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The Necessity of Systems Engineering for Nuclear Power Deployment

February 26, 2021

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Artistic concept of the NuScale Power Plant

NuScale's Mission

NuScale Power provides scalable advanced nuclear technology for the production of electricity, heat, and clean water to **improve the quality of life for people around the world.**

We will achieve this mission by providing technology that is:

- SMARTER
- CLEANER
- SAFER
- COST COMPETETIVE

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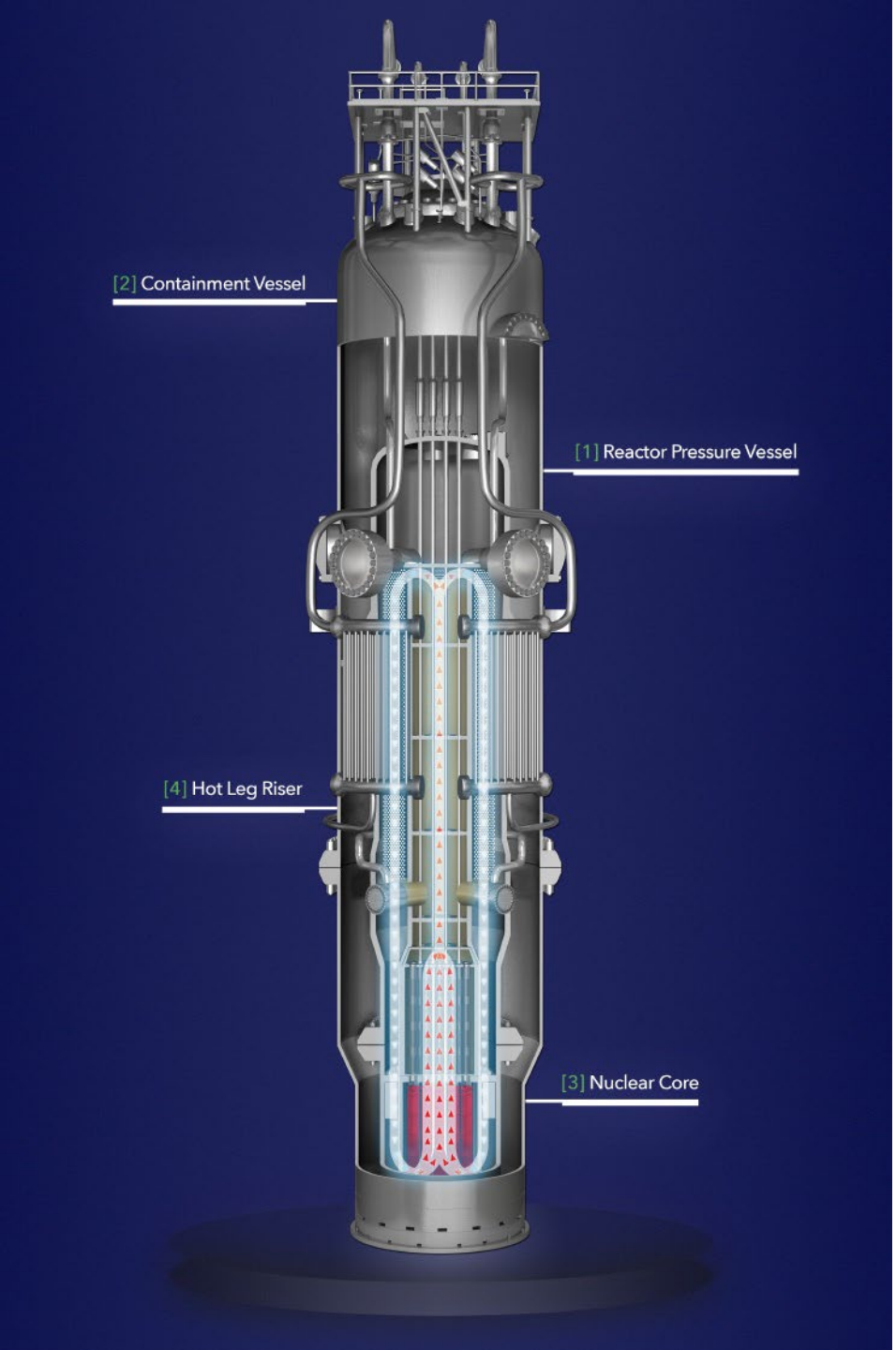
Agenda

- NuScale technology development and deployment
- Introduction to systems engineering
- Systems engineering value proposition
- Tailoring and implementing systems engineering processes
- Summary and conclusions

Core Technology: NuScale Power Module™



- A **NuScale Power Module™** (NPM) includes the reactor vessel, steam generators, pressurizer, and containment in an **integral package** – simple design that eliminates reactor coolant pumps, large bore piping and other systems and components found in conventional reactors
- Each module produces **up to 77 MWe**
  - Small enough to be factory built for easy transport and installation
  - Dedicated power conversion system for flexible, independent operation
- Modules are incrementally added to match load growth
  - Up to **12 modules for 924 MWe** gross output
  - Smaller power plant solutions available for 4-module (308 MWe) and 6-module (462 MWe) plants

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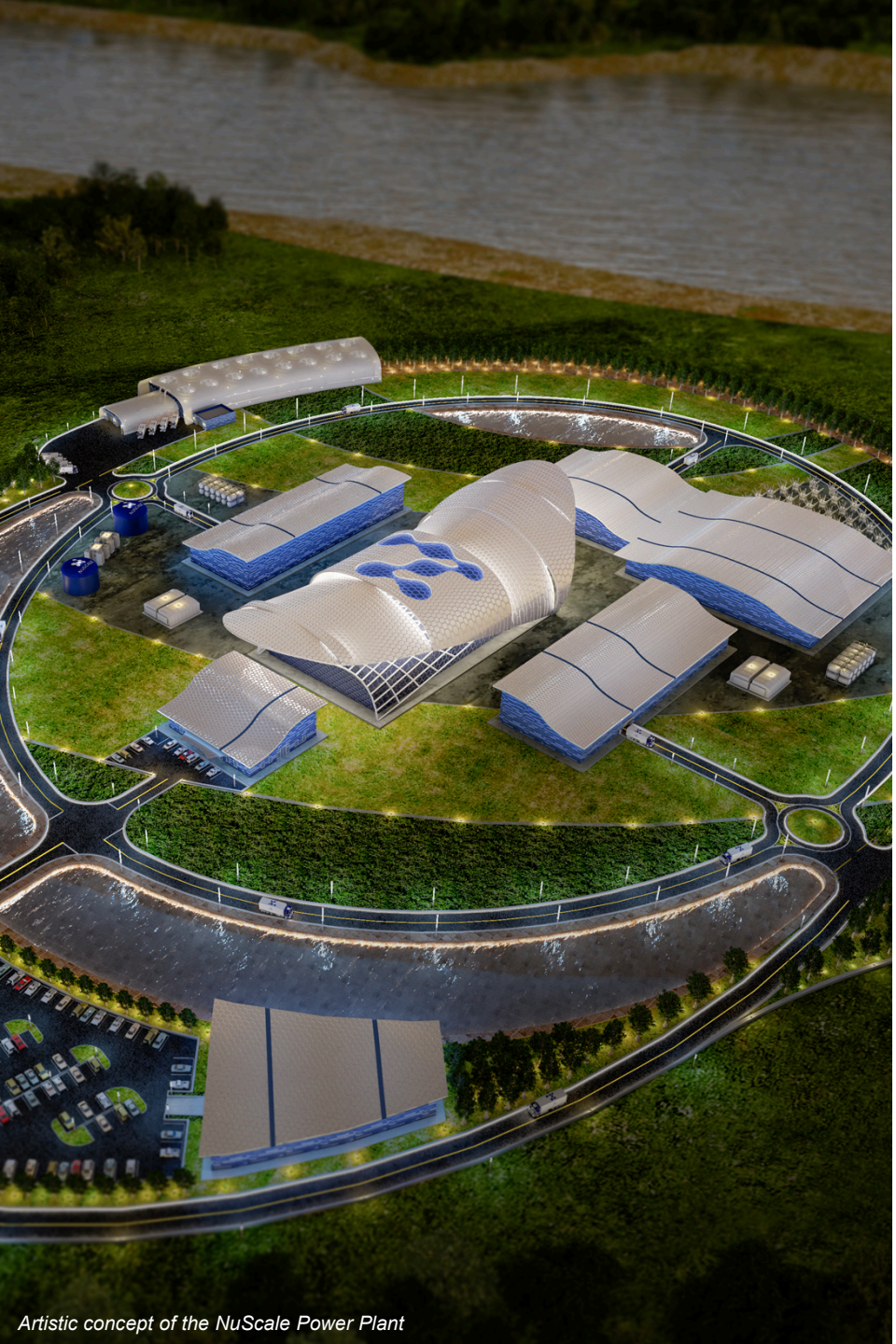

Artistic concept of the NuScale Power Plant

NuScale Product Offerings

- Reference plant design
  - Scalable 12-NPM, 924 MWe power plant
  - Design approved by US NRC in August 2020
- Smaller power plant solutions
  - Scalable 4-NPM, 308 MWe power plant
  - Scalable 6-NPM, 462 MWe power plant
  - All features and capabilities of reference plant
- Micro-reactor concepts
  - 10-50 MWe Micro-NPM
  - 1-10 MWe Heat Pipe Reactor
- Research & Development
  - Numerous design improvements identified and in development

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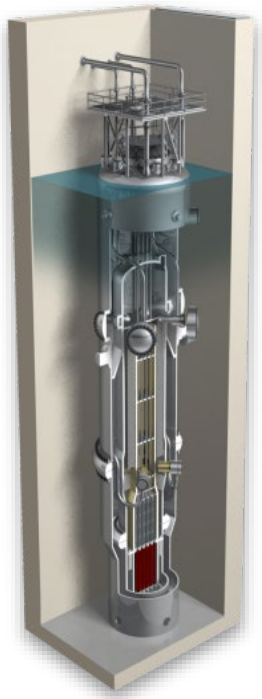
A New Approach to Construction and Operation

NuScale has revolutionized the nuclear supply chain with modular manufacturing of NPM units in-house that are shipped to sites



1

Factory fabrication

2

NuScale Power Module including containment and reactor vessel

Low carbon, secure electricity

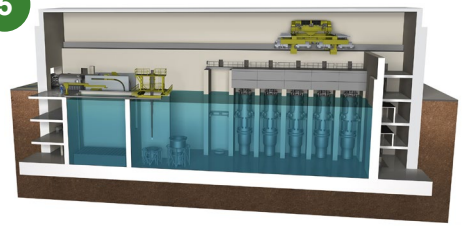
3

Shipped by truck, rail, or barge

4

To the plant site

5



Housed in a 12-module reactor building

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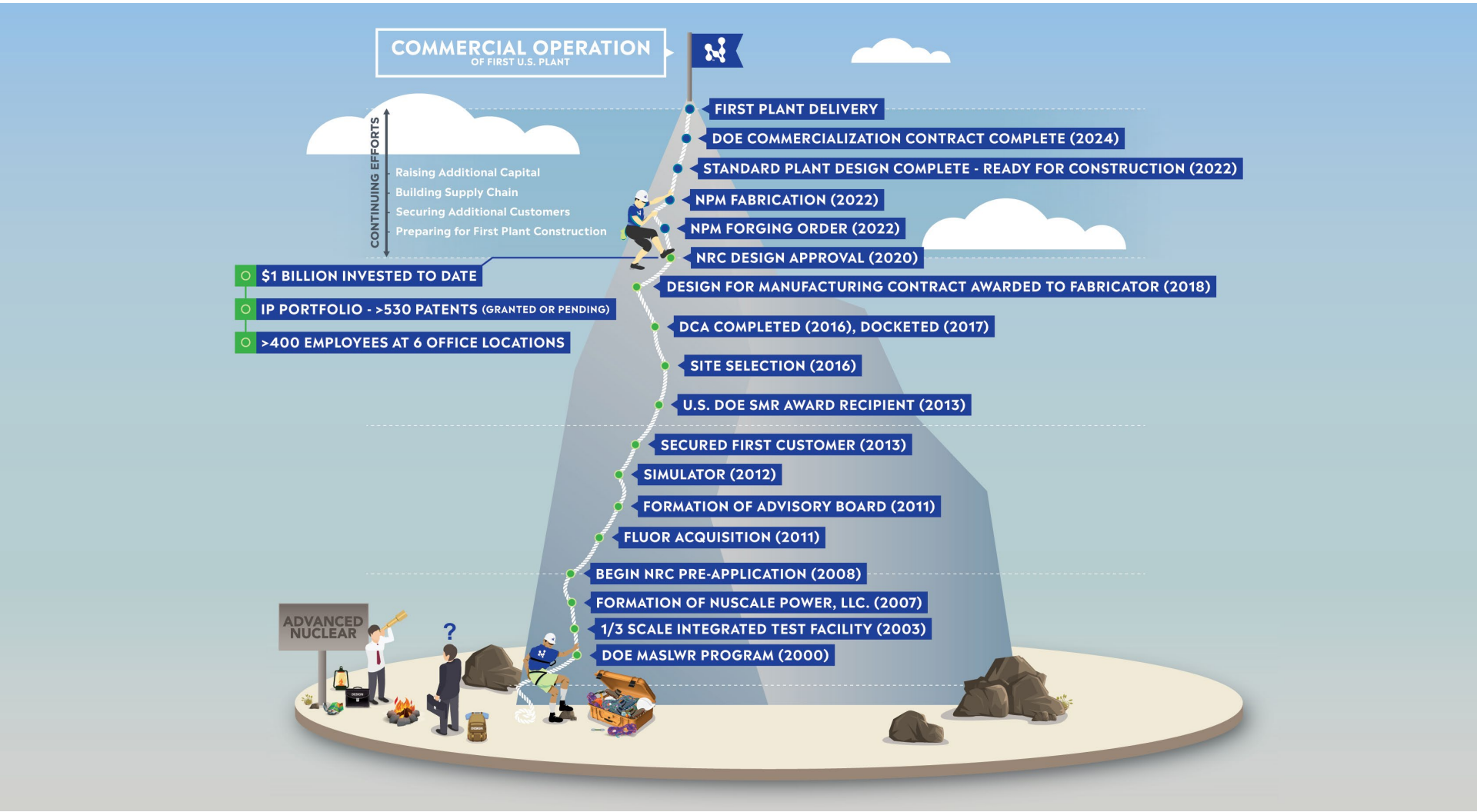
Blazing the Trail to Commercialization



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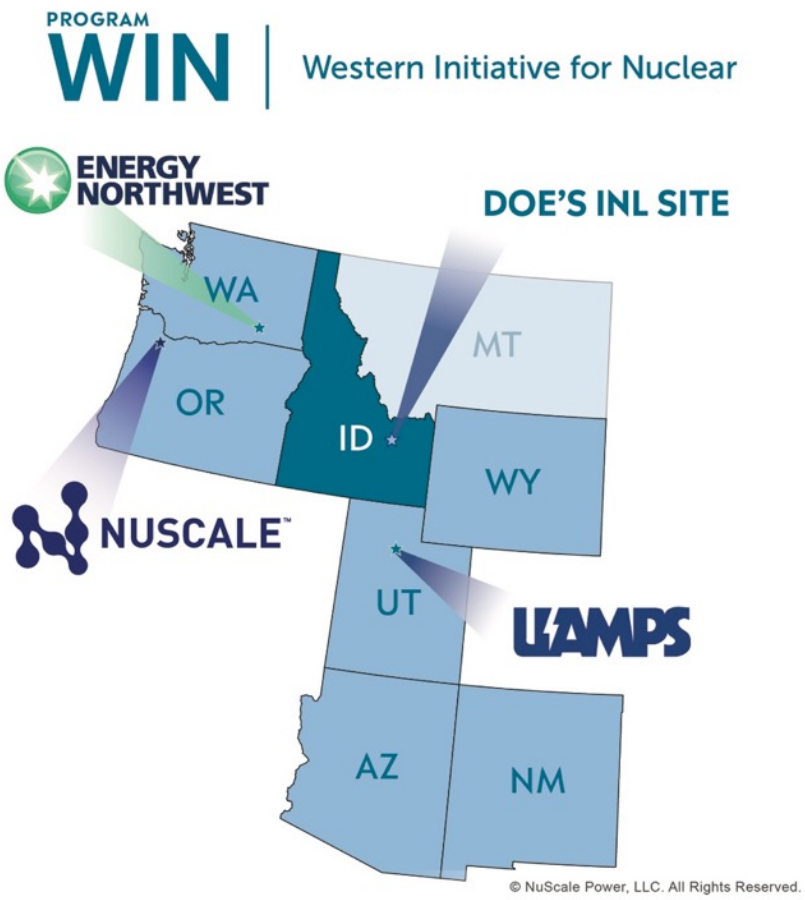
First Deployment: UAMPS Carbon Free Power Project



- Utah Associated Municipal Power Systems (UAMPS) provides energy services to community-owned power systems throughout the Intermountain West
- First commercial deployment of the NuScale plant will be at the Idaho National Laboratory (INL) as part of the UAMPS Carbon Free Power Project
- In January 2021, UAMPS and Fluor signed a cost-reimbursable development agreement to provide estimating, development, design and engineering services to develop the site-specific cost estimates for deployment of the NuScale technology at the INL site.

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Carbon Free Power Project (CFPP) Timeline

2020

2020
Site characterization activities began

2021-2023
Site characterization activities increase

2024
Full site mobilization for construction

2029
First NuScale Power Module™ installed

2030
Remaining modules installed for full plant operation

2030

Artistic concept of the NuScale Power Plant

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Vessel cladding testing at Doosan

Automated cladding machine at Doosan

Supply Chain Development and Manufacturing of NPM

- Design for Manufacturing
  - Manufacturer feedback to optimize design and lower costs
  - Manufacturing plan development
  - Forging procurement drawings
  - Performed by Doosan and BWXT (performing same scope)

- Manufacturing Trials (Doosan)
  - Cladding distortion (2 sided) of reactor pressure vessel
  - Steam generator tube bending
  - F6NM material (martensitic stainless steel) use for containment vessel

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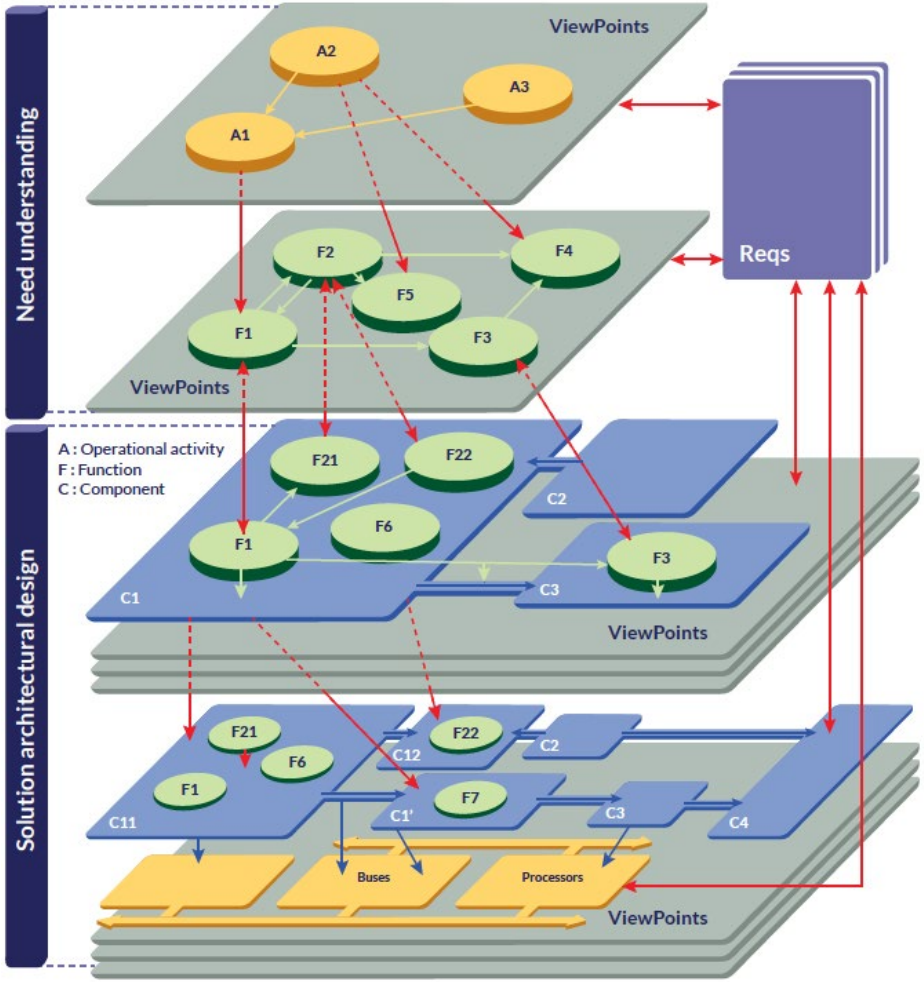

Arcadia Model-Based Systems Engineering Method

What is Systems Engineering (SE)?

- A set of proven tools and techniques for ***managing the complexity*** of large projects/products in order to control cost, schedule, and quality.

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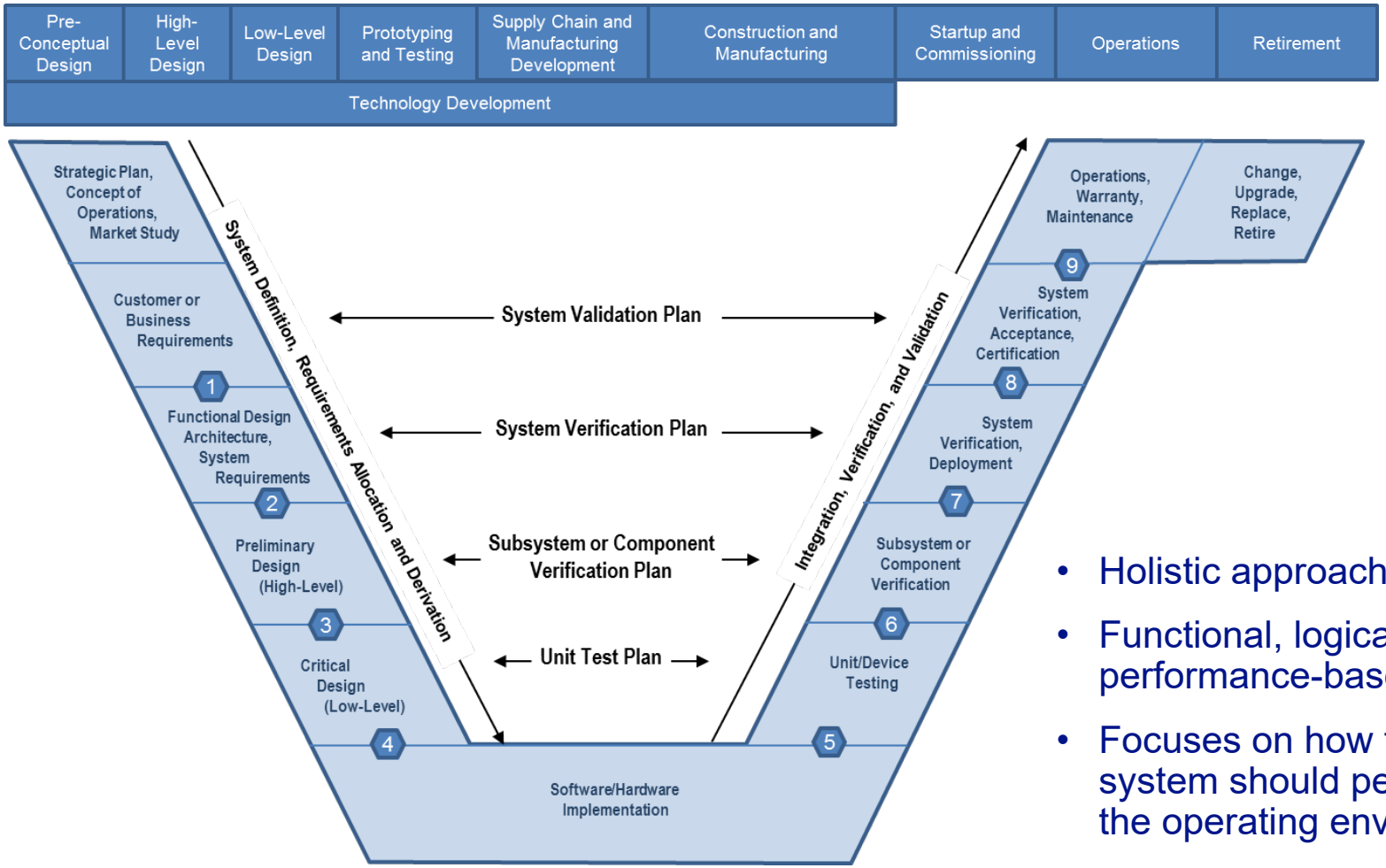
Systems thinking and the “V” development model

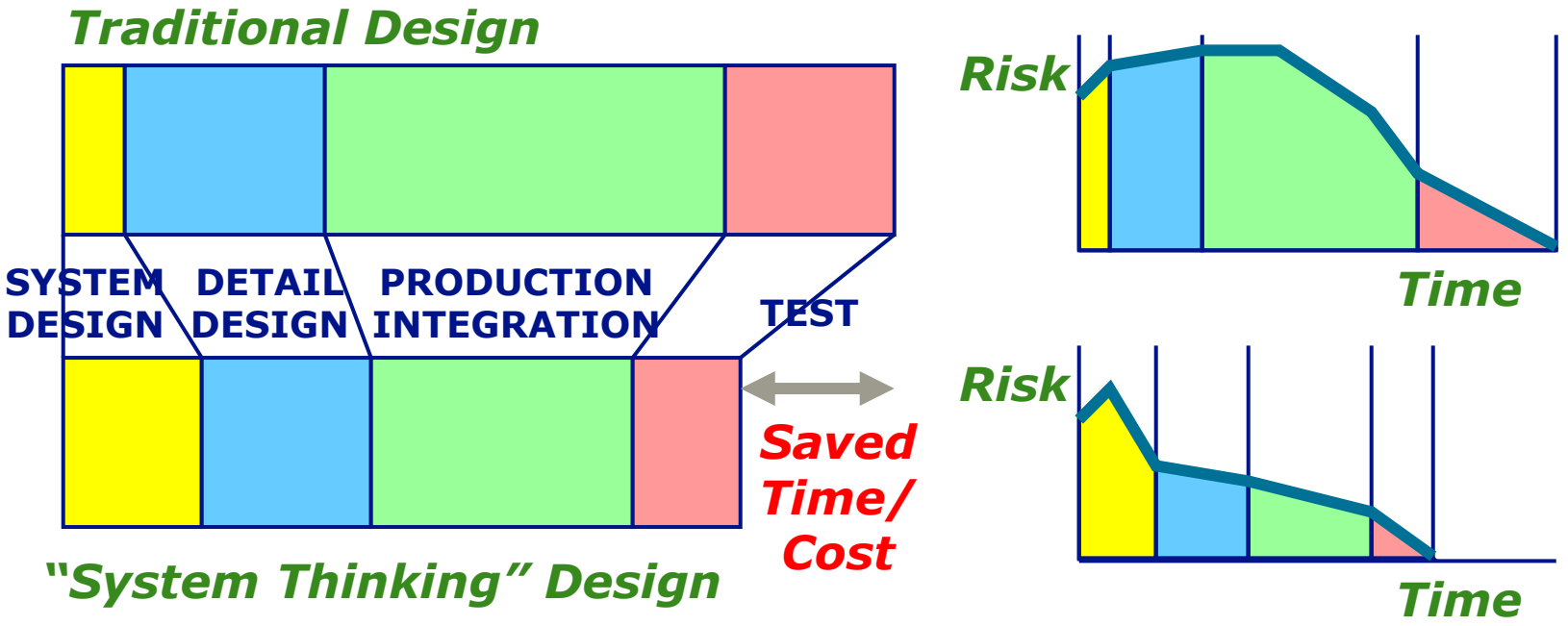


- Holistic approach
- Functional, logical, performance-based
- Focuses on how the system should perform in the operating environment

SE Value Proposition

Better systems engineering leads to

- Lower costs
- Shorter schedules



Need to Know: How Much Is Enough?

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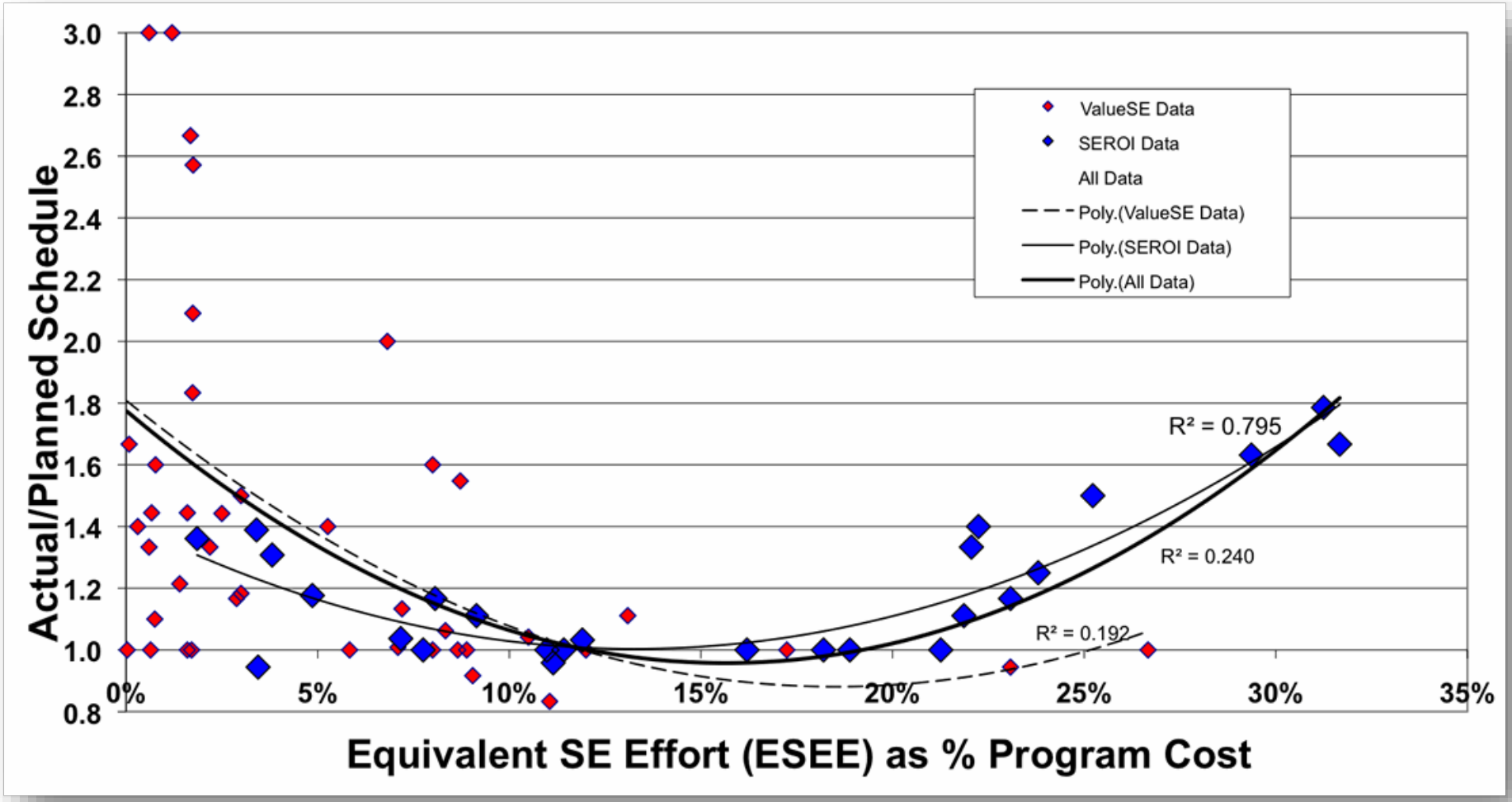
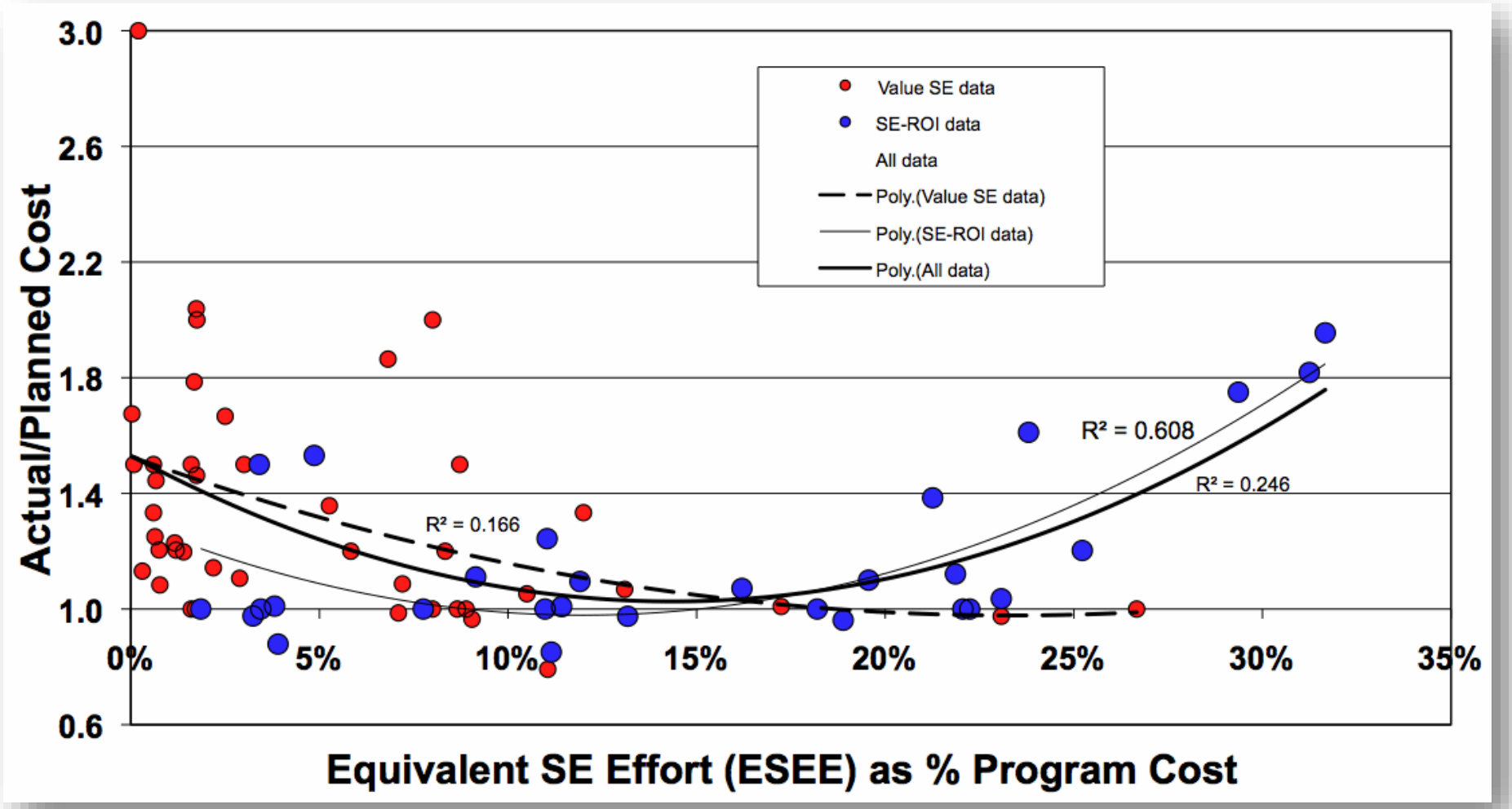
Schedule vs SE Effort



Honour, EC, Systems Engineering Return on Investment, PhD thesis, Univ South Australia 2013

Cost vs SE Effort



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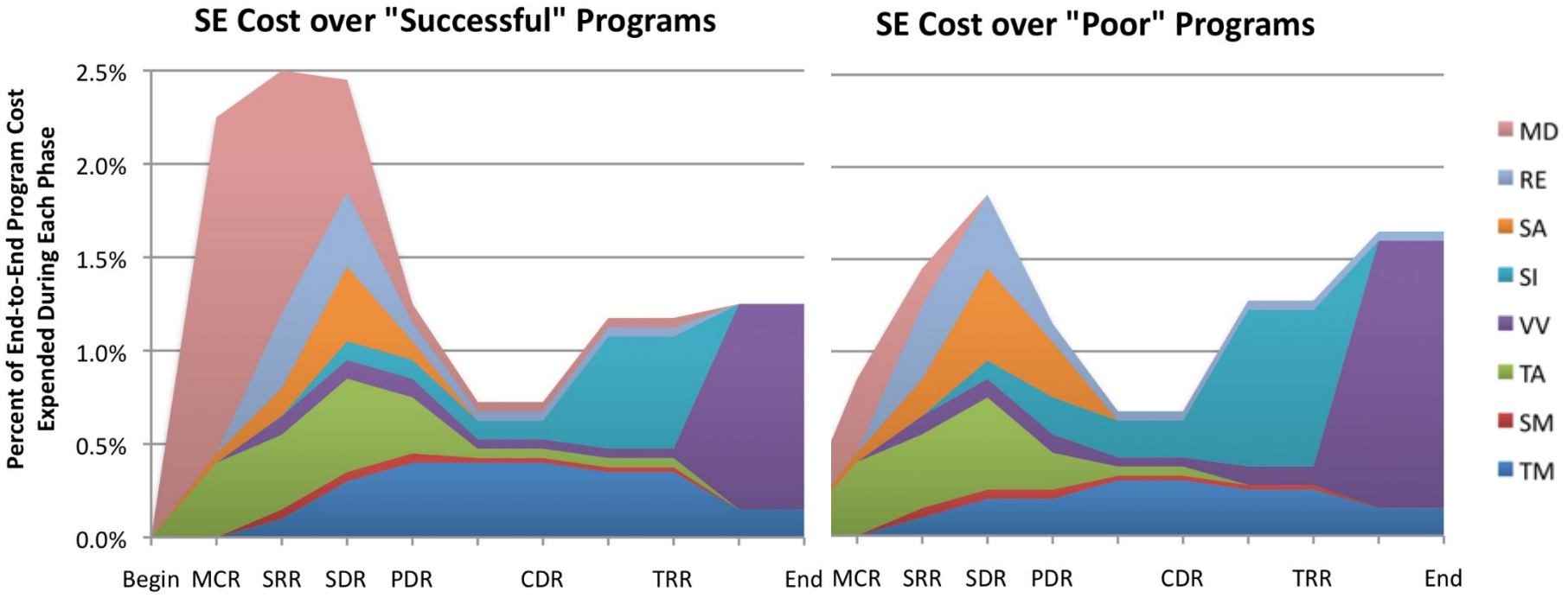
Mega Project Breakout by Success



Success *(~on cost)*
- More mission/purpose def.
- More tech leadership/mgmt
- More Systems Engineering

Fail *(overran cost)*
- More system integration
- More V&V
- Less Systems Engineering

Honour, EC, Systems Engineering Return on Investment, PhD thesis, Univ South Australia 2013

NuScale SE Value Proposition

- A tailored SE program will help to:
  - Ensure all stakeholder requirements for successful deployment (not just regulatory requirements) are identified, decomposed, and allocated to the appropriate structures, systems and components (SSCs), thereby reducing future rework and ensuring a licensable, constructible, operable, and cost-effective plant.
  - Increase confidence in project cost and schedule in order to ensure NuScale products meet stakeholder expectations
  - Support tailored requirements, functional, and product architectures for each major aspect of the plant, allowing for differences in repeatability (i.e. NPM vs BOS), delivery mechanism (manufactured vs purchased vs constructed), and safety significance.
    - Provides a better understanding of technical, regulatory, and project risks associated with each major element, allowing for better visibility and mitigation of those risks.

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NuScale SE Standard

- Purpose
  - Establish systems engineering process requirements for product management to reduce costs and accelerate schedules, while maintaining quality and creating products which delight our customers.
- Scope
  - Systems engineering processes in the areas of system design, technical management and control, and product realization for NuScale end-products to be delivered to customers
  - Addresses integration of specialty engineering disciplines and the overall systems engineering effort.
  - Although this standard provides process requirements for the entire product life cycle, subsequent implementation documents (e.g., plans, procedures, guides, etc.) are expected to focus on product development and realization.
  - Does not invoke requirements from the NuScale quality assurance program.
  - Subsequent procedures that are developed based on this standard will invoke appropriate quality requirements for that specific process area.

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NuScale SE Technical Processes

3. System Design
3.1 Stakeholder Expectations Elicitation and Validation
3.2 Technical Solution Definition
3.3 Architecture Definition
3.4 Integration of Specialty Engineering (Systems Analysis)

4. Technical Management and Control
4.1 Technical Planning
4.2 Configuration Management
4.3 Technical Risk Analysis
4.4 Technical Assessment
4.5 Technical Data Management
4.6 Technical Decision Analysis

5. Product Realization
5.1 Product Implementation
5.2 Product Integration
5.3 Product Verification
5.4 Product Validation
5.5 Product Transition

NuScale SE processes were tailored based on guidance from ISO/IEC/IEEE 15288, the NASA Systems Engineering Handbook (2nd Edition), and industry benchmarking.

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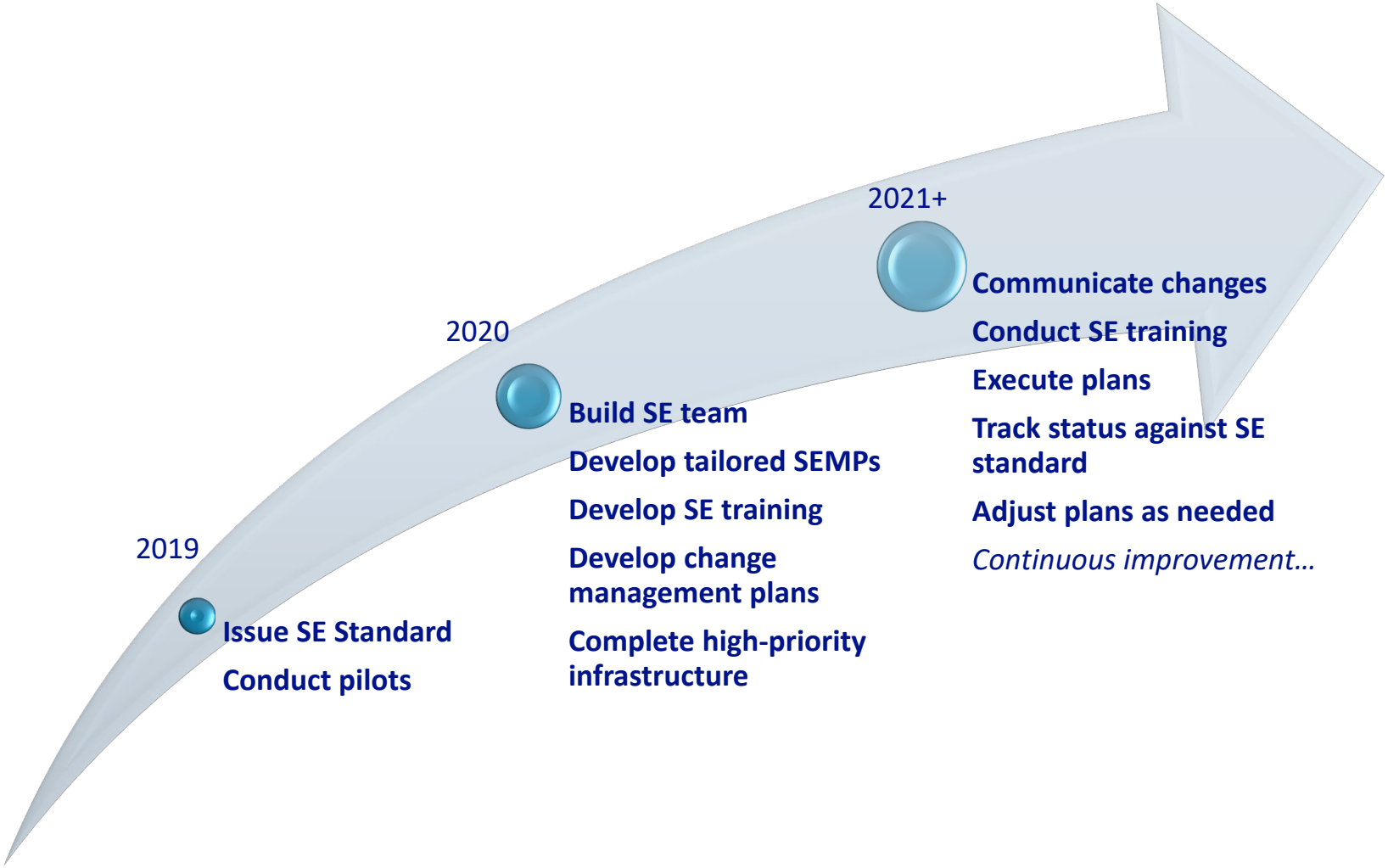
SE Implementation Approach



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SE Group Roles and Responsibilities

- Support product lines with tailored SE management plans (and activities) by leveraging established SE best practice process, which could include:
  - Stakeholder needs elicitation and validation (e.g., product concept document)
  - Technical solution definition (e.g., plant design specification, top-level product specifications)
  - Product structure modeling
  - Product life cycle modeling
  - Functional architecture modeling
  - Operational concept modeling
  - Requirements architecture modeling
  - Requirements capture and centralized maintenance
  - Interface identification and management
  - Technical assessment (e.g., design reviews, product life cycle gate reviews, technical performance tracking and measurement, technical audits)
  - Technical risk assessment (e.g., technology readiness reviews, TRL maintenance, risk and opportunity database)
  - Technical decision analysis (e.g., trade studies, decision criteria, decision tools)
  - Product or system verification and validation planning
  - Product implementation, integration, and transition support (e.g., plans, requirements traceability matrices)

Successful SE Implementation

- **Tailored** to problem/opportunity set
- Early and frequent stakeholder involvement/education
- Change management planning
- Leverage SE Community of Practice and outside expertise
- Program requirements first, then product-specific plans
- SE-informed PLM architecture and configuration management process
- Common understanding of key concepts
- Strong Executive Leadership sponsorship

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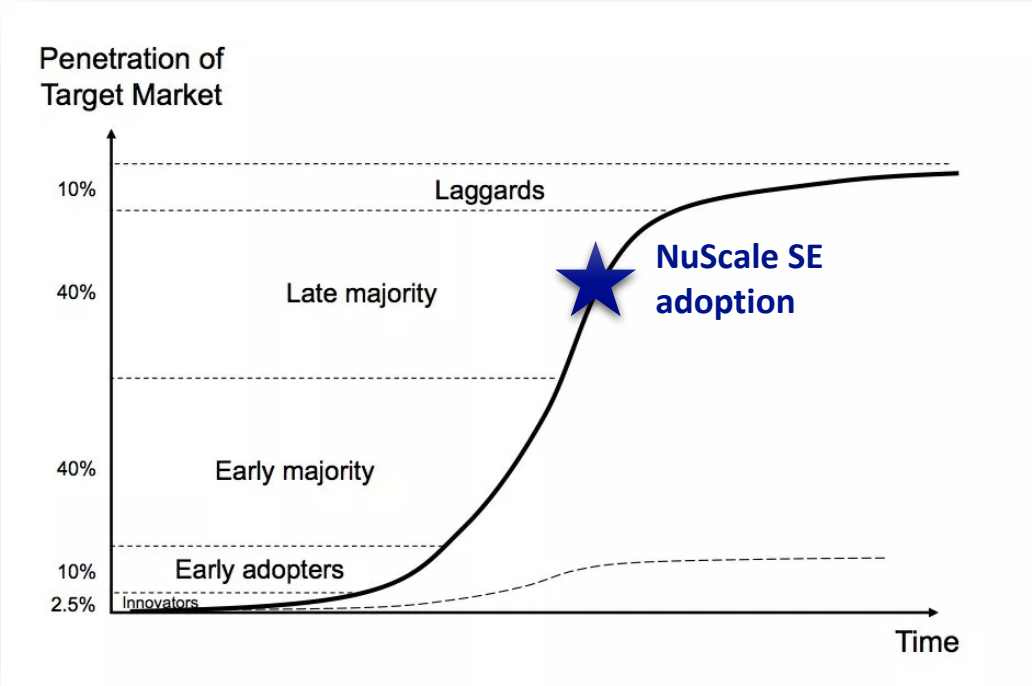
Summary and conclusions

- Research on the success and failure of mega projects conclusively shows that the right amount and type of SE effort can help to control costs, maintain schedules, and reduce risk.
- Reactor vendors and constructors realize these findings and are moving towards increasing their systems engineering efforts.
- NuScale believes that implementation of systems engineering best practices are essential for controlling costs and maintaining schedules.
- NuScale has spent considerable effort implementing a formal SE program/group over the past 3 years.
- From a corporate acceptance perspective, we are in the middle of the late majority phase of adoption, such that the majority of NuScale groups understand and support SE efforts.



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Background slides

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System Engineering Standards

- ISO/IEC/IEEE 15288:2015 Systems and software engineering -- **System** life cycle processes
- ISO/IEC/IEEE 12207:2017 Systems and software engineering -- **Software** life cycle processes
- ISO/IEC/IEEE 24748 Systems and software engineering -- Life cycle management
  - 2018 -- Part 1: Guidelines for life cycle management
  - 2018 -- Part 2: Guidelines for the application of ISO/IEC/IEEE 15288 (**System** life cycle processes)
  - 2011 -- Part 3: Guide to the application of ISO/IEC 12207 (**Software** life cycle processes)
  - 2016 -- Part 4: **Systems** engineering planning
  - 2017 -- Part 5: **Software** development planning
  - 2016 -- Part 6: System integration engineering

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