Uranium Resources in the State of Texas - A Comprehensive Review

Final Report

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List of Acronyms

BLM	Bureau of Land Management
CPP	Central Processing Plant
DNN	Deep neural networks
DOE	Department of Energy
DU	Depleted Uranium
EIA	Energy Information Administration
EPA	Environmental Protection Agency
GIS	Geographic information systems
GW	Gigawatt
IAEA	International Atomic Energy Agency
IP	Induced Polarization
ISR	In Situ Recovery
LiDAR	Light Detection and Ranging
MW	Megawatt
NGO	Non-Governmental Organization
NPS	National Park Service
NRC	Nuclear Regulatory Commission
NU	Natural Uranium (Section A)
NURE	National Uranium Resource Evaluation (Section II)
OECD NEA	Organization for Economic Cooperation and Development Nuclear Energy Agency
PAA	Production Area Authorization
PFN	Prompt Fission Neutron
ppb	Parts Per Billion
ppm	Parts Per Million
RAR	Reasonably Assured Resources
RMCT	Radioactive Materials Compliance Team
RMS	Radioactive Materials Section
RRC	Railroad Commission
SMR	Small Modular Reactors
STU	South Texas Uranium
TCEQ	Texas Commission on Environmental Quality
TFWS	Texas Fish and Wildlife Service
TPWD	Texas Parks and Wildlife Department
U_3O_8	uranium oxide or “yellowcake”
UAS	Unmanned aerial system

UEC	Uranium Energy Corporation
USGS	United States Geological Survey
US	United States
USACE	US Army Corp of Engineers
USFS	US Forest Service
XRF	X-ray fluorescence

I. Introduction

Since its original development in the 1940s, nuclear energy used to generate electricity has been studied with great interest. The first demonstration project for a nuclear reactor capable of electricity generation was successfully developed in 1951 by the Argonne National Laboratory. The first commercial reactor was designed by Westinghouse Corporation and started operations in 1960 (WNA, 2020). Since then, commercial nuclear reactors have grown significantly all over the world. Reducing the dependence of the United States (US) on foreign uranium from World War II to the 1970s, domestic uranium was purchased by the government for national security and weapon production. Some decline was experienced during the 1980s and 1990s, but development of a new generation of reactors after the year 2000 and concern with climate change has generated resurgence in this industry, as shown in Figure 1 (WNA, 2020; WNA, 2024a). As a new generation of smaller and more efficient and modular nuclear reactors is under development, it is expected that an increase in nuclear energy generation capacity will be experienced in the near future (DOE, 2023a). Additional information about Small Modular Reactors (SMR) is provided in a further section of this report.

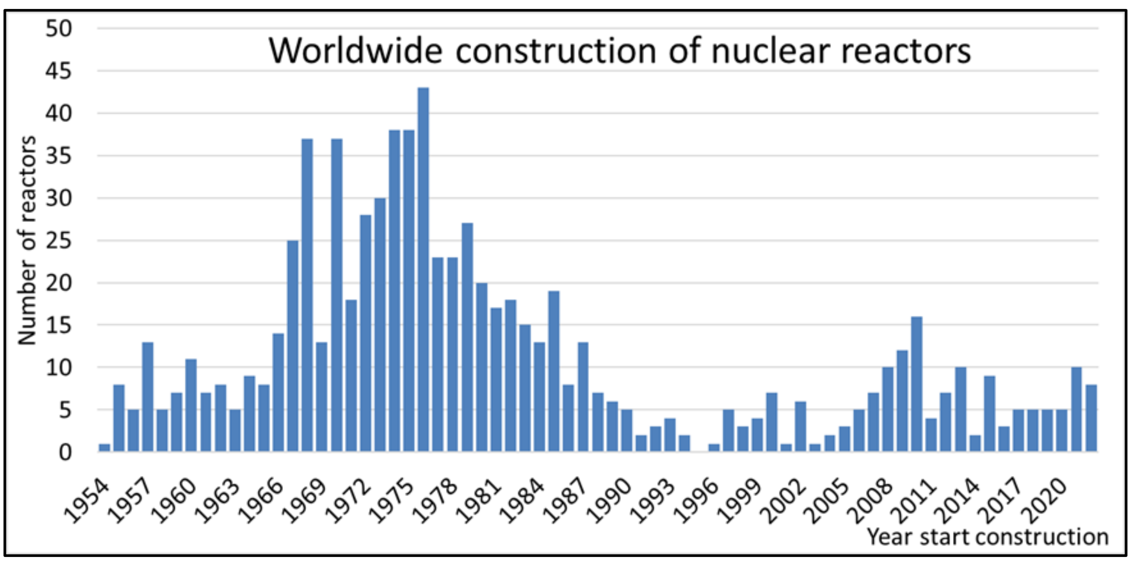


Figure 1: Worldwide construction of nuclear reactors (IAEA, 2023).

According to the Power Reactor Information System, in 2022, there were 415 nuclear reactors located in 31 countries, with the United States hosting the largest number of them with 94 reactors (IAEA, 2024). Nuclear reactors currently generate more than 18% of the electric power in the U.S. and make up almost 10% of electric generation all over the world (IAEA, 2024; WNA, 2024a).

These reactors provided 373,257 gigawatts (GW) of electricity-generating capacity globally in 2022, and 57 new reactors were reported to be under construction in multiple countries, with a potential additional electricity-generating capacity of 59,200 GW (IAEA, 2024).

The enormous size of the nuclear industry across the world, and particularly in the US, highlights the great need to generate a secure and stable supply of the elements and materials required for the operation of this essential sector. One of the most critical elements required for continuous operation of nuclear reactors is the enriched uranium used as fuel in these facilities. For this reason, uranium mining and its processing has been closely linked with the nuclear industry from the beginning. As nuclear energy grew in the US, the mining of uranium increased in diverse locations, while increasingly more efficient and beneficial technologies were applied. However, its performance has been uneven in the US as the nuclear mining industry decreased its growth during the last two decades of the twentieth century and the imported supply of uranium from international locations increased. This caused local mining operations to decline significantly across the US and in Texas. Considering the recent restriction of global supply and continuing interest in growing electricity generation from nuclear energy, there has been a noticeable interest to increase uranium production across the US, and particularly in Texas (EIA, 2023f).

This report will explore the historical development of the uranium mining industry, specifically in Texas, and will assess the existing uranium resources and supply over time. Existing resources in the state will be evaluated with regard to emerging technologies and challenges for both the global and local nuclear industry and uranium mining sector. This assessment will lead to the development of recommendations for Texas to incentivize the development of the uranium mining industry and its processing to become fuel adequate for current and future nuclear reactors. Geopolitical changes in international locations for uranium supply have generated uncertainty on the availability of this critical resource. Therefore, incentivizing local uranium production and processing will generate a resilient domestic uranium supply chain system capable of supporting current nuclear industry needs and the significant growth expected in Texas and across the US.

A. Background on uranium mining in Texas

Uranium is a valuable natural resource primarily used as a fuel in nuclear power plants (Vrhovnik et al., 2014). Given the current population growth statistics, sustainability depends on making energy more available, less resource-costly, and cheaper to produce. The 2019 annual report of the US Energy Information Administration (EIA) reported a purchase of 21,927 tons of uranium oxide (U_3O_8) or 'Yellow Cake' (equivalent) by US utilities of which 20,009 tons were from foreign sources (91%). Only 1,906 tons of US-origin U_3O_8 (equivalent) were delivered in 2019. For every ton of natural uranium (NU), only 13% becomes enriched fuel, and the rest is depleted uranium (DU). The effort to increase domestic production of uranium in the US is imperative due to instability in some areas where foreign uranium is exported. In this effort to improve production, the state of Texas plays a pivotal role.

1. Historical context of uranium mining in Texas

Uranium mining in Texas began in the 1950s and experienced significant growth during the Cold War due to the demand for nuclear weapons and energy production. The geologic formations where uranium is found in south Texas include the Whitsett formation of the Jackson Group, the Catahoula Formation, the Oakville Sandstone of the Fleming Formation, and the Goliad Sands. The Catahoula Formation and the Oakville Sandstone are accountable for about two-thirds of uranium produced in the region (Hall, Mihalasky, Tureck et al., 2017). The ore is hosted in sandstones, which are loose and unconsolidated, making underground shaft mining impractical. Therefore, exploitation has been conducted by open-pit mines and in situ leaching and recovery operations in the state of Texas.

Conventional mining: Historically, conventional open-pit mining methods were employed for uranium recovery in Texas. The first open-pit mines for uranium were in the Hackney and Nuhn deposits in Karnes County in the late 1950s (Bunker & MacKallor, 1973). However, these methods are less common today due to their higher environmental footprint and cost. Currently, no open pit uranium mines are in operation in the state of Texas. More detailed explanations of this mining method can be found in Section III.

In-Situ Recovery (ISR): In Texas, ISR has become the predominant uranium mining method. This technique involves the injection of lixiviant solutions into the ore body to dissolve uranium, which is then pumped to the surface for processing. Ammonium-based alkaline solutions were initially used for lixiviants (Buma et al, 1981), until the early 1980s. The ammonium-based solution was discontinued due to the difficulty of returning the aquifer to its original state after uranium production ceased. Palangana Dome (Gallegos, 2022), along with Lamprecht Project, Zamzow Project and Pawnee Project (Intercontinental Energy Corporation, 2023) were the only sites in the coastal plains that used ammonium-based solutions. Sodium bicarbonate, natural bicarbonate, and carbon dioxide with oxygen gas were used in the other sites and continue to be the primary chemicals used in lixiviant. The lixiviant solution (now rich in uranium) upon pumping to the surface, is concentrated for uranium using an ion exchange method in the processing plant. Precipitating the uranium concentrate yields a solid form of mixed uranium oxide called 'Yellow

Cake' as the final product of the ISR method. It has been reported that nearly 40% of the proven uranium reserves in Texas are suitable for in situ recovery mining, with over 70% of those reserves being low-permeability sandstone deposits (Shi et al., 2021).

2. Significance of uranium as an energy resource

Globally, fossil fuels are the largest source of greenhouse gas emissions (Zammit et al., 2014). In the face of climatic warming, alternative energy solutions – such as nuclear, wind, and solar – are imperative to mitigate the effects of these emissions. With nuclear power providing more energy than other renewables (Karakosta et al., 2013), according to Adamantiades and Kessides (2009), the nuclear power industry globally has led to a 10% decrease in CO_2 emissions from energy production. Nuclear power plants are more expensive to construct than renewable energy systems, but the operating costs are as low as $0.0075 per kilowatt-hour (EIA 2019).

The International Atomic Energy Agency (IAEA, 2012) predicted an increase in global energy consumption of approximately 39% by 2050, and the ongoing development of 4th-generation nuclear reactors suggests that nuclear energy will continue to be an important contributor in meeting future energy needs. This will therefore increase the demand for various sources of uranium.

In the search for sustainable energy solutions, uranium is playing an important role by serving as a low-carbon power source (Mayhew, 2018; IAEA, 2016). It significantly reduces greenhouse gas emissions in comparison to energy from fossil fuels. Secondly, the abundance of uranium in nature (e.g. 4 billion tons of dissolved uranium in seawater, see Section VI.B.3) underscores its capacity to meet current and future energy demands. The current advancements in nuclear technologies, such as advanced reactors and fuel recycling, present an opportunity to optimize uranium utilization while simultaneously minimizing waste generation. Furthermore, uranium has a long characteristic lifespan due to its high energy density. It can produce as much energy as 1.5 million kilograms of coal from just one kilogram of uranium and undergoes radioactive decay very slowly (U-238 has a half-life of approximately 4.5 billion years and U-235 has a half-life of around 700 million years). This means that power generation can be sustained for prolonged periods using relatively small quantities of fuel, reducing reliance on fossil fuels and strengthening energy security (Mayhew, 2018). Uranium mining in Texas supports economic growth and provides job opportunities for local communities. In conclusion, the significance of uranium as an energy resource lies in its role in providing a low-carbon source of power, its abundance and potential for meeting future energy demand, and its ability to promote sustainable and reliable energy solutions.

B. Objectives

The objectives of this report are four-fold, namely, to present the current uranium resources in the State of Texas, to describe the different methods of uranium ore recovery, to discuss the resources that have been recovered to date in the state, and to estimate the sources that remain for potential future recovery.

Current state of uranium resources in the State of Texas: The objective will be to demonstrate where the resources of uranium ore are located within the state of Texas, to describe the characteristics of these in-situ resources, as well as the potential recoverability of said resources. An important distinction will be whether resources are known and verified deposits, suspected deposits, prospects, or suspected prospects. The majority of the evaluations conducted in this report will deal only with verified deposits and suspected deposits.

Review of forms of uranium recovery methods: The objective of this portion of the report will be to describe the various methods of uranium recovery, and the applicability of those methods to the uranium resources identified within the State of Texas. The use of different methods of ore recovery varies in the approach to retrieve the metal, in the extent to which cover land is disturbed, and in the efficacy of uranium recovery. The applicability is driven by the type of geologic material that the uranium resides in.

Estimate the amount of uranium resources recovered to date: The objective of this portion of the report will be to summarize the estimate of the amount of uranium recovered in the State of Texas since inception of mining activities in the 1950s. This information will be based on reports of various dates, so some data is older and some more recent. Also, this section will illuminate the locations where recovery has occurred.

Determine the amount of remaining uranium resources: This part of the report's objective will be to summarize estimated remaining uranium resources from different sources.

II. Geological overview

A. Description of uranium resources in Texas

The National Uranium Resource Evaluation (NURE) program was initiated in 1973 to identify uranium availability in the United States. It was originally administrated by the Atomic Energy Commission and later by the US Department of Energy. Closing in 1984, the NURE program sampled diverse areas of US territory during its existence. Information from this program is publicly available in geospatial format, as shown in Figure 2 (EIA, 2020a). The data presented in this shapefile was originally developed as part of the National Uranium Resource Evaluation (NURE) program from 1974 to 1982. Through this program the U.S. Department of Energy assessed systematically the resource potential for uranium in the US (Hall, 2013). The EIA received the NURE dataset from the United States Geological Survey (USGS) in February of 2019 to generate updated maps to ascertain uranium resource distribution in the US (EIA, 2020a). These maps were updated on October 21, 2020 by the EIA (EIA, 2020a).

Probable, Possible and Speculative locations are identified in the NURE program. The three resource categories are defined as follows.

- **NURE Probable resource category:** Have a higher level of certainty on the availability of the uranium resource considering that the location occurs in known productive districts where there are known deposits or there are undiscovered resources in areas with known geologic trends or mineralization areas. Therefore, extensions of recognized uranium resources and new resources identified by exploration in known locations are identified in the Probable class.
- **NURE Possible resource category:** Locations that form part of geologic settings that elsewhere are productive are identified by NURE as Possible resources. In more detail NURE Possible categories are undiscovered or partly defined deposits corresponding to geologic settings or formations which are productive in other locations in the same geologic province.
- **NURE Speculative resource category:** Speculative locations are those yet to be explored or to become productive but share geologic characteristics of productive locations. As such, NURE Speculative resources are those uranium deposits that remain undiscovered but that are assumed to exist in the location due to its geological characteristics, which have been present in other locations with similar conditions.

The NURE program has identified a limited number of locations that have Probable and/or Possible resources which could be expanded to additional capacity due to Speculative resources in that location. These locations have been identified as coincident for these Probable and Speculative categories (DOE, 1976; McLemore, 1981; Hall, Mihalasky & Van Goshen, 2017; EIA, 2020a). Results from this geo spatial analysis indicate that 23.94% of all US Speculative uranium resources are located in Texas. Furthermore, 9.12% of all Probable and/or Possible and 3.64% of all coincidence of both Probable and Speculative uranium resources in the nation are in Texas. This is relevant and provides a positive outlook for Texas uranium production, considering that it ranks first in Speculative and sixth in the Probable uranium categories for the US.

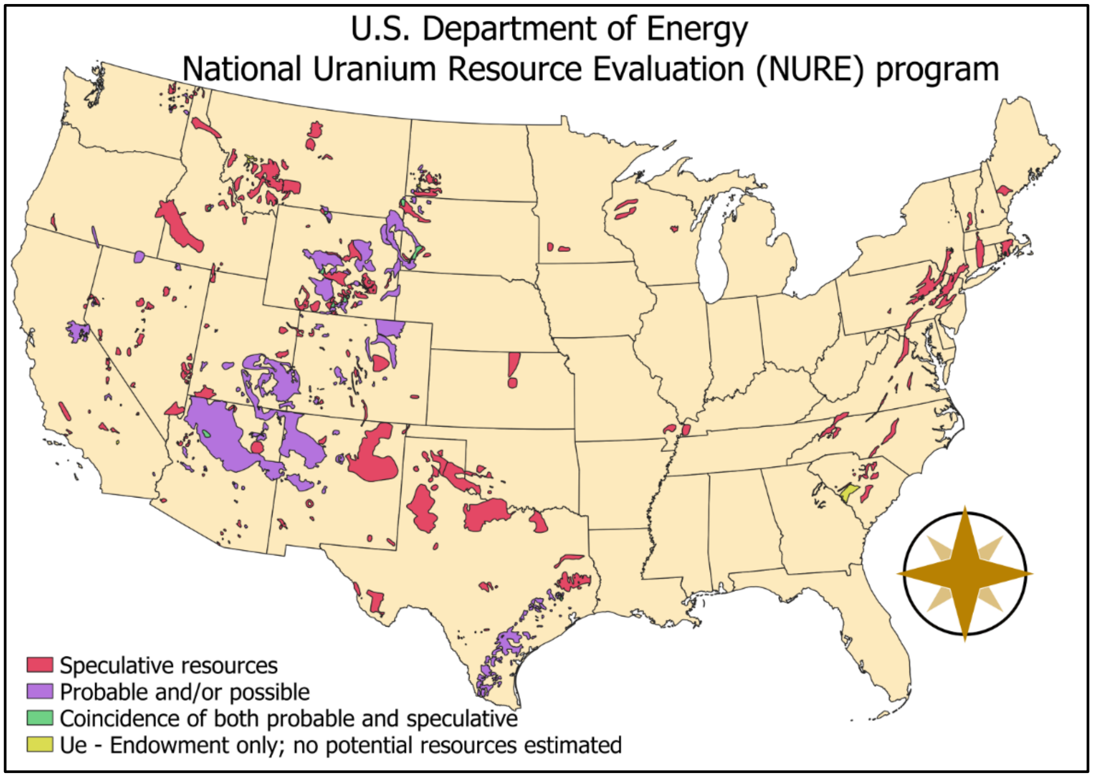


Figure 2: National Uranium Resource Evaluation (NURE) areas, as provided by the US Department of Energy (EIA, 2020a).

NURE Probable and/or Possible resources in Texas are located along the Gulf of Mexico coastal area, spread over 18 counties, as shown in Figure 3. This area has been identified as the Gulf Coast Uranium Province, with the NURE program estimating U_3O_8 reserves of 87 million pounds in the $30/lb. category at 1980 prices. It is estimated that 40 million pounds were mined, 38 million pounds are unmined resources, and 9 million pounds are in the NURE estimate for reserve or production categories, as of 2012 (Hall, 2013). These resources have remained unmined due to the low market prices of this resource (Hall, Mihalasky and Van Goshen, 2017). The Speculative resource locations identified by the NURE program are in North and West Texas, encompassing a much larger area for potential uranium resources.

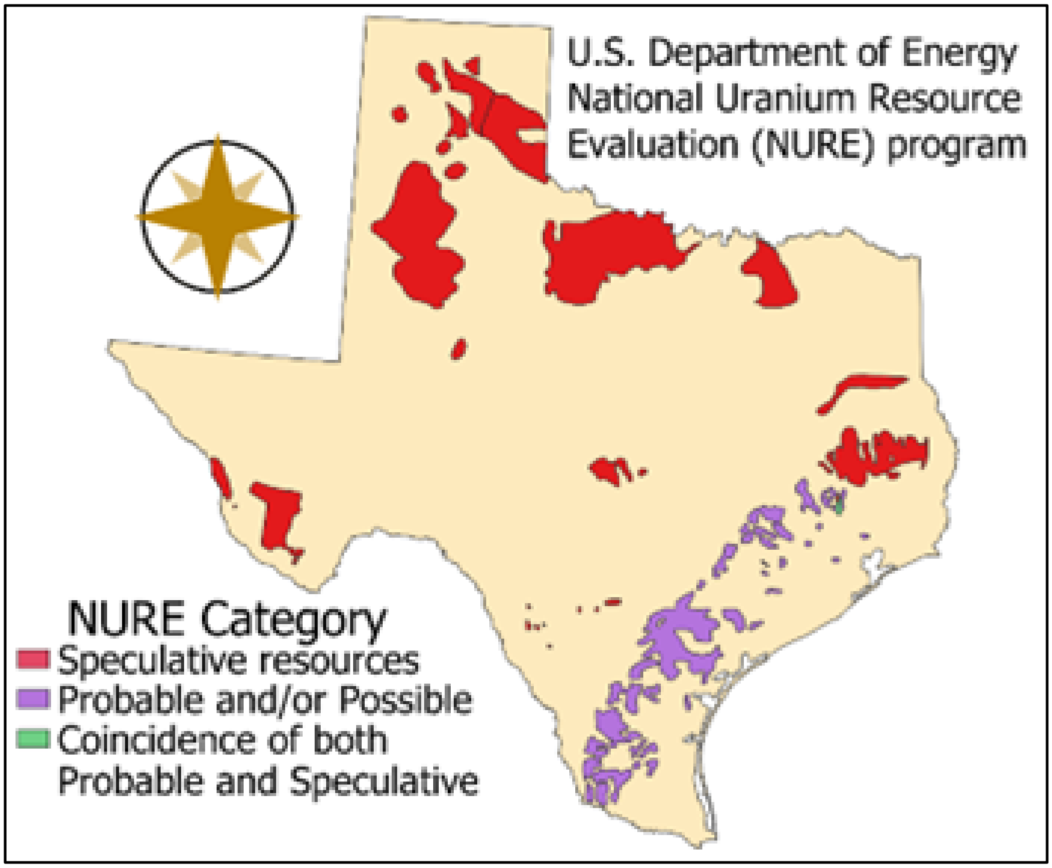


Figure 3: National Uranium Resource Evaluation (NURE) areas for Texas, as provided by the US Department of Energy (EIA, 2020a).

Geospatial analysis was performed with the shapefiles provided from the NURE areas for Texas (EIA, 2020a). Results indicated that the NURE Probable and/or Possible category covers an area of 20,795 km^2 distributed over 34 counties in the Texas Gulf Coast area, as shown in Figure 4(a). This is a very significant area, considering that it is equivalent to 3% of the total area of Texas. For these categories, six counties contain 48% of the area, while 14 counties account for 78% of the area. The NURE Speculative resources are mostly located in the northern and western regions of Texas, comprising an area of 67,182 km^2 distributed across 86 counties, as shown in the map in Figure 4(b). This is a significant surface area, equivalent to almost 10% of the state. The concentration of this surface is also significant, considering that just 15 counties contain 49% of the NURE Speculative resources areas, while 33 counties enclose 80% of the area.

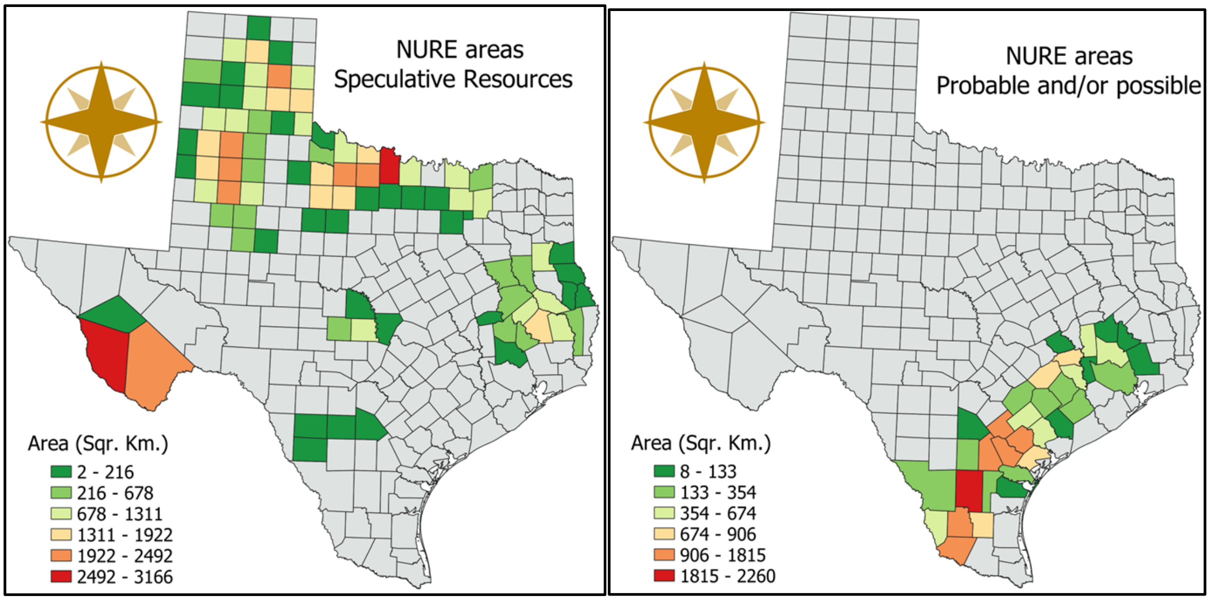


Figure 4: National Uranium Resource Evaluation (NURE) areas for Texas, indicating the areas covered by each category per county (EIA, 2020a) (a) NURE Probable and/or Possible. (b) NURE Speculative.

Figure 5 helps to better understand the distribution of NURE resources across diverse counties in the state, and complements the information presented in Figure 4. In Figure 5(a) the bar chart represents the area (km^2) of the surface categorized as Probable and/or Possible by NURE, with the values indicated in the primary vertical axis in dark blue color font. The counties presented in this figure represent 84% of the surface area for this category in the state. The orange line represents the proportion of the total county area under this category, with the percentage values indicated in the secondary vertical axis, highlighted in orange font color. For the Probable and/or Possible category, the proportion of the county area ranges between 20 – 80%. The NURE Speculative resources areas are shown in Figure 5(b), which presents the area analysis for the counties which contain 70% of the surface area for this category, in the state. The surface of three counties is almost entirely comprised in this category while five counties have a proportion higher than 90% of NURE Speculative area resources. On the other hand, Presidio and Brewster counties, both located in the western border of Texas with Mexico, have one of the highest surface areas for this category, but the proportion of its total areas is lower, considering that these counties have large overall territories.

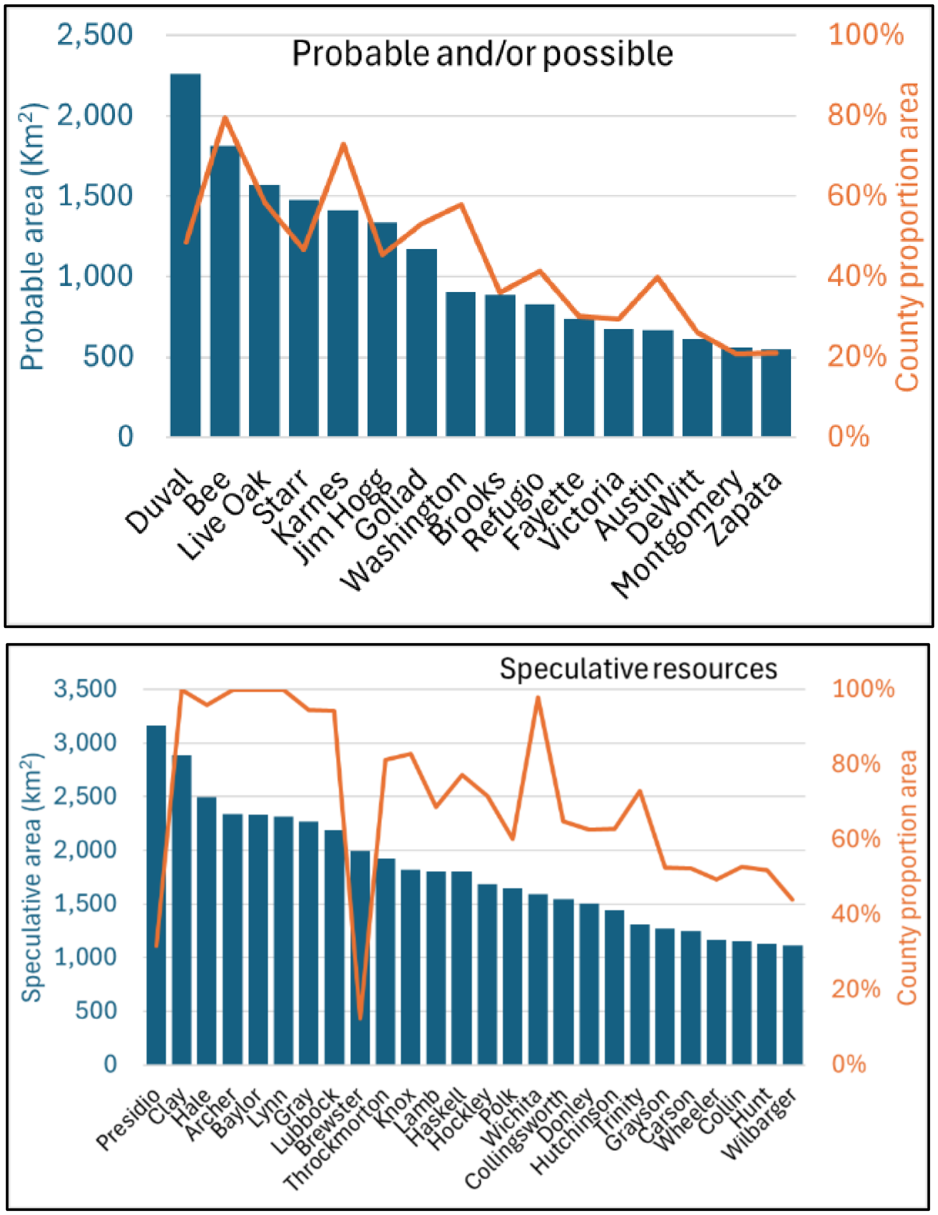


Figure 5: Bar charts indicating the surface area by county of the National Uranium Resource Evaluation (NURE) areas for Texas (EIA, 2020a) (a) NURE Probable and/or Possible. (b) NURE Speculative.

Identified uranium deposits are those that have been delineated directly, and feasibility studies have been conducted on them. This information allows stakeholders to make decisions on potential uranium mining or perform additional measurement to make investment decisions (IAEA, 1998; Organization for Economic Cooperation and Development Nuclear Energy Agency (OECD-NEA) & IAEA, Uranium 2022). Figure 6 was developed from data provided by the U.S. Energy Information Administration (EIA), showcasing the location for these identified uranium deposits in the US and in Texas (EIA, 2020b). Figure 6(a) indicates that Texas is one of a few states in the nation with identified uranium deposits and as previous literature and databases have indicated, the Gulf Coast region of Texas was one of the most active and prolific uranium mining locations in the US before the 1980's uranium price decline. A significant number of uranium mines, in diverse stages of operation, are located in this area, making it a very relevant location for uranium mining incentives with the goal to rejuvenate this industry (Hall, 2013; Hall et al., 2017).

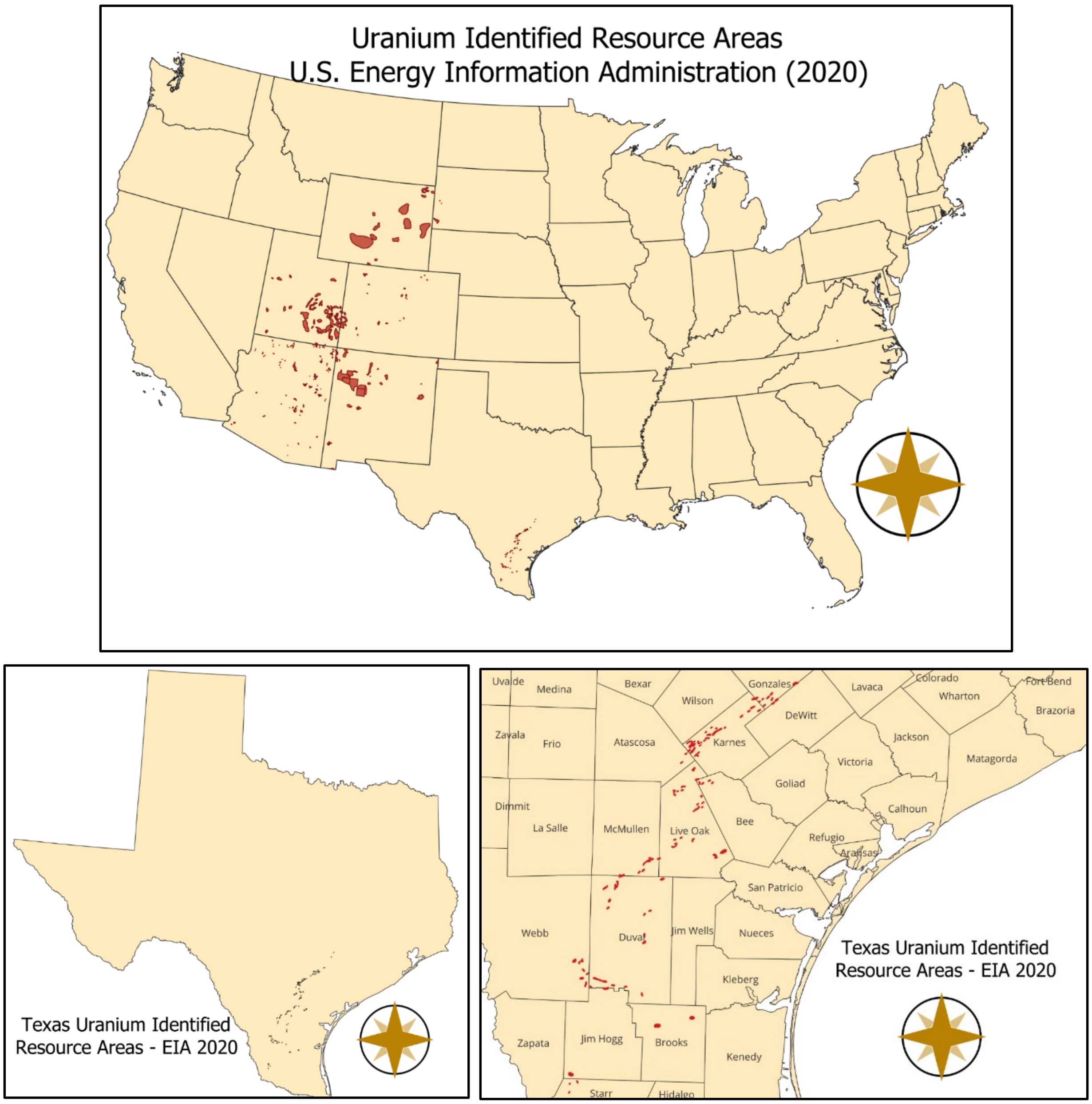


Figure 6: US Energy Information Administration Uranium Identified Resource Areas for the (a) United States, (b) Texas and (c) South Texas with counties (EIA, 2020b).

Figure 7 presents analysis for the surface area on the Texas Uranium Identified Resources areas, categorized by county. The shapefile was provided by the EIA with its latest update on October 21, 2020. This data was originally provided by the USGS to the EIA in February 2019. The database was compiled by USGS geoscientists from diverse sources that were published on different dates, from 1980 to 2018, as indicated in the shapefile metadata (EIA, 2020b). The total surface area is significantly smaller than for the combined NURE categories, which is expected, considering that these resources are more targeted and have a higher level of certainty on the availability of uranium. The 175 km^2 of Uranium Identified Resources in Texas is distributed across 14 counties in the southern part of the state along the Gulf of Mexico coastline.

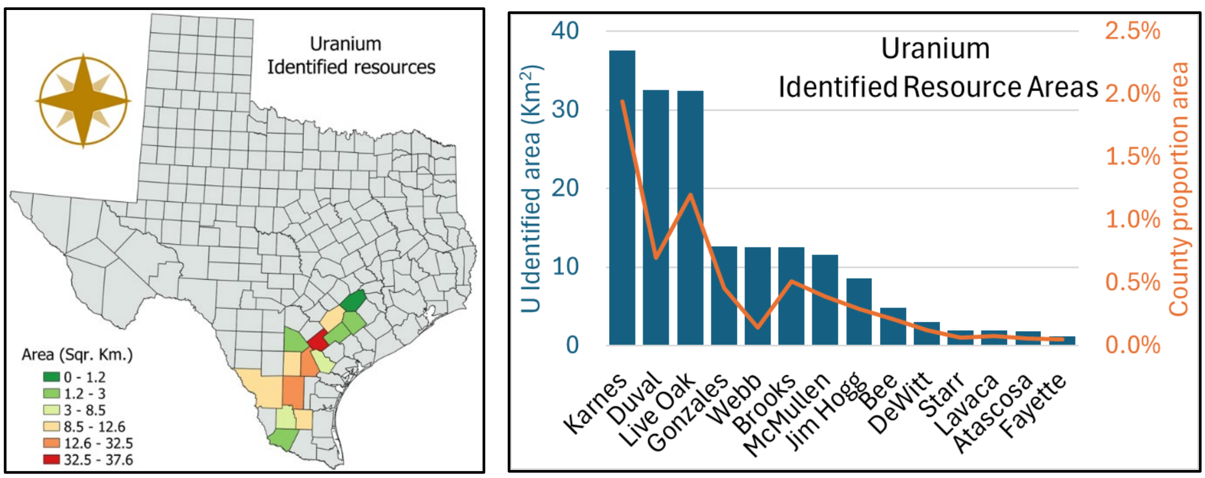


Figure 7: US Energy Information Administration Uranium Identified Resource Areas by county (a) counties in Texas with ranges of surface area in the identified uranium area category (b) bar chart indicating the surface area for the identified uranium area category (EIA,2020b).

Figure 8 presents maps for the United States and Texas indicating the Uranium In-Situ Leach Plants, from data provided by the EIA 2022 Domestic Uranium Production Report and quarterly reports. These results describe the locations according to their identification number and are classified according to their operational status (EIA, 2023a; EIA, 2023d; EIA, 2023e). According to the 2023 First Quarter EIA Domestic Uranium Production, the only uranium extraction method considered or currently in operation in the United States is ISR. There are 21 extraction plants in the US, only four of which are in operation; two in Wyoming and two in Texas, as of summer 2024 (EnCore Energy, 2024d). Texas is home to seven uranium mines, as reported by EIA for 2023. The Hobson facility in Karnes County Texas, is a uranium processing plant, and does not include groundwater extraction (EIA, 2024).

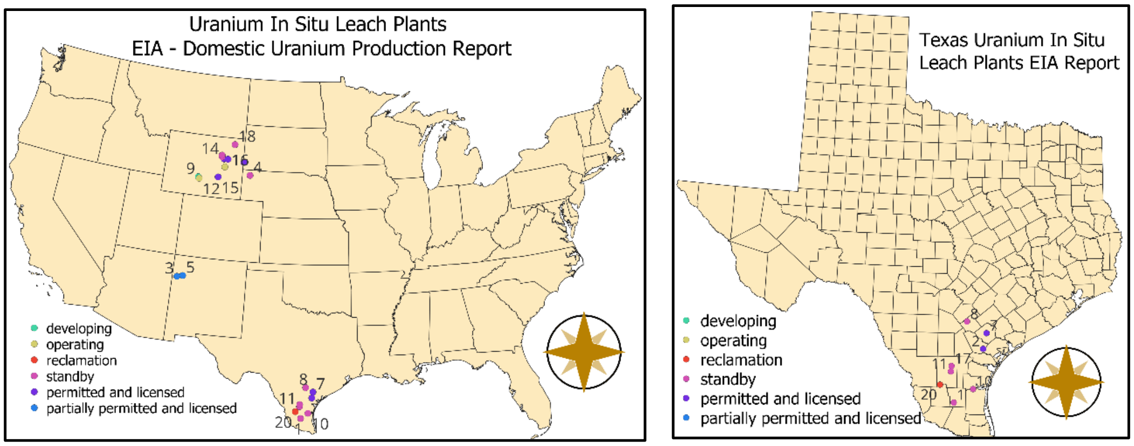


Figure 8: Location of uranium in situ recovery plants, classified according to their operational status (a) in the United States and (b) in Texas. The Hobson location, in Texas, is a uranium processing plant.

B. Identification of key geological formations hosting uranium

The state has substantial uranium reserves, primarily found in the Coastal Plain and the High Plains regions. Four major units were identified to host economic uranium deposits in the South Texas region (Walton-Day, 2022). Section VI subsection A discusses current estimates of total uranium reserves in Texas and the probability of uranium reserves in the Texas Coastal Plain. A map showing geological formations for the Coastal Plain region is shown in Figure 9.

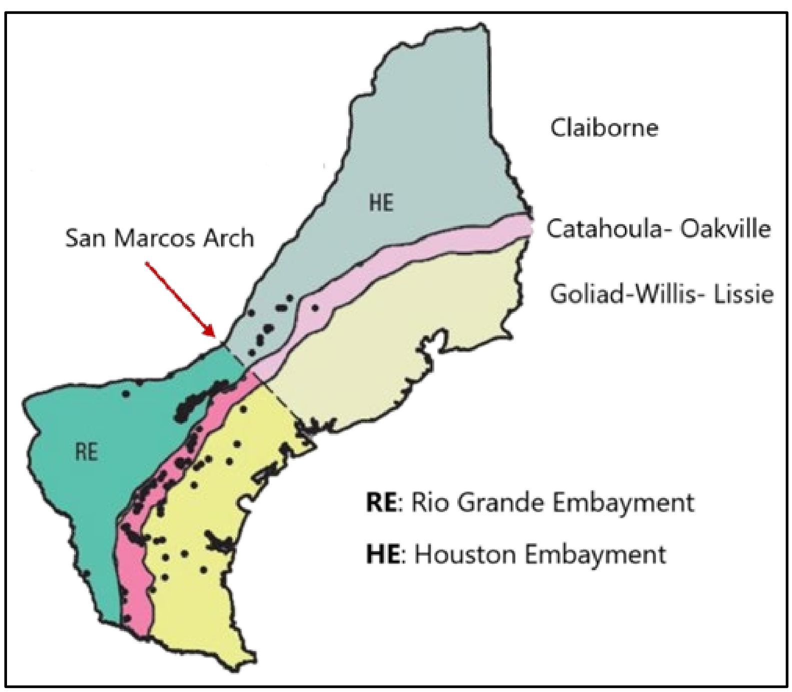


Figure 9: Map indicating geological regions for the Coastal Plains region in Texas.

- **The Eocene Whitsett Formation of the Jackson Group**: The Jackson is the oldest of the documented uranium deposit-bearing units in the Tordilla Hill area in Karnes County (Hall, Mihalasky & Van Gosen, 2017). Fisher et al. reported the geological features of the formation as dip-oriented constructive deltaic sands, muds, and lignite in the East and strike-oriented strand plain/barrier bar sand bodies in the south, accompanied by associated lagoonal muds and lignite (Fisher et al., 1970). The southern region also contains minor landward, dip-oriented channel sand bodies and gulfward shelf muds that grade eastward across the San Marcos Arch, transitioning into the prodeltaic muds of East Texas. The dynamic nature of lateral facies within the formation poses challenges for the regional correlation of the units, leading to confusing nomenclature. However, integrating surface and subsurface geology with meticulous depositional analysis, Fisher et al. 1970 addressed the challenge, clarifying the stratigraphic interpretation within the Jackson formation. There are some roll front uranium occurrences in the Eocene Claiborne group. The Claiborne group consists of formation in Carrizo sand, Queen city sand and Reklaw. (Mihalasky et al, 2015). The Claiborne is a geologic formation distinct for sedimentary deposits comprising of clays, sands and lignite (Eagles, 1968). The roll font type uranium deposits are due to the permeability and porosity of sandstone formations which allow the movement of uranium-bearing fluids.
- **The Oligocene to Miocene Catahoula Formation**: This is a highly tuffaceous fluvial unit of volcanic origin overlying the Frio Clay and the onlapped Jackson Group (Galloway, 1977). Catahoula is a major host for uranium deposits in South Texas. In the context of the subsurface, the strata identified as the Catahoula Formation include the lower Frio Sand, alternatively referred to as the Frio Sandstone or Frio Formation, along with the overlying Anahuac Shale and the basal segment of the Oakville Formation (Dahlkamp, 2010).
- **The Miocene Oakville Sandstone of the Fleming Formation**: In outcrop exposures, the Oakville formation manifests as a coarse clastic fluvial unit, originating from a pronounced episode of tectonically induced rapid sedimentation along the coastal plain. The Oakville formation's composition is notably marked by reworked volcanic debris, chert, and Cretaceous rocks and fossils sourced from the Edwards Plateau. In South Texas the Lagarto shale formation overlies the Oakville Sandstone. In east and southeast Texas, the Lagarto shale and Oakville sandstone are in the Fleming Formation (Galloway et al., 1986). The inclusion of the latter materials is attributed to heightened tectonic activity and erosion along the Balcones Fault System (Dahlkamp, 2010).
- **The Pliocene Goliad Sand**: The Goliad Formation overlies the Fleming Formation and recent research showed the Goliad was of Upper Miocene to Early Pliocene age. In South

Texas the Goliad Formation overlies the Lagarto shales (Galloway et al., 1986). In east Texas the Lagarto formation is mapped as Fleming Formation (Mihalasky, 2015). The Goliad is a coarse, clastic fluvial unit deposited by moderately low-gradient, intermittently torrential streams across the broad, flat coastal plain. The Goliad is also a major aquifer and a host for several known major uranium orebodies (Hall et al., 2017).

C. Exploration methods and technologies employed for resource assessment

There have been various exploration methods and technologies employed to assess uranium resources in Texas. In reference to the methodology, many of the uranium resource assessments have utilized a 3-part quantitative method in the goal of estimating available resources. The first of the three-part process is to create a geographic region, i.e. tract, that is permissive for the occurrence of deposits, which is guided by known uranium deposits. The second is a probabilistic estimation of numbers of undiscovered deposits that lie within each permissive tract. The last of the three-part method is then the calculation of the probable amount of undiscovered material (Hall, 2013).

The earliest discovery of uranium resources could be said to be accidental. In 1954, an independent oil company believed oil was associated with anomalous radioactivity (Eargle & Weeks, 1961). An airborne radiometric survey was conducted of the outcropping Whitsett Formation of the Jackson Group around Tordilla Hill in Karnes County (Hall, 2013). Aerial radiometric surveying involves gamma-ray detectors on board helicopters or fixed-wing aircraft. The detected radioactive signatures are recorded and mapped, to be verified later on the ground. The use of this method allows for a large area to be examined. This method, in addition to being able to map out a large area, is used in identifying sites to reduce unnecessary ground checking costs. Similarly, in South Australia, airborne electromagnetic surveys were created to provide reliable data to aid in the search for energy and mineral sources, such as in the sandstone-hosted uranium deposits in the region of Lake Frome (Roach et al., 2014).

The ground follow-up for confirmation is known as the surface radiometric survey. Here, hand-held spectrometers, borehole loggers, or radon monitors are employed. Spectrometers are instruments made to detect and measure the gamma rays emitted by natural elements (Uranium, Potassium-40, Thorium) in hopes of discovering uranium deposits. These devices are found in all phases of exploration and are sometimes mounted onto a vehicle as a car-borne radiometric survey. Confirmed areas are then further inspected by the implementation of borehole logging. This step involves the drilling of boreholes, sometimes hundreds of feet deep. The drill cuttings are examined, and data is collected by lowering a gamma-ray detector into the recent borehole and recording the radioactivity at various depths. Gamma-ray detectors are versatile tools that detect gamma radiation in various contexts, whether it be in oil exploration, nuclear physics applications, or homeland security (Wang et al, 2022). Utilizing the drilling examination and the logging technique is essential in evaluation, mine development, and grade control in uranium production (Barretto, 1981). Radon monitors are beneficial for uranium detection as radon is a product of uranium decay (Khattak, 2011).

An early example of borehole examinations in the south Texas region was performed in 1983 at the Burke Hollow site and was done by Nufuels Corporation (Mobil Uranium). They drilled eighteen (18) exploration holes on or near Uranium Energy Corp's (UEC) 1,825-acre Welder lease. The average depth of the exploration holes reached 1,100 feet to test the entire prospective Goliad Formation. Later, in 1993, twelve (12) holes were drilled on a permitted piece of land within the Thomson-Barrow lease. Eleven of the twelve holes drilled showed signatures indicative of uranium mineralization. The boreholes were made using truck-mounted drilling rigs. The drilling used conventional rotary drilling methods, with drilling mud fluids in vertical holes. From there, the drill cuttings were collected from the drilling fluid returns that circulated upward from the borehole. The samples during this exploration were done in 5-foot intervals and laid out for review and examination by geologists. The specimens were then logged for gamma-ray, self-potential, and resistance by Century Geophysical, the contracted logging company (Carothers et al., 2013).

Uranium resource signatures can also be found in the gamma-ray surveys done of oil and gas boreholes. These logs are commonly used in formation evaluations for drilling oil wells, due to detailed subsurface geology lithology and mineral composition, which aids in identifying potential uranium deposits (Gallegos et al., 2022). The sedimentary sequences, along with the geological history, can be mapped. In the oil and gas industry these logs assist with identifying hydrocarbon-bearing formations, but since the logs include gamma ray data, their gamma ray signatures can help identify radioactive minerals like uranium, thorium, and potassium (Saunders, 1993).

In a recent 2023 news release from enCore Energy, a Texas-based uranium mining company announced it had acquired exclusive rights to the Prompt Fission Neutron (PFN) technology. This application replaces traditional methods of uranium exploration which proved to be lacking reliability. Traditional methods rely on the measuring of gamma radiation emitted from uranium daughter products of decay and not uranium directly. In some of the geological formations where the mineral is hosted, the uranium and products of decay are not in equilibrium which can lead to over or under-estimation of uranium mineral deposits. This leads to the need for expensive and time-consuming calibrations for verification. On the other hand, PFN uses neutron activation to detect uranium from drill holes. The PFN tool excites uranium atoms at the atomic level, causing them to emit neutrons, which are then measured as fast (epithermal) and slow (thermal) neutrons. By analyzing the ratio of epithermal to thermal neutrons, the grade of U_3O_8 ore can be accurately identified. These direct measurements and real-time data provided by PFN technology are beneficial for making immediate decisions during drilling operations (enCore, 2023).

III. Uranium recovery methods

Uranium mining, a pivotal aspect of the nuclear fuel cycle, involves the extraction of uranium ore from the Earth's crust for subsequent processing into nuclear fuel. In the context of Texas, various methods have been employed to extract this valuable mineral. This section clarifies the primary techniques utilized in uranium mining within the geographical confines of Texas. Since the fortuitous discovery of uranium in the western precincts of Karnes County during the fall of 1954, the extraction of this valuable element in Texas has been facilitated through two distinct methodologies: traditional surface mining, also known as open pit mining, and ISR. Deciding which method to use depends on the deposit grade, size, location, geology and economics (Campbell, 2015).

A. Conventional mining

Open-pit mining is from the traditional mining methodology known as surface mining. Underground mining approaches are not favorable in the South Texas setting. One reason is that the uranium roll front deposits are typically located in sandstone, which is generally loose and unconsolidated unlike consolidated rock formations that make underground (shaft) mining functional. There was an attempt at underground mining on record in the Goliad Formation (Walton-Day et al., 2022). In 1958, Union Carbide Corporation (UCC) acquired the Palangana Project property and initiated underground mining (UEC, 2023). However, further attempts were halted due to the hydrogen sulfide encountered (Adams & Smith, 1981). The Palangana project ceased operations until 1967 after it was recognized that the uranium would be recoverable from the emerging ISR technologies. In situ recovery (ISR) falls under the non-traditional category. Uranium was initially extracted through open-pit mining from the 1950s through the 1990s. In the 1970s, ISR method was added to the Texas uranium resource recovery.

1. Open-pit mining techniques

Since the first open-pit extraction, there have been eighty-six (86) (Hall, Mihalasky, Tureck et al., 2017) open-pit mines in operation in Texas, of which twenty-three (23) were mined and abandoned all before 1975 (Walton-Day et al., 2022). Open-pit mines were completely phased out in the 1990s. While open-pit mining is the traditional method of extracting valuable minerals such as uranium, it involves extensive land disruption. The site must be prepared, creating zones for access to the mines by clearing vegetation and topsoil. That is followed by drilling and blasting the area to break up the overlying rock layer to expose the uranium ore body. Large trucks, excavators and bulldozers are employed to haul the large masses of rock, also known as overburden, leading to an open excavation or open pit. The pit depths sometimes range between 90 to 300 feet (Texas Railroad Commission, 2002). This pit is created to expose the target material: minerals, ores, or rocks. Some of these pits were more than a mile in length, while many more were small surface excavations up to a few acres in size (Parker & Herbert, 2000). This method is favorable when the target material is located at shallow depths. The overburden typically becomes the pit walls, which vary in height and have been recorded to be up to 120 feet (Texas Railroad Commission, 2002). The E. Brysch site was mined in this manner prior to 1973. The pit comprised ten (10) acres and was approximately forty (40) feet high (Texas Railroad Commission, 2002). From there, the ore or minerals are extracted using large equipment and machinery and sent to a mill, typically on-site, to crush the ore. After crushing, the process known as leaching is done to extract the uranium concentrate, Yellow Cake. The leaching process mixes the crushed ore with a solvent, like a weak acid or base, to separate and concentrate the uranium. Once mining operations are done, the pit is meant to be reclaimed and rehabilitated to regulatory standards. This may include the pit being backfilled with the site waste rock and soil and revegetating the area with native plant species.

2. Historical context and current relevance

Uranium was discovered near Deweesville, Texas, during the fall of 1954 as a result of an airborne radiometric survey done by Jaffe-Martin and Associates, an oil company based at the time in San Antonio. The purpose then was to find any radiometric anomalies associated with oil exploration. It was also noted that around the same time, at another site near Tordilla Hill in the western part of Karnes County, signs of high radioactivity were observed, and yellow uranium minerals were found in an exposed sandstone rock. Clarence Ewers discovered this area using a hand counter. By 1956, fifteen (15) potential prospects had been located in the vicinity of Fayette County and Starr County, a few miles north of the Rio Grande River. The first extraction came in December of 1958 when an eight-ton load of high-grade, hand-picked ore was taken from the pits of Tordilla Hill. Large-scale mining began west of Deweesville in July of 1959. A year later, in December, a stockpile of 100,000 tons of low-grade ore awaited processing. In 1966, a resurgence of securing new leases in the area was seen, as construction of nuclear reactors for power generation fostered increased demand and exploration for uranium. The open-pit mines near Tordilla Hill were about 120 feet deep by 500 feet wide. By 1970, the United States Atomic Energy Commission had estimated Texas uranium reserves to be 6,622,323 tons of ore at 0.16% U_3O_8 concentration, making Texas fourth in production compared to the rest of the nation. By the mid-1970s, with the substantial increase in uranium prices, over a million acres had been put under lease, with eighteen (18) major companies and independent operators harvesting the mineral. The exploration for uranium was concentrated on a strip that was approximately 10-20 miles wide and 200 miles long. Around the same time, the Continental Oil Company and Pioneer Nuclear Corp began a joint venture, known as the Conquista project, to mine and build a 1,750-ton-per-day processing mill in Karnes County. Over ninety percent (90%) of the yellowcake produced in Texas came from the Conquista mill, with the raw ore coming from ten open pit mines in both Karnes and Live Oak counties. By the 1980s, Texas ranked fifth among the states in uranium output, but the decreased demand and decreased price brought a sharp decline in the operations (Texas State Historical Association, 1976).

B. In-Situ Recovery (ISR)

The ISR method started in the mid-1970s, and Karnes County, Texas, was home to one of the earliest ISR mines worldwide (Walton-Day et al., 2002). The Atlantic Richfield Company's Clay West uranium recovery plant and expanded pilot test project became the United States' first commercial in situ uranium solution mine (Texas State Historical Association, 1976). By the 1990s, ISR accounted for most of the uranium mining projects in Texas and most of the United States. The World Nuclear Association reported in 2019 that ISR accounted for fifty-seven percent (57%) of the world's uranium extraction methods. In Texas, the shift from conventional open-pit surface mining to the ISR method can be associated with the passing of The Texas Surface Mining and Reclamation Act of 1975, which was followed by The Surface Mining Control and Reclamation Act of 1977 (Shrestha & Lal, 2011; Thomas et al., 2023). Due to surface disruption and upheaval of land from conventional surface open-pit mining, these laws were created and aimed to address environmental concerns, and mandated that the mined land be restored for future use. Unlike open pit, in situ does not involve the mass disruption of the landscape, creating piles of uprooted earth in the form of hills in its surroundings; instead, the ore is left in its place in the ground. Currently, in the state of Texas, based on the EIA 4th quarter report of 2023, there are five ISR processing plants on standby: Alta Mesa, Hobson, La Palangana, Kingsville Dome, and Rosita. It should be noted that the Hobson Processing Plant is only a processing site handling material from other ISR sites such as La Palangana, as they are owned by the same company. Rosita, however, resumed production in November of 2023 as per a news release from enCore Energy on March of 2024 (enCore, 2024). Additionally, the Alta Mesa site resumed production in June of 2024 (enCore, 2024d). The Vasquez site is in the reclamation phase, and there are two sites permitted and licensed, but not yet operational: The Burke Hollow and Goliad ISR.

1. Explanation of ISR process

In the ISR process, uranium is recovered by dissolving it in place and pumping the mixture to the surface through a network of wells. The disruption to the terrain is minimal in comparison to surface mining. In situ recovery can be considered a selective mining technique where the target ore mineral is leached or dissolved in its geological setting using specific leach solutions (Larson, 1984). What has made ISR a suitable method for uranium extraction in South Texas is when the mineral is in permeable sand or sandstones, confined above and below by impermeable strata, and below the water table. A series of injection and recovery wells are positioned in a pattern that, by design, will efficiently extract the uranium as seen in Figure 10. As in the figure, the extraction well is positioned between two injection wells, where the lixiviant is pumped into the ore bearing formation. Around the injection and extraction wells, monitoring wells can be seen above, below and away from the production zone in case any contamination spreads.

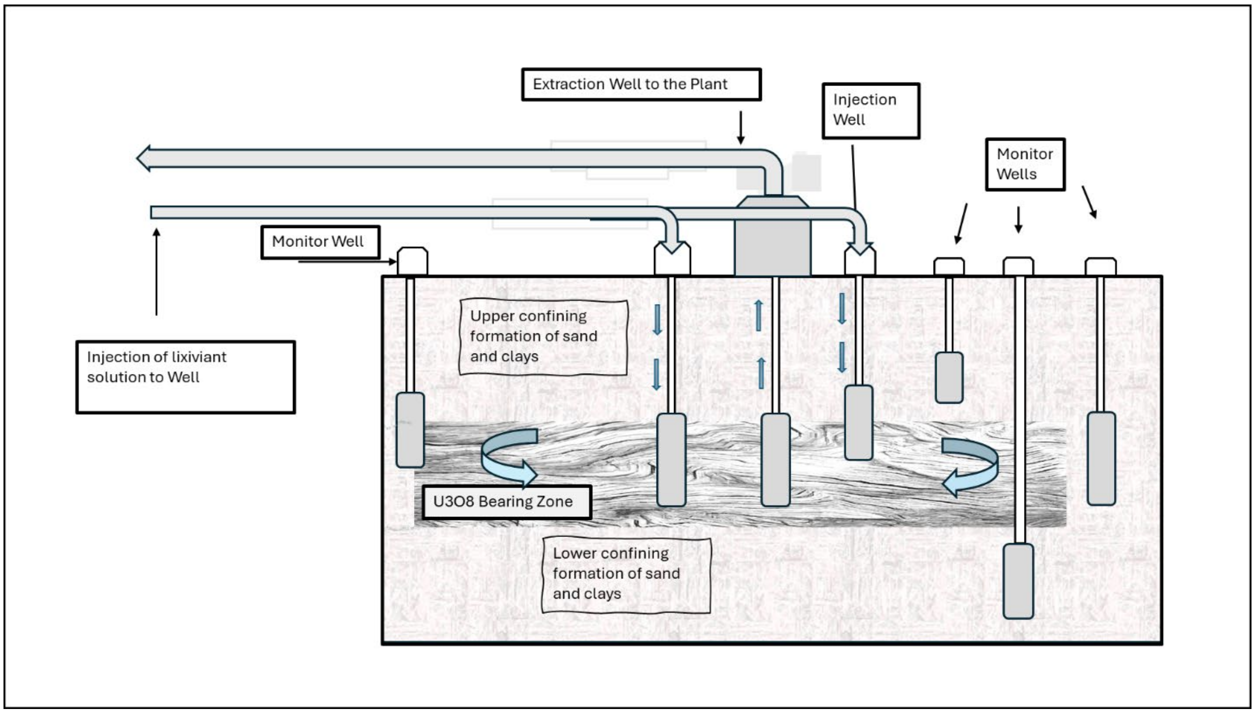


Figure 10: Cutaway of the ISR process.

The ISR process involves the injection of a specially formulated leaching solution, also known as a lixiviant, which is pumped into the injection well and introduced into the uranium-containing porous rock formation to dissolve the uranium in place, followed by the extraction of the uranium-laden solution at the surface for further processing (Shen, 2020). The leaching solution consists of native groundwater, to which a complexing agent and, in most cases, an oxidant are added. The geology of the area determines the decision process for using ISR. If there is significant calcium in the orebody (such as limestone or gypsum, more than 2%), then a typical option is to use an acid lixiviant such as a leaching solution containing vinegar with a pH of 2.5-3.0 (World Nuclear Association, 2020). It is more than likely that other minerals are present in the location, so the solution used is specific to create a reaction that targets the uranium alone.

The process originally used an acid or alkaline lixiviant (leaching solution) mixed with an injection fluid. They began with acid-leaching techniques that used sulfate of dilute sulfuric acid as the chelating agent, with the uranium mobilized as the uranyl sulfate complex. Should there be signs of a significant amount of uranium, then large amounts of acid are required, which brings up the issue of possible precipitation. This outcome has limited the use of acid for ISR of uranium. The early uranium mining industry used ammonium carbonate-bicarbonate leach solution with hydrogen peroxide as the oxidizing agent. However, it was noticed that, with the use of ammonium lixiviants in areas of certain clays, the ammonium would exchange with cations, which in turn would make the restoration of the aquifer more difficult. The industry switched to sodium carbonate-bicarbonate leaching solution with oxygen as the oxidizing agent to avoid this issue.

Lixiviant is a combination of locally pumped groundwater that is amended with a complexing agent, which is often a carbonate (or sulfates) and an oxidant (often oxygen or hydrogen peroxide) (Rice, 2013; Gallegos, 2022). The oxidant then converts uranium from a relatively insoluble state to a soluble state. At that point, the complexing agents combine with the oxidized uranium to form anionic or neutral complexes that remain in solution (Charbeneau, 1984). Once the injection fluid has reached the uranium-bearing sandstone formation via injection well, the solution oxidizes, complexes, and mobilizes the uranium ore.

The solution, now referred to as a pregnant solution due to the presence of the dissolved uranium, is removed from the extraction wells. From the extraction wells the solution is sent to an ion exchange column as shown in the block flow diagram in Figure 11. Once enough material has been drawn onto the ion exchange column, it is removed from the production stream, and the resin is cycled to the elution step after it has passed the filter at the shaker table. At this step, the resin is in contact with a pure elute mixture of water, salt, and soda ash that separates uranium from the resin. Hydrochloric or sulfuric acid treatment is done to the eluant to break the uranium carbonate complex. Then with the addition of hydrogen peroxide uranium precipitates to uranyl peroxide. The neutralization of any remaining acid is performed. Then, the now slurry is sent into a conical tank so that it thickens and settles at the bottom. After the product settles, it is washed to remove the chlorides and is filtered and sent to the dryer. It now arrives as a yellow-colored precipitate known as yellow cake. The yellow cake is then packed into barrel drums, sealed, and sent to a uranium conversion facility, where it then is processed through stages of the nuclear fuel cycle (Larson, 1984).

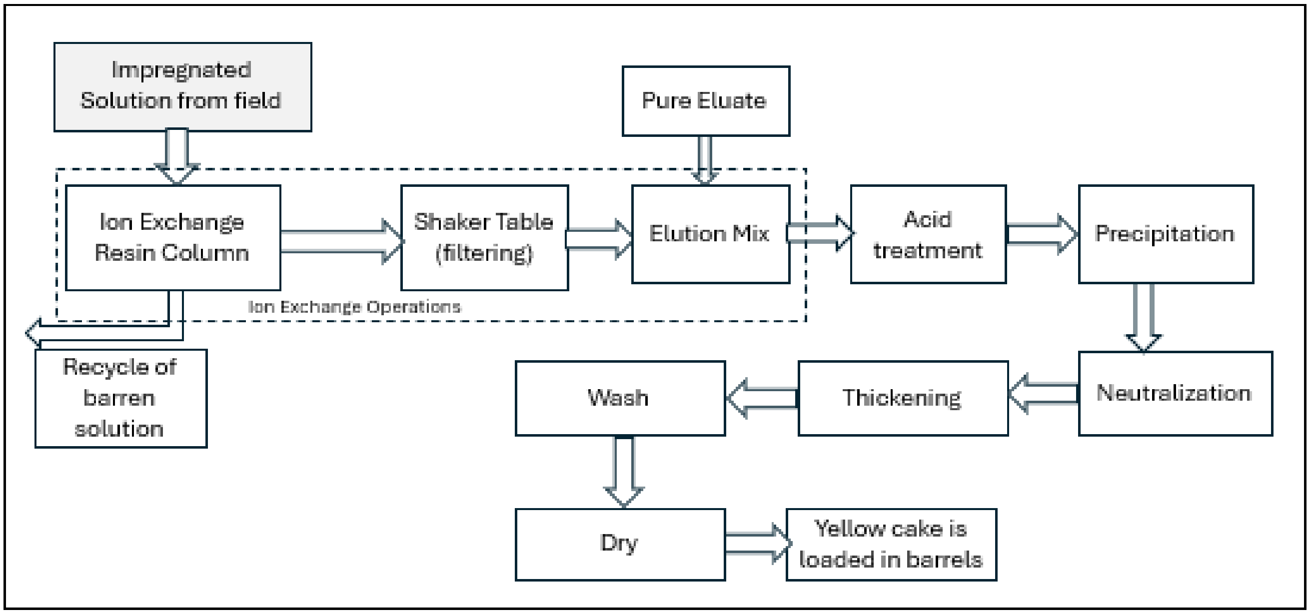


Figure 11: Block flow diagram from post wellfield retrieval.

2. Advantages and challenges

In contrast to open-pit mines where much of the terrain is excavated, leading to a broad and deep pit, ISR fields do not require nearly as much surface disturbance. The amount of time, energy, and money needed to prepare the area to be mined is decreased, as is also the reclamation efforts required by state and federal law. Open-pit mining is preferred when the ore deposits are shallow and near the surface, while ISR mining operations are meant for deeper locations that are much harder to reach for large machinery. The minimal surface disturbance lowers the surface environmental impact, preserving much of the natural habitat (Walton-Day et al., 2022).

While ISR can be economically beneficial over open-pit mining, particularly for low-grade sandstone-hosted ore deposits (Yang et al., 2022), it still has its own environmental considerations. These include potential aquifer contamination in regions down-gradient from the mining area. Due to the ISR process inducing a chemical reaction to extract the uranium from the sandstone, the local groundwater may exhibit higher than safe concentrations of uranium or its products of decay, radium and radon (Saleh et al., 2016).

C. Comparative analysis of recovery methods

1. Efficiency of ISR over conventional mining methods

The fundamental advantage of ISR over other mining techniques is reduced costs. Bringing the reagents directly into the ore body minimizes bulk material handling. The absence of a mining fleet, milling capacity, and heavy preparatory work (removal of the overburden for open-pit mines and development of access shafts for underground mining) drastically reduces upfront capital costs (Heili, 2018). The ISR method strategically targets uranium-rich zones, thereby maximizing recovery rates and minimizing the duration of mining projects. ISR mining plans are also highly flexible: new fields can be quickly developed, or production rates can be reduced without substantially impacting production costs. This progressive development allows for a reduced return on investment time and provides dynamic adjustment to the demand.

Reduced environmental footprint is another crucial advantage of ISR. While conventional mining moves rock particles, ISR is concerned with the movement of only liquid, thereby minimizing surface disturbances on the mining site (IAEA, 2001). Hence, a significant benefit is the absence of tailings; the quantity of solids generated by the exploitation is limited chiefly to cuttings from the well drilling. Other important features are limited landscape impact, and better air quality (no milling operations).

2. Environmental and Health Impacts

ISR minimizes surface disturbance and reduces environmental impacts compared to conventional mining methods (Gallegos et al., 2022). Diverging from conventional underground and open-pit mining approaches, ISR operations exhibit the following distinctions:

- Absence of large open pits: ISR operations circumvent the necessity for expansive open pits, minimizing surface disruption and visual impact.
- Elimination of rock dumps and tailings storage: Unlike traditional mining methods, ISR does not generate large quantities of rock dumps or necessitate extensive tailings storage facilities, mitigating landscape alterations.
- Non-dewatering of aquifers: ISR operations refrain from dewatering aquifers, thereby preserving groundwater levels and preventing potential ecological imbalances.
- Reduced volumes of mining and hydrometallurgical effluents: ISR processes yield significantly smaller mining and hydrometallurgical effluents, mitigating the risk of surface, air, and water contamination from potentially harmful substances.

- Absence of exhaust pollution: ISR operations contribute to environmental preservation by eliminating exhaust and dust pollution associated with heavy machinery and equipment.

These differences show the eco-friendly characteristics of ISR, as outlined by the IAEA in 2001 and corroborated by O'Gorman et al. in 2004. In the ISR method, the primary risk is the contamination of soils, surface waters, and aquifers, from the reagents used for mineral leaching, and from the metals in pregnant solutions. This can be mitigated by performing ISR operations under strict surveillance both during the ISR process and subsequent site reclamation. A reclamation/restoration of the contaminated groundwater and long-term monitoring programs ought to be established to ensure the contamination does not spread into uncontrolled aquifers or other areas (IAEA, 2001). In Texas, upon completion of groundwater restoration, the monitoring wells are subsequently plugged and abandoned.

The primary concern during operations is the risk of groundwater contamination by the leaching solution (Mudd, 2001). Migration from the ore formation is limited when ISR is applied only in confined aquifers, and surface risks can be limited by applying best practices. Closure operations are also facilitated since no legacy sites are created. The critical point in post-mining is restoring water quality in the ore formation, known as the reclamation/remediation phase. Once all viable uranium has been extracted, it is the responsibility of the licensee to restore the groundwater contamination levels to pre-mining conditions. The pre-mining conditions or baseline conditions are established by groundwater sampling in advance of initial uranium extraction. Commonly used methods of remediation are groundwater sweeping and reverse osmosis. However, oftentimes not all the baseline conditions are met after multiple attempts at restoration. The next step would be for the licensees to petition for an amendment so that the restoration level of the chemical constituent be raised from the baseline restoration level.

It is known that uranium can cause air, soil, and water radioactive contamination through mining and reclamation, nuclear research, nuclear fuel, depleted uranium weapons, war, and other means (Li, 2012). Uranium has biologically dynamic toxicity, metabolism toxicity, and chemical toxicity, leading to potential long-term harm to mammalian reproduction and development with reduced biological fertility and abnormal and slow embryonic development (Domingo, 2010). Additionally, uranium has been designated as a human carcinogen, based upon exposure to alpha radiation. However, no known human cancers have been tied directly to uranium exposure.

IV. Economic considerations

A. Current consumption of uranium

Figure 12 shows the world uranium consumption in 2021 classified by country and the number of reactors in operation and construction. Under the category "others", eighteen countries that consume less than 500 tons of uranium each are included. These results indicate that the United States (US) is the country which consumes the most uranium in the world, accounting for more than 28% of global supply, almost twice the consumption of the second ranked country, China. Furthermore, the US has almost one fifth of all reactors in operation or in construction in the world. Considering that procuring uranium for reactors is of critical importance for their continuing operation, securing supply of this fuel is a main priority to ensure the resilience of the electricity-generating system in the US.

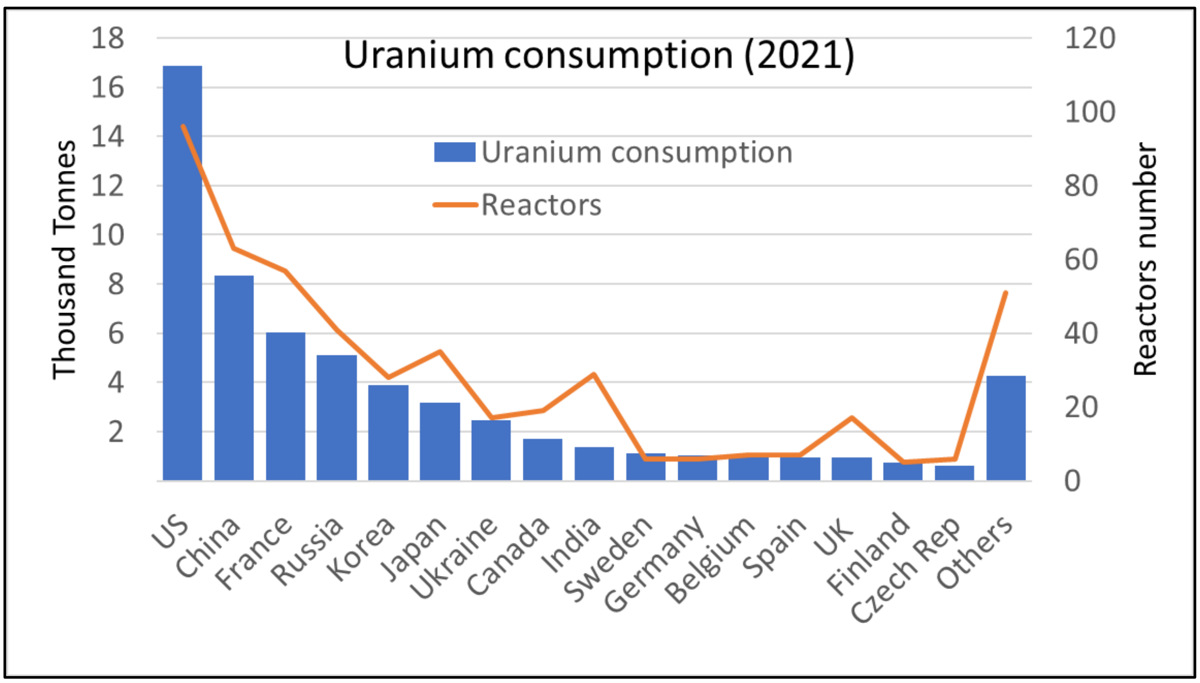


Figure 12: World uranium consumption per country including number of reactors in operation and in construction as reported by the Nuclear Energy Agency and the International Atomic Energy Agency (NEA, 2022; BGR, 2023).

B. Uranium production

However, data from the World Nuclear Association, as reported in Figure 13, shows a significant imbalance between the uranium consumption by the United States and its mining production. It indicates that, although the US consumed 28% of the world uranium supply in 2021, it mined less than 0.02%. Furthermore, more than 60% of uranium production takes place in locations affected by geopolitical instability such as the war in Ukraine and civil war in Niger. Since acquisition of uranium as fuel for reactors is indispensable for their operation, securing a stable supply is imperative for their operators to support sustainable electricity generation. Lack of local uranium production in the United States may therefore generate vulnerabilities for the electrical energy required to support consistent economic growth and development.

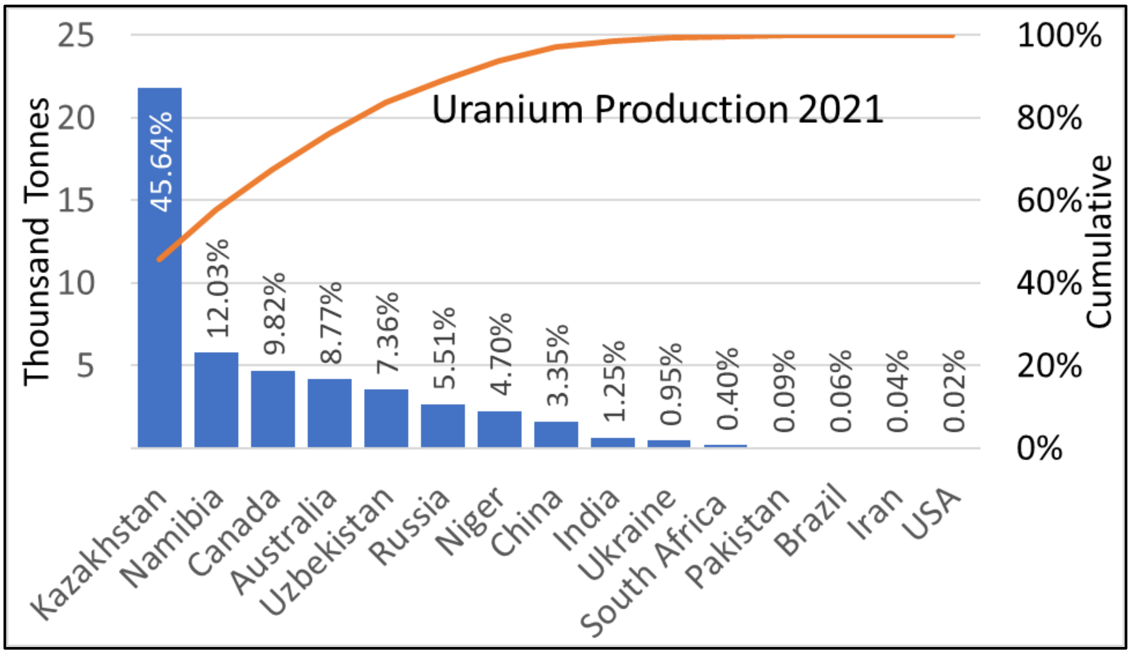


Figure 13: World uranium mining production as reported by the World Nuclear Association (OECD-NEA & IAEA, Uranium 2022).

A significant volume of the uranium supply used by reactors in the US is imported, mostly from six countries, as shown in Figure 14. The volume of imported uranium has fluctuated since 2010, depending on its price, as indicated in Figure 15. As weighted average prices per country decreased, its contribution to the supply of uranium has increased. Purchase of uranium per country was impacted by its price, with lower prices reflecting higher import volumes per country with the opposite effect occurring as prices increase. However, several of the major suppliers of uranium have been affected by current geopolitical instability, with the war in Ukraine impacting supply from Russia, Kazakhstan, and Uzbekistan. Furthermore, these international conflicts and its associated instability led to the passage of H.R. 1042 Prohibiting Russian Uranium Imports Act, which took effect on August 11, 2024. This law bans uranium imports from Russia, seeking to eliminate U.S. dependence on Russia, while simultaneously developing a strong U.S. national uranium supply. Reviving the U.S. nuclear fuel production is one of the goals of this legislation, providing $2.72 billion dollars, previously appropriated by the US Congress to develop national uranium enrichment and conversion capacity (DOE, 2024d). This development is expected to expand US uranium mining operations in the US, significantly benefiting Texas (Day, 2024). All these factors accentuate the desirability of promoting uranium production in the US, especially in Texas.

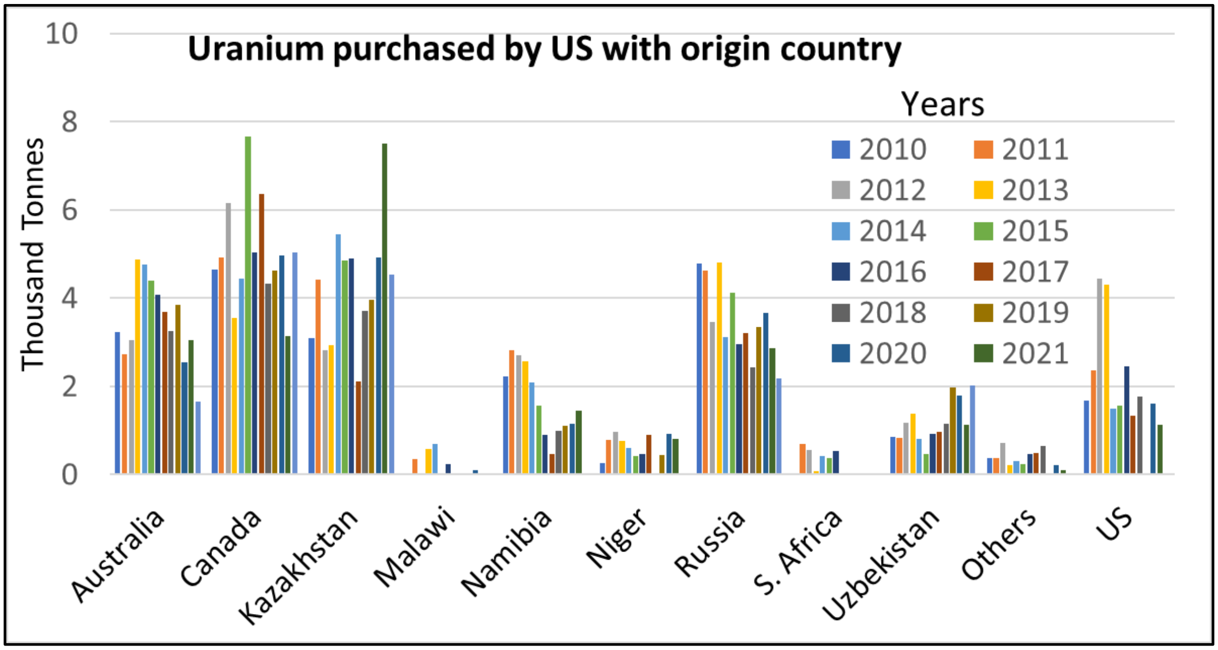


Figure 14: Uranium purchased by owners and operators of U.S. civilian nuclear power reactors by origin country. Metric (EIA, 2023; EIA, 2019; EIA, 2015).

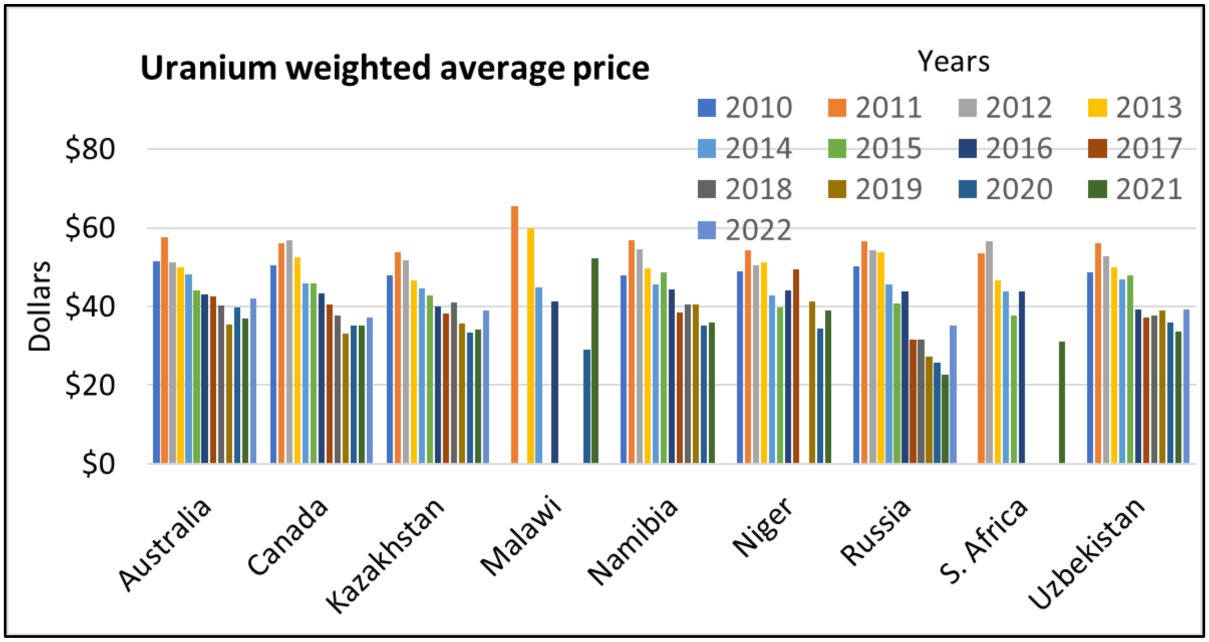


Figure 15: Uranium weighted average price paid by owners and operators of U.S. civilian nuclear power reactors by origin country. Metric (EIA, 2023; EIA, 2019; EIA, 2015).

A main reason for the decrease of the US national uranium production is the low price that uranium resource has experienced over the last two decades, as shown in Figure 16(a). The uranium price has remained below $60 dollars per pound, except for a period in 2007. This low price, generated by abundant supply from government and inexpensive imports, caused many of the US uranium producers to scale down or close their facilities. Recently a significant increase in prices has been experienced (see Figure 16(b)), due to the restriction on the world uranium supply, geopolitical instability for some of the major international producers, and a renewed interest in nuclear energy generation to curb climate change. This confluence of factors is expected to continue maintaining high uranium prices, creating incentives for US producers to reactivate their facilities.

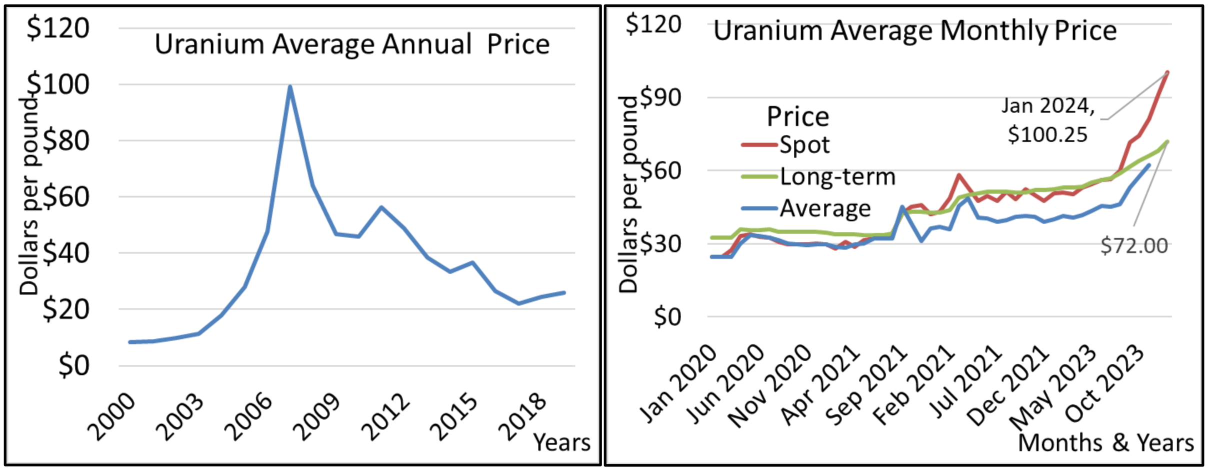


Figure 16: Prices of uranium (a) world average annual price (St. Louis Fed., 2023a) (b) world average monthly prices (St. Louis Fed., 2023b; Cameco, 2024).

Figure 17 displays the significant decrease in uranium mine production in the United States after 2014. These results highlight the impact that lower prices, international uranium availability and reduced demand have had on uranium mining. The number of operational mines changes according to the price and demand and supply fluctuations. However, as indicated by EIA reports and information provided by TCEQ in the preparation of this report, as of the end of 2023, there are 21 registered mines in the US of which three are operating, eight are on standby status and ten are on partially or fully permitted and licensed status (EIA, 2023; EIA, 2024). Reactivating these mines would allow the sector to increase uranium output to satisfy demand and reduce reliance on international suppliers. For mines that have active permits and can be reactivated with relative expediency, increasing output will allow them to benefit from higher current prices.

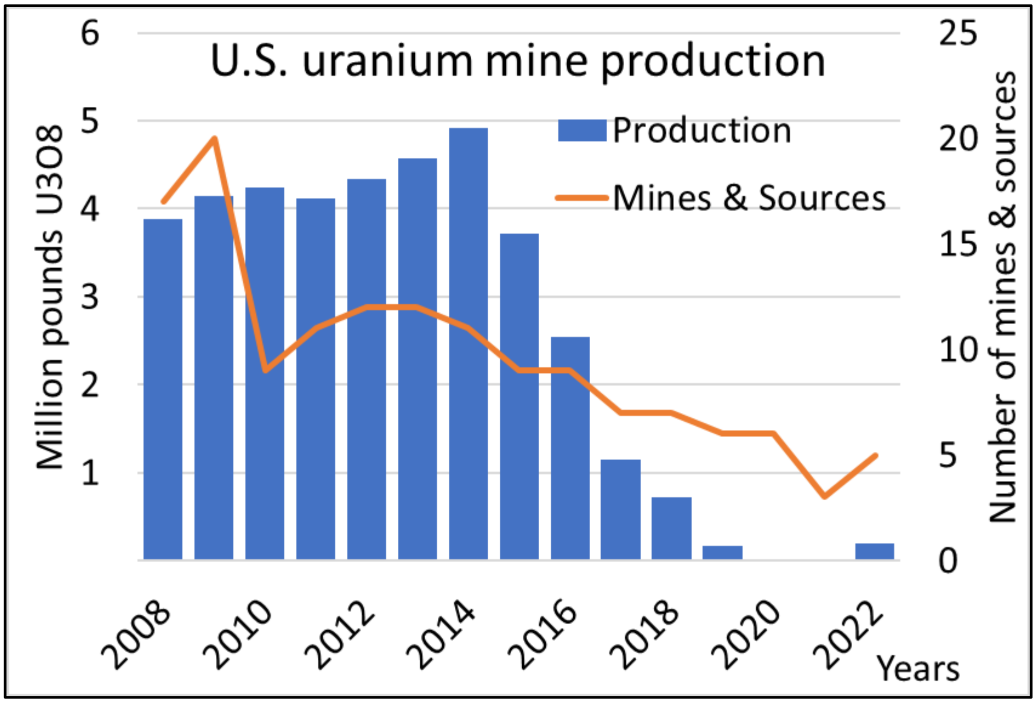


Figure 17: United States mine production including U_3O_8 production and the number of mines (EIA, 2022).

Uranium mining expenditures, reported by the US Energy Information Administration (EIA, 2022), are shown in Figure 18. However, the cost per pound of uranium increases significantly due to this low production, as indicated in Figure 19. Therefore, under a reduced-price scenario, uranium mining becomes unprofitable, leading to stakeholders further reducing operations. This negative cycle can be broken by the increase in price of this resource, allowing producers to attain a profitable cost per pound window.

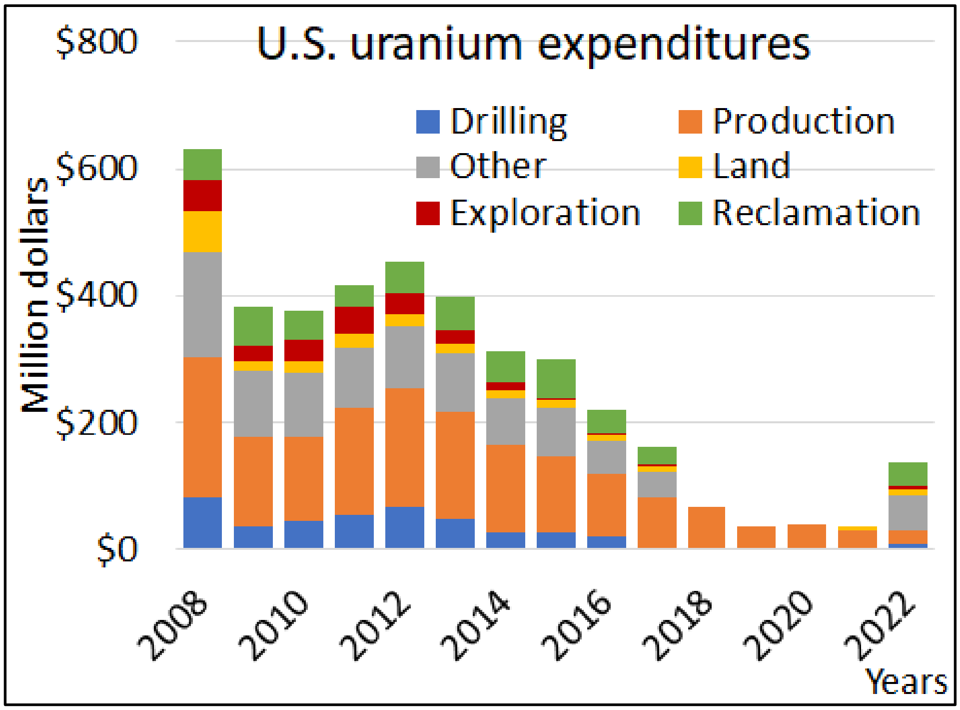


Figure 18: US uranium expenditures as reported by the US Energy Information Administration since 2008 (EIA, 2022).

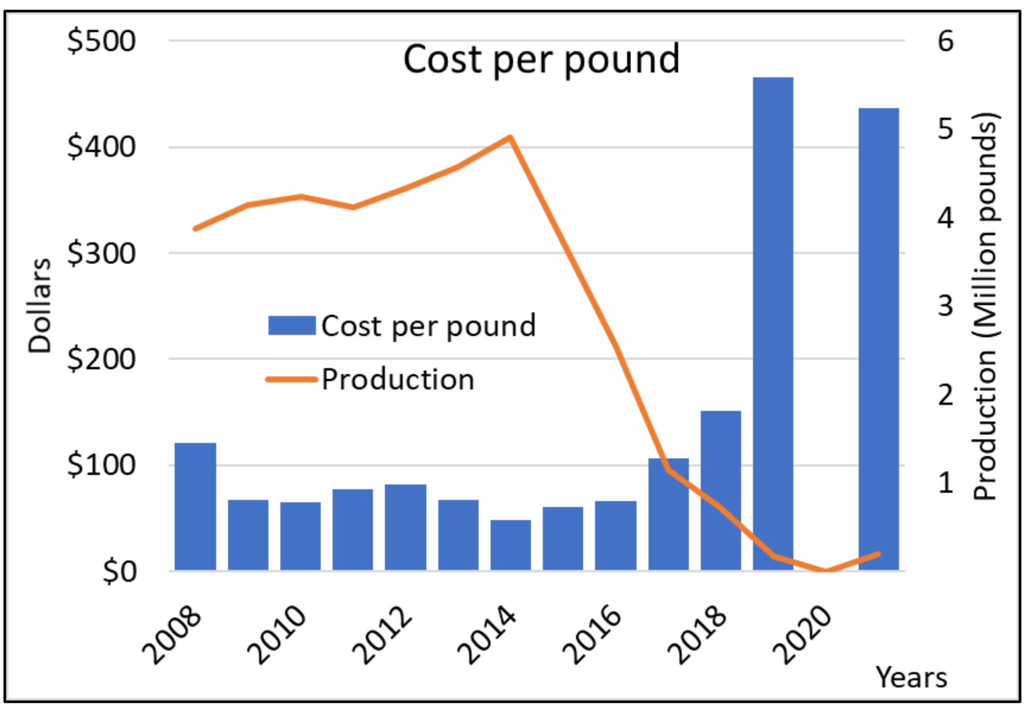


Figure 19: Cost per pound to US uranium producers considering uranium expenditures and mine production, as reported by EIA (EIA, 2022).

V. Estimated amount of uranium resource recovered to date

The uranium extracted in Texas has been from sandstone-hosted deposits, which are the most common type in the continental United States. There are four main types of sandstone-hosted deposits: basal, tabular, roll front, and tectonolithologic (Kyser & Cuney, 2009). Regarding uranium production in the United States, roll front and tabular are the two most important classes of deposits (Walton-Day et al., 2022). The United States has three major sandstone-hosted uranium regions: the Colorado Plateau, the Wyoming Basins, and the Texas Coastal Plain. The Texas Coastal Plain is the smallest producing of the three major uranium regions and the only location in Texas where there has been any uranium mining. The South Texas uranium (STU) deposits are classified as roll front, even though more recent ore-deposit models refer to them as roll type (Kyser 2009; Hall et al., 2017). Due to the Texas Coastal Plain uranium's resource geological setting, open-pit mining and ISR have been used in uranium resource recovery since 1955 (Hall et al., 2016).

A. Overview of historical uranium production in Texas

In an earlier 2016 assessment of uranium resources of the US, it was determined that approximately 80 million pounds of U_3O_8 were recovered in Texas between 1955 and 2013 from an estimated ninety-two mines and one tailings facility (Hall et al., 2017). In the same assessment, about 200 million pounds had been mined from Wyoming Basins and 340 million pounds from the Colorado Plateau. As mentioned earlier in the text, there are four geological host formations in Texas which the sandstone-hosted uranium deposits are found: Jackson Group, Catahoula Formation, Oakville Formation, and the Goliad Sand. It was noted that the precise quantitative figures are uncertain due to the information derived from the Department of Energy database, which only sometimes tracks production from a specific mine. In addition, we consider the influence uranium prices have had on the recovery of valuable minerals.

B. Data on uranium production by formation

Information from multiple reports and sources from 2008-2013 is summarized in Table 1 below to provide an idea of the amount of uranium resources extracted as recorded by three different sources. While difficult to ascertain the exact amounts from each mining location, ranges of the amount of material produced can be determined, as well as the estimated amount remaining in the Texas Coastal Plain. In addition to the ranges of material produced per mining location, amounts of mineral production per geological formation can also be obtained. In Table 1 below, the amounts of uranium extracted are quantified based on the formations from both open pit and ISR mining. The second column (Total Estimated) provides the expected total of what has been produced thus far, and what is thought to remain in the formation. The third column (Produced) shows what has been produced as of 2013/2014. The fourth column (Remainder) is the probable amount remaining in place. Summing up formation productions from the respective sources provides an insight into the variation in production amounts. Based on Hall's 2016 assessment – in which 67.4 million pounds was estimated to have been produced as of 2013 – this report focuses on the past producing deposits to create a summation of amounts based on which formation the deposit was located. Based on what was gathered from the Walton-Day 2022 report, an estimated 73.6 million pounds have been produced. In Table 2, the types of operations utilized in each formation are presented.

Table 1: Texas Gulf Coast uranium hosted formations.

Formation	Total Estimated (lbs. U_3O_8)	Produced (lbs.)	Remainder (lbs. U_3O_8)	Reference
Goliad	>10,000,000	5,000,000	5,500,000	i
		10,380,000	30,400,000	ii
		11,442,094	33,464,600	iii
Jackson	40,171,000	31,961,000	8,210,000	i
		20,800,000	3,160,000	ii
		22,937,815	3,490,614	iii
Oakville	27,250,000	18,260,000	11,100,000	i
		33,600,000	10,560,000	ii
		37,026,575	11,629,994	iii
Catahoula	24,175,000	12,175,000	9,000,000	i
		8,780,000	9,920,000	ii
		9,672,382	10,936,813	iii

i: from Genetic and grade and tonnage. Hall et al, 2017
ii: Geoenvironmental, as of 2013 Walton-Day, 2022
iii Assessment of Undiscovered... Hall et al, 2017

Table 2: Operation types used per formation host unit. Data extracted from Hall et al, 2017.

Operation type	Goliad	Jackson	Oakville	Catahoula	Total
Open pit	0	65	13	8	86
ISR	15	3	20	16	54
Unknown	1	8	3	17	29
Total	16	76	36	41	169

C. Current uranium ISR in Texas

Based on historical information, it is known that open-pit mining ended in Texas by the 1990s, leaving ISR to be the only method of uranium mining. From a legacy of dozens of uranium mines, there are currently only eight ISR sites in the state, listed in Table 3 below. Based on what was reported in the U.S. Energy Information Administration's Annual Uranium Reports from 2012-2023, only two plants were operating in that time range. La Palangana and the Hobson ISR Plant were in operational status from 2012-2015. The Hobson ISR Plant processed uranium concentrate that came from La Palangana, as they were part of the same project. Based on the S-K 1300 technical report done by WWC Engineering and described in the EIA annual report, La Palangana produced 0.56 million pounds of uranium between 2010 to 2016 by ISR. From 2005-2013, Alta Mesa produced 5 million pounds of U_3O_8 (enCore, 2023).

Table 3: Texas uranium in-situ-leach plants by owner, location, capacity, and operating status at end of the year, information from EIA 2012-2023.

ISR Plant Name	Alta Mesa	Hobson	La Palangana	Kingsville Dome	Rosita	Vasquez	Burke Hollow	Goliad
IN-SITU PLANT OWNER	Encore Energy	Uranium Energy	Uranium Energy	Encore Energy	Encore Energy	Encore Energy	Uranium Energy	Uranium Energy
COUNTY	Brooks	Karnes	Duval	Kleberg	Duval	Duval	Bee	Goliad
Yearly Production Cap. (lbs. U_3O_8)	1.5M	2 M	1 M	1 M	1 M	1 M	1 M	1 M
2012	P	O	O	S	S	RS	N/A	P&L
2013	P	O	O	RS	RS	RS	N/A	P&L
2014	P	O	O	RS	RS	RS	N/A	P&L
2015	S	O	O	RS	RC	RS	N/A	P&L
2016	S	S	S	RS	RC	RS	N/A	S
2017	S	S	S	RS	RC	RS	N/A	S
2018	S	S	S	RS	RC	RS	PP&L	P&L
2019	S	S	S	RS	RC	RS	PP&L	P&L
2020	S	S	S	S	S	RC	P&L	P&L
2021	S	S	S	S	S	RC	P&L	P&L
2022	S	S	S	S	S	RC	P&L	P&L
2023	S	S	S	S	P	RC	P&L	P&L

Legend: O=Operating (indicates the in-situ-leach plant usually was producing uranium concentrate at the end of the period), P=Producing, S=Standby, RS=Restoration, RC=Reclamation, P&L=Permitted and Licensed, PP&L= Partially Permitted and Licensed, N/A=Not Applicable, M= Million. Hobson Only processes U3O8 from La Palangana as they are part of same project.

In the preparation for this report, the Radioactive Materials Division of Texas Commission on Environmental Quality (TCEQ) indicated that that there are currently nine uranium In-situ Recovery (ISR) and/or processing facilities regulated by TCEQ. Of these nine sites, three are on standby, two are actively producing, two are licensed and not yet constructed, one is undergoing decommissioning, and one is undergoing license termination. Looking towards the future, one application for the addition of a new uranium ISR site is currently under review by the agency.

D. Factors influencing production trends over time

1. The nuclear fuel cycle

The nuclear fuel cycle, illustrated in Figure 20, serves as a guide to evaluate diverse factors influencing uranium production and utilization. In the first stage of the process (mining & milling) uranium is extracted through open pit mining or ISR. Globally both methods are used almost in the same proportion, but in the United States all active extraction facilities operate through ISR. After extraction, material goes through milling to remove all other materials and minerals from the uranium, generating a powdered variety of uranium (U_3O_8) usually called "Yellow Cake", which has an 80% uranium concentration (IAEA, 2012; Omland & Andersen, 2023). Natural uranium consists of three isotopes: U-234 (trace amounts by mass), U-235 (0.7% concentration by mass), and U-238 (99.3% concentration by mass). To be useful as fuel for nuclear reactors, uranium needs to be converted and enriched (second stage of nuclear fuel cycle) to increase the concentration of U-235. Most modern reactors require U-235 concentrations between 3 – 5 %. To achieve this enrichment, "Yellow-Cake" goes through two processes. It is converted into gaseous UF_6 (uranium hexafluoride) which is afterwards transformed into a solid state, lowering its temperature, for transportation to different facilities where enrichment will take place. In the enrichment facility, the UF_6 temperature is increased for it to regain its gaseous state, and it is injected into a centrifuge to separate parts of U-238 and increase U-235 concentration. The resulting enriched UF_6 is converted afterwards into nuclear fuel to be used by nuclear reactors. Through chemical process UF_6 is converted into powdered UO_2 (Uranium Dioxide) and compressed into small ceramic fuel pellets. The pellets are stacked and formed to create fuel rods, which are bundled together to create a fuel assembly (EIA, 2023; Omland & Andersen, 2023).

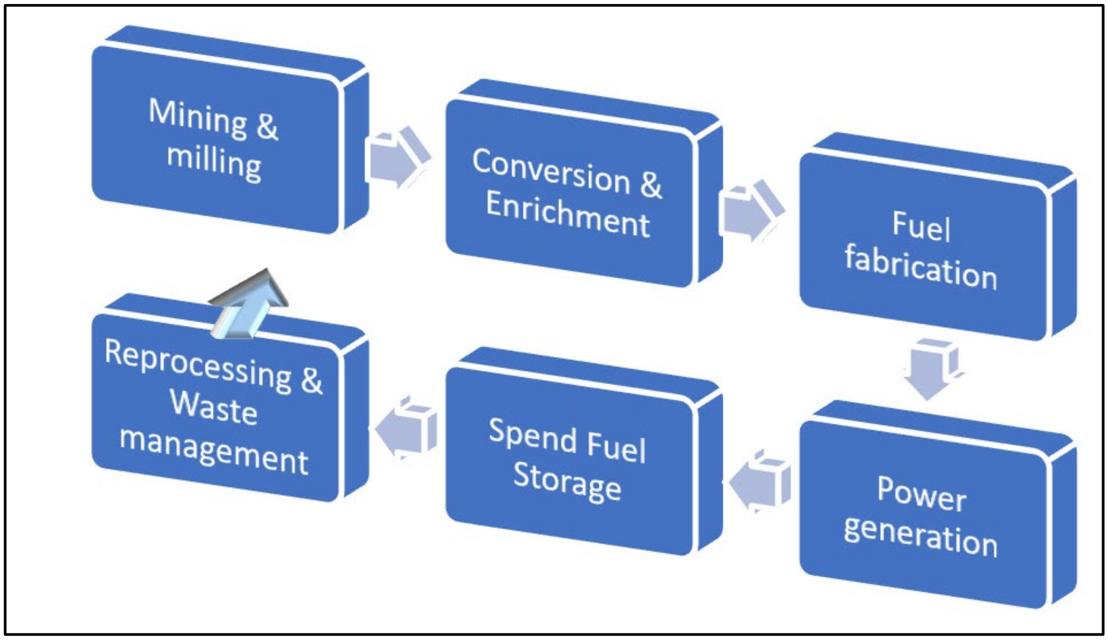


Figure 20: Nuclear fuel cycle (IAEA, 2012; Omland & Andersen, 2023).

2. Uranium recovery trends over time

As illustrated in Figure 21, from 1955 to 1980, there was a dramatic increase in uranium mining in the United States, with significant government incentives (DiChristopher, 2018). However, incentives were reduced during the 1960s, causing the first drop in domestic production observed in Figure 21. In 1975, overseas supplies were allowed in the US, with low-cost, high-quality uranium from Australia and Canada being integrated into the local uranium supply chain. In 1987, US uranium output fell to 13 million pounds, a significant reduction from production peaks shown in Figure 21 (DiChristopher, 2018). Nuclear reactor incidents over the last three decades further reduced the price of uranium, which was accelerated by government decommissioned uranium made available to nuclear reactor operators. This created challenges for US uranium mining companies, which were not able to cover their production costs at such low prices. National uranium production continued to decrease well into the 2000s, and currently most supply is provided by foreign suppliers. However, as uranium prices have increased recently, the opportunity for US mining operations to reactivate has significantly increased. This will allow national producers to compete with international stakeholders that may access uranium deposits with lower extraction costs.

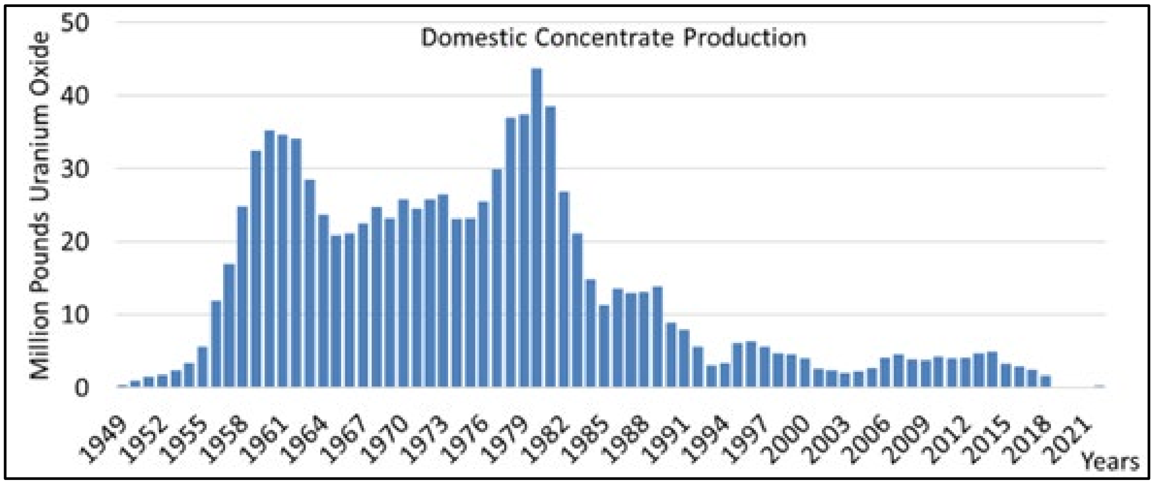


Figure 21: Domestic concentrate production in millions of pounds of uranium oxide (EIA, 2024a).

3. Nuclear energy demand

Nuclear energy is also expected to grow as an alternative to curb climate change. It provides significant benefits when compared with other electricity generation technologies. It has a much lower carbon footprint in contrast with hydrocarbon fuels. Nuclear energy can maintain stable electricity generation, which is a significant advantage compared with the inherent variability of wind and solar renewable energy. Several countries are discussing expanding their nuclear energy generation, including China, France, and the United Kingdom. Sixty nuclear reactors are under construction in seventeen countries worldwide (Shan, 2024). China currently has 55 nuclear reactors in operation, with 24 under construction and 150 planned (Murtaugh & Chia, 2021; Webb, 2024; ETI, 2024). Furthermore, it is expected that by 2030, a new generation of small nuclear reactors could go online (Lewis, 2023). Coupled with the reactivation and life extensions of many existing nuclear reactors worldwide, demand for uranium is expected to keep at high levels for the foreseeable future. Uranium prices are therefore also expected to continue at high levels, with Citibank forecasting the average price per pound of uranium reaching $110.00 (Shan, 2024). This creates significant incentive for US producers to reactivate and increase output in their uranium mining facilities (Lee, 2024; Shan, 2024).

4. Political instability

Political instability has impacted the outlook for uranium, creating uncertainty on forecasts, limiting output, and expanding competition between uranium consumers to access potentially limited supply, therefore pushing prices higher. It is reported, for instance, that France, which generates 60 - 70% of its electricity from nuclear reactors, stopped receiving uranium shipping from Niger, the 7th largest world producer, after a military coup in July 2023 (Vock, 2023; Shan, 2024). This creates further pressure on uranium producers to increase output to satisfy the growing demand, as Niger was the second largest uranium supplier to the European Union in 2022 (Lee, 2024). War in Ukraine has created uncertainty on the conversion and enrichment of uranium to be used in nuclear reactors. Russia hosts nearly half of the world's uranium enrichment facilities, as shown in Figure 22. The US contains just one enrichment facility in New Mexico, owned by the British-German-Dutch consortium Urenco. The results in Figure 22 showcase potential vulnerabilities for uranium enrichment as nuclear power generation begins to grow. For some Eastern European countries, which operate soviet design nuclear generators, Russia was originally the only potential supplier, increasing potential vulnerabilities and creating pressure on uranium demand. Russia supplied twenty percent of the enriched fuel to nuclear reactors in the United States in the early 2020s (Freebairn, 2022). As operators have tried to diversify their suppliers, this has further strained world uranium markets. To overcome these challenges, great interest has been indicated, in different countries, to grow uranium enrichment capacity. The US federal government initiated a process to incentivize US investment in uranium enrichment services, earmarking $2.2 billion dollars to achieve this objective (NEI, 2023). The goal is promoting the development of enrichment facilities to process domestic uranium resources. Additionally, as H.R. 1042 the Prohibiting Russian Uranium Imports Act bans all uranium imports from Russia, expanding these domestic capabilities has critical importance. Investing the funds appropriated by the US Congress to develop uranium enrichment and conversion capacity will provide local suppliers with many opportunities to expand and develop their capabilities, providing sustainable and secure energy for the US (DOE, 2024d; Day, 2024). Considering that advanced smaller reactors will require higher grade uranium, the proposal indicates that the new facilities should be able to enrich beyond the current 5% U-235 to reach up to 20% concentrations (Krellenstein & Wilkinson, 2023; DOE, 2024a).

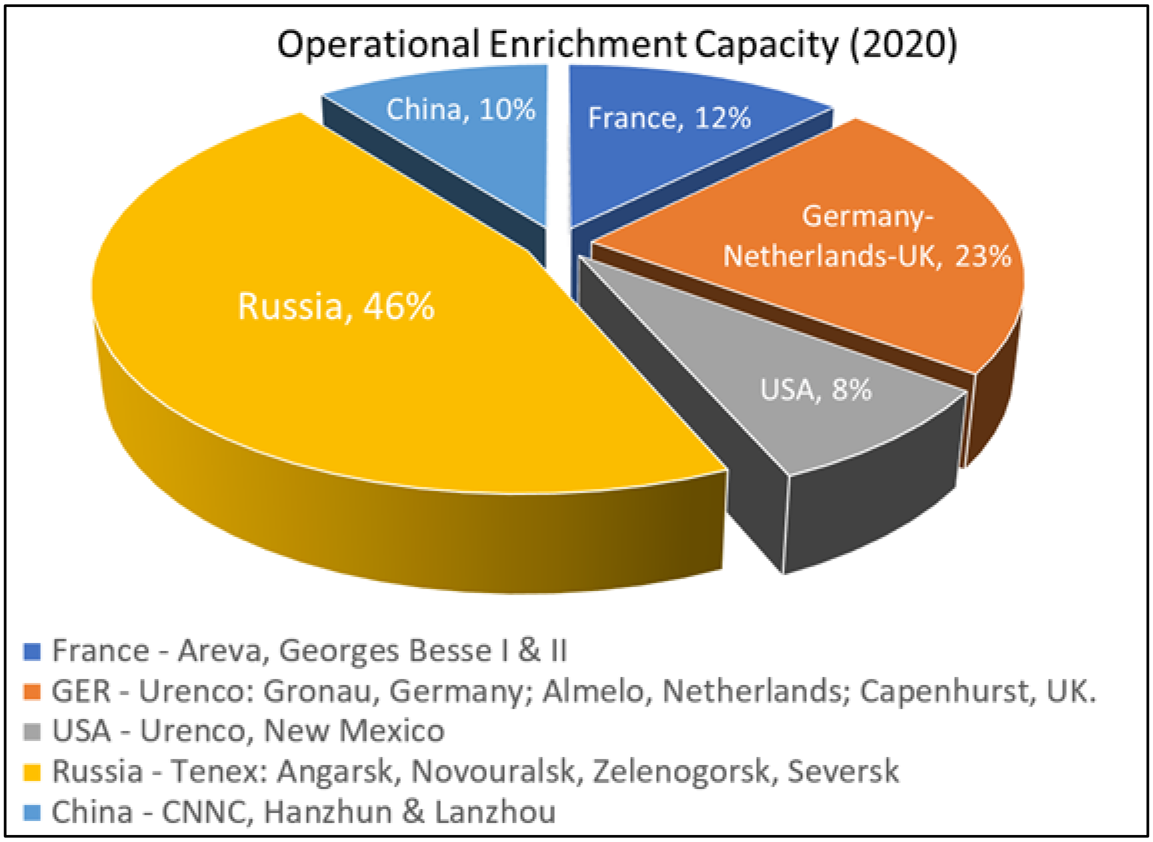


Figure 22: World enrichment capacity operational as 2020 (WNA, 2022) (a) by country and (b) enrichment locations by company per country.

5. Technical issues

Technical issues have impacted several uranium mining operations in different locations. Kazatomprom (located in Kazakhstan), one of the world's largest uranium suppliers, with a 43% market share, reported that production targets will be missed through 2025. Challenges in the supply of sulfuric acid, essential in the mining and milling of uranium, are an important factor in this issue (Lee, 2024; Shan, 2024). Cameco, the second largest uranium producer in the world, located in Canada, also reported challenges in their operation that will restrict their forecasted uranium supply. It reported that new mining operations impacted productivity, with additional issues in equipment reliability hindering operations. Some of the other reported challenges indicated by Cameco involved lack of personnel with necessary skills and experience, supply chain issues regarding reagents and materials, and operational challenges (Cameco, 2023). It is important to consider among the technical challenges the fact that smaller reactors, which may be deployed in the short term, require higher enrichment levels of U-235. These generators require concentrations between 10 – 20% (Krellenstein & Wilkinson, 2023; DOE, 2024a). However, enrichment facilities that generate concentrations above 10% are considered sensitive technology, due to the relatively lower efforts required to continue enrichment beyond these concentrations (WNA, 2022). Therefore, enhanced physical security and different licensing is required for these facilities, with reconversion and enrichment performed in the same location to avoid transportation (WNA, 2022; NRC, 2023)

6. Workforce challenges

Constraints on the availability of qualified workers have also been indicated as a potential challenge for the uranium industry. Different activities in the nuclear fuel cycle will require diverse qualifications and availability for the worker resources of each organization. In the United States, during the 1970s and 1980s, there was significant growth in the uranium and nuclear industry workforce, met by college graduates, construction workers, and former military personnel (Townsend et al., 2022). The college programs are principally in nuclear engineering that focuses on nuclear reactor technology, design, and operation, while the military program is similarly focused on nuclear reactor technology for ship and submarine propulsion. However, the technical expertise needed for the uranium recovery through the ISR process is best addressed by technologists trained in chemical engineering (for uranium recovery from lixiviant solutions) and hydrogeology (for lixiviant delivery and recovery from the subsurface). However, as the nuclear energy industry's growth decreased and uranium prices decreased in the following decades, workforce numbers declined significantly. For these reasons employment has fallen by more than 20% in the last ten years in the mining sector, and there is a significant reduction in academic programs and training related to this sector (Barich & Kuykendall, 2022). Cameco, for instance, reported challenges related to a lack of personnel with the necessary skills and experience, leading the company to ramp up its hiring processes to handle uranium demand increases (Barich & Kuykendall, 2022; Cameco, 2023). The drop in employment for uranium production in the US has been more drastic, as shown in Figure 23 Employment in person-years in the US uranium production sector has decreased from more than 1,500 in 2008 to less than 200 in 2022. Therefore, the uranium industry may face challenges in hiring and retaining a qualified workforce as their operations need to ramp up soon to increase mining and enriching activities. Workforce development specific to uranium ISR mining could be enhanced by offering chemical engineering courses in lixiviant processing and uranium enrichment as an addition to current nuclear engineering minor programs that already exist at Texas schools such as Texas A&M University, Texas A&M University-Kingsville, and University of Texas at Austin.

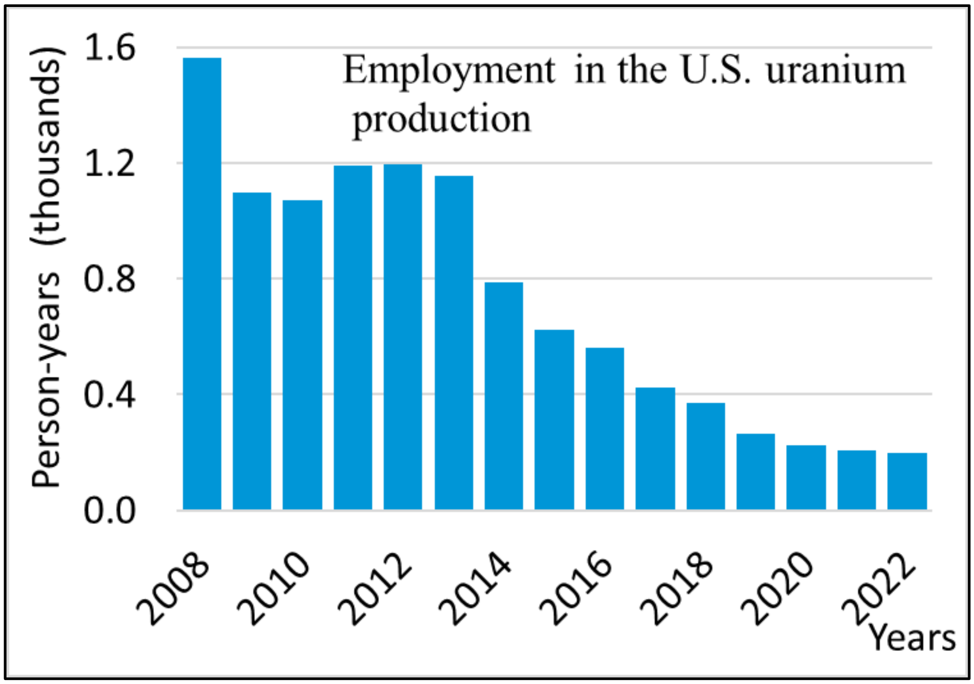


Figure 23: Employment in the U.S. uranium production (EIA, 2023a).

VI. Amount of Resource Remaining

To address the remaining quantity of resources in the area, it is imperative to consider the ongoing and past evaluations and estimations pertaining to the uranium reservoirs.

A. Current estimates of total uranium reserves in Texas

It has been estimated that 60 million pounds of U_3O_8 identified resources remain within the Texas Coastal Plains (Hall, 2017; DOE/EIA, 2010). Potential discrepancies in reported figures may arise due to instances of non-reporting or limitations in land access, thereby potentially skewing the numerical representations. In 2012 an assessment was made by the USGS on analyzing the results of the NURE program's comprehensive assessment on the estimate on uranium resources in Texas. In that assessment, they estimated an unconditional potential resource of 1.4 billion pounds of U_3O_8. That estimate included the Houston embayment, the Texas Gulf Coast, and the Rio Grande embayment area. The resources were assessed up to a depth of 4,500 ft. Previously, 500 ft had been the economic choice and historical benchmark depth for uranium mining. The Houston embayment proved to be a non-productive region. It is labeled non-productive as the depths of the uranium minerals are too deep to be extracted economically and the geological characteristics are not conductive to uranium deposit formation. After removing depths below 750 ft. and the non-producing Houston embayment, the estimated 1.4 billion pounds reduces to around 920 million pounds in all cost categories of economically viable U_3O_8. Then if only taking into consideration a 1980s $30/lb (current day is $113/lb) rate, this further reduced to 399 million pounds of U_3O_8. The NURE has been seen as fairly correct in its estimations on favorable location identification for mining as much of the area that has been mined and produced U_3O_8 have fallen within the favorable identified areas, except the Kingsville Dome and the Alta Mesa mines.

Then, in 2018, at the International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle, Mihalasky – a research geologist, spatial data analyst, and uranium resource specialist – presented that the U.S. Geological Survey had recent uranium resource assessment re-evaluations from two locations in Texas that the 1980 NURE program had also previously considered. One location that was assessed was that of the Texas Coastal Plain in south Texas, which happens to be the only Texas location that has been mined. The coastal plain assessment was previously studied in the 2015 and 2017 reports that Mihalasky and Hall co-authored. The second reassessed location was the Southern High Plains (SHP). That region encompasses the western and northwestern parts of Texas which were also deemed Speculative areas by NURE and can be seen in Figure 3. The SHP was the subject of the paper by Van Gosen and Hall in 2017. The area was first assessed in the mid-1970s by the Kerr-McGee Corporation (Kerr-McGee) who conducted an exploration program that led to the discovery of two shallow uranium deposits that had gone unreported until then (Van Gosen & Hall, 2017). Van Gosen reported that Kerr-McGee had determined that one deposit contained about 2.1 million metric tons of 0.037% U_3O_8 concentration and another about 0.93 million metric tons at 0.047% U_3O_8 concentration. The deposit areas are near Big Spring. One is known as the Buzzard Draw deposit, and the other is the Sulfur Springs Draw deposit, which are located on privately owned land, and exploration was allowed through lease agreements (Van Gosen, 2017). By 1981, an economic analysis was conducted for the two newly discovered areas; however, due to the marginal profitability, Kerr-McGee was dissuaded from the development of the two mines. With that, the exploration program ended. From the three-part quantitative assessments done on roll-front and calcrete uranium respectfully of the Southern Texas and the Southern High Plains Provinces, Mihalasky stated that a collective total of 155,000 tons of uranium were estimated. This equates to roughly 341 million pounds of uranium. This summation breaks down as follows: in the Southern Texas roll-front there was 54,000 tons of uranium of identified resources along with an estimated average of 85,000 tons of uranium undiscovered. From the calcrete uranium in the Southern High Plains there are 1,000 tons of uranium of identified resources with an additional estimated average of 15,000 tons of uranium undiscovered (Mihalasky, 2018).

In 2022, an assessment estimated that the South Texas uranium region had a potential undiscovered resource mean of 99,790 metric tons (220 million pounds) of recoverable uranium oxide. These resources are said to be distributed among three defined permissive tracts north and south of the San Marcos Arch. A permissive tract is a region that is delineated for the occurrence of deposits, guided by an analysis of known deposits and a descriptive model (Walton-Day et al., 2022). Should these identified and estimated undiscovered uranium resources be economical, this resource can represent eight years of civilian nuclear power reactor fuel for the United States.

1. Current activities by Texas ISR Companies

As of the present date, the ownership of In-Situ Recovery (ISR) facilities in the State of Texas are held by two companies: enCore Energy and Uranium Energy Corp. enCore Energy is presently engaged in the operation of ISR uranium plants and undertakings located in South Texas, South Dakota/Wyoming, and New Mexico. Uranium Energy Corp possesses projects in Arizona, Wyoming, Texas, Canada, and Paraguay.

enCore Energy encompasses six mining sites in south Texas, including Rosita Extension, Alta Mesa (which includes Mestena Grande), Upper Spring Creek (Brown and Brevard), Rosita South, and Butler Branch. Rosita and Alta Mesa are licensed and permitted processing facilities and production areas. Rosita commenced processing operations in 2023, and Alta Mesa is operational as of June 16th, 2024 (enCore, 2024). The formal inauguration of the Rosita facility took place in February 2024, accompanied by the initial shipment of uranium to their utility customers. Notably, the Rosita ISR processing plant is the first facility in Texas to produce uranium in the past decade. With Alta Mesa now in production, enCore joins a select group of companies worldwide with more than one uranium plant in production. Alta Mesa is reported to possess 3.4 million pounds of measured and indicated resources of U_3O_8, in addition to 16.7 million pounds of inferred resources. Anticipating a rise in domestic uranium demand, enCore has entered into a joint 70/30 venture deal with Boss Energy Ltd., enabling them to utilize the proceeds to advance project timelines across the company. Notably, as per the 2023 annual report, enCore has secured its sixth uranium sales agreement, the fifth of which was with a US nuclear utility. Over the next three years, enCore's production strategy primarily focuses on its two fully licensed sites, Rosita and Alta Mesa. These facilities are designed to process feed resin from relocatable satellite plants at various deposits within a 100-mile radius of each facility. The Rosita Central Processing Plant (CPP) boasts a production capacity of 800,000 pounds per year, while Alta Mesa has a production capacity of 1.5 million pounds annually (enCore, 2024e). With the expected increase in domestic uranium needs, the company is establishing scholarships and other programs, such as internships and co-ops, to develop the next generation of ISR experts. As of September 11, 2024 based on EIA Q1 Domestic Uranium Production Report, 35,979 pounds of uranium have been produced from the Rosita ISR site. It was stated that in Q2 about the same amount of uranium was produced and by the time Q2 came around, there had not been enough time to accumulate production for drying and packaging at the Alta Mesa ISR site (Sanchez, 2024b). In a recent news release, enCore Energy (Encore), who acquired the Alta Mesa Uranium Project (which is composed of the Alta Mesa and Mestena Grande properties) in 2023, stated they had encountered significantly higher-grade thickness drilling results (Beahm, 2023). In a technical report from 2023, Encore cited that the grade thickness in the area was averaging 0.59 to 0.68. The cutoff grade thickness for ISR in Texas is at 0.3 for economic extractions. From the latest company news release, Encore reported they found a significant number of the delineation holes with 3.0 to 8.4 grade thickness and a maximum thickness of 13.5 ft (enCore Energy, 30 March 2024). Per the NI-43-101 Technical Report from 2023 that indicated averaged grade thickness of 0.59 to 0.68, Alta Mesa and Mestena has a combined indicated mineral resource of just around 3.4 million pounds and a total inferred resource of 16.7 million pounds uranium (enCore Energy, 2023).

Uranium Energy Corp. (UEC) possesses five uranium project sites in Texas as of the 2024 corporate report: Goliad, Longhorn, Salvo, Burke Hollow, and Palangana. The Palangana mine, located 94 miles from the Hobson processing plant, has obtained complete permits and is progressing towards a re-start. The Burke Hollow site has received its final permits and is striving to commence uranium extraction in the near future. The Hobson CPP plant has a four million lbs./yr licensed production capacity. The five satellite projects mentioned above contain a combined measured and indicated 9.1 million lbs. and an inferred 9.9 million pounds of U_3O_8 resources (UEC 2024). The Burke Hollow ISR project is anticipated to be the newest and most extensive wellfield under development in the United States. UEC has been awarded by the Department of Energy to supply 300,000 pounds of U_3O_8 to the uranium reserve (UEC, 2024).

2. Economic viability of uranium recovery

Forward Cost of uranium is considered the break-even point at which it is economically viable to extract the resource. It is comprised of many costs involved in mining uranium, including labor, materials, insurance, power and administrative costs. However, it excludes previous expenditures, such as cost of acquisition, exploration, development and construction, as well as cost of money and income taxes. Nevertheless, it is a very important parameter to assess and compare uranium reserves in diverse geological settings and locations. Depending on the forward cost estimates, the availability of the resources changes significantly, with higher costs generating higher potential uranium reserves (Grant Canyon Trust, 2022; EIA, 2024b).

This is reflected in results from the Uranium Resources, Production and Demand 2022 joint report by the Nuclear Energy Agency and the International Atomic Energy Agency (OECD-NEA & IAEA, 2023), presented in Figure 24. This report indicates that the United States holds over 1% of the identified in situ resources for uranium, ranking fourteenth among the world nations. For our nation, 62% of uranium in situ identified resources are in the highest forward cost category ($117.93), 33% in the $58.97 level and the remaining 5% on the $36.39 segment. No resources were indicated for the US in the lowest category ($18.14). Identified in situ resources are relevant for evaluation, as it considers existing uranium in the location without accounting for the losses that the mining and milling processes incur (OECD-NEA & IAEA, 2023). As mining and milling technologies improve, losses can be reduced, and recoverable uranium from the mineable ore can increase.

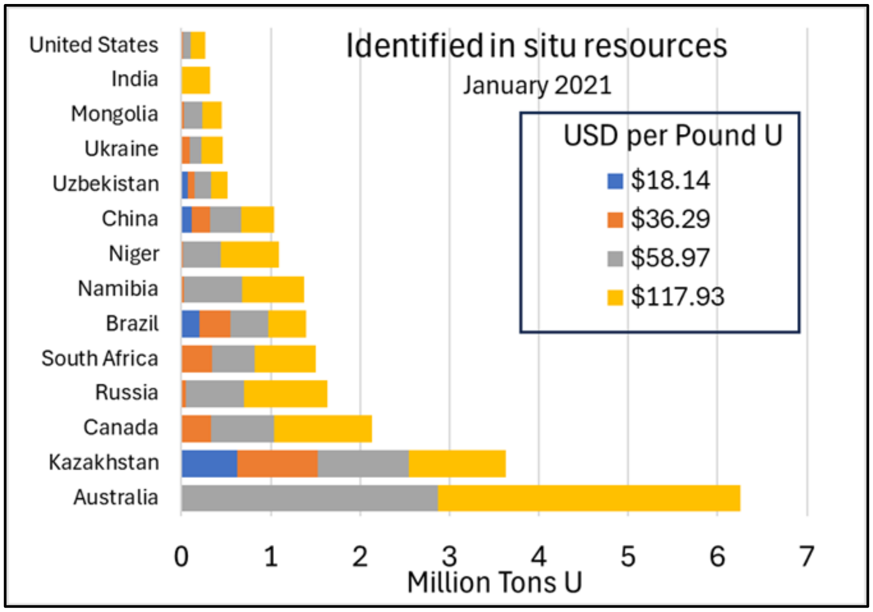


Figure 24: World's uranium in situ resources per country from the Uranium Resources, Production and Demand 2022 report (OECD-NEA & IAEA, 2023).

Results from uranium identified recoverable resources are presented in Figure 25. This category refers to the uranium which is actually extracted from mineable ore, after accounting for the losses from milling and mining. Resources are, therefore, lower than the in-situ quantities indicated in previous results. However, these values could improve as technological advances increase effectiveness of extraction rates. Results from Figure 25 are in line with previous results from the identified in situ resources, showcasing that the US also holds over 1% of the world's uranium identified recoverable resources, with the first five ranked countries accounting for almost 63% of these resources. Furthermore, the US proportion of the uranium identified recoverable resources is very similar to Figure 26 results, with 62% in the $117.93 forward cost category, 33% in the intermediate $58.97 rank, only 5% is on the $36.39 and no resources in the lowest $18.14 segment.

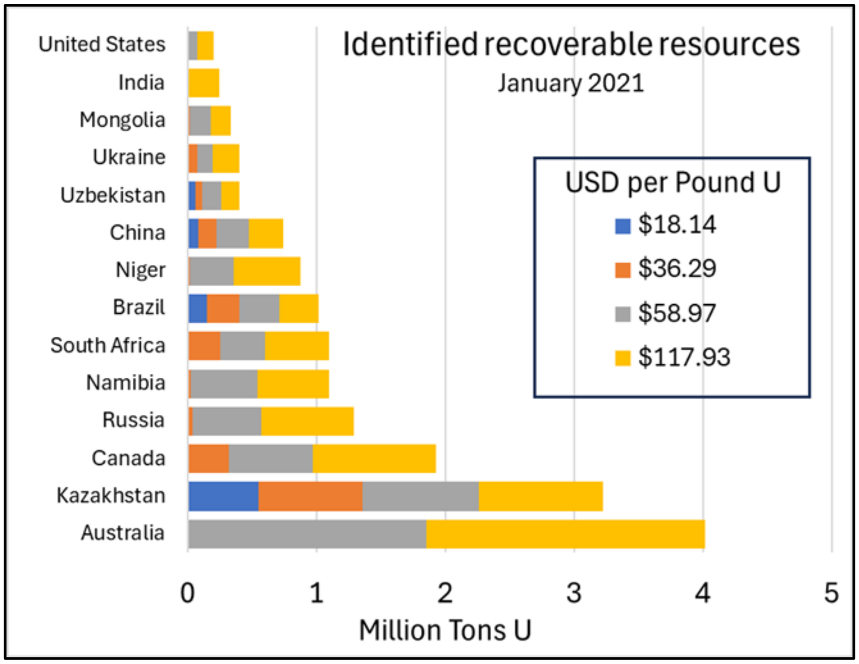
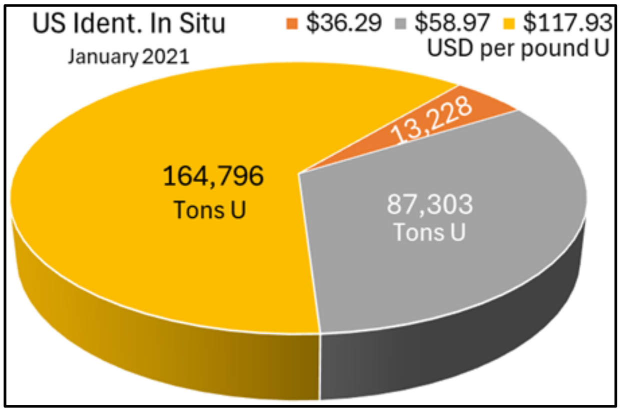


Figure 25: World's uranium identified recoverable resources per country from the Uranium Resources, Production and Demand 2022 report (OECD-NEA & IAEA, 2023).

Figure 26 presents the uranium identified inventory as of January 2021 according to the OECD-NEA report for both in situ and recoverable deposits (OECD-NEA & IAEA, 2023). More than two thirds of these resources are in the highest forward cost category, providing a good outlook for a significant increase in the extraction of this resource considering the recent increase in price. The inventory levels assessed in this report are lower than the ones reported by the US Energy Information Administration, which will be presented in the following paragraphs. This may be related to the lower uranium prices prevalent at the time the 2022 report was prepared. Therefore, it is relevant to assess forward cost uranium inventory in the US for both 2008 and 2022, as presented by the US EIA, to provide a broader view of the potential availability of this resource and the impact that price increases can have on the incentive for extraction.



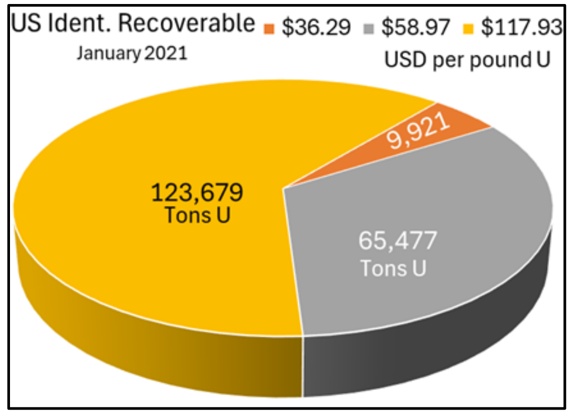


Figure 26: Uranium identified resources in the United States classified by forward cost category considering (a) In Situ resources and (b) Recoverable resources (OECD-NEA & IAEA, 2023).

Results from Figure 27 confirm that the EIA uranium inventory for 2008 (EIA, 2010) reflects a larger estimate than the OECD 2021 assessment (OECD-NEA & IAEA, 2023). This is relevant, considering the time frame between these two reports, during which uranium mining in the US was significantly reduced, due to prevailing prices below favorable forward cost levels for the US. Therefore, it is possible to consider uranium inventory levels for these EIA reports. Furthermore, EIA 2008 results indicate that ISR has similar levels for the other two mining options for the lower forward cost category, but it has lower reserve estimates for the $100 per pound category. As uranium prices continue to increase, ISR becomes more competitive. Considering that Texas is exclusively uranium mining by ISR, the highest prices may provide a competitive advantage for the state.

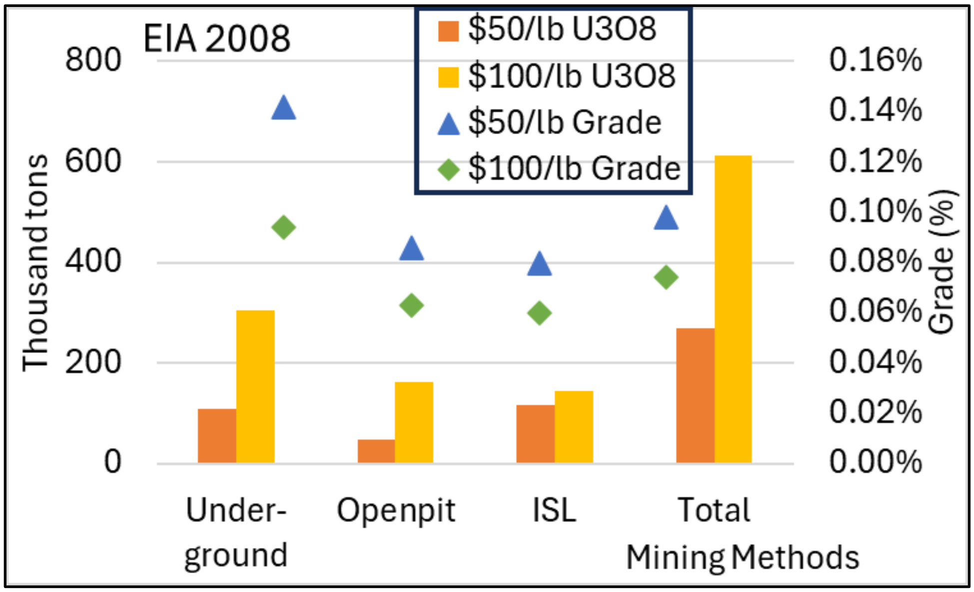


Figure 27: Uranium reserve estimates in the United States for 2008 as reported by the Energy Information Administration classified by mining method (EIA, 2010).

Figure 28 provides an historical outlook of US Uranium Reserve Estimates from 1993 to 2003 and 2008. Results showcase a yearly reduction from 1993 to 2003 in available uranium accounting for the facilities under operation and yearly uranium extraction. Forward cost for the analysis considers energy, workforce expenditures, insurance, materials, severance, administrative costs and taxes. As costs increase and uranium in the ground is depleted due to yearly production, values in each category change to reflect these factors. The assessment for 2008 was impacted by the facilities remaining in operation due to the uranium price decrease and the higher forward cost assessments. However, it is important to consider that as prices increase beyond $100 per pound, the uranium inventories are reevaluated, and its availability could significantly increase (EIA, 2010).

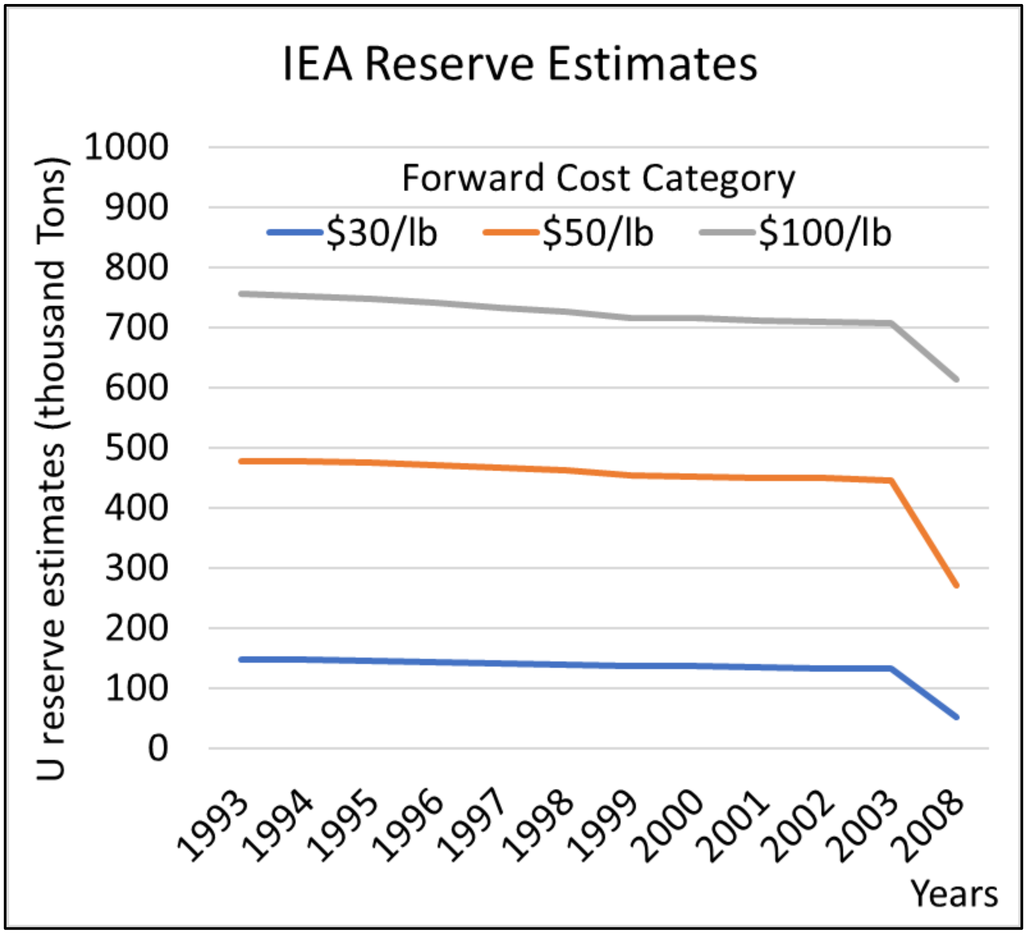


Figure 28: Uranium reserve estimates in the United States from 1993 to 2003 and for 2008 classified by forward cost category as reported by the Energy Information Administration (EIA, 2010).

Evaluating uranium inventory for Texas is relevant to better assess potential development of mining activities. Assessment of Uranium Reserve Estimates classified per state was reported for 2008 by the EIA, considering forward cost categories and mine operating status, as shown in Figure 29. This report indicates that, although Texas has lower reserves for both the forward cost categories shown, it is the second state in the nation with the most mine reserves, as shown in Figure 29(b). For the standby category, 47% of the reserves are in Texas and 20% of the permitted and licensed mining inventory in the nation is also in Texas. This provides a positive outlook for the development of uranium mining in Texas. Standby, permitted and licensed mines have the potential to start or reinitiate operations in the short term (EIA, 2024b).

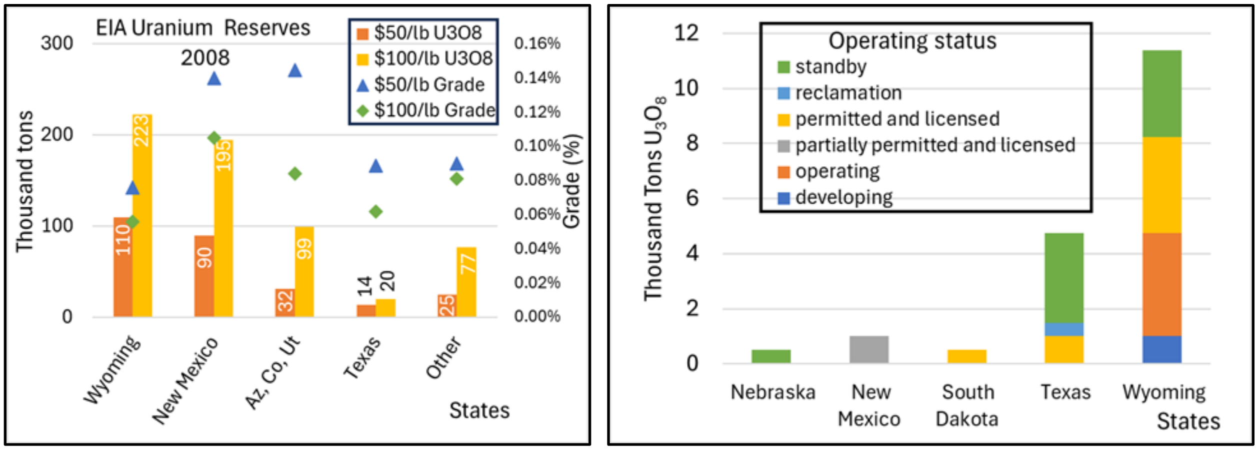


Figure 29: Uranium reserve estimates in the United States for 2008 classified by states and by (a) forward cost category (b) operating status of the mining facilities (EIA, 2024b).

The Texas Coastal Plain has been the main source of uranium mining activity in the state. Assessing its current and future development will provide a better understanding of diverse strategies to incentivize this activity. The US Geological Service, as part of its Domestic Uranium Assessment, provided a report for the potential for this resource in the Texas Coastal Plain (Mihalasky et al., 2015). Results from this report are summarized in Figure 30, with section (a) presenting the area under study in Texas. The Texas Coastal Plain was segmented into three tracts parallel to the coast categorized according to its sandstone geologic units. Each tract is in turn segmented in sub-tracts by the San Marcos Arch as indicated in the composite map presented in Figure 30(a). The Rio Grande Embayment sub-tract (RE), to the south, historically reports greater-known uranium occurrences and the Houston Embayment sub-tract (HE) to the north reports fewer known occurrences. Figure 30(b) primary vertical axis showcases the probability of undiscovered uranium (U_3O_8) resources, and the secondary vertical axis reflects identified uranium deposits. For both categories, resources in the RE sub-tract are higher, reflected in the abundant number of mining operations that have been established in this area for the last six decades. The Catahoula-Oakville tract in the RE sub-tract reports the largest deposits for both categories, with all the tracts in the RE sector having important present and future potential. However, the lower levels in the HE sub-tract may be derived from the lack of exploration and extraction in these locations. Further assessment may be warranted in these locations, considering that it's comprised in similar geologic units that may report similar inventory levels to its RE counterparts.

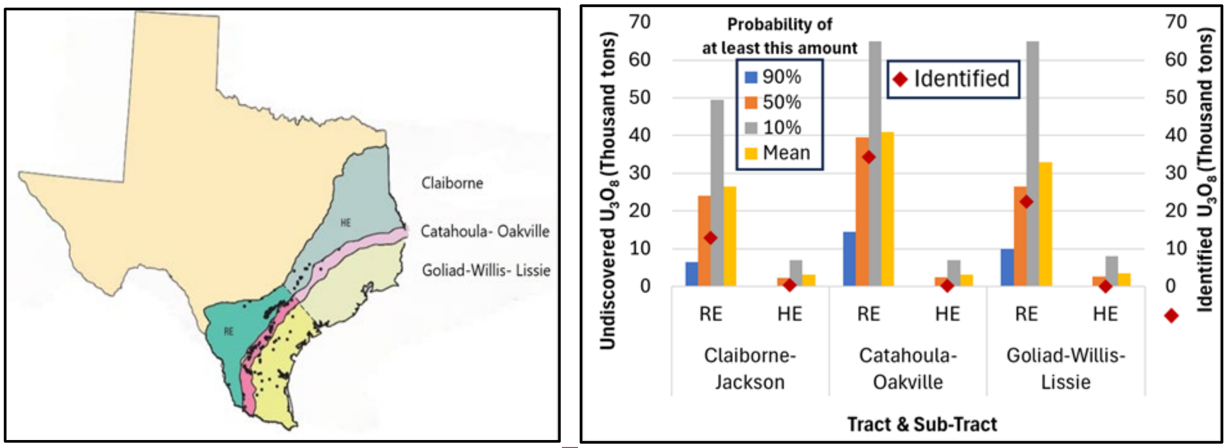


Figure 30: Assessment of uranium resources in the Texas Coastal Plain (a) Composite identification map (b) chart indicating classified by identified and undiscovered and location Tract and Sub-Tract (Mihalasky et al., 2015).

B. Assessment of recoverable uranium considering technological advancements

Over the last seven decades, a large body of data related to uranium resources, mining, and processing has been growing worldwide. In the US, diverse federal, state, and local agencies have developed and hosted significant databases with relevant uranium information. These databases are, in many cases, publicly available or access can be requested. This extraordinary collection could provide significant insight into all aspects of uranium development, from its current inventories, extraction, processing, fuel application, reprocessing and disposal. However, the databases have diverse formats, composition, periods and data frames, making it challenging to integrate them into a coherent collection that can be applied by diverse stakeholders. Therefore, the development of a taskforce that explores, collects, integrates and develops analytical tools to apply this huge data source could provide significant boost to the development and growth of the uranium industry in Texas.

These technological advancements over the years ranged from improving resource identification to enhancing ore extraction and include:

- Remote sensing: In conjunction with uranium pathogenic theory, predictions of favorable areas with uranium deposits can be made (Huang Xianfang et al., 2001). Satellite imagery and aerial surveys (such as Landsat) have proven invaluable tools in searching for uranium deposits (De Voto, 1984). They can identify geological features on the earth's surface that may indicate uranium mineralization, such as alteration zones, fault structures, and mineral assemblages. These images can also reveal variations in subsurface and vegetation patterns that may hint at the presence of underlying uranium deposits. Aita & Omar (2021) used satellite imaging to identify a site for uranium ore exploration in the mountainous area of Serbal Southwestern Sinai, Egypt, a testament to the effectiveness and reliability of these methods.

- Geophysical surveys: Geophysical methods measure earth's properties using physical principles (electric, gravitation, magnetic); the methods include magnetometry, gravity surveys, and induced polarization (IP) to detect subsurface anomalies that may be associated with uranium mineralization. For example, magnetometer surveys can identify magnetic anomalies caused by magnetite-rich alteration zones often related to uranium deposits. Gravity surveys can detect density variations caused by the presence of uranium-bearing minerals. A 3D-seismic survey was used to determine the feasibility of ore at the mine planning stage at Millennium uranium deposit, Saskatchewan, Canada (Juhojuntti et al., 2012).
- Radiometric surveys: Gamma-ray spectrometry measures the natural radiation emitted by uranium and its decay products, such as thorium and potassium, to delineate areas with elevated radioactivity. Portable gamma-ray spectrometers are used for ground-based surveys, while airborne gamma-ray surveys cover larger areas more efficiently. These surveys help identify uranium anomalies and map the distribution of radioactive minerals. Below, in Figure 31 is a zoomed in view of an aero radiometric map of uranium from the USGS website. This data generated by aerial sensing of radiation emanating from the earth's surface provides general estimates of the geographic distribution of uranium. It can be observed that areas in red on the map's southern coast correlate to those that have been mined in the past. In addition to the coastal area of the Texas map below, it can also be noticed that the areas in red in the north and northwestern portion also correlate to NURE's Speculative locations that were shown in Figures: 3, 4a and b, and 6c.

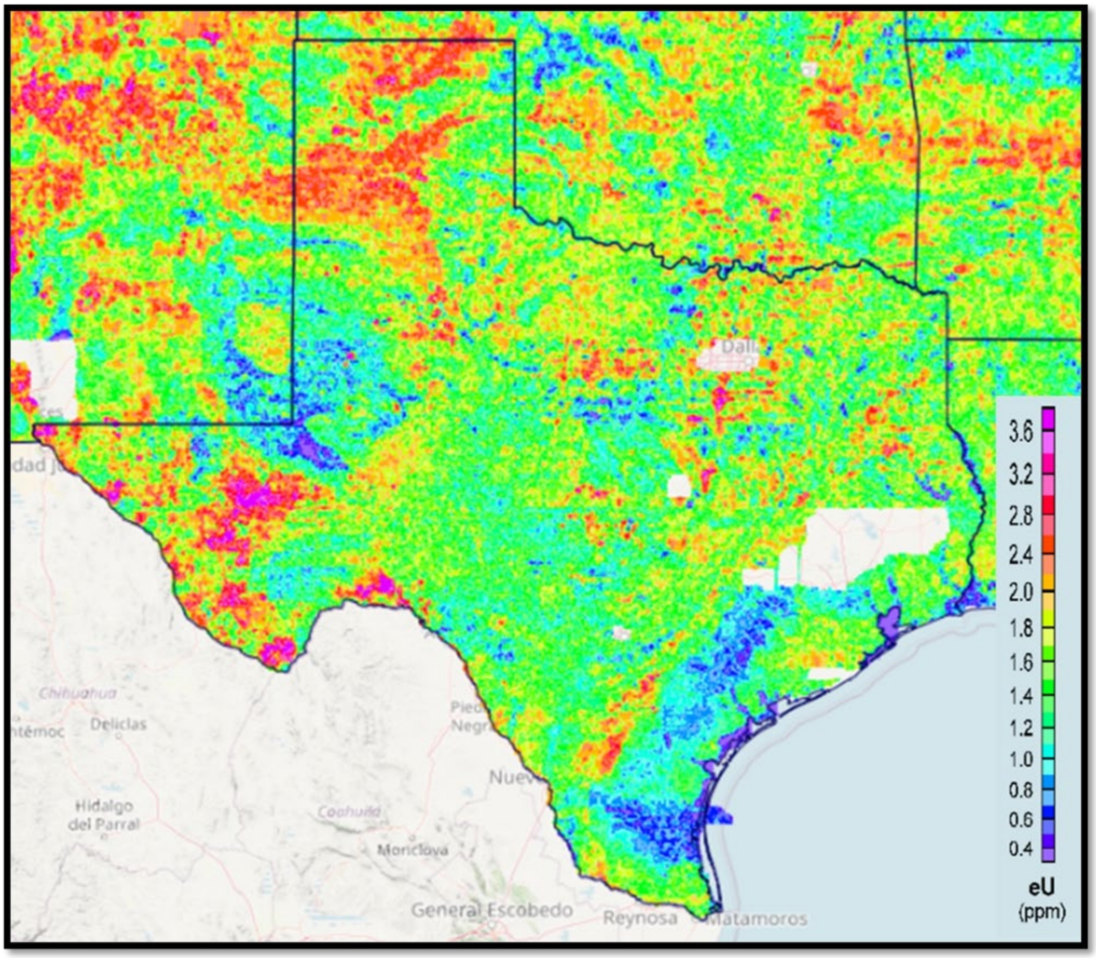


Figure 31: A zoomed in aero radiometric map of Texas terrestrial radioactivity (Kucks, 2005).

- Geochemical analysis: Soil and water samples collected from target areas are analyzed for geochemical signatures associated with uranium mineralization. Mass spectrometry and X-ray fluorescence spectroscopy quantify trace elements and isotopic compositions indicative of uranium deposits. Geochemical anomalies detected in surface samples can guide further exploration efforts. Groundwater samples collected from target areas are analyzed for uranium concentrations and isotopic compositions.
- Hydrogeochemical surveys help identify pathways of uranium migration and accumulation and potential sources of uranium enrichment in the subsurface. Isotopic analysis can distinguish between natural and anthropogenic sources of uranium contamination. De Voto (1984) showed a pattern of uranium content in shallow groundwater within the Wind River and Ft. Union strata in Wyoming.
- Drone technology: Drones with light detection and ranging (LiDAR) and multispectral cameras can capture detailed images and topographic data of specific areas. LiDAR data

helps reveal intricate terrain features, while multispectral imagery can identify vegetation stress and spectral signatures linked to alteration zones. This information supports geological mapping and ground-based exploration activities. A low-cost, low-altitude small unmanned aerial system (UAS) generated high-resolution radiation maps covering a large terrain area in the South Terra mining site of Cornwall, England (Martin et al., 2015). The instrument was produced within a shorter duration than the traditional method, with meter-scale radiation plots of the area regardless of the terrain. Also, the UAS identified and measured areas of land contaminated with radiation and determined the nature of the contaminants.

- Machine Learning and Data Analytics: Advanced algorithms are trained on geological, geophysical, and geochemical datasets to identify patterns and correlations indicative of uranium mineralization. By leveraging deep learning models, it is now possible to estimate the probability of finding uranium deposits by analyzing existing deposit characteristics and exploration data. With the help of advanced data analytics techniques, diverse datasets can be integrated and interpreted to generate potential targets and optimize exploration strategies. Zhang et al. (2022) designed three deep neural network (DNN) models for mineral identification and mapping using hyperspectral images from Baiyangbe uranium mining sites (in Northwestern Xinjiang, China) as the database. The models improved mineral identification accuracy compared to other mapping methods.
- Portable analytical instruments: Handheld x-ray fluorescence (XRF) analyzers and gamma-ray spectrometers are used for real-time analysis of rock samples during field exploration. These instruments provide rapid elemental analysis and identify radioactive minerals associated with uranium deposits. Field measurements help guide sampling efforts and provide immediate feedback on exploration results.
- Nanotechnology: Nanomaterial-based sensors are designed to detect trace amounts of uranium in environmental samples with high sensitivity and selectivity. These sensors offer potential applications in on-site monitoring of uranium contamination and in-situ exploration of uranium deposits.
- Integrated data fusion: Diverse datasets from geological, geophysical, geochemical, and remote sensing surveys are integrated and interpreted using advanced data fusion techniques. Integrated data analysis allows a holistic understanding of target areas' geological settings and mineralization potential, guiding exploration decision-making and resource assessment.

1. Integrated uranium information database

An integrated tool capable of performing complex data analysis with the collected and integrated databases from diverse federal, state, and local agencies, as well as research institutions, could aid in the assessment of recoverable uranium and accelerate the development of this industry. For instance, databases from the Texas RRC reporting radioactivity in oil and gas wells combined with the EIA, DOE, USGS, TCEQ, and EPA databases could provide powerful insight into the availability of uranium in the north and west regions in Texas. The collection, analysis, integration into a standardized database, and performance of analytics applying novel technologies, not available at the time of the original data collection, will most likely expand the inventory of available recoverable uranium.

2. Classifying uranium resources

As part of the database integration task, it would be critical to make the nomenclature uniform in identifying diverse uranium mining inventory resources. The NURE program indicates four potential classes for uranium resources: (1) Speculative resources; (2) Probable and/or Possible; (3) coincidence; and (4) endowment only (EIA, 2020a). The Energy Information Administration provides information for the Identified Resources Areas in its publicly available databases (EIA, 2020b). On the other hand, the Nuclear Energy Agency, in collaboration with the International Atomic Energy Agency, provides a more extensive classification of uranium resources, aiming to develop a harmonized global scheme, considering the geological certainty of the resource and its production costs. The Uranium 2022 Resources Production and Demand report (OECD-NEA & IAEA, Uranium 2022) described these categories as shown in Table 4. Additionally, each classification is further segmented into sub-categories, considering the feasibility of extraction costs for economic viability of the projects. Four additional sub-classes are created in addition to the ones indicated in Table 4, considering incremental cost ranges, using dollars and kilograms of uranium. The ranges for these cost values are indicated in Table 5, additionally indicating the equivalency into dollars per pound of uranium.

Table 4: Uranium resources classification. All textual references and denominations taken from the cited report (OECD-NEA & IAEA, Uranium 2022).

Class	Description class	Sub-class	Description sub-class
Identified resources	"Uranium deposits delineated by sufficient direct measurement to conduct prefeasibility and sometimes feasibility studies"	Reasonably Assured Resources (RAR)	"High confidence in estimates of grade and tonnage are generally compatible with mining decision-making standards"
		Inferred Resources (IR)	"Not defined with such a high degree of confidence and generally require further direct measurement prior to deciding to mine"
Undiscovered resources	"Resources that are expected to exist based on geological knowledge of previously discovered deposits and regional geological mapping. This class requires significant amounts of exploration before uranium existence can be confirmed and grades and tonnages can be defined"	Prognosticated Resources (PR)	"Resources expected to exist in known uranium provinces, generally supported by some direct evidence"
		Speculative Resources (SR)	"Refer to those resources expected to exist in geological provinces that may host uranium deposits"
Unconventional resources	"Very low-grade uranium resources or those from which it is only recoverable as a minor by-product or co-product"		

Table 5: Additional classification for the extraction of uranium, considering the cost to make it feasible (OECD-NEA & IAEA, Uranium 2023).

Metric to Imperial Conversion	
Resource category metric	Resource category imperial
<USD 260/kg U	<USD 117.93/lb U
<USD 130/kg U	<USD 58.97/lb U
<USD 80/kg U	<USD 36.29/lb U
<USD 40/kg U	<USD 18.14/lb U

Figure 32 showcases the world uranium identified resources with segmentation by Reasonably Assured Resources (RAR) and Inferred Resources. It clearly indicates that, as the price of uranium increases, the availability of resources that become economically feasible for extraction increases significantly. For instance, as the cost increases from the second to the third category ($36.20 to $58.97 per pound) the potential to extract recoverable identified resources triples. As the price continues to increase, resources continue to increase in volume. From the third to the fourth category, the availability of identified recoverable uranium increases by more than 30%. Therefore, these results indicate that, as the price of uranium continues to increase, the United States can activate locations that have higher cost, expanding the available inventory from this resource. Additional assessment is required to explore locations in the US that have potential uranium resources but have not been assessed due to the previously depressed price of this resource (OECD-NEA & IAEA, Uranium 2023).

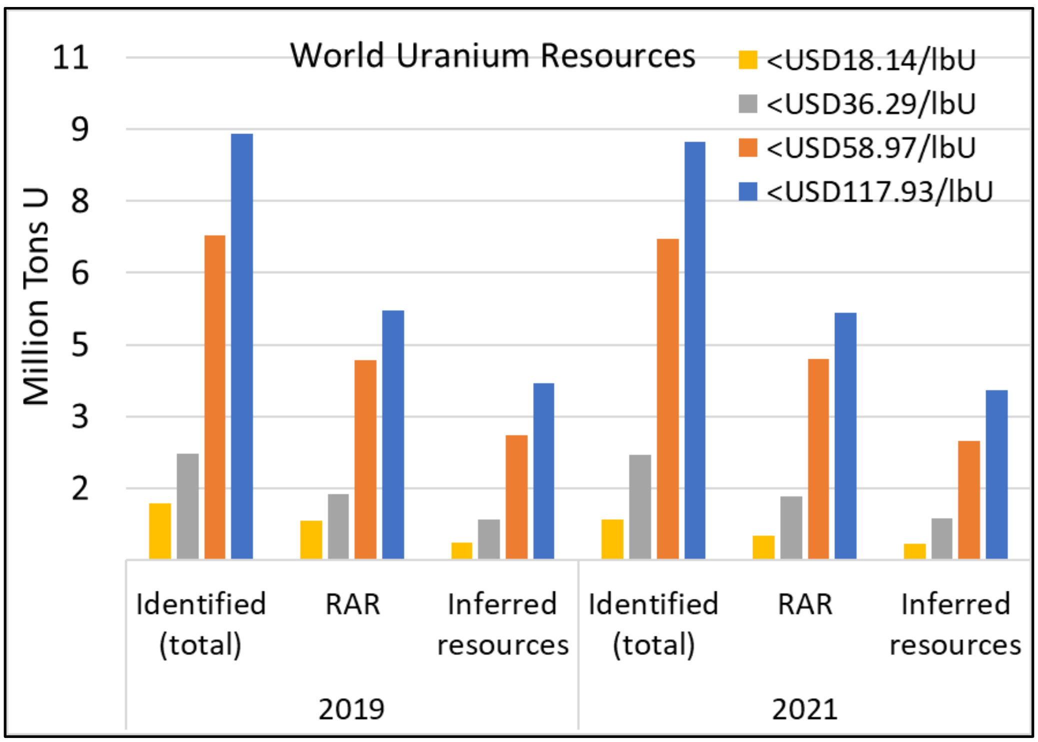


Figure 32: World uranium resources (OECD-NEA & IAEA, Uranium 2022).

3. Uranium in seawater

In uranium mining, terrestrial (on the surface) uranium mining methods typically come to mind. However, uranium and other critical minerals have been known to be found in the sea for decades.

Almost every element in the periodic table can be found within the vast ocean, and mining of the sea for minerals has been attempted (Lindner et al, 2015). The sea contains around 4.5 billion tons of dissolved uranium, which is 1,000 times more than what's found in the ground (Wang et al, 2016). Texas has about 367 miles of coastline which provides a large amount of sea access. The amount of uranium in seawater is enough to power the world nuclear power fleet at a 2013 uranium consumption rate for 13,000 years. In contrast, the current global supply of uranium from terrestrial sources is enough to power the world nuclear power fleet for 80 years (Lindner et al, 2015). The International Atomic Energy Agency (IAEA) projects that global nuclear capacity will increase, and uranium requirements will increase correspondingly to between 94,000 and 122,000 tons a year by 2030 (Cochran, 2010). Rubidium, strontium, lithium and some other critical minerals are also found in the seawater at low concentration (Nur et al, 2021). The concentration difference between land-mined uranium versus from the sea is a large magnitude difference; on land, it is 1,000 ppm, where as in seawater it is 3 parts per billion (ppb). Due to its low concentration, the methodology for recovery needs to be economically sustainable. There are a couple of contributing factors that would encourage countries to pursue recovering uranium from seawater. One main reason would be supply/energy security. The other would be the possible future scarcity of the mineral itself. It is recharged or replenished by natural mechanisms such as interchange with seabed or from run off. Seawater extraction of the mineral can create a price cap or what is known as a backstop. Backstop resources are available in essentially limitless quantities and displace other exhaustible resources. If land resources are unavailable or uranium prices become overly inflated, vast amounts of uranium in seawater can theoretically remedy this situation.

Since the 1960s, the collection of uranium from seawater has been evaluated using a process that utilizes the adsorption of uranium onto a solid material adsorbent specifically selected for its ability to attract the uranium ion. Early on, hydrous titanium oxide was the adsorbent of choice for uranium recovery from seawater, whereas later an amidoxime ligand tied to a polyethylene backbone was developed for this purpose and has proven to have significantly greater capacity. The adsorbents would be deployed at large scale into the ocean in a manner to take advantage of natural ocean currents or seabed variations. From there, recovery of the captured uranium and its processing would continue by physical recovery of the adsorbent material or in –place removal of the uranium from the adsorbent. The overall process is projected to be challenging and cost-intensive (range of $400 - $1,000/kg or $181 - $453/ lb. of uranium) due to the manner used to extract compared to the mineral concentration (Lindner et al., 2015). The methodology of extracting uranium from seawater is based on the fact that uranium exists as uranyl carbonate ions ($UO_2(CO_3)_3^{-4}$) in the seawater.

Another method of recovering uranium and other minerals is from the brine seawater waste from desalination plants. Desalination plants extract seawater, and reverse osmosis is used to make the seawater potable. About half of the water entering the process becomes drinkable, and the other half (the brine) is typically pumped back into the sea via pipelines like those that discharge municipal and industrial wastewater (Chandler, 2019). It has been observed that the brine contains some valuable minerals such as lithium, potassium, and uranium. Additional processes can be conducted to filter out the valuable minerals from the brine, so that the overall energy and production costs can be offset. In the past, global production of water from desalination was around 27 billion gallons a day, and similarly, the same amount was produced in brine quantities. The drawback to seawater reverse osmosis is that it, too, is an energy-consuming process. The amount of energy required to achieve the high pressures needed for the seawater to pass through the reverse osmosis membrane is very high. Rather than fully implementing a desalination plant, a side option could be acquiring the seawater brine from an existing desalination plant. This could become a partnership venture in which the brine from the plant could be utilized rather than be pumped back into the ocean. Currently, the city of Corpus Christi is in the process of implementing two seawater desalination plants, one in Inner Harbor and the other in La Quinta Channel, which would produce a combined amount of 70 million gallons a day at total production. Based on this volume of seawater being processed and the 3 ppb level of uranium in seawater, approximately 0.3 tons (600 lbs.) of uranium could be recovered per year from the brine reject of these desalination plants. This level of uranium recovery for a planned desalination plant in Texas is likely too small an amount to make the process feasible.

C. Factors affecting the remaining resource

As the price of uranium increases in international markets, the possibility of reactivating existing mining facilities in Texas increases significantly. Furthermore, exploration of potential additional locations for uranium extraction may significantly increase the Texas inventory of the critical resource. However, several factors impact the potential to extract and process uranium. The nuclear fuel cycle will be a useful framework for diverse factors impacting the future of uranium extraction and processing in Texas.

There is a lack of uranium enrichment facilities in Texas. In fact, there is only one facility in the US, located in Eunice, New Mexico, which accounts for 8% of the world's enrichment capacity. This is concerning considering that 56% of the world enrichment capacity is hosted by Russia and China (WNA, 2022). The Urenco enrichment facility in North America has received authorization to expand its capacity by 15% (WNN, 2023). Therefore, promoting the development of facilities required in the nuclear fuel cycle will support the development of this industry. As smaller nuclear reactors are developed, requiring significantly higher enrichment uranium levels, security and safety measures will need to be strengthened, limiting the transportation of this enriched resource to avoid unsafe situations. Therefore, creating extraction-processing-operational small nuclear reactor fuel hubs will provide significant synergetic advantages to Texas. Our state hosts one of the nation's most abundant uranium mining areas. Collocating processing and enrichment facilities close to the mining facilities will reduce operational cost and potential risk factors. Furthermore, this will incentivize the installation of small nuclear reactors in our state, reducing nuclear fuel transportation risks, and supplying stable and inexpensive electricity to support the growth of the Texas economy. There is great interest from industry, the public sector, private funding and financial entities to promote the growth of this energy resource, which will provide reliable electricity which has a much lower carbon footprint.

As previously indicated, lack of a qualified workforce in the uranium and nuclear fuel industry has been identified as one important obstacle to growth in this sector in the short term (Day, 2022). As the industry reactivates, hiring enough qualified workforce has been identified as one of the most relevant challenges for the industry. The nuclear and uranium industries require a broad variety of skills in their workforce, from the administrative personnel to the extraction areas, processing, enrichment, reprocessing, transportation, remediation, and disposal. An in-depth assessment of the industry workforce needs, and Texas educational availability, will be a very important factor in incentivizing the development of the uranium and nuclear energy sector in our state. Promoting the growth of this industry in Texas will require colleges and other educational institutions in our state to produce the required skilled workforce in the short term.

Streamlining the permitting process for uranium mining and processing facilities will be an important factor to incentivize the reactivation and opening of new extraction opportunities. The National Mining Association reports that it takes between five to ten years to complete the permitting process to operate a uranium mining and processing facilities in the US (NMA, 2023). TCEQ personnel indicate that the permitting process within the State of Texas typically takes three to five years. There are a significant number of federal, state and local laws and regulations that apply to this industry, administered by various federal, state and local agencies. This creates a complex and delayed process in obtaining all the required permits. It is important to recognize that these regulations aim to protect the public and the environment and their correct application is critical for the success of the uranium industry. However, if a single application framework could be developed, it would significantly reduce the time, cost and effort required to obtain the required permits. To achieve this goal, a task force could be created to develop this single uniform application framework. The goal would be the collection of all required information and documentation into a single file to be submitted to an inter-agency receiving window. This will achieve the goal of strengthening the US uranium extraction industry competitiveness by streamlining permitting regulatory and governmental processes, while additionally leveling the playing field for the US uranium industry (DOE, 2020; NMA, 2023).

1. One-stop shopping on permitting applications

National, state and local governments and agencies have tried to improve permitting application processes by implementing "one-stop shopping" approaches. These systems rely on permit assistance programs that incorporate many previously dispersed discrete permitting activities in one location. The goal is to streamline the process, reduce costs, delays and rejection risks by creating outreach processes which provide applicants with all relevant information, processes and submission avenues. Mining activities become a more attractive investment opportunity for stakeholders as all those benefits are realized. Furthermore, environmental regulations are not compromised, as review processes are strengthened and streamlined (Robinson, 1999). Many activities subjected to permitting processes have implemented this "one-stop shopping" approach, looking to realize significant benefits generated by potential growth for the involved sectors. Some relevant examples are described below.

The US Department of Energy in April of 2024 launched a one-stop-shop online portal for the permitting process to streamline federal electricity transmission projects, maintain the integrity of the environmental review process, and reduce review times (DOE, 2024b). The Danish Energy Agency has developed one-stop-shop for the development of offshore wind projects, looking to reduce one of the main challenges on offshore wind projects development, reducing delays and uncertainties (DEA, 2020). The US Congress enacted the Workforce Innovation and Opportunity Act, which developed a national system of one-stop centers to provide training and employment activities responsive to local employer's demands (CRS, 2022). Several states and local governments have implemented this one-stop approach for diverse permitting activities. For instance, in New York state the RAPID Act was introduced in January of 2024 to create an environmental permitting and review process as a one-stop-shop process for major transmission and renewable energy projects (Misbrener, 2024). In South Dakota the Department of Agriculture & Natural Resources has initiated the process to implement one stop permitting for the environmental permitting process required for mining permits (DANR, 2024a; DANR, 2024b).

2. Community and social acceptance of uranium mining

Community and social acceptance are considered one of the main factors that can impact the successful development of new mining and industrial activities. Delays in project development, challenging operational conditions and even early termination can ensue when projects face social opposition from local communities or stakeholders (Prager, 1997; Romero-Schmidt et al., 2020; Campbell & Roberts, 2010). For uranium mining, social and community opposition in diverse locations have impacted its successful development and operations, hindering its growth and financial viability. Extraction of resources in locations inside or neighboring protected areas has generated significant community and social opposition to these projects (Clark, 2017; Tilousi, 2017; Rao, 2023). Therefore, assessing the placement of uranium mining facilities in relationship to protected areas is relevant, to evaluate the potential development and operational risk for these projects. The US Geological Survey (USGS) provides a repository of geographic information systems (GIS) features pertaining to protected areas per state in the US, as shown in Figure 33. This figure presents the protected areas for the states of Wyoming, Colorado, New Mexico and Texas, which possess some of the highest potential uranium reserves in the US. This information will allow stakeholders to ascertain the level of potential risk from community and social opposition to uranium mining. Locations with higher density of protected areas may increase the probability of opposition to uranium mining facilities placed in their neighborhood. A general overview of these figures shows that Texas has the lowest density for protected areas among these states, potentially reducing the risk of social and community opposition for uranium mining.

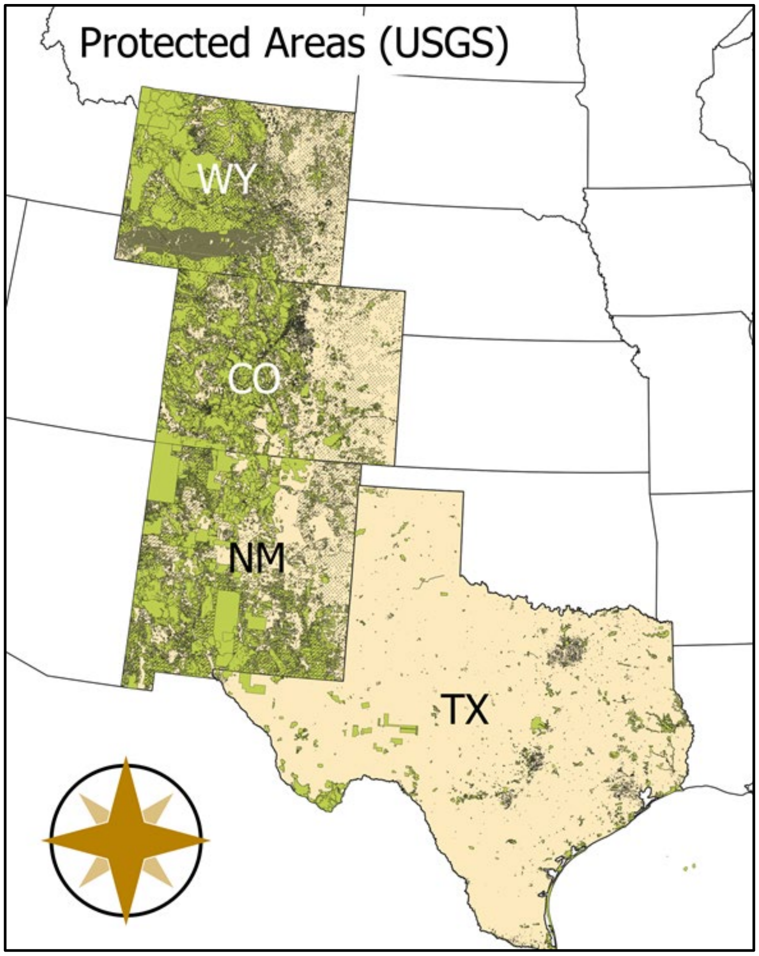
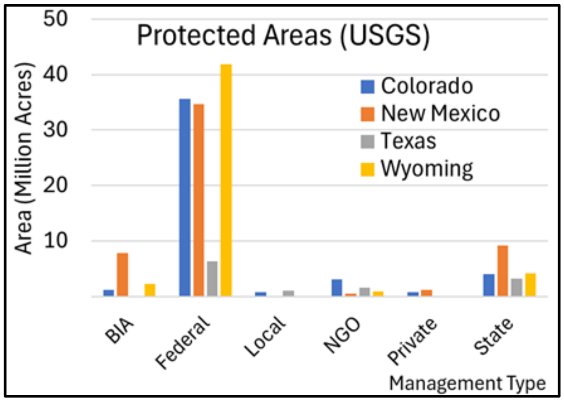


Figure 33: Map indicating the protected areas in the states of Wyoming, Colorado, New Mexico and Texas as high potential locations of Uranium, as reported by the USGS.

Figure 34(a) indicates the surface area (in millions of acres) classified as Protected Areas according to the inventory held by the USGS for the four states which have high uranium deposits. The results indicate that New Mexico is the state with the highest amount of Protected Areas, followed by Wyoming, with 8% less, and Colorado, with 15% lower Protected Areas. Texas has a much lower amount of Protected Areas compared with the other states with high uranium deposits. This gives Texas a potential competitive advantage, considering that the risk for community and social opposition could be significantly reduced as less Protected Areas may be affected by mining activities. All the states have the highest areas on the Federal Management class, with Wyoming indicating 85% of its protected areas under Federal management, Colorado 78%, New Mexico 65% and Texas 47%. This may create further limitations on the potential to successfully develop and operate uranium mine facilities in these states. Figure 34(b) evaluates the Protected Areas considering the proportion of the total state area. Results indicate that that the Federal management areas for all states, except Texas, range between 45% and 66%, with Texas representing less than 4% of the state area. For the state management category, the covered area is less than 2% for Texas, with the other states ranging between 6% and 12%. For the Bureau of Indian Affairs, surface area for Texas is less than 0.01 % of the state area, while for other states it is much higher. This continues to reflect the lower risk for social and community opposition in Texas generated by potential conflicts on land use.



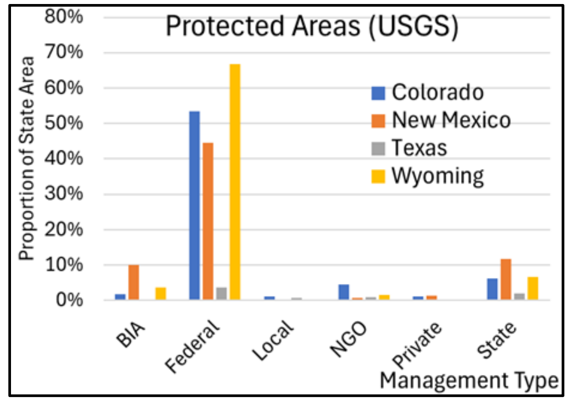
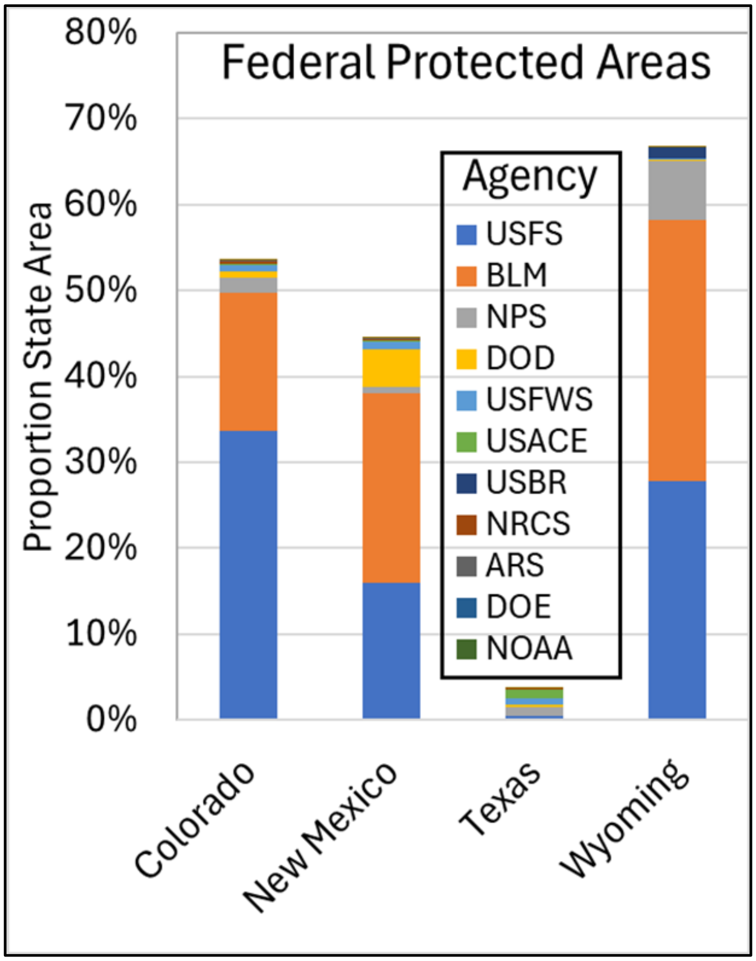


Figure 34: Bar chart indicating protected areas as reported by USGS in the four states under consideration considering Management Types (a) protected area surface in acres, and (b) Proportion of the state total area occupied by protected areas.

A higher granular classification for Federal Protected Areas in the states under analysis is presented in Figure 35. For all states, excluding Texas, the two highest categories are the Forest Service (USFS) and the Bureau of Land Management (BLM), representing between 85% and 93% of all its Federal Protected Areas. For Texas these two categories represent less than 14% of all its Federal protected areas. Wyoming is the state with the largest proportion for National Park Service (NPS), representing almost 7% of all Federal protected areas. For Texas, the three largest Federal protected areas classifications are the NPS, the U.S. Fish and Wildlife Service (USFWS) and the Army Corps of Engineers (USACE), comprising 2.7% of the state areas and representing 75% of its Federal Protected Areas.



Acronym	*Agency*
USFS	Forest Service
BLM	Bureau of Land Management
NPS	National Park Service
DOD	Department of Defense
USFWS	U.S. Fish and Wildlife Service
USACE	Army Corps of Engineers
USBR	Bureau of Reclamation
NRCS	Natural Resources Conservation Service
ARS	Agricultural Research Service
DOE	Department of Energy
NOAA	National Oceanic and Atmospheric Administration

Figure 35: Proportion of the states under consideration under Federal Protected Areas classification, indicating the Federal Agency managing these locations.

Figure 36 provides a more detailed panoramic of the Protected Areas, as reported by the USGS. It showcases the limited impact that these areas have in the total surface availability of the state and the lower risk of social and community opposition due to uranium mining in the neighborhood of these locations. It provides a more detailed perspective of the Federal category, supplying additional segmentation for the diverse Federal Agencies that manage those locations. This figure indicates that Non-Governmental Organizations (NGO) manage a significant area of Protected Areas, which reinforces the community outreach required as part of the development of management of uranium mining with the corresponding organizations. State protected areas play an important role in this assessment, with the Texas State Land Board, the Texas Parks & Wildlife (TPWD) and the Texas Fish and Wildlife Service (TFWS) managing most of the surface in this category. Preparing an in-depth geospatial analysis for the development of uranium mines and identifying potential land use conflicts will significantly help ameliorate risks for these facilities' successful development and operation.

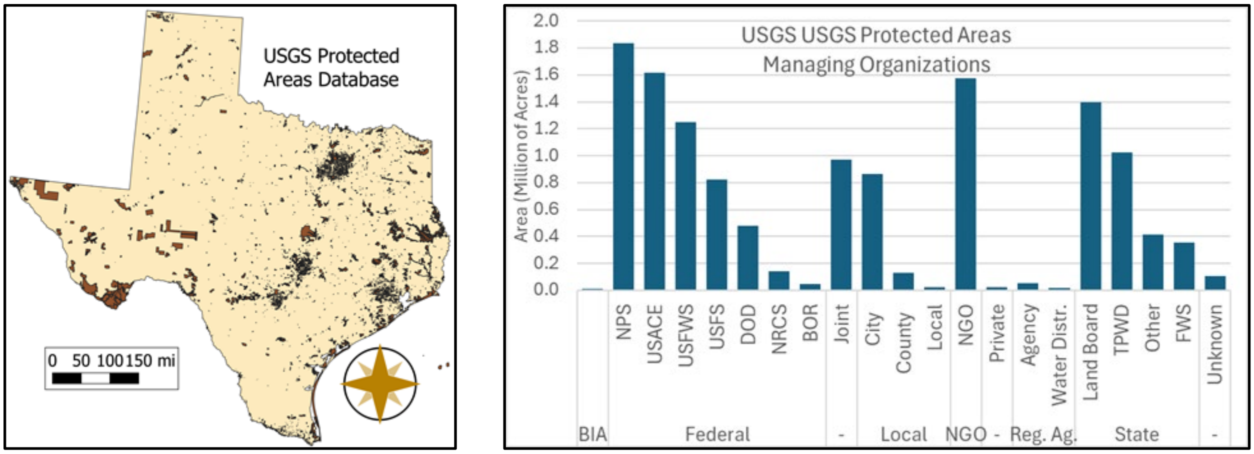


Figure 36: (a) Map of Texas indicating all the Protected Areas as reported by USGS. (b) Bar chart reporting the surface of the Protected Areas in Texas classified by Managing organizations.

3. The future of nuclear energy generation

a. Projected increases in electricity consumption

Electricity consumption in the US has remained relatively without change since 2005, as shown in Figure 37. Several factors have contributed to this low demand growth, among them, significant expansion of electricity efficiencies in commercial buildings and homes, as well as more efficient equipment and appliances. The shift from manufacturing to service activities over the last 20 years in the US has also contributed to this low electricity growth rate (Schwartz et al., 2017). Furthermore, until several years ago forecasts indicated that electricity consumption would remain relatively flat until 2040, under the assumption that existing trends would continue unchanged. However, the impact of the 2020 Covid pandemic on global supply chains, climate change and deterioration of the international geopolitical outlook caused the US to change strategies and priorities. Reshoring diverse industries to shorten supply chains and ensure availability of high technology products, including microchips, accelerated the development and construction of new industrial facilities in the US. Efforts to curb emission of greenhouse gases and pollutants have accelerated the adoption of electric vehicles (EVs) across the US. The development of new informatics industries and technologies, among them AI (artificial intelligence) and data analytics, have led to the exponential development of data centers in the US. These industries share one common denominator, high consumption of electricity. The transportation sector in the US consumed 18.3 terawatt hours (TWh) of electricity in 2023, which is expected to increase to 131

TWh by 2030, driven by the growth of EVs (Hendry and Selvaraju, 2024). Goldman Sachs reported that a ChatGPT search required ten times more electricity than a simple Google search. Furthermore, Sam Altman, the CEO of Open AI indicated that AI would use vastly more energy than expected and breakthroughs on clean energy will be needed to support its growth (Bhutra, 2024).

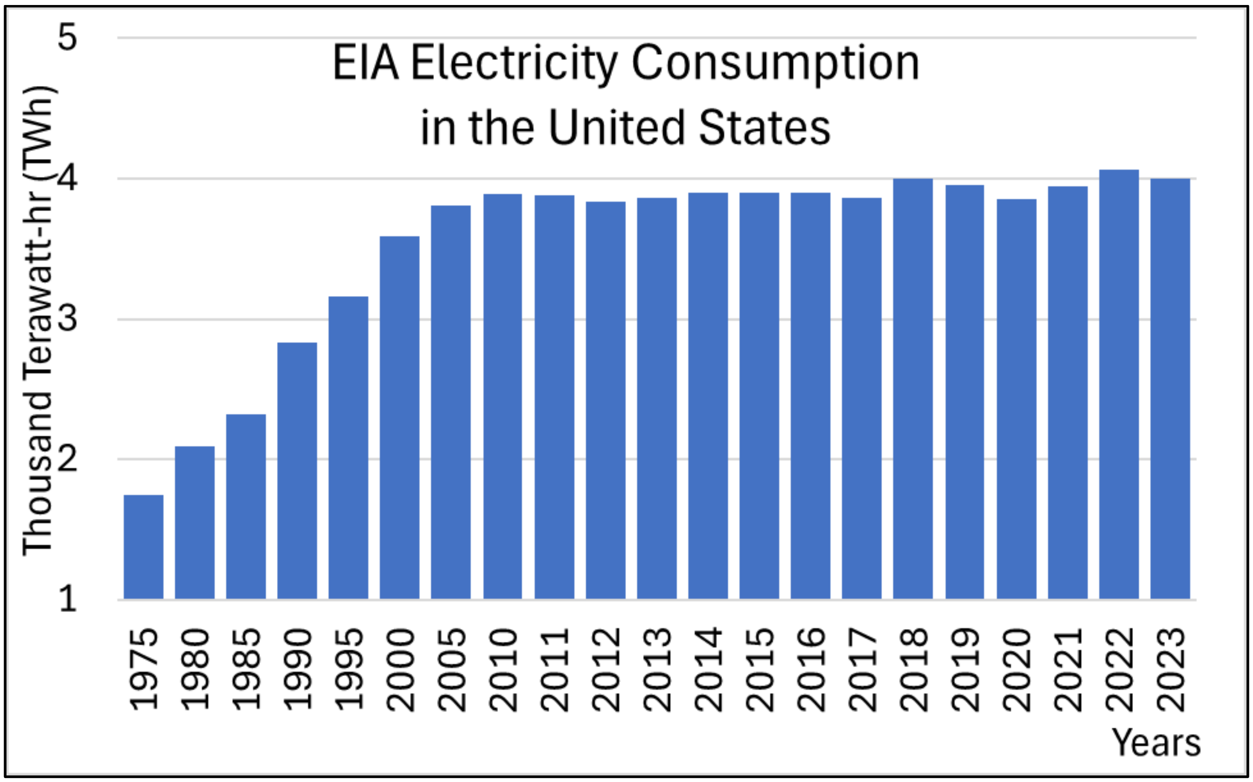


Figure 37: Historical electricity consumption in the United States (EIA, 2024c).

As construction and development of manufacturing activities in the US increase, as EVs continue to exponentially penetrate US markets and as data centers expand, electricity demand has started to significantly grow (Mackenzie, 2024). In February 2024 year-over-year manufacturing construction spending increased 32%, representing an 181% growth compared with pre-Covid levels. Data center expansion, fueled by the development of AI, is expected to consume 7.5% of all electricity in the US by 2030, growing from 130 TWh in 2022 to 390 TWh (Mackenzie, 2024). The impact on this potential electricity consumption has been modeled by the National Renewable Energy Laboratory (NREL) through its State and Local Planning for Energy system (SLOPE). The system assesses electricity consumption through 2050, considering diverse generation scenarios and diverse generation mix (NREL – SLOPE, 2024). Figure 38 presents results through 2050, considering Low Demand Growth Scenario, Mid-case Scenario and High Demand Growth Scenario, both for the United States and for Texas. As shown in Figure 38(a) the US will experience a growth in the low scenario of 14% (2030), 29% (2040) and 43% (2050), compared with the baseline of 2020. For the Mid growth scenario, the expansion of electricity demand will expand considerably, to 22% in 2030, 59% in 2040 and 92% in 2050 compared with 2020. It is notable that electricity consumption is projected to almost double by 2050 on the mid-level scenario. When the High growth scenario is considered, the expansion becomes very significant. For 2030 the growth is similar to the Mid scenario, at 23%. However, by 2040 the increase reaches 97% and 142% by 2050. Considering that the US will experience significant growth in industrial activity, data centers and EV market penetration, the High Growth scenario needs to be evaluated with great attention. Figure 38(b) indicates the electricity growth scenario for Texas, showcasing a much more significant expansion when compared with the national level. The low scenario is almost double when compared with the US, 27% for 2030, 49% for 2040 and 67% by 2050 compared with the base level of 2020. On the Mid scenario the forecasted growths to 39% for 2030, 76% for 2040 and for 114% for 2050, more than doubling the 2020 consumption. In the High Consumption category 2030, compared with 2020, increases 51%, which is very significant considering the potential investments required to achieve this high generation capacity in the short term. For 2040 the growth will reach 130% and for 2050 it is expected to be 164%. These results are critical to evaluate the expansion of the generation mix required to achieve these levels and the relevant participation that nuclear energy may have in these scenarios.

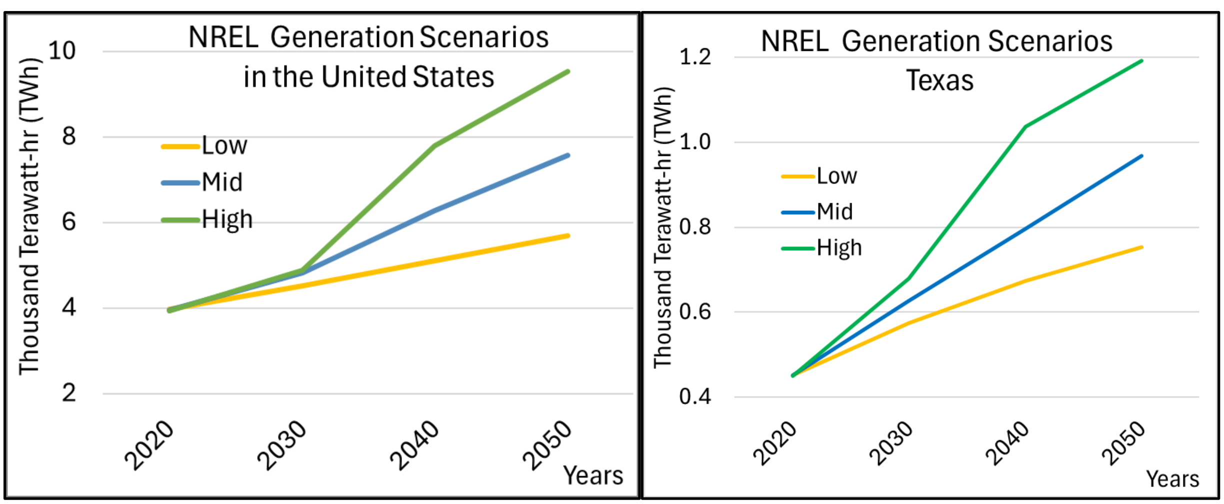


Figure 38: NREL State and Local Planning for Energy system (SLOPE) for low, mid-case scenario and high demand generation scenarios both for (a) United States and (b) Texas.

b. Nuclear energy's role in the electricity generation mix

As electricity demand significantly expands in the next decades it is critical to grow electricity generation. Nuclear energy can play a critical role in the electricity generation mix, not just by keeping current nuclear facilities in operation but by building additional reactors, including novel Small Modular Nuclear Reactors (IAEA, 2022; Forbes, 2023; DOE, 2024c). Many activities that will contribute to the high growth of electricity demand, such as manufacturing and data centers, require constant electricity supply across all hours of the day, not just at peak hours (Mackenzie, 2024). This creates a significant opportunity for nuclear reactors to supply this additional energy demand, considering that they have a high-Capacity Factor that does not change during its daily operation as shown by Figure 39. Figure 39(a) indicates the average daily electricity generation in Texas every fifteen minutes through a 24-hour period during 2023, as reported by the Electric Reliability Council of Texas (ERCOT, 2023). Section (b) for this chart represents the monthly average electricity generation in Texas for 2023, as reported by ERCOT. Both charts reflect the very high variability both in hourly and seasonal frameworks, requiring that the generation adjusts to satisfy the demand, causing the fuel mix to change for each situation. For both analysis it shows a stable supply from nuclear energy, not changing through the year or through the hours of the day. On the other hand, it showcases the high variability of wind and solar power, depending on meteorological and natural factors. To cover this high variability, through the day and through the year, the figure presents the ramp-up and ramp-down by Gas-CC and Gas. Electricity generation using combined cycle gas turbine (Gas-CC) applies a recovery steam generator which captures the hot exhaust to in turn produce additional steam, making the system more efficient. Results show that coal generation has significant stability in this scenario and natural gas also shows a minimum baseline. Therefore, nuclear energy growth could be a suitable alternative to cover coal electricity generation and the minimum baselines from natural gas. Since nuclear energy does not generate greenhouse gases or air pollutants, this could be a sustainable alternative to supply growing electricity demand.

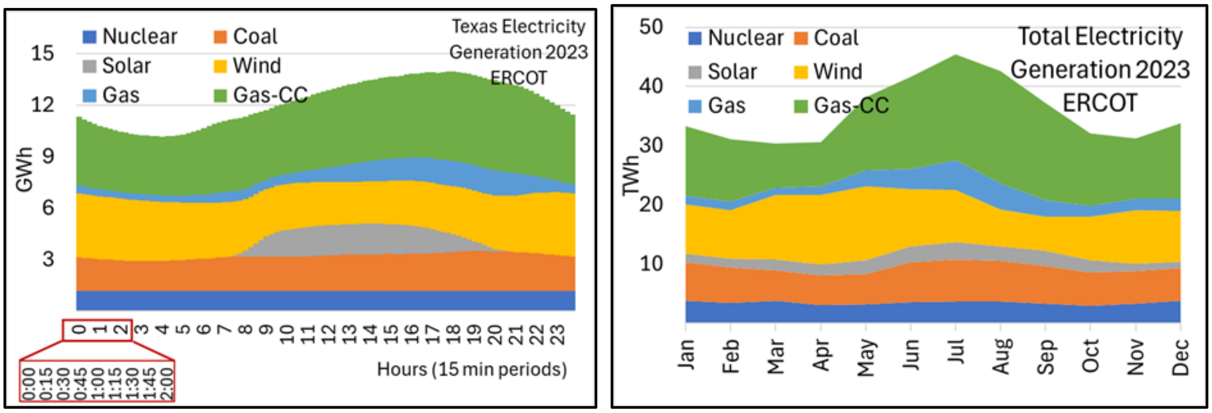


Figure 39: Electric Reliability Council of Texas (ERCOT) electricity generation based on fuel mix for 2023 in Texas (a) Average for every fifteen-minute range throughout a 24-hour period, as reported by ERCOT. (b) monthly average electricity generation for every fifteen-minute range throughout a 24-hour period, as reported by ERCOT.

However, NREL SLOPE system forecasts that the overall participation of nuclear energy through the year 2050 will significantly decrease (NREL, 2024b). This is concerning considering the benefits that this technology can bring for the sustainable development of Texas and the United States. Figure 40 shows the generation mix as modeled by NREL SLOPE for the United States on the Mid and High scenarios. The low growth scenario may not be applicable considering that recent events indicate that the future electricity generation will be driven by economic and technologic events that require high energy consumption. In the US, as of 2020, the highest generation fuel in the mix was Gas-CC, with an average of 39%, followed by nuclear with 20% and coal at 12%. Onshore wind, on the other hand, corresponds to 9% and solar energy to 3% of the fuel mix. However, by 2050 the generation mix for the mid generation scenario is expected to be radically transformed, with Gas CC representing 11%, nuclear 7%, and coal 1%. On the other hand, wind (onshore and offshore) will represent 35% and solar 28% of the US generation mix. For the high generation mix, results indicate 13% for Gas CC with nuclear and coal remaining at 7% and 1% respectively. Wind will increase to 37% and solar will remain at 28%.

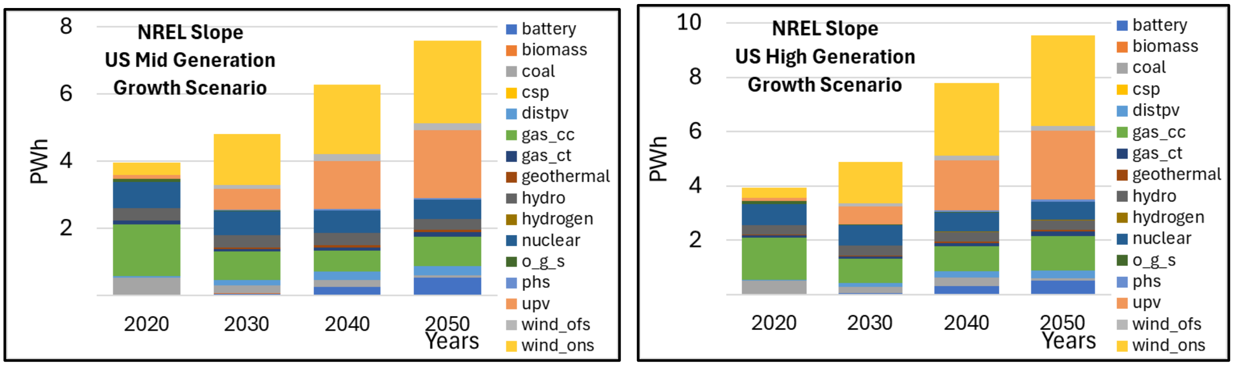


Figure 39: Generation mix as modeled by NREL SLOPE for the United States on the (a) mid and (b) high scenarios.

Texas results on the Generation mix for the mid and high growth scenarios are presented in Figure 41. The generation mix in 2020 relies heavily on Gas CC, with an average participation of 51%, followed by wind onshore at 21%, nuclear 9% and coal 8%. However, when analysis for the NREL Slope high generation growth scenario is assessed for 2050, the transformation for the generation mix is significant. Gas CC decreases to 4%, coal to 1% and nuclear to 2%, with onshore wind soaring to 49% and solar energy to 32%. When the NREL Slope high generation growth is considered, Gas CC (combined cycle), coal and nuclear stay at similar levels, with wind contributing 46% and solar energy increasing to 37%.

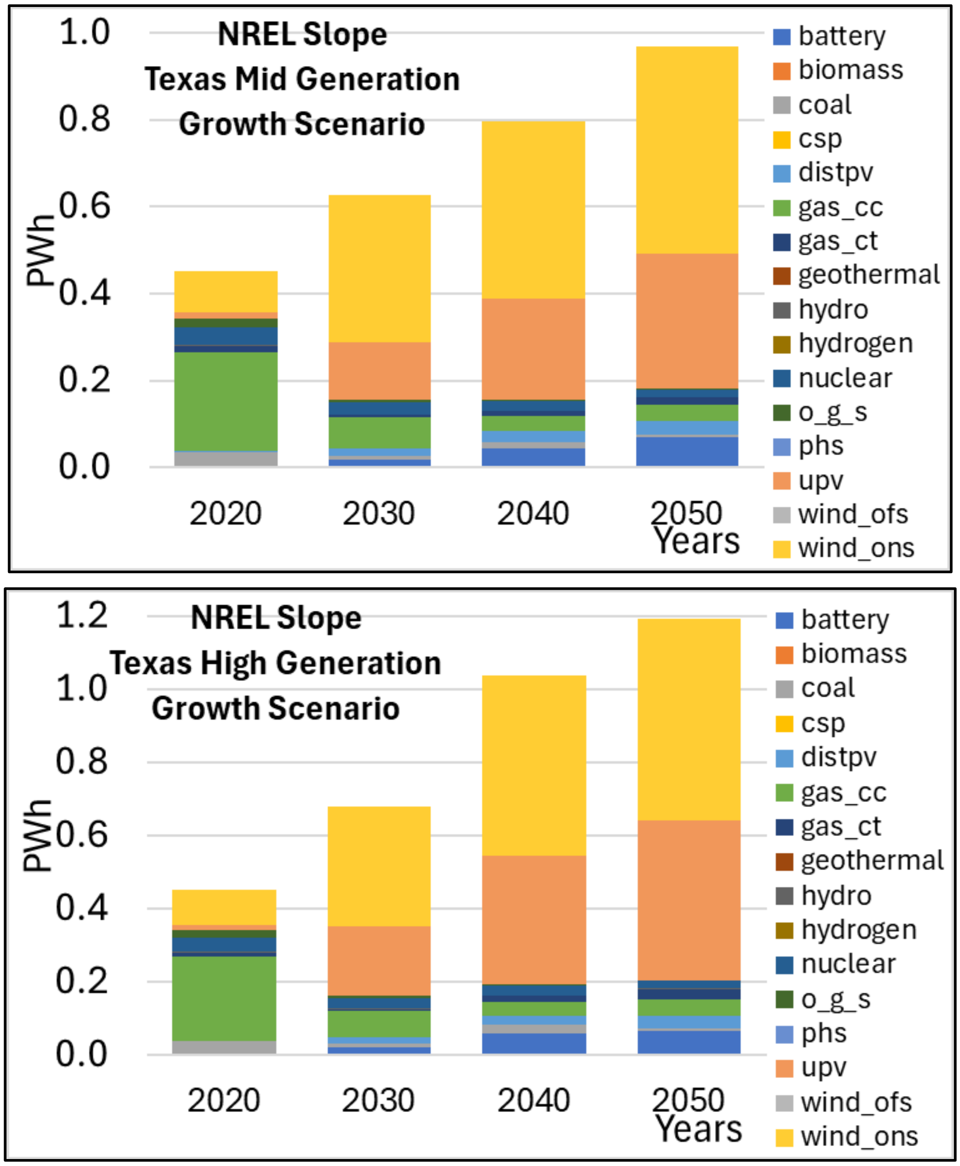


Figure 40: Generation mix as modeled by NREL SLOPE for Texas on the (a) Mid and (b) High scenarios.

c. Financial assessment of nuclear energy generation

It is relevant to assess the financial reasons for the significant change in the electric generation mix in the US and Texas, and for the significant reduction of nuclear energy generation. The Levelized Cost of Energy (LCOE) is an important parameter to perform comparisons between diverse generation technologies. It helps to better understand the underlying reasons for the significant growth of wind and solar energy and the proportional reduction of other electricity fuels. LCOE evaluates the generator's electricity average net-present cost over its lifetime, including among other concepts, cost of fuels, CapEx (Capital Expenditures) and O&M (Operations and

Management). The LCOE range shown in Figure 42 was provided by the NREL for different technologies (NREL, 2024a). For this report we will focus on wind and solar to compare to nuclear energy, considering that these two will be the dominant generation technology in the future. Nuclear, wind and solar energy have the significant advantage of helping to overcome the challenge presented by climate change, as none of these technologies generate greenhouse gases or air pollutants. However, wind and solar energy generate significant intermittency on electricity production, considering that these two technologies are dependent on meteorological and natural factors, outside the control of its operators. On the other hand, nuclear energy has the highest capacity factor of these technologies, consistently remaining at the same output levels, which is ideal for industrial applications and data centers, fitting their demand requirements. As shown in Figure 42, the lowest ranges for LCOE correspond to wind (land) from $29 - $74, followed by Solar – Utility PV ($39 - $62), distributed wind ($54 - $344) and then nuclear, ranging from $69 - $123. Furthermore, results indicate that Solar – Utility with battery has a higher LCOE than nuclear ($75 - $123). This is pertinent, considering that for renewable energy the incorporation of batteries is considered necessary to overcome the variability challenge. All remaining renewable energy options shown in the figure present higher LCOE than nuclear energy. This is relevant, considering that if over the next decade the cost of nuclear energy can be reduced by the introduction of newer, smaller, nuclear reactors, nuclear energy could become more competitive with wind and solar, with the additional benefit of preventing generation intermittency.

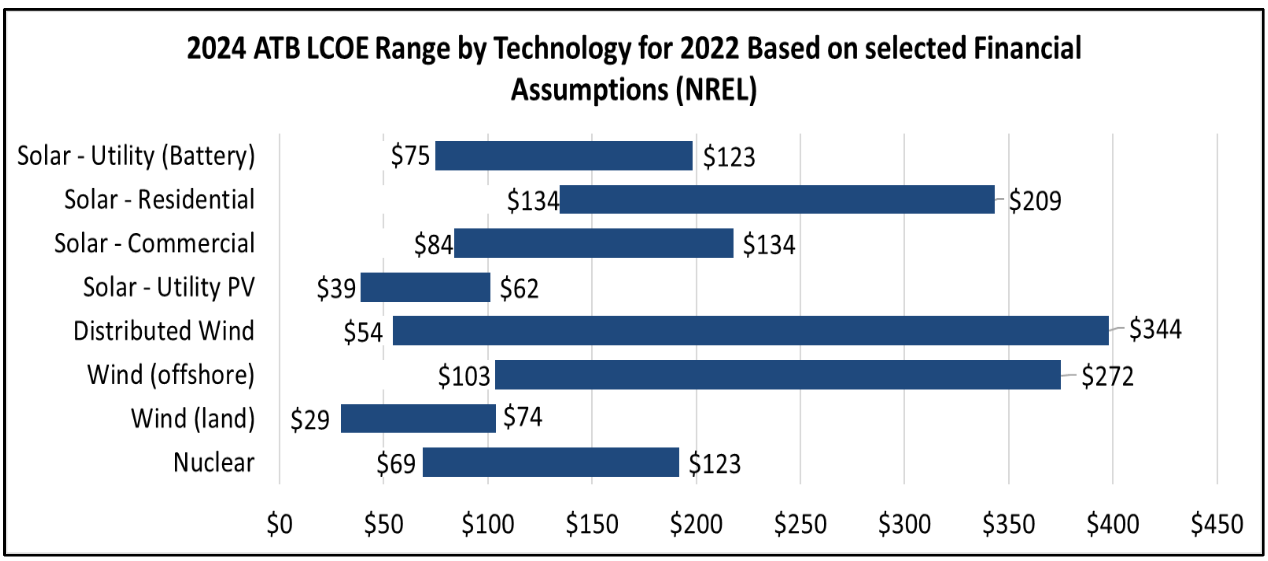


Figure 41: Levelized Cost of Energy (LCOE) ranges for diverse electricity generation technologies (NREL, 2024a).

d. Small Modular Reactors

LCOE in SMR and microreactors are expected to decrease in the future due to diverse factors related to the standardization of manufacturing processes and the integration of efficient supply chains, incorporating existing partners for industrial components. This is expected to achieve a number of synergies, that will contribute to reduce CapEx and O&M, leading to progressive reductions of LCOE. Some of the relevant expected synergies include economies of scale, technology innovations through learning curves, modular design and simplified designs optimization, shorter and more efficient construction times and potential scalability of facilities using numerous SMR. Government incentives and support are expected to play a significant role in incentivizing and promoting the development of this more efficient and inexpensive technology. The World Nuclear Association reported on efforts by developers to increasingly reduce LCOE for nuclear energy. It indicated that some developers in the United Kingdom (2021) aimed to reduce LCOE as low as $47 MWh for SMR. In addition, WNA reported that in the US developers were targeting LCOE at $55 MWh for SMR (WNA, 2024b). It is expected that as SMR and microreactor manufacturing becomes a standardized process, applying production line framework, costs for each successive generation will continue to decrease.

Current LCOE for nuclear reactors are based on the significant challenges that nuclear reactors have faced in their construction and operating phases. These facilities have required vast construction costs, which coupled with large project delays and cost overruns contribute to higher LCOE. As previously described; to overcome these challenges, the nuclear industry initiated the development over the last decade of small modular reactors (SMR) and more recently of microreactors. These generators occupy just a fraction of the space of conventional reactors. They are much cheaper and faster to build and the project risks on delays and cost overruns are curtailed by using modular standardized equipment (IAEA, 2022; EC, 2024; Liou, 2024). The main concept is to manufacture modules in industrial facilities which are transported to the site for assembly. Since components are modular and standardized, assembly of the nuclear reactor is straightforward, reducing risks for delays and cost overruns. Furthermore, as manufacturing is done in an assembly line format, quality control and production times can be tightly controlled. Some companies building SMR have borrowed concepts and off-the-shelf components from the oil and gas and automotive manufacturing industries to create efficient and reliable processes (Forbes, 2023). An SMR can generate up to 300 megawatts (MW) of electricity which may be able to power a medium-size town or a subdivision. Some companies have developed microreactors, capable of generating between 10 – 20 MW of electricity, which can power individual industrial facilities or datacenters (Liou, 2024). These smaller nuclear reactors have the advantage that they can be installed right beside the industrial facility, data center or subdivision. This eliminates the need of new expensive and very challenging high voltage transmission lines, which in many cases may be a primary obstacle to new energy generation projects (IAEA, 2022; Forbes, 2023). There are many companies all around the world developing this new technology. Some of these companies have significant experience in building electricity generation equipment and nuclear equipment, such as Westinghouse, Rolls-Royce and GE-Hitachi (IAEA, 2022). The U.S. Nuclear Regulatory Commission (NRC) is responsible for licensing Small Modular Reactors under 10 CFR Part 52 (Ostendorff & Cubbage, 2015). In 2023 the NRC issued a final rule, published in the Federal Registry, certifying an SMR design from the company NuScale Power. This rule took effect on February 21, 2023, and allows utilities to reference this design when they submit applications for combined license to build and operate SMRs (DOE, 2023b). An interesting case is Last Energy, which proposed a 20 MW SMR to power industrial facilities on site. The reactors will be manufactured in Texas, using standardized modular equipment already in use and tested by the oil and gas industry (Forbes, 2023). They have reportedly signed a significant number of contracts with companies in the UK, Poland and other European countries (Judge, 2023).

Promoting the development of SMR and microreactors industry in Texas may generate significant technological and manufacturing breakthroughs that could reduce nuclear LCOE to make it competitive with wind and solar energy. This will bring the additional benefit of having a clean and constant electricity generation source in close proximity to industrial facilities and data centers. Furthermore, in many locations in the US and all over the world the lack of electric grid infrastructure, coupled with limited wind and energy power potential, generate much higher LCOE for wind and solar. For these locations SMR and microreactors would be highly competitive. For these locations, such as remote cold places, rural locations or islands, a higher LCOE for nuclear power would be acceptable. In addition, for locations that need to expand electricity generation through the layout of new and extensive electric grids, local SMR installed on site may generate a financially viable option, which becomes even more attractive when the reduced nuclear LCOE in the near future is considered. Diverse businesses and organizations are currently considering SMR and microreactors as an optimal alternative to satisfy their growing electricity requirements (Kimball and Cortes, 2024). Oracle announced, in an earnings call with its investors, that considering the massive electricity requirements for its data centers, it is considering installing SMR to power these facilities. Furthermore, it indicated that it has secured building permits for three SMRs to support a new data center that they are planning to operate (Kimball, 2024).

VII. Regulations

Stringent regulations in Texas and the US aim to protect natural resources and public health during uranium extraction. Thorough processes are in place for licensing, environmental impact assessments, and monitoring. Compliance with these regulations is essential for minimizing ecological disruption and promoting sustainable resource management. This section provides detailed information about the specific regulatory bodies, key legislations, and compliance strategies crucial for environmentally sound uranium mining practices.

Key agencies involved in this process include the Texas Commission on Environmental Quality (TCEQ), the Texas Railroad Commission (RRC), the Environmental Protection Agency (EPA), and the Nuclear Regulatory Commission (NRC). The NRC provides regulations for ISR facilities, uranium mills, and waste tailings disposal. The NRC gives state agencies the authority to regulate these activities as so-called "Agreement States". Texas is one of these Agreement States which allows the TCEQ to exercise regulatory authority over all operations that the NRC would otherwise regulate. In Texas, uranium exploratory wells are permitted by the RRC before an application for a class III injection well permit, production area authorization (PAA), and EPA approved aquifer exemption are submitted to the TCEQ (Sass & Willis, 2013). The TCEQ holds jurisdiction over the construction of wells for actual production, uranium mining, and the restoration of mining sites upon completion of mining activities (Sass & Willis, 2013). The TCEQ has three sections which regulate uranium recovery, namely the underground injection control (UIC) permits section (permits the well fields), the radioactive materials section (RMS) for licensing the facility, and the radioactive materials compliance team (RMCT) for inspections.

Production Area Authorization and mining permit documents include:

- A detailed description of production area geology and hydrology;
- Drilling wells to establish baseline chemical and radiological characteristics of the area;
- A proposed plan for mining operations; and
- Proposed restoration procedures after mining is complete (restoring groundwater to its original conditions as set by baseline values)

Note: The exemption of mining areas from being classified as an underground source of drinking water implies that until the exemption status is removed, there is no current or anticipated future use of this source for drinking.

The Texas Commission on Environmental Quality (TCEQ) is also responsible for overseeing the cleanup of releases and spills of the leaching solution from the well field and associated pipelines. The regulations and legislation associated with uranium mining encompass several key aspects.

First, mining companies must obtain licenses and permits from relevant regulatory bodies. The licenses and permits include comprehensive mining plan assessment, environmental impact statements, and safety measures. This includes preventing groundwater contamination, habitat disruption and soil degradation, and enforcing best practices for land reclamation. Regulations also govern radiation exposure levels for workers and the public during all uranium mining, processing, and transportation phases, with mandatory monitoring and reporting to ensure compliance. Waste management regulations dictate the proper handling and disposal of radioactive waste generated during uranium mining and processing, with strict oversight to prevent leakage and contamination. Mining companies must engage with local communities and address concerns related to uranium mining, with public hearings and consultations forming part of the regulatory process to ensure transparency and gather community input.

Emergency response plans are mandatory, requiring the development and implementation of measures to address potential accidents or incidents during uranium mining operations. Regular training programs and drills ensure preparedness for any unforeseen events. Regulations outline procedures for closing and decommissioning abandoned sites and ensure they are adequately secured and monitored. Additionally, financial mechanisms must be in place to cover site restoration costs and long-term monitoring.

Before acquiring a new mining license, it is imperative to comprehend the regulatory framework governing mining activities in Texas. The TCEQ ensures that all mining operations adhere to state environmental standards. In particular, TCEQ regulations encompass Title 30, Texas Administrative Code, with the following relevant areas:

- Chapter 331, Underground Injection Control
    - Subchapter E, Standards for Class III Wells
    - Subchapter F, Standards for Class III Well Production Area Development
- Chapter 336, Radioactive Substance Rules
    - Subchapter D, Standards for Protection Against Radiation
    - Subchapter L, Licensing of Source Material Recovery and By-Product Material Disposal Facilities

A. Application for a license, renewal, or amendment

An applicant applying for a new operating license, renewal, or amendment of an existing license must provide detailed information on the following:

- Facilities;

- Equipment;
- Procedures to be used; and
- Environmental report detailing the effect of proposed operations on public health and safety, as well as the impact on the environment.

The process is designed to meet the most rigorous safety and environmental protection criteria. The flow diagram in Figure 43 outlines the general licensing process. In certain cases, during the review process, an in-situ leach source and byproduct material application may be denied or rejected. Commencing the construction of process facilities, well fields, or other significant actions that could harm the environment of the site before the staff has determined that the appropriate action is to grant the proposed license may result in the rejection of the application [10 CFR 40.32(e)]. The applicant's failure to demonstrate compliance with requirements [10 CFR 40.31(h)] or refusal or failure to supply information requested by the staff to complete the review (10 CFR 2.108) is also grounds for denial of the application.

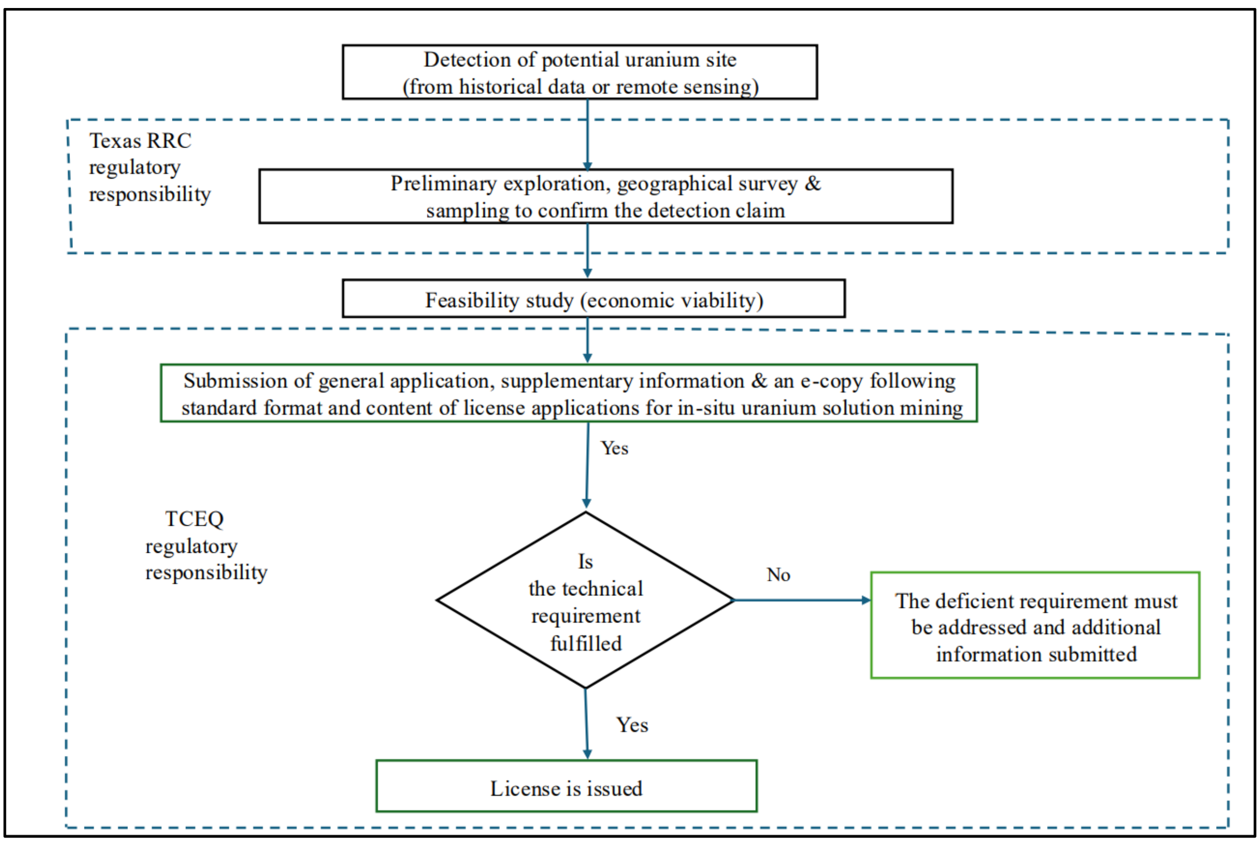


Figure 42: General licensing process.

Before granting a license, the reviewer must thoroughly examine the summary of the proposed activities. This will provide a basic understanding of the proposed activities and their potential impact on human health and the environment. The staff needs to assess the corporate entities involved, the location and ownership of the proposed activities, the locations of ore bodies, and the estimated uranium (U_3O_8) content. They should also review the proposed solution extraction method and recovery processes, operating plans, design throughput, anticipated annual U_3O_8 production, radiation safety protection measures, construction schedules, startup schedules, and the expected duration of operations. Additionally, they need to review plans for project waste management and disposal, transportation plans for source and byproduct materials, plans for groundwater quality restoration, decommissioning, and land reclamation, as well as surety arrangements that cover eventual facility decommissioning, groundwater quality restoration, and site reclamation. Reviewers should be aware that the initial licensing of an in-situ leach facility is based on limited information, with more details being developed as each area is brought into production. Therefore, reviewers should ensure sufficient information is presented for initial licensing without expecting a full description of every aspect of the operation.

1. The acceptance criteria

According to US-NRC (2003) report, the proposed activities are acceptable if they provide the following information:

(1) The application summary of proposed activities includes descriptions of the following items that are sufficient to provide a basic understanding of the proposed activities and the likely consequences of any health, safety, and environmental impact.

- (a) Corporate entities involved
- (b) Location of the proposed facilities by county and state, including the facility name
- (c) Land ownership
- (d) Ore-body locations and estimated U_3O_8 content
- (e) Proposed solution extraction method and recovery process
- (f) Operating plans, design throughput, and annual U_3O_8 production
- (g) Estimated schedules for construction, startup, and duration of operations
- (h) Plans for project waste management and disposal
- (i) Plans for groundwater quality restoration, decommissioning, and land reclamation
- (j) Surety arrangements covering eventual facility decommissioning, groundwater quality restoration, and site reclamation
- (k) For license renewals, a summary of proposed changes, a record of amendments since the last license issuance and documentation of inspection results

B. Regulatory Suggestions and incentives

To stimulate increased mining activity, it is essential to assess both legislative and regulatory changes as well as potential economic incentives. By examining proposed changes in regulations and the introduction of targeted incentives, such as tax breaks or streamlined permitting processes, we can identify strategies that not only encourage investment and innovation within the mining sector but also ensure sustainable and responsible resource extraction. To understand the potential regulatory improvements, various state agencies and uranium mining companies were consulted. This approach provided us with diverse perspectives on existing challenges and opportunities, helping to identify areas where regulatory adjustments might be most impactful. By engaging with these stakeholders, we aimed to gather comprehensive insights into how policy changes could facilitate more effective and efficient mining practices.

In Texas, uranium mining is currently conducted by two companies: enCore Energy and Uranium Energy Corp. (UEC). The South Texas Coastal Plain represents the sole region in the state where uranium mining activities occur. These companies were selected for interviews due to their involvement in uranium mining across various other states, including Wyoming, South Dakota, Colorado, and New Mexico. Through discussions with Paul Goranson, Chief Executive Officer and director of enCore Energy and with Craig Wall, V.P. of Environmental, Health, and Safety at Uranium Energy Corp., Texas and Wyoming were noted for having the most efficient permitting processes by far. One of the reasons is that these states are designated as Agreement States, having received regulatory authority from the Nuclear Regulatory Commission to license and oversee the use of byproduct and source materials.

1. Legislative or regulation change suggestions

A few areas that could use some improvement from the point of view of the permit holder were mentioned. Wyoming, being a newer Agreement State Program, was more efficient in the permitting process as it didn't have an accumulation of statutory regulatory changes. Texas has a mature Agreement State Program and the state Legislature creates regular changes in law that impact TCEQ. An example is the recent legislation to add more public input for air pollution caused by cement kilns. The language, as per the Legislature, applies to all of TCEQ's jurisdictions. Uranium recovery permits by ISR already has their own rigorous public hearing process as per federal laws, the Atomic Energy Act, and the Safe Drinking Water Act, that TCEQ is required to follow as part of their Agreement and Delegated programs (NRC and EPA, respectively). Therefore, the need for better clarification of the public hearing and comment process done at the Legislative level is needed to empower TCEQ with the authority to revert to the former processes that comply with Federal requirements but not be subject to rules meant to address other programs (Sanchez, 2024b).

Another suggestion is a modification of the renewal period for Mine Area Permits, Radioactive Material Licenses, and the Class I Disposal Well Permits. Currently they require a 10-year renewal should there be no changes made to the permit. In addition, the companies are required to submit quarterly and annual compliance data to the TCEQ to keep the department up to date. Similarly, at the federal level, an Early Site Permit (ESP) is valid for 10-20 years for new reactors (NRC, 2022). It is suggested to either extend the renewal periods or even eliminate them given that regular reporting is being carried out. This also relates to giving the TCEQ more power (Sanchez, 2024a) from the Legislature.

Both parties have identified the high turnover rate within TCEQ staff as a particular item of concern. The high turnover rate may be due to lower salaries for agency employees. Staff are often hired and trained to get familiar with the application review process and then subsequently resign to take new employment elsewhere for a higher salary. Both Goranson and Wall mentioned it would be in the best interest for the overall licensing process that TCEQ were to receive increased funding due to the job's requirement for extensive institutional knowledge to navigate its detailed permitting process. The permitting process can take anywhere from three to six years should there be no errors on the side of the permittee in the forms. In some cases, it seems each application goes through at least two project managers before it makes it past all the permitting hurdles, due to turnover. Without the retention of knowledgeable and tenured staff, the permitting process is sure to have delays due to the detailed nature of the process. In any industry, tenured staff with institutional knowledge are worth their weight in gold. Typically, state salaries lag compared to Federal and private industry. Increased salaries can aid in the retention and attracting of experienced employees to retain the institutional knowledge needed for the permitting process. Without addressing the principal issue of high turnover, it is improbable that any changes in regulations will enhance permitting efficiency.

2. Incentive suggestions

Incentives are typically financial and non-financial stimuli used by organizations or countries to attract investors and investments into a specific sector or economy. In Texas, legislative incentives that could be used to stimulate increased uranium mining include:

1. Tax Incentives: Providing tax credits or deductions for exploration and production activities related to uranium mining.

2. Regulatory Support: Streamlining permitting processes and reducing regulatory hurdles to make it easier for companies to start and expand mining operations.

3. Research and Development Funding: Allocating funds for research and development in uranium mining technologies to improve efficiency and reduce environmental impact.

4. Infrastructure Investment: Supporting infrastructure development, such as roads and utilities, to facilitate easier access to mining sites.

5. Public-Private Partnerships: Encouraging partnerships between government entities and private companies to share risks and costs associated with uranium mining projects.

6. Educational and Workforce Development: Investing in training programs and educational initiatives to build a skilled workforce for the uranium mining industry.

These incentives can help attract investment, reduce costs, and mitigate risks associated with uranium mining in Texas.

Examples of other states in the US with increased uranium mining activities through incentives are:

1. Wyoming provides reductions or exemptions on severance taxes for uranium mining operations to boost production, particularly during low market prices. The state has implemented measures to streamline the permitting process for uranium mining, aiming to increase efficiency and reduce the time required for companies by passing SB250 in 2022 thus creating an exploration tax credit available for certain non-coal minerals operations (Legislative Service Office, 2024).

2. Utah provides tax credits and exemptions for mining operations, including sales tax exemptions on equipment and machinery used in mining. The state also offers favorable terms on mineral lease royalties to promote uranium development and other mineral resources (Minerals Exploration Tax Cre | Oil, Gas, and Mining, 2022).

3. In Colorado, mining companies are offered regulatory assistance to facilitate their navigation through the permitting process. Furthermore, the state has allocated funds for research aimed at developing more sustainable and efficient mining practices, thus benefiting uranium mining operations (Energy/Mineral Impact Assistance Fund | Division of Local Government, 2024).

Texas could look to these states for models of successful legislative incentives.

VIII. Conclusion

Uranium mining commenced in Texas during the 1950's and became a thriving economic activity due to the availability of uranium in the state, its high demand and relatively high market price. However, in the mid 2010's, uranium mining activity decreased in the U.S. due to diverse factors, which led to most extraction facilities ceasing operations. A significant amount of uranium was estimated to remain in the ground in Texas at dormant mining locations, mostly in the Coastal Plains region. However, dispersed historical records did not provide a clear picture of the existing resources. Additionally, data indicates that there were significant potential uranium resources in other locations of the state, that may expand the known resources of this fuel. This report compiles these records, data and reports into a comprehensive review of existing uranium resources in Texas.

The report additionally explores the diverse reasons that have caused uranium prices and demand to increase in recent times. International political instability, including the war in Ukraine and insecurity in some international uranium mining locations, has reduced uranium availability, which has pushed prices to very high levels. This has created significant opportunities for reactivation of US uranium mines and has led to extraction of the resource at competitive prices, while simultaneously strengthening energy security for the US. Texas has numerous uranium extraction facilities, some of which have restarted production and contribute to the supply of this critical element. Furthermore, as prices are maintained at high levels, it may be economical and technically feasible to explore for uranium extraction in other previously untapped locations in the state.

Nuclear energy can be a critical factor to supply the significantly increasing demand for electricity in the U.S., in part generated by the growing economy, data centers, artificial intelligence and electric vehicles. Nuclear energy does not generate air pollutants or greenhouse gases during its operation and therefore can significantly contribute to curbing climate change effects. This report explores diverse electricity demand growth scenarios and the potential to use new, more advanced nuclear reactors to supply this growing energy demand in the US. Small modular reactors are being developed at an accelerated pace, and once deployed, will require significant amounts of uranium to operate. Current and future demand of this fuel creates a positive outlook for the development and expansion of uranium mining activities in Texas.

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