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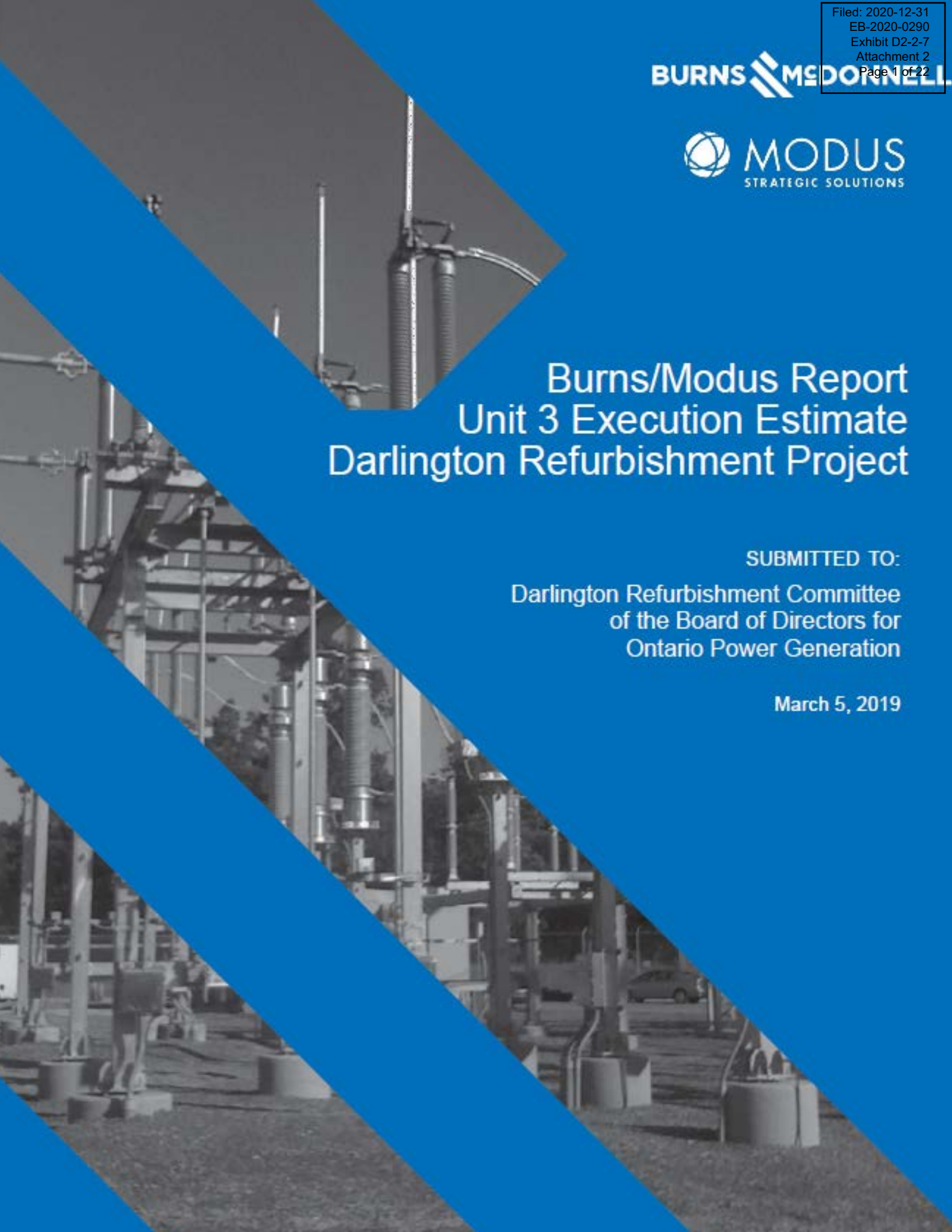


# Burns/Modus Report
# Unit 3 Execution Estimate
# Darlington Refurbishment Project

SUBMITTED TO:

Darlington Refurbishment Committee
of the Board of Directors for
Ontario Power Generation

March 5, 2019

# I. Executive Summary

Burns & McDonnell Canada and Modus Strategic Solutions Canada Company ("Burns/Modus") have been requested by the Darlington Refurbishment Committee ("DRC") of the Ontario Power Generation Board of Directors to provide the following report regarding the Darlington Refurbishment Project's ("DR Project") current cost and schedule forecast for the refurbishment of Darlington Unit 3 (the "Unit 3 Execution Estimate Forecast" or "U3EE"). Specifically, Burns/Modus has been requested to examine the reasonableness of the process OPG is using to develop the U3EE, how OPG and its vendors are utilizing Unit 2's actual events and progress, the operational experience ("OPEX") and lessons learned from performing the Unit 2 refurbishment to its benefit for Unit 3, and how the U3EE effort compares to industry best practices for similar projects.[1]

The DR Project Team's U3EE is an updated forecast to the Unit 3 portion of the DR Project's $12.8 Billion Release Quality Estimate ("RQE") approved by the Board of Directors in November 2015. In our November 12, 2015 Report to the DRC on RQE, Burns/Modus stated: "While the DR Team will continue to refine unitized estimates for each of the four units in order to make specific funding requests, the Control Budget, if accepted by the Board, will be the baseline against which both the stakeholder confidence and public trust will be measured." (Burns/Modus RQE Report, November 12, 2015) The DR Project's U3EE is intended to provide a current snapshot of the cost and schedule compared to RQE, with a data cut-off of November 28, 2018.

The DR Team's current U3EE forecast shows Unit 3's target Working Schedule has been reduced from Unit 2's 1071 days to 1028 days; while the current cost estimate (including contingency) is $2.487B, $12M over the Unit 3 estimate in the "Current Target Budget" established by the DR Team in November 2016. These forecasted differences are due to allowable adjustments, funding of improvements to all three future units, and allocation of funds between the units.[2] Overall, U3EE reflects a reduction in contingency based on the increased maturity of the DR Project since RQE as a result of Unit 2 actual experience and costs and improved estimates for some work. This increased maturity has allowed the DR Team to narrow the potential risk and range of outcomes around the Unit 3 forecast through the incorporation of lessons learned into the base estimate and schedule. Overall, the total $12.8B approved in RQE is unchanged by this forecast and appears not to be at risk based on U3EE's results.

Unit 2's execution is ongoing[3] and lessons learned from the remaining work series will need to be reflected in the final Unit 3 Control Budget and Working Schedule.[4] While risk remains with the completion of Unit 2, current projections by the DR Team indicate Unit 2 will finish within the 40-month commitment date

[1] Notably, Burns/Modus has not been requested to provide an opinion regarding the accuracy of the DR Team's U3EE forecast nor the sufficiency of the identified budget for performing the work.

2 The Unit 3 Target Budget is based on approved changes that have been tracked, managed and reported through OPG's approved change control process from RQE to present. See OPG's Figure 4 in its Memorandum to the Unit 3 Board of Directors that tracks the progression of the Unit 3 forecast and OPG's Table 3 that reflects approved budgetary changes.

3 As of this writing, the remaining work on Unit 2 is Fuel Channel Installation, Feeder Installation, Vault Restoration and Return-to-Service. As of 8-Feb-2019, Unit 2 work is 75.9% complete. The actual durations for these series will need to be factored into the Unit 2 OPEX for subsequent units.

[4] The "Unit 3 Control Budget" and "Working Schedule" are the budget and schedule that OPG will use for measuring performance. As with the Unit 2, the Unit 3 Control Budget and Working Schedule are based on aggressive targets and used for setting up performance Key Project Indicators, like "Schedule Performance Index (SPI)" and "Cost Performance Index (CPI)."

(February 27, 2020) and within the Control Budget. Completing Unit 2 is a critical accomplishment which forms an outer boundary for Unit 3's likely cost and schedule performance. The DR Team intends to finalize its Unit 3 Control Budget and Schedule in 3Q 2019 to reflect the remaining Unit 2 execution results, lessons learned from these final work series and remaining analysis of cost and schedule opportunities for Unit 3.

Based on our review of the DR Team's progress to date with the development of the current U3EE forecast, Burns/Modus finds that:

- The DR Team's process for collecting, vetting and interpreting lessons learned from Unit 2 is consistent with best practices we have observed in other multi-unit projects (including OPG's Pickering A Return to Service), and the DR Team has made significant progress identifying technical improvements for Units 3/1/4;
- The U3EE represents a bounding forecast of Unit 3's budget and schedule; the next step the DR Team has articulated in the process is to further increase certainty and analyze the results of remaining work before setting the Unit 3 Control Budget and Working Schedule;
- In performing this review of the U3EE, Burns/Modus found that the process for developing the estimate was consistent with the method the DR Team has used to date on the DR Project, starting with RQE. U3EE is based on estimates that have progressively matured, and as more is known, certainty around estimates increases. U3EE's increased base cost estimate and decreased contingency from the Unit 3 Target Budget is a consequence of this ongoing building of project maturity.
- The development of the U3EE contingency has followed the same basic process as used for RQE and was confirmed using OPG's risk management system and quantitative assessment techniques (i.e. Monte Carlo). OPG is prudently maintaining contingency for the distinct risks for Unit 3, including potential limits to trades labour, Ontario supply chain support, overlaps of units for the first time, Bruce Power's simultaneous MCR Program and other project risks;
- The DR Team has made reasonable assumptions regarding its functional costs that are spread across the remaining three units and is looking for other opportunities for economies of scale and cost reduction;
- Based on the results OPG has achieved to date on Unit 2 relative to RQE and the preparations OPG is making for Unit 3, the current U3EE forecast is consistent with and bounded by RQE and incorporates the assumption that Unit 3 Project's performance will improve upon the schedule and cost outcome of Unit 2.

Notwithstanding the DR Team's efforts to date, there are a number of key issues and opportunities that the DR Team intends to pursue prior to completing the Unit 3 Control Budget and Working Schedule:

- All Unit 3 contractor derived estimates for improving direct field labour ("DFL") productivity and Project Management Team ("PMT") for Unit 3 require additional vetting, so that assumptions used in their Unit 3 bases of estimates ("BOE") can be fully tested and understood. If, as an example, there are adjustments needed in a contractor's estimate from RQE (i.e. to incorporate missed scope or underestimated complexity), that same adjustment will be required for the control budgets for all three subsequent units. Thus, all vendors should update their BOE documents to incorporate Unit 3 assumptions, changes and improvements, including the impact

of changes made to their Construction Work Packages ("CWPs") that are being revised based on Unit 2 OPEX.

- Each Unit 3 contractor needs to fully identify how it intends to retain, train and deploy qualified DFL and PMT to improve labor proficiency in the field because these details will adjust both upfront cost and DFL productivity projections.
- Some scopes of work, particularly the Turbine Generator ("TG") Digital Controls, require more mature and detailed estimates. Currently the TG estimates from CanAtom are not sufficiently developed to meet Class II (+20%/-15%) requirements. The demands of the Unit 3/1/4 schedule will require CanAtom to perform significantly more TG work than on Unit 2 in a shorter period, with significantly less float.
- The revised schedule for Unit 3 will continue to evolve as lessons learned and the results of readiness activities, such as horizontal and vertical slice reviews, are conducted.
- Innovations the DR Team has examined for Unit 3 for tooling, radiological protection and other potential improvements need to be monetized, and if OPG Management determines there is a positive business case, these improvements need to be pursued.

In summary, the reduced risk that comes from repeating the work should provide confidence that Unit 3 can complete within the total RQE envelope, thus increasing the certainty of maintaining the total $12.8B RQE budget. Moreover, the DR Team's U3EE process for analyzing and processing learnings from Unit 2 is likely to increase the probability of OPG meeting its commitments for Unit 3. The DR Team's work also sets a good course for continuous improvement of Units 1 and 4.

## *II. Burns/Modus Methodology*

Burns/Modus's examination into the U3EE began in early January 2019, concluding with this report. Our focus was on choosing a representative sample of OPG's process for developing the U3EE. We embedded with the DR Team and used a risk-based approach in examining the DR Team's methodology, focusing on the execution work, the largest variables for Unit 3 and where scope is different from Unit 2.

We structured our review around the following key questions:

- How does the U3EE compare to the cost and schedule performance from Unit 2 and the Unit 3 RQE estimate?
- Has the DR Team established, to date, a reasonable process for examining the various elements of cost that compose the U3EE?
- What additional work is required to complete Unit 3 Control Budget prior to Breaker Open?

Burns/Modus examines each of these issues herein. We provide an overview of the buildup of the current U3EE, the lessons learned process the DR Team used for extracting technical issues and one-time events that impacted schedule and productivity on Unit 2, and how effective that process has been to date. We also describe the development of each major execution bundle's forecast, as the method each contractor used varies.

In addition, we identify the status of each of the major components of the U3EE and the specific issues that will need closure prior to the setting of the Unit 3 Control Budget in 3Q 2019 and provide some additional opportunities for the DR Team to consider.

## *III. Analysis of U3EE Forecast Process*

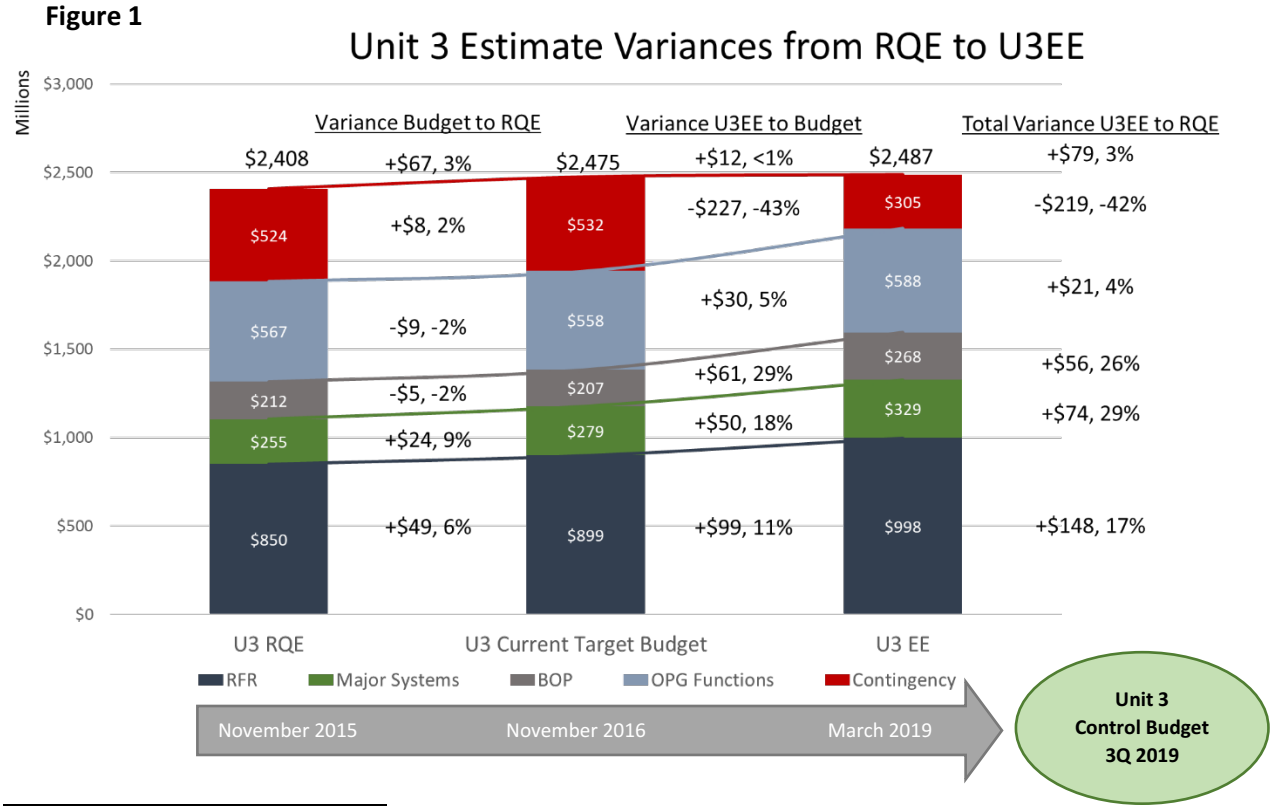
### A. Comparisons U3EE Forecast to RQE Assumptions

#### 1. U3EE Forecast Build-Up

The starting point for the DR Team's current U3EE forecast is the Unit 3 portion of RQE approved by the Board of Directors in November 2015 (see Table 3, Darlington Refurbishment's Memo to Board of Directors). The approved 4-Unit RQE was based on a Class 2/3/4/5 series of estimates that were further matured through the first three quarters of 2016. The resulting Unit 2 Execution Estimate ("U2EE") formed the Unit 2 Control Budget and has been the basis for measuring Unit 2's performance. The plan at RQE was for Unit 2 to have the largest budget (including contingency) and schedule duration commensurate with the risk of its being performed for the first time. OPG has planned to gradually reduce the cost and schedule duration for each subsequent unit.[5]

The DR Team's current Unit 3 forecast of $2,487M is inclusive of $305M of contingency, which is $12M over the Unit 3 Target Budget as demonstrated below. For the U3EE, the DR Team has the benefit of reviewing and analyzing the performance of Unit 2 with the corresponding actual costs. As a result, the U3EE starting point is more mature than the Unit 3 portion of RQE. Figure 1 represents the result of this maturity:

**Figure 1**




[5] In its Memorandum to the Board of Directors, OPG's Table 3 shows the original split of units at RQE and subsequent weigh points. The Unit 2 budget is included with development costs at RQE and is part of the budget approved at that time.

As depicted above, the U3EE represents an estimate with a reduced uncertainty band that reflects the majority of the work as repeated performance while still recognizing certain first-of-a-kind ("FOAK") scopes. The $79M increase in base cost reflects the maturation of Unit 3's base estimate since RQE, factoring the analysis of Unit 2 actual experience, lessons learned, delays, one-time events, approved changes, and productivity gains. Moreover, Unit 3 is adding $59M of one-time investment costs in tooling innovation projects for RFR, known as D3IP, while the benefits of these improvements will be realized on each subsequent unit.

### 2. Unit 2 Performance Trends

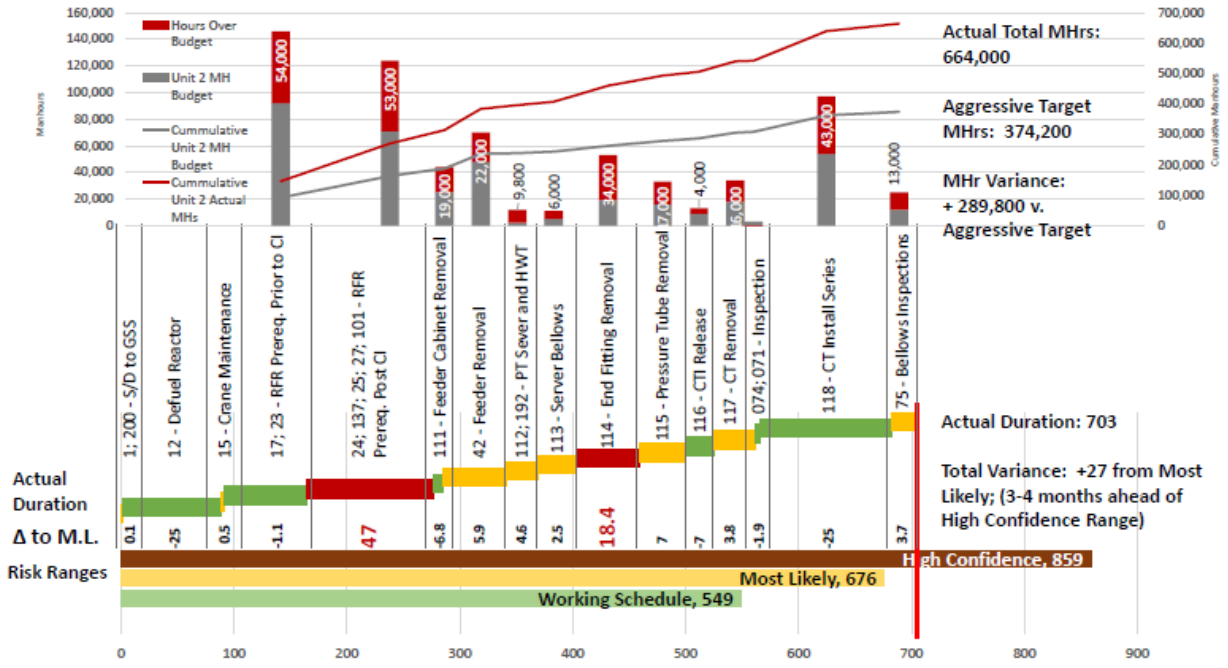
The DR Team is utilizing the actual experience and learnings from Unit 2 as a basis for improving performance certainty for Unit 3. The "High Confidence Budget and Schedule" is the measuring stick the DR Team is using as the 4-unit baseline, with a 112-month schedule duration and $12.8B Control Budget. As noted, the DR Team is also using the Control Budget and Working Schedule to drive the DR Project to more aggressive targets and to measure performance. The DR Team's expectation for Unit 2 (and all subsequent units) is to drive performance to the lowest cost and shortest schedule that could be prudently and safely achieved, while ensuring the overall performance was within the High Confidence commitments.

The DFL budgets for execution manhours to perform the work were developed to be aggressive from the outset. These budgets were based on OPEX from prior CANDU refurbishments. Series estimates were then modified by time trials performed in the mock-up that were generally very aggressive. In addition, there were improvements to the tooling first used for Unit 2 that were not field tested, and unique first-of-a-kind circumstances at Darlington, such as the size of the vault and volume reduction outside of containment, that needed to be accounted. Thus, the High Confidence Budget and Schedule established sufficient margin for the first-time performance on Unit 2 in the form of contingency; that performance can now be reviewed to identify how it may be improved for Unit 3 and the other units, and appropriate adjustments can be made to base cost to incorporate that OPEX. This is a critical part of the work the DR Team has done in preparation of the U3EE forecast.

Unit 2 is 75% complete, and to date tracked the midpoint between the aggressive target Working Schedule and the High Confidence Schedule, though the manhours used to date range above the aggressive Control Budget target, which was accounted for in contingency. Figure 2 is a chart that depicts the relationship between schedule and cost performance on Unit 2 to date[6]. Figure 2 also shows a comparison of the actual schedule duration for the activities completed to date, against the "Working Schedule", "Most Likely" and "High Confidence" risk ranges predicted in the Monte Carlo risk simulation used for Unit 2 at RQE.

[6] The work depicted in this chart is critical path from the inception of Unit 2 to the current Fuel Channel Installation ("FCI"), which is in progress at this time. As noted, the Project is currently 75% complete with FCI, Lower Feeder Installation, Vault Restoration and Return to Service remaining.

**Figure 2** **Unit 2 Performance v. Working Schedule and Budget**




From our review of the Unit 2 results depicted in Figure 2, we have the following observations:

- **Schedule Duration**: This comparison shows how close Unit 2's actual critical path duration to date was to the Most Likely duration modeled at RQE. The total actual Unit 2 critical path duration is 703 days, which is only 27 days longer than the modeled "Most Likely" duration of 676 days in the schedule. On an individual series basis, only two individual durations exceed the "High Confidence" range (post-Containment Preparation and End Fitting Removal); these delays were primarily caused by unforeseen conditions, tooling issues and FOAK discoveries. Of the remaining series, five either met or exceed (i.e. were shorter) than the "Most Likely" duration while four series had durations exceeding Most Likely though were shorter than High Confidence. In aggregate, the Unit 2 schedule performance to date has been comfortably within the expected range of outcomes, which is a good result for the first unit of the DR Project.

- **Critical Path DFL Manhours/Productivity**: As noted, the DFL budgets for manhours were developed to be aggressive from the outset. As depicted in this chart, Unit 2 has been challenged to meet the aggressive DFL manhour target set in the Control Budget. Unit 2 carried sufficient contingency within the High Confidence Budget to cover these exceedances. U3EE is the initial attempt to learn from the Unit 2 experience and reset these budgets based on that experience. This is among the reasons the DR Team has increased the Unit 3 base budget, as discussed throughout this report.

Nevertheless, this Unit 2 performance to date should provide confidence that the remaining units in the DR Project can learn from, meet or improve upon Unit 2's schedule performance, which notwithstanding some challenges, met the High Confidence Budget and Schedule. Figure 2 also shows that for Unit 2, the DR Team mitigated the impact of any potential or actual delays, one-time challenges and other schedule slippage by increasing craft manhours above the Control Budget; thus, in reviewing the impact of these events on Unit 2, the opportunity for Unit 3 will be to meet or beat the Unit 2's schedule performance while increasing productivity and reducing DFL manhours.

## 3. Summary of Changes in Unit 3 Planning Assumptions

The U3EE forecast remains within the overall RQE budget and represents a natural progression of the maturity level from RQE. The DR Team's Unit 2 experience has driven increases to the size of the base cost of Unit 3, resulting in higher base cost certainty and less contingency (See Figure 1) Overall, the DR Team has taken a bounding approach to U3EE in anticipation of performing additional work to increase certainty for the Unit 3 Control Budget. This approach is appropriate at this time with Unit 2 in progress and work remaining to confirm details of the Unit 3 schedule and approach. The following is a brief summary of the major planning assumptions embedded in the U3EE.

- **DFL Productivity**: The DR Team's approach toward anticipating productivity gains from Unit 2 for the U3EE forecast has been generally conservative, knowing that additional details will emerge. As an example, CanAtom's current cost performance index ("CPI") on Unit 2's RFR is 0.52. Even though CanAtom's forecast for Unit 3 improves this by ~25% or to 0.73, the DR Team has adjusted it downward 0.62 because they believe CanAtom's current forecast is optimistic, which reflects a lesson learned from Unit 2. Additional vetting will occur prior to setting the Control Budget for Unit 3.

- **Contingency**: The DR Team has reduced contingency on Unit 3 from $524M at RQE to $305M for its U3EE. This resulted in distribution of RQE-held contingency into the base cost, including $157M in field labour productivity costs that were risks but are now, in essence, baked into the U3EE forecast based on the Unit 2 experience (See Figure 1 that depicts this comparison). This reduction in contingency further reflects the increase in maturity that the DR Project gains from having Unit 2 actual costs and experience. This was an expected part of the maturation of the Project.

- **Balance of Plant ("BoP")**: The scope for BoP and Shutdown Layup ("SD/LU") is much smaller on Units 3/1/4 because Unit 2 included the building of one-time facilities and systems. In addition, certain projects that were performed in the BoP bundle on Unit 2 were moved to the new Major Systems bundle for the subsequent unit, including Adjuster Rods, Flux Detectors and Valves which are traditionally maintenance programs.

- **Major Systems Including Turbine Generator ("TG")**: The largest unit-over-unit scope difference is on the Turbine Generator project. The Turbine Generator Controls and the stator replacement will be performed for the first time on Unit 3 as will repeated scope from Unit 2, the excitation upgrade and installation of generator auxiliary skids. In addition, the TG project has a much narrower schedule window. Unit 3's schedule also overlaps with Unit 1 leaving only approximately 10 weeks of float between the two units' TG work. The size and importance of this TG scope has resulted in the DR Team establishing a new bundle, Major Systems,[7] with additional management in place.

- **Engineering:** With the vast majority of the work on Units 3/1/4 a repeat of Unit 2, OPG has taken control of and is self-performing the replication engineering work for all BoP projects. This approach is geared toward reducing cost and completing the replication of all three units at this stage.

[7] The Major Systems Bundle consolidates TG with other scopes of work (Fuel Handling, Defueling and Specialized Projects) that previously had been performed as stand-alone scopes of work. Bundling of these scopes allows for more efficient management and spreading of PMT and Functions. In addition, Major Systems is performing certain like scopes (adjuster rods, flux detectors) that for Unit 2 were part of the BoP.

- **Unit Overlaps**: Early in the Unit 2 planning process, OPG Management decided to simplify the approach to the first unit by "unlapping" it from the subsequent units. Unlapping Unit 2 has allowed the DR Team to focus on its performance and collect lessons learned for the subsequent units. Starting with Unit 3, each of the remaining units will have a significant portion of its execution simultaneous to refurbishment of another Darlington unit; in the case of Unit 1, its entirety is planned to be "lapped" by Unit 3 and Unit 4. Therefore, risks related to retention of staff need to be analyzed and actions need to be put in place

- **Bruce Power MCR and Life Extension:** At the time of RQE, Bruce Power's plans for its refurbishment of six of its eight units were not finalized. Now that Bruce Power's plans have solidified, its Unit 6 MCR project is scheduled to begin on essentially the same schedule as Darlington Unit 3, and Bruce Power's Units 3 and 4 will be partially concurrent to Darlington Units 1 and 4. Moreover, Bruce Power has awarded contracts for execution to many of the same vendors. OPG and Bruce Power are collaborating on identifying resources to support demands, sourcing of engineered components and lessons learned.

- **Support Buildings**: The completion of most of the Campus Plan buildings and the RWPB has reduced the overall scope of Unit 3. Also, supporting facilities inside the powerhouse were mostly accomplished during Unit 2.

## B. Evaluation of DR Team's Process for Developing U3EE

### 1. OPEX and Lessons Learned Collection Process

For the development of the U3EE, the DR Team has executed a plan for extracting critical OPEX from Unit 2's performance. As each work series completed, the DR Team immediately held lessons learned sessions with the performing contractors for work on the critical path and near the critical path. These meetings were attended by the field superintendents, engineers, project management staff and others as necessary. The DR Team and contractor teams reviewed the schedule, actual performance and sequence of work and identified issues for further review and disposition. The contractor representatives used the information gathered in these sessions to modify their schedules, budgets and corresponding Comprehensive Work Packages ("CWPs"). We sampled the information gathered from these sessions and found it to be well organized and substantive.

Monetizing the impact of the lessons learned has varied depending on the contractor or work group involved. The following are high-level descriptions of how each Project bundle utilized lessons learned it the U3EE:

- **RFR/CanAtom**: The RFR bundle conducted lessons learned meetings which highlighted one-time events and other challenges that both extended durations of activities and caused additional DFL manhours to be expended. CanAtom collected this information and created series-based depictions of the impacts of these events on its plan. CanAtom is now incorporating this information into revised CWPs for use on Unit 3. As of this writing, CanAtom was 16% complete with its Unit 3 CWPs. Once complete, CanAtom will have a fuller picture of the cost and schedule differences between the completed Unit 2 and the estimated Unit 3. Separately, CanAtom also provided a cost estimate for U3EE that includes a re-estimate of man-loading, shift strategies and shift lengths for Unit 3, as well as best-and-worst case scenarios. CanAtom also adjusted its manhours where its team felt necessary. The result of this U3EE estimate from CanAtom is a revised Class II estimate with somewhat different assumptions than it was carrying at RQE based

on this OPEX. It is important to note that the CanAtom's U3EE estimate does not at this time directly factor the Unit 2 actual costs or attempt to monetize the one-time events. Once the Unit 2 execution work is complete, CanAtom's dual approaches to its Unit 3 estimate need to be reconciled.

- **Balance of Plant/ES Fox**: The BoP bundle has largely used the actual DFL manhours from Unit 2, subtracted the hours associated with Unit 2's one-time events and applied a 5% improvement to the remaining work budget; where BoP didn't have actual hours, ES Fox and the BoP team performed a new bottoms-up estimate.

- **Major Systems/CanAtom and Darlington Station**: For Unit 3, the DR Team has bundled some of the scope differently than on Unit 2 into the Major Systems bundle. The Turbine Generator estimates were all provided by CanAtom based on its Unit 2 experience. The lessons learned sessions for Unit 2 TG work have been not completed to date; thus, there was no formal approach to using the lessons from Unit 2 in the U3EE. These details as well as more mature estimates will be needed for setting the Unit 3 Control Budget.

### 2. Schedule Development for U3EE

RQE assumed a 40-month (1217 days) planned high-confidence duration for each of Unit 2 and Unit 3. Unit 2 proceeded with a Working Schedule of 1071 days. The current 1028-day Unit 3 forecast duration reflects an overall improvement of 43 days v. Unit 2's 1071-day planned Working Schedule. The DR Team's adjustments reflect removing the duration of one-time events, tooling improvements and assumptions regarding workforce proficiency. This current forecast was developed in consultation with CanAtom and the other work groups who have performance windows on or near critical path.

Burns/Modus has reviewed the methodology for the DR Team's Unit 3 schedule improvement and agree with the process the DR Team used to derive these savings. The following are highlights of the DR Team's process:

- **One-Time Events**: The impact of one-time events on Unit 2 was reviewed and categorized by the DR Team through the Lessons Learned process described herein. In our review, we analyzed the attribution of one-time events for each series on the critical path, and how that analysis is reflected in the DR Team's analysis of the schedule. The DR Team's approach to schedule duration was reasonable.

- **Tooling Savings**: The tooling innovation team known as D3IP has identified a number of initiatives that are projected to increase efficiency in the field. As of the time of the U3EE, the DR Team had accepted one improvement (addition of work tables) and modeled the potential improvement of a second initiative (simultaneous Pressure Tube/Calandria Tube Removal) resulting in ~30 days of improvement.

- **Increased Proficiency:** A key lesson learned from Unit 2 was the need to increase the workers' proficiency for performing at the outset of a work series. There are multiple proposals under consideration from CanAtom and ES Fox to retain workers and PMT from Unit 2 to Unit 3; this could reduce cost by re-employing workers who are already trained and indoctrinated into the work. In addition, CanAtom is in the process of revising its training plans for Unit 3 as a result of some of the learnings from this Unit 2 review.

- **Scope Differences from Unit 2**: There are differences in scope and contractor means and methods that vary from Unit 2 to Unit 3. A 12-day reduction to the Working Schedule was taken for the elimination of bulkhead shielding; this work was difficult to perform on Unit 2 and omitting the shielding can be mitigated through operations. However, there is some work forecasted to last as long or longer on Unit 3. As an example, due to the likelihood of extended start-up due to the new TG Controls, the DR Team has added 23 days at the end of Unit 3.

The following chart provides some illustrative examples of how the lessons were translated from Unit 2 execution into the Unit 3 plan. Note this work is ongoing and will complete after all Unit 2 series are completed.

| Sample of Work Series Lessons Learned Review – Unit 2 v. Unit 3 Plan | | | | | |
|---|---|---|---|---|---|
| **Critical Path Work Series** | **Unit 2 Plan** | **Unit 2 Actual** | **Unit 3 Plan** | **Unit 2 Events** | **Unit 3 Plan Rationale** |
| Defueling | 116 | 87 | 90 | Defueling exceeded the most optimistic duration | Unit 3 has assumed +3-day margin over best-ever performance on Unit 2 |
| Bulkhead; Containment Isolation; Prerequisite Work | 74 | 73 | 56 | Execution was impacted by welding issues | Planned reduction in duration based on simplified bulkhead design from Unit 2; reduction in welding time; less complex pre-requisite work for Unit 3 |
| Post-Containment Isolation | 65 | 111.7 | 79 | 20-days identified due to significant unforeseen work; difficulty installing shielding and removal of bridges | Change in means and methods results in -12 days impact ; drain and dry lessons incorporated; team assessed complexity of work, unforeseen conditions on Unit 2 for Unit 3 margin |
| End Fitting Removal | 37 | 55.8 | 40 | 6-day late start; 20-day late finish; 10 documented incidents | Repairs to End Fitting tool to improve reliability; increase to base duration due to overall difficulty. |
| Pressure Tube Removal | 34 | 40.6 | 35 | 16 issues identified resulting in 12 days of impacted performance | Maintaining original Unit 2 planned duration |
| Calandria Tube Installation | 108 | 116 | 95 | 12 days impacted by numerous one-time events | Reflects elimination of one-time delays and set-up issues |

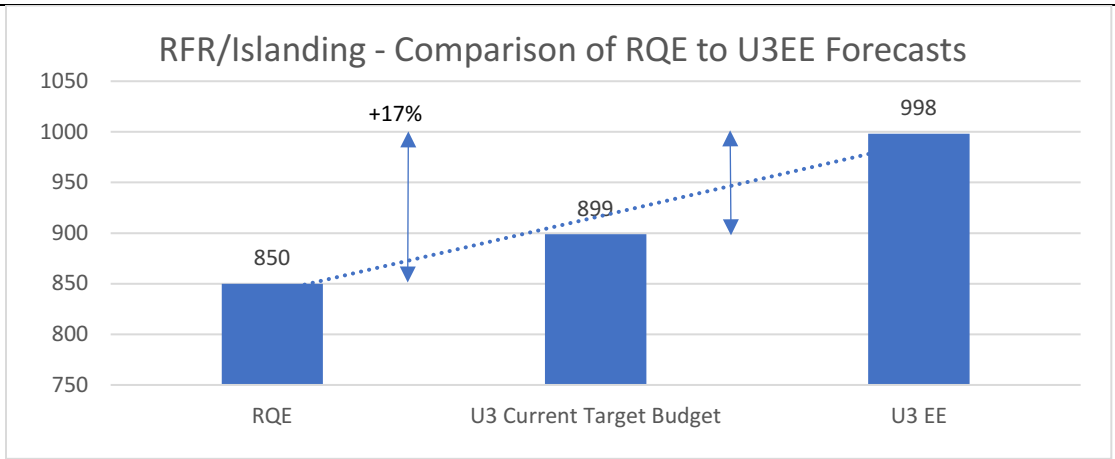
In summary, the DR Team's process for translating schedule lessons appears to be reasonable. As identified above, the DR Project's planned durations for Unit 3 were modified to be both longer and shorter than Unit 2 depending on the circumstances that drove the Unit 2 actual durations. In addition, the DR Team embedded some operational margin for transitions from one segment to the next to cover the issues from Unit 2. There are additional opportunities for improvement that the DR Team intends to pursue, as discussed below.

## C. Summary of Vendor and Functional Cost Forecasts – U3EE Forecast

The cost estimate embedded in the U3EE forecast is made up of a combination of contractor-derived forecasts and OPG forecasts for its Functional costs, with the DR Team's leadership making appropriate adjustments based on its view of the Unit 2 experience and other critical factors. The lesson learned process was intended to identify the technical details of schedule and workhour challenges that each work group embedded in their U3EE forecast. The collection of Unit 2 events and actual costs to date provided the contractors with a good basis for reflecting on their U3EE forecasts. Initially, the DR Team sought to have the contractors derive their estimates from the actual costs to date, though with ongoing work in the Unit 2 execution phase, this proved to be premature for U3EE.

CanAtom and ES Fox utilized their own forecasting methods. The following identifies how these (and OPG) estimates were developed. Prior to the setting of the Unit 3 Control Budget, by which time the remaining contractor-driven critical path activities will be completed, we recommend that the contractors provide an-OPEX driven versions of their forecasts which directly utilize the actual costs and events from Unit 2 as an alternate source of data.

### 1. RFR and Islanding




Major Cost Drivers from RQE to U3EE:

- Modified Work Tables (D3IP) +$59M
- Actualized field productivity based on Unit 2 +$55M
- Increased cost of goods, subcontracts and equipment +$47M
- Additional Vendor PMT +$11M
- Additional contract adjustments +44M
- Reductions in Interest, Escalation and Contingency due to retired risks based on Unit 2 lessons learned -$58M.

#### a) Estimating Methodology

CanAtom performed a bottom-up re-estimate similar to an estimate it performed at RQE. The estimate is largely driven by Unit 2 OPEX, though in a different manner than was initially sought by the DR Team. Based on the work to date on Unit 2, CanAtom's field superintendents were tasked with reformulating their mixes of shift patterns, crew sizes and varying working conditions (e.g. in or out of plastic suits) to re-estimate the work based on the known quantities in the original RQE estimate.

During this process, variances from Unit 2 were classified into several categories, including: lessons learned, CPI improvement, tooling improvements, scope changes and no change. These codes were used to indicate the Team's reason for the variance. Several challenges were conducted between the DR Team and CanAtom and agreement was reached of the total forecasted man-hours to be carried for U3EE for each series. The result was revised Class II estimate that improved productivity (in aggregate) from Unit 2 levels (approximately 0.50 CPI) to a 0.72 CPI for its DFL, a 38% improvement. As noted, the DR Team thought this level of improvement was too optimistic at this time and reduced the productivity forecast from 0.72 to 0.63, which resulted in a $55M addition to the RFR base budget amount. This forecast will be progressively updated and challenged as the remaining Unit 2 work series are completed.

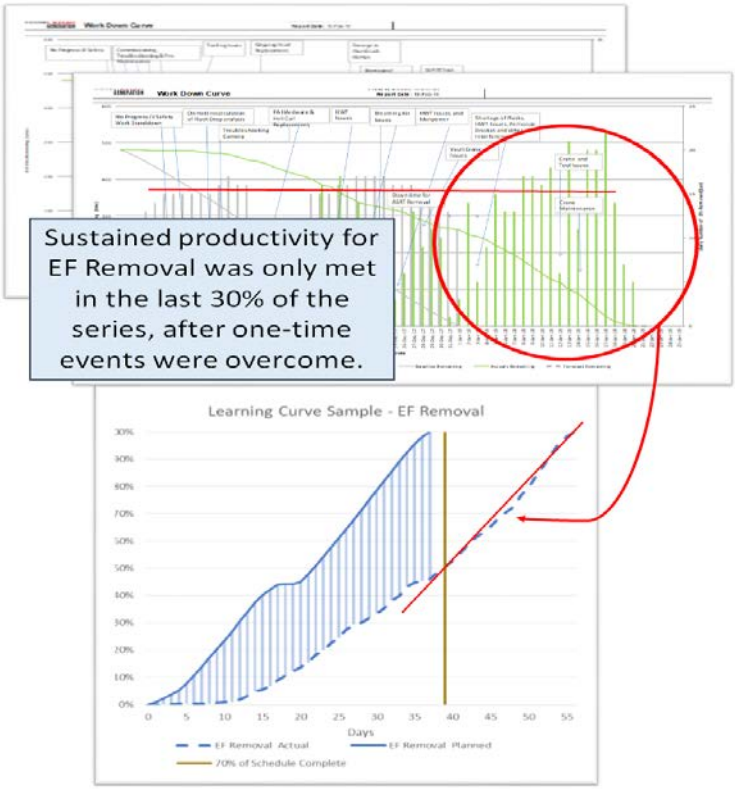
CanAtom's PMT was calculated based on FTE's on a monthly basis for the duration of U3 and converted to manhours. This forecast will need to be vetted and updated for the Unit 3 Control Budget.

### b) Opportunities for Unit 3 Control Budget – RFR/Islanding

Based on the results of the U3EE forecast, the following represent areas of improvement for RFR's estimate prior to the completion of the Unit 3 Control Budget:

#### (1) DFL Productivity

Labour productivity was identified as the primary contributor to Unit 2 cost increases from the Control Budget. When actual productivity is compared to the planned production, CanAtom's CPI averaged ~0.50 for all work series. CanAtom's commodity work down curves consistently show a slow ramp up for each series, but eventually meet or exceed their planned production rate by the end of the series, albeit sometimes behind the Working Schedule. The following chart shows CanAtom's planned and actual production curves for End Fitting Removal with a generalized depiction of the execution.




The charts on top of Figure 2 depict CanAtom's recap of the EF Removal series' lesson learned process in which the production and work down curves were discussed. The charts describe direct impacts to the

work from one-time events and other challenges. The horizontal red bar represents approximate planned peak of sustained productivity. The vertical green bars represent the actual daily production, which only reached a sustained level at or above the red bar in the later stages of the work series. The bottom chart is Burns/Modus' analysis of the same EF Removal work series that compares the planned production versus the actual production. The planned curve shows a fairly steep slope, indicating a quick ramp up in production; however, the actual curve shows CanAtom started late and did not achieve the same slope of production until the last 30% of the work series. The gap between the two indicates the difference between planned and actual percent complete over time. This analysis indicates that once the one-time events were overcome, planned production rates were achieved. This is indicative of the opportunity of eliminating the impact of one-time events. Based on this analysis and lesson learned from other work series, CanAtom and the DR Team can improve DFL productivity for U3.

U3EE adjusts the labour portion of the forecasted base budget by $55M due to learnings from Unit 2. Steps to improve DFL productivity for Unit 3 have been identified by the respective CanAtom and DR Teams and are briefly summarized below:

- Addressing and applying Lessons Learned
- Identifying and eliminating one-time field events
- Update, revise and simplify CWPs
- Optimizing series crews and shift patterns, reduction of work in plastic suits
- More hands-on training to facilitate proficiency of crews before working on reactor face
- Optimizing Radiation Protection ("RP") support by scheduling needs in the field as opposed to "demand-as-needed"
- Improve cooperation and coordination with CanAtom to resolve issues proactively rather than reactively
- Reduction of overtime, which was used on Unit 2 to mitigate schedule impacts and effects on worker productivity
- Improved Project Controls real-time reporting and transparency of actual hours to target specific areas of concern in a timely manner

**(2) PMT**

While most of the attention on RFR has been focused on the DFL productivity, both CanAtom's overall cost and the ratio of Project Management personnel (PMT) need to be examined and vetted. CanAtom's leadership identified that their RQE Class II estimate for PMT was low which drove increases through the course of Unit 2. On Unit 2, CanAtom's actual cost through September 2018 reflects a DFL-to-PMT ratio of 2:1. In its U3EE forecast, CanAtom increased its DFL-to-PMT ratio to 3:2, a 30% increase over Unit 2 actuals. In establishing the final Unit 3 Control Budget, these numbers need to be vetted and CanAtom should be tasked with right-sizing the PMT, as well as justifying these costs and establishing a plan for roll-over of resources to Units 1/4 that is reasonable and verifiable.

### (3) Tooling Improvement Opportunities

D3IP was launched during the course of Unit 2 to bring innovation and a potential new approach to RFR tooling and construction methods. There have been over 30 different opportunities identified, some deemed more promising than others. In addition, OPG is vetting through D3IP whether to adapt its tool set with some of the improvements Bruce Power has made in preparation for its MCR Program. The DR Team has decided that it will only make changes to the RFR tooling's function if the expected improvements carry a high-level of certainty and return. The RFR Project Team will need a positive business case to support any Unit 3 D3IP innovations, including the following:

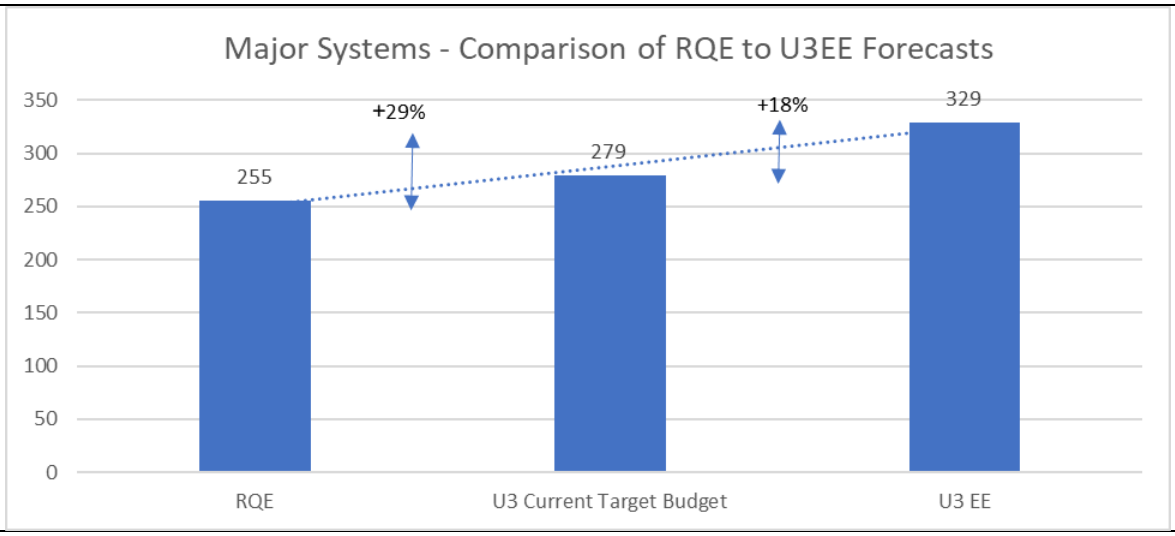
- ***Doubling Work Tables for Calandria Tube Installation and Calandria Tube Sheet Bore Cleaning***: Detailed design is complete on improved work tables which would allow more parallel activities in the field and provide up to 26 days in schedule savings per unit, which was included in the U3EE. An added benefit is that Bruce will be using this tooling approach that will support similar training which may facilitate the ease of movement of workers between the projects. This may help optimize supply of resources between the utilities.

- ***PT/CT One-Piece Removal*** – another improvement for the Removal Phase would be removing and disposing the Pressure Tubes and Calandria Tubes together, which could have a positive gain of approximately 30 days on critical path per unit and reduce cost by $20M cost/unit. CanAtom was tasked with progressing the engineering analysis needed to accelerate this option for Unit 3. The DR Team believes there is a 60% chance the engineering analysis will be complete in time for this change to affect Unit 3. ATS, the tooling vendor, is concurrently working on the same engineering solution for Bruce Power. Thus, the DR Team has accounted for the risk that this work will not be completed on time as part of the Monte Carlo for Unit 3; this is part of Unit 3 contingency.

- ***Bellows Cut Tool Improvements –*** This tool was problematic in operation during Unit 2, and changes to the design are intended to make it more robust and less prone to failure. The potential impact to Unit 3 is less than $10M and fewer than 10 days saved on critical path. The revised design is also being developed by ATS for Bruce Power. U3EE assumes this tool will not be used on Unit 3, though will be incorporated if ready by the Unit 3 Control Budget.

- ***CT Install Leak Test tool*** – This is in very early stages of development and may not be ready for Unit 3. The current view is the potential impact is less than $10M and will result in fewer than 10 Days of schedule improvement. U3EE assumes this tool will not be used on Unit 3.

## 2. Major Systems – Turbine Generator, Fuel Handling, Defueling




Major Cost Drivers from RQE to U3EE within Unit 3:

- Flux detectors, adjuster rods and fission chambers transferred from BOP +$34M
- Reduction in risk and contingency -$38M
- Productivity of .50 improving to .63 CPI.

### a) Estimating Methodology

CanAtom's estimate for TG projects will require additional maturation and detail. As of U3EE, for costs related to the Turbine Generator, CanAtom prepared the Unit 3 execution estimate by adjusting the budget to reflect Unit 2 lessons learned, challenges and productivity, though as with RFR, Unit 2 actual costs were not used, except as a reference. One-time events were "removed" by using the U3 budget at Unit 2EE as the estimate starting point. OPG oversight cost are based on the start and finish date of the approved OPG resources as per the org chart. This is optimized for the multi units overlapped schedule. The other part of the Major Systems bundle is the small Specialized Projects transferred from BoP, Defueling and Fuel handling Projects. The scope transferred from BOP is to be performed by the Inspection and Reactor Innovation (IRI) division of OPG. OPG oversight is being performed and estimated based on assignment of resources documented in the team's organizational chart.

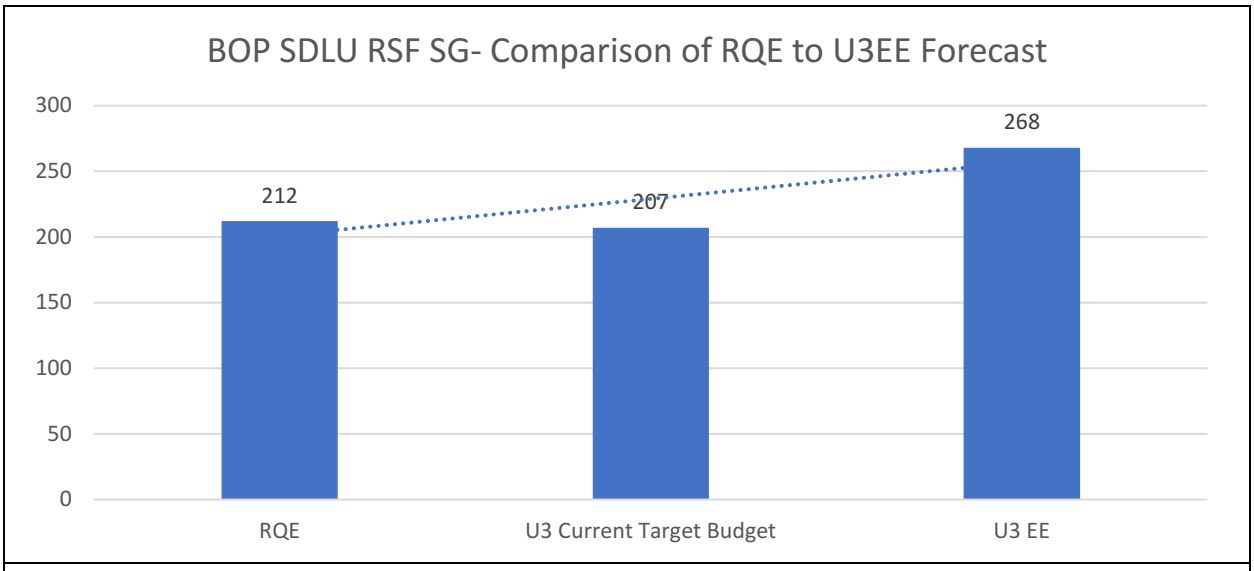
### b) Opportunities for Unit 3 Control Budget – Major Systems

The following areas of improvement for Major Systems have been identified:

- Elimination/monetization of one-time events for repeated scope
- Revise CWPs to incorporate Lessons Learned
- Improve training, hoisting, rigging performance
- Use experienced resources from Unit 2 as available
- CanAtom to retain experienced personnel for its execution team
- Consolidate CanAtom, GE and OPG engineering into one integrated hub to timely resolve issues

OPG has forecasted 25% improvement in CPI from Unit 2 of .50 to 0.63 for U3 EE.

### 3. Balance of Plant Bundle (including BoP, Shut Down/Lay Up, Refurbishment Support Facilities and Steam Generator)




Major Cost Drivers from RQE to U3EE:

- Vendor PMT +$22M
- Additional cost of ASDC project +$17M
- Additional PHT pump repairs +$15M
- Unit 3 valve scope to be performed by Ops and Maintenance within DR Project budget-$17M
- Unit 3 consolidation of projects under Major Systems -$24M
- Transfer of risk/contingency to base -$48M

#### a) Estimating Methodology

ES Fox's estimate overall reduced DFL by 5%. Where available, ES Fox used Unit 2 Actual costs as a starting point, and adjusted actuals to remove one-time events and delays, apply lessons learned and an efficiency factor. Where Unit 2 actual costs were not available, because the work was not yet performed, ES Fox estimated the work on a bottom up basis with quantities/hours and unit rates. As part of the changes OPG initiated for Units 3/1/4, OPG has assumed the design responsibility for this and future units for BoP work. This has reduced cost for design work, as the replication for all three remaining units from Unit 2 can be done simultaneously. ES Fox's recent Unit 3 performance of the pre-requisite Vacuum Vapour Recovery System ("VVRS") project illustrates how the application of Unit 2 lessons learned can immediately improve the performance of Unit 3 work. The VVRS Project is the first Unit 3 project to be completed incorporating lessons learned from Unit 2. There were two windows of work. The Working Schedule duration was reduced from 178 days for Unit 2 to 73 days for Unit 3 for the first window, and 114 days for Unit 2 to 73 days for Unit 3 for the second window. The overall cost decreased: Unit 2 actual cost was $23M, Unit 3 cost is $9M. The overall cost impact still needs to be determined and confirmed. However, the project should be viewed as a success story.

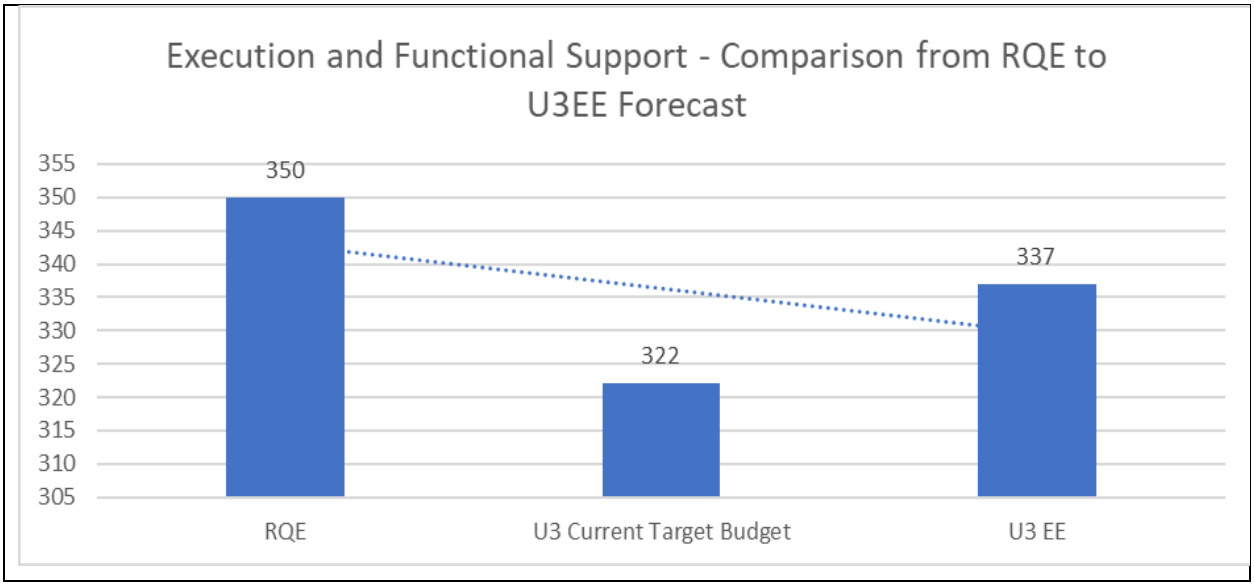
On Unit 3, ES Fox attributed the improved results on VVRS to training and continuity of using the same field personnel and removing impediments so the crews could perform. In addition, one-time events identified on Unit 2 and were eliminated for Unit 3. The lessons from this project are being applied across all bundles on Unit 3 as a model for improved performance.

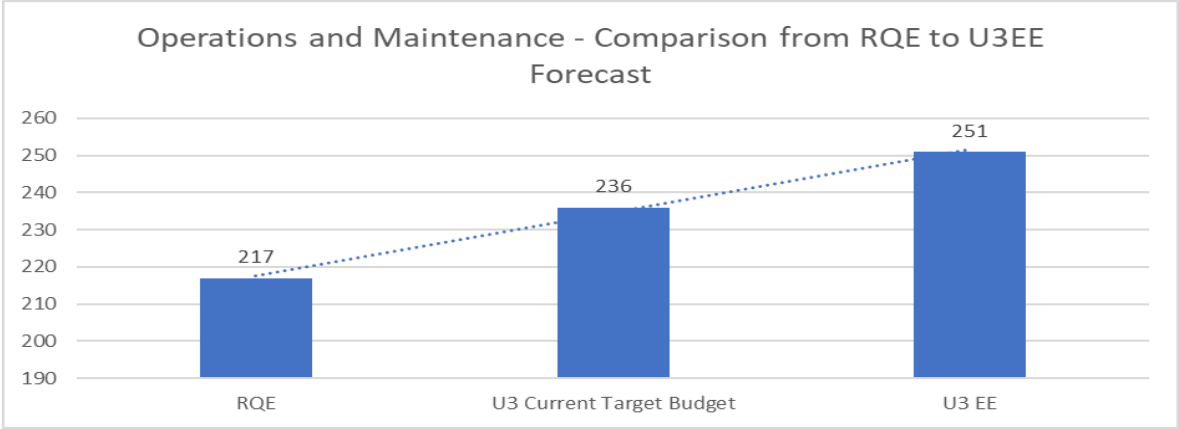
### b) Opportunities for Unit 3 Control Budget – BoP

The following areas of improvement have been identified:

- Update CWPs to incorporate Lessons Learned
- Vendor engagement in constructability review
- Utilize same work force involved in previous unit (e.g. VVRS)
- Streamline PMT organization: identifying specific individuals and roles going forward into future units
- Improved response to Field Initiated Changes ("FICs")
- Optimizing RP: enabling trades to perform low-level RP tasks to free up Green qualified staff
- Retaining qualified field resources to reduce learning curve

## 4. OPG Functions






Major Cost Drivers from RQE to U3EE:

- Bottom up assessment of project management and functional support, reductions of headcount from Unit 2, increases in Radiation Protection support from Operations & Maintenance

#### a) Estimating Methodology

OPG utilized a bottom-up assessment of project management and function support based on an organizational chart, needs established for personnel and unit-over-unit roll-over of the work.

#### b) Opportunities for Control Budget - Functions

The following areas for improvement have been identified for the Unit 3 Control Budget:

- Reduction in management/oversight costs
- Align the shift patterns for Operations and Maintenance and Radiation Protection Personnel to match ongoing construction work, and ensure resources are part of scheduled tasks in P6.

Optimization of FTEs will be reviewed through further enhancement of the Unit 3/1/4 plan, in which:

- PMT is spread through single overhead pool that gets allocated to the units as the work requires;
- Monthly reporting can evolve to show metrics for common work on all three units.

## *IV. Remaining Work to Complete Unit 3 Control Budget*

### A. Work to Complete Unit 3 Control Budget

Throughout this report, Burns/Modus noted that the DR Team took steps to improve the overall certainty of its cost and schedule forecasts in the U3EE. Further review of OPEX from Unit 2's ongoing work (Fuel Channel Installation and Upper Feeder Installation) is planned prior to the setting of the Unit 3 Control Budget. With the current U3EE forecast complete, the DR Team can now focus on the opportunities for further improving the outcome of Unit 3. The DR Team intends to lock down the Unit 3 Control Budget and Working Schedule in 3Q 2019, including setting targets for the High Confidence Work Schedule, project performance metrics, contingency and expected cash flow. Doing so will require the team to

continue its process for analyzing the lessons learned from the remaining Unit 2 work series, revisiting the work already completed and vetting of contractor provided work product to ensure the Unit 3 Schedule and Control Budget are appropriately and fully defined. The following is a summary of this remaining work:

- **Finalizing Unit 3 Working Schedule**: The DR Team has followed a process for assembling, integrating, vetting and finalizing the Unit 3 Execution Working Schedule by September 2019. The following are the steps in this process:
    - The DR Team completed its most recent update to its Level 1 Schedule in time for the U3EE forecast. This Level 1 schedule includes the results of all lessons learned sessions through to the Fuel Channel Installation. As the remaining series are completed (FCI, Upper and Lower Feeders, and RTS), the Level 1 will incorporate the high-level lessons learned into the work durations.
    - The contractors have until the end of March 2019 to complete their Level 2/3 schedules. Once these project schedules are received and quality checked by the DR Team, they will be integrated in the Unit 3 Master Schedule. The DR Team intends to begin vertical and horizontal slice reviews of the Unit 3 Master Schedule in April 2019, during which the execution team will take a very granular look at the construction process and confer on the final logic, sequence, support activities and other details needed for execution. This process could require 2-3 months to ensure there is full analysis from all groups supporting execution. It is also another opportunity to air out and vet lessons learned from Unit 2 and bring ideas forward for increasing efficiency.
    - The contractors continue to update/revise/simplify their CWPs to incorporate lessons learned and changes to work series, all of which impact the work hours, sequence of work, logic and duration; these changes need to be reflected in the contractors' Level 3 schedules. Currently, CWPs from the vendors are behind schedule; this could have an impact on the completion of the Unit 3 Working Schedule if these issues persist.
    - The DR Team will baseline the schedule at all levels (1/2/3) by September 2019. There could be changes in work hours that require adjustments to the Control Budget at the time of the baseline.

- **RFR Project**: The following are outstanding actions for finalizing the RFR Unit 3 Control Budget:
    - Completion of Unit 2 RFR Work: As noted, CanAtom has remaining key work series that will require review and scrutiny of the lessons learned process. It is critical that the DR Team fully vet these series to determine if the schedule and cost increases on these series represent a one-time event or a potential adjustment to the estimate. If it is the latter, this kind of estimate adjustment will also have an impact on each of Units 3/1/4.
    - Analysis of RFR Forecast using Unit 2 actual costs: As noted, CanAtom's current Unit 3 forecast for DFL and PMT was generated as a refreshed, bottoms-up estimate. For purposes of comparison, the DR Team will need to perform a full, detailed vetting process for the entire CanAtom estimate for Unit 3 based on Unit 2 actual costs and results. Included in this review should be optimization of shift strategies, PMT support and application of lessons in revisions to work strategy.
    - Bridging Strategy: An unintended consequence of the unlapping of Unit 2 from Unit 3 is the risk that CanAtom (as well as the other contractors) could lose trained, skilled craft workers. CanAtom has submitted a proposal to OPG known as its Bridging Strategy that covers the purported costs of holding approximately 50-60 craft workers during the interim period between the completion of Unit 2 and the start of Unit 3. CanAtom's

proposal also includes using these resources and its PMT to rewrite CWPs and improve upfront training programs, practice in the mock-up, planning and preparation. If there is no agreement on this plan or some other strategy for maintaining continuity at the craft level, CanAtom may let its craft workforce go at the end of its Unit 2 work, creating risk that they will not be able to rehire them when Unit 3 starts up. A business case is being reviewed to disposition this request.

  - D3IP Innovations: As noted, there are additional D3IP projects that the DR Team is pursuing that will require a decision and a path forward.

- **Major Systems**: CanAtom's TG project estimates and schedules will require additional attention. Currently, these estimates are not at Class II maturity or detail. While the TG scope on Unit 2 was off-critical path and didn't impact the Project's schedule, the TG work scope on Units 3/1/4 is larger and must be performed in significantly shorter duration, as the unit-over-unit roll-over has very little float between performance periods, plus the TG controls will be installed during a concurrent Unit 2 outage.

- **Tier 0 Initiatives**: Based on lessons learned and OPEX from Unit 2, the DR Team has identified certain critical and cross-cutting issues that impacted schedule duration, cost of performance or both. Many of these Tier 0 are focused on contractor actions (such as D3IP and Bridging) while others are OPG-led, such as Radiation Protection support and processes; use of non-destructive examination ("NDE") methods for inspections; increase efficiency of owner reviews. There are currently 30 Tier 0 actions that are in progress, each one of which could have a positive impact on cost or schedule. These will need to be dispositioned and built into the schedule for the work going forward.

## B. Burns/Modus Opportunities

The following are additional opportunities for Management to consider for refining the U3EE.

- **Lessons Learned Process:** As noted, the DR Team's lessons learned process has been effective at identifying technical issues and one-time events. Going forward, this process would be enhanced by monetizing the cost and schedule impacts (when possible) of events and issues that were identified. This will enhance the team's ability to range potential improvements and increase the quality of future forecasts.

- **Multi-Unit Management Approach:** The DR Team has identified the potential cost savings and economies of scale that could be gained from performing the remaining units as a single program. As noted, a key lesson learned from Unit 2 is the value of retention of skilled resources and the repetition of work tasks. A 3/1/4 approach could focus on the rolling wave of similar work from one unit to the next, with work crews staying in unified teams. Doing so will require changes the DR Team as well as advancing the development of the Unit 1 and Unit 4 execution schedules and details, which may prove difficult. This approach could reduce cost, risk and schedule, and provide greater certainty if it is feasible.

- **Ontario Supply Chain**: OPG has a team in place and a number of key initiatives aimed at monitoring the readiness of the Project's key suppliers and sub-suppliers who are fabricating materials needed for Units 3/1/4 as well as the six units at Bruce Power. The current stress on the suppliers is likely to increase; thus, Burns/Modus recommends instituting additional metrics and increasing surveillance of these suppliers as necessary to obtain additional comfort that they can meet schedule.

- **Project Controls Improvements:** The DR Team has developed project controls systems and reporting that excel at collecting information, though there are certain enhancements that would

improve the accuracy of the team's forecasting of field performance. These include simplification of reporting analytics, trend analysis and expanded use of Monte Carlo/risk analysis. In addition, the DR Team and the contractors should consider using common platforms for input and extraction of risks, issues and corrective actions where practicable. We have provided a more granular identification of these enhancements directly to the DR Team for its consideration.

## *V. Conclusion*

The U3EE forecast presented to the Board of Directors for the March 2019 meeting should provide confidence that the current estimate for Unit 3 is consistent with and generally bounded by the Unit 3 portion of RQE. Based on the information the DR Team has prepared, Burns/Modus can support that the process used to date should result in a Unit 3 Control Budget and Working Schedule that will leverage Unit 2's lessons learned to increase certainty in Unit 3's potential outcome.