lift®

Where Manufacturing Technology and Talent Matter

A Materials Future

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LIFT is operated by the American Lightweight Materials Manufacturing Innovation Institute (ALMMII), a Detroit-based nonprofit public-private partnership

Opening Thoughts

Materials are a fundamental part of transformative developments

Modern material development often cannot meet the pace of product development

Digital approaches in concert with manufacturing will help us achieve our mission

Distinguishing capabilities at LIFT will support computational design, scale-up, and testing for the domestic materials community

What is LIFT?

Driving American Advanced Manufacturing Into the Future Through Technology and Talent Development

LIFT is an accelerator convening and connecting government, industry and academia in the fields of **advanced materials, manufacturing processes, systems engineering and talent development** to enhance America's manufacturing competitiveness, national economy and national security.

DEPARTMENT OF DEFENSE MANUFACTURING INNOVATION INSTITUTES

Manufacturing USA®

Nonprofit 501(c)3 | Public-Private Partnership | Member Based

Bridging The Gap In Manufacturing Innovation

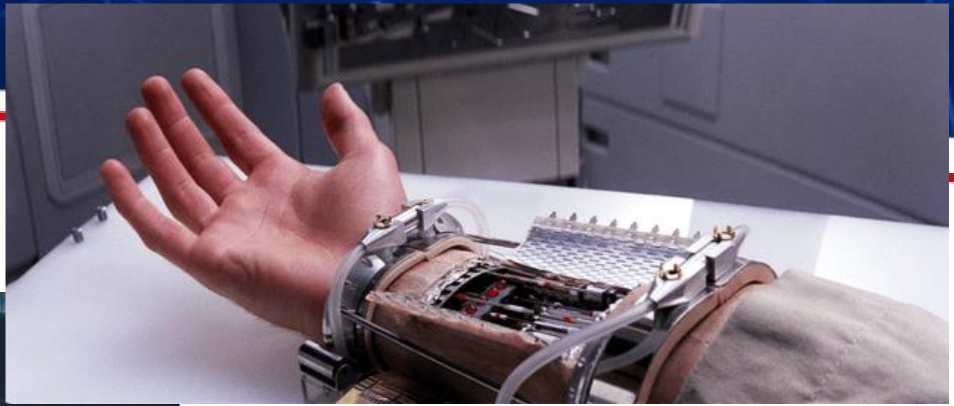
Accelerating advanced technologies into manufacturing, scale up and commercialization

lift®

ADVANCED MATERIALS + MANUFACTURING PROCESSES + SYSTEMS ENGINEERING + TALENT DEVELOPMENT

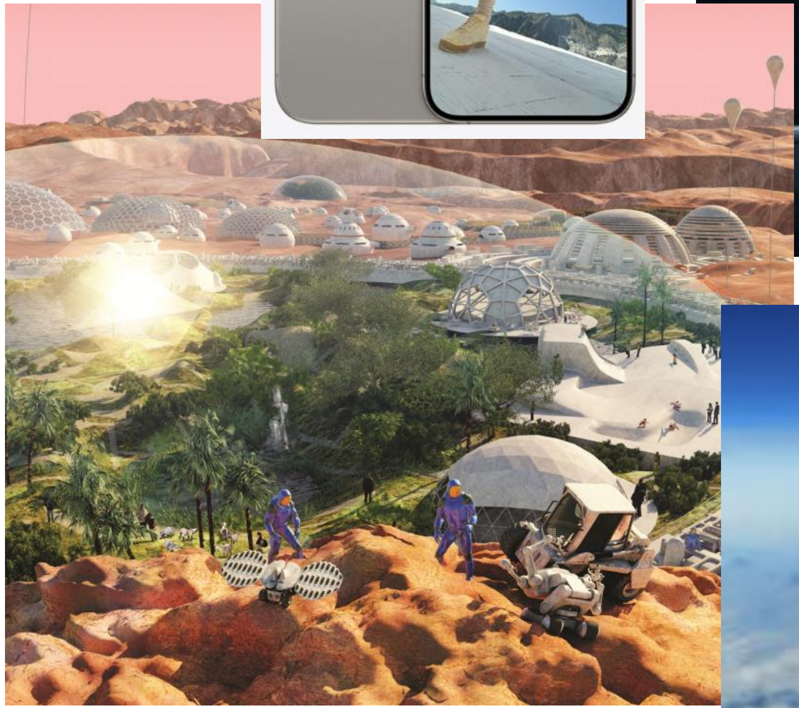
Materials – An Engineer's Dream

Smartphones, e.g., Apple iPhone



Smart prosthetics

Porsche-Boeing flying car concept



Artist's interpretation of a human colony on Mars

Hypersonic vehicles

DARPA Soft Exosuit

Materials Are of National Importance

"An improved Materials Innovation Infrastructure would deliver between **$123 billion** and **$270 billion** in value annually."

Economic Analysis of National Needs for Technology Infrastructure to Support the Materials Genome Initiative, 2018

"Advanced materials explore **innovative new materials** and **novel manufacturing techniques** that can dramatically improve many of the Department's capabilities. Materials that **have higher strength, lighter weight, higher efficiency**, and can handle more **extreme temperatures** will have the potential to better protect our service members and enhance their ability to accomplish their missions."

Office of the Under Secretary of Defense, Research & Engineering (OUSD(R&E))
Strategic Vision & Critical Technology Areas, 2022

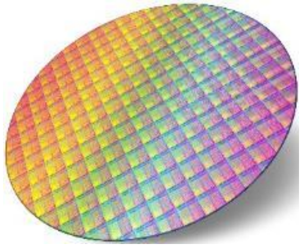
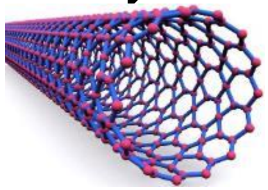
Traditional Material & Process Development

- Materials fundamental to the advancement of civilization

Stone Age 2.5M-3000 BCE	Bronze Age 3000-1200 BCE	Iron Age 1200 BCE – 300 CE	Porcelain Age 300-1300 CE	Steel Age 1300-1950 CE	Silicon Age 1950-2010 CE	Digital





- Through experiment or by chance through much of history
  - Add a little of this, a little of that trial and error
  - Try new ways of melting, cooling, processing

- "Historical" approach that isn't that historical

Image from delish magazine

Aluminum: Planes, Trains, and Automobiles (& More)

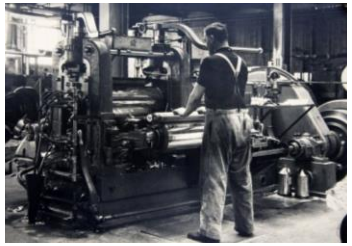
1825
First successful production of Aluminum

1850-1900
Aluminum is precious




1890-1910
Aluminum key to specialized transportation


1907-1910
Aluminum foil production replaces tin



1914-1918
Aluminum essential to lightweight aircraft design in WW I

1929-1939
Hydroelectric projects established key electrical capacity in U.S.; 6061 developed

1939-1945
296,000 Aluminum aircraft in WW II; 7075 developed

1957-1958
Space & consumer products



1969
Wide body aircraft and high-speed rail


1998
1st components of ISS, including aluminum, launched into space

2007-2013
Global aluminum production by China grows from 33-50%

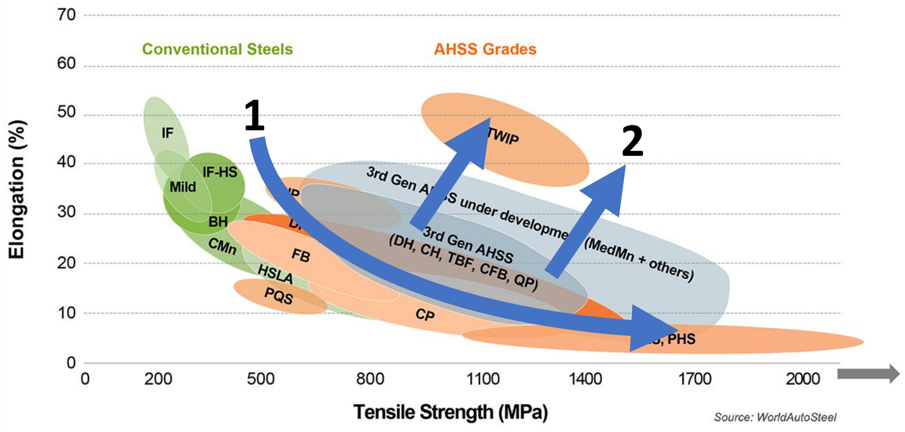
2014
Ford F-150 with fully aluminum body

Sustainability
Additive Mfg.
Digital Design
New Alloys

The Aluminum Association, 2024
Aluminum Leader, 2024

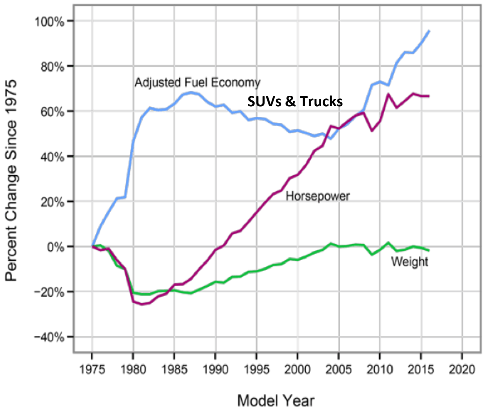
Lightweight Steel Development

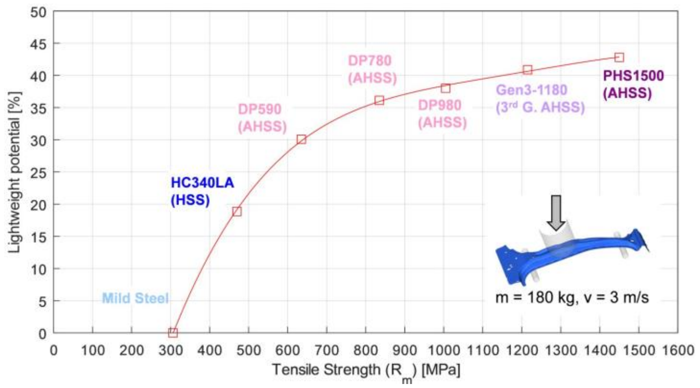
- Automotive body in white structures have rapidly evolved over the last 50 years due to regulatory and political pressures
  - 1970 Clean Air Act
  - 1970 National Highway & Traffic Safety Administration
  - 1973 oil crisis




1957 Cadillac Coupe DeVille

- Few metal options, primarily mild steels (ferrite)
- Thick sheets to compensate for strength
- Smaller, relatively flat body panels





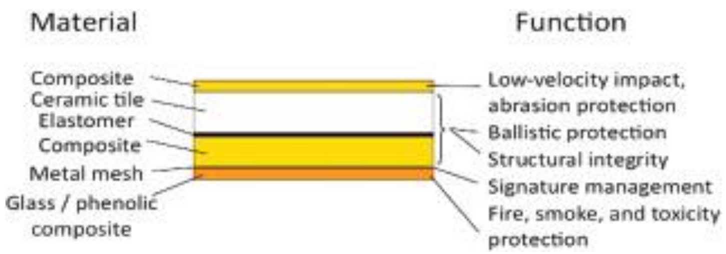

2023 Cadillac CT5-V

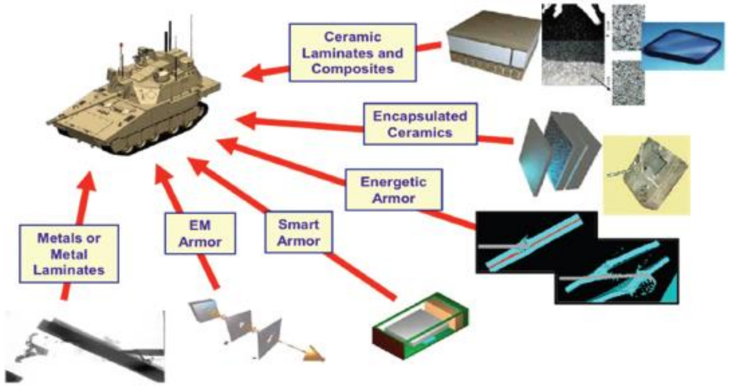
- Many options including AHSS (martensite, bainite, retained austenite), Al, Mg, …
- Thinner, higher strength sheets reduce BIW weight
- Larger, curved body panels
- Joining challenges

WorldAutoSteel, 2021
FormingWorld, 2023
Ozkan & Bach, 2019
International Council on Clean Transportation, 2024

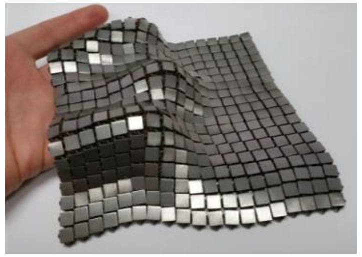
Systems of Materials

- Body & vehicle armor are systems of materials
- The right material, in the right form, in the right application
- Goal: Lightest & most survivable systems
  - Soldier loads can be as much as 120lbs
  - M1 Abrams tank ~70 tons
- Materials manufactured in new ways (AM) can yield lightweight solutions
  - Lightweight titanium replacements
  - Futuristic chainmail structures for spacecraft
- Will the traditional paradigm be fast enough?
  Design → Make → Test → Repeat





Medieval chainmail



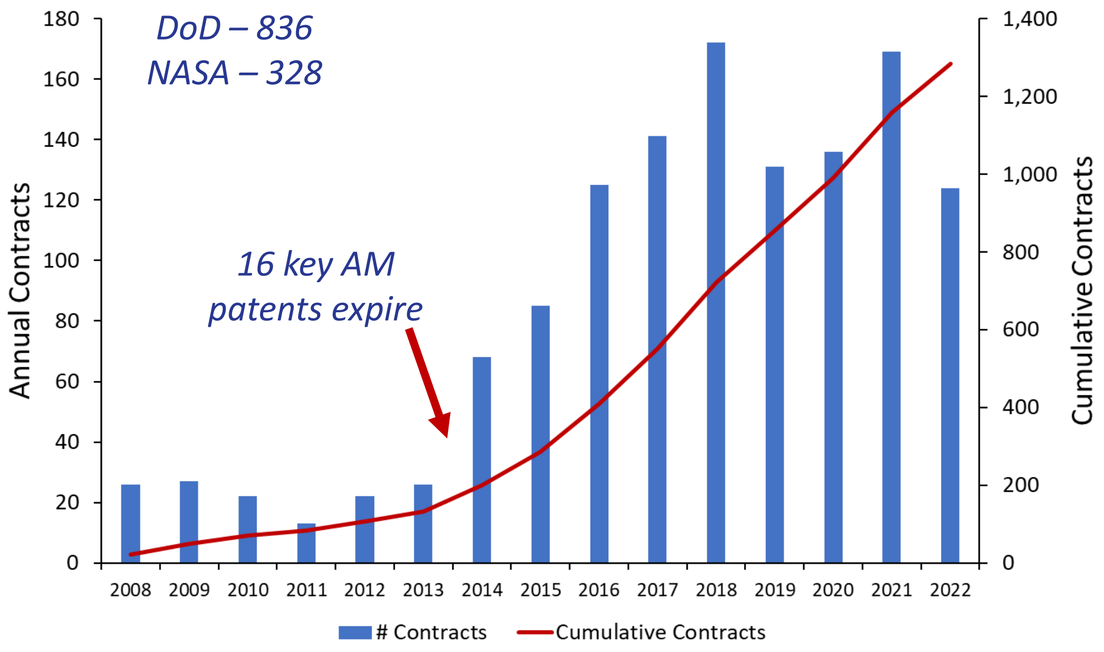
Futuristic AM chainmail

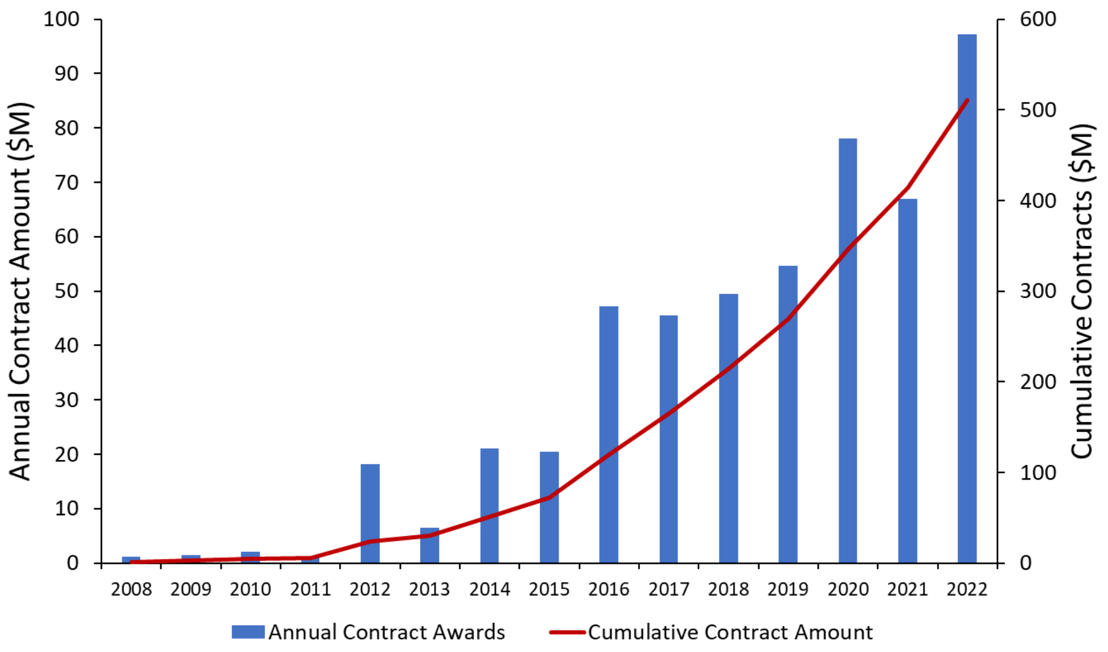
National Research Council of The National Academies, 2011
Warrior Maven, 2020
Boston University, 2017
Defense News, 2021
NASA/JPL-Caltech, 2017
Mini Museum, 2024

US Government Additive Contracts & Grants

2008-2022

- USG leveraging significant resources to advance the state of additive manufacturing across all materials & applications
- "Additive Manufacturing" and "3D Printing" related contracts & grants exceeded 1,250, with corresponding $511M in total contract awards
- Bulk of initiatives lead by DoD & NASA

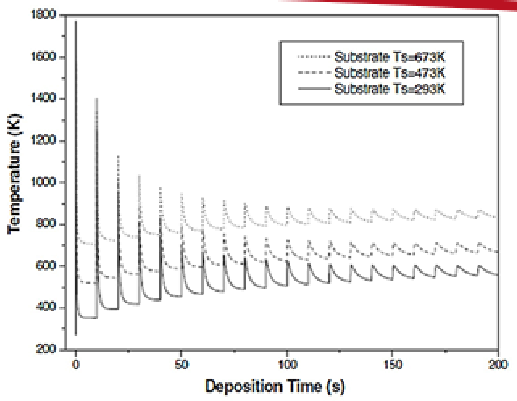


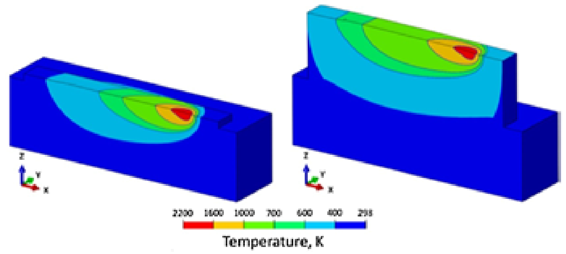


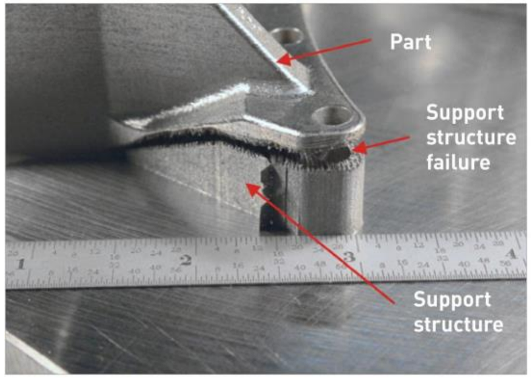
USASpending.gov, 2022

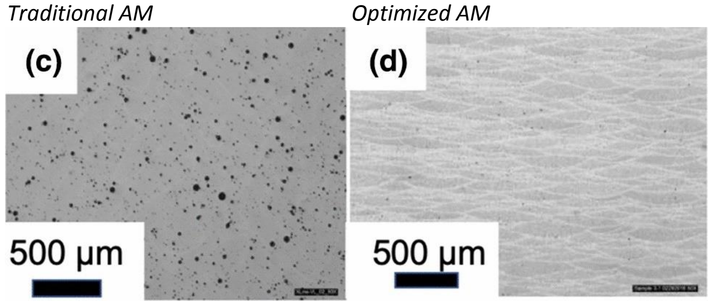
Additive Manufacturing of Materials

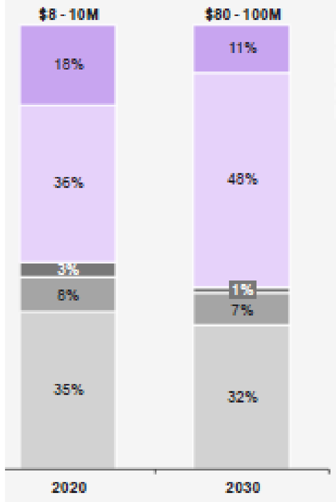
- Future of mass customization of “everything”
- AM makes the part and the material simultaneously
- Repeated heating and cooling cycles
- Traditional materials don’t behave the same
- Novel materials time consuming to obtain
  - Lead times 6-24 months
  - Finding domestic toll processors willing to execute is challenging
- Greater requirements for verification & validation











CUSTOM ALLOYS	2020 $Mn	2030E $Mn	CAGR (2020 – 2030)
Aluminum and its alloys	1.4 – 1.8	9 – 11	+20%
Titanium and its alloys	2.8 – 3.5	30 – 48	+30%
Steels	0.3 – 0.3	1 – 1.3	+15%
Nickel and its alloys	0.6 – 0.8	6 – 7	+25%
Others (copper, cobalt - chrome, tungsten, gold, silver, etc.)	2.8 – 3.4	28 - 32	+25%

U.S.-based AM custom metal alloys market forecasted to grow from $8-10M in 2020 to $80-100M in 2030

Bandyopadhyay & Traxel, 2018
Pollock, et al., 2022

Qualification Requirements for AM Parts

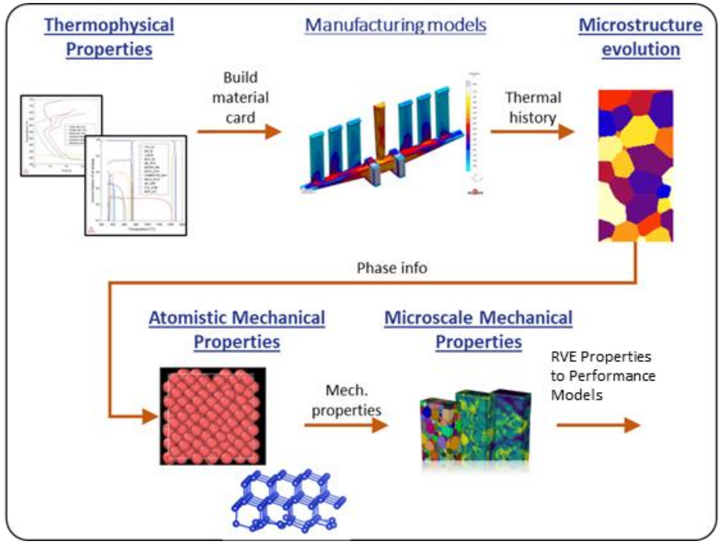
- Current Verification & Validation (V&V) processes are resource intensive
- For additive manufacturing (AM), parts must be built and tested each time there is a change
  - Onboarding new AM equipment
  - AM equipment is moved
  - AM equipment gets software or hardware update
  - New powder batch or vendor
  - Geometry change
  - Process change (print parameters)
- Nonrecurring engineering (NRE) investment can range from 6-18 months and $500,000 - $1,500,000 or more

QUALIFICATION REQUIREMENT
AM PART

- Chemical composition of multiple specimens
- Porosity of n+ printed specimens measured via microscopy in n+ orthogonal directions
- Tensile Testing:
  - Specimens printed in vertical orientation
  - Specimens printed in horizontal orientation
- Surface roughness of printed part, not coupon
- No rework is allowable unless permission is granted by Design Authority

Digital Augmentation of Conventional Design Cycles

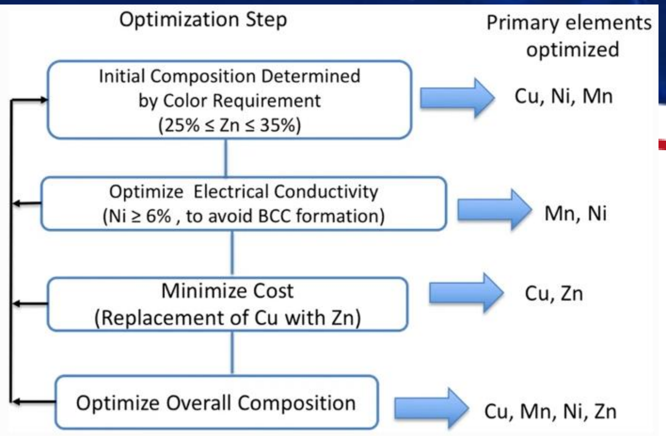
- Insertion of new materials technologies more difficult & less frequent as materials fail to keep pace with the rapid design process
- Rapid iterations of multi-scale materials and system modeling is an enabler for design & manufacturing
  - Reduce product development time and costs
  - Improve quality, reduce weight, achieve new targets
  - Increase manufacturing efficiency
  - Simulate environments that cannot be physically tested
- Real economic & strategic benefits from this type of digital solution
  - Eliminate ~half of project attrition (mitigate risk)
  - 35% acceleration of projects to market (-3.5 years)
  - 71% increase in efficiency
  - Reduce relative costs in discovery, design, development, manufacturing, & deployment
  - Overall potential economic impact estimated at $123-270B per year



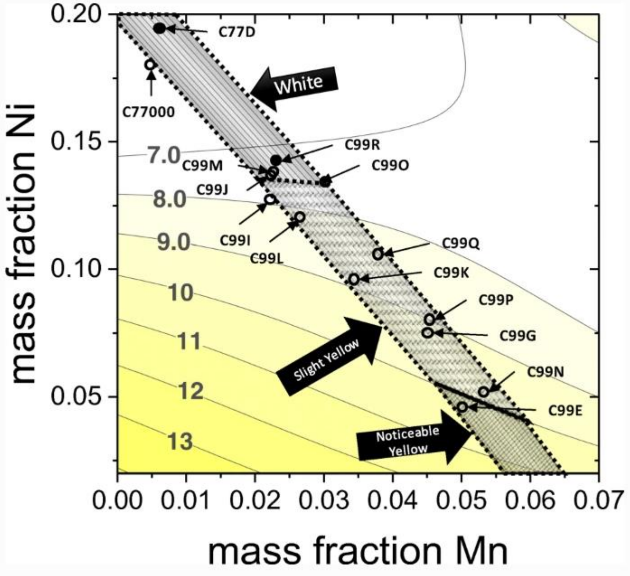
NRC, 2008
The National Science & Technology Council, 2011

Example: Another Day Another Nickel

- "Nickel" has been a Cu-25Ni alloy since 1866
- In 2006, cost of producing US nickel exceeded coin face value due to increases in raw material costs
- Objective:
  - Reduce cost by 40%
  - Maintain: electrical conductivity, color, yield strength, work hardening, corrosion resistance, electromagnetism, and toxicity
- Using ICME, a solution identified in <1 year vs. multiple years in the past
- C99R identified as the alloy meeting all design requirements → Cu-14Ni-28.5Zn-2.5Mn
- Additional cost reductions can be achieved by relaxing the color restraint (C99G alloy)
- Expected to save the U.S. Mint $Millions



Flowchart for key design calculation. Right side indicates the primary elements that are optimized during each design step



Cross plot of b^* color vector (numbered contour lines) and electrical conductivity (grayscale band with center corresponding to 5.35% IACS and the gray bands extending ± 0.25% IACS from that value) for a constant mass fraction of 26% Zn

Lass, et al., 2018

Model Based Systems Engineering for Materials

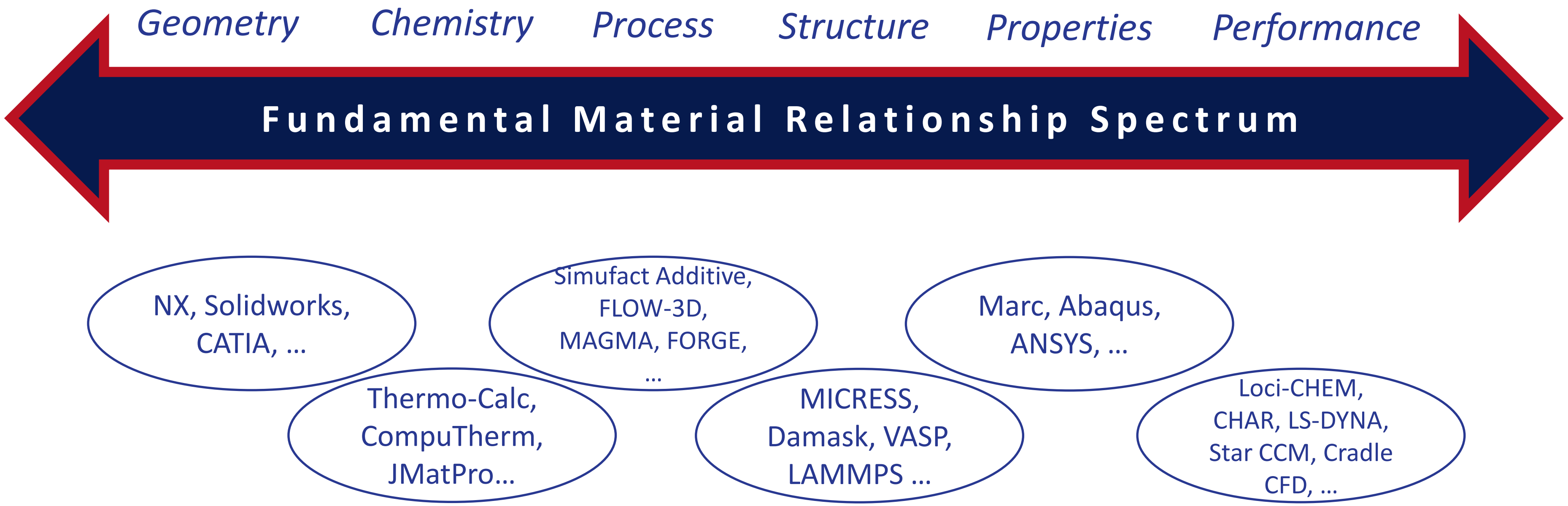
Materials
Discovery & Design

Manufacturing
Process

Structures
Application & Design

- Prominent silos exist, limiting solution development
  - What if an appropriate material isn't in the drop-down menu?
  - What good is a material or product if you can't make it (domestically)?
- Materials-focused MBSE should aggregate knowledge:
  - Materials, manufacturing, application
  - Science & engineering
  - Experiment, theory, simulation
  - Digital & physical
- Challenges with aggregation of sensitive information using this approach

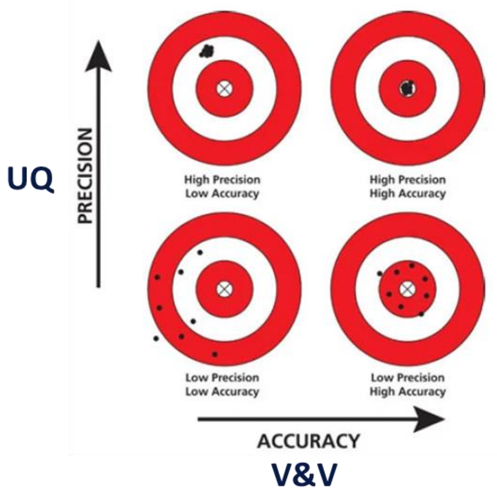
Many Tools, Many Time & Length Scales

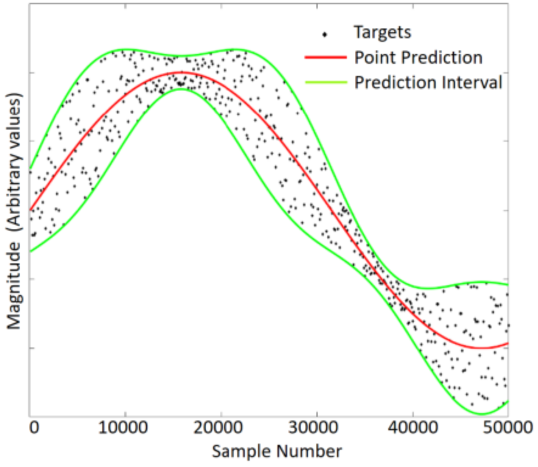


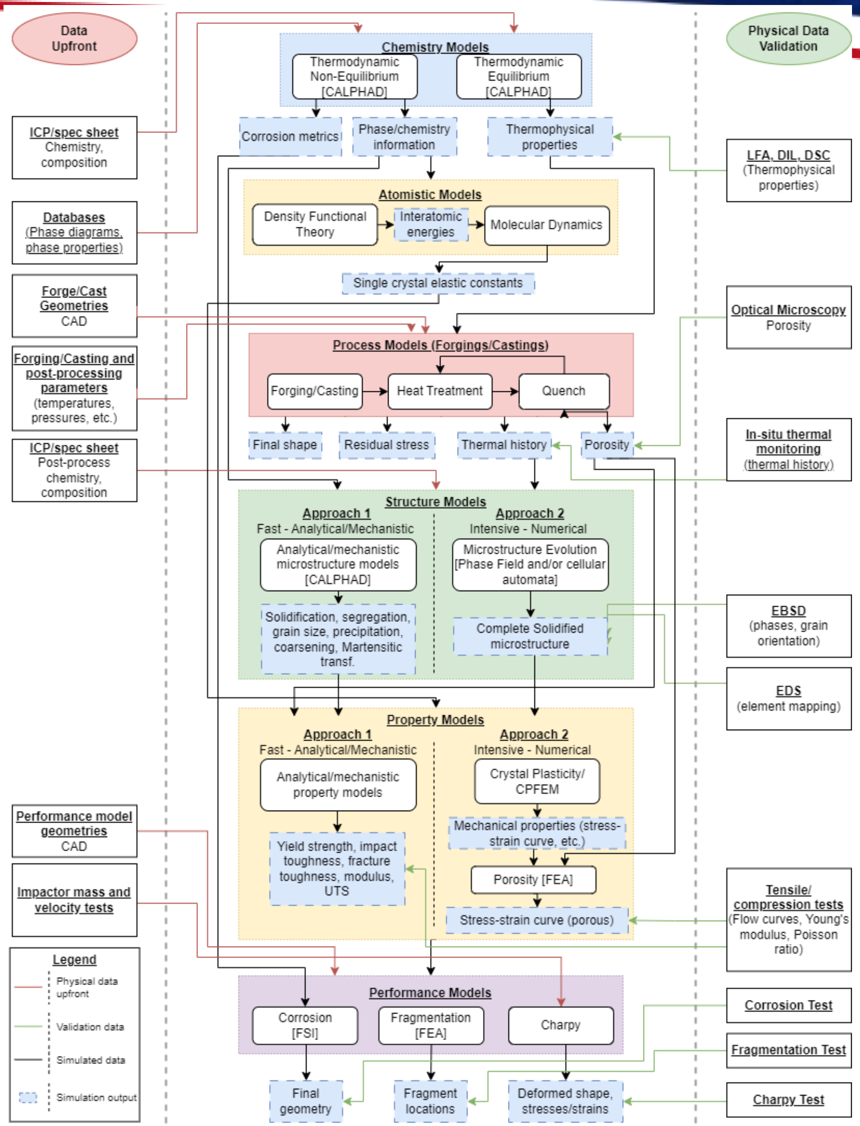
- Materials-focused MBSE approach must consider full material relationship spectrum ("traditional" ICME + CAE)
- No singular software tool exists to address the varied needs of the materials manufacturing community

Example Simplified Workflow for Additive

- MBSE is an iterative process, bringing the make & break cycle into the digital space
- Investment required in software licenses and talent to support materials-focused MBSE
- Challenges with integrating results from disparate software vendors: GOTS, COTS, OSS
- Incorporation of physical data into the ICME process is imperative for model V&V
- Propagation of uncertainty necessary to qualify results







Kabir, et al., 2008

Database Solutions

"The federal government and the private sector should work cooperatively to establish a national computerized materials properties data bank network that would effectively provide carefully evaluated information to our industrial designers."

The National Academy of Sciences 1983

"Currently, no infrastructure exists to allow different engineering teams to share data or models."

The National Science & Technology Council, 2011

"Both experimental & computational data are critical to breakthroughs, yet the value & impact of much of the materials data that is produced is currently far from being fully realized… due to a lack of concerted, coordinated materials data storing & sharing efforts across the MSE & related communities."

The Minerals, Metals & Materials Society, 2017

- Federal funding led to "silos of excellence" lacking:
  - Cross-platform discoverability
  - Interoperability
- Efforts have been built and not sustained
- DoDI 5000.97 (2023): Calls for iterative development of a digital engineering capability that makes data visible, accessible, understandable, linked, trustworthy, operable, and secure

Himanen, et al., 2019

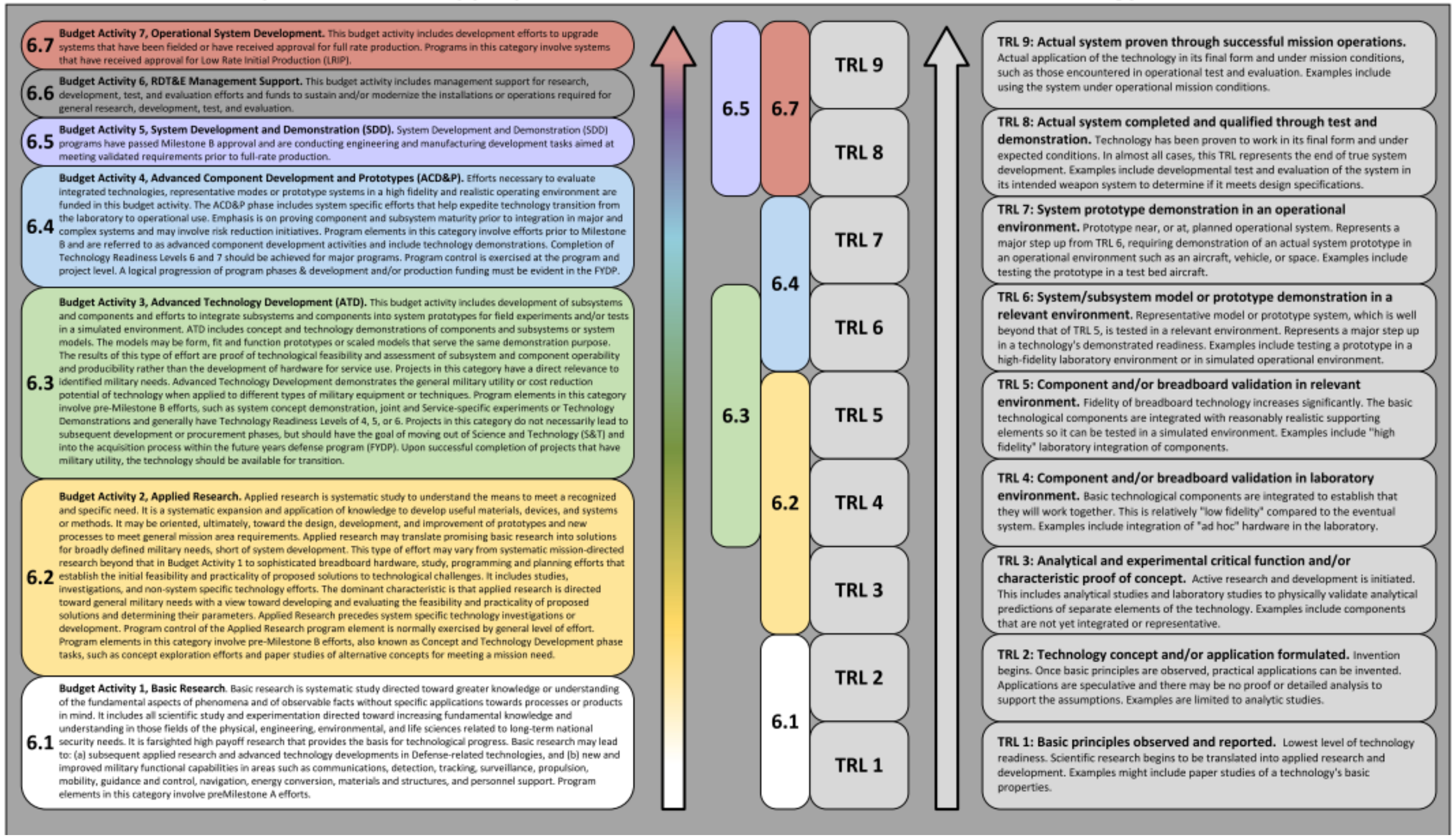
State of Existing Digital Solutions

To move forward, look to the past

- Open RFPs call for continued model development
- What has already been developed?
- What is the maturity level?
- Who has it?
- Is it still of value?
- Can we build on what has already been done (funded)?

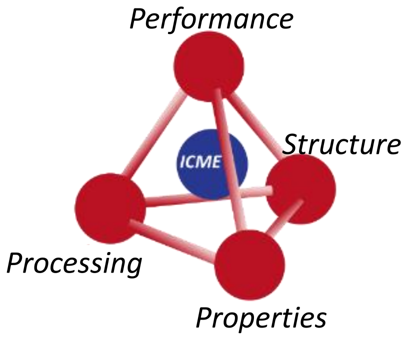
DoD Financial Management Regulation Volume 2B, Chapter 5, RDT&E Appropriations

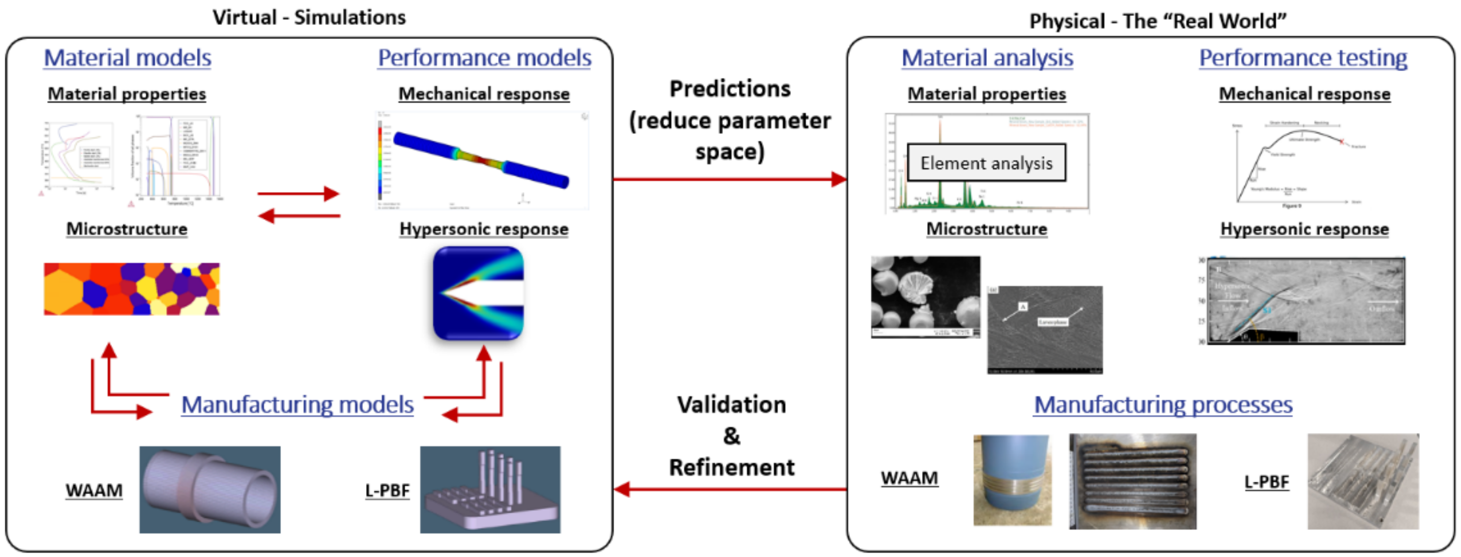
DoD Defense Acquisition Guidebook Technology Readiness Level



Digital at LIFT

- Tools addressing **materials-focused MBSE**
- **ICME workflows** for a variety of alloys, manufacturing processes, & applications
- Build interfaces between software tools via middleware to form a **digital materials factory**
- **Digital performance evaluation** of materials produced by discrete manufacturing methods
- **Secure database** for aggregation of data from models & tests

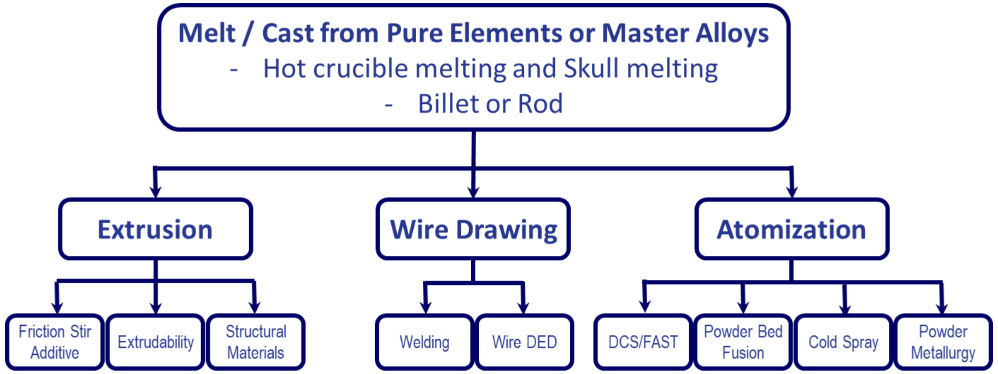




Adjacent Initiatives

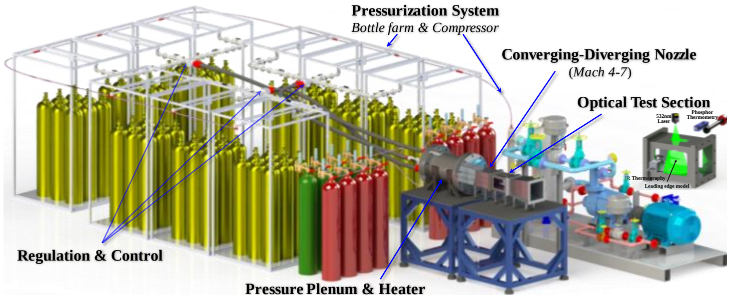
AMPP: Advanced Metallics Production & Processing

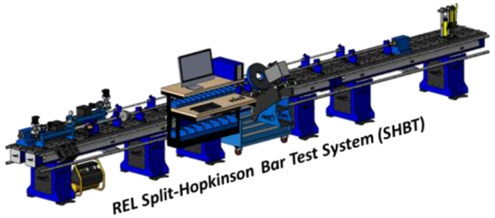
- Infrastructure development to manufacture custom alloys & feedstocks in pilot-scale quantities to support scale-up from R&D to industry
- Facility commissioning Q3 2024

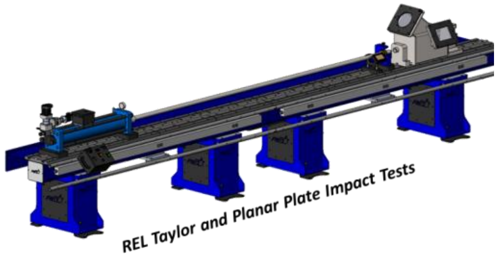


HEET: Hypersonic & Extreme Environment Testing

- Develop a facility to test material properties and performance in high temperature, high strain rate, ablative, and corrosive environments to address strained infrastructures
- Address technology and workforce development strategies, plans, & capabilities
- Planning phase kicked off 11/2023







Parting Thoughts

Materials are a fundamental part of transformative developments

Modern material development often cannot meet the pace of product development

Digital approaches in concert with manufacturing will help us achieve our mission

Distinguishing capabilities at LIFT will support computational design, scale-up, and testing for the domestic materials community

Time is of the essence

Leaping ahead of our global competitors takes *transformational* – not incremental – change.

Thank You

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