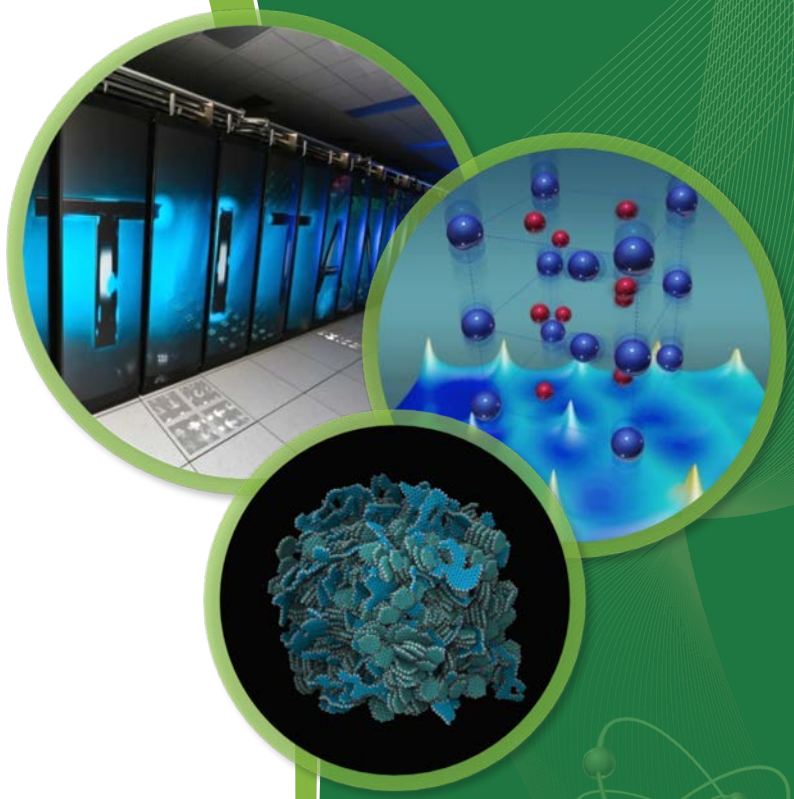
# Perspectives on Next Generation Critical Infrastructure

## Big Science Question

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Resilience Week 2016
Chicago, Illinois
August 16-18, 2016


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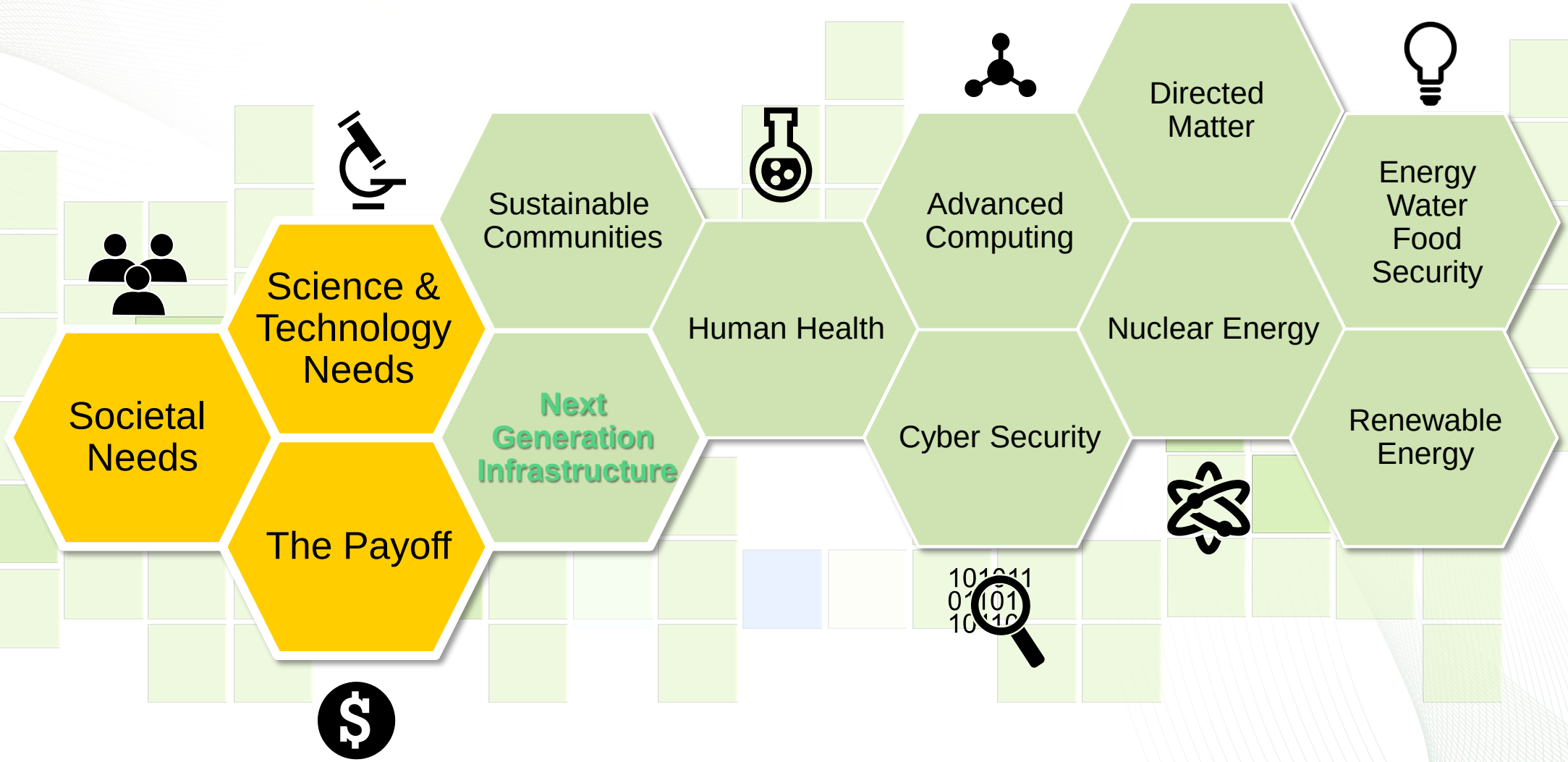
# A FEW BIG SCIENCE RESILIENCE PROBLEMS




NGI is prevalent to each of the 8 other resilience problems.



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# What are CI: The DHS National Infrastructure Protection Plan Defines the Nation's 16 Critical Infrastructure Sectors:

Life Line Sectors

- Energy
- Chemical
- Dams (Levees)
- Defense Industrial Base
- Public Health and Healthcare
- Communications
- Transportation Systems
- Water and Wastewater Systems
- Emergency Services
- Food and Agriculture
- Information Technology
- Critical Manufacturing
- Government Facilities
- Nuclear Reactors, Materials and Waste
- Banking and Finance
- Commercial Facilities
- National Monuments and Icons
- Postal and Shipping

Not Included in NIPP

Our national well-being relies upon secure and resilient critical infrastructures – those assets, systems, and networks that underpin American society.

Executive Summary, National Infrastructure Protection Plan (Partnering for Critical Infrastructure Security and Resilience), December 2013

Presidential Proclamation 21 for Critical Infrastructure Security and Resilience (PPD-21) emphasizes CI security and resilience as a national security priority.



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# Challenges Facing the Resilience of CI: Complex and Complicated

The nation's CI are tasked to operate and perform in the 21st century beyond their 20th century design and capacity.


S & T Challenges

- Ecosystem Genomics (Aging & Mapping)
- Metrics
- Scale
- Risk Management
- Physical & Cyber Threats/Hazards

Other Challenges

- Rhetoric / Language
- Incentives
- Culture
- Policies
- R&D Funding

***The Nation's critical infrastructure is diverse and complex. It includes distributed networks, varied organizational structures and operating models (including multinational ownership), interdependent functions and systems in both the physical space and cyberspace, and governance constructs that involve multi-level authorities, responsibilities, and regulations.***

**PPD-21 (February 12, 2013)**



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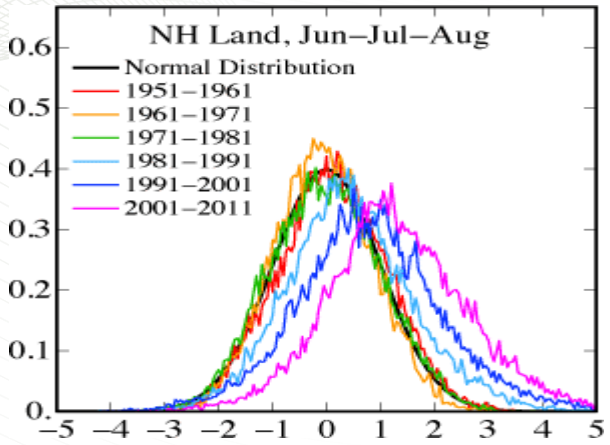
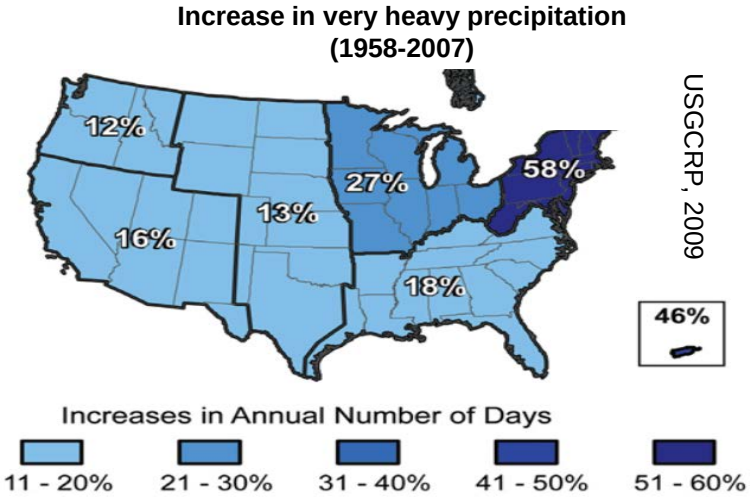
# Typical Example of S&T Challenge: Climate and Extreme Weather

## Extreme Heat

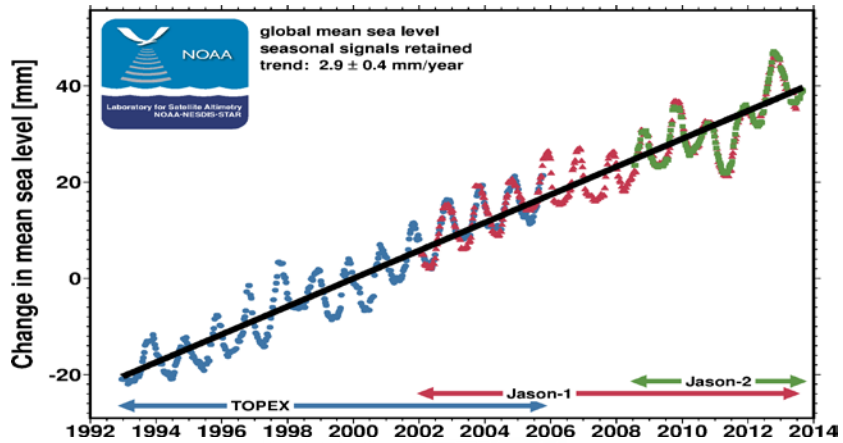



Hansen et al. (*PNAS*, 2012)

## Heavy Precipitation

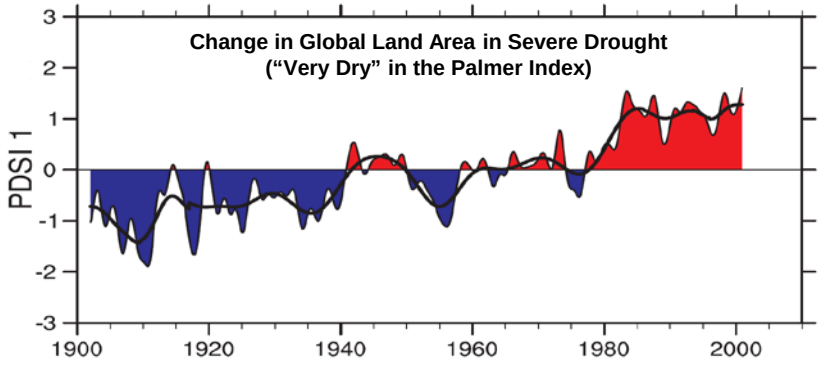



## Sea Level Rise



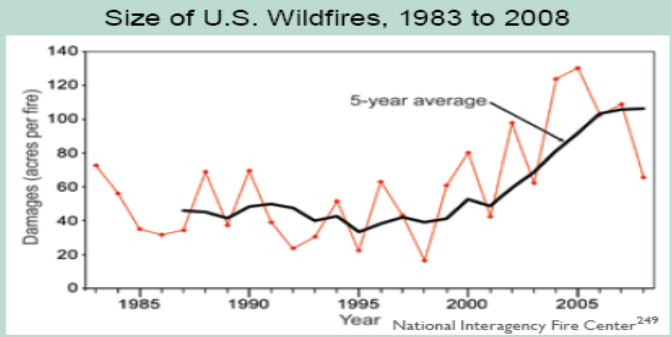

## Coastal Vulnerability


## Increasing Drought




Dai, et al. (2004) *J. Hydromet.*

## Wildfire Trend




Data on wildland fires in the United States show that the number of acres burned per fire has increased since the 1980s.

**There is a need to understand the impacts to critical infrastructures for all extreme events.**



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# NGI BSQ: How can we transform infrastructures to connect urban environments and produce sustainable communities that are resilient to all-hazards and to emerging threats?

**Key Requirements**

## Functionality

- Secure
- Resilient
- Sustainable
- Self-healing
- Intelligent
- Integrated systems and supply chain
- Situational awareness
- Adaptable to rapidly changing conditions (loads, global threats, etc.)
- Efficient and effective energy functions

**S &T Capabilities**

## Technical Resources

- Advanced materials and manufacturing
- Autonomous and advanced controls
- Data science engineering
- Computational science and engineering
- Large scale systems engineering
- Sensing
- Machine learning
- Urban Planning

**Strategic Partnerships**

## Stakeholders

- Private sector (e.g., infrastructure owners and operators)
- Government (local, state, federal)
- Universities
- Regional alliances

**Subject Matter Experts**

## New Career Paradigm

- CI science
- CI scientists
- CI technologists
- CI degrees
- CI certifications
- CI domain experts

**Specialized RDT&E Facilities**

## National Investment

- Technology development and assessments
- Extreme events test facilities
- Product testing and evaluation

**THE PAYOFF:** NGI systems that are adaptable to population growth, reduced GHG emissions, and diverse **global** threats.



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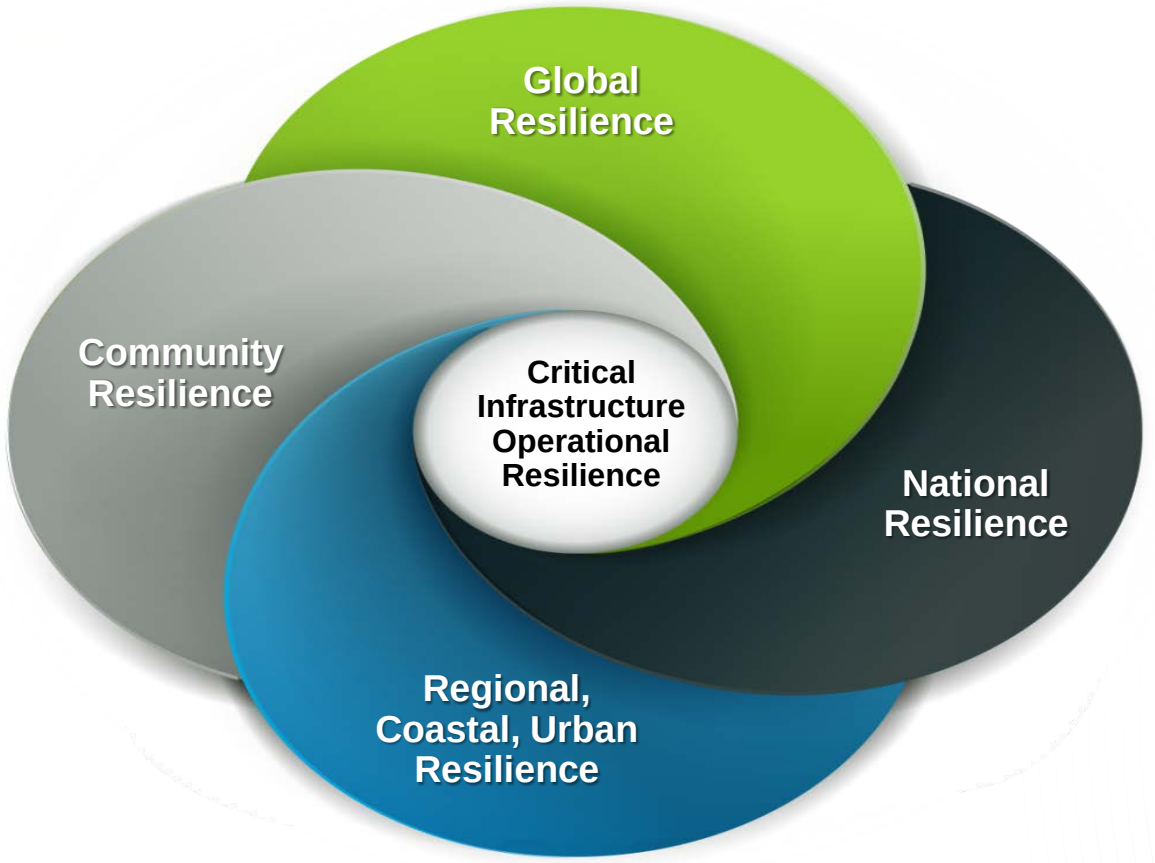
# Improving Critical Infrastructure Operational Resilience Is Complex And Complicated

RESILIENCE FACTORS
- Threats
- Awareness
- Geography
- Mitigation Measures




RESILIENCE TRADITIONAL COMPONENTS
- Robustness
- Redundancy
- Resourcefulness
- Response
- Recovery

RESILIENCE PRINCIPLES
- Capacity
- Flexibility
- Tolerance
- Cohesion

RESILIENCE SUBSYSTEMS
- Economic
- Environmental
- Governance
- Infrastructure
- Social

A PERSPECTIVE: CI OPERATIONAL RESILIENCE SHOULD BE REGARDED AS A **BIG DATA PROBLEM** WITH MULTI-DIMENSIONAL INTERDISCIPLINARY SOLUTIONS WHICH REQUIRE PUBLIC-PRIVATE PARTNERSHIPS.



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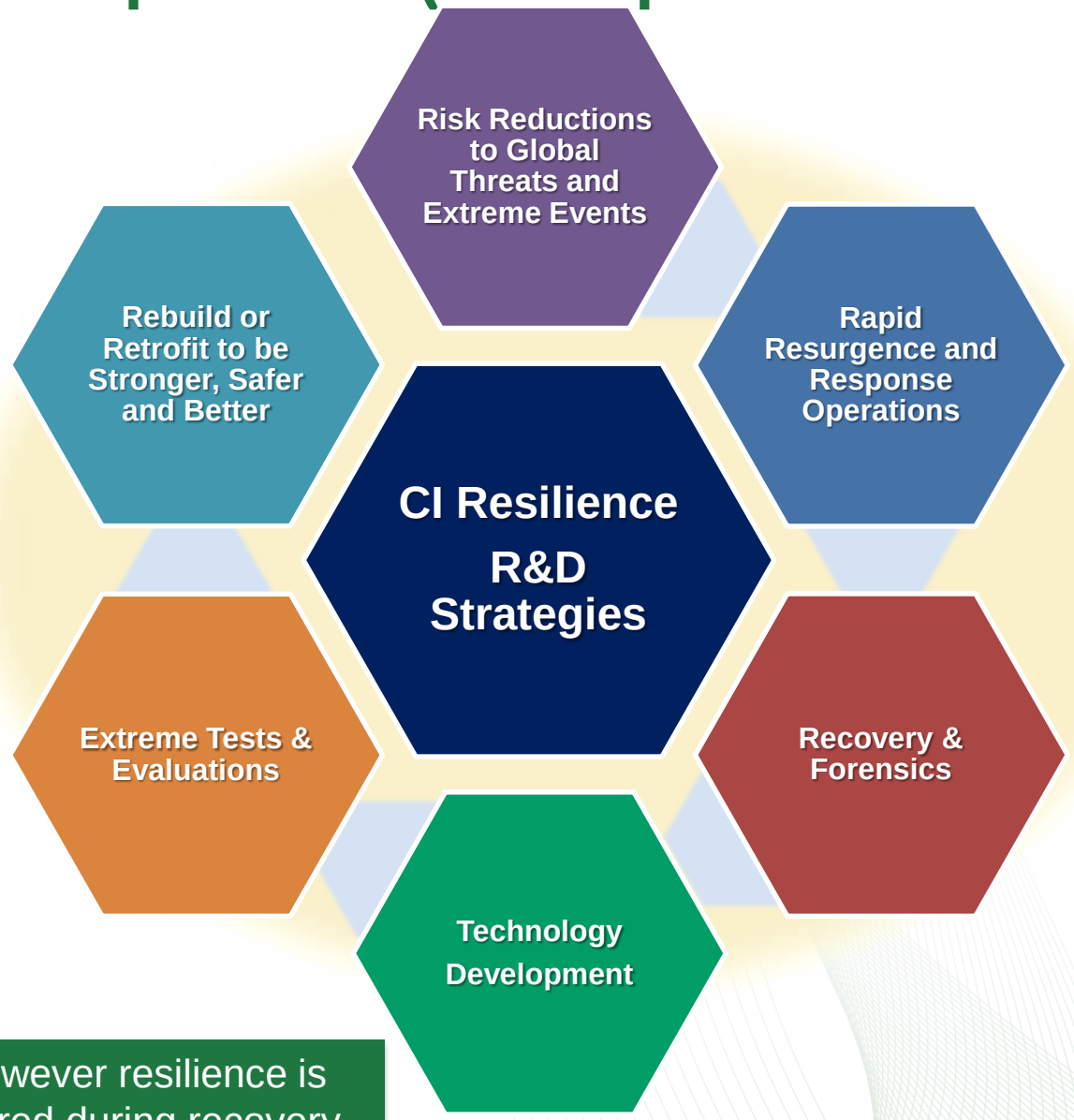
# Perspective: CI Resilience R&D Components (A Simple Framework)

- **R**isk Reduction
- **E**mergency Operations
- **S**tandards (Policies) Based on Scientific Evidence (Including Social Sciences)
- **I**nfrastructure Continuity of Operations
- **L**arge Systems Analyses & Interdependencies
- **I**ntelligence (Smart Devices, Sensors & Machine Learning)
- **E**nvironmental and Economic Resurgence
- **N**ovel (Unfamiliar, Irregular, Unusual) Threats
- **C**ommon Catastrophic Threats (Cyber, CBRNE, Climate)
- **E**xtreme Testing & Evaluation




NOTE: Resilience in any area may be assumed by design. However resilience is only tested or proven during an attack, and is likely best measured during recovery.



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# A Perspective: Improving Critical Infrastructure Operational Resilience May Require The Nation Establish A Disaster Research National Laboratory

- Specialized R&D that integrates broad-based S&T is critical to the design and resiliency of next generation CI.
- A new paradigm for materials should be developed to allow materials to “wisely” adjust their functions based on their environments.
- Facilities are needed to test/evaluate CIs and technologies under extreme conditions.
- HPC capabilities are needed to model CIs as networks of ecosystems or as genomic specimen.
- Big data analytics allows for better understanding of the interdependencies among CIs and cascading impacts upon failure.
- Key R&D objectives for CI operational resilience may include:
  - Advancing the science to develop improved metrics and better policies for critical infrastructure resilience.
  - Developing a customizable framework for critical infrastructure resilience.
  - Engineering resilience products that are scalable or customizable for urban, regional (including coastal), national, and global resilience.
  - Building scalable tools and frameworks for urban, regional, national and global resilience.

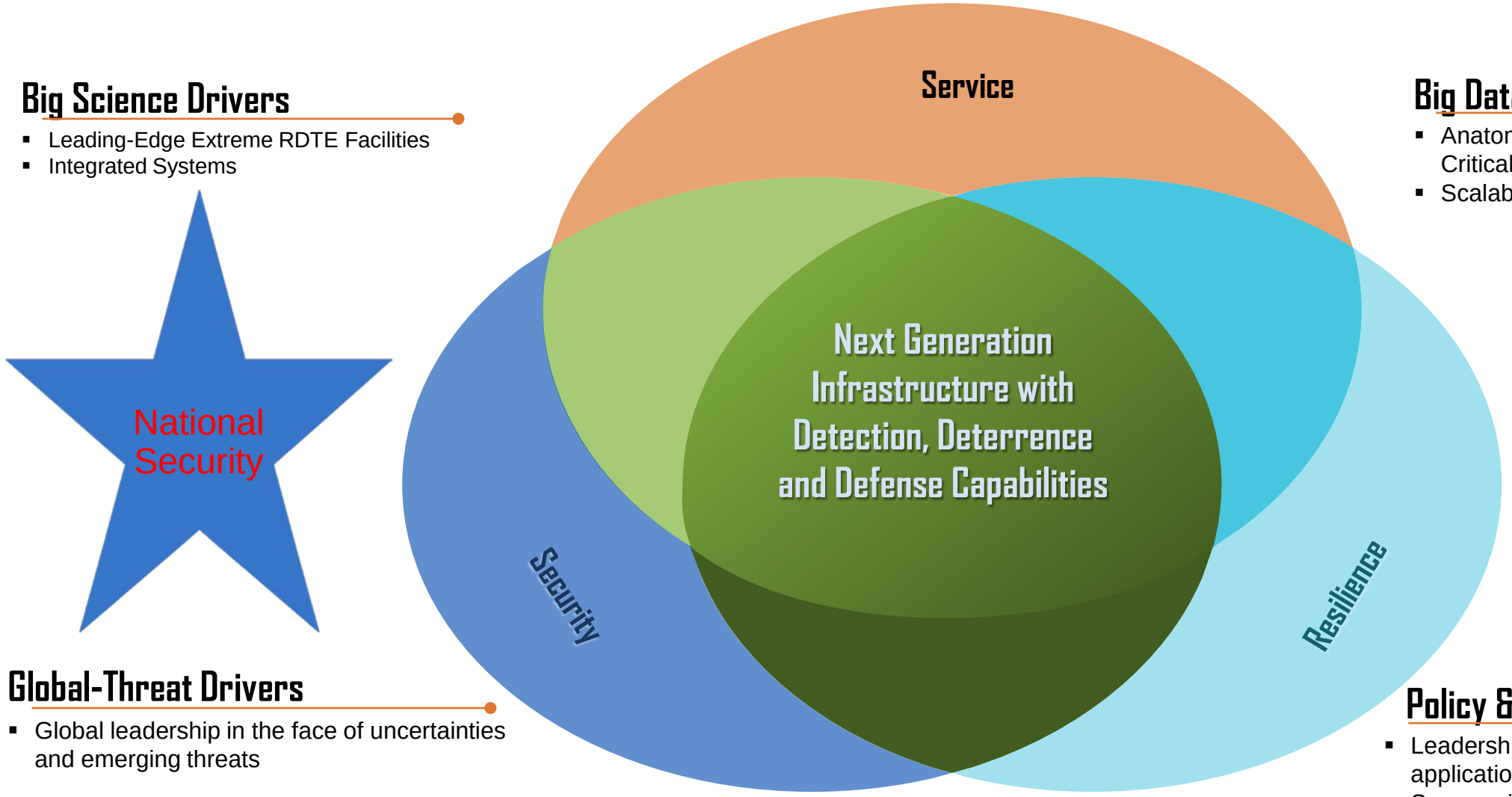
# A Perspective on Today's Vital NGI Need: Establishing the Long-Term International Infrastructure Leadership Strategy

## Big Science Drivers

- Leading-Edge Extreme RDTE Facilities
- Integrated Systems

## Big Data Drivers

- Anatomical Structure of the Nation's Critical Infrastructure
- Scalable Models




## Global-Threat Drivers

- Global leadership in the face of uncertainties and emerging threats

## Policy & Economic Drivers

- Leadership in translating science to application to policy
- Success in innovation and technology transfer

**Designing the NGI to detect, deter, and defend against existing and emerging threats is an opportunity and a challenge for science.**

# One Vision of a Sustainable Community Embedded with NGI

## Green Intelligent Buildings

- Commercial and residential integration
- Envelopes
- Appliances
- Cool roofs



## Industrial

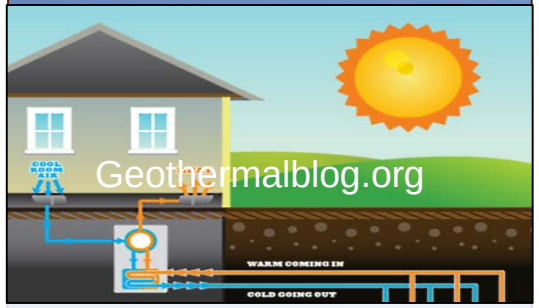
- High efficient processes
- Advanced Manufacturing

## Smart Grid

- Situational awareness
- Advanced communications and controls
- Energy storage

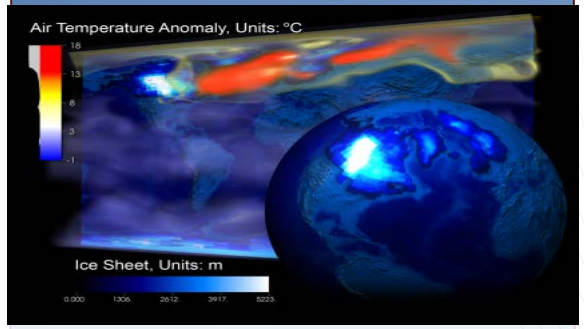

## Renewables

- Bioenergy
- Solar
- Geothermal systems
- Wind




## Climate and Sustainability

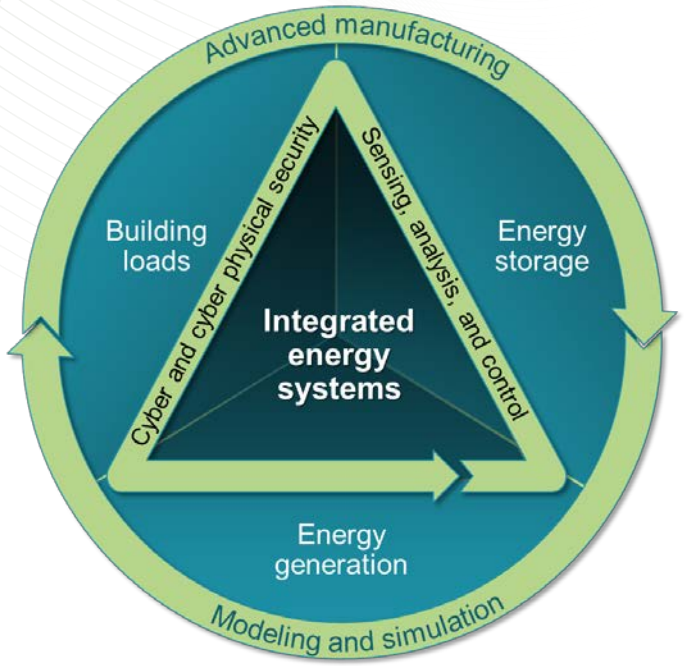
- Large scale environmental experiments
- Climate modeling

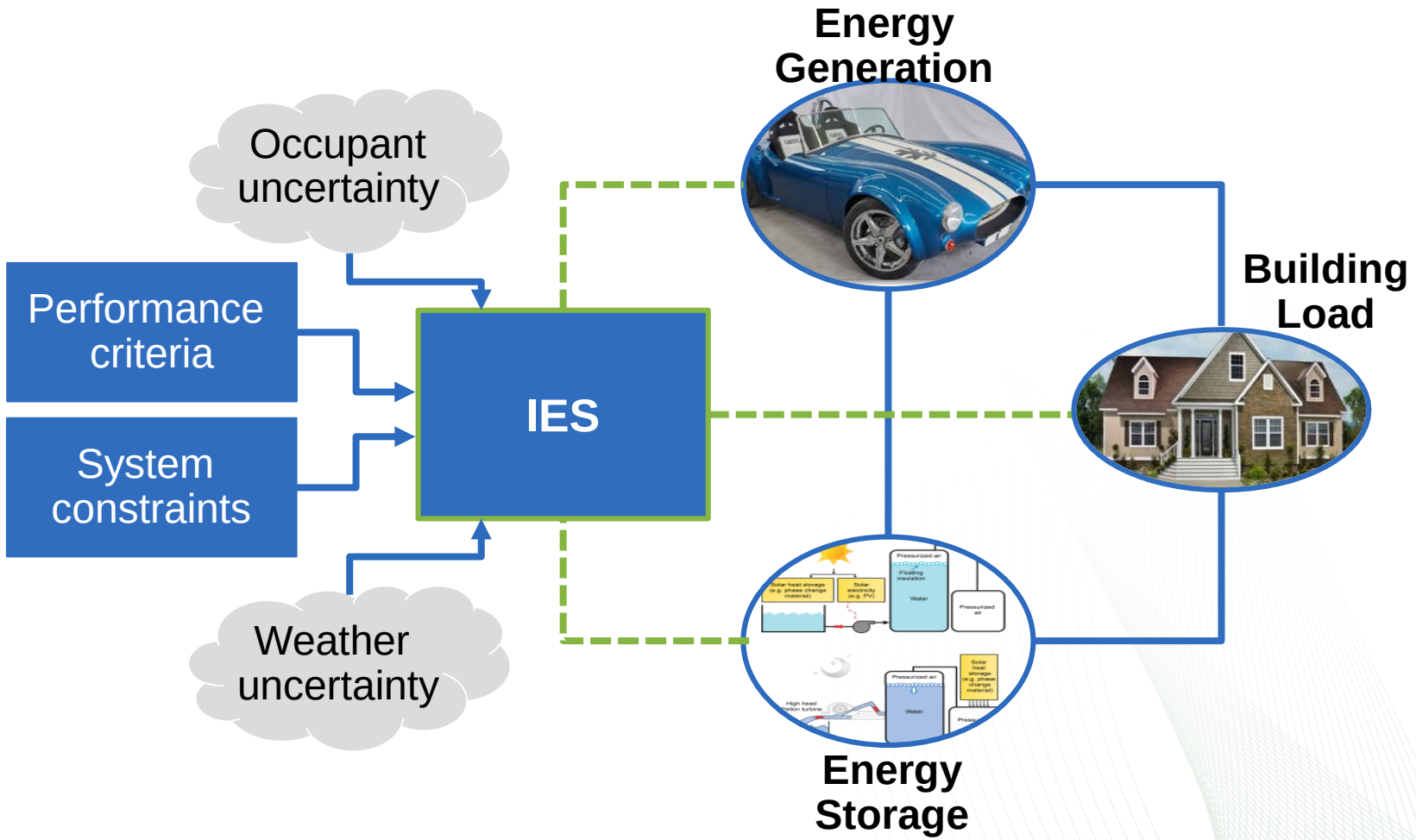



## Intelligent Transportation Systems

- Integrated land use planning
- Public transit friendly
- Alternate mobility choices (incl. freight)
- Clean fuels
- Intelligent vehicles and infrastructure

# A concept for NGI with integrated energy systems that control building loads and energy generation and storage



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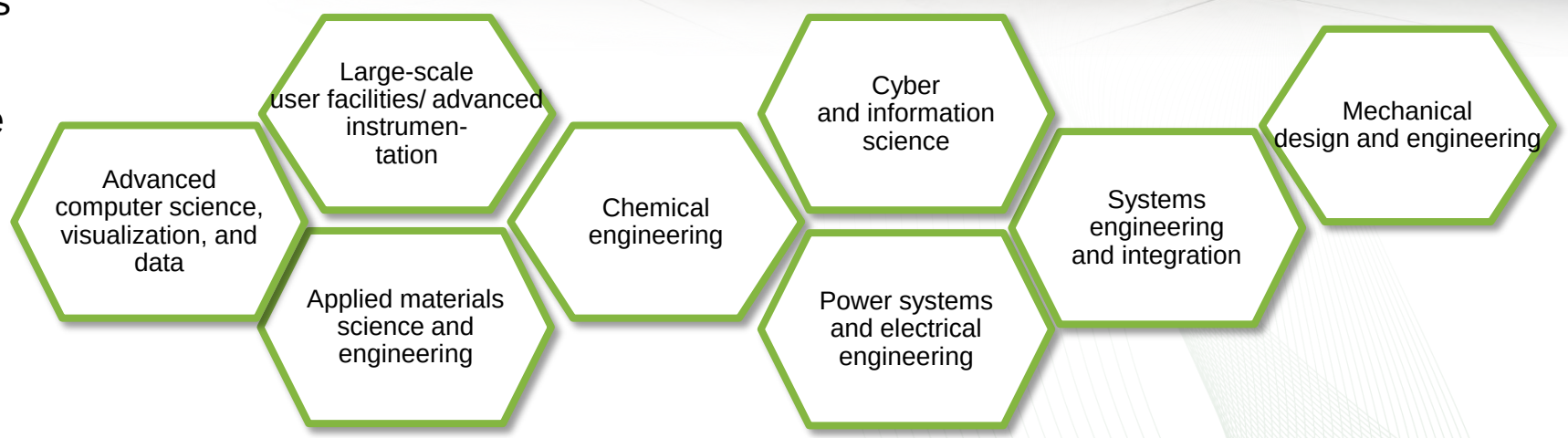
# Additive Manufacturing Integrated Energy (AMIE): Towards development and demonstration of an innovative integrated energy system (a typical example of NGI)

- Additive manufacturing at DOE's Manufacturing Demonstration Facility
  - 3D-printed high-performance building, incorporating low-cost vacuum insulated panels
  - 3D-printed hybrid electric vehicle, powered by natural gas
- Bidirectional wireless transfer of power between building and vehicle
- Advanced building control and power management strategies
- Partnerships with industry to ensure development of market-appropriate solutions



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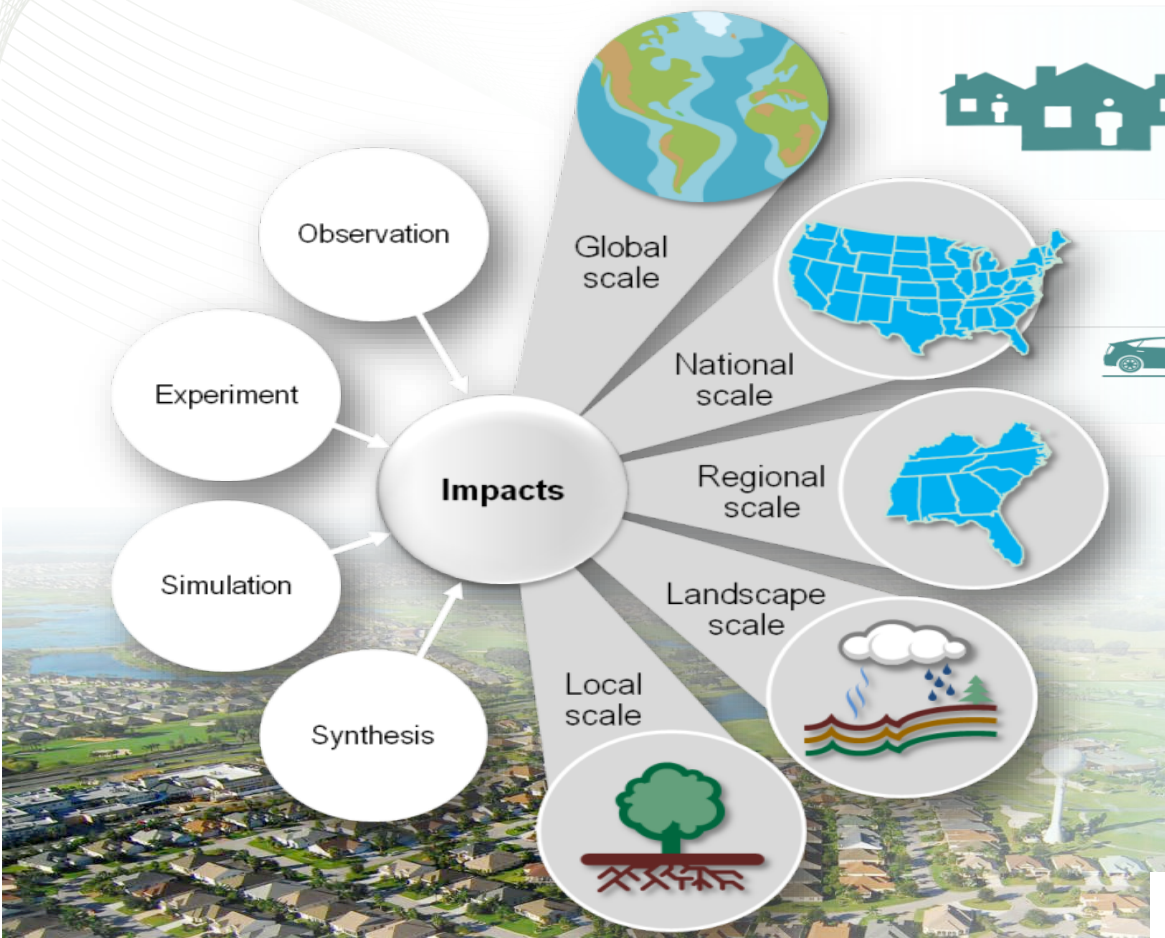
# Implementing the NGI Perhaps Requires Holistic Thinking

Including understanding and optimizing the impact of future technologies, policies, and populations




**Population and land use**
Distribution/dynamics,
land use change, citizen science

**Sustainable mobility**
Connected vehicles,
driver assistance systems, safety

**Water and energy**
Efficiency, pollution, sustainability

**Urban resiliency**
Cybersecurity, communication,
disaster management

The term "**holistic thinking**" refers to a big picture mentality in which a person recognizes the interconnectedness of various elements that form larger systems, patterns and objects. **Thinking holistically** is the opposite of analyzing something, which involves breaking down a larger system into its details. ***Holism*** (from Greek ὅλος holos "all, whole, entire") is the idea that systems (physical, biological, chemical, social, economic, mental, linguistic, etc.) and their properties should be viewed as wholes, not as collections of parts.

**Summary:** Developing the NGI which have high levels of efficiency, resiliency, stability and economic benefit is an imperative and will help the nation realize the international call for innovation in clean energy technologies and systems.


# Questions



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