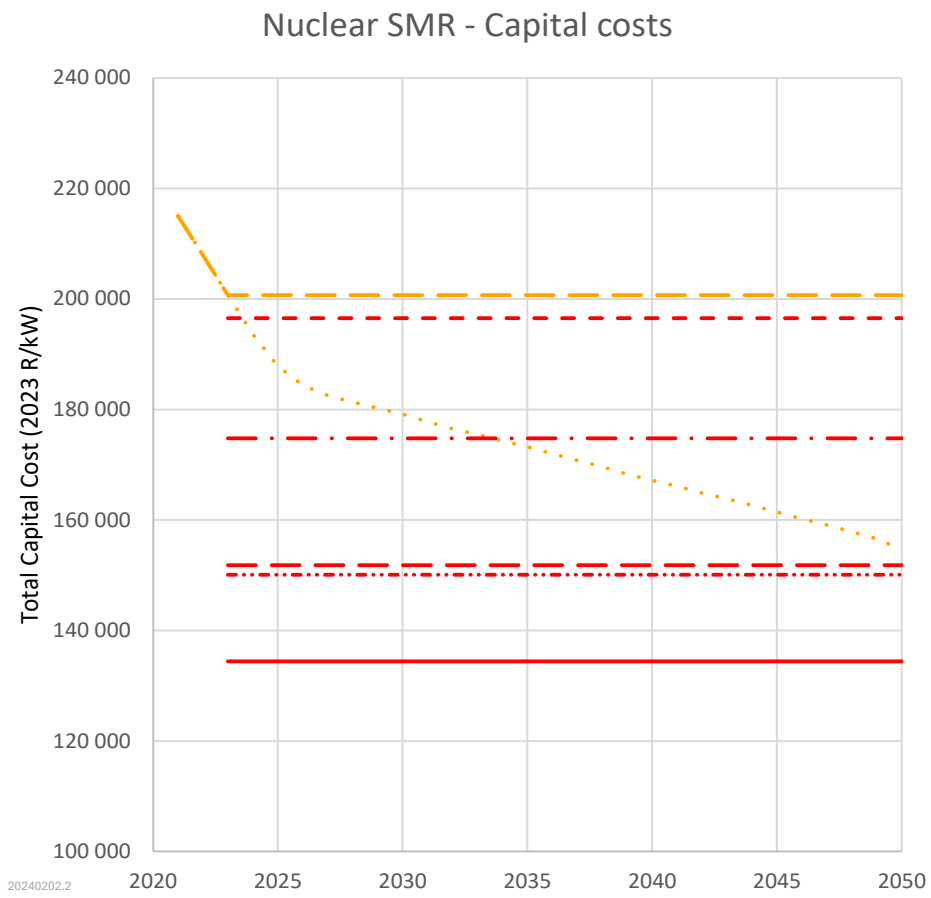


# NUCLEAR SMALL MODULAR REACTOR

## LCOE AND CAPITAL COST

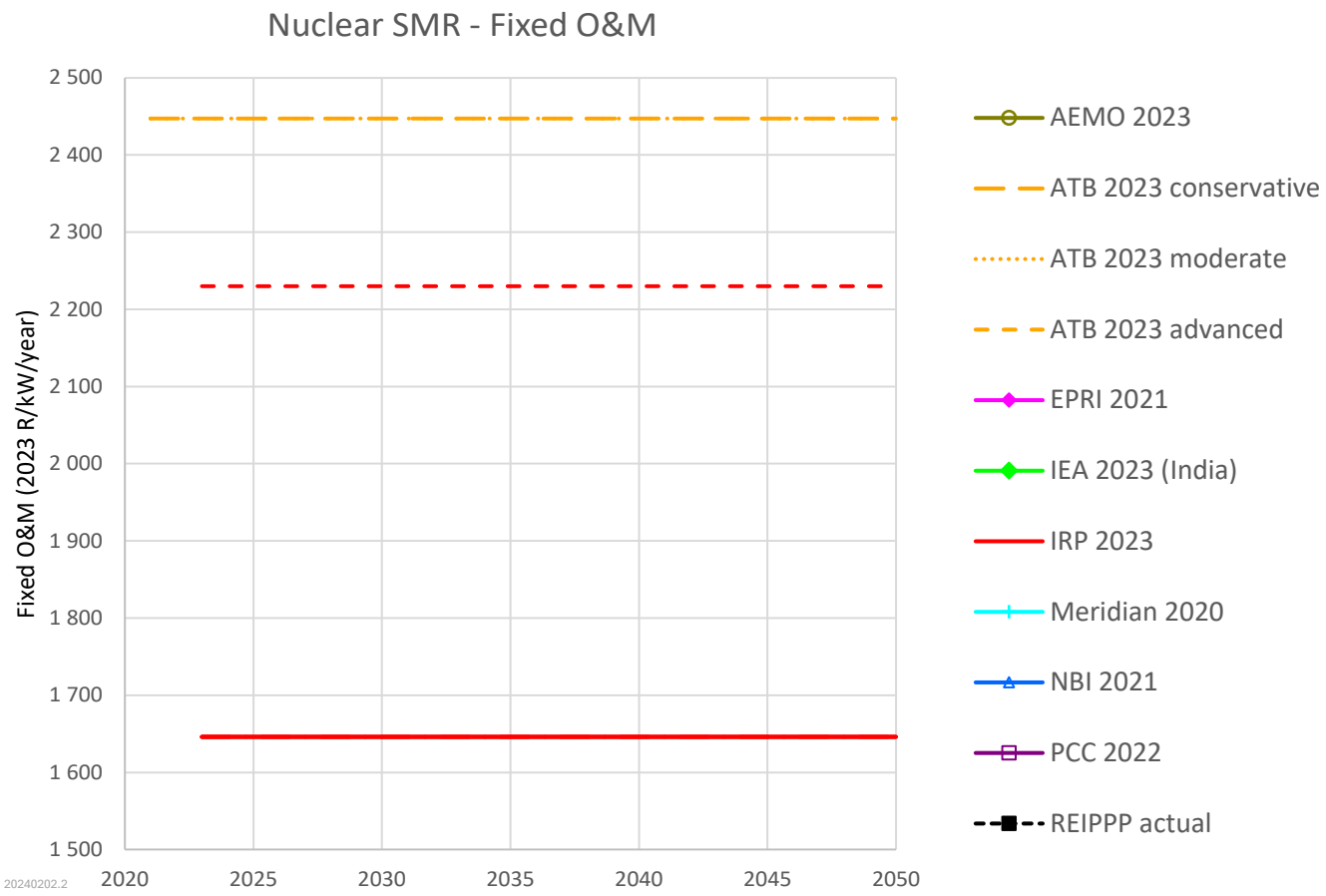


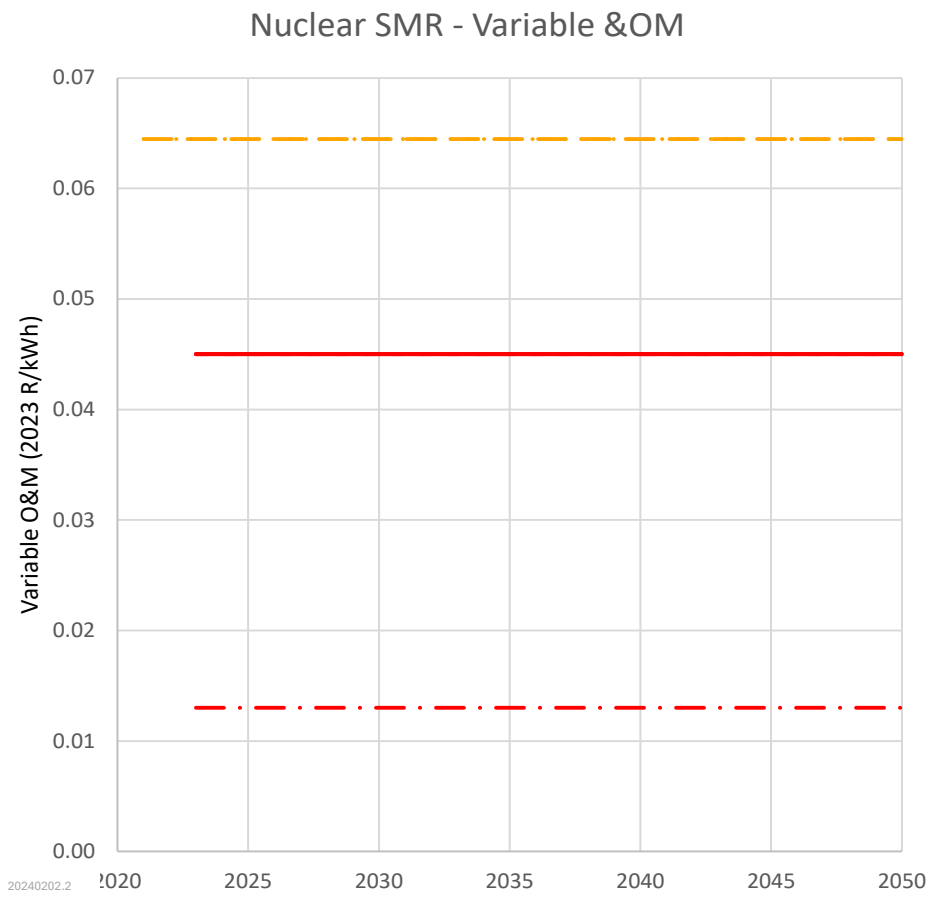




Refer to Excel spreadsheet for more information on datasets with multiple technology options.

# NUCLEAR SMALL MODULAR REACTOR

## FIXED O&M AND VARIABLE O&M




Refer to Excel spreadsheet for more information on datasets with multiple technology options.