NUCLEAR FUEL COSTS

1.0 PURPOSE

This evidence presents the forecast of nuclear fuel costs including the key cost drivers and assumptions.

2.0 OVERVIEW

OPG is requesting approval of nuclear fuel costs of $178.3M in 2022, $182.1M in 2023, $209.4M in 2024, $188.6M in 2025, and $148.2M in 2026. Nuclear fuel costs for 2022-2026 are provided in Ex. F2-5-1, Table 1.

As in prior applications, nuclear fuel costs consist of the following:

- The weighted average cost of manufactured uranium fuel bundles loaded into a reactor ("nuclear fuel bundle cost").
- Used nuclear fuel storage and disposal, which is discussed in Ex. C2-1-1.
- Fuel oil, which is used to run stand-by generators at OPG's nuclear stations.

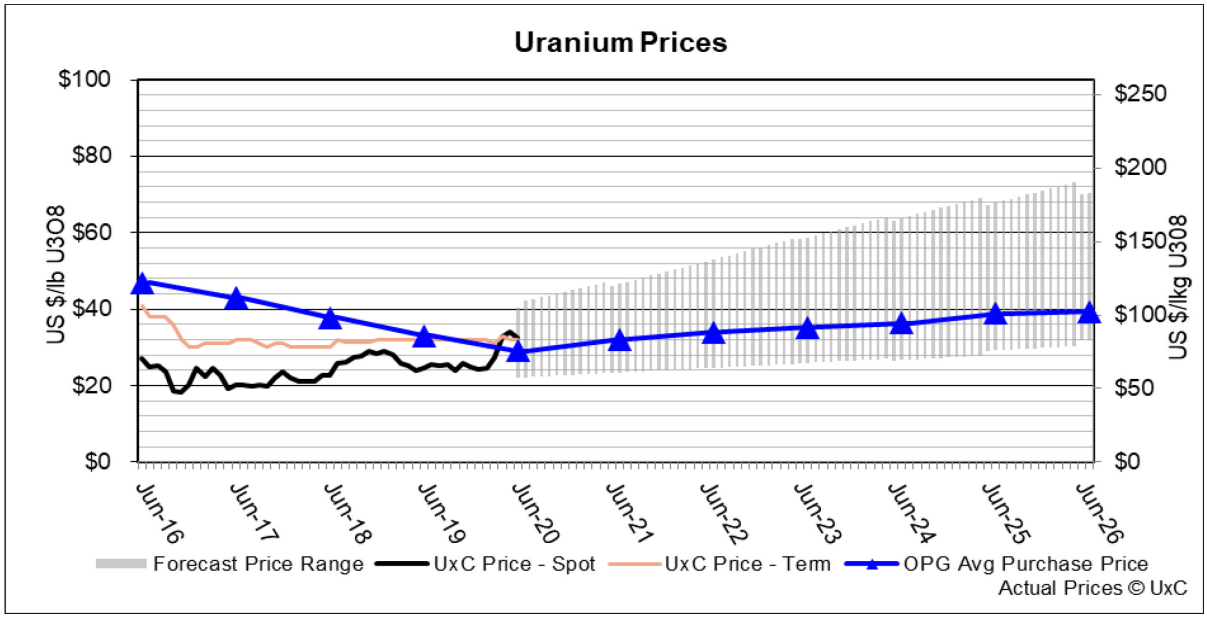
The annual nuclear fuel bundle cost for OPG's nuclear facilities is forecast to decrease by $95.0M over the 2016 to 2026 period, reflecting the impact of lower production on fuel usage, partially offset by an increase due to changes in the individual component costs that make up the cost of a fuel bundle (uranium concentrate, uranium conversion and fuel bundle manufacturing costs) plus changes in fuel utilization efficiency. Specifically:

- **Production:** Nuclear fuel cost is impacted by variations in generation which drive fuel usage. Drivers over the period include reduced generation due to the outages for the refurbishment of the Darlington units and the planned shutdown of the Pickering units in 2024/2025. The impact of changes in production between 2016 and 2026 on the annual nuclear fuel bundle cost is a decrease of $106.0M.
- **Uranium Concentrate, Conversion Services and Nuclear Fuel Bundle Manufacturing Costs:** Offsetting the impact of reduced generation on nuclear fuel costs is the impact of an increase in OPG's average price of a manufactured nuclear fuel bundles loaded into a reactor. A key driver of the increase in fuel bundle costs is the

- forecast market price of uranium concentrate. Chart 1 below shows the actual (2016 to mid-2020) and forecast (mid-2020 to 2026) price of uranium concentrate. As shown, the forecast price of uranium concentrate over the IR term increases from CDN$117.30 (KgU)/U308 to CDN$136.33 (KgU)/U308, or 16%. Over the 2016-2026 period, the net impact of changes in the costs of Uranium Concentrate, Conversion Services and Nuclear Fuel Bundle Manufacturing, on the annual nuclear fuel bundle cost, along with changes in fuel utilization efficiency, is an increase of $11.0M.
- **Darlington New Fuel:** Included within the above noted $11.0M impact on the nuclear fuel bundle cost is the requirement for a one-time full load of new fuel to be included in the reactor core of each of the refurbished Darlington units prior to start-up. As in EB-2016-0152, one-half of the nuclear fuel bundle cost for the new fuel load is removed from inventory and capitalized when the new fuel is loaded into the reactor and then, after the refurbished unit is declared in service (approximately six months later), the capital cost is declared in-service and depreciated over the station's remaining life. This is consistent with the concept that half of the fuel in the fuel channels will be unused at the end of the station life. The other half of the nuclear fuel bundle cost of the new fuel load is expensed when each unit is declared in-service. There are four one-time, full loads of new fuel into the refurbished reactors at Darlington over the 2020-2026 period, i.e., Unit 2 loaded in 2019 and in-service in 2020; Unit 3 to be loaded in 2023 and in-service in 2024, Unit 1 to be loaded and in-service in 2024, and Unit 4 to be loaded in 2025 and in-service in 2026. These initial fuel loads contribute between $14.9M and $16.5M to the nuclear fuel bundle costs.

Chart 1

Uranium Concentrate Prices

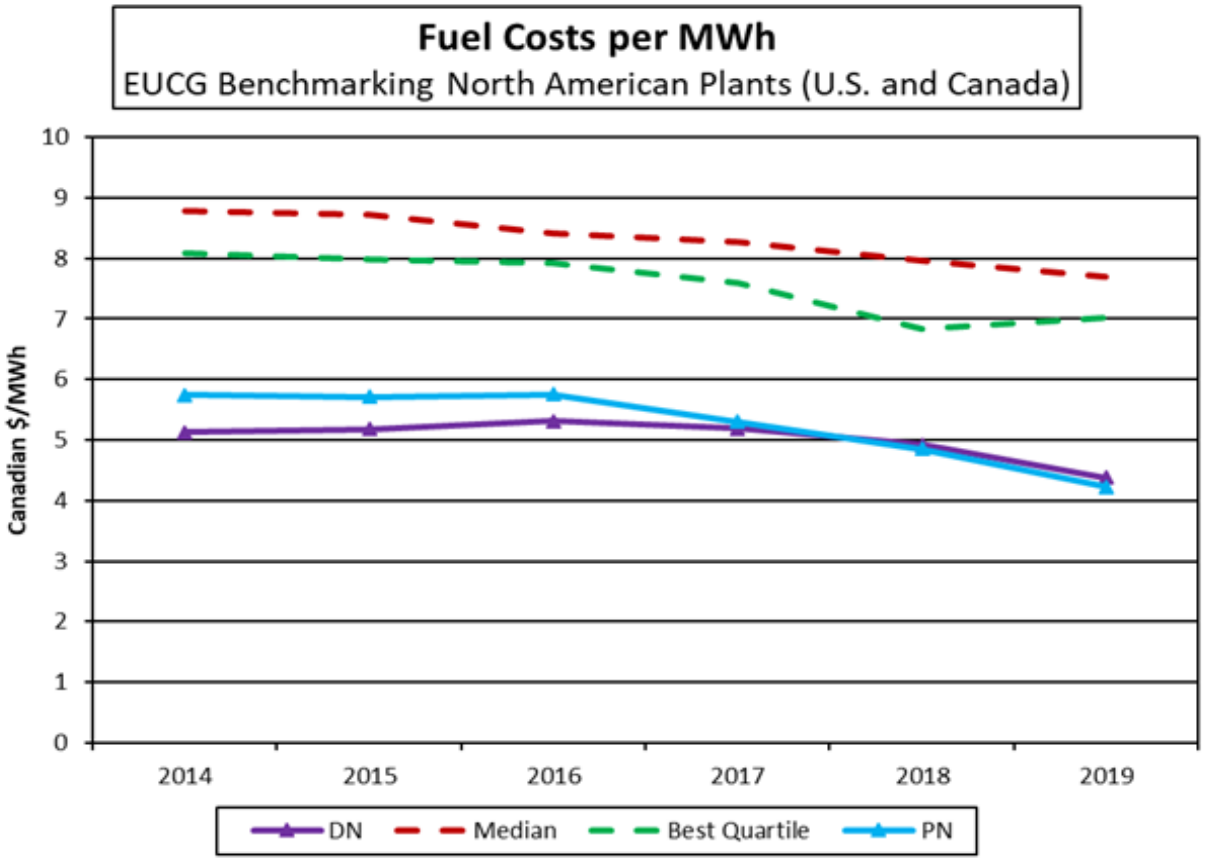


More detailed explanations of nuclear fuel cost variances over the period 2016-2026 are provided in Ex. F2-5-2.

3.0 BENCHMARKING OF NUCLEAR FUEL COSTS

Darlington and Pickering continue to rank among the top North American Electric Utility Cost Group ("EUCG") plants in terms of fuel costs mainly due to the use of natural uranium by CANDU reactors. The trends in OPG's fuel bundle costs are also consistent with other North American nuclear operators, based on EUCG data ((which includes CANDU, Pressurize Water Reactors ("PWR") and Boiling Water Reactors ("BWR") units)) as discussed in the 2020 Benchmark Report (Ex. F2-1-1, Attachment 2, p. 73-75) and reproduced in Chart 2 below.

Chart 2



4.0 NUCLEAR FUEL SUPPLY

The sections below discuss OPG's nuclear fuel supply methodology, which is substantially unchanged from that filed in EB-2016-0152.

4.1 General

OPG's nuclear fuel supply strategies and procurement plans are reviewed and approved by OPG's senior management, including consideration of nuclear fuel quality, because the supply and quality of nuclear fuel are extremely important factors in maintaining nuclear safety.

To ensure high quality nuclear fuel supplies, OPG requires its fuel bundle manufacturer to maintain a quality program which conforms to a rigorous Canadian quality standard (N299.1-2016). This ensures that all phases, including design, procurement, manufacturing and inspection, are appropriately controlled. OPG performs surveillance of all manufacturing processes to monitor conformance to design requirements and verify conformance to OPG's quality standard requirements. Potential vulnerabilities in the supply chain need to be carefully managed by OPG as only two vendors have been qualified by OPG and licensed by the CNSC to manufacture the fuel bundle designs required by OPG units.

The OPG nuclear fuel supply objectives are to:

- Ensure security of supply: OPG must reduce the risk of its reactors being shut down due to lack of fuel bundles, including the risk that any step in the supply chain is substantially delayed due to a lack of materials from an earlier step.
- Minimize cost: OPG seeks to obtain its fuel supply at the lowest cost, consistent with its fuel quality requirements.

OPG's nuclear fuel procurement supply chain is made up of the following three stages:

- The purchase of uranium concentrates.
- The purchase of services for the conversion of uranium concentrate to uranium dioxide pellets.
- The purchase of services for the manufacture of nuclear fuel bundles containing the uranium dioxide pellets.

OPG's fuel procurement planning for the IR term begins with a five-year forecast of the required number of manufactured fuel bundles to be loaded into OPG's reactors. OPG's production forecast from the approved nuclear generation plan (Ex. E2-1-1) determines the forecast of fuel bundles required for fueling, adjusted by forecasts of fuel burn-up and reactor thermal efficiency rates. From this forecast and considering existing inventories, OPG determines its need for purchasing additional manufactured fuel bundles. This determines the need for uranium dioxide conversion services and the need to procure and deliver new supplies of uranium concentrates.

OPG currently purchases each of these components separately and maintains ownership of the uranium at each stage of the nuclear supply chain. OPG does this because its fuel bundle manufacturing service providers are not willing to accept the supply risk associated with the uranium concentrates and uranium conversion services portions of the supply chain. OPG therefore arranges each stage to protect itself from possible supply disruptions.

OPG seeks to maintain a 12 month supply of fuel bundles to allow continued fueling in the event of a disruption in the supply of fuel bundles or uranium conversion due to production issues or labour unrest. The inventory of fuel bundles begins to decline starting in 2025 reflecting the planned shutdown of Pickering. The decline is temporarily offset by the requirement to maintain additional inventory for the first load of fuel for Darlington Unit 4 in late 2025. Post 2025, OPG will continue to maintain a strategic inventory of fuel bundles for the four operating units at the Darlington station, representing approximately 12 months of forward usage.

A three month supply of uranium dioxide is targeted to feed the fuel bundle manufacturing process. In addition, the uranium conversion supplier is also contractually required to maintain an inventory of certified uranium dioxide for OPG's use in the event of a supply interruption at the supplier's facilities.

Beginning in 2013, OPG has adopted a minimum uranium concentrate inventory target of 288,000 KgU, representing a four month supply to feed the production of uranium dioxide. This target continues to be viewed as reasonable and adequate relative to the current level of supply/demand in world uranium markets. Having approached the minimum target by the end of 2019, OPG's inventory targets also reflect the need over the IR term to maintain sufficient quantities of uranium concentrate (as well as uranium dioxide and manufactured fuel bundles) in order to accommodate a one time, full load of new fuel required for each reactor core to prior to the restart of Darlington Units 3, 1 and 4, as discussed above. In the earlier years of the forecast period, this is expected to contribute to a temporarily higher level of uranium concentrate inventory. Otherwise, the target of 288,000 KgU remains in effect to the planned Pickering shutdown at the end of 2025.

For 2026, OPG has lowered its strategic uranium concentrate inventory target to 225,000 KgU. The post-Pickering shutdown uranium concentrate inventory target will continue to be monitored through the IR term.

Nuclear fuel inventories are set out in Ex. B1-1-1, Section 3.2.3.

4.2 Uranium Concentrate Procurement

4.2.1 Objectives

The primary objectives of OPG's uranium concentrate procurement program are to ensure an adequate supply of uranium is available to meet the operational requirements of OPG's nuclear units, while minimizing the price, market and credit risks associated with this supply. In addition, OPG also must ensure quality standards are met.

As in EB-2016-0152, the procurement program has the following requirements:

- **Purchase within pre-established physical coverage limits.** OPG uses a quantitative risk management model to establish long-term physical coverage limits. These limits establish the maximum and minimum percentages of future uranium requirements that can be under contract. The minimum limit ensures security of supply by requiring a certain amount of OPG's future requirements be under contract or in inventory. The maximum limit ensures more regular entry by OPG into the market, thereby encouraging a diversity of suppliers which reduces the impact of individual supply source disruptions.
- **Purchase within pre-established financial coverage limits**. OPG's risk management methodology also establishes financial coverage limits. Financial coverage limits specify the maximum and minimum portion of supply to be under "fixed" price arrangements, expressed as a percentage of OPG's aggregate amount under contract. This mitigates near term cost uncertainty and encourages a diversity of contract pricing mechanisms.
- **Maintain, as market conditions dictate, a strategic target inventory of uranium.** This further mitigates the impact of supply disruptions and ensures continuous reactor operations.
- **Employ competitive and fair procurement practices**. The use of these practices provides value for money. OPG's standard procurement practice is to employ competitive

processes where available, using pre-determined evaluation criteria that include quality, security of supply and costs.

OPG completed an internal review of its physical and financial coverage limits in November 2016 and November 2018. Following the 2016 review, changes were made to the financial coverage ratios. As noted above, financial coverage limits specify the minimum and maximum portion of supply to be under "fixed" price arrangements, expressed as a percentage of OPG's aggregate amount under contract. The revised range of the limit for "fixed" price arrangements was changed from a minimum/maximum of 50% to 70% to a minimum/maximum of 45% to 65%. This change was made to reflect the downward pressure in uranium prices at the time. No changes were made following the 2018 review of the risk limits. The internal review of the uranium coverage risk limits was completed in 2020, and no changes were made to the risk limits.

4.2.2 Uranium concentrate pricing provisions and fuel contracts

OPG periodically purchases uranium concentrate under long term contracts, short-term spot contracts, or a combination of both. OPG's existing term contracts for the supply of uranium concentrates contain a mix of pricing provisions, as shown in Chart 3 below. Under contracts with market-related pricing terms, quantities are priced at a market price established at or near the time of delivery. Contracts with fixed or indexed pricing include base prices, set at the time of contract signing, which escalate to the time of delivery by formula or by published, inflation-related, indexes. Combination, or hybrid contracts, provide for a combination of market-related pricing and fixed/indexed pricing. For spot market purchases, OPG generally enters into contracts priced for delivery within three months of contracting.

Chart 3

Summary of Existing Fuel Contracts[1]

Contract	Contract Award	Date of First Delivery	Delivery Period	Total Quantity (000 kgU)	Pricing (MR = Market related)
A	2014 3rd Q	2016	6 years	385	MR
B	2014 3rd Q	2016	6 years	385	Fixed
C	2015 3rd Q	2017	6 years	260	MR
D	2015 3rd Q	2017	6 years	220	Fixed
E	2016 3rd Q	2019	5 years	356	Fixed
F	2016 3rd Q	2019	5 years	356	MR
G	2017 4th Q	2019	6 years	692	MR / Fixed
H	2019 1st Q	2020	6 years	865	MR / Fixed
I	2020 1st Q	2021	6 years	846	MR / Fixed

OPG enters the uranium market annually by making purchases under medium to long-term contracts typically with five or six year durations. With uranium supply and demand generally in balance, this strategy has been effective in driving OPG's average unit input cost lower over the period 2016-2020. Overall, the uranium market continues to be well supplied and it is expected that the price should remain range bound along the forward price curve with minimum market volatility. A number of factors could impact the price going forward including fluctuations in exchange rates, startup of new uranium production, suspension of existing uranium production, the rate of new reactors coming on line, closures/restarts in countries with reactors (U.S., France, Japan, Korea), as well as the role of trade policies (i.e., access to Russian supplies).

In forecasting nuclear fuel costs and inventory balances, OPG models its existing contracts using forecasts of cost escalators, foreign exchange rates, and market price indicators. For its uncontracted uranium requirements, OPG uses a forecast based on information from

[1] Chart 3 lists all existing contracts that have deliveries within the IR term.

industry market participants, specifically the annual average of the Ux Consulting Company's spot forecast and the TradeTech Company spot forecast.

4.3 Uranium Conversion Services Procurement

To meet fuel quality requirements, OPG's uranium conversion suppliers must conform to CSA standard N299.2-2016, Quality Assurance Program. This standard ensures that all phases of production, including procurement, manufacturing and inspection, are appropriately controlled. OPG performs audit and surveillance of the conversion supplier and verifies conformance to the quality standard.

In 2011, OPG negotiated an agreement for uranium conversion services for the period 2012-2021 inclusive. The price charged under this agreement is indexed to inflation and is subject to adjustment for cost (or benefit) sharing if actual cost changes go beyond a threshold. OPG anticipates entering into discussions for an extension of uranium conversion services beyond 2021 based on similar terms. OPG's IR term forecast assumes no adjustment for cost or benefit sharing. Cameco Corporation continues to be the only domestic CANDU provider of uranium conversion services, and it currently supplies both OPG and Bruce Power.

4.4 Manufactured Fuel Bundles Procurement

OPG currently has a supply contract with BWXT Nuclear Energy Canada (one of the two domestic CANDU fuel bundle manufacturers) to supply OPG's requirements through 2023. The base price under this contract is subject to future adjustments for inflation and changes in zirconium costs, a key component in fuel bundles. As OPG has not negotiated pricing terms for a fuel bundle contract post 2023, the pricing in the current contract is assumed to continue with escalation over the remainder of the IR term, 2024-2026. OPG anticipates entering into discussions prior to 2023 for extension of the fuel bundle manufacturing contract beyond 2023 based on similar terms.

Numbers may not add due to rounding.

Table 1
Nuclear Fuel Costs ($M)

Line No.	Description	2016 Actual	2017 Actual	2018 Actual	2019 Actual	2020 Budget	2021 Budget	2022 Plan	2023 Plan	2024 Plan	2025 Plan	2026 Plan
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
	Uranium:											
1	**Darlington NGS**[1]	113.4	86.0	87.3	83.4	101.8	67.4	53.5	40.3	60.1	67.6	103.7
2	**Pickering NGS**	85.3	92.0	89.2	94.4	78.2	78.7	73.8	81.7	85.7	71.6	0.0
3	**Total Fuel Bundle Cost**	198.7	178.0	176.5	177.8	180.0	146.1	127.3	122.0	145.8	139.2	103.7
4	**Total Fuel Bundle Cost**[2] **($/MWh)**	4.36	4.37	4.31	4.08	4.28	3.81	3.83	3.96	4.37	4.61	4.82
5	**Used Fuel Storage & Disposal**[3]	61.0	45.1	51.8	65.0	53.6	51.7	46.2	55.2	58.6	44.1	42.9
6	**Fuel Oil**	2.4	2.1	3.3	1.7	4.6	4.7	4.8	5.0	5.1	5.2	1.6
7	**Total Nuclear Fuel Costs**	262.1	225.2	231.6	244.5	238.2	202.5	178.3	182.1	209.4	188.6	148.2

Notes:

1 Includes the impact of an initial fuel load required prior to unit start up of each of the refurbished Darlington units

2 Line 3 divided by nuclear production from Ex. E2-1-1 Table 1.

3 Used Fuel Storage & Disposal is discussed in Ex. C2-1-1.