U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Nuclear Energy Advanced Modeling and Simulation (NEAMS)

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Nuclear Energy Can Benefit from Modeling and Simulation in the Near, Mid, and Long Terms

Time (* Dates Approximate)

Nuclear Energy Issues

2010 — 2020 — 2040

Power Uprates

Higher Burnups

Deployment of Gen III+ Reactors

NGNP

Small Modular Reactors

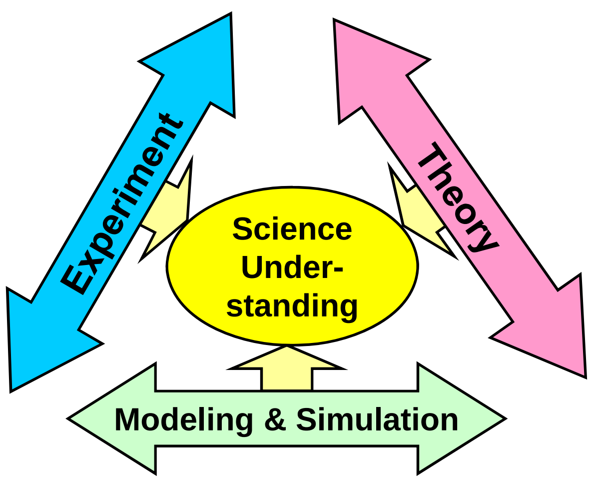
License Extensions

Gen IV Reactors

Waste Repository

Closed Fuel Cycle

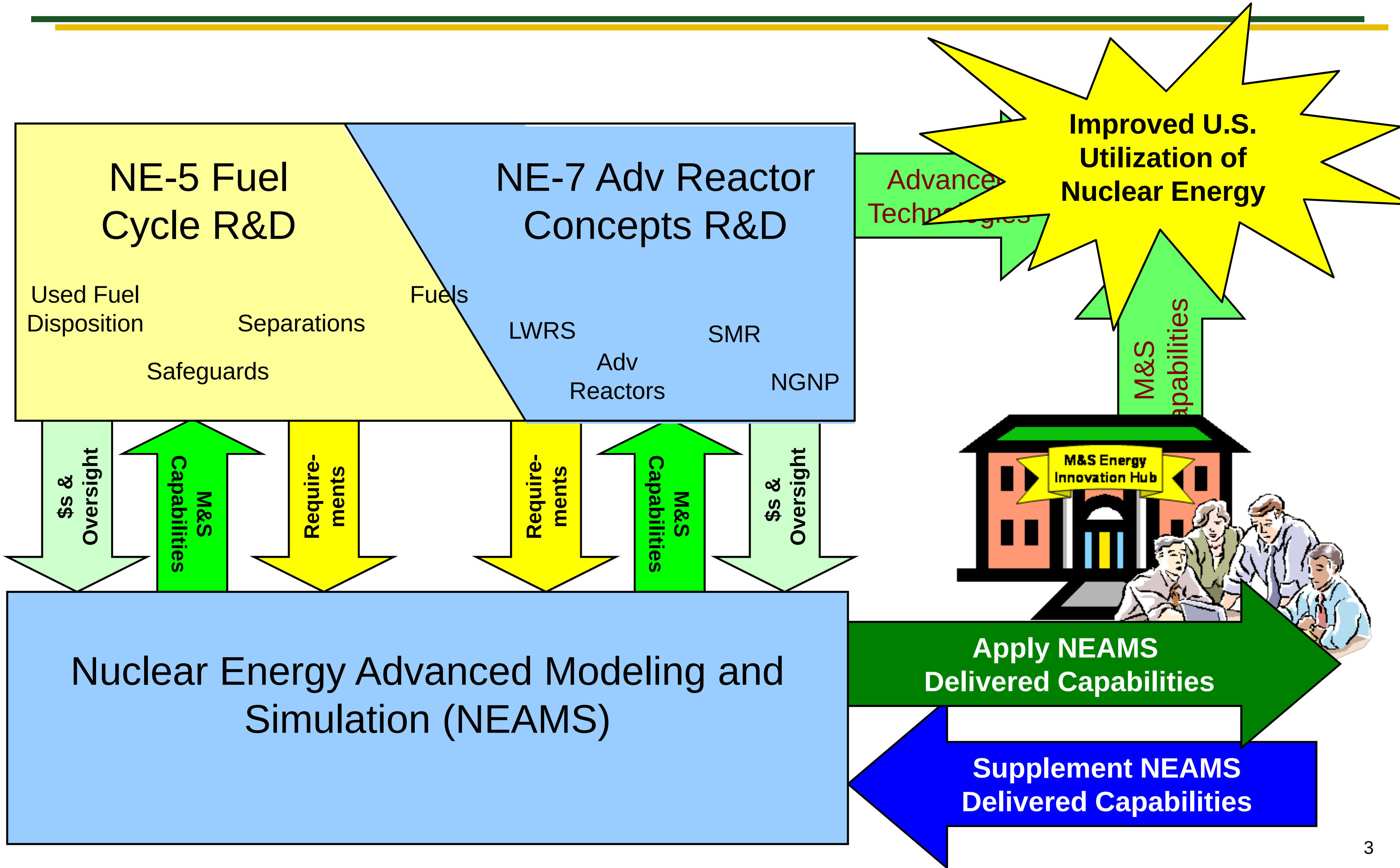
Near-Term — Mid-Term — Long-Term



New means of improved understanding nuclear energy Issues

Modeling and simulation has become a peer to theory and experiment to develop science insight

NEAMS and the Energy Innovation Hub Will Play Important Roles



Value of Modeling and Simulation

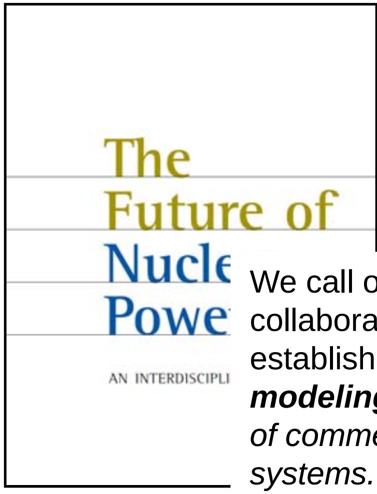
National Goals for Nuclear Energy Technology Development

- Decrease costs
- Improve performance
- Increase pace of deployment
- Enhance innovation
- Responsively deal with nuclear waste
- Promote non-proliferation

- **We need to go beyond traditional "test-based" approach to understanding nuclear energy**
  - **Very successful for over last 40 years – current fleet is very safe and performs well**
  - **However, test-based approach is:**
    - Very slow
    - Very costly
    - Very hard to optimize

- **Development, deployment and use of advanced modeling and simulation will:**
  - **Provide a new means of obtaining science-based insight that will**
    - Increase the pace of innovation
    - Reduce costs by eliminating unnecessary margins
    - Optimize operations
    - Reduce uncertainty and risk

Calls by the Experts

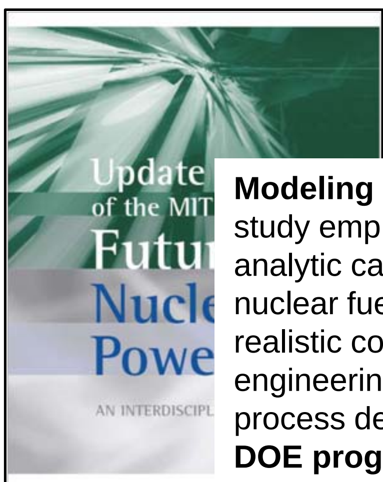


MIT 2003 Report

We call on DOE, perhaps in collaboration with other countries, to establish *a **major project for the modeling, analysis, and simulation** of commercial nuclear energy systems.*

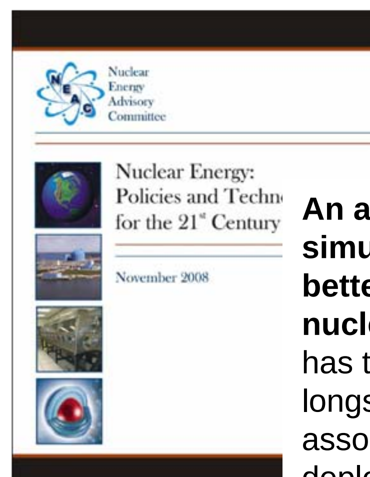
Robert Rosner 2008 Bulletin of Atomic Scientists Article

High-fidelity (science-based) integrated simulations must form the core of design efforts, allowing for rapid prototyping that minimizes the need to experiment.



MIT 2009 Update

Modeling and simulation The 2003 study emphasized the need for greater analytic capability to explore different nuclear fuel cycle scenarios based on realistic cost estimates and engineering data acquired at the process development unit scale. The **DOE program has moved in this direction but much remains to be done.**



2008 NEAC Report

An advanced modeling and simulation effort can lead to better understanding of nuclear energy systems and has the potential to resolve longstanding uncertainties associated with the deployment of these systems.

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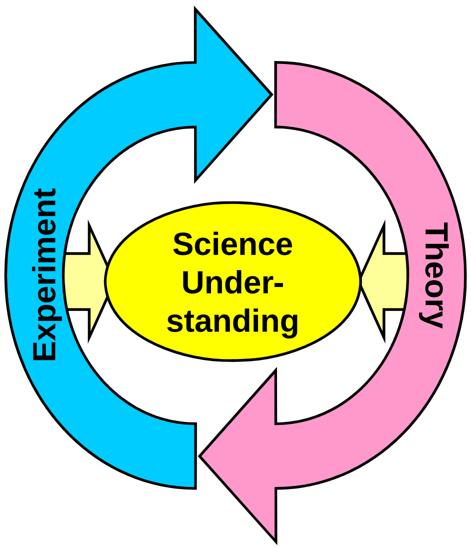
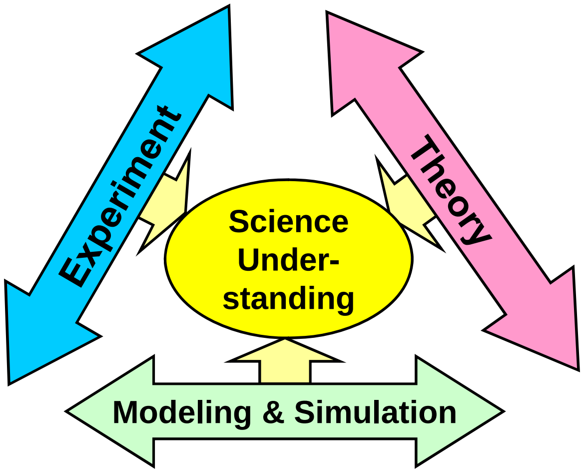
NEAMS Builds on the Success of ASCI & SciDAC

- **Important Lessons from ASCI**
  - **Vision** – Have a clear and compelling vision of the mission, and develop a <u>comprehensive program</u> to create new capabilities
  - **Leadership** – Headquarters need a “team of rivals” at the national laboratories for leadership of the program
  - **Partnership** – Success requires the best from universities, industry and national laboratories
  - **Endurance** – Accomplishing the ambitious goals will take time and funding. But it must deliver increasing capabilities “early and often”

ASCI History Available at https://asc.llnl.gov/asc_history/Delivering_Insight_ASCI.pdf

Enabling a Shift to a Modern Science Based Approach



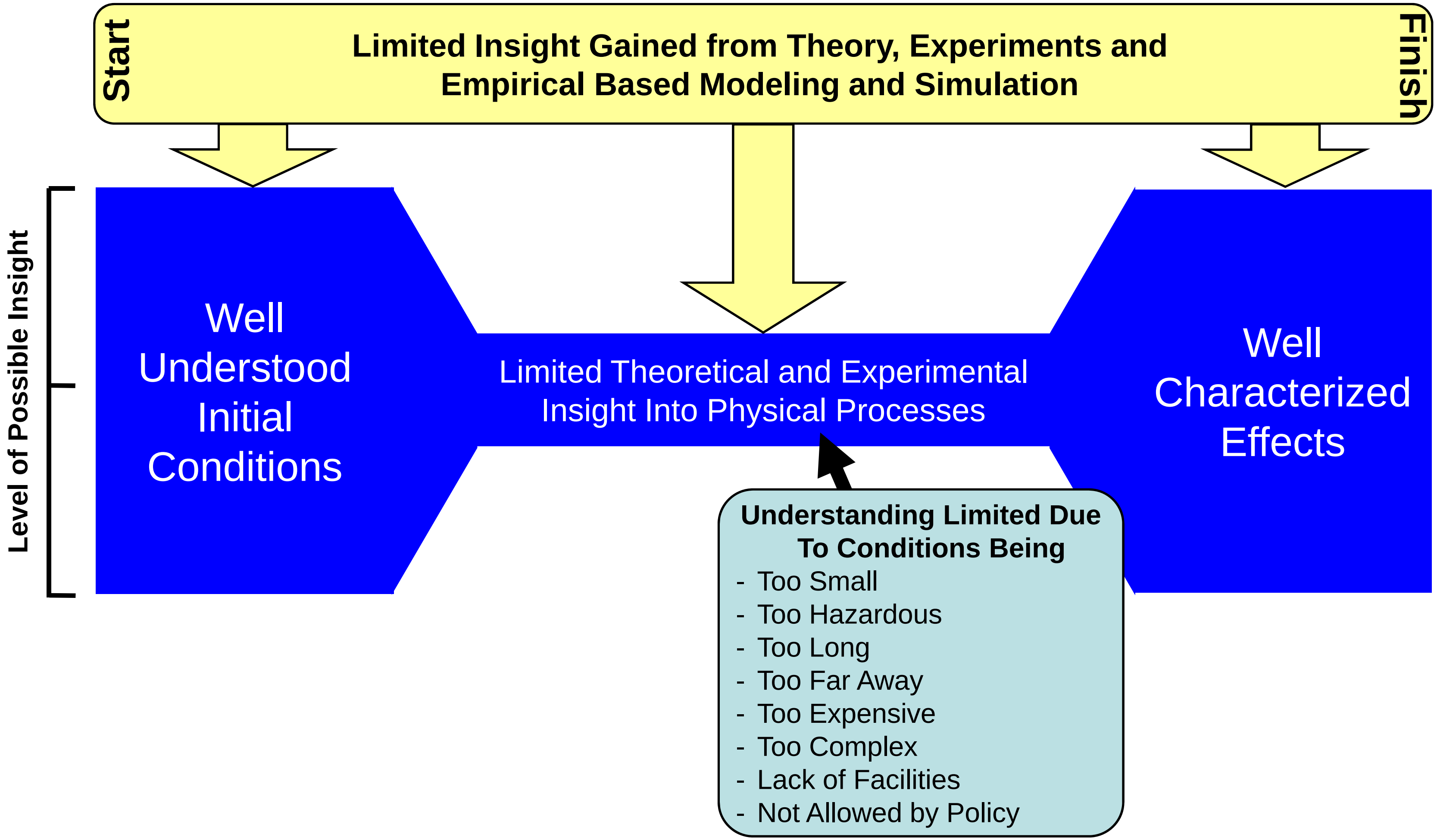


- **Traditional Science Approach**
  - Theory drives design of Experiments
  - Experiments provides discoveries to drive Theory
  - Empirically based modeling and simulation heavily dependent on staying close to experimental basis

- **Addition of Science Based Modeling and Simulation**
  - Science (1st principles) based modeling and simulation used to extrapolate and predict beyond tested states
  - Can quickly confirm or disprove Theory hypotheses
  - Improve experiments by predicting “areas of interest” and expected results

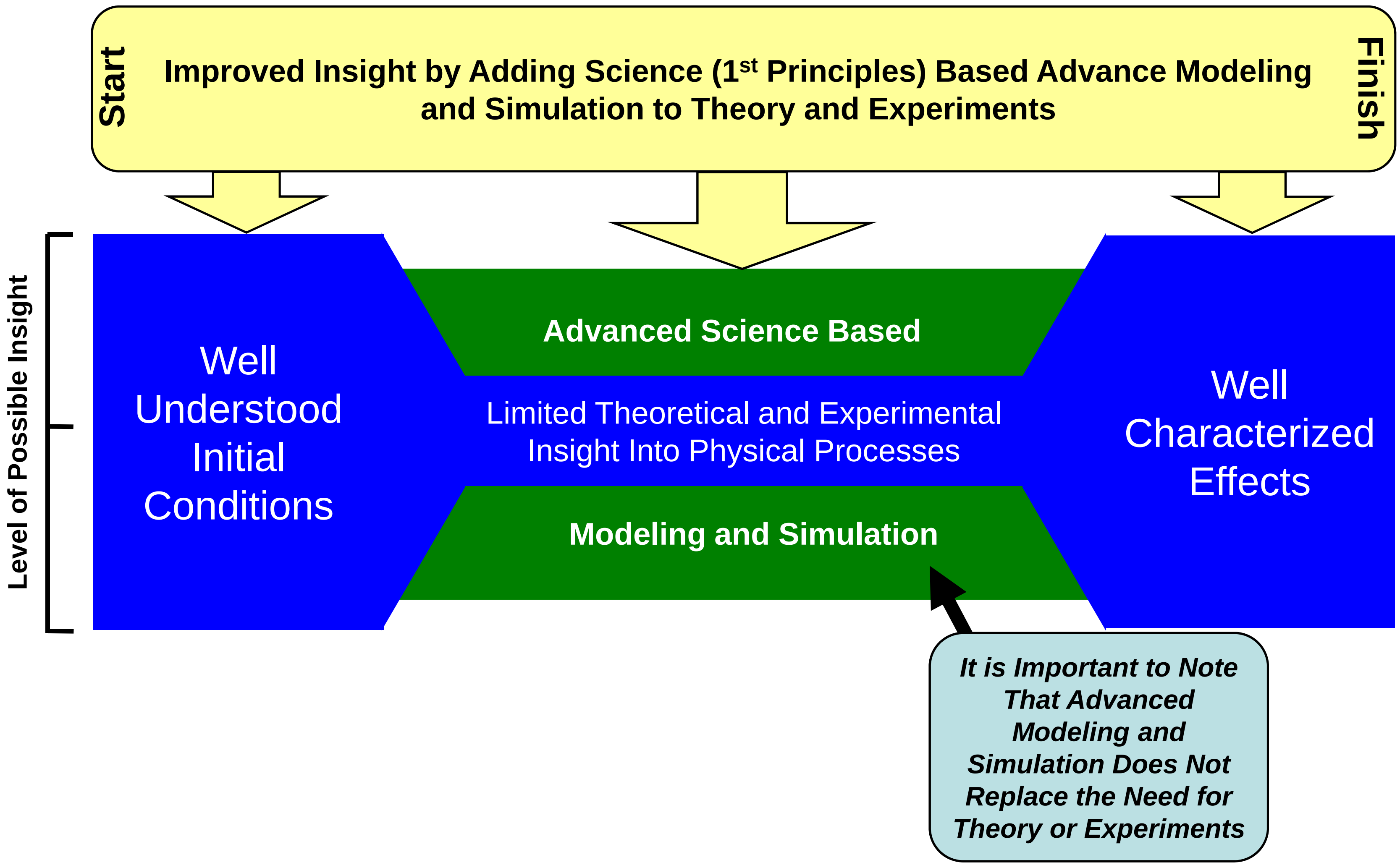
Why Step Up to New Methods of Gaining Insight?

Understanding of Complex Physical Process

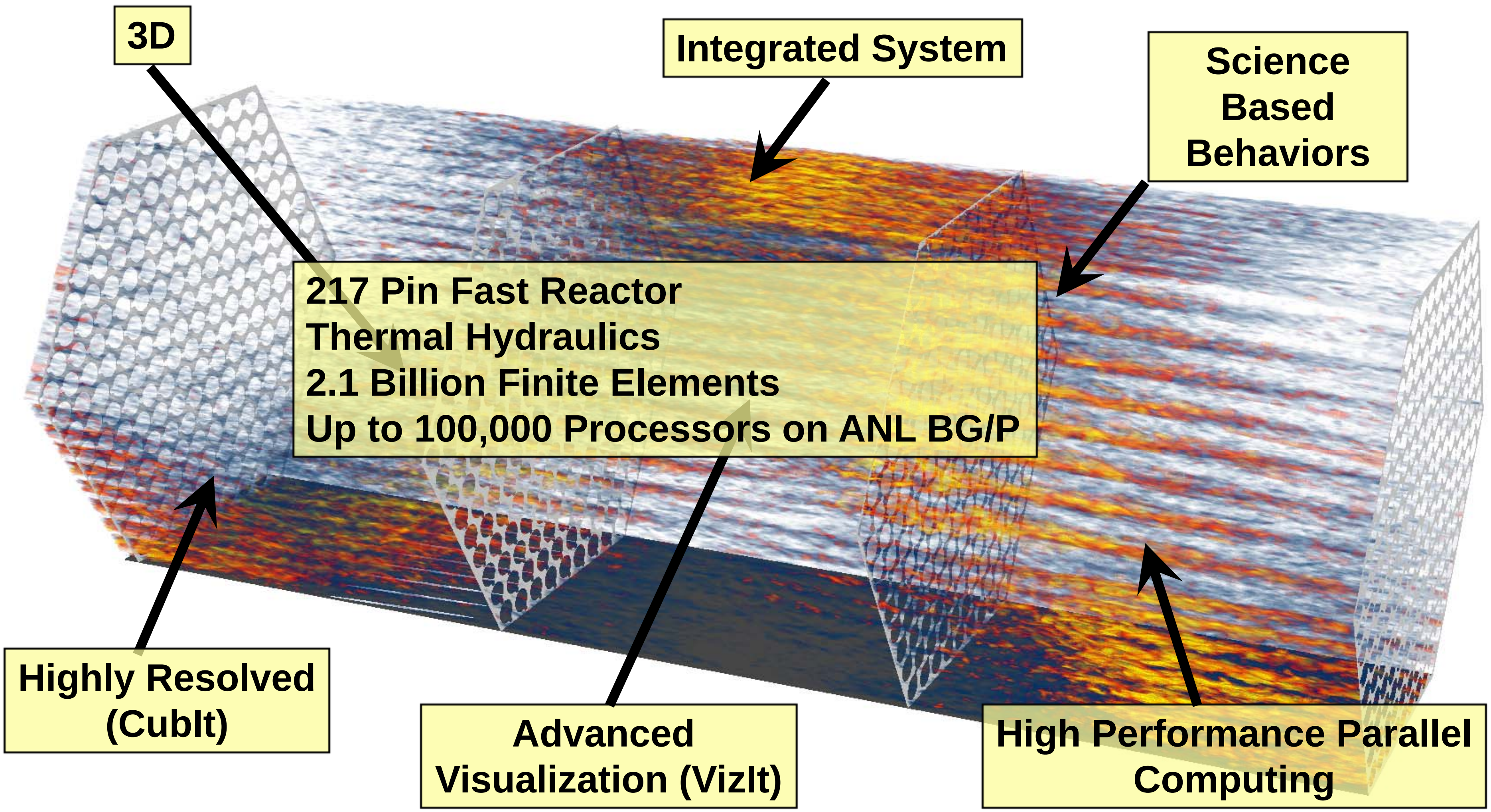


Supplements Theory and Experiment to Explain "How" Things Happened

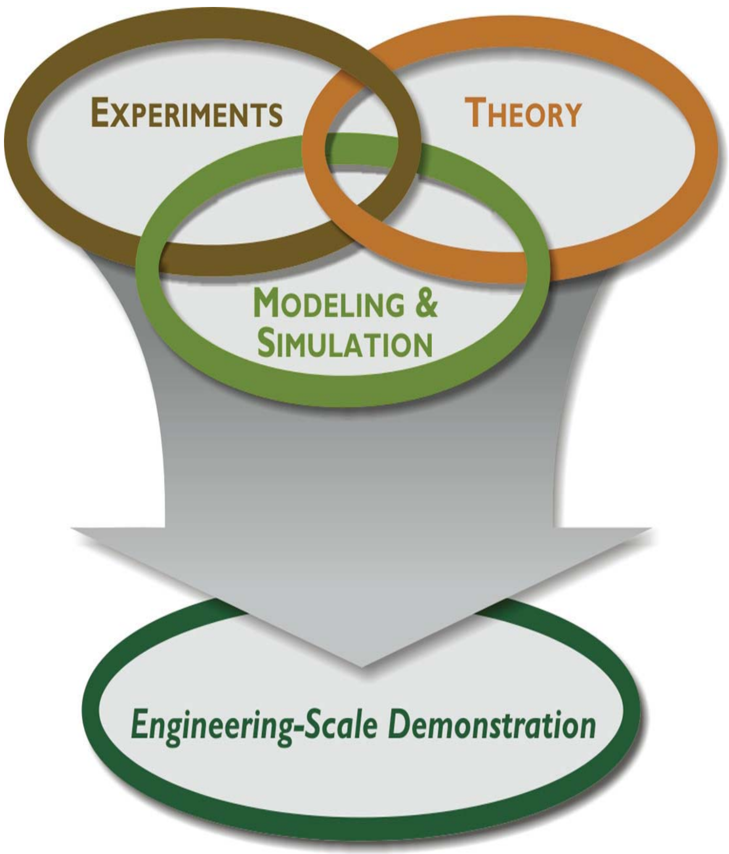
Understanding of Complex Physical Processes



What Does Simulation for Discovery Look Like?

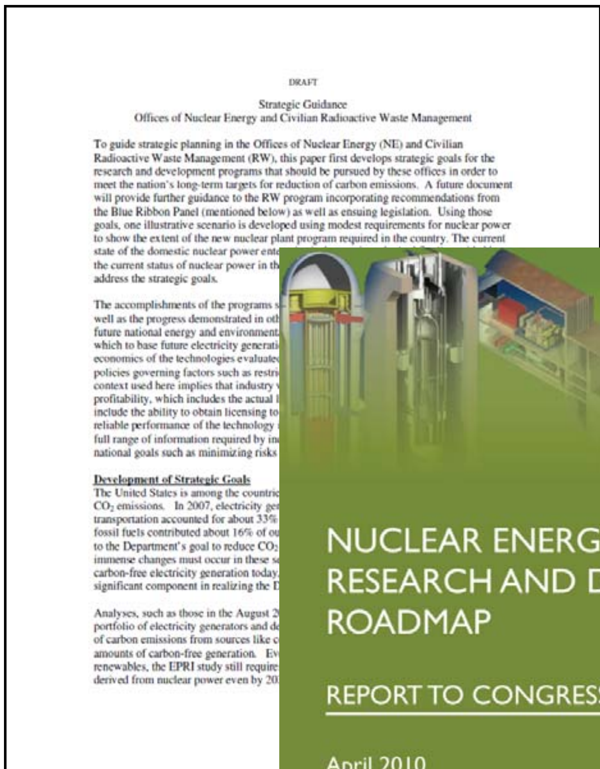


Advanced Modeling and Simulation has become an Essential Part of NE R&D



- ***R&D Objective 1*** – Develop technologies and other solutions that can improve the reliability, sustain the safety, and extend the life of current reactors.
- ***R&D Objective 2*** – Develop improvements in the affordability of new reactors to enable nuclear energy to help meet the Administration's energy security and climate change goals.
- ***R&D Objective 3*** – Develop sustainable nuclear fuel cycles.
- ***R&D Objective 4*** – Understand and minimize the risks of nuclear proliferation and terrorism.

Prominent in the Recent NE Report to Congress


DRAFT

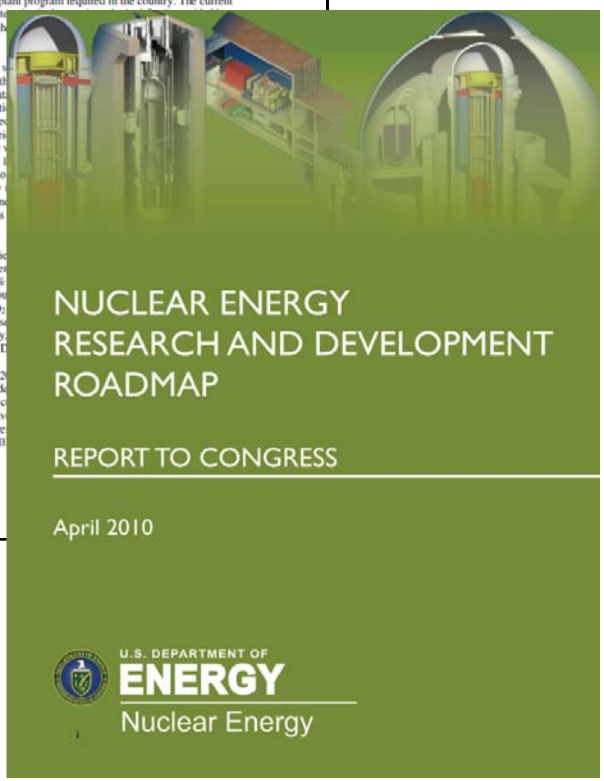
Strategic Guidance
Offices of Nuclear Energy and Civilian Radioactive Waste Management

To guide strategic planning in the Offices of Nuclear Energy (NE) and Civilian Radioactive Waste Management (RW), this paper first develops strategic goals for the research and development programs that should be pursued by these offices in order to meet the nation's long-term targets for reduction of carbon emissions. A future document will provide further guidance to the RW program incorporating recommendations from the Blue Ribbon Panel (mentioned below) as well as ensuing legislation. Using those goals, one illustrative scenario is developed using modest requirements for nuclear power to show the extent of the new nuclear plant program required in the country. The current
state of the domestic nuclear power ente
the current status of nuclear power in th
address the strategic goals.

The accomplishments of the programs s
well as the progress demonstrated in oth
future national energy and environment
which to base future electricity generati
economics of the technologies evaluate
policies governing factors such as restri
context used here implies that industry
profitability, which includes the actual
include the ability to obtain licensing to
reliable performance of the technology
full range of information required by in
national goals such as minimizing risks

Development of Strategic Goals
The United States is among the countri
CO_2 emissions. In 2007, electricity ge
transportation accounted for about 33%
fossil fuels contributed about 16% of ou
to the Department's goal to reduce CO_2
immense changes must occur in these s
carbon-free electricity generation today
significant component in realizing the D

Analyses, such as those in the August 2
portfolio of electricity generators and d
of carbon emissions from sources like c
amounts of carbon-free generation. Ev
renewables, the EPRI study still require
derived from nuclear power even by 20



- **Advanced Modeling and Simulation Tools –** Conduct R&D needed to create a new set of modeling and simulation capabilities that will be used to better understand the safety performance of the aging reactor fleet. These tools will be fully three-dimensional, high-resolution, modeling integrated systems based on first-principle physics. To accomplish this, the modeling and simulation capabilities will have to be run on modern, highly parallel processing computer architectures.

Roadmap Modeling and Simulation Deliverables

R&D Objective 1

- 2014 – State of the art predictive reactor core analysis capability
- 2019 – Performance models developed to enable applications for reactor life extensions
- 2019 – Fully-coupled safety analysis tools validated and issued to industry

R&D Objective 2

- 2015 – Complete 3-D high fidelity reactor core simulator
- 2015 – Demonstrate advanced modeling and simulation tool for SMR plant design, performance, and safety validation

R&D Objective 3

- 2015 – Development of a framework for advanced computational models for disposal system performance

R&D Objective 4

- 2020 – Test fully integrated advanced material measurement and information analysis systems

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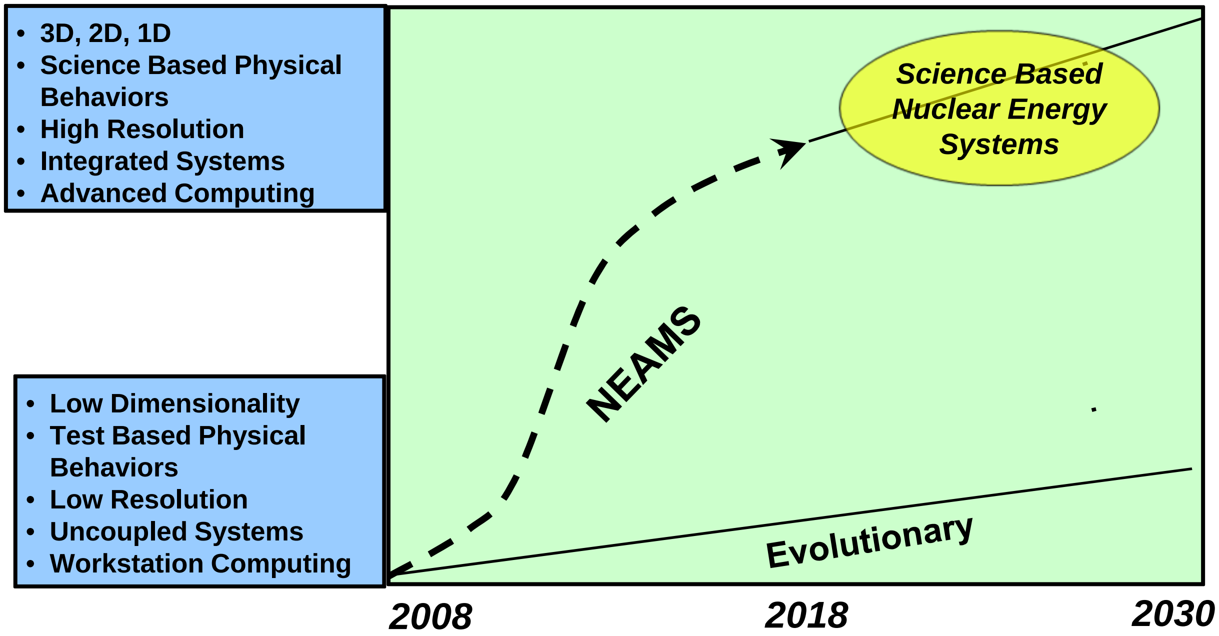
Nuclear Energy Advanced Modeling and Simulation (NEAMS)

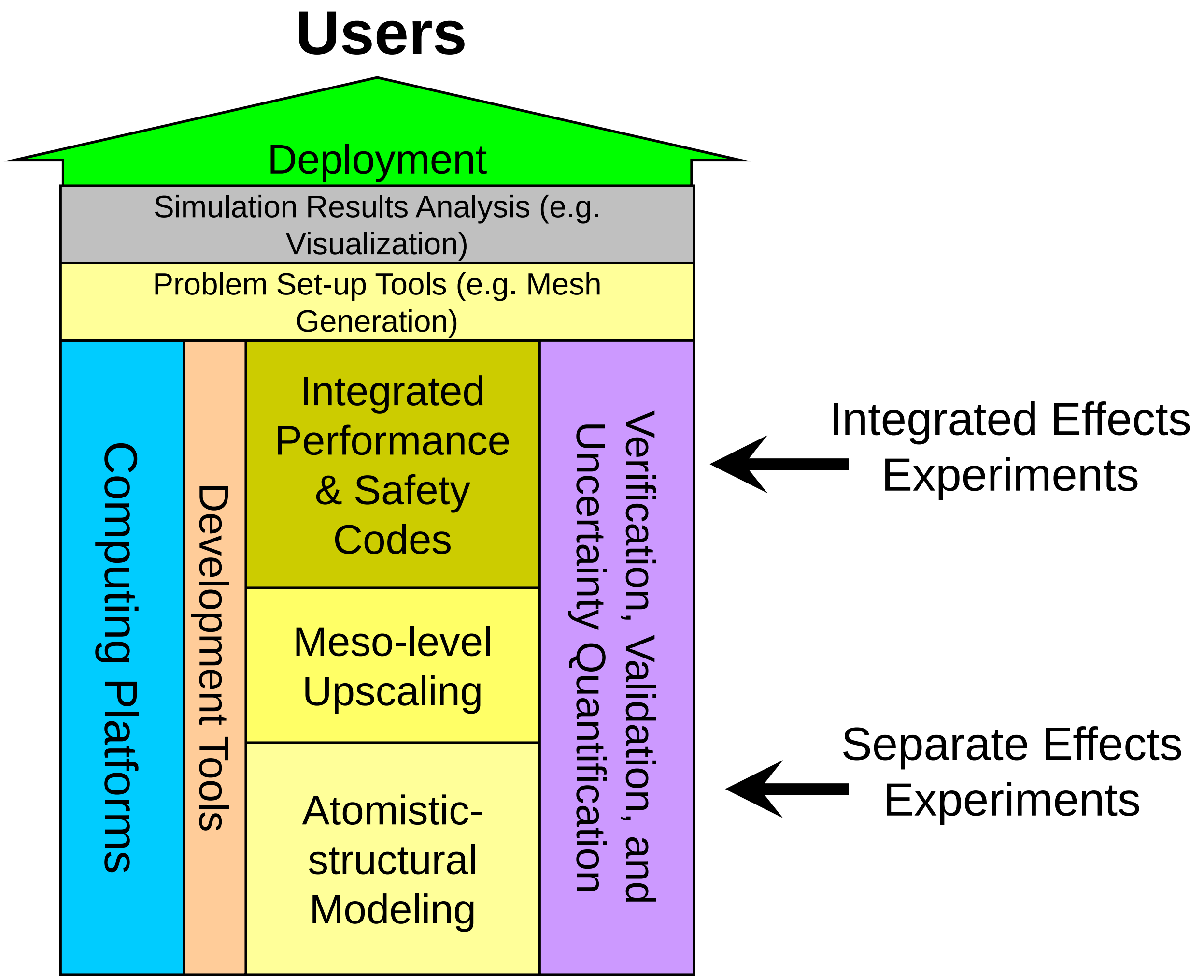
Vision

To rapidly create and deploy "science-based" verified and validated modeling and simulation capabilities essential for the design, implementation, and operation of future nuclear energy systems with the goal of improving U.S. energy security

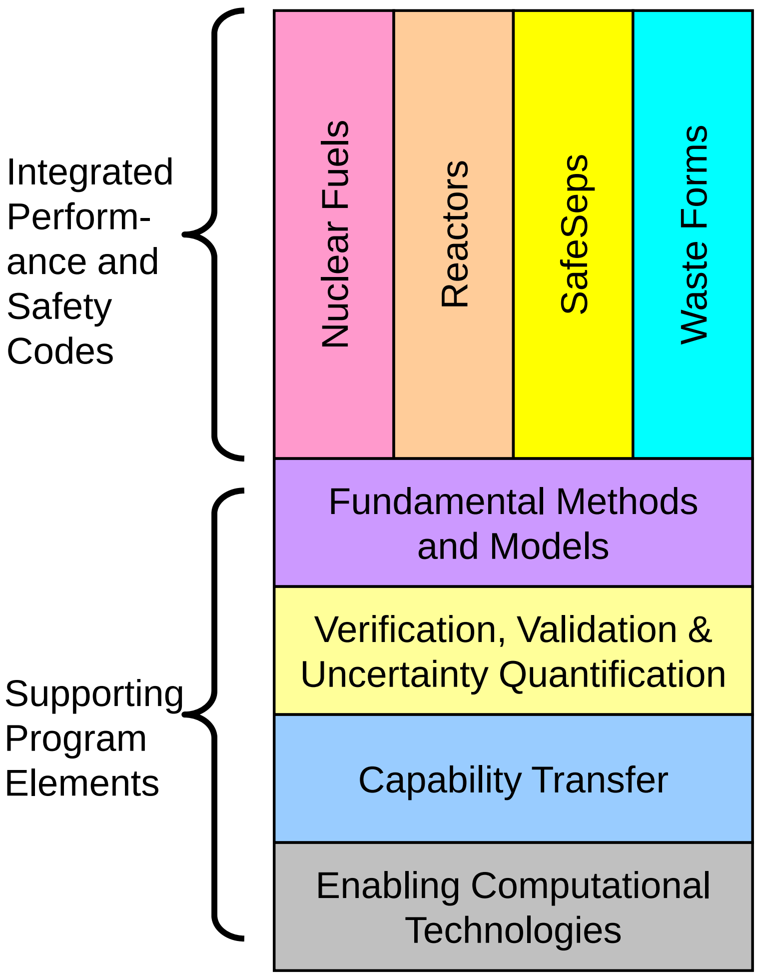


Anatomy of a Generic Program to Build Advanced Modeling and Simulation Capabilities

Note: An advanced modeling and simulation program does not have to build all of the elements. However, it must ensure that all of the elements exist and are integrated in order to build advanced capabilities



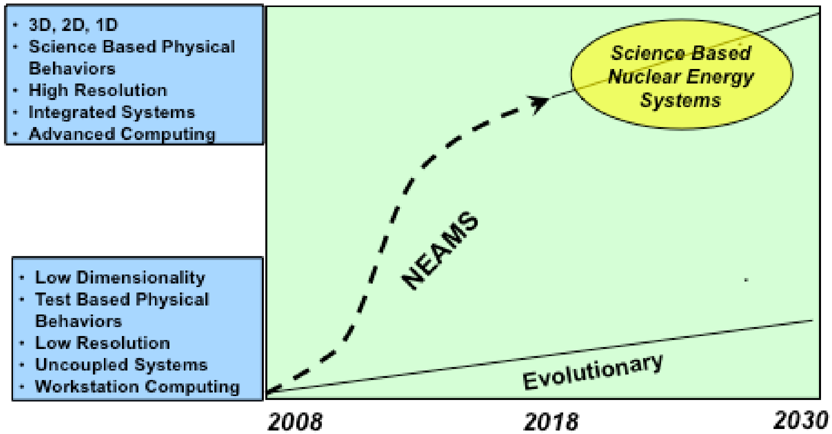
NEAMS Program Elements



- **Integrated Performance and Safety Codes (IPSC)**
  - Continuum level codes that will predict the performance and safety of nuclear energy systems technologies
  - Attributes include 3D, science based physics, high resolution, integrated systems
  - Large code teams (~25 people)
  - Single “center of gravity”
  - Long-term commitment (~10 years)
  - Codes “born” with verification, validation and uncertainty quantification
  - Using interoperability frameworks and modern software development techniques and tools
- **Program Support Elements**
  - Develop crosscutting (i.e. more than one IPSC) required capabilities
    - Fundamental Methods and Models
    - Verification, Validation and Uncertainty Quantification
    - Interoperability frameworks
    - Enabling Computational Technologies
  - Provide a single NEAMS point of contact for crosscutting requirements (e.g. experimental data, computer technologies)
  - Smaller, more diverse teams to include laboratories, universities and industries.
  - Shorter timelines

NEAMS Will Deliver . . .

- **Continuously increasing capability for predictive simulation of the performance and safety of:**
  - Nuclear reactors
  - Fuels
  - Safeguarded Separations
  - Waste Forms in a Repository Environment



- **These capabilities will be flexible so they can be applied to differeny types of nuclear energy technologies**

- **NEAMS will implement a comprehensive approach that ensures that new capabilities are fully developed and "born" with appropriate verification, validation and uncertainty quantification.**

- **Modeling and simulation capabilities that can be used to create scientific understanding, design, and license nuclear energy technologies for:**
  - Sustainment of the current LWR fleet
  - Near term deployment of new advanced reactors
  - Innovative uses of nuclear energy
  - Proper disposal of waste
  - Closing the fuel cycle

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NEAMS Users

- **Research and Development**
  - To make discoveries and obtain insight into the physical behavior of nuclear energy technologies (e.g. reactors, fuels, waste)

- **Technology Designers**
  - To conduct design studies for new nuclear energy technologies to understand performance, safety, and cost with the potential of a design of a system submitted for licensing.

- **Regulators**
  - To evaluate submitted designs and supporting analysis to determine if the technologies will meet the requirements to protect human health and the environment

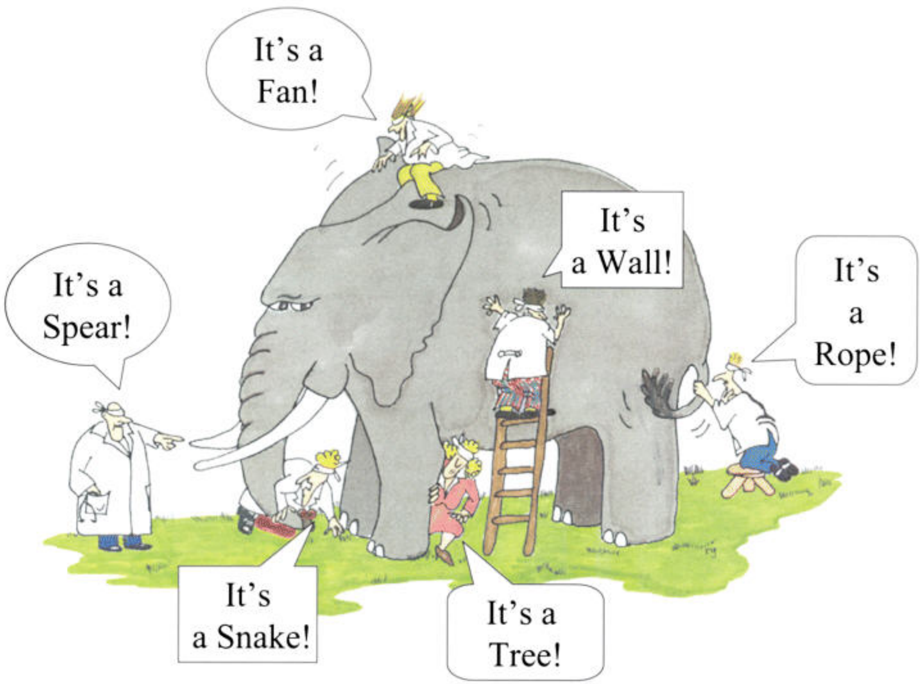
- **Utilities & Operators**
  - To understand and optimize the operations of nuclear energy technologies

NEAMS Has Assembled the "A" Team of Labs, Universities and Industry

- **Integrated Performance and Safety Codes**
  - Nuclear Fuels
    - LANL – lead
    - ORNL
    - LLNL
    - INL
    - Texas A&M
    - UC Davis
    - Oklahoma State
  - Reactors
    - ANL – lead
  - SafeSeps
    - LANL – lead
    - ORNL
    - ANL
    - SUNY Stonybrook
  - Waste
    - SNL – lead
    - LBNL
    - ANL

- **Supporting Program Elements**
  - Fundamental Methods and Models
    - PNNL – lead
    - SNL
    - ORNL
    - North Carolina State
    - Michigan
    - Nevada, Reno
    - Wisconsin
  - Verification, Validation and Uncertainty Quantification
    - INL – lead
    - SNL
    - LANL
    - University of Idaho
  - Capability Transfer
    - ORNL
    - ANL
    - IBM
  - Enabling Computational Technologies
    - LLNL

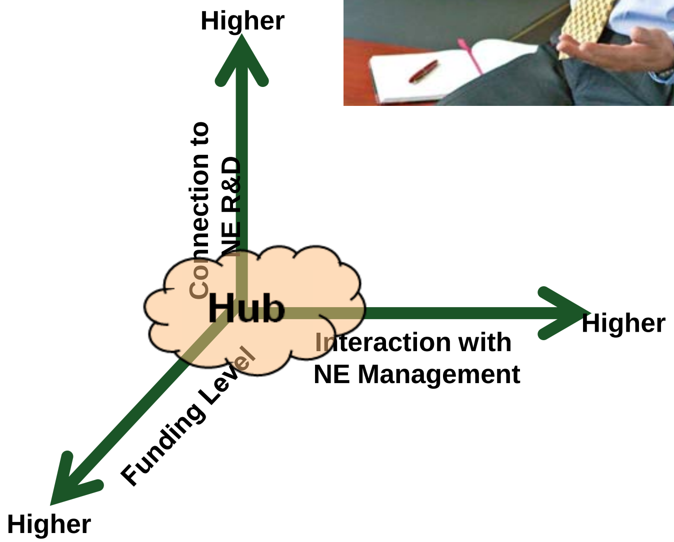
The Elephant in the Room is an Important Part of the Answer



- **The NE Modeling and Simulation Energy Innovation Hub**
- **What can we say?**
  - At this point – we can talk about things from the workshop and the FOA.
- **What we (specifically I) cannot say?**
  - Anything about about the details of the applications or the substance of the review process

Hub Characteristics

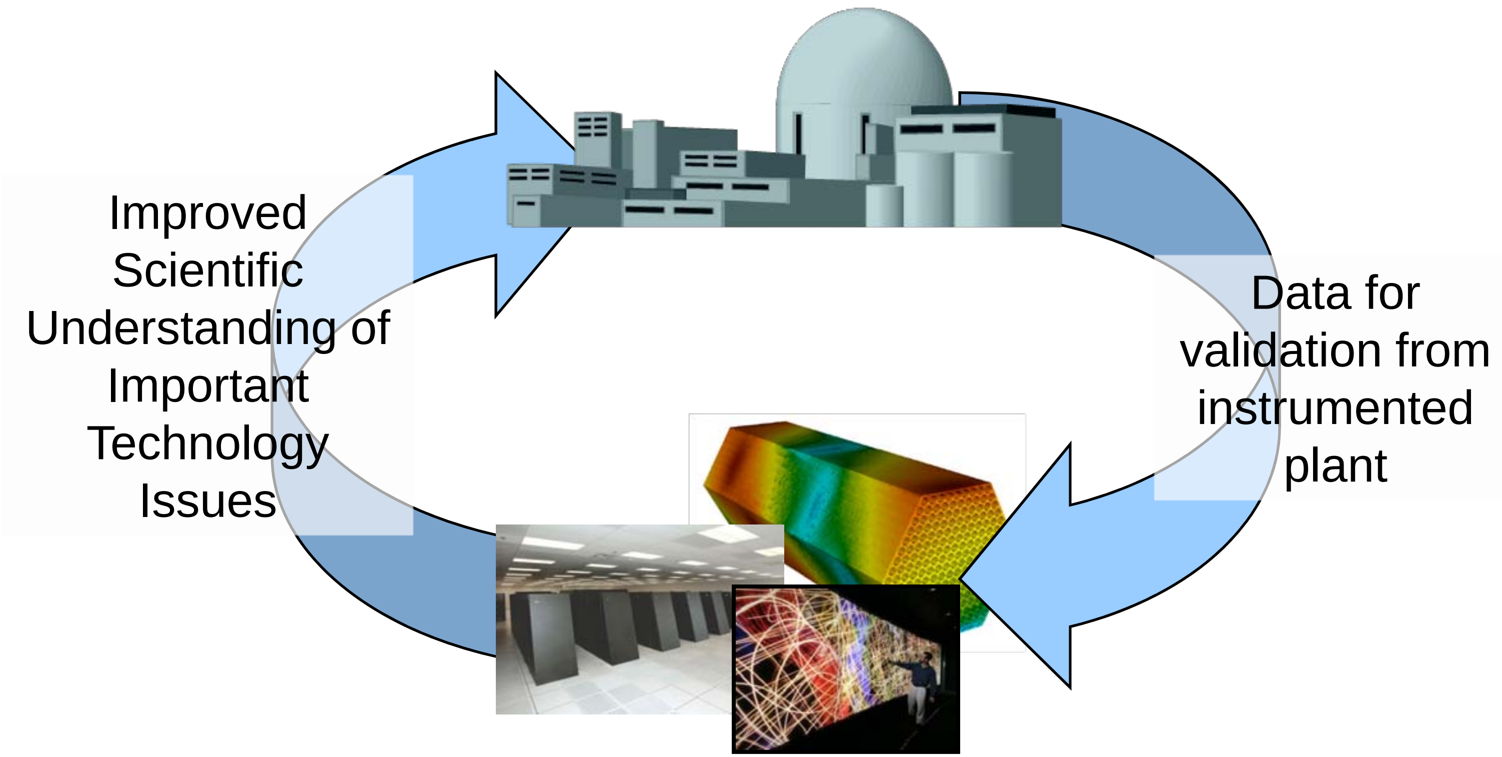
"The proposed Energy Innovation Hubs will take a very different approach – they will be multi-disciplinary, highly collaborative teams ideally working under one roof to solve priority technology challenges"



- **Leadership**
  - Outstanding scientist leaders who will have flexibility on a day-to-day basis to guide Hub activities
- **Connection to NE R&D**
  - Focused on a small range of important problems to maximize impact
- **Funding**
  - Lower ($25M per year for 5 years), but stable

Achieving the Promise of the Hub Requires a Mission Focus

Operating Reactor



Advanced Modeling and Simulation of the Operating Reactor
(aka “Virtual Reactor”)

Mutually Supportive Roles

- **Clearly the Hub**
  - Current LW Reactor Simulation
  - Current LW Reactor Fuels
  - Verification, Validation, and Uncertainty Quantification for the Above
  - Enabling Computational Technology (frameworks and user environments) for the Above
  - Capability Transfer
  - Fundamental Methods and Models for the Above?

- **Clearly NEAMS**
  - Safeguards and Separations IPSC
  - Waste and Repository IPSC
  - Advanced Reactors IPSC
  - Advanced Fuels IPSC
  - Fundamental Methods and Models for the Above
  - Verification, Validation, and Uncertainty Quantification for the Above
  - Enabling Computational Technology (frameworks and user environments) for the Above

Both are important, but neither are sufficient

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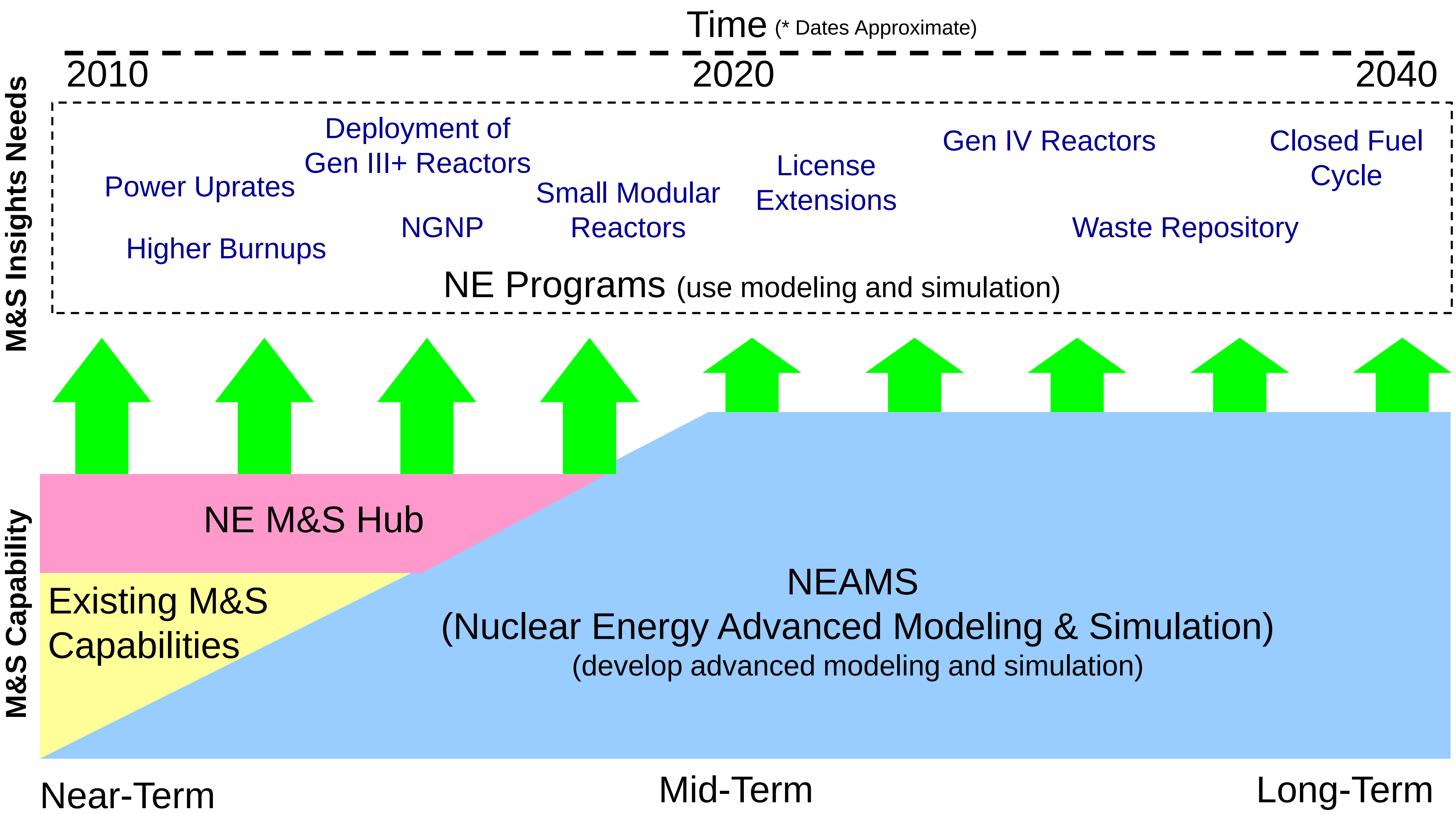
Putting it All Together NEAMS + Hub Are Important for Success



NEAMS and the Energy Innovation Hub Will Play Important Roles