PRODUCTION FORECAST AND METHODOLOGY - NUCLEAR

1.0 PURPOSE

This evidence provides the production forecast for the nuclear facilities and a description of the methodology used to derive the forecast.

2.0 OVERVIEW

The period between 2022-2026 encompasses a number of significant changes to OPG's nuclear line of business. OPG is continuing with the Darlington Refurbishment Program ("DRP") and planning to end commercial operations at Pickering in the IR term, both of which have a negative impact on nuclear production. Additionally, both Pickering and Darlington pre-refurbishment are aging facilities that inherently face equipment issues and increased maintenance requirements. At the same time, OPG has successfully implemented a number of nuclear outage initiatives that have resulted in improved equipment reliability, and outage planning and execution performance, the benefits of which are included in the 2022-2026 production forecast.

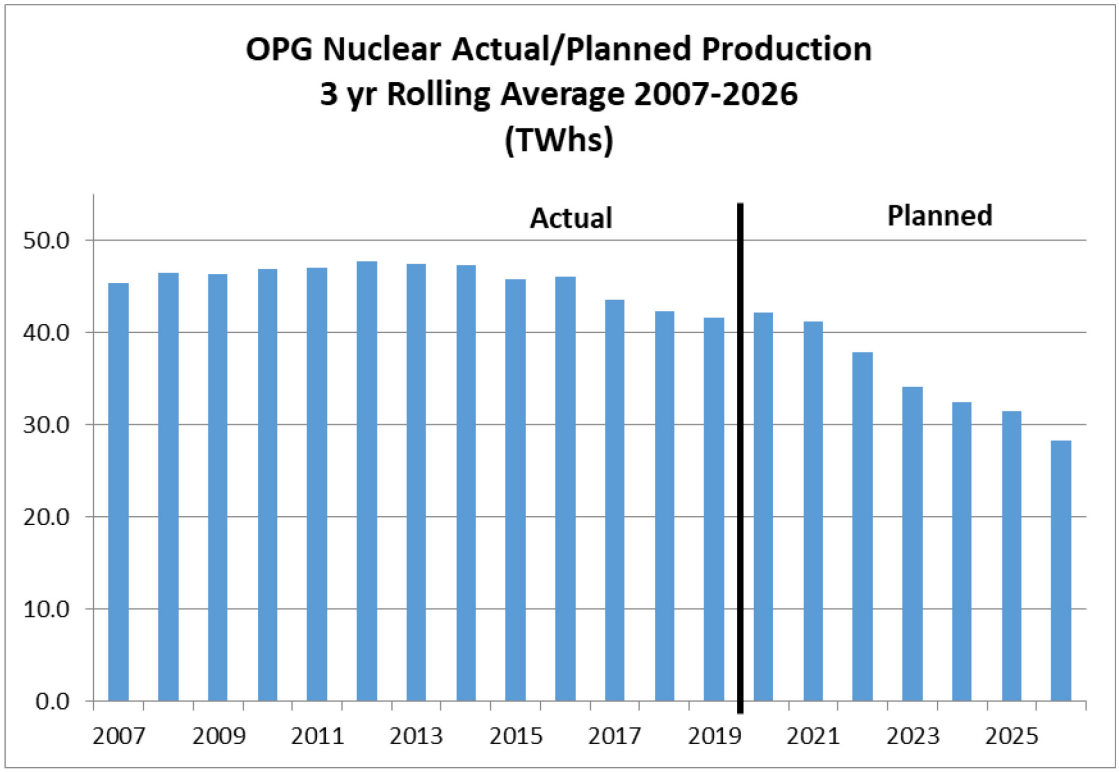
OPG is seeking approval of a nuclear production forecast of 33.2 terawatt-hours ("TWh") for 2022, 30.8 TWh for 2023, 33.3 TWh for 2024, 30.2 TWh for 2025, and 21.5 TWh for 2026. This amounts to a total 149.1 TWh nuclear production forecast for the IR term.

The actual nuclear production for 2016-2019 and the forecast for 2020-2026 are presented in Ex. E2-1-1, Table 1. The monthly nuclear production forecast for 2022-2026 is presented in Ex. E2-1-1, Table 2.

2.1 Historical Results

Overall, actual and forecast nuclear production (three year rolling average) over the 2016-2026 period declines, having peaked in 2012, as shown in Chart 1.

Chart 1



The decline in nuclear production over the 2016-2026 period primarily reflects the impact of DRP and the end of commercial operations at Pickering by the end of 2025, partially offset by the successful implementation of various outage-related improvement initiatives and efficiencies over 2017-2019 resulting in:

- Improved Forced Loss Rate ("FLR") at Pickering as a result of initiatives by OPG to improve plant equipment reliability and fuel handling. These initiatives are addressed in the discussion of OPG's gap closure initiatives in the Nuclear Benchmarking and Business Planning evidence (Ex. F2-1-1).
- Fewer Planned Outage days being utilized at both Darlington and Pickering stations due to a combination of factors:

- Outage optimization at Pickering, resulting in a transition from a 24-month to 30-month planned outage cycle for each Unit. This is the primary factor that favourably impacted production, and has been incorporated into the 2022-2026 production forecast (see Section 3.2.1 for additional details).
- Better outage execution performance as a result of outage improvement initiatives that improved the outage planning process, tooling, scope of work assessments, and training. For example, OPG introduced a Machine Delivered Scrape tool at Pickering, which reduced Pickering Units 5 and 8 scrape campaigns from 22.5 days to 10.5 days for outages in the fall of 2018. The scope of work improvements also resulted in the removal of scope from planned outages, which reduced their critical path and overall duration, such as low level drains that were removed from the scope of two Pickering outages (Unit 6 in 2017 and Unit 7 in 2018) and will not be rescheduled into future outages. These improvements in planned outage execution performance will continue to favorably impact generation during the IR term and have been factored into the generation forecast. See Ex. F2-2-1, Attachment 1, for details on OPG's outage improvement initiatives.
- OPG did not take mid-cycle outages at Pickering in 2017-2019. Mid-cycle planned outages were designed to focus on preventive maintenance for Units 1 and Unit 4 to maintain reliability and lessen the risk of forced outages.[1] OPG was able to substantially reduce Pickering's deficient critical maintenance backlogs and corrective maintenance backlogs (Ex. F2-1-1, Attachment 2) and realize improvements in FLR performance without resorting to mid-cycle outages. Pickering's FLR was close to plan in 2017 and 2018 and substantially lower than plan in 2019 (Section 3.3 Chart 3).
- OPG was able to replace the majority of the Darlington Primary Heat Transport ("PHT") pump motors in regular scheduled planned outages and refurbishment

[1] Forced Outage**:** A Forced Outage is an unplanned electricity system component failure (e.g., immediate, delayed, postponed, startup failure) or other condition that requires the unit be removed completely from service immediately and, per WANO industry performance reporting guidelines, for which OPG did not provide at least 28 days advance notice to the IESO for the start of the outage. See Attachment 1 for a glossary of defined production terms.

outages rather than mini-outages. In EB-2016-0152, OPG had planned to replace PHT pump motors during seven mini-outages, as opposed to regular scheduled planned outages, due to the high risk of failure and uncertainty regarding availability of motor replacements.[2] Ongoing monitoring and component condition assessments of the risk of failure and the availability of replacements motors allowed OPG to avoid six of the seven budgeted planned PHT pump motor specific mini outages. A single mini outage was required in July 2018 due to an assessment of risk that indicated the motor replacement could not wait an additional six months until the next regular planned outage. All pump motors replaced by Q1 2019 in regular planned outages, a mini-outage or refurbishment outages.

Chart 2: Planned Outage Durations[1]

	2017	2018	2019
Pickering Planned Outage Days (OEB Approved)	541.6	530.8	517.2
Pickering Planned Outage Days (Actuals)[2]	336.1	349.1	233.3
Variance	205.5	181.7	283.9
Darlington Planned Outage Days (OEB Approved)	148.4	143.3	119.1
Darlington Planned Outage Days (Actuals)[2]	110.9	112.1	84.9
Variance	37.5	31.2	34.2

[1] Excludes Planned Outage Days for the DRP
[2] Includes Forced Extension of Planned Outage (FEPO) Days[3]

Although OPG had fewer Planned Outage days compared to plan in 2017-2019, it experienced equipment issues at both Pickering and Darlington, reflective of the facilities aging, which led to a number of unbudgeted planned outages[4] such as:

[2] EB-2016-0152, Ex. L 5.1 Sch 12 OAPPA-006
[3] Forced Extension to Planed Outage refers to an extension to a planned outage which is not scheduled with the IESO at least 28 days in advance, and is unavoidable because the unit is not capable of safe operation at the scheduled outage completion time (e.g., an unexpected condition discovered during the scheduled outage which drives critical path).
[4] An Unbudgeted Planned Outage is an emergent outage that was not included in the approved integrated nuclear outage and generation plan that underpins the business plan, but for which OPG had sufficient time to notify the IESO at least 28 days prior to the start date. Although not included in the approved plan, the notice provided allows the outage to be categorized as “planned” for performance reporting purposes as per WANO industry guidelines. See Attachment 1 for a glossary of defined production terms.

- An unbudgeted planned outage at Darlington in November 2017 to replace Air Conditioning Unit ("ACU") Vault Coils (10 days).
- An unbudgeted planned outage at Pickering in October 2017 to inspect and replace a high pressure turbine spindle (40.6 days).
- An unbudgeted planned outage at Pickering in March 2019 to replace a high pressure turbine rupture disc (7.9 days).
- An unbudgeted planned outage at Pickering in February 2020 related to repairs of leaks on the primary heat transport system (19.3 days).
- An unbudgeted planned outage at Pickering in April 2020 related to repairs of leaks on the primary heat transport system (20.25 days).
- An unbudgeted planned outage at Pickering in July 2020 related to repairs of leaks on turbine end failing seal (11.5 days).

2.2 Production Forecast Assumptions

The production forecast in the 2020-2026 Business Plan takes into account the recent historical results including the Planned Outage execution performance improvements realized since 2016 and incorporates the following key components:

- **Revised DRP Schedule**: The production forecast assumes that each Unit at Darlington will operate until its planned refurbishment date (Ex. F2-3-1). As discussed in Ex. D2-2-1 and accompanying schedules, Unit 2 was taken out of service in 2016 and successfully returned to service in June 2020. As set out in Ex. D2-2-5, in response to the COVID-19 pandemic, OPG revised the schedule for the DRP by deferring the Unit 3 refurbishment outage to start in September 2020, to be followed by Unit 1 in 2022, and Unit 4 in 2023. Each of the future unit refurbishment projects will take more than three years to complete. Unlike Unit 2, subsequent unit refurbishments will be executed with various degrees of overlap. As a result of the deferred DRP schedule, OPG also had to move a Unit 1 regular planned outage from 2020 to 2021 and to add a regular planned outage in 2021 to support Unit 4 operation until its start of refurbishment.

- **Post-Refurbishment Outages:** For each Darlington unit returning to service, two post-refurbishment outages have been scheduled to address equipment issues that are expected to emerge. As discussed in EB-2016-0152, the need for these post-refurbishment outages is based on operating experience at other nuclear facilities that underwent major refurbishment.[5] For Units 3, 1 and 4, the first post-refurbishment outage (55 days) is scheduled within six months following return to service, with the second (31 days) planned within 18 months. The total duration for the Unit 2 post-refurbishment outages is approximately the same, but split between 44.4 days for the first post-refurbishment outage, and 43 days for the second post-refurbishment outage as discussed in Section 3.2.1.
- **Pickering Optimized Shutdown**: Under the Pickering optimized shutdown plan discussed in Ex. F2-1-1, Units 1 and 4 are forecast to be shut down in 2024, followed by the staggered shutdown of Units 5-8 at the end of December 2025.
  - The extended operation of Units 1 and 4 from 2022 to 2024 results in two additional regular planned outages, one in 2022 and one in 2023, totaling 202.8 Planned Outage days.
  - The extended operation of Units 5-8 from 2024 to 2025 results in one additional Unit 5 outage of 100.8 days in 2024 and additional life cycle management scope in existing outages.
- **Pickering Planned Derates:** Inclusion of 13.6 equivalent outage days per year for planned derates[6] on Pickering Units 1 and 4 until end of life in order to maintain fuel handling equipment reliability. These days will allow additional online maintenance time to address what has been a major contributor to station FLR. Maintaining and ensuring the reliability of fueling machines is necessary both for production and, in the post-production period, for the efficient decommissioning of the units.
- **Darlington Planned Derates:** Over the IR term there are five planned derates at Darlington due to the constraints on fueling units while bulkheads for refurbishment Unit isolation are installed or removed. Bulkheads are installed near the start of each Unit refurbishment and are removed near the end. Two derates are to support bulkhead

[5] EB-2016-0152, Ex. L5.1 Sch.1 Staff-082
[6] A derate is the situation where a unit is delivering a portion but not all of its full electrical power. See Attachment 1 for a glossary of defined production terms.

installation (22.3 equivalent outage days), and three derates are to support bulkhead removal (17.8 equivalent outage days).

- **Outage Cycles:** Maintaining a three year outage cycle for Darlington and transitioning to a 30-month outage cycle for Pickering (Section 3.2 below).
- **Equipment Aging:** As discussed in Section 2.1, OPG has observed increasing occurrences of equipment aging issues at both Pickering and Darlington, requiring unbudgeted planned outages to repair. As a result, based on recent operating experience, OPG has planned for outages to address equipment aging issues currently being tracked (Section 3.2.1 below), as it is not feasible or economical to proactively mitigate all possible modes of failure.
- **Pickering Vacuum Building Outage ("VBO") in 2022**: As accepted by the CNSC, the Pickering VBO has been rescheduled from 2021 to 2022 as discussed in Section 3.2.2.
- **Darlington FLR:** Taking into account expectations of higher FLR immediately after Units return from refurbishment, Darlington's FLR target varies between 1.2% and 6.4% per year, averaging 4.0% over the IR term, as discussed further in Section 3.3.
- **Pickering FLR**: Pickering's annual FLR target has been set at 3.5% for 2020-2025, compared to actual average FLR of 5% for the 2014-2019 period and same for the target in EB-2016-0152, as discussed further in Section 3.3.

3.0 NUCLEAR PRODUCTION PLANNING PROCESS

3.1 Methodology

Nuclear facilities are designed as baseload generators. OPG's annual nuclear production forecast is equal to the sum of the nuclear generating units' capacity multiplied by the number of hours in a year, less the number of hours for planned outages, planned derates, forced production losses (i.e., unplanned outages and unplanned derates, as defined in Attachment 1 to this exhibit) and corrections for sources of generation losses (i.e., lake temperature, grid losses, consumption (station service), as defined in Attachment 1).

OPG's nuclear planning process is focused on establishing annual planned outage schedules and calculating variances to planned generation due to forced production losses. Outage durations are determined based on the scope of work defined for each outage while

considering recent benchmarking efforts and industry best practices, with a commitment to continuous improvement. The objective is to establish a realistic and accurate annual nuclear production forecast based on the generation and outage plan, with the following deliverables:

- A planned outage schedule for all stations that includes unit outage start dates, end dates, and durations based on the major elements comprising the scope of work that will be executed during each outage.
- Operational reliability targets such as Unit Capability Factor ("UCF") and the level of forced production losses aligned with the forecast FLR.
- Generation forecasts (in TWh) for individual nuclear units and an aggregated forecast for each station.

The nuclear generation and outage plan is an input to OPG's overall corporate business plan. As discussed in Ex. F2-4-1, outage resource requirements and cost estimates for the outage OM&A budget are also tied to the nuclear generation and outage plan.

3.2 Planned Outages

3.2.1 Schedule

OPG's planned outage schedule identifies the number of days required for inspections and maintenance activities to ensure continued safe, reliable and long-term operation. The planned outage schedule is prepared in accordance with OPG's aging and life cycle management programs and in compliance with OPG's nuclear operating licenses issued by the Canadian Nuclear Safety Commission ("CNSC"), with consideration for Ontario's electricity grid system demand (i.e., IESO constraints). The planned outage schedule also incorporates "lessons learned" from past OPG outages and operating experience outside of OPG.

Planned outages are complex, involving many OPG divisions and individuals working together. Outages require focus, expertise, high levels of coordination and a level of detail that exceeds that of many major construction projects (due to regulatory complexity and constraints in work execution). They require careful preparation and the safe execution of a

well-developed plan that accounts for nuclear, radiological, and industrial safety, as well as, the efficient achievement of production goals and cost controls. Outages typically involve more than twenty thousand work activities, involving many persons and hours of labour, sequenced in the optimal order to ensure safe and effective execution.

Planned outages consist of a combination of “routine” inspection and maintenance activities and “non-routine” activities specific to a particular outage. Examples of routine activities are preventive maintenance, fuel channel and feeder inspections and steam generator inspections and maintenance. Non-routine activities include corrective and deficient maintenance, and replacements or modifications of the equipment or plant configuration that can only be done when the unit is shut down. The majority of work in an outage typically is routine preventive maintenance and inspection activities, while the remaining work is non-routine maintenance and modifications.

Planned outages must be submitted to, and be “time-stamped” by the IESO. In most cases, OPG submits its nuclear outage schedule early in order to secure an early time-stamp date; this date determines the outage’s advanced approval priority in the IESO’s outage queue. In addition to this advance approval process, all outages must receive final approval from the IESO before they can begin. The IESO can deny approval of a planned outage at any time up to the start of the outage. OPG works with the IESO to proactively address concerns regarding grid demand and planned nuclear outages.

As in prior applications, planned outage durations continue to include a station-level allowance under the control of the site for uncertainty related to potential discovery work. Planned outage durations also continue to include nuclear fleet-level allowance under the control of the Chief Nuclear Officer to address risks to the completion of planned outages on schedule due to complexity in fleet level activities (e.g., availability of Inspection and Reactor Innovation (formerly Inspection and Maintenance Services) resources to service multiple outages).

The four Darlington Units are on a three year (36-month) planned outage schedule, which means that either one or two regular single unit planned outages occur each year for routine inspection and maintenance.

The DRP impacts the regular planned outage schedule. There are three units remaining to be refurbished (Units 1, 3 and 4) with generally two units refurbished concurrently during the IR term. As a consequence of the planned unit refurbishments, there are no regular scheduled planned outages in the period for these units. However, following refurbishment, there are two short duration post-refurbishment outages planned for each unit, as described in Section 2.0 above.

As discussed in EB-2016-0152, as well as in Ex. D2-2-3, the installation of turbine generator controls ("TG Controls") was excluded from Unit 2 refurbishment scope in order to mitigate risk as Unit 2 was the first unit to be refurbished. In addition to the regular planned outage in 2023, Unit 2 will have a 190.1 day planned outage in 2025 to install the TG controls. An additional 20 day outage in 2026 is scheduled to address any emergent post-installation equipment issues for this complex modification.

As noted above, the six Pickering units are transitioning to a 2.5 year (30-month) planned outage cycle, compared to the 2 year (24-month) cycle discussed in the EB-2016-0152 payment amounts application. This six month cycle increase was initiated in 2018 after a feasibility study that was completed as part of the outage improvement initiatives identified in the 2016-2018 Business Plan. The intent of implementing a 30-month cycle is to:

- reduce outage overlaps and resource conflicts;
- add additional outage preparation time; and
- increase outage execution efficiency.

The implementation of the 30 month planned outage cycle for Pickering in the nuclear generation forecast for the IR term reduces outage costs and increases production, because in some years, Pickering will be subject to only two planned outages rather than three

planned outages. Specifically, Pickering will be subject to two planned outages in 2022 and 2024, and three planned outages in 2023, before the planned shutdown in 2025.

As discussed in Section 2.1, OPG has recently experienced unbudgeted planned outages due to the aging of the Darlington and Pickering facilities. In all of the instances discussed above, OPG was able to monitor the risk and plan in advance for an unbudgeted outage rather than being forced to suddenly take the unit offline. As a result, OPG's outage plan for the IR term contains planned outages to address similar equipment aging issues at both stations (two outages at Pickering totaling 35 days in duration in each year at Pickering; one 30-day outage at Darlington in 2022 and 2023 at Darlington for pre-refurbishment units). These outages are expected to be taken in response to specific active risks that OPG is currently tracking based on recent operating experience, namely, Primary Heat Transport system leaks (~21 days duration) and Unit 4 Steam Generator conditions (~30 days duration) at Pickering and Instrumentation Tube leaks at Darlington (~19 days duration).

While each station has an extensive preventative maintenance program that is realized through online or planned outage repairs, some equipment is subject to a "run to maintenance" strategy, as it is not feasible or economical to proactively mitigate all possible modes of failure. Unless there are safety concerns or regulatory limits requiring immediate action, OPG will take an equipment aging outage at an appropriate time to repair components that fail.

3.2.2 Vacuum Building Outage

A six unit Pickering VBO is scheduled in 2022. Historically, OPG has undertaken VBOs at Pickering on an established 10-year regulatory test interval. The initial VBO date was 2020 to be consistent with the established 10-year regulatory test interval from the last executed VBO in April 2010. Based on innovative maintenance and inspection activities and after extensive technical reviews, the CNSC accepted OPG's request in March 2019 to increase the interval from 10 to 12 years, allowing the VBO to be deferred until 2022.[7] This twelve year frequency is consistent with the frequency used at Darlington.

[7] In EB-2016-0152, OPG had forecast a deferral of the VBO until 2021 subject to CNSC approval.

OPG continues to investigate the use of innovative technology to perform vacuum building inspection work, including while the units continue to operate. Subject to the CNSC's approval, the use of this technology may allow OPG to reduce the duration of the planned 2022 VBO (currently 30 days duration for each of the 5 reactors not otherwise in a planned outage). At the time of writing (i.e., the fourth quarter of 2020), OPG expects to seek the CNSC's approval in the first quarter of 2021. OPG will update its application should there be any resulting material change related to the 2022 VBO. Absent CNSC approval, OPG must plan to execute the 2022 VBO over the currently scheduled duration.

There is no VBO or Station Containment Outage ("SCO") scheduled for Darlington during the IR term.

3.3 Forced Loss Rate

Forced production losses (i.e., unplanned outages and derates) are a source of variance to planned generation. OPG forecasts FLR targets that reflect the risk of forced production losses at Darlington and Pickering. The FLR targets are based on the plants' historical performance, any known improvements or component condition issues, and initiatives to improve equipment reliability.

Pickering's FLR performance is set out in Chart 3 below:

Chart 3
Pickering Forced Loss Rate

	2014	2015	2016	2017	2018	2019	Avg.
FLR- Actual (%)	10.7	2.9	4.1	5.2	5.3	1.6	5.0
FLR-Forecast (%) [1]	7.8	5.5	5.0	5.0	5.0	5.0	5.6

[1] EB-2016-0152, Ex. E2-1-2, Table 1

Pickering's FLR performance has averaged at 5.0% over the 2014-2019 period compared to a target of 5.6%. To drive further improvement, Pickering's FLR target has been set at 3.5% for each year over the 2020-2026 period (see Ex. E2-1-2, Table 1), a significant reduction compared to the achieved historical performance and EB-2016-0152 forecast. This more

aggressive FLR target reflects an expectation that ongoing equipment reliability improvement initiatives will lead to a sustained lower FLR as the station approaches end of commercial operations.

While Pickering's FLR was 2.9% in 2015, post-2015 Pickering's FLR increased for three years in a row due to significant, one-off forced outages primarily related to the fueling machine issues. OPG continues to target improved fuel machine reliability to prevent recurrence and drive further improvement in FLR, including through the use of planned derates. Reductions in deficient critical maintenance backlogs and corrective maintenance backlogs are also expected to contribute to improved overall equipment reliability.

Darlington's FLR performance is set out in Chart 4 below.

Chart 4
Darlington Forced Loss Rate

	2014	2015	2016	2017	2018	2019	Avg.
FLR-Actual (%)	1.5	4.9	2.3	1.7	1.1	4.8	2.7
FLR-Forecast (%)[1]	1.3	1.0	1.0	1.0	1.0	1.0	1.1

[1] **EB-2016-0152, Ex. E2-1-2, Table 1**

Darlington's FLR performance has averaged at 2.7% over the 2014-2019 period compared to a target of 1.1%. As discussed in EB-2016-0152, the higher than forecast FLR at Darlington in 2015 was primarily attributable to PHT pump motor failures (PHT electrical protection trip; pressurized heater leak). The higher than forecast FLR at Darlington in 2016 was caused by various minor equipment issues resulting in seven forced outages of one to seven days in duration each. In 2019, the increased FLR was primarily due to two forced outages on Unit 3; one to repair an instrumentation tube leak in the heat transport system and another to repair a cross shaft failure on the east bridge of the fueling machine. In addition, there was a forced outage on Unit 4 to repair a process leak on the turbine side.

The recent historical performance represents a potential challenge to the 1% FLR target at Darlington pre refurbishment. However, OPG has decided to maintain this industry-leading FLR target in the 2020-2026 Business Plan with a view to continuous improvement.

Darlington's FLR over the planning period is expected to be impacted by the return to service of units after refurbishment. The overall Darlington station FLR forecast averages 4.0% per year over the IR term, taking into account the refurbishment schedule. The FLR target for each unit is set at 1.0% until refurbishment, with the FLR for units returning to service after refurbishment is forecast at 12.0% for the first year, 6.0% for the second year, 2.0% for the third year, and returning to the 1.0% target thereafter. This return to service three year FLR schedule is based on industry operating experience.

ATTACHMENTS

Attachment 1 Glossary of Outage and Generation Performance Terms