TRISO-X Fuel Production Capabilities

GAIN Advanced Fuels Workshop

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Process Engineer

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Outline

- Background on X-energy and TRISO-X
- Difficulties facing a category II fuel facility
  - Issue 1: HALEU availability and transport
  - Issue 2: Facility design
  - Issue 3: Licensing
  - Issue 4: Funding and scheduling

Overview and History of X-energy

X-energy is reimagining nuclear's role in solving tomorrow's energy challenges

- X-energy founded in 2009 by Kam Ghaffarian to address the world's most serious energy challenges and make a lasting contribution to clean energy technology
- Dr. Ghaffarian has committed ~$38.5M since X-energy inception to date
- Secured two Department of Energy (DOE), Office of Nuclear Energy Cooperative Agreements
  - Advanced Reactor Concept (ARC)15: Xe-100 Pebble Bed Small Modular Reactor: Solving Critical Challenges to Enable the Xe-100 Pebble Bed Advanced Reactor Concept ($53M total project)
  - Industry Funding Opportunity Announcement (iFOA)18: Design and License Application Development for TRISO-X: A Cross-Cutting, High Assay Low Enriched Uranium (HALEU) Fuel Fabrication Facility ($38M total project)

Dr. Kam Ghaffarian
Founder/CEO

Elements of Reactor and Fuel Programs

Reactor Development

- Xe-100 Conceptual Design
- X-battery Conceptual Design
- TCF CRADA
- Graphite Qualification
- Heat Transfer Modeling CFD
- Probabilistic Risk Assessment (PRA)
- MST Code Development
- NRC White Paper Development
- NRC Topical Report Development

TRISO-X Fuel Development

- Pebble Fuel Development
- Nuclear Criticality Safety Evaluation
- Fresh Pebble Transport Package Evaluation
- Conceptual Layout of Production Module
- Systems Engineering
- TRISO-X Facility Design (Preliminary/Final)
- TRISO-X License Application Development
- NRC Interaction

Issue 1: HALEU Availability and Transport

Advanced Reactor HALEU Needs

All advanced reactors require uranium enriched to >5% to achieve higher burn-ups and operational efficiencies

Issues

- Lack of uranium enriched to 20%, i.e. high assay low enriched uranium (HALEU)
  - HEU for NNSA stockpile not available to advanced reactors
  - No domestic enricher of HALEU
- Lack of HALEU transport packages available for commercial use
  - Existing commercial UF_6 packages not licensed to 20%
  - HALEU packages for test reactor and military fuel not NRC licenses
- Lack of fresh fuel transport packages
  - Various advanced reactor fuel elements may require more than one transport package

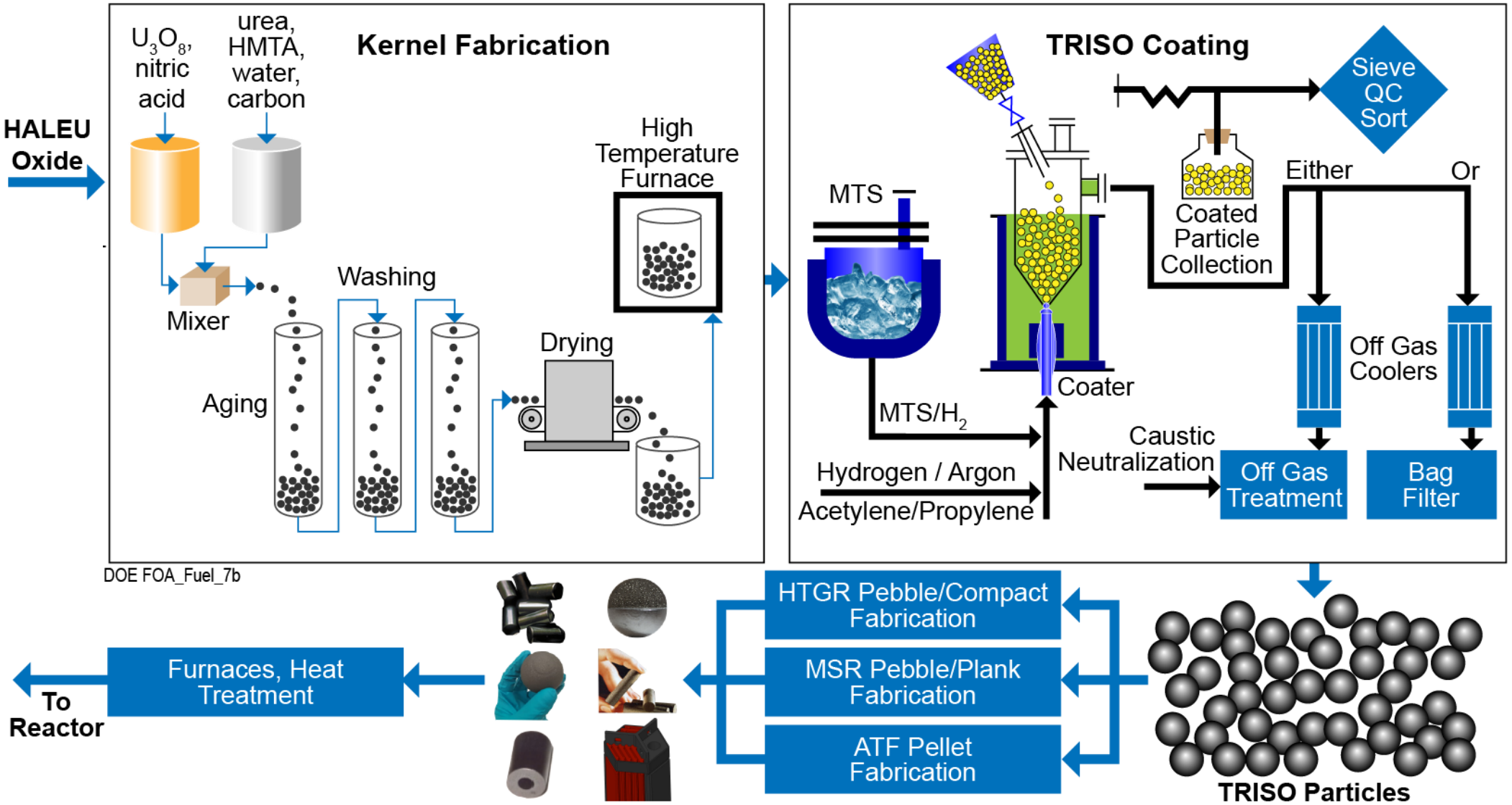
Solutions

- DOE-NE plans to sole-source HALEU enrichment contract to American Centrifuge Project (X-energy strategic partner) using DOE Portsmouth site located in Piketon OH
- Availability to co-locate enrichment and fuel fabrication processes eliminates the need for one type of transport packages
- TRISO as a common fuel element to multiple reactor designs presents the opportunity to have a single fresh fuel transport package

Under a DOE-NE cooperative agreement, X-energy is actively engaged with the NRC on these issues

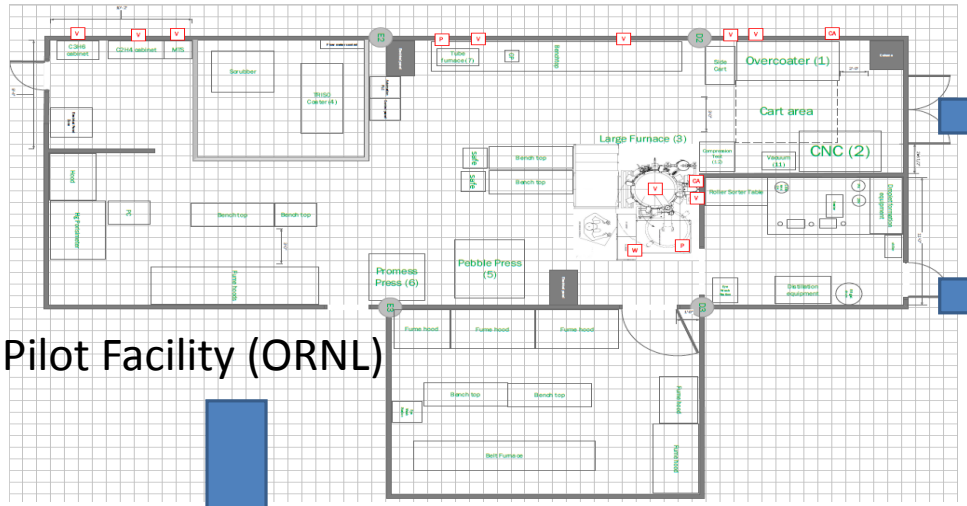
Issue 2: Design a Commercial Facility

TRISO-X: A Crosscutting Facility for Advanced Reactors (ARs) & Current Fleet



DOE FOA_Fuel_7b

Transition from Pilot to Commercial



TRISO-X Pilot Facility (ORNL)

Develop kernel/coating/pebbles processes with natural uranium

Fabricate “Xe-6/7/8” pebbles for Irradiation with HALEU

Replicate equipment

TRISO-X Commercial Facility (Centrus)

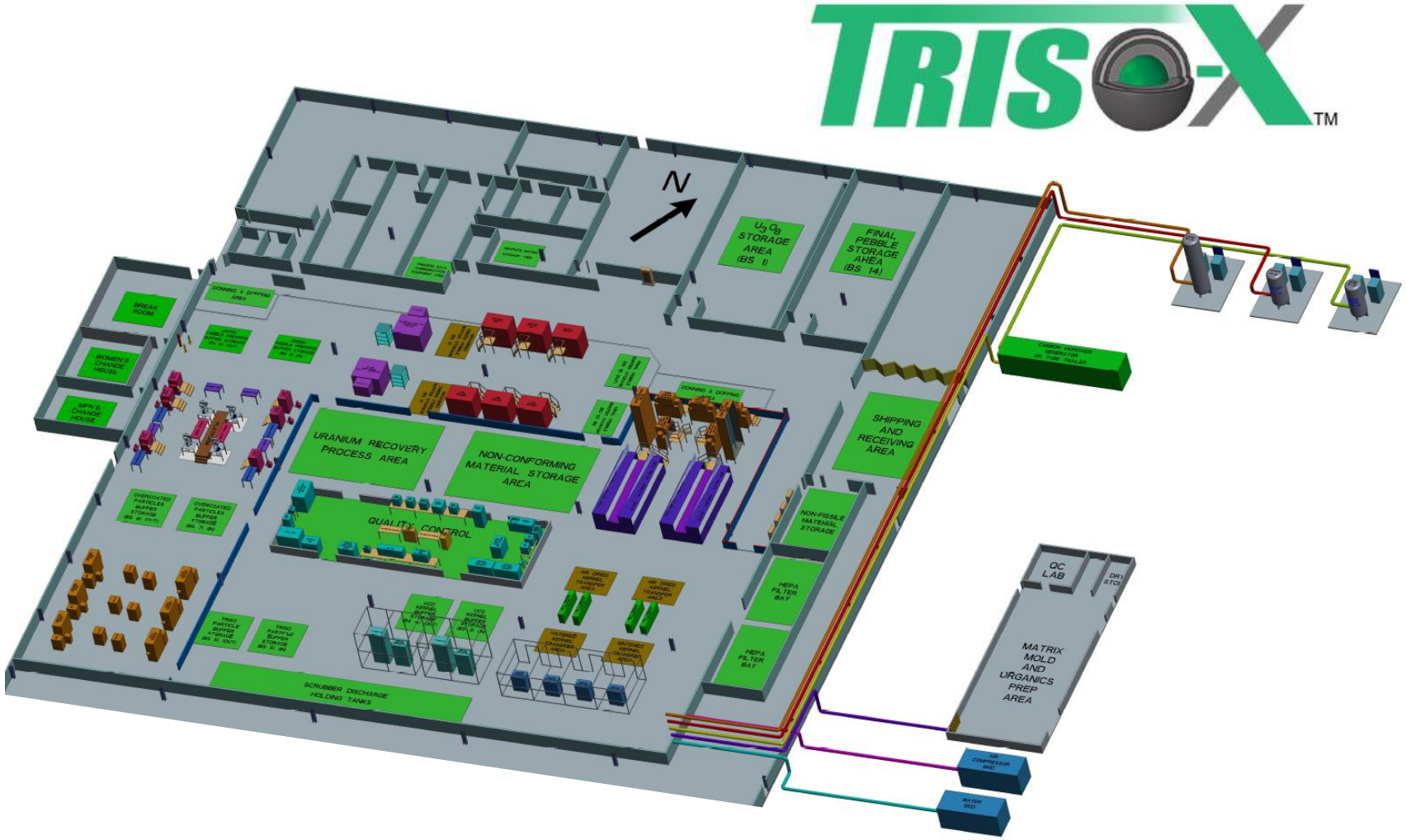
Fuel elements for first advanced reactor customer to market

Additional TRISO based fuel elements

Continuous refueling support

Conceptual Design

- Completed August 2018
- Modular/scalable design
- Lean layout
- Adaptable to multiple fuel forms
- No visual impact at the site boundary
- Implements a number of first of a kind design and regulatory features



Preliminary Design

- 2019 Design Focus
  - Auxiliary systems that are ready to proceed & have little risk of substantive change
  - Manufacturing systems stable enough in conceptual design to begin detailed development
- Design & development conducted under rigorous quality program
- Configuration controlled processes and design
- Work organized by Engineering Service Orders (ESOs) within the overall project work breakdown structure
- 68 ESOs currently in document control system
- Design activities integrated with Nuclear Criticality Safety Evaluations and License Application Development
- End-in-mind with respect to conduct of operations
- Thorough and robust lines of communication between design, licensing, and safety analysis teams
- Substantial effort (22 Design Engineers, 12 NCS Analysts, 4 Process Engineers, 8 support staff)
- 3 year design schedule

Issue 3: Licensing a CAT II Nuclear Fuel Facility

License Application Development

- Regulatory framework – primary drivers
  - 10 CFR 70, “Domestic Licensing of Special Nuclear Material”
  - NUREG-1520, “Standard Review Plan for Fuel Cycle Facilities License Application”

- NRC engagement
  - 8/8/2018: submitted initial Regulatory Engagement Plan (REP)
  - 8/24/2018: pre-application meeting to introduce project and discuss REP
  - 12/12/2018: pre-application meeting on Nuclear Criticality Safety approach
  - 2/11/2019: NRC team visited TRISO-X Pilot Facility at ORNL and Centrus site
  - Additional pre-application meetings will include:
    - Environmental reviews
    - Integrated safety analysis
    - Material control and accountability
      - Security plan considerations
  - **Q1 2021: target submittal of license application**

Site Selection Process

Phase 1

- 24 sites reviewed using 16 criteria
  - ✓ **3 sites moved forward**

Phase 2

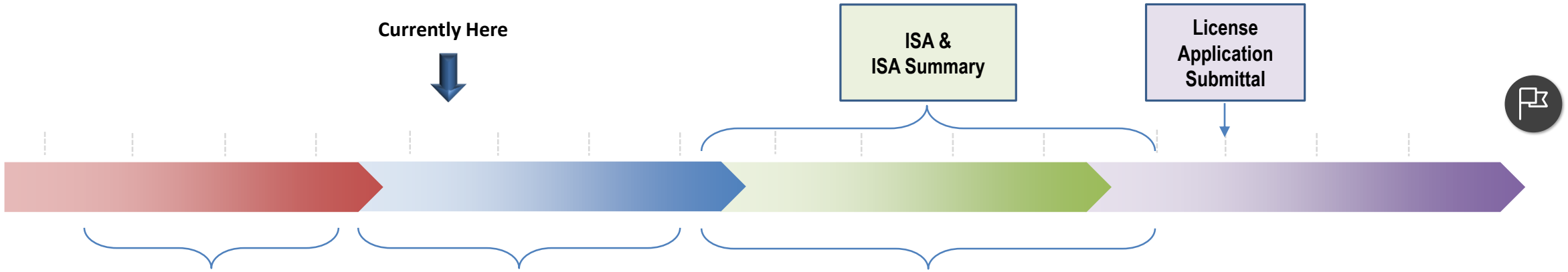
- 3 sites reviewed using 36 criteria
  - ✓ **1 site moved forward**

Currently Here

Phase 3

Evaluate preferred site in Environmental Report

Nuclear Criticality Safety Status



Solid NCS Foundation

- NCS Engineer Qualifications
- NCS Orientation to TRISO
- Design Team NCS Orientation
- NCS Program Description (Chapter 5 of License Application)
- NCS Program Procedures
- NCS Software Configuration Control
- SCALE Verification & Validation
- MCNP Shielding Verification & Validation
- NCS Scoping Calculations
- NCS Input for Concept. Design

Preliminary Design & Licensing Support

- Preliminary Nuclear Criticality Safety Evaluations (PNCSEs)
- Design Interface
- License Application Support

Follow-On Support

- Complete Nuclear Criticality Safety Evaluations (NCSEs) based on final design
- Incorporate NCS hazards into ISA
- Complete Criticality Accident Alarms System detector placement calculations
- Complete NCS Program implementing procedures (e.g., oversight, training)
- Develop NCS training program (includes NCS engineer qualification training and basic NCS plant training)

NCS Design Philosophy

NCS is integrated into the design from the onset of the TRISO-X project

NCS limits are based on

Preferred Design Approach

Criticality Safety Evaluations

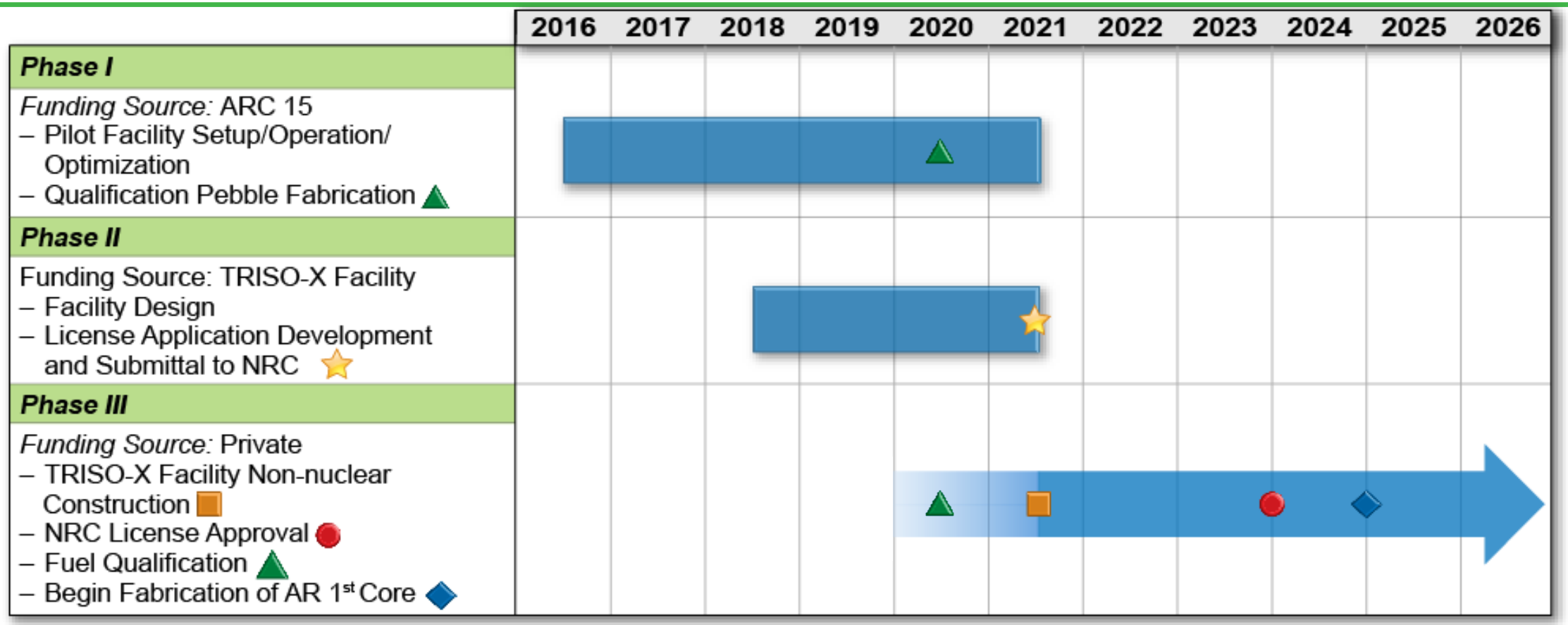
- The approach for establishing NCS design requirements during the early design stage is through the development of Preliminary Nuclear Criticality Safety Evaluations (PNCSEs).
- PNCSE includes the following:
  - Description of operation
  - Normal case (described in terms of parameters and limits on parameters)
  - Hazard identification
  - Hazard evaluation
  - Proposed controls
  - Assumptions
  - Calculational/data needs
- PNCSEs converted to final NCSE upon design completion

PNCSE BENEFITS

- Provides documented NCS analyses without having final design complete
- Provides mechanism to identify issues early in design to prevent major redesign if hazards identified later
- Provides mechanism to identify data and calculational needs for final NCSE

Issue 4: Funding and Scheduling

Commercialization Phases and Funding



TRISO-X development is divided into three phases:

1. Work under DOE ARC15 Cooperative Agreement (Lab and Pilot Facility, concept design)
2. Work under DOE iFOA Cooperative Agree. (Prelim/Detailed facility design, license app dev.)
3. Private debt financing of NRC license review/approval and TRISO-X facility construction

Thank you
Questions?

Please contact Dr. Pete Pappano, VP of Fuel Production, for more information: ppappano@x-energy.com