CONCISE GUIDE TO WYOMING URANIUM

WYOMING MINING ASSOCIATION

2021 -2022

WMA Uranium Resource Tool

The Concise Guide to Wyoming Uranium is produced by the Wyoming Mining Association and Central Wyoming Section of the Society for Mining Engineers.

BEGINNINGS

Uranium is a nearly ubiquitous, naturally occurring chemical element. It can be found all over the world, throughout the earth's crust, and even in seawater. Normally, its concentration is so low as to often time be insignificant. But uranium is part of the natural ecosystem of our planet. The Earth's uranium was probably formed in a supernovae explosion over six (6) billion years ago.

In its pure form, uranium is a white metal heavier than lead with about 99 percent the density of gold. Uranium occurs in three main isotopes. Isotopes are atoms of the same element that have different numbers of neutrons. Uranium occurs as U238 (99.28 percent), U235 (0.71 percent) and U234 (0.0054 percent). U235 is the only isotope that exists in nature that is "fissile," meaning that it will support a nuclear chain reaction. This is important because only U235 can be used as nuclear fuel and uranium's only significant commercial use is fuel for nuclear power plants.

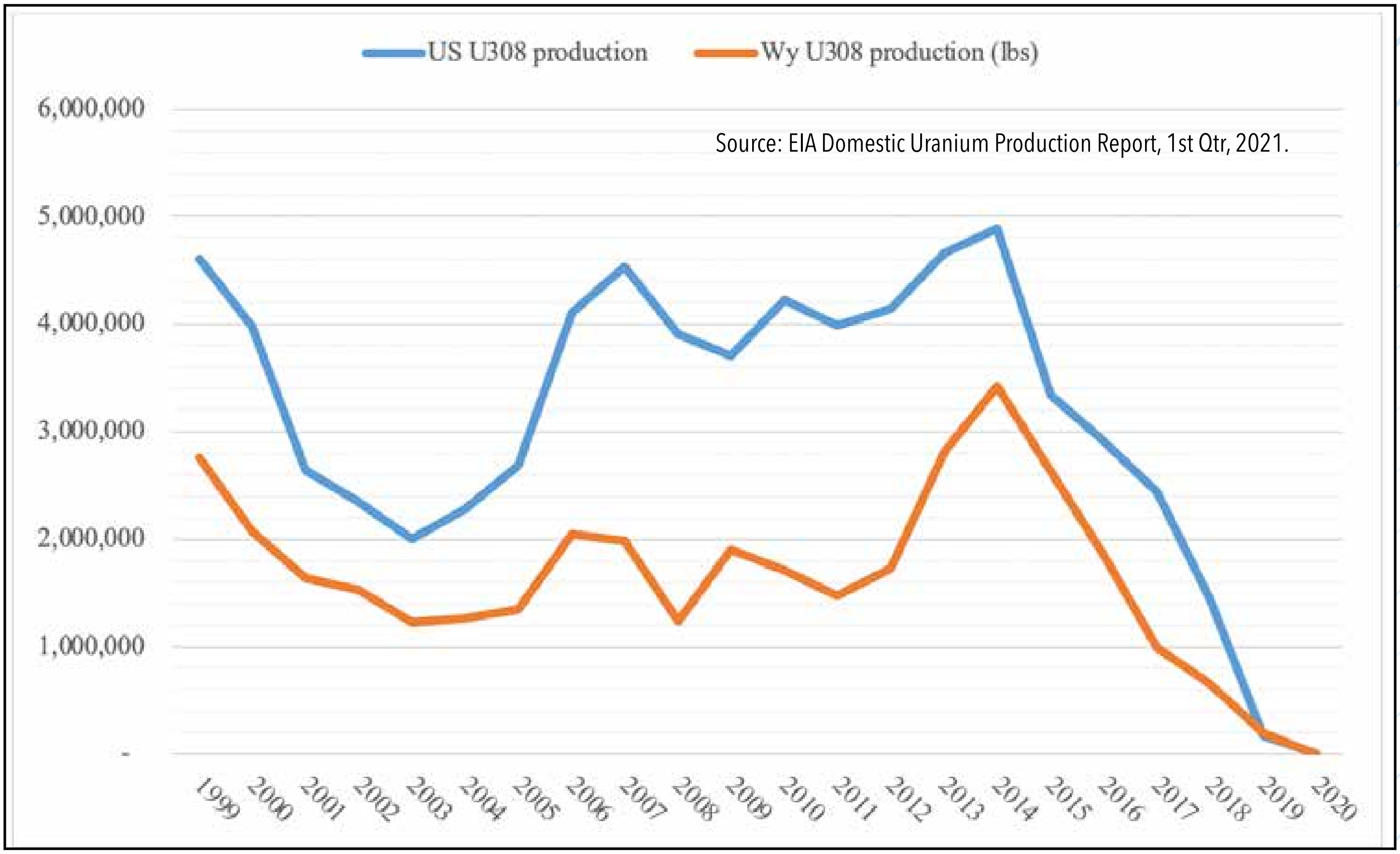
The process of recovering uranium, separating out U235, manufacturing fuel and using it in nuclear reactors is known as the "nuclear fuel cycle." This is a complicated and highly regulated process that is beyond the scope of this bulletin. Cameco Resources provides an instructive link for the process on its website: http://www.cameco.com/uranium_101/. The product of the mining process in Wyoming is uranium oxide, U3O8, also known as "yellowcake." Yellowcake contains the proportions of the isotopes listed above. This yellow powder, the consistency of talcum powder, leaves Wyoming in drums to be processed into nuclear fuel and other products through conversion and enrichment. This ends Wyoming's involvement with the nuclear fuel cycle.

USES

People have been using uranium for millennia. The first known use of uranium was by the Romans in 79 A.D. They made a yellow colored glass and yellow ceramic glazes. Yet, it was not until the late 19th century with the discovery of natural radioactivity by Henri Becquerel that scientists started to take notice of uranium. The goals of those researchers were to understand the nature of matter and the structure of the atom. The radioactive properties of uranium provided a vehicle for study.

The vast majority of uranium mined is used in the electrical power sector. Nuclear power currently (2020) is responsible for 19.7% percent of US electricity production.

US AND WYOMING URANIUM PRODUCTION, 1999-2020.



PRODUCTION TRENDS

Uranium production has a long history in Wyoming starting in 1918 near Lusk by prospectors looking for radium for Marie Curie. Other discoveries were made in the Great Divide Basin and in Crook County. The first major discovery in state was made in 1951 by Dr. John Love near Pumpkin Buttes. On September 13, 1953 Neil and Maxine McNeice of Riverton, Wyoming discovered uranium in the Gas Hills in Eastern Fremont County. Their discovery eventually became the Lucky Mc Mine. Commercial mining of uranium began in 1953, reaching its peak in 1980 at 43.7 million pounds. After the Three Mile Island incident in 1979, the uranium industry collapsed as uranium prices plummeted and production shrank. Wyoming has led the country in uranium production since 1995.

Wyoming is still the US leader in uranium production even though production has declined precipitously since 2014. This is because Wyoming's uranium resources have the lowest production cost and are the most easily accessible in the country. Other states that currently produce uranium include Utah, Nebraska and Texas.

The recovery in uranium production after Three Mile Island was short lived. In 1986, an older Soviet reactor at Chernobyl in what is now Ukraine caught fire and melted down leaking radioactive materials in a wide area and forcing the evacuation of thousands of surrounding residents. Unfortunately, this incident added to the perceived fear of nuclear power that many people have to this day. Yet nuclear power continued to be used, and production and prices started rebounding in the following years.

Uranium production started to decline in the late 1990s. With the end of the Cold War and the thawing of relations, the US partnered with Russia to reduce the former Soviet Union's stockpiles of highly enriched uranium by down blending it for use as nuclear fuel. The process had the effect of dampening US uranium production and was part of US national policy to reduce the risk of nuclear proliferation.

Due to contracting requirements, there appears to be about a two-year lag in market reaction. US uranium production increased in 2014 and has fallen precipitously since.

By the middle of the last decade, stocks of surplus weapons-grade uranium in the former-Soviet republics were mostly drawn down and relations between the US and Russia deteriorated to the point where the partnership collapsed.

In the early part of the first decade of this century, there were fears that our supply of natural gas was running low. Interest in nuclear power increased, along with uranium production. There were calls to build more nuclear power plants in the US to satisfy growing demands for electricity. Two events derailed what was being billed by some as the "nuclear renaissance."

The first of these and by far the most influential was the rise of natural gas supplies due to the widespread adoption of horizontal drilling and hydraulic fracturing, or "fracking" technologies. Fracking unleashed a torrent of natural gas on the market at extremely low prices. This combined with low-cost modular generating sets re-structured the US's electrical generating sector away from coal.

The other factor weighing against the nuclear renaissance was the earthquake and subsequent tsunami in Japan in 2011 that destroyed the nuclear power plant at Fukushima. Despite the incident resulting in no direct radiation induced fatalities, photos and videos of hydrogen gas explosions in facility buildings and the tsunami scouring the landscape heightened fears that nuclear power is not safe. What followed was a global wave of cancellations of proposed plant construction and the closing of operating plants in Germany and Japan. Reactors in Japan are slowly being restarted. It is planned to restart thirty (30) of its reactors by 2030.

Interest in Wyoming uranium resources increased. However, the events in Japan created an enormous backlash against nuclear power around the world. In the wake of Fukushima, Germany announced that it intended to phase out all of its nuclear plants over time.

In fact, a partnership with Rocky Mountain Power and TerraPower will develop the first Natrium reactor in Kemmerer, Wyoming with the intent to evetunally use domestic uranium from Wyoming as a primary fuel source.

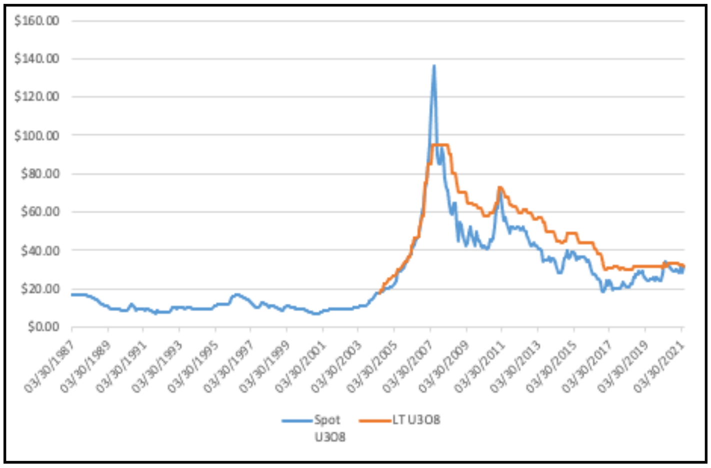
THE IN-SITU RECOVERY PROCESS

There are two different methods used to mine uranium. One is the conventional mining (open pit or underground) where ore is removed via mechanical means for processing in a conventional mill.

The other method is called in-situ mining. In-situ mining uses water wells installed in the ore body to inject a solution into the ground to dissolve and flush the uranium ore out of the host rock. The uranium containing fluid is then recovered and processed into yellowcake. Currently, all mining operations in Wyoming are in-situ.

The in-situ process consists of pumping a solution of native groundwater mixed with oxygen, carbon dioxide and sodium bicarbonate (as needed) through the ore body in an area commonly called a well field. This solution in known as "lixiviant." Using computer technology, the flow is closely controlled and monitored to maintain a balance, with slight over-recovery of groundwater to create an inward hydraulic gradient toward the well field. The uranium bearing groundwater is removed from the ground and transferred via pipeline to a remote satellite or central processing plant. Once the uranium laden groundwater reaches the processing plant it is pumped through ion exchange columns that contain millions of uranium-specific resin beads to which the uranium chemically exchanges with bicarbonate or chloride on the resin, thereby removing the uranium from the groundwater. With the uranium removed, the groundwater exiting the ion exchange columns is re-fortified with oxygen and carbon dioxide (and bicarbonate) and returned to wellfield. Typically, around 99.5% of all groundwater is recycled in this way.

US LONG-TERM AND SPOT URANIUM PRICES, MARCH 1987-MARCH 2021.



Source: UxC, LLC. The Ux U3O8 Price® and other Ux Price indicators are developed by UxC, LLC and are proprietary and exclusive intellectual property of UxC. Used by permission.

If a remote satellite facility is utilized, once the resin in a column is fully loaded with uranium, the resin is transported by truck to a central processing plant for additional processing. At the central processing plant, the resin is transferred to a resin elution (stripping) column where a concentrated solution of sodium chloride (salt) and sodium bicarbonate are added, in several progressive steps, which displaces the uranium off the resin. At the end of the elution cycle, the stripped resin contains very little uranium. The resin is then regenerated with a concentrated salt and/or bicarbonate solution then transferred back to the ion exchange vessels for reuse.

The precipitation of the uranium from the uranium-laden eluant is conducted in a separate area of the plant near the filtration and drying areas. The precipitation process consists of several pH modifications and the addition of hydrogen peroxide to create the final product, uranyl peroxide. The precipitated uranium is then pumped to a filter press where it is washed and dewatered. The resultant slurry is then commonly sent to a thickener for additional dewatering and storage before drying.

Stored uranium slurry is further dewatered in a low-temperature vacuum dryer. These dryers are commonly used in the food industry and are zero-emission dryers. The uranium product, "yellowcake," is then packaged for shipping in steel drums that are weighed, numbered and surveyed to ensure there is no external contamination.

THE CONVENTIONAL RECOVERY PROCESS

The conventional uranium recovery process involves conventional open pit or underground mining of the uranium bearing rock. Following removal, the ore is transported to a mill for processing. Milling is generally performed via the following discrete steps:

- **Grinding step**

  o Fresh ore is fed onto a conveyor and crushed to a +10 to -20 mesh in the mill with the aid of 3 – 4 inch in diameter steel grinding balls. The crushing action takes place inside the mill with the lifting action of the SAG mill as it slowly rotates. The ground ore leaves the sag mill and is pumped to the leaching circuit.

- **Leaching step**
  The flow to the leach circuit consists of ground ore from the sag mill. The slurry is generally treated in rubber lined steel leach tanks with steam, sodium chlorate, and sulfuric acid to dissolve the uranium. The dissolving of the uranium is a slow process. The slurry flows from the leaching circuit to the counter-current decantation circuit.
- **Counter-current decantation step**
  The counter-current decantation circuit consists of thickener tanks. The now soluble uranium is washed out of the slurry into an aqueous solution in these tanks. The uranium bearing aqueous solution is clarified and sent to the solvent extraction portion of the circuit. The now barren slurry is pumped to the tailings impoundment.
- **Solvent extraction step**
  Here the clarified uranium bearing aqueous solution is mixed with an organic liquid mixture consisting of kerosene, isodecanol and amine. The uranium leaves the aqueous phase and transfers to the organic phase in a process called liquid ion exchange. In some mills, this process is accomplished through the use of ion exchange columns and solid ion exchange resins. The uranium is concentrated in this step. It is then further concentrated by transferring it from the organic phase of the ion exchange resin to a second aqueous phase and that aqueous solution is pumped to the yellowcake circuit.
- **Yellowcake step**
  The uranium is then precipitated from the aqueous solution in this circuit. This yields yellowcake slurry which is dried, barreled and shipped to the converter to be processed into uranium hexafluoride.

RECLAMATION

Because there is no overburden removed and little top soil is disturbed, reclamation of in situ mining sites is much simpler and more environmentally friendly than conventional mining. The affected groundwater is treated using various techniques and returned to its pre-mining class of use as defined by the state of Wyoming. After the state approves the groundwater restoration, the wells are abandoned and all pipelines and buildings are removed. The final act is to complete a thorough radiologic survey to demonstrate the soils are clean. Upon successful completion of reclamation at an in situ mine, the site is released for unrestricted use which means there are no remaining radiological safety concerns and the land can be used for any purpose.

Conventional uranium mine reclamation is performed by plugging underground mine workings and reclaiming the surface or reclaiming any open pits. Upon cessation of operations, conventional uranium mills are decommissioned and the ground surface scraped to remove any residual contamination. All contaminated materials are placed in the lined tailings impoundment which is then capped. Reclaimed tailings sites are then deeded to the Federal government for long term custody, surveillance and monitoring.

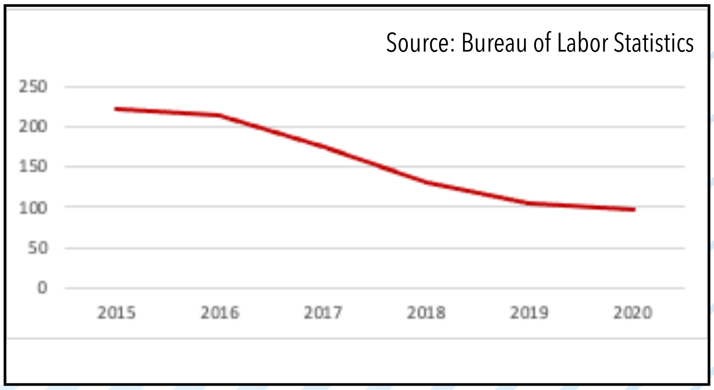
ECONOMIC BENEFITS TO WYOMING'S ECONOMY

As many people who have lived in Wyoming for some length of time know, mining is a highly cyclical business. Currently, there are four in-situ uranium mines in operation in Wyoming. There is also one conventional mill that is on stand-by. 2020 production was negligible, with producers operating in standby or in the permitting process.

Comparatively, in 1975, Wyoming uranium operations produced an estimated 7.9 million pounds, and employment in the uranium mining industry was over 1,800 employees. However, the slide in production over the decades has taken employment numbers with it. In 2020, an estimated 22 thousand pounds were produced in Wyoming, and employment hovered around 120 workers.

Today, the promise of the sector is for future expansion; however the permitting arc for these types of operations is long. It takes a considerable amount of time to complete permitting for a uranium recovery operation.

WYOMING URANIUM SECTOR EMPLOYMENT, 2015–2020



A NEW DAWN?

The last thirty years have been a time of increased awareness of the potential effects of climate change. Various protocols (Kyoto, Copenhagen, and Paris) from the Intergovernmental Panel on Climate Change (IPCC) have called for more and more global response. Many environmentalists who formerly eschewed nuclear power, and governments (especially from emerging countries) realize that the current slate of renewable power production methods will not meet their future demands for electric power. Some of them, such as India and China continue to build coal-fired as well as nuclear power plants, both in their own countries and as third-party contractors elsewhere.

More broadly, there is a gradual realization that nuclear power is the only current viable power source that does not emit greenhouse gases and will supply the amount of base load power required for sustained economic development. This has created glimmers of a new dawn for the uranium-mining sector.

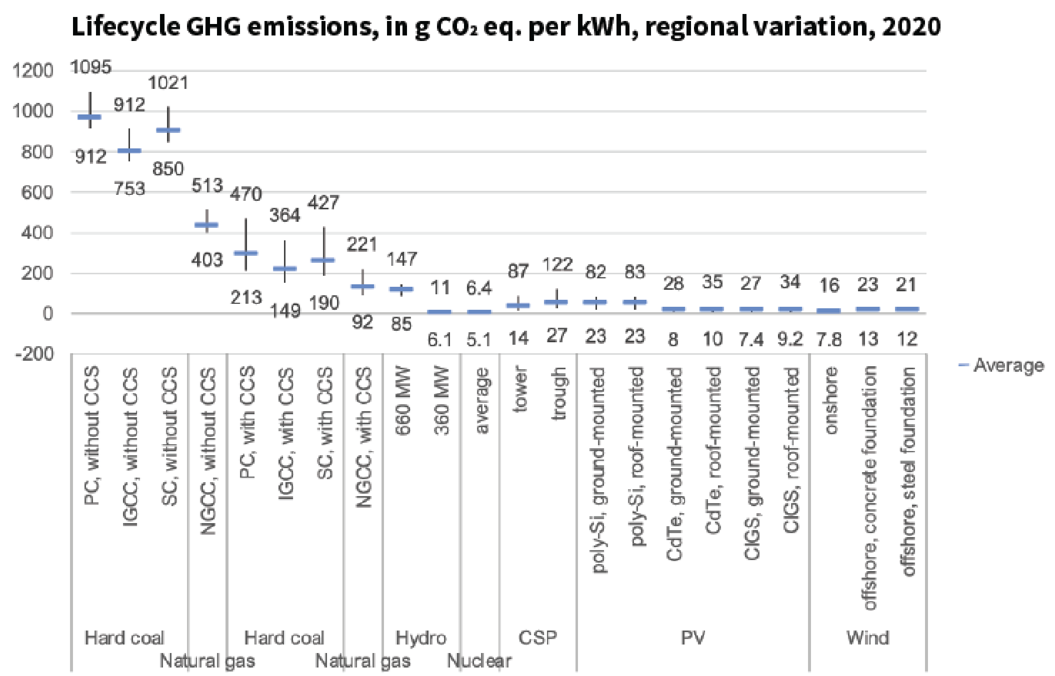
A recent United Nations' report entitled Life Cycle Assessment of Electricity Generation Options shows that nuclear power has the lowest life cycle greenhouse gas emissions per kilowatt–hour in 2020. Please see Figure 1 below from this report:

The potential shift in power demand away from fossil fuels has spurred mining companies to look for additional uranium resources, especially here in Wyoming.

In the U.S. there are currently 93 nuclear power plants operating in 28 states with two additional reactors under construction. Nuclear power has consistently supplied between 15 and 20 percent of the country's electrical power needs for the last 31 years and currently provides 55 percent of our carbon free electricity.

Additionally, in 2018 an investigation was launched under a Section 232 of the Trade Expansion Act into the national security implications of the trade practices and excessive imports of state sponsored foreign uranium producers. President Trump subsequently announced the formation of the United States Nuclear Fuel Working Group made up of federal officials to develop recommendations for reviving and expanding domestic nuclear fuel production. Among other things, recommendations were made for the creation of a domestic uranium stockpile whereby the federal government would purchase domestically produced uranium over a 10-year period. Should the stockpile come to fruition, Wyoming uranium producers stand ready to provide the supply.

Figure 1 Lifecycle greenhouse gas emission ranges for the assessed technologies



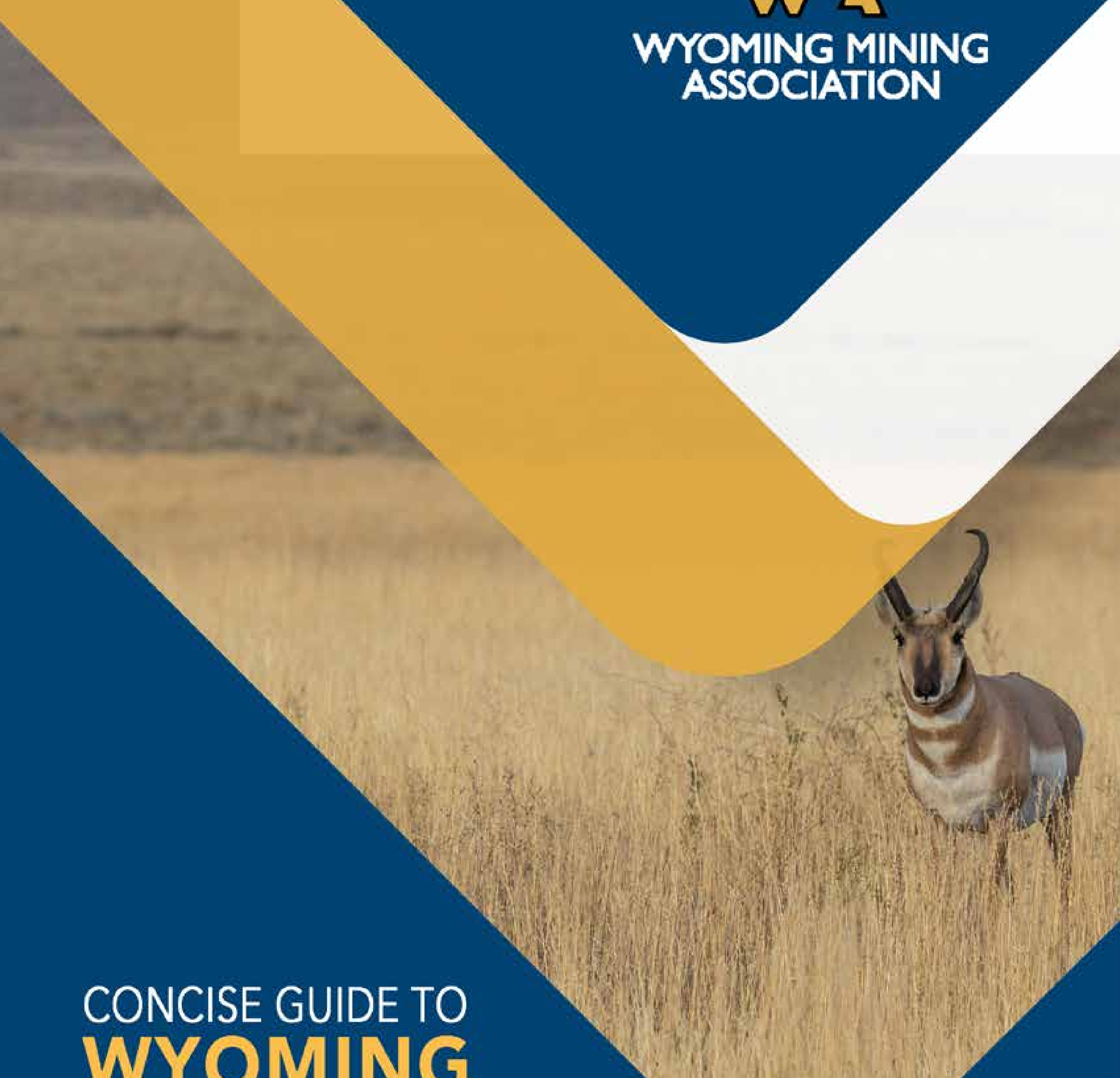
Source: Life Cycle Assessment of Electricity Generation Options - https://unece.org/sites/default/files/2021-10/LCA-2.pdf

Wyoming is part of this new dawn. On June 3rd 2021, Governor Mark Gordon announced that a company called TerraPower, supported by the Gates Foundation, has started a new project to build an advanced 345 megawatt (MW) Natrium nuclear reactor in Wyoming.

WYOMING URANIUM OPERATORS, 2020

2020 Location/operator	Mine/In-situ site	Status	Production Capacity*
Campbell County			
Uranium Energy Corporation	Reno Creek	Partially permitted and licensed	2,000,000
Uranium Energy Corporation	Moore Ranch	Permitted and licensed	500,000
Uranium Energy Corporation	Willow Creek Project	Standby	1,300,000
Energy Fuels	Nichols Ranch ISR project	Standby	2,000,000
Carbon County			
Pathfinder Mines Corporation	Pathfinder Shirley Basin	Developing	1,400,000
Converse County			
Cameco Resources	Smith-Ranch Highland operation	Operating	5,500,000
Crook County			
Strata Energy Inc.	Ross CPP	Standby	3,000,000
Sweetwater County			
Kennecott Uranium Company	Sweetwater Uranium Project	Standby/licensed	4,100,000
Ur-Energy Corporation	Lost Creek Project	Operating	2,000,000
Uranium Energy Corporation	Jab and Antelope	Developing	2,000,000
Source: 2020 Domestic Uranium Production, (released 21May21) Available from EIA.gov and other sources.		**Mine total**	**23,800,000**

WYOMING MINING ASSOCIATION



CONCISE GUIDE TO WYOMING URANIUM

2021