Space Technology Industry-Government-University Roundtable – Fission Surface Power Overview

Dr. John C. Kennedy, Space Nuclear Programs

4 October 2023

Changing the World

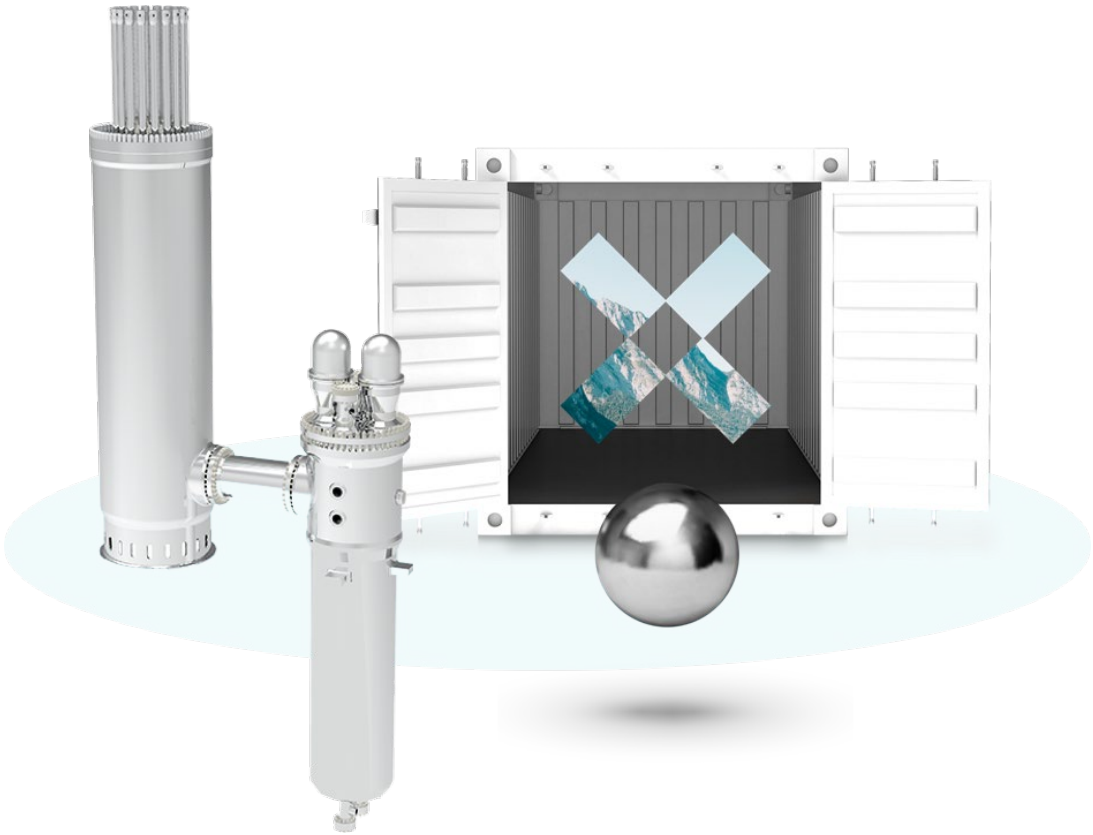
Dr. Kam Ghaffarian,
Founder and
Executive Chairman

"President Kennedy once said that we are in a space race and my work with NASA reflects the progress he had hoped for.

Today, I believe we are in an energy race. Providing clean energy across the world is my vision for X-energy and I believe that clean, safe, reliable nuclear energy is necessary to making this possible."

- Dr. Kam Ghaffarian is a globally recognized technology visionary across energy, space and information technology.
- Created and grew Stinger Ghaffarian Technologies (SGT), Inc. to $650 million in annual revenue and 2,400 employees. SGT was ranked as the U.S. National Aeronautics and Space Administration's second largest engineering services company prior to being acquired by KBRwyle, subsidiary of KBR, Inc.
- Founded X-energy in 2009 to address innovation in critical energy solutions. In 2016 X-energy was awarded ~$60M from DOE to focus on an advanced nuclear reactor and TRISO fuel. In 2020 X-energy awarded the Advanced Reactor Demonstration Program for a value of $2.4 billion
- Founded Intuitive Machines in 2016 to leverage NASA technologies for commercial space and terrestrial applications. Intuitive Machines won its first Commercial Lunar Lander Contract from NASA in 2018 with first landing scheduled for fall 2023
- Founded Axiom Space in 2017 to develop the first commercial space station, to be launched by 2022.

We design & build reactors and the fuel that powers them



Reactor: Xe-100

We're focused on Gen-IV High-Temperature Gas-cooled Reactors (HTGR) as the technology of choice, with advantages in sustainability, economics, reliability and safety.

Reactor: Xe-Mobile

To address the need for ground, sea and air transportable small power production. We've developed reactor concepts with potential civilian government, remote community and critical infrastructure applications.

Fuel: TRISO-X

Our reactors use tri-structural isotropic (TRISO) particle fuel, developed and improved over 60 years. We manufacture our own proprietary version (TRISO-X) to ensure supply and quality control.

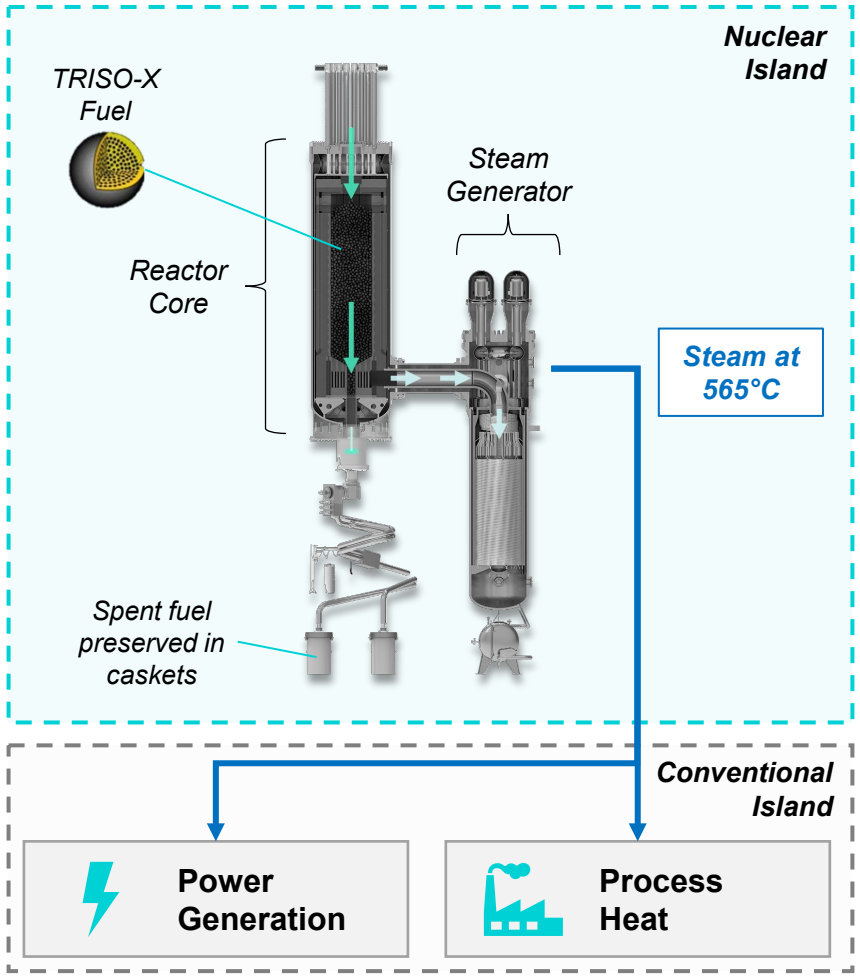
Space Applications

NASA, DOE, and DOD are exploring our technology and fuel for nuclear thermal propulsion and fission power for the lunar surface.

Xe-100 – A Pioneering Gen IV Nuclear Reactor

80 MWe modular design & manufactured components designed to drive scalability, accelerated timeline and cost control

Xe-100 Schematic



Modular & Standardized

- Each reactor module is connected to its own steam turbine generator or process heat offtake, so **modules can be constructed / operated independently, and even added as demand grows**
- Onsite work is reduced, and a significant portion of quality control is shifted to centralized fabrication & integration facilities

Manufacturable, Road-Shippable Components

- Simpler, standardized design allows for **mass production of road-shippable components**
- In contrast, the complex design of traditional nuclear construction has required on-site construction

Intrinsically Safe

- **Xe-100 is designed to avoid the need for additional safety systems**
- Intrinsically safe design means **1/6th the safety systems of a traditional reactor** and fewer materials (e.g., ~95% less concrete than legacy nuclear plants)
- Simple control system with only 4 variables expected to allow for more automated operations & fewer personnel

Microreactor Development

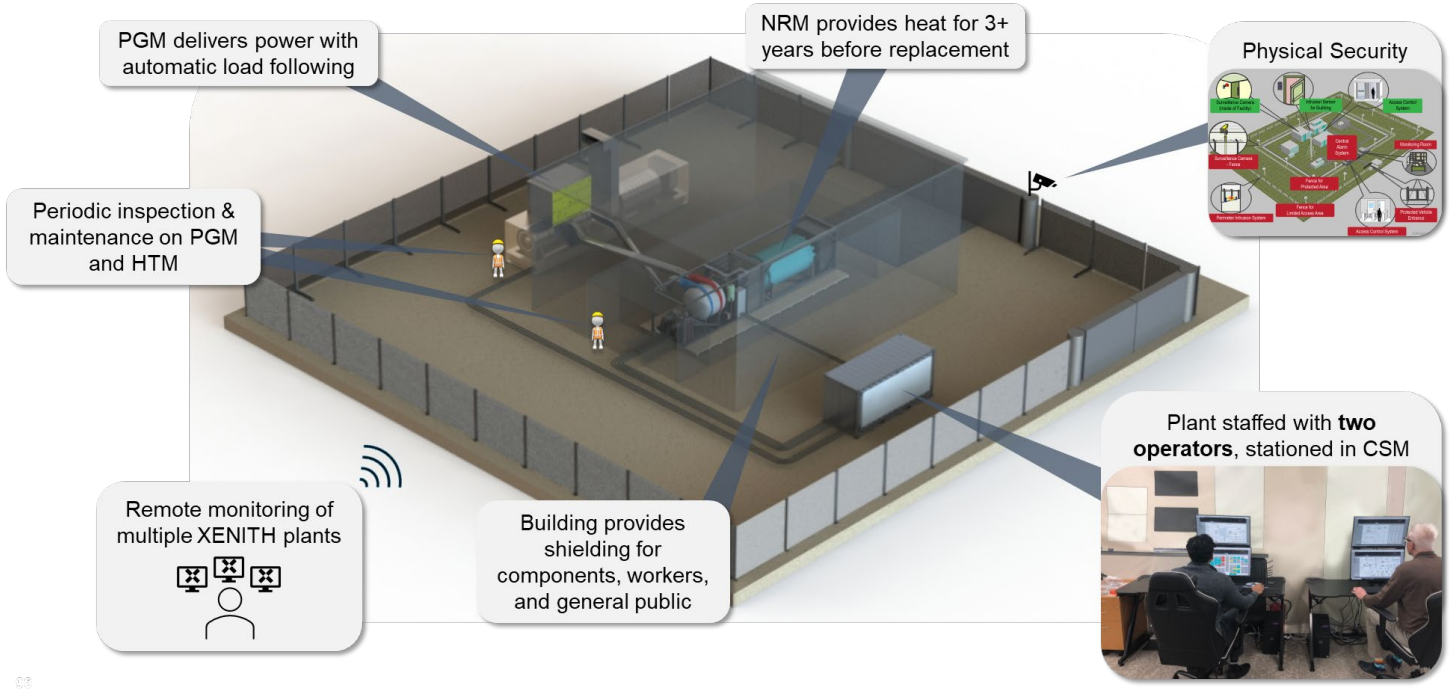
X-Energy Next-generation Integrated Transportable High-temperature (XENITH) Microreactor Plant

DoD Project Pele

- Experienced staff and design processes matured under ongoing DoD Project Pele work
  - Over $60M of DoD and X-energy investment to date

XENITH Commercial Microreactor

- Continuing design under 2023-2024 DOE iFOA Award
- Modular design supports rapid deployment, operational flexibility, maintenance & inspection
- 19.75% enriched TRISO fuel
- Targeting 5+ MW net electric output with optional combined heat and power cycles
- Rapid power ramp rates and step load changes



TRISO-X Fuel – Intrinsic Safety

The Department of Energy describes TRISO fuel as "the most robust nuclear fuel on Earth"[1]
It retains waste and fission products within the fuel during all foreseeable adverse conditions, even worst-case accidents, and it is designed not to melt

- **X-energy manufactures its own proprietary TRISO encapsulated fuel ("TRISO-X")** to ensure supply & quality control. TRISO Fuel has a 60+ year demonstrated track record through prototype and full-scale reactors
- HALEU-based fuel like TRISO-X increases burnup and efficiency, which decreases costs
- Because **TRISO-X Fuel IS a containment vessel and is designed not to melt**, the Xe-100 does not require large, expensive concrete & steel containment structures
- The low reactor power density and self-regulating core design means that if cooling stops, the core naturally shuts down. This **prevents the reactor from melting under foreseeable adverse conditions and requires no operator actions under such adverse conditions**

➡ **Physics, not mechanical systems, ensures safety**

Fuel Process

Step 1

~15.5% Enriched Uranium Kernel
Feedstock sourced from third parties

Step 2

TRISO Fuel Particle (~1mm Diameter)
Uranium kernel encased in carbon and ceramic layers

Step 3

TRISO-X Fuel Pebble (60mm Diameter)
~18,000 TRISO particles per pebble set in graphite matrix

Step 4

Pebble Bed
>200,000 pebbles form the core of each Xe-100 reactor

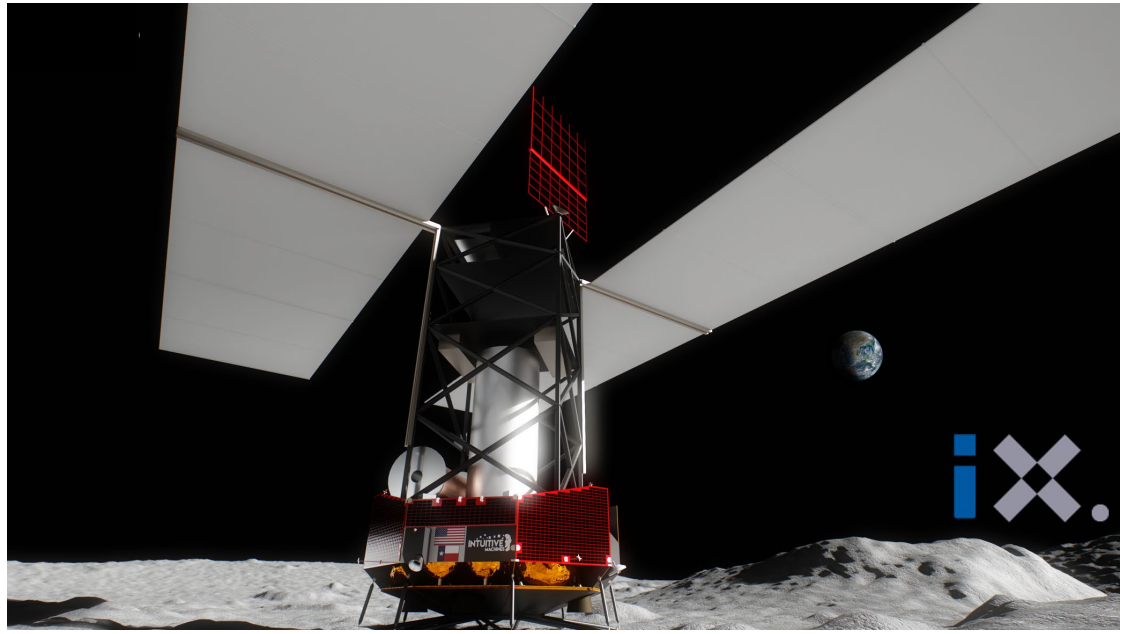
1) *Source: Office of Nuclear Energy – TRISO Particles: The Most Robust Nuclear Fuel on Earth (July 2019)*

Fission Surface Power

IX, a Joint Venture of Intuitive Machines and X-energy

With Partners Boeing and Maxar

- Best-of-industry space-nuclear partnership
- Safe, commercially available coated particle fuel
  - Similar to Xe-100 and XENITH
- Stirling engine power conversion
  - Simple, high reliability, fault-tolerant design
  - Plant is compatible with Brayton at higher power levels
- Unique solutions for shielding and operation
  - Derived from experience gained in Pele and XENITH microreactors
- >40 kWe for >10 years
- Extensible to Mars and NEP
- Completed 1-year Phase 1 study



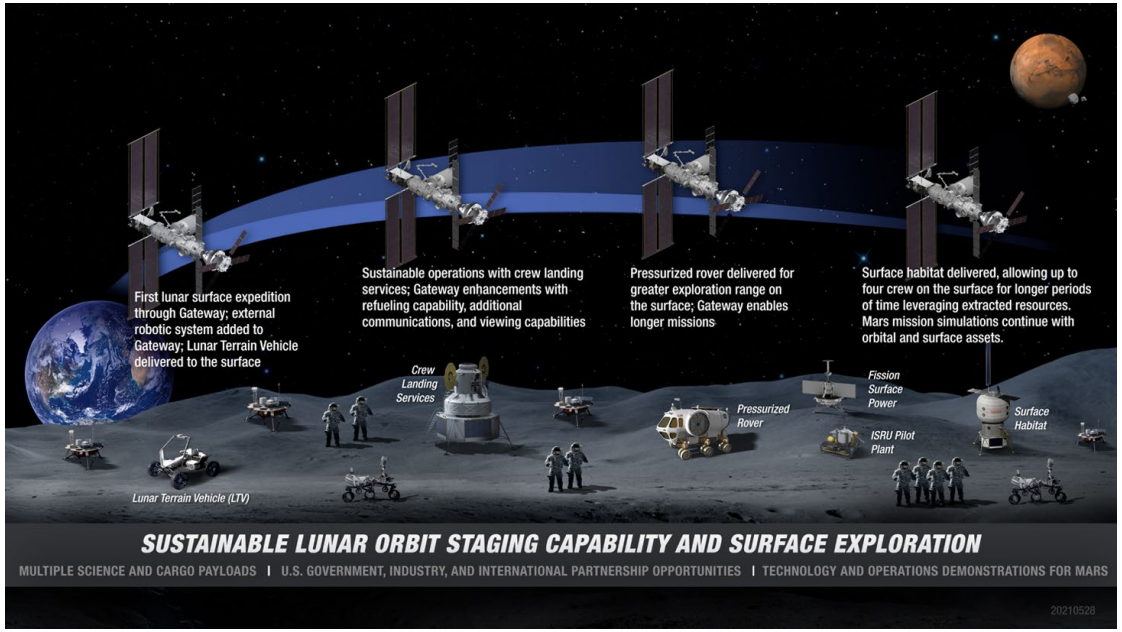
FSP as a Key Enabling Technology for the Artemis Base Camp and Beyond

Near Term Focus

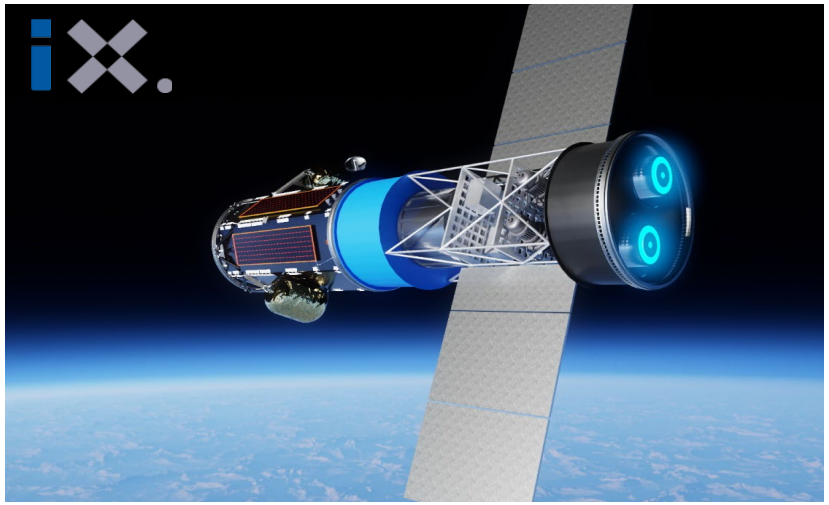
- Component, subsystem, & materials characterization and optimization
- Impact of specific mission requirements on design & performance

Motivation

- FSP provides reliable power during lunar day and night
- Enables long term habitation of a lunar base camp
- Accelerated FSP deployment can enable accelerated construction of a lunar base camp



P. Kessler, T. Prater, T. Nickens and D. Harris, "Artemis Deep Space Habitation: Enabling a Sustained Human Presence on the Moon and Beyond," 2022 IEEE Aerospace Conference (AERO), Big Sky, MT, USA, 2022, pp. 01-12, doi: 10.1109/AERO53065.2022.9843393.
https://ntrs.nasa.gov/citations/20220000245



Future

- Nuclear Electric Propulsion based on similar architecture

X Energy, LLC

x-energy.com @xenergynuclear