Modeling Creep-Fatigue-Environment Interactions in Steam Turbine Rotor Materials for Advanced Ultrasupercritical Coal Power Plants

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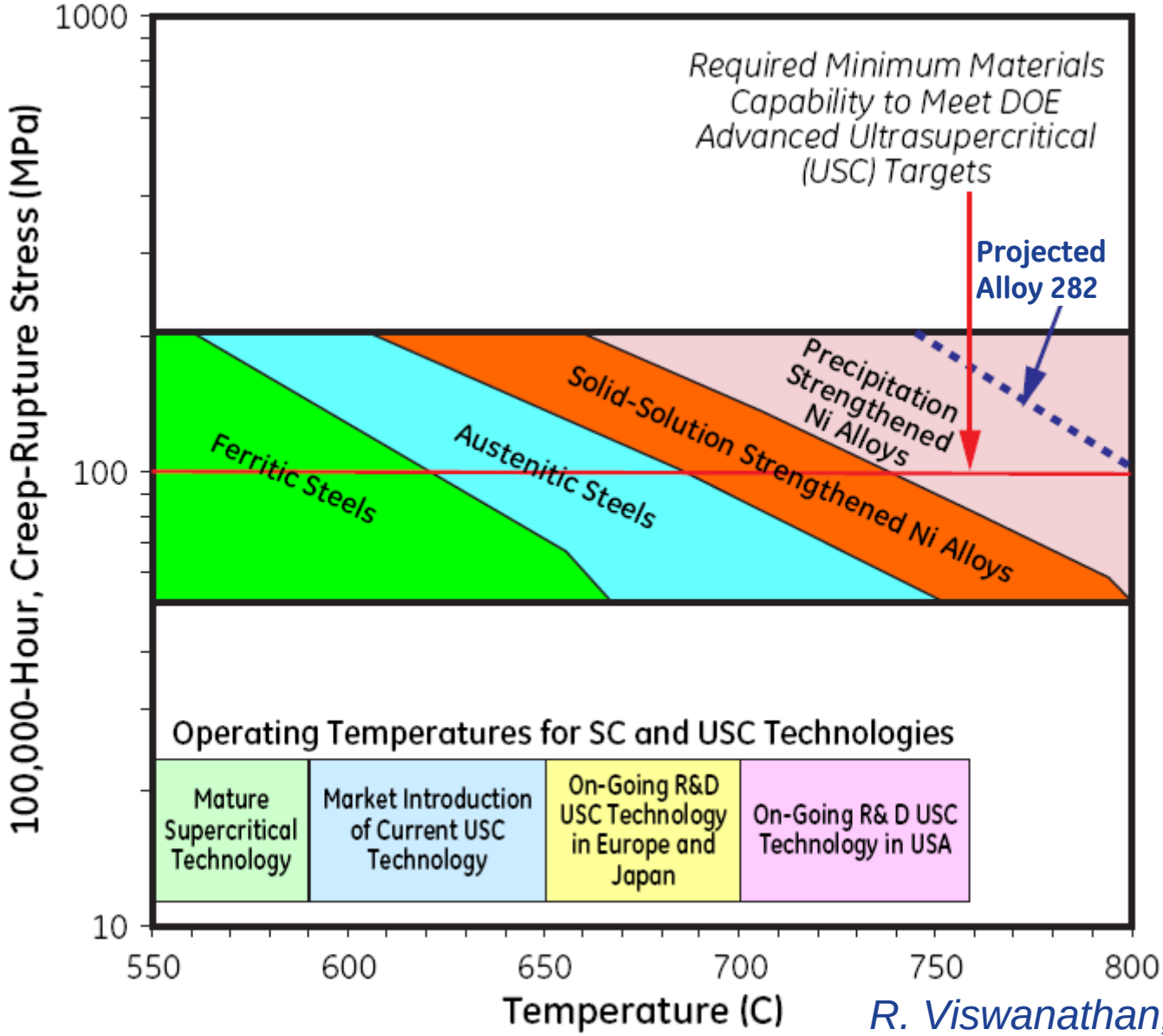
Outline

1. Technical background of the project
2. Project objective
3. Technical approach
4. Project status

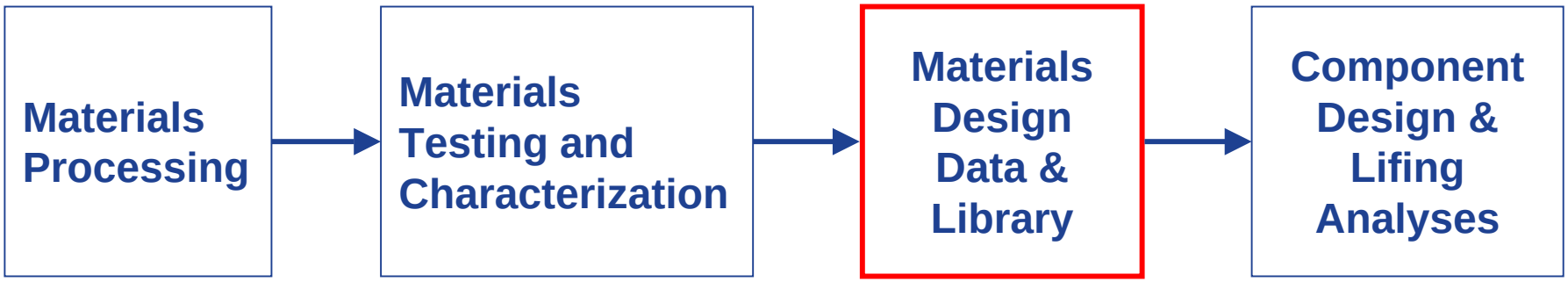
Advanced USC Steam Turbine Rotor Materials



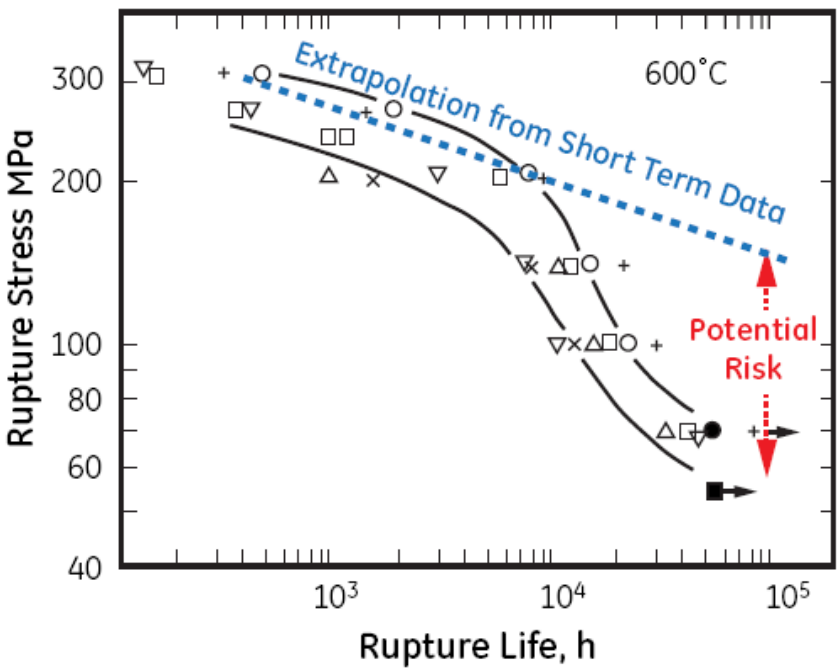
R. Viswanathan, 2007, 2009

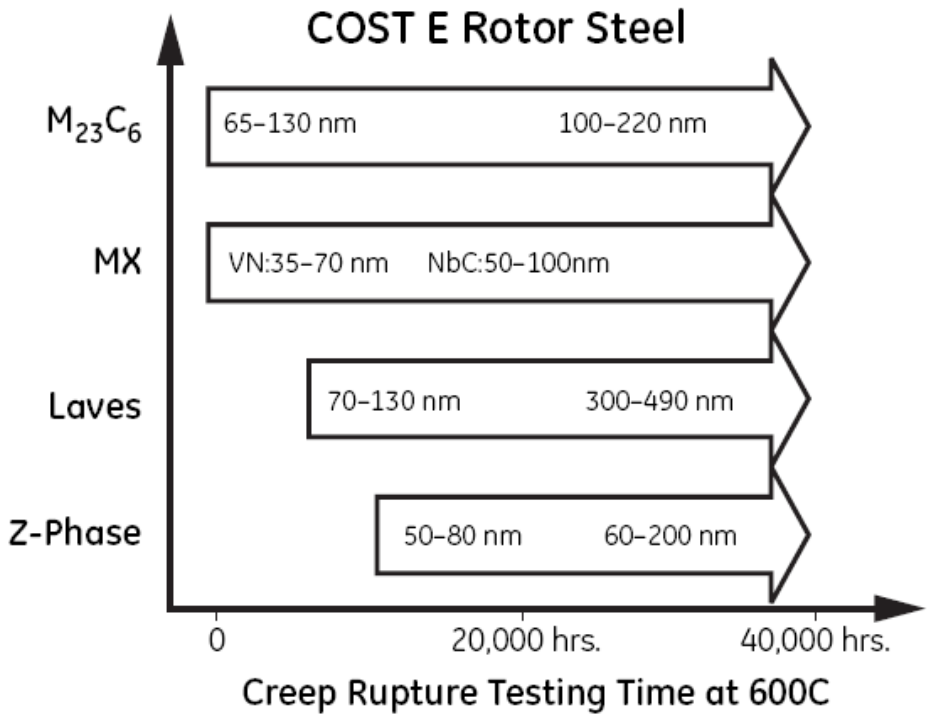
imagination at work

Existing Materials and Design Practice



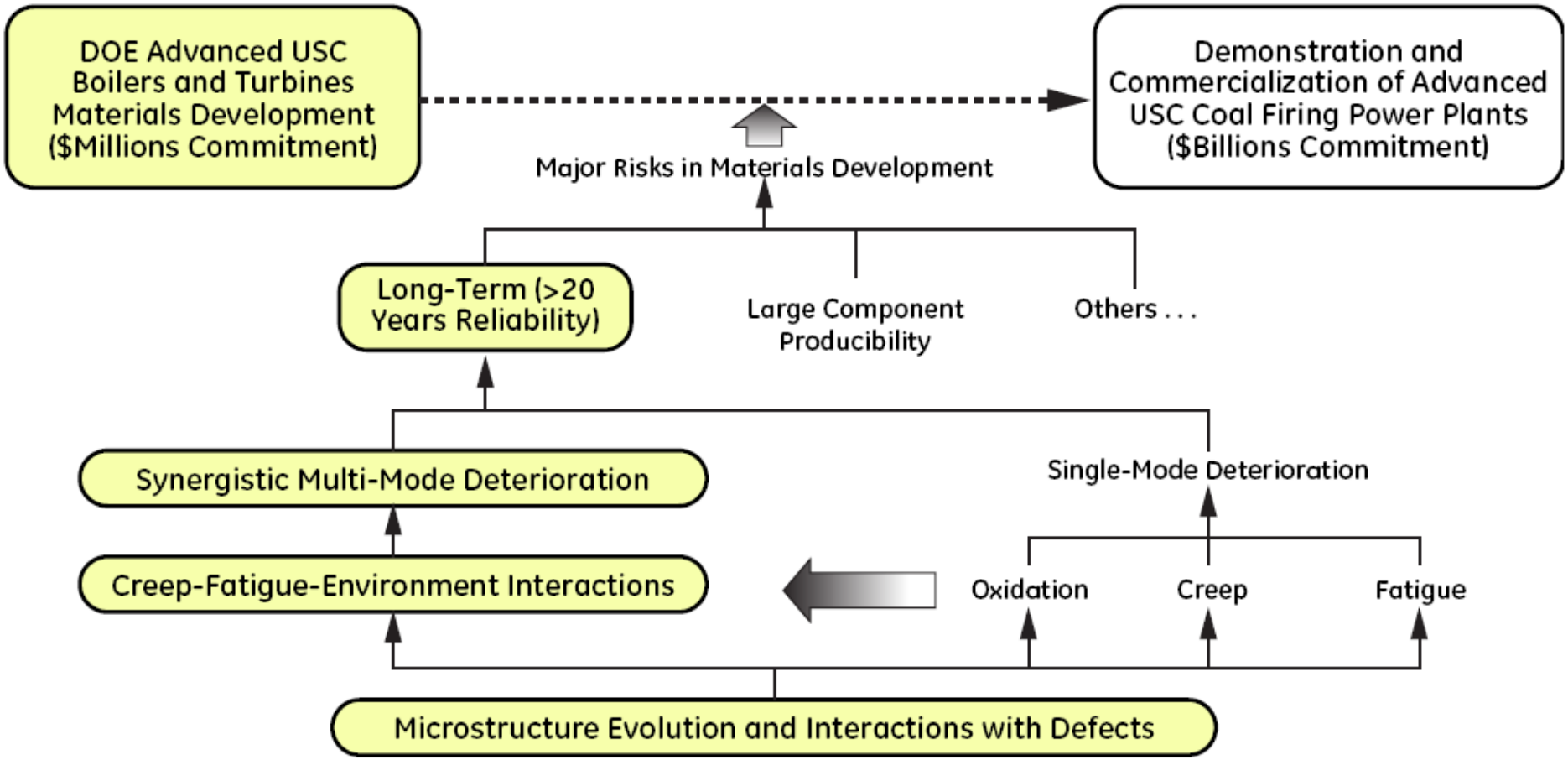
Prior USC Materials Development Experience





R. W. Vanstone, 1998

Challenge – Long-Term Reliability



Project Objectives

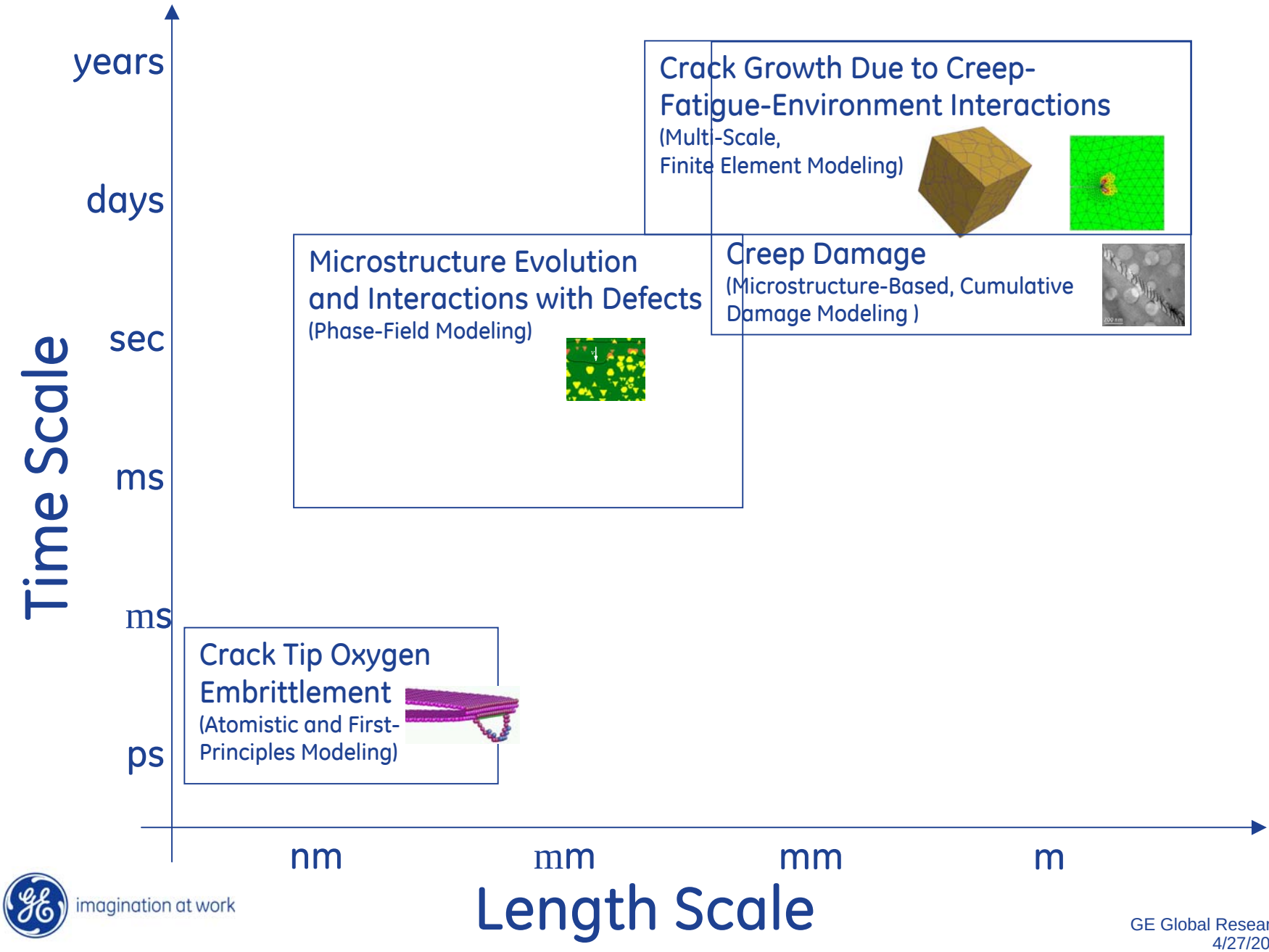
Model creep-fatigue-environment interactions in steam turbine rotor materials for advanced ultra-supercritical (AUSC) coal power plants

- develop and demonstrate computational algorithms for alloy property predictions
- determine and model key mechanisms that contribute to the damages caused by creep-fatigue-environment interactions

Project Tasks

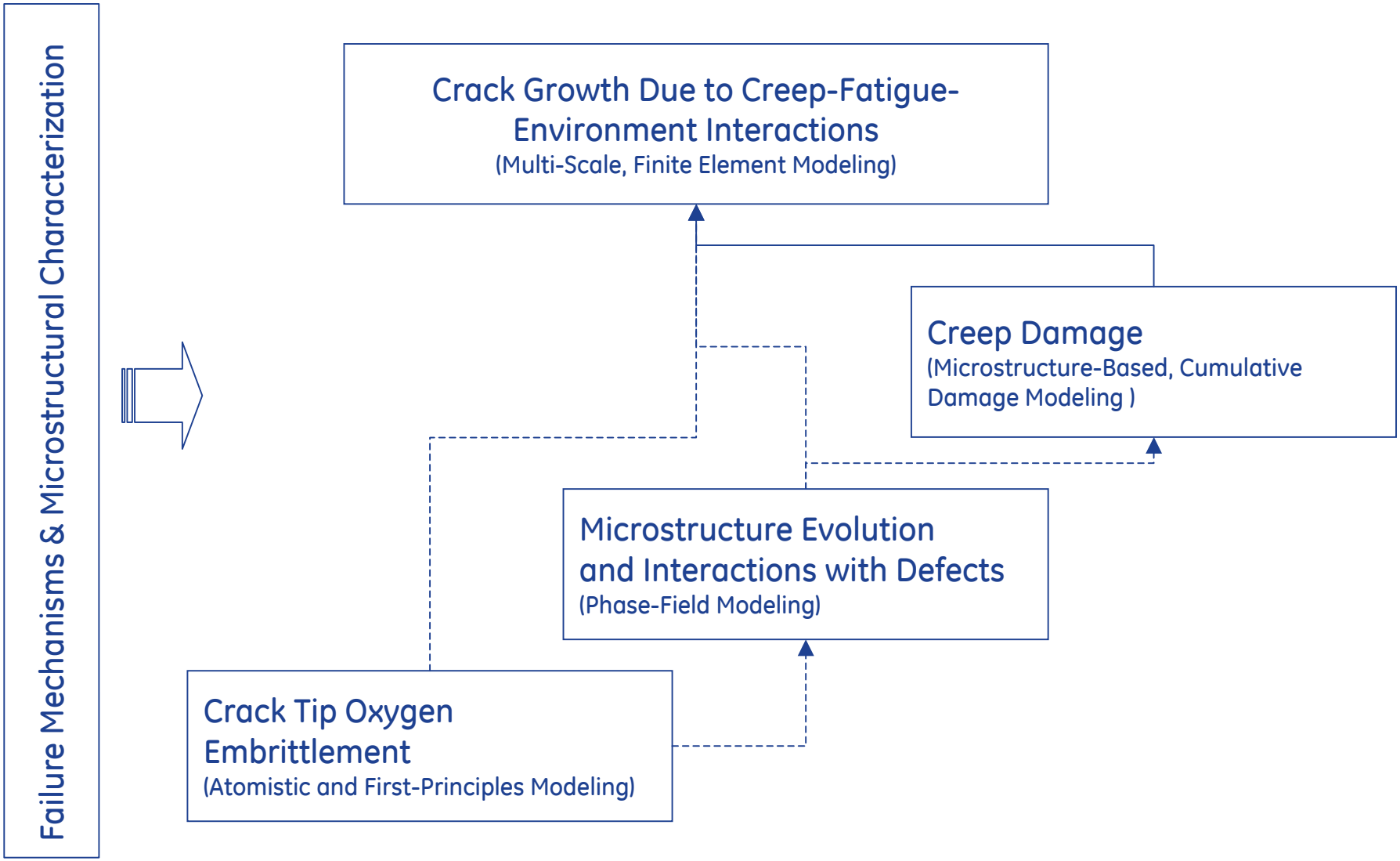
1. Project Management and Planning
2. Failure Mechanism and Microstructural Characterization
3. Atomistic and First Principles Modeling of Crack Tip Oxygen Embrittlement
4. Modeling of Gamma- Prime Microstructures and Mesoscale Microstructure-Defect Interactions
5. Microstructure and Damage-Based Creep Prediction
6. Multi Scale Crack Growth Modeling Considering Oxidation, Viscoplasticity and Fatigue

Time and Length Scales of Modeling Methods

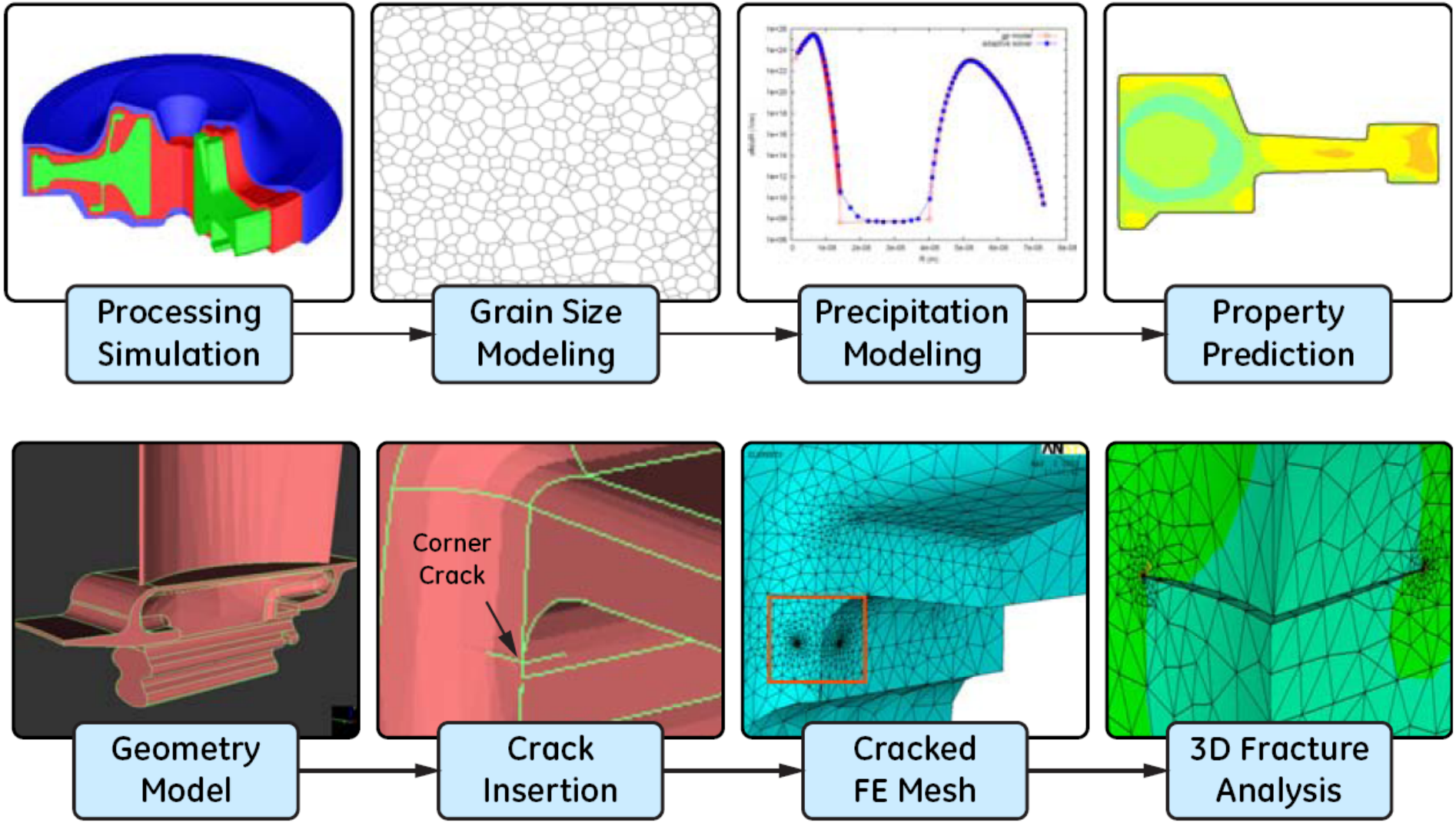


imagination at work

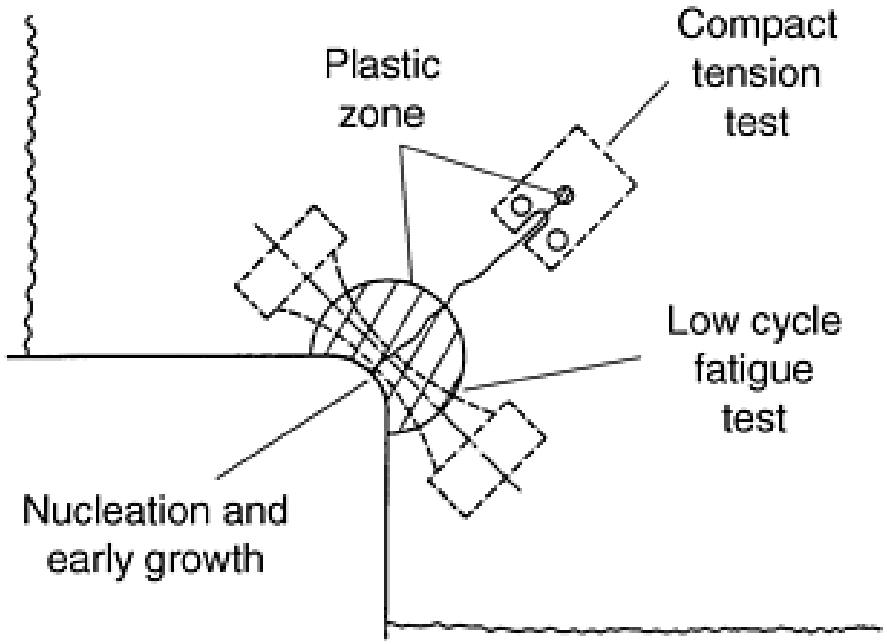
Project Approach and Interactions



Build Upon Current Computational Framework



Multi-Stage Fatigue Process

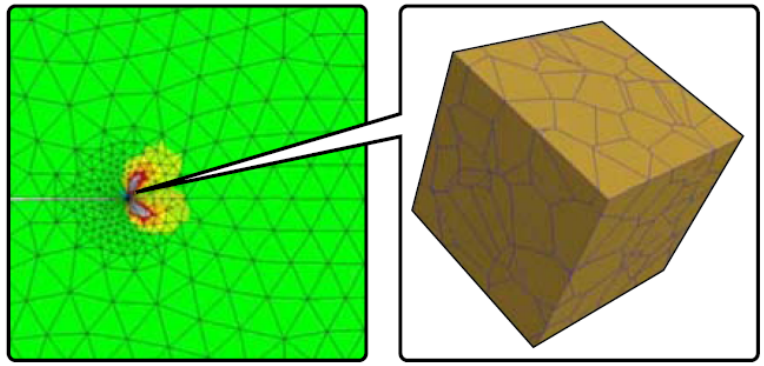


L.F. Coffin, Fatigue and Microstructure, ASM, 1979

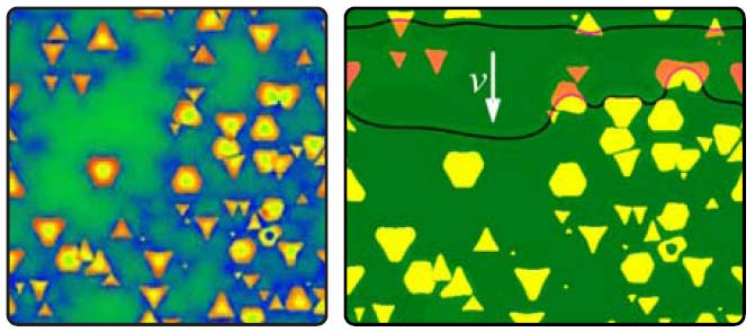
Materials Processing → **Materials Testing and Characterization** → **Materials Design Data & Library** → **Component Design & Lifing Analyses**

Multi-Scale Crack Growth Modeling

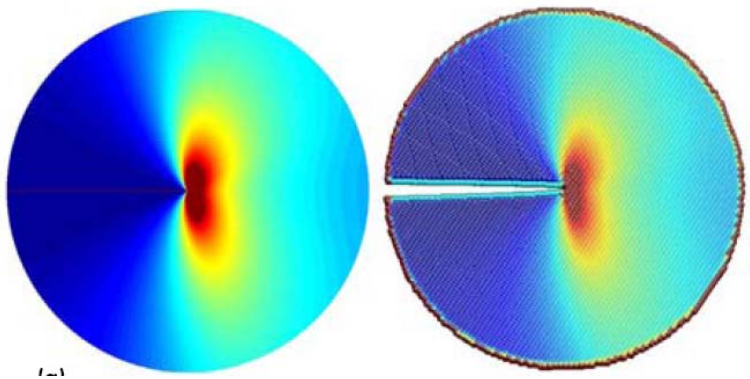
Macro-Scale



Meso-Scale

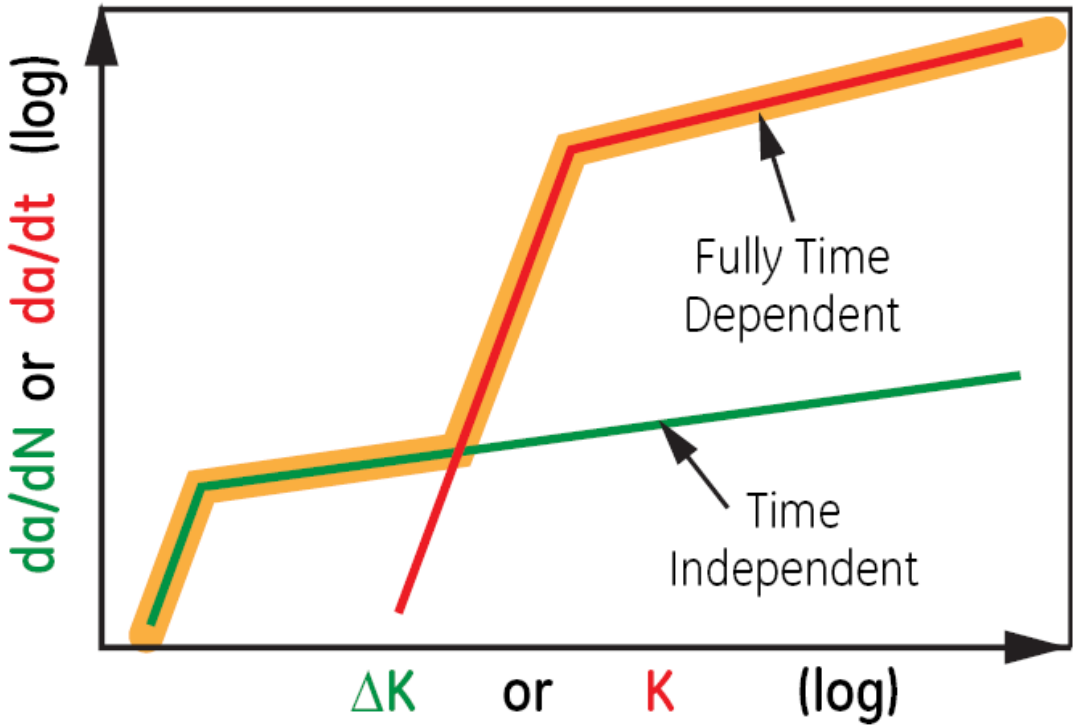


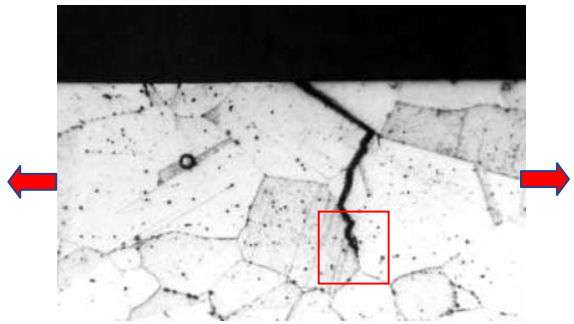
Atomistic-Scale



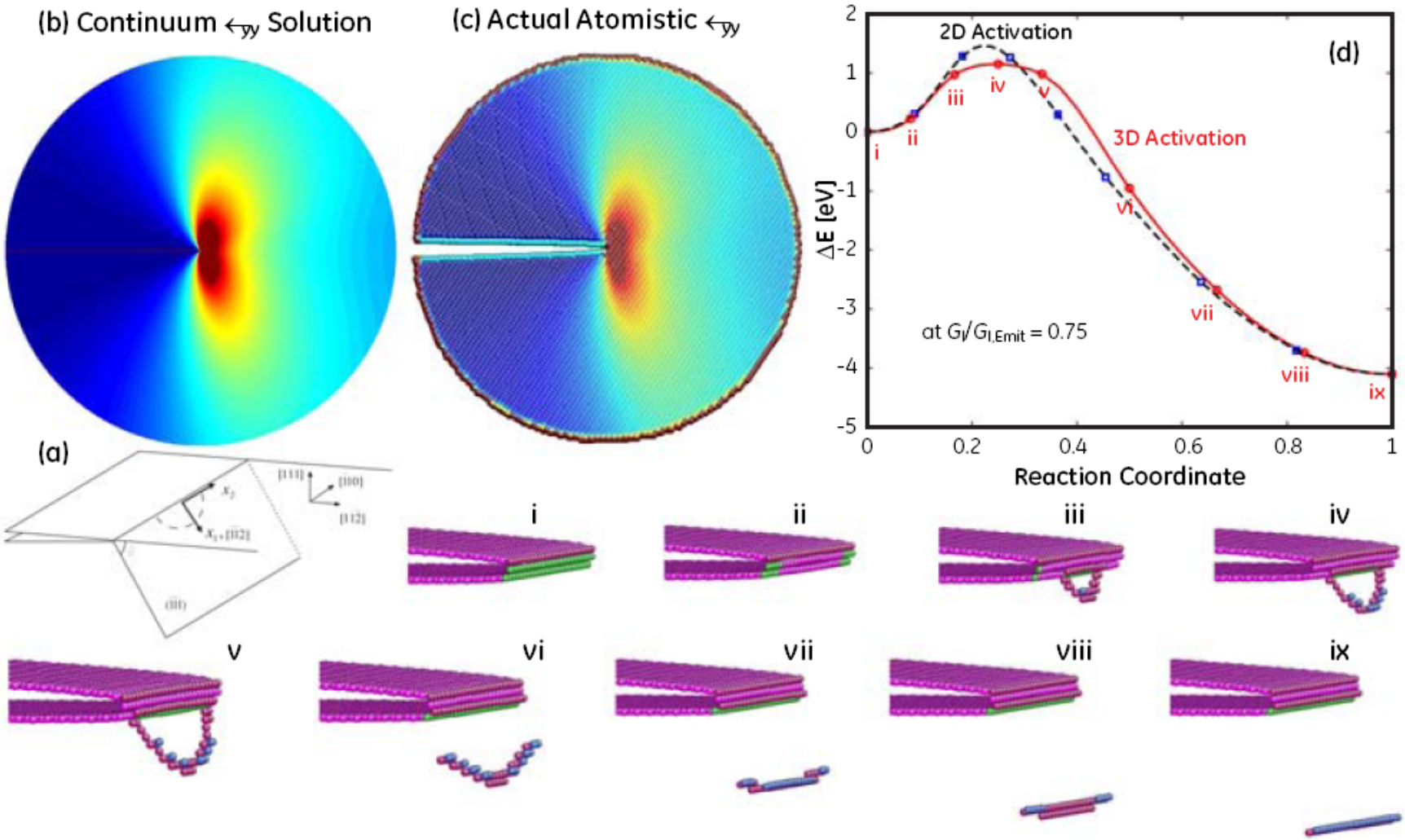
Failure Mechanism Characterization

Cracks growing in hold time fatigue follow the upper bound of the time independent and time dependent curves

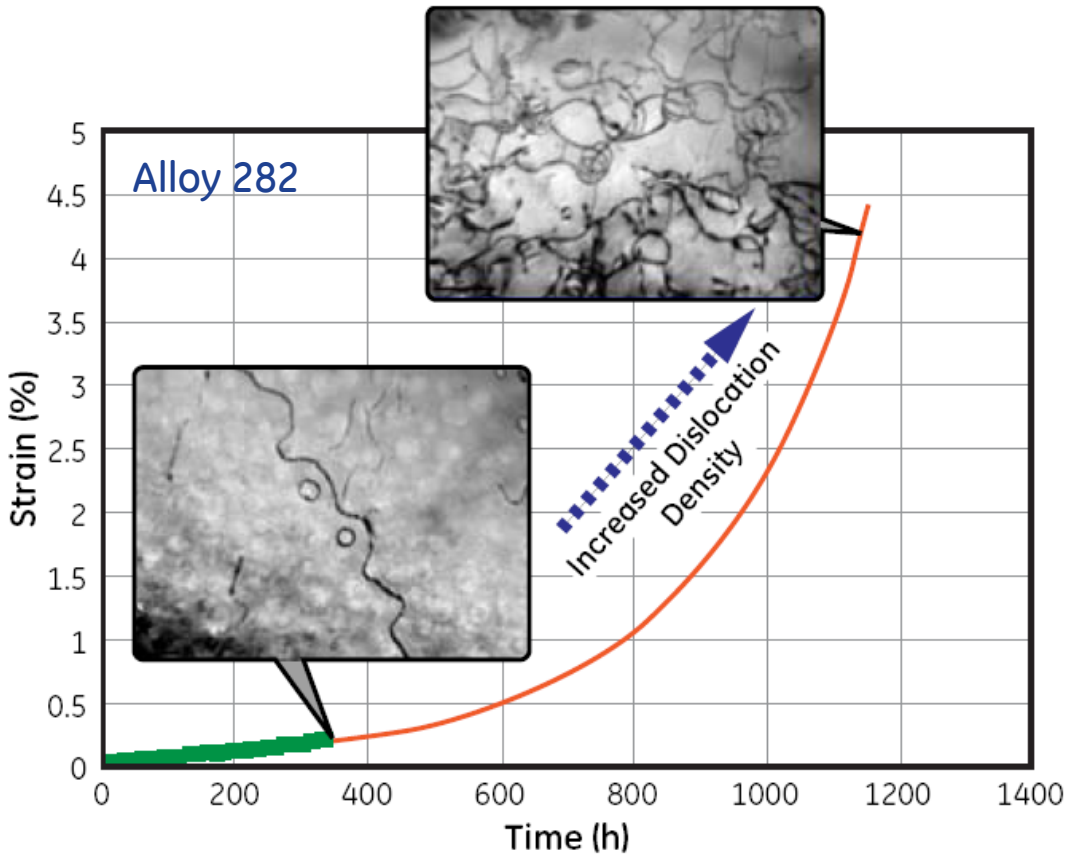


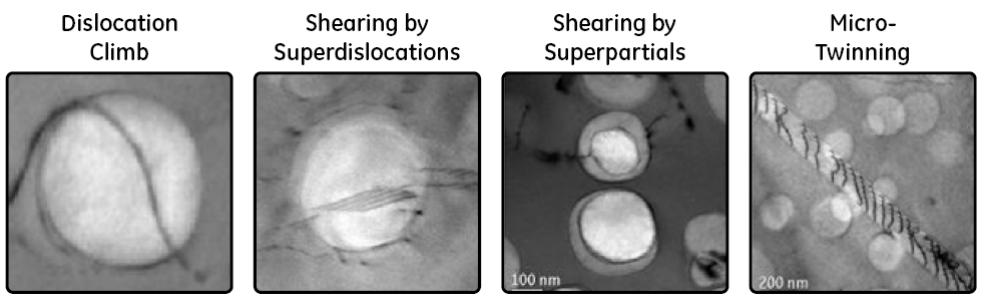


Atomistic Scale Simulation

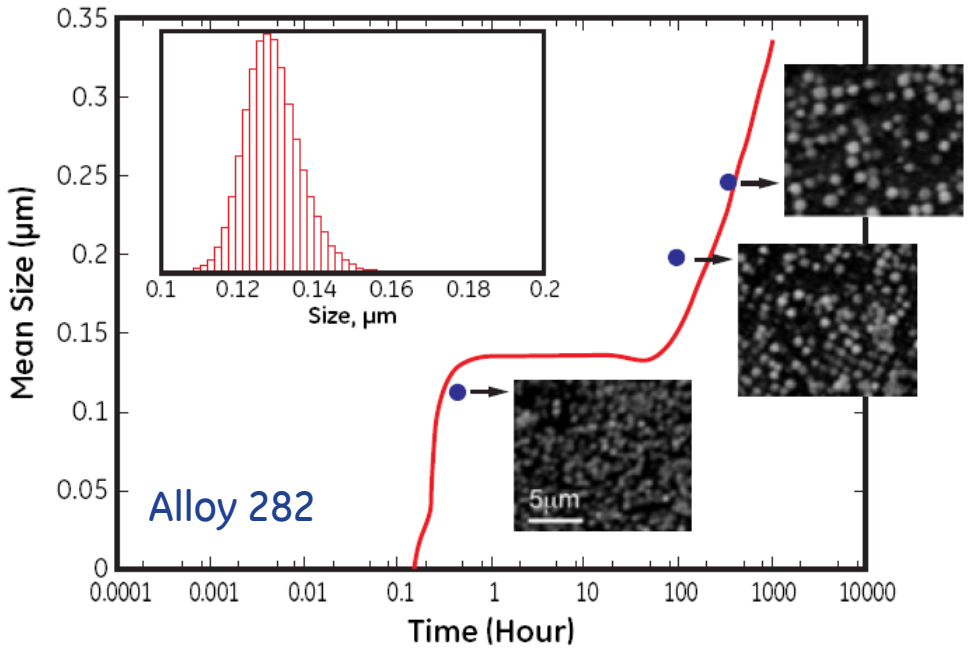


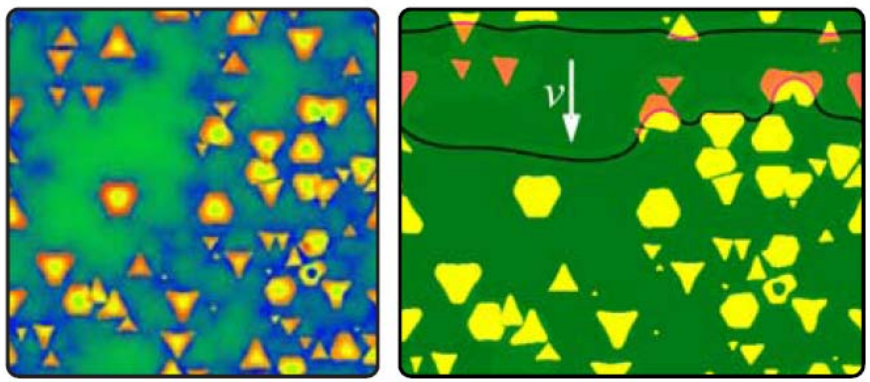
Microstructure and Damage-Based Creep Prediction



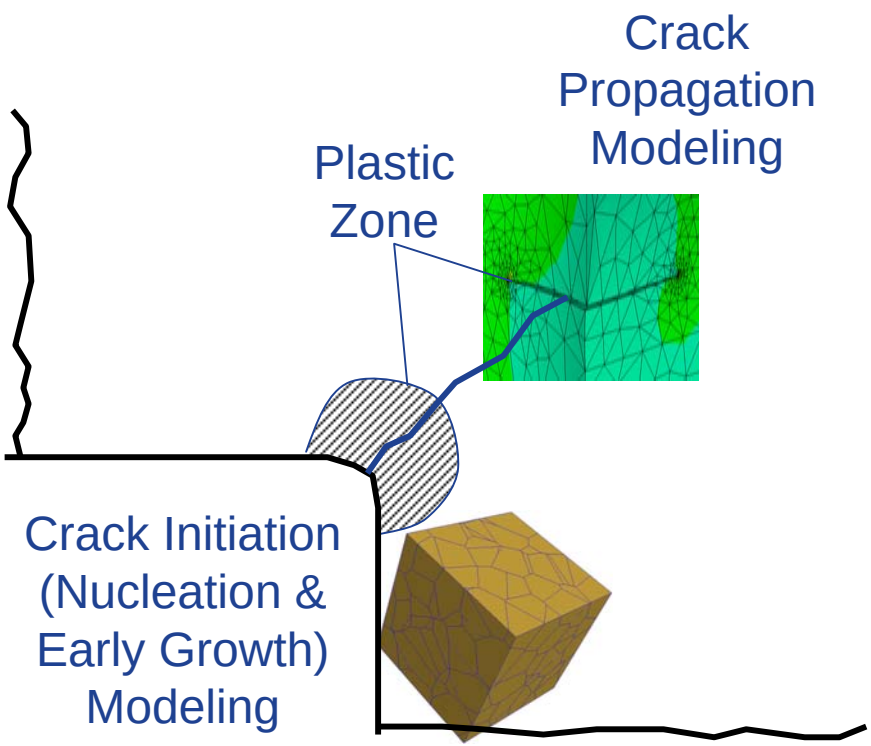


Microstructure Evolution and Interaction with Defects





Modeling Multi-Stage Fatigue Process



Materials Modeling → **Fatigue & Lifing Analyses**

Integrating materials and mechanics models for fatigue prediction

Modeling Creep-Fatigue-Environment Interactions

Modeling Creep-Fatigue-Environment Interactions in Steam Turbine Rotor Materials for Advanced Ultrasupercritical Coal Power Plants

Program Team

GE Global Research
GE Energy

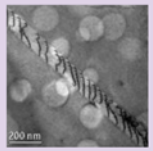
Penn
University of Pennsylvania

Relevant Prior Work

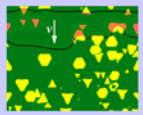
- DOE steam turbine materials for ultra supercritical cool power plants project
- GE materials design acceleration tools
- DARPA accelerated insertion of materials program

Modeling Creep-Fatigue-Environment Interactions

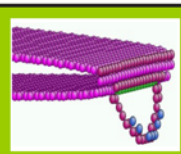
Creep Damage (Microstructure-Based, Cumulative Damage Modeling)



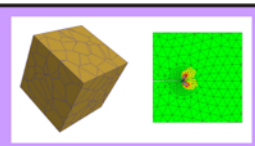
Microstructure Evolution and Interactions with Defects (Phase-Field Modeling)

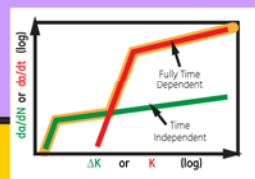


Crack Tip Oxygen Embrittlement (Atomistic and First-Principles Modeling)



Crack Growth due to Creep-Fatigue-Environment Interactions (Multi-Scale, Finite Element Modeling)





Failure Mechanism and Microstructural Characterization

Technical Approach

- Micro/macro-scale modeling for alloy property predictions
- Atomic/meso-scale modeling for mechanistic understanding
- Diagnostic experiments to validate, guide, and refine models

Program Deliverables

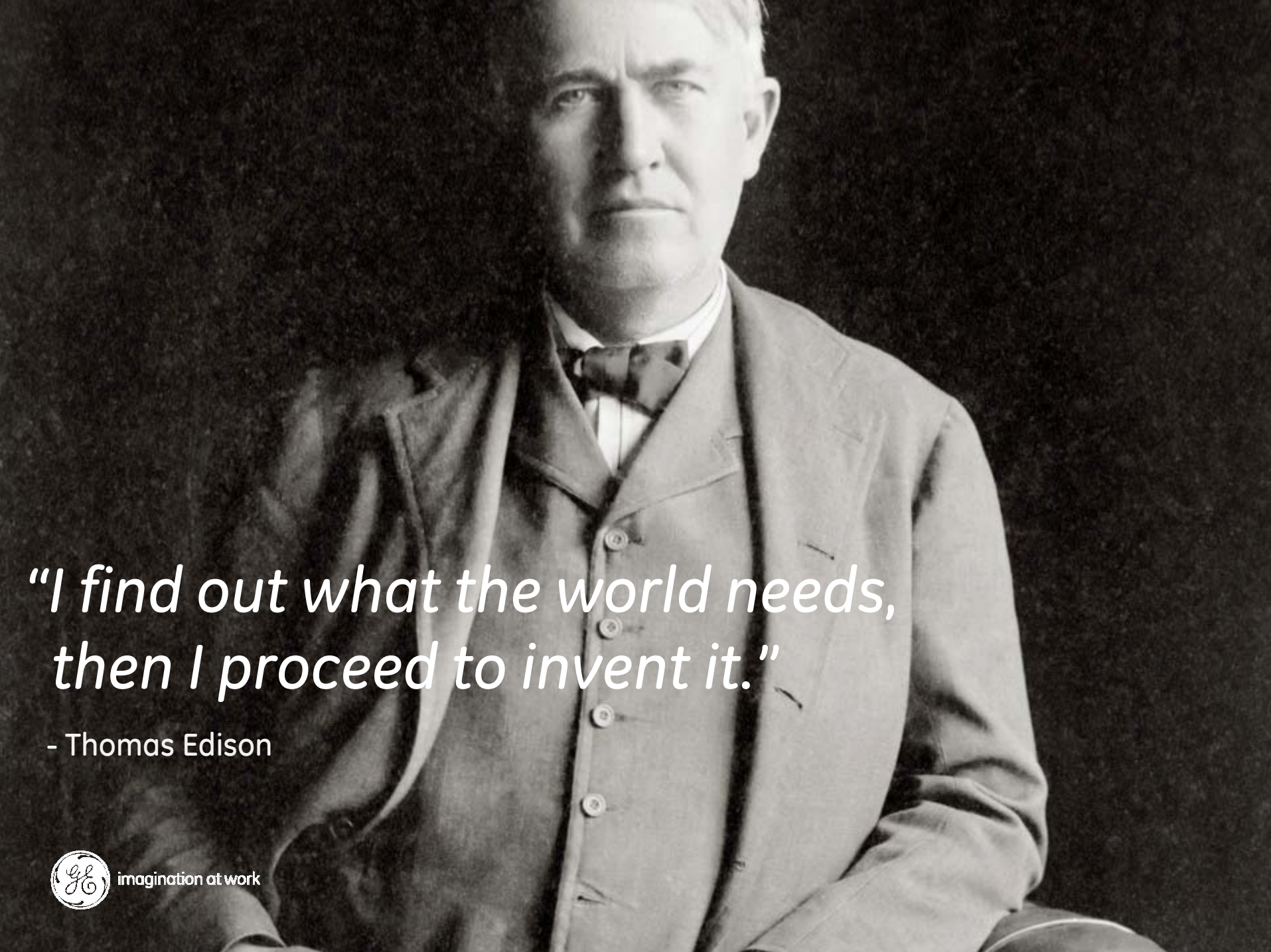
- Demonstration of computational modeling algorithms for alloy property predictions
- Determination of key mechanisms contributing to the damages of creep-fatigue-environment interactions

Anticipated Benefits of the Proposed Technology

- Accelerate the materials development and enable lifetime/reliability prediction methods for the next generation fossil energy power systems
- Establish key computational technology for development in materials area of DOE NETL Advanced Research
- Enable advanced fossil energy systems to achieve the DOE efficiency and environmental goals

Project Status

1. Project Management Plan, January 31st, 2011
2. Opened project, Feb 19th, 2011
3. FOA000260 Awardees Project Kickoff Meeting, Feb 23rd, 2011
4. Project kickoff at GE Global Research, March 18th, 2011
5. Continue discussion with DOE A-USC Materials Team
6. Procure Alloy 282, machine, and test
7. Review Alloy 282 Literature
8. Move forward with modeling efforts


"I find out what the world needs,
then I proceed to invent it."
- Thomas Edison
imagination at work