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May 2018 Research Note – Uranium
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The perfect storm?

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Introduction

As value investors, we usually shy away from resources and materials because the factors influencing their price are inherently unpredictable – namely macro factors, the inability to reliably measure and forecast supply and demand, and the timing of cycles – not to mention the poor capital allocation of most miners. Most of the time we conclude that our time is better spent elsewhere.

However, at a recent investment conference, Paladin (ASX:PDN) presented a bullish case for the global uranium market which triggered our interest and this report. The uranium market is in an interesting situation where the **price is now sitting below the cost of production** while **demand is strengthening**, setting up the stage for a significant change in uranium prices. The bear market has been savage **with the spot price falling 85%** from 2007 highs and **reducing the number of Uranium focussed stocks from over 500 to around 40.**

Uranium is a unique situation in the sense that statistics for market demand, and to a lesser extent supply, is entirely measurable – all nuclear reactors and facilities report their statistics to the World Nuclear Association. We can know how many new facilities are being built, how much uranium they consume, and what future demand will look like (through government mandates). This ability to reliably measure most variables in the industry is the distinguishing feature that separates Uranium from other commodities, making the ability to forecast much less haphazard. Having said that, there are opaque components of this politically sensitive industry.

The current environment has led us to make a compelling case for uranium as an investment with an asymmetric return profile: a significant upside potential with limited downside risk. Our analysis suggests that supply is being reduced just as demand is starting to increase due to various drivers that should continue. There is a cross over point where we expect the market to tighten and drive prices higher.

Notes:
All figures are quoted in US dollars.
lb = pounds
mlbs = million of pounds

Summary of analysis

This trade focuses on an outcome within the next 2-4 years, while **demand is increasing and supply falling** there are enough variables to make an exact timing uncertain. Significant supply and demand imbalances exist for uranium which, we expect, will push the price back up to at least $50-60/lb by 2020-2022.

Both bull and bear cases are explored and an asymmetric return profile established suggesting the probability of the bull case playing out heavily outweighs the bear case.

Most notably**, the bull case suggests that the current price, which is below the cost of production, will be forced higher due to a mix of supply cuts, utility demand increasing** as discretionary supply depletes, and contract renewals. Industry insiders believe that many utilities will have no inventories by 2022 at the current draw down rate. This is highly unlikely to happen.

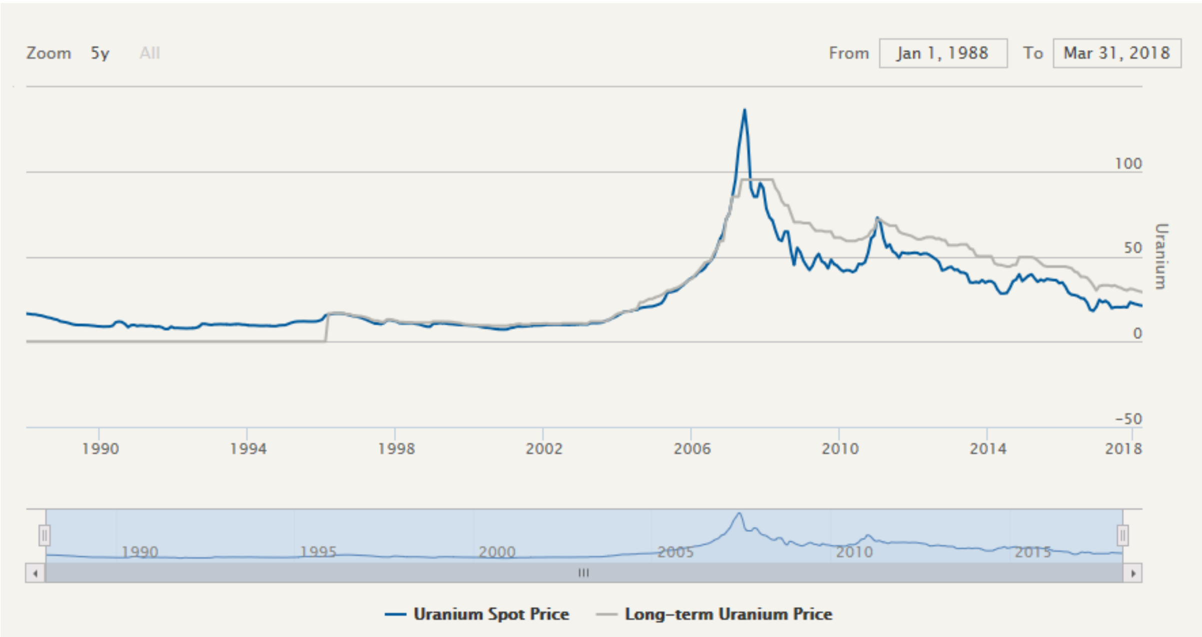
Uranium is mainly sourced from medium-long term contracts, and another variable playing out right now is that **75% of contracted supply comes off contract between now and 2025**. Most utilities are mandated to hold at least 3 years worth of supply stockpiled. Our analysis suggests most are at or below this figure now.

The obvious bear case revolves around Japanese demand, one material wildcard in this trade. While Japan has been slower than expected switching its fleet of nuclear reactors back on, the Abe government remains (publicly) pro nuclear with a goal to get nuclear back to 20% of electricity production. However, at current prices, the market is already factoring in a scenario with little to no Japanese demand, hence limited downside potential. Given the supply side of the industry is adjusting to an environment of lower demand, we feel that this negativity is priced in.

The Black Swan style risk in the uranium market is another Fukushima style disaster that leads to global rebuke of nuclear power and a significant shutdown of generating capacity. While this can't be considered impossible, it would be highly unlikely considering how safe Nuclear has proven to be over the last 50 or so years with very few major problems and Fukushima has put utilities on notice all over the world to be prepared for almost anything.

On balance we consider the risk/reward scenario attractive with huge potential upside. We have risked a small portion of the portfolio with the view that odds favour us making good profits for our investors. This may change in time but at this point, the situation appears compelling.

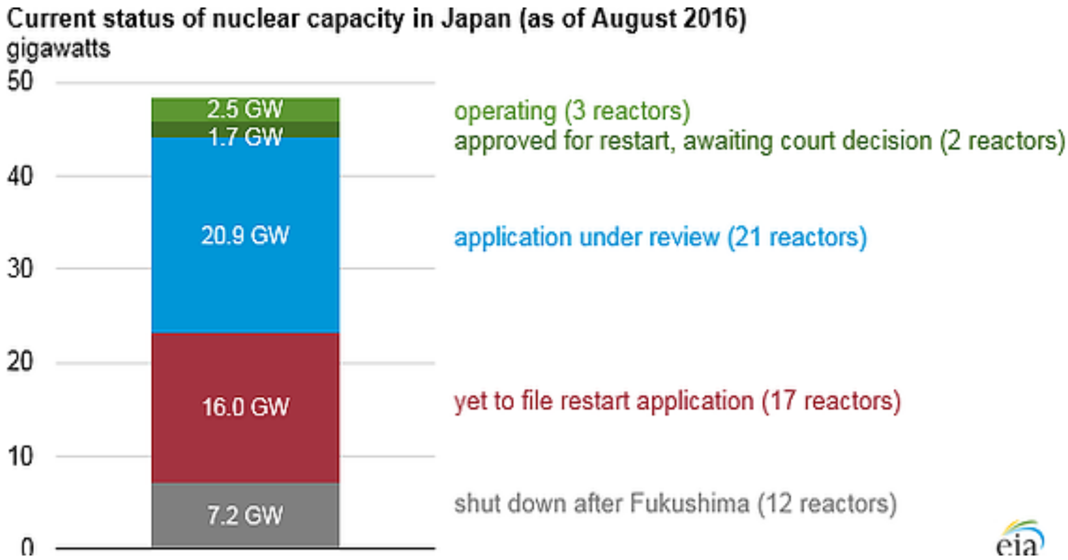
Overview



Source Cameco

The uranium price has dropped by roughly 85% from its June 2007 high of \$135/lb and currently sits at \$21/lb. There are a few main catalysts that spurred on this aggressive price drop:

- Firstly, the most important factor triggering the price fall was the Fukushima incident in 2011 **which led Japan to immediately close down all 54 of its reactors** (54 reactors provided 30% of Japan's electricity in 2010). This led to the elimination of ~13% of global uranium demand, and post-incident the Japanese have simply accepted delivery on their contracts and sold back on the spot market at a loss. As at May 2018, there have been 8 nuclear reactors in Japan that have been switched back on.



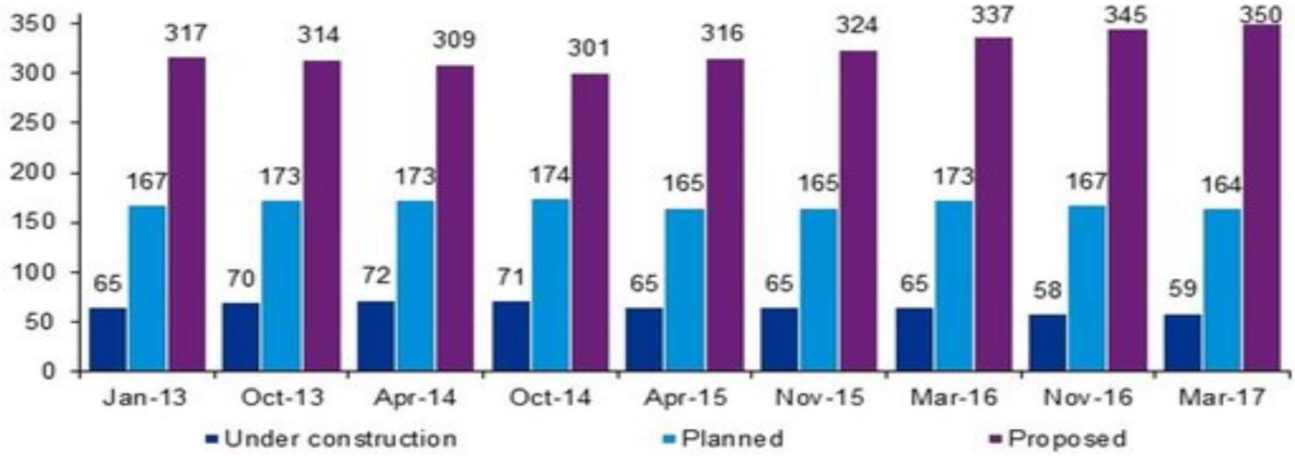
Source: U.S. Energy Information Administration, based on Institute of Energy Economics, Japan, and IAEA Power Reactor Information System (Link)

- Secondly, **utilities overbought during the bull market** of 2001-2007 with the fear that uranium prices would keep going up and hence locked in contracts at higher and higher prices – similar to what happened with iron ore during the mining boom. However, as the utilities overbought, **they have since been running down their inventories** which, has accounted for roughly 50mlbs/year less demand for uranium over the past 7 years. That is, **users have been buying less than they have been consuming.**

- Thirdly, **there has been extra secondary supply** coming from several sources including nuclear weapon de-commissioning and uranium enrichment underfeeding. The science behind underfeeding is that essentially, after the conversion processes, mined uranium only contains around 0.7% of Uranium-235 and the remainder Uranium-238 and processing facilities enrich the U-235 to ~4-5% to be usable fuel. However enrichers have had extra capacity due to the low demand environment and have effectively sold excess yield after fulfilling client orders. In 2016, the market supplied 184mlbs, with 160mlbs mined, 10mlbs recycled, and 14mlbs from underfeeding. Historically, underfeeding accounted for 4-6mlb of supply.

On the demand side, there are currently 450 operable nuclear reactors, 57 under construction, 158 planned, and ~350 proposed. The chart below shows that despite Germany and other Western nations shunning Nuclear there are plenty of reactors being built and more still being proposed.

Operable = Connected to the grid
Under Construction = First concrete for reactor poured, or major refurbishment underway
Planned = Approvals, funding or commitment in place, mostly expected in operation within 9-10 years
Proposed = Specific programme or site proposals, timing of start of operation may be uncertain



Source: World Nuclear Association, World Nuclear Power Reactors & Uranium Requirements, accessed April 2017.

The largest users of nuclear generation are summarised in the table below.
The top 10 nuclear electricity generation countries by TWh.

COUNTRY	NUCLEAR ELECTRICITY GENERATION 2016		REACTORS OPERABLE 1-Feb-18		URANIUM REQUIRED 2017	
	TWh	% e	No.	MWe net	tonnes U	**Mlbs (Equivalent)**
USA	805.3	19.7	99	99647	18996	41.87901471
France	384	72.3	58	63130	9502	20.94832585
China	210.5	3.6	38	34647	8289	18.27411839
Russia	179.7	17.1	36	27876	5380	11.86087066
Korea RO (South)	154.2	30.3	24	22505	4730	10.42786584
Canada	97.4	15.6	19	13553	1592	3.509759498
Ukraine	81	52.3	15	13107	1944	4.285786723
Germany	80.1	13.1	7	9444	1480	3.262841744
United Kingdom	65.1	20.4	15	8883	1772	3.906591602
Sweden	60.6	40	8	8376	1188	2.619091886

Source: International Atomic Energy Agency Power Reactor Information System (PRIS); company data; World Nuclear Association estimates (Link)

Comparing demand with supply, global uranium consumption was roughly 190mlbs while total uranium production was 137mlbs and total global supply was 162mlbs.

The difference between total supply and total production is secondary supply, while the difference between total supply and total consumption is the utilities running down their inventories.

Below is a summary of the major producers of uranium by country, the top 3 (Kazakhstan, Australia and Canada) plus Africa are the significant producers but Russia is a significant strategic player with influence or ownership of a large amount of resource both in Russia and outside. Kazakstan only became a major producer in the 21st century so is a relative new and very large comer to the market.

Production by Country (Mlbs U3O8)

Country	**2016**	**2016 (%)**
Kazakhstan	54.18	39.4%
Canada	30.95	22.5%
Australia	13.92	10.1%
Niger	7.67	5.6%
Namibia	8.06	5.9%
Russia	6.62	4.8%
Uzbekistan (est)	5.30	3.9%
China (est)	3.56	2.6%
USA	2.48	1.8%
Ukraine (est)	2.22	1.6%
South Africa	1.08	0.8%
India (est)	0.85	0.6%
Czech Republic	0.30	0.2%
Romania (est)	0.11	0.1%
Pakistan (est)	0.10	0.1%
Brazil (est)	0.10	0.1%
France	0.00	0.0%
Germany	0.00	0.0%
Malawi	0.00	0.0%
Total World Production (Mines)	137.49	100.0%
Total World Supply	162.15	117.9%

Source: World Nuclear Association, "World Uranium Mining Production" (Link)

The major companies that contribute to production are summarised below. Again significant concentration amongst a small number of companies with the 2 largest cutting production in 2017.

Production by Company (Mlbs U3O8)

Company	**Mlbs**	%
KazAtomProm	28.62923	20.8%
Cameco	23.01185	16.7%
Areva	18.025	13.1%
ARMZ - Uranium One	17.44518	12.7%
BHP Billiton	7.127546	5.2%
CNNC & CGN	6.534502	4.8%
Rio Tinto	5.37928	3.9%
Navoi	5.299913	3.9%
Paladin	3.130564	2.3%
Other	23.04933	16.8%
Total	137.4935	

Source: World Nuclear Association, "World Uranium Mining Production" (Link)

There is actually plenty of Uranium around but mines are not being developed due to low prices. Known resources are available but will take some time (and money) to come on stream. As with any mine the time to get a mine to operating capacity takes years and in the uranium market requires long term contracts (usually) from customers in order to get funded.

Known recoverable resources
Uranium (Mlbs) (2015)

Country	**Mlbs**	**% of World**
Australia	3668.7	29.1%
Kazakhstan	1643.1	13.0%
Canada	1123.9	8.9%
Russian Fed	1119.5	8.9%
South Africa	710.8	5.6%
Niger	642.6	5.1%
Brazil	610.2	4.8%
China	600.8	4.8%
Namibia	588.6	4.7%
Mongolia	312.0	2.5%
Uzbekistan	289.0	2.3%
Ukraine	255.3	2.0%
Botswana	162.0	1.3%
USA	138.7	1.1%
Tanzania	128.1	1.0%
Jordan	105.2	0.8%
Other	512.4	4.1%
World total	12606.9	

Source: World Nuclear Association, "World Uranium Mining Production" (Link)

Now that the facts on why the price has experienced such a percipetous decline, along with an overview of the supply and demand of the market, we are in a position to look at the investment case in more detail.

Bull case

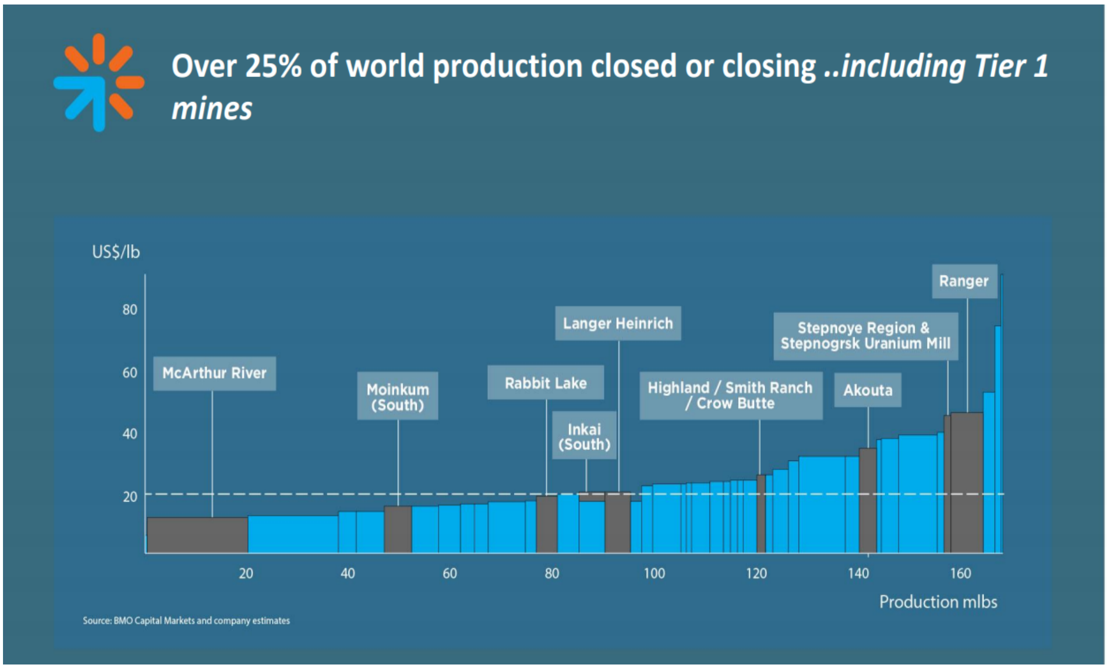
1. Price is now below cost of production: An unsustainable situation

The cash costs to produce uranium across the industry is around $30/lb, but the all-in sustaining cost, when you add maintenance and exploratory capital expenditures, royalties etc., for even the "lower cost" uranium explorers or near term producers is near $50-$60/lb. With uranium currently at ~$20/lb on the spot market and $40/lb for long-term contracts. Simply put, **these prices are not sustainable for producers** – miners are responding to the low prices by reducing production and closing mines.

Other examples include producers not only shutting down mines, but also effectively arbitraging the differential between spot and contract prices, by buying on the spot market while making delivery on contract prices. Below are examples of Cameco and Peninsular Energy doing this. However, not all producers can do this as contracts mostly mandate where the uranium must come from (because it is a politically sensitive resource) – i.e. a contract usually stipules that the uranium supplied must come from XYZ mine. This limits miners from attempting to arbitrage this gap and serves to maintain the difference.

The assessed marginal cost of a new mine is ~$45/lb

Closed mines



Source: Berkeley Energia 2018 Cape Town Presentation (Link), BMO Capital Markets and company estimates

Peninsular Energy example:

Revenue for the year was approximately US$18 million from the sale of 350,000 pounds of uranium at an average price of US$52 per pound, including sales of 100,000 pounds of uranium mined from the Lance Projects. The Company sold a further 250,000 pounds of uranium which was purchased on market, taking advantage of the current low spot price. During the year the Company entered into a contract to acquire a further 900,000 pounds of uranium at an average purchase cost of US$25 per pound to meet non-Lance sourced delivery commitments under term contracts. These purchases have provided attractive margins and revenue streams that have helped insulate the Company from the challenging uranium market at present.

Source: Peninsular Energy Limited Annual Report 2017

Cameco example:

2018 financial outlook

* see slide 23 for assumptions used in this table

Cameco

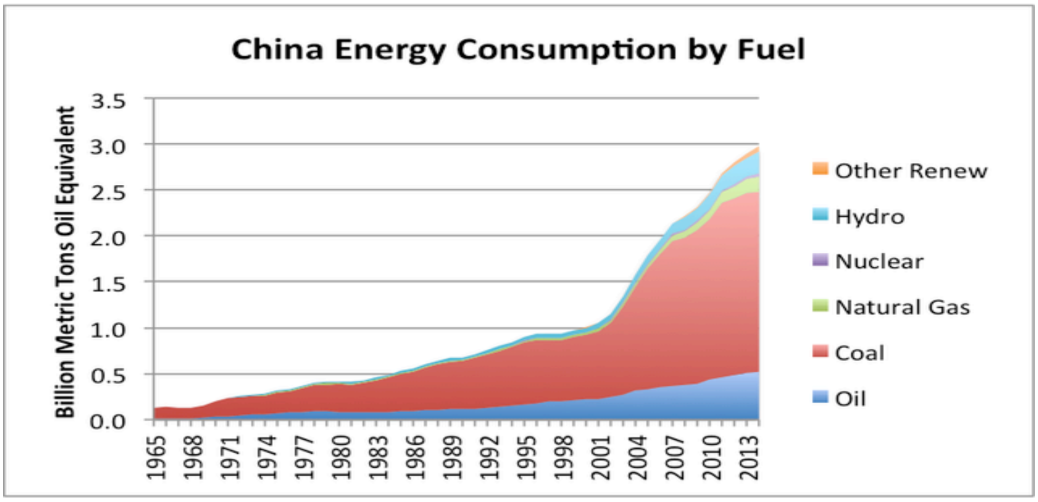
Expected contribution to gross profit	Consolidated 100%	Uranium 85%	Fuel services 15%
Production (owned & operated properties)	-	9.1 m lbs	9 to 10 m kgU
Purchases	-	8 to 9 m lbs[1]	-
Sales/delivery volume[2]	-	32 to 33 m lbs[3]	11 to 12 m kgU
Revenue[2]	$1,800 - 1,930 m	$1,460 -1,550 m[4]	$280 to 310
Avg. realized price[3]	-	$46.30/lb[4]	
Avg. unit cost of sales (including D&A)	-	$38.00-40.00/lb[5]	$21.60-22.60/kgU

Source: Cameco Q4 2017 Investor Presentation (Link)

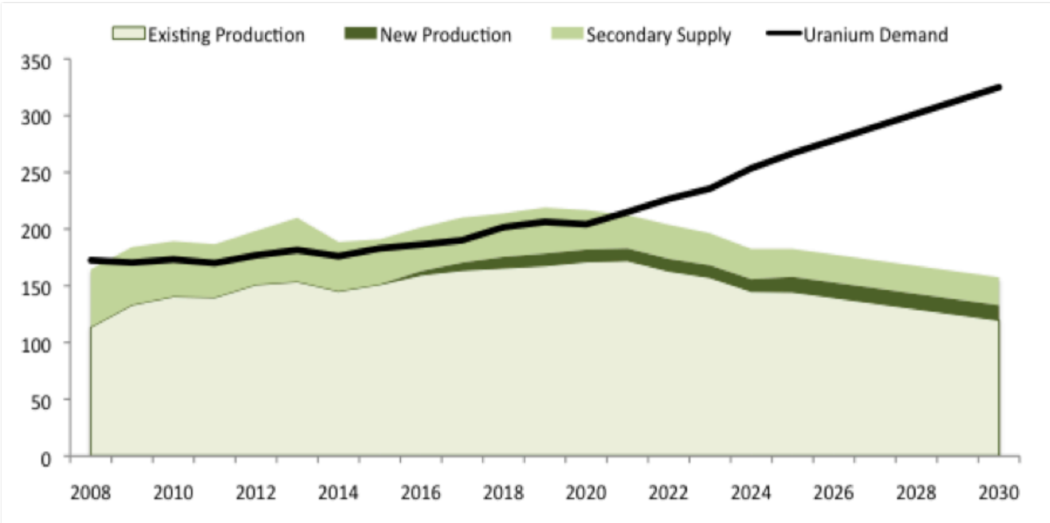
2. Demand increasing

With the current global climate situation and most EU countries mandating a ban on the sale of petrol and gas cars by 2040 (driving electricity consumption higher) – there is a strong case for a source of reliable and clean, base load energy to meet targets and reduce greenhouse gases. Reliable sources currently burn fossil fuels, while clean options are mainly unreliable – nuclear happens to offer both a clean and reliable option, with China, India and others investing heavily in Nuclear.

Although the mandated demand above constitutes a more long-term trend which is not necessarily relevant to this trade, as highlighted in the overview, there are currently 57 nuclear reactors being built of which 37 are due to be complete by 2020. China and India account for 26 of the reactors currently under construction. Both have mandated a target of 20% nuclear power generated by 2030 in line with the USA. In China it is currently at 3.2% (keeping in mind that 20% in 2030 will be larger than 20% today in terms of terawatts generated) – to be in line with the US.



Source: BP Statistical Review of World Energy 2015 (Link)



Source: UxC, World Nuclear Association (Link)

3. **KazAtomProm supply cuts and float**

Similar to OPEC, KazAtomProm, Kazakhstan's state-owned uranium producer (the largest in the world), has announced two production cuts – in January 2017, a 10% cut in planned production for 2017. Then, in December 2017, announcing a 20% cut in planned production over three years, starting from January 2018. This will result in a reduction of global mined supply of around 13mlbs or C9% Cameco has also announced the shut down of the Macarthur River mine, which removes an estimated 13.7mlbs (9%), the combined supply reduction of **KazAtomProm and Cameco's reduced production accounts for roughly 18% reduction in global uranium mined.**

Why has the price of uranium not increased with such a steep reduction in supply when a mere 2.5% supply cut from OPEC + Non-OPEC collaborators pushed oil prices meaningfully higher? Although the price did spike on announcements made by KazAtomProm and Cameco, the prices have since stabalised again at similar levels. There are a few factors at play:
The supply cycle is different – uranium tends to be contracted for delivery (~85% contracted, ~15% spot) and so cuts may not translate into immediate

shortages (although not in-line with economic theory), and the supply from secondary sources and inventory have been enough to absorb the supply drop.

Furthermore, for what it's worth – Similar to Aramco (Saudi Arabia), KazAtomProm has engaged JPM in discussions on a possible float. Any real chance of a float happening will probably see the Kazakhs attempting to manipulate or drive up the price of uranium in order to get a deal away. Realistically, while they say they want to IPO, it may struggle to get away. KazAtomProm is an ex-Soviet industrial combine, and aside from producing uranium, the government also uses it to provide infrastructure support etc. People in the government may be motivated to keep it in Government hands as they (reputedly) receive kickbacks/bribes which may be at risk if it goes public and a Big 4 auditor is brought in to audit the books.

4. **Inventories & contract cycle**

Inventories and contract cycles are difficult to measure because certain countries do not report their inventories and contract terms. For instance, Japanese, Chinese, and non-Western (i.e. countries outside of US and EU) utilities do not report inventories or contracts. However current estimations indicate inventories (pounds) at: US 116m, EU 138m, Japan 160m, China 280m, Supplier-held 50m.

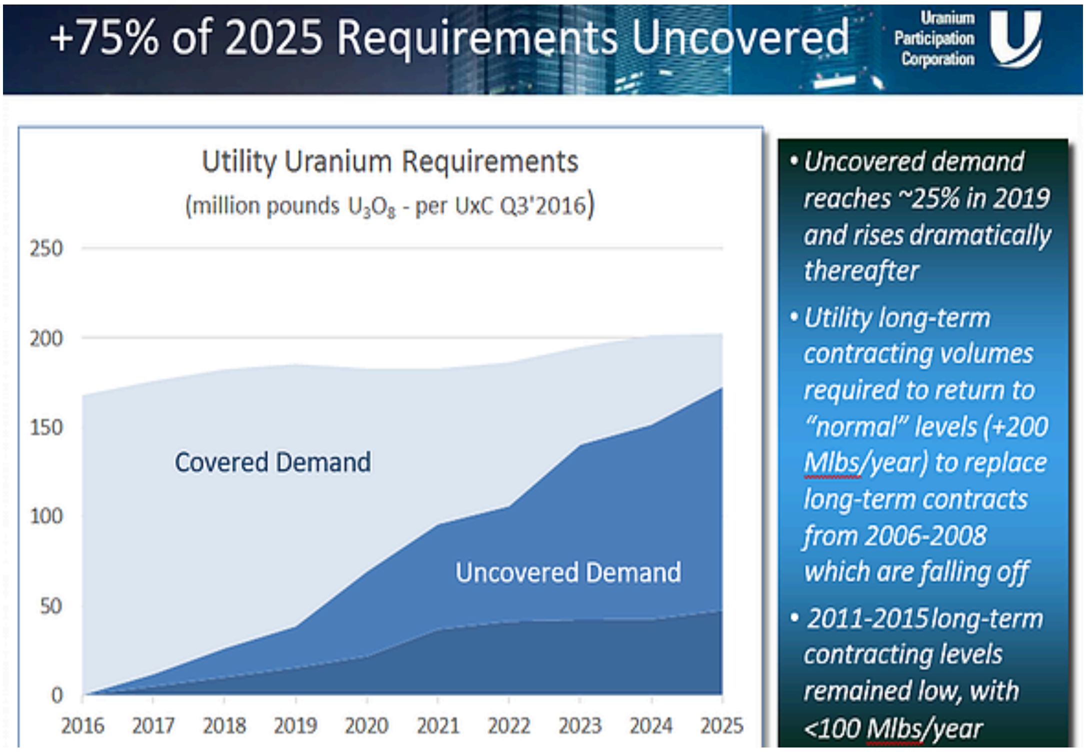
On a relative scale, excluding China, this means that utilities now have roughly 2.5 years' worth of discretionary supply. Which essentially equates to ~1 cycle's worth of supply – It takes 18-36 months to process uranium from the time it is mined, converted, enriched, and assembled then delivered to the end-user. Typically, they lock-in 3-5 year contracts to secure reliable supply. Discretionary supply essentially acts as a buffer of supply in-case any supply disruptions occur – and assuming (Western) utilities continue to run down their discretionary supply to dangerously low levels, say 0.5 cycles worth, it still means that they can only continue to do so for another few years, but not indefinitely. Nuclear reactors need to remain operational, short term shut downs are not an option.

China is a little different. As part of its strategic policy, the Chinese government has mandated 7-years worth of supply to be held in inventories at all times. Stated above, China's current consumption is 18.27mlbs/year while holding and estimated 280mlbs in inventory –Although current consumption rates equate to 15 years worth of supply, estimates by UBS suggest that China will consume 40mlbs by 2020, and doing the math, that equates to exactly 7-years' worth of 2020 inventory being held today.

> *China's uranium demand is set to expand at 14%p.a to 40Mlbs by 2020. China's build programme is a very bullish long term driver for uranium demand, but it is also an important near term demand support. China now has 36 operating reactors, with another 21 under construction & 41 in the planning stage. Beyond that there is another 170 proposed. This could see installed capacity that is currently 32.6GWe almost double to 58GWe by 2020-21 & then up to 150GWe by 2030. This compares to the current global installed fleet of 447 reactors & 391.4GWe. The large driver here is China's efforts to improve air-quality around cities.*

Source: UBS, "Australian Resources Weekly: Uranium 101", Feb 2017.

Furthermore, 70% of existing long-term contracts are due to expire within 3 years, meaning that utilities will soon *have to* renegotiate contracts to secure supply. 75% of 2025 nuclear power plant uranium requirements are uncovered. It reaches 25% uncovered in 2019 and accelerates from there. US utilities have less than 50% of their uranium supply under contract from 2020 onward while EU utilities will have less than 50% coverage from 2022.

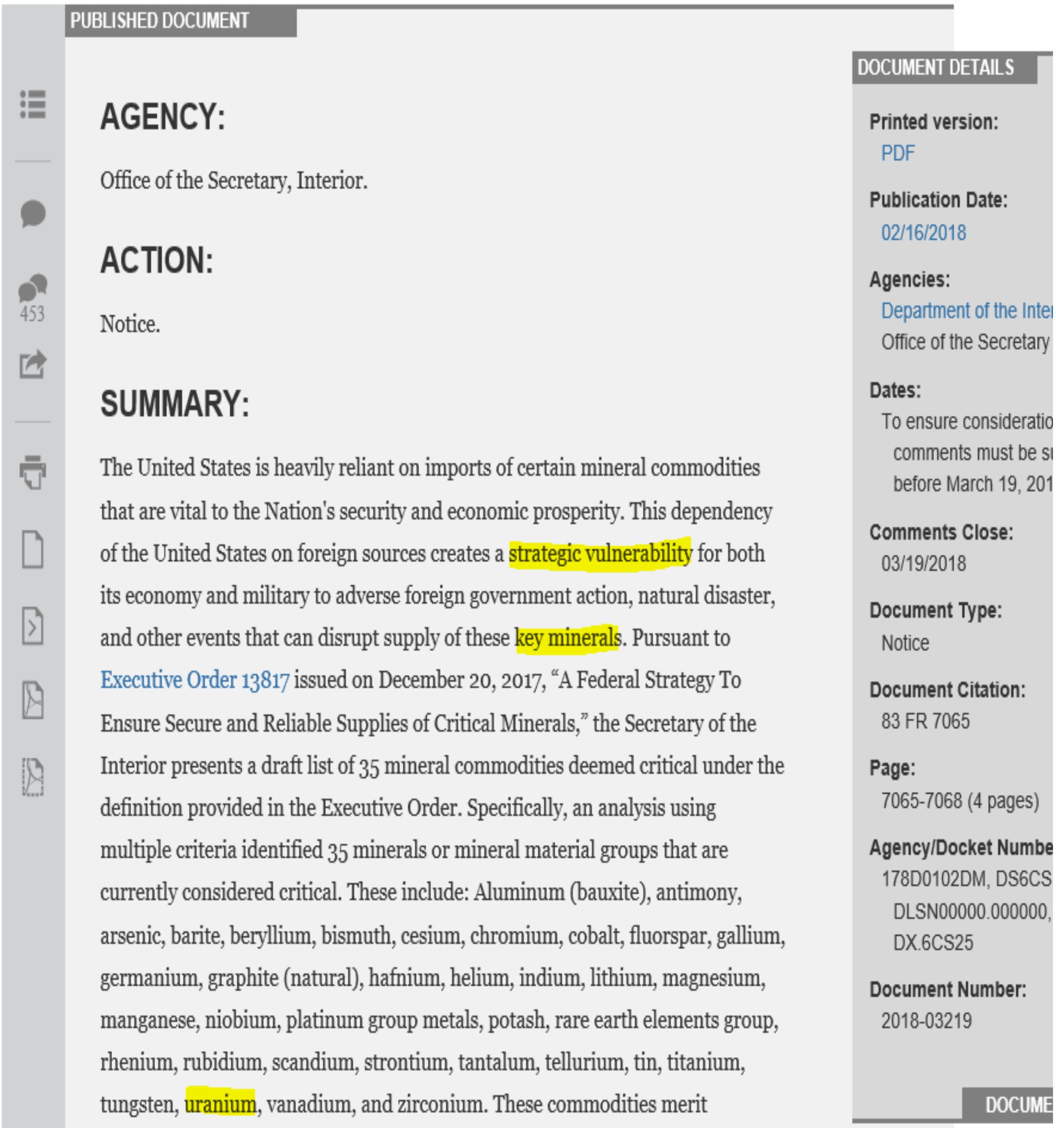


Source: The Stock Calatyst Report (Link)

5. **Russian influenced supply**

Russia and Russian-influenced countries produce ~60% of the world's uranium with Kazakhstan accounting for ~40% of world production. Meanwhile, the US generates 20% of their power from nuclear energy, 95% of which is imported, and roughly 50-55% of the imported uranium comes from Russian & Russian-influenced countries. With the current geo-political tensions at cold war levels, it is not only a national security concern for the US, but also means that Russia has cornered the market and has the capacity to influence prices at its discretion. And Russia's recent cooperation with OPEC in influencing the oil price proves her ability and willingness to influence the prices of commodities for her benefit.

As recent developments would have it, the Trump administration has issued an executive order to assess US reliance of imported 'critical materials' and address the 'strategic vulnerability'. If tariffs are announced, what happens to the price? Of course, it's not wise to bank on any of this happening.



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AGENCY:

Office of the Secretary, Interior.

ACTION:

Notice.

SUMMARY:

The United States is heavily reliant on imports of certain mineral commodities that are vital to the Nation's security and economic prosperity. This dependency of the United States on foreign sources creates a strategic vulnerability for both its economy and military to adverse foreign government action, natural disaster, and other events that can disrupt supply of these key minerals. Pursuant to Executive Order 13817 issued on December 20, 2017, "A Federal Strategy To Ensure Secure and Reliable Supplies of Critical Minerals," the Secretary of the Interior presents a draft list of 35 mineral commodities deemed critical under the definition provided in the Executive Order. Specifically, an analysis using multiple criteria identified 35 minerals or mineral material groups that are currently considered critical. These include: Aluminum (bauxite), antimony, arsenic, barite, beryllium, bismuth, cesium, chromium, cobalt, fluorspar, gallium, germanium, graphite (natural), hafnium, helium, indium, lithium, magnesium, manganese, niobium, platinum group metals, potash, rare earth elements group, rhenium, rubidium, scandium, strontium, tantalum, tellurium, tin, titanium, tungsten, uranium, vanadium, and zirconium. These commodities merit

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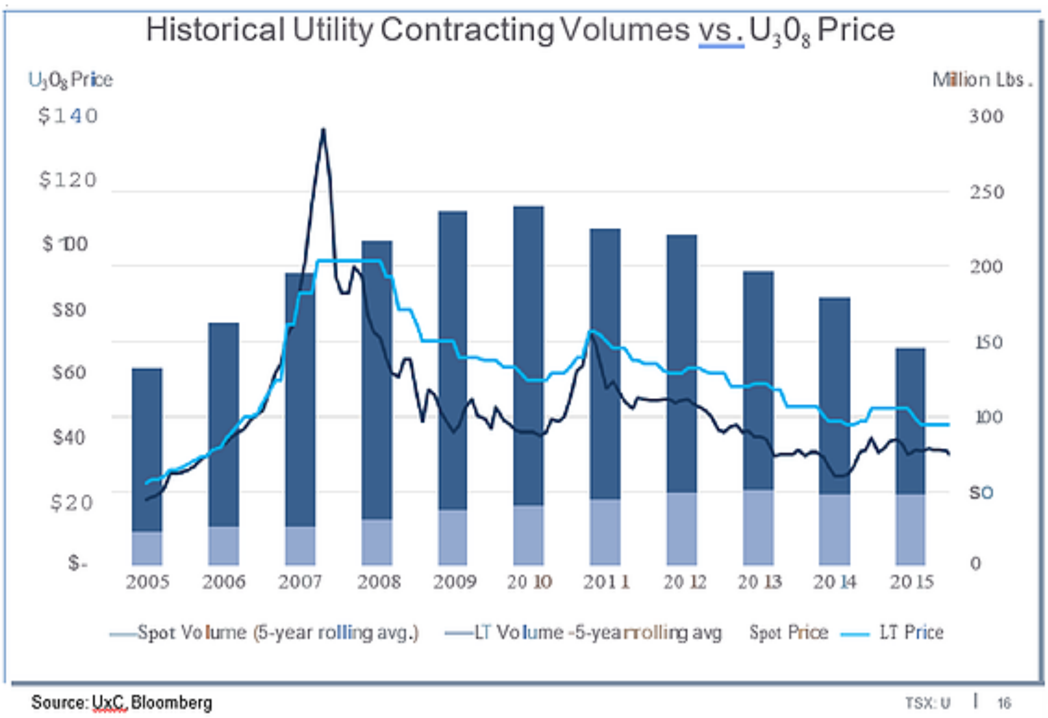
Source: US Office of the Secretary, Interior (Link)

6. **Primary supply: will miners re-open?**

   It is rational that miners will only re-open closed capacity if the contract prices are set significantly higher than the current spot at levels that producers earn at least a reasonable margin above their cost of production of ~$50-60/lb. It is unlikely shareholders and funders will continue to support unproftable production.

   It doesn't make economic sense for a mine to reopen only to breakeven or lose money. If an economic return is not provided resources will not be reopenned nor new ones established. Reserves will stay in the ground.

Source: UxC estimates, Cameco ([Link](#))



Furthermore, the long lead-time nature of uranium (and most other commodities) mine development means that producers are not able to respond quickly to sudden increases in demand or significant supply disruption.

7. **Will Japan come back online?**
   Japan has had a troubled past with nuclear, and so it is a very sensitive social and political topic. This is the most uncertain factor of the thesis. What happens in Japan will be material in affecting the price of uranium going forward. It was a buyer of over 10% of world uranium production.

   Although social headwinds may exist, there is also an economic tailwind which, builds a strong case for reactors to be switched back on.

   - Japan is currently accepting delivery of its contracted uranium and selling it at a (significant) loss on the spot market.

- The current 140mlbs inventory held by utilities is not fungible. The inventory comprises rod assemblies which, are only suitable for Japanese-type reactors. Tokyo Electric Power cannot go to China National Nuclear and sell fuel because it will not be suitable for a Chinese-type reactor. If the Japanese cannot sell it, then it makes sense for them to at least use the remaining inventory. It is essentially a source of free, clean, and reliable energy **that Japan can use to stimulate its economy**. The fuel is paid for and so are the reactors, it is the cheapest and cleanest source of baseload available. There has already been progress in this area, since early 2017 Japan has progressively switched back on 8 reactors out of 45, the Government has not withdrawn its commitment to generate 20% of electricity via Nuclear. Time will tell.

Another factor is that energy is a strategic resource. Consequently, most countries hold strategic reserves: the US holds vast oil reserves and China has a 7-year nuclear energy reserve mandate. Assuming Japan eliminates its use of nuclear energy, storing several years supply of coal and LNG will simply take far too much space.

8. **Reactor life extension**

Reactors built in the 1960s-1980s are generally assumed to have an estimated useful economic life of 40 years – however these were *financial* estimates (project finance requirement), and although the estimated *economic* life may be 40 years, the actual *operable* life in reality can be much longer. Reactors are now regularly being extended to have a useful life of ~60 years – there is incentive for the authorities to provide extensions, so long as the power plants meet safety requirements. Building a new reactor requires a huge amount of capital expenditure. Estimates by thought leaders indicate that an average of 60 years useful life is not unreasonable - Below are 2 real examples of US nuclear power plants with extentions of useful life to ~60 years.

H.B. Robinson Steam Electric Plant, Unit 2

Location: Hartsville, SC (26 miles NW of Florence, SC) in Region II
Operator: Duke Energy Progress, LLC
Operating License: Issued - 07/31/1970
Renewed License: Issued - 04/19/2004
License Expires: 07/31/2030
Docket Number: 05000261

Reactor Type: Pressurized Water Reactor
Licensed MWt: 2,339
Reactor Vendor/Type: Westinghouse Three-Loop
Containment Type: Dry, Ambient Pressure

Plant Diagram

Nine Mile Point Nuclear Station, Unit 1

Location: Scriba, NY (6 miles NE of Oswego, NY) in Region I
Operator: Nine Mile Point Nuclear Station, LLC
Operating License: Issued - 12/26/1974
Renewed License: Issued - 10/31/2006
License Expires: 08/22/2029
Docket Number: 05000220

Reactor Type: Boiling Water Reactor
Licensed MWt: 1,850
Reactor Vendor/Type: General Electric Type 2
Containment Type: Wet, Mark I

Plant Diagram

Source: US Nuclear Regulatory Commission (Link)

The extension of useful life ensures that the uranium consumption profile of a certain country remains stable for some time.

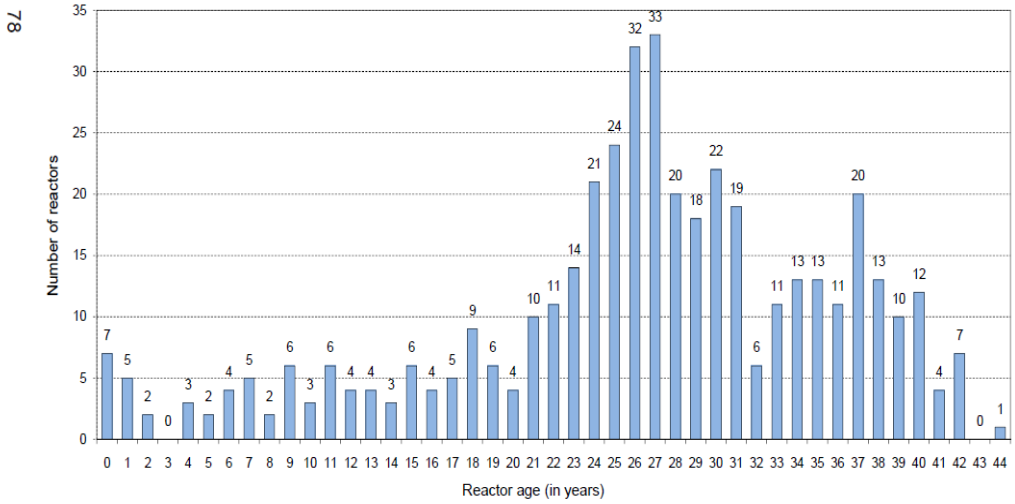


Figure 5. Number of reactors in operation by age (as of 31 Dec. 2011).

Source: International Atomic Energy Agency "Nuclear Power Reactors in the World", "Numer of reactors in operation by age".

9. Utilities insensitive to price of Uranium

The World Nuclear Association estimates that fuel for nuclear reactors account for roughly 14% of operational costs – however the completed product (the rod assemblies) go through a series of conversions, enrichments, and fabrications, before they can be used as fuel. Therefore the cost component of the raw uranium is much lower.

> *The US Nuclear Energy Institute suggests that the cost of fuel for a coal-fired plant is 78% of total costs, for a gas-fired plant the figure is 87%, and for nuclear the uranium is about 14% (or 34% if all front end and waste management costs are included).*

Source: World Nuclear Association, "Economics of Nuclear Power" (Link)

However, the price of uranium has dropped since the time this report was written, and so the cost at current prices may very well be lower than the 14% stated. Below is a cost breakdown of the nuclear fuel:

Front end fuel cycle costs of 1 kg of uranium as UO_2 fuel

Process	Amount required x price*	Cost	Proportion of total
Uranium	8.9 kg U_3O_8 x $68	$605	43%
Conversion	7.5 kg U x $14	$105	8%
Enrichment	7.3 SWU x $52	$380	27%
Fuel fabrication	per kg	$300	22%
Total		$1390	

Source: World Nuclear Association, "Economics of Nuclear Power" (Link)

The price of uranium is now $21/lb, which equates to $46.29/kg. Furthermore, we are interested in how sensitive the utilities are in changes to U3O8 as the conversion, enrichment, and fabrication costs will tend to be fixed. U3O8 is also the compound quoted in the market. Reverse engineering the above table with an updated price we get:

Scenario A: Base Case

A	B	C = A*B	D = C*1196.64	E = 0.14*(1196.64/1390)	F = D*E
Amount Required (KG)	**Price ($)**	**Amount * Price**	**Proportion of total**	**Fuel cost as % of total cost**	**U3O8 as % of Fuel Cost %**
8.9	46.30	412.04	34%	12.05%	4.1%
7.5	14	105.00	9%		
7.3	52	379.60	32%		
1	300	300.00	25%		
		1196.64	100%		

This means that the cost of raw uranium itself accounts for only C4% of a reactor's operating cost – at such a low percentage, utilities are relatively insenitive to the price of uranium. *A 300% increase in the price of uranium will only increase the cost of fuel by 8%.*

Scenario B: 3x increase in uranium price to the above scenario

A	B	C = A*B	D = C*2020.73	E = 0.14*(2020.73/1390)	F = D*E
Amount Required (KG)	**Price ($)**	**Amount * Price**	**Proportion of total**	**Fuel cost as % of total cost**	**U3O8 as % of Fuel Cost %**
8.9	138.89	1236.13	61%	20.35%	12.4%
7.5	14	105.00	5%		
7.3	52	379.60	19%		
1	300	300.00	15%		
		2020.73	100%		

9. **Megatons to Megawatts**

As part of a nuclear disarmament deal between the US and Russia, a program called Megatons to Megawatts was agreed upon whereby Russia would reduce its nuclear warhead stockpile by diluting the Highly Enriched Uranium (HEU) of the warheads and selling the diluted product to the US to be used for energy generation. This came into effect in 1993 and ended in 2014. The diluted uranium acted as a reliable secondary supply source of fuel for US nuclear utilities, and with this agreement now finished, utilities will need to source their uranium from open markets and contracts with producers.

To give an indication of exactly how much uranium was sourced by the US from this method – the program converted 475.2 metric tons of HEU to 13,723 metric tons of low-enriched uranium. In 2017 US consumed 18,996 tons of uranium.

Bear case

1. **Secondary supply**
   The most influencial factor supporting the bear case is the uncertainty surrounding whether Japan will turn the bulk of its nuclear reactors back on. This is a major factor in predicting demand. We believe it is the factor that may make-or-break the thesis. The Japanese have a strong resolve to live by what they feel is right and an almost superhuman ability to disregard self-interest in achieving the national interest – When Fukushima incident happened all nuclear reactors were closed. At the urging of the government to conserve power, Japanese power consumption dropped 18%. Imagine the same scenario happening in a Western country! There are already political parties involved in petitioning for the closure of all reactors and ending nuclear generation. The Abe government remains pro nuclear – who knows which way the winds will blow?

   Although political outcomes are unpredictable, we can still make assumptions on fundamental factors influencing the needs of a country. Politicians are famous for breaking election promises, not because they like breaking promises, but because there is a fundamental disconnect between what is promised and what can be delivered.

   Taking this perspective of assessing underlying fundamentals, we are still of the view that Japan ***has*** to switch the reactors back on – they have 140mlbs of inventory sitting in storage which is essentially no-cost, carbon-free energy which they cannot sell. Electricity prices have been very strong and a material lowering of prices would be seen as a huge boost to industry. Japan currently has a 20-22% nuclear energy target, down from the 2010 actual generation of 30% and the 2010 target of 40% nuclear generation by 2018.

   Aside from Japan selling into the spot market, other sources of secondary supply come from underfeeding and recycling.

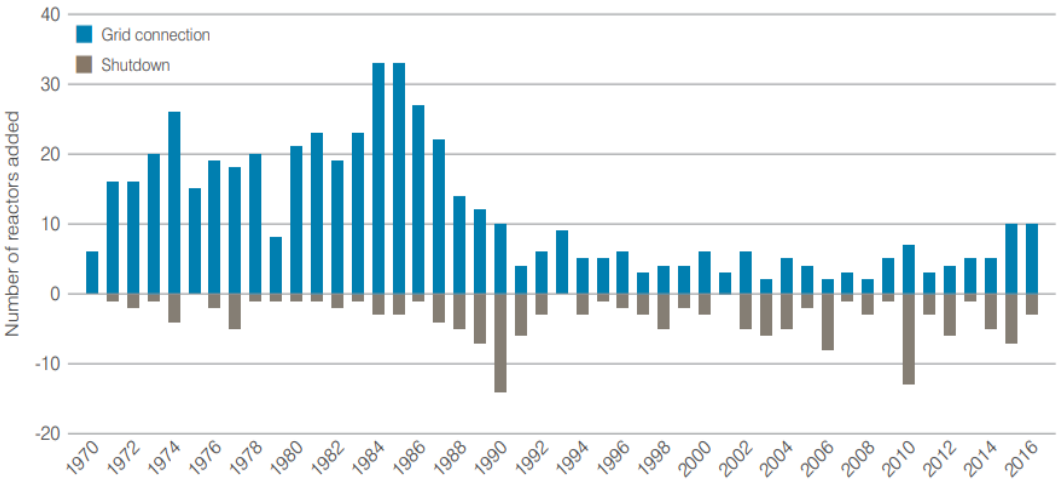
   Underfeeding is the process whereby the enrichment facilities generate a higher yield of reactor-grade uranium than demanded by their client. Uranium isotopes are separated in a centrifuge machine. When demand from clients is low, as it currently is, the enrichment facilities have extra capacity to operate their machines to squeeze out some extra yield. After fulfilling the contracted amount for the client, the extra yield is sold on the spot market. Currently this accounts for ~14mlbs of the ~160mlbs supplied. If the demand for uranium fails to pick up, the facilities are likely to continue to have extra capacity and to provide this secondary supply. However, their capacity has an inverse relationship to demand, and as demand increases, facilities will have less capcity, thereby generating less underfeeding supply.

   Finally, recycling accounts for ~6mlbs of supply, a level which has been stable for some time as the current available technology makes it much more expensive to recycle than to mine (est. ~$200/lb price before recycling becomes viable). Current recycling programs exist more for legal reasons than economic reasons.

2. **Primary supply**
   KazAtomProm has cut production by first 10% then 20%, eliminating around 9% of global uranium supply. Although there is an incentive for the Kazakhs to influence the price as the largest single producer, there remains a risk that Kazakstan fails to remain supply disciplined. The Governments could mandate a ramp up in production to generate short-term revenue should the need call for it but given the questionable profitability it doesn't make compelling sense. However, a material ramp in production based upon a minor increase in uranium pricing could pose a risk to much higher prices.

3. **Another nuclear accident and existing bias against nuclear**
   After the Three Mile Island (1979) and Chernobyl (1986) incidents, there was a sharp decline in the number of new reactors coming online. The cold war, images of deformity and illness resulting from exposure to radiation, and… Homer Simpson, have all contributed to a bias against nuclear. Another accident may very well stall progress in nuclear for several decades. However, the strong growth in new reactor construction is coming in countries such as Russia and China with less public influence perhaps, than we in the West are used to. The below shows the dramatic decline of nuclear post Chernobyl & Three Mile.

Figure 12. Reactor grid connection and shutdown 1980-2016



Source: World Nuclear Association, IAEA PRIS

4. **The price of substitutes**
   Thermal coal and Natural Gas (LNG) have had significant drops in price in recent years, making coal and gas more competitive alternatives to nuclear than before. Furthermore, new developments in technology have allowed the cost of renewable energy to come down as well. The limiting factor to burning fossil fuels is that most countries have emissions targets which means they are incentivised to reduce reliance on fossil fuels, and renewables (to date) are an inherently unreliable source of base load power. The wind doesn't always blow and the sun doesn't always shine. There is still an underlying need for reliable clean base load power and nuclear provides this albeit with its Black Swan style risk.

Furthermore, thorium proves to be an incredibly viable replacement alternative to uranium. Scott Montgomery and Thomas Graham write in their book "Seeing The Light":

> *Thorium-232 is not a fuel itself but is fertile and can be "primed" with neutrons to become U-233, which is fissionable. This can be done in a reactor with graphite as moderator, and it can be done in liquid form, as thorium-fluoride molten salt. Thorium has certain advantages over uranium, and they are not trivial. It is three to four times more abundant in nature (even produced as a waste product in the mining of rare earth metals) and requires no enrichment though it does need a small amount of enriched fissile material to start up. A thorium molten salt reactor would require a small fraction of the fissle material and would produce far less waste, which would also be radioactive for a much shorter time. Because it does not breed a large surplus of U-233 and produces only small amounts of plutoium, mostly Pu-238, a molten salt design arguably reduces proliteration concerns. In addition, such a reactor could be refueld while operating and achieve higher efficiencies (45-50 percent) than curren reactors (~33 percent).*

Although a clear advantage, the authors also state that there is a lack of experience with Thorium and its adoption would call for the need of research, pilot, and demonstration of experimental full-scale versions. Not only that, it would require the complete redesign of reactors and the fuel source (molten salts vs. pellets/rod assemblies). Although a clear rival in the longer term, uranium is the incumbent and will be utilised until, at least, reactors are due for decommission – which is several decades away at the earliest. **We found little evidence of political will to fund research in this space.**

5. **New reactors become more efficient**
   There is no doubt that current reactors built today are more efficient than those built in the 60s and 70s. Currently, Light Water Reactors (LWR) make up 85% of the nuclear reactor fleet globally, and they typically achieve an efficiency ratio of 33-35%. The cladding of the reactor core puts certain limits on LWR performance, because it begins to corrode above 350℃. These reactors cannot operate at the high temperatures needed for efficiencies of 40% or more. However, this doesn't discount the fact that newer technologies available: typically Gen 4 reactors, such as Supercritical-water-cooled reactor (SCWR) where efficiencies of 45% are available, or reactors using Fluoride salts as primary heat coolants can attain 45-55% efficieny.

Nuclear power plants in commercial operation or operable

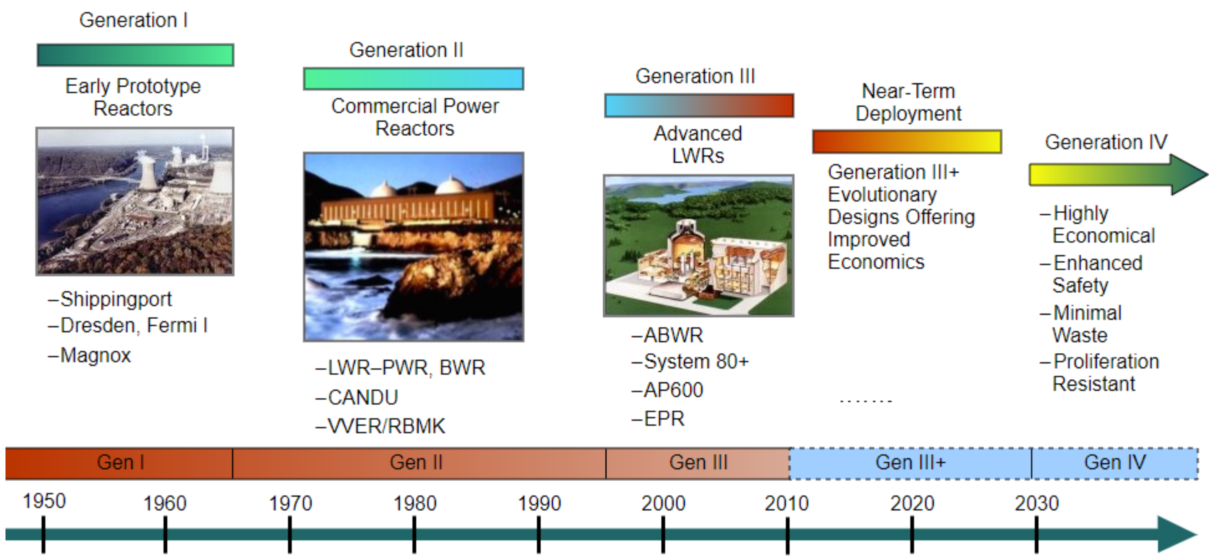
Reactor type	Main countries	Number	GWe	Fuel	Coolant	Moderator	Efficiency
Pressurised water reactor (PWR)	US, France, Japan, Russia, China	292	275	enriched UO_2	water	water	33-35%
Boiling water reactor (BWR)	US, Japan, Sweden	75	73	enriched UO_2	water	water	33-35%
Pressurised heavy water reactor (PHWR)	Canada, India	49	25	natural UO_2	heavy water	heavy water	40-45%
Gas-cooled reactor (AGR & Magnox)	UK	14	8	natural U (metal), enriched UO_2	CO_2	graphite	
Light water graphite reactor (RBMK & EGP)	Russia	11 + 4	10	enriched UO_2	water	graphite	
Fast neutron reactor (FBR)	Russia	3	1.4	PuO_2 and UO_2	liquid sodium	none	
	TOTAL	448	392				

IAEA data, end of 2015. GWe = capacity in thousands of megawatts (gross)

For reactors under construction, see information paper on Plans for New Reactors Worldwide

Source: World Nuclear Association, "Nuclear Power Reactors" (Link)

Generation IV: Nuclear Energy Systems Deployable no later than 2030 and offering significant advances in sustainability, safety and reliability, and economics



However, it's not expected that improvements in efficiency will be felt until well into the future – the magnitude of the gains in efficiency are more incremental and not necessarily game changing either. Specifically, for the purposes of this trade, which is expected to be a hold period of 2-4 years, reactor efficiency improvements should not be a real threat.

The ongoing technological development of nuclear reactors would lead us to consider more not less nuclear generation to be adopted in future.

6. **Trend away from long term contracts**

There is a risk that, like the iron ore and coal markets, there is a trend away from long term contracts. However, given the sensitive nature of the nuclear industry, it is usually mandated that the utilities have a stable source of long term supply, with clauses stating exactly which mine the uranium comes from, who processes and converts the ore, and who enriches the yellowcake, and who assembles the rod assemblies. It appears that long term contracts are likely to play a role as historically 15% of supply came from the spot market and 85% came from long term contracts.

Catalyst and Investment strategy

The above commentary attempts to provide an unbiased view of the current context and drivers of demand and supply of uranium. From the analysis above, **it is our opinion that uranium presents an incredibly asymetric payoff profile,** with significant upside potential and limited downside risk for patient investors. However, in order to uncover value, there needs to be a specific catalyst for this to avoid becoming a value trap. The catalyst in this strategy revolves around a demand pick up more so than a supply drop but both are happpening:

- **Utilities have been running down their inventory over the past 8 years by roughly 50mlbs/year.** As indiciated above, utilities only have ~3 years of discretionary supply available, and they ***can*** keep running down inventories at current rates until 2021/22 when contract coverage will be 0. However, there is no nuclear utility in the world that would risk running down their discretionary supply to 0, most start renegotiating contracts to ensure that they have 2-3 years coverage on hand. Theoretically they should be renegotiating coverage very soon, if not immediately. Because they cannot keep running down their inventories at current rates forever, there comes a point where they ***must*** come back to the market to repurchase the volumes at which they are consuming. We believe this is the key catalyst which will spark movement in the price, however it is difficult to pinpoint exactly when, but we expect it to be anywhere between 1-4 years away.

- 75% of 2025 uranium requirements are currently ***uncovered by contracts***. Utilities typically ensure that their uranium requirements are covered and renegotiate contracts 3-5 years before requirements fall due – this makes sense as it takes roughly 18-24 months from ore in the ground to fuel in rod assembly. This means that utilities ***must*** renegotiate contracts to cover 2025 demand by 2020/2022 at the latest. And as indicated above, with mines being closed, producers will not re-open unless it makes economic sense for them to do so. They will not re-open just to break-even. No business owner will restart their business just to break even. This indicates that, at a very minimum, prices by 2022 should reach $50-$60 which would be the breakeven point. ($30/lb cost of production + $20-30/lb sustaining capex, exploratory costs, royalties etc.)

To gain exposure to this trade, the strategy may involve investment into:

- A uranium ETF, either: Global-X URA or VanEck NLR. However, an investment into either ETFs does not maximise leverage. Both contain nuclear engineering companies, large diversified miners, and nuclear utilities. They do not give uranium pure play exposure.

- Invest in uranium resource holders such as Vimy or Boss , uranium miners such as Cameco or Paladin Energy or major diversified miners like BHP. This will require fundamental analysis as each company will have a different risk profile. I.e. Cameco is a fairly stable cash-positive business which is considered a blue-chip in the uranium field, whereas Paladin is laden with debt, but is highly leveraged to price increases.

- Exposure through OTC contracts such as futures/forwards.

Resources, Information, and Useful Links

Cambridge House: (Please watch these videos that accompany the investment thesis)
https://www.youtube.com/watch?v=gfvAIor53Ig
https://www.youtube.com/watch?v=jkGPdd_PZBg

Uranium Inventories:
http://www.world-nuclear-news.org/UF-Uranium-inventories-driving-markets-1509157.html
http://www.mining.com/web/uranium-collapse-signals-2020-positive-supply-shock-goviex-ceo/
KPMG Commodity Insights – Uranium Q4 2016:
https://home.kpmg.com/xx/en/home/insights/2017/05/uranium-q4-2016-q1-2017.html
Production cuts:
https://investorintel.com/sectors/uranium-energy/uranium-energy-intel/stars-may-aligning-long-awaited-uranium-market-recovery/
KazAtomProm production cut:
http://www.kazatomprom.kz/en/news/kazatomprom-announces-further-production-cuts
http://www.kazatomprom.kz/en/news/kazakhstan-reduce-uranium-production-10
US executive order – review of strategic minerals:
https://www.federalregister.gov/documents/2018/02/16/2018-03219/draft-list-of-critical-minerals
https://www.federalregister.gov/documents/2017/12/26/2017-27899/a-federal-strategy-to-ensure-secure-and-reliable-supplies-of-critical-minerals
http://www.energyfuels.com/news-pr/energy-fuels-ur-energy-jointly-file-section-232-petition-u-s-commerce-department-investigate-effects-uranium-imports-u-s-national-security/
Economics of nuclear reactors:
http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx
Berkley Energia 2018 Presentation:
https://www.berkeleyenergia.com/wp-content/uploads/2018/02/180206-Cape-Town-Presentation-2018_FINAL.pdf
Uranium cost of production:
https://www.crugroup.com/knowledge-and-insights/insights/cost-deflation-renders-the-majority-of-uranium-mines-cash-positive-in-2015/

Japanese energy consumption (by year):
https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html
Stock Catalyst Uranium Report:
http://www.thestockcatalystreport.com/uranium

Hundreds of websites and articles were visited in the process of completing this report, however it is not feasible to have them all reported here. The above are just some highlights of saved articles during the research process. Please also see articles and Excel spreadsheets attached which accompany this report.

Note: Harness Asset Management Small Companies Value Fund (the Fund) may own shares mentioned in this report. The above is in no way intended as financial advice, nor any recommendation by the manager of the fund.