



# Additive Manufacturing Technology Roadmap for Casting & Forging



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## **Executive Summary**

#### Background

Cast and forged components lie at the heart of critical weapons platforms across the Department of Defense (DoD), providing a vital contribution to warfighter readiness for the United States. With a 67% reduction in the number of US foundries since 2000, the US Castings and Forgings (CF) ecosystem supply chain is dwindling. Accounting for offshoring and persisting economic headwinds, the remaining highquality domestic purveyors of castings and forgings tend to prioritize high-quantity orders and customers. This problem is particularly exacerbated by the nature of legacy platforms, whose designs and processes were largely conceived, defined, and stored on paper. In tandem with the pervasive challenge of workforce availability, the challenges for the DoD to acquire low-volume cast and forged components pose a critical and enduring issue amid geopolitical turmoil.

This report defines a multi-year technology roadmap to develop and deploy Additive Manufacturing (AM) capabilities at scale to augment existing CF operations. The use of advanced technology, particularly that which poses compelling advantages at low production volumes, unlocks a crucial capability for the Defense Industrial Base (DIB) to respond to warfighter needs rapidly and in an economically viable manner. There are many examples of AM's benefit in principle and a few in practice, developed within siloed pockets of expertise over numerous years and at a significant cost. This effort recognizes the timebound need to rapidly scale AM capabilities out of the lab, beyond proof of concept, and onto shop floors nationwide. America Makes is poised to lead the way in delivering these capabilities at scale.

#### Approach

The roadmap has been intentionally shaped to be broadly applicable yet meaningfully specific. It has been structured for use across two manufacturing industries and all military branches, with products of nearly all risk levels, materials, sizes, and applications having been considered. The complexity of AM has been overlaid with these spaces to identify what sits at the intersection of need and capability, charting a path forward for how it can be achieved. These layers were navigated through a three-phased approach to gather data, construct execution plans, and validate the path forward. Diverse sets of experts across the CF and AM ecosystems representing Government and Industry stakeholders were strategically convened at each phase and across geographical regions. Extensive data collection from these collaborations has been supplemented by and compared against academic literature searches, subject matter expert interviews, production site visits, and DoD order data.

#### Roadmap

The roadmap comprises a portfolio of 21 projects and their execution plans over a 57-month duration. The underlying strategy is focused on deploying technology at scale. Within its scope, 40 material-process combinations and 52 individual components are assessed alongside 25 demonstrations to transfer key outcomes and five pilots to perform stress tests in production environments.





## **Executive Summary Continued**

To realize the capabilities identified through this process, investment is required in four critical areas:

- **Scale Current State:** This group of projects aims to disseminate established technology beyond siloed pockets of expertise. The capabilities that these projects promote tend to be more mature compared to the Prove Production Capability Swim Lane
- **Prove Production Capability:** This group of projects seeks to mature demonstrated and emerging technology to meet production needs predictably. The capabilities that these projects promote tend to be less mature compared to the Scale Current State Swim Lane
- **Build Digital Foundation:** These projects will help establish an infrastructure for components and simulation models to drive agility and accelerated design cycles. As the name describes, these projects are foundational for the future deployment of advanced manufacturing technologies across the Defense and Organic Industrial Bases (DIB and OIB)
- **Supporting Efforts:** These projects centralize common activities across the projects in other swim lanes to drive the adoption of the developed capabilities. These projects standardize documentation, drive efficient delivery, and strive to build awareness and competency across the DIB and OIB

#### **No Regrets Next Steps**

Through the roadmap and the process of crafting it, America Makes has gained valuable insight into how development and funding should be positioned and delivered to impact casting and forging supply chains. With a path forward established, continued, and sustained investment is required to ensure that warfighter readiness is enabled by arming the CF ecosystems with accessible and capable AM solutions. To realize a broad and enduring national capability, continued focus is required to ensure technology development is transferred from demonstration to production, realized through three key next steps:

#### **Lower Adoption Risk**

While the benefits and potential of AM are well known, so are many examples of failed printing pilots. Many risks driving these failures are seemingly hidden as they sit adjacent to the printing process. Providing small and medium manufacturers with resources to make informed decisions on when to use AM and to upskill staff without major financial investment will support the broader adoption of AM technologies. **Invest in Technology Deployment** 

Implementing AM successfully requires much more than a capable printer. Continued focus on transferring key outcomes out of the lab and onto the shop floor is crucial to drive familiarity with AM and create true learning environments for users. Guidance for everyday process control should be established and provided as oversight to onboard new technology.

#### **Incentivize Expertise**

Early adopters of AM have significantly invested in developing their internal capabilities and intellectual property. These key examples have the potential to be replicated at scale but can only be done so by establishing incentives for knowledge sharing.

These areas are the "No Regrets Next Steps" necessary for the longterm success of an AM-augmented, agile, and resilient supply chain for the DoD.



# **Roadmap Structure & Navigation**



## The Roadmap Structure



TimeTine (months) 12	24	35 48	60 	Priority. Cost. & Duration
Perdoare Brothanting	finition	Define Deal Structural Resemblers Vocal-Austral Design Built Structure Dearston Banda Houses Davelopment Democification for Stranlog Fel		Priority: 3 Casting Projects 48 Month Total Duration
Hardware Selection Like Case TDP De	efinition	Define Shell Structural Parameters		Output     Techno-Economic Framework     Process Deployment Guide
		Oxfore Smill Structure Presenters Mode-Kasteet Swige Rule Environment Rule Environment Deversional Societion As Streaming Environmental Societion As Streaming FeV		Outcomes - All ceramic technology selection for 3 materials systems - Grade C performance of material assessed - 3 products assess through FAI - Transferability of outcomes assessed
Prentivera Benommarking Prentivera Setextain Use Case TDP De	Whiten	Defre Datt Skutskaf Parweters Mozek-katised Delge Datt Envision Eugenion Particle Process Desegoner: Diversion Schoor for Streeting		Impact - Demonstrate 50%+ lead time reduction potentits - Network of capable suppliers for rapid deployment - Network of capable supplices for rapid deployment - Network of capable suppli

21 PROJECTS

#### **4 SWIM LANES**

Scale Current State	Disseminate established technology beyond siloed pockets of expertise
Prove Production Capability	Mature demonstrated and emerging technology to predictably meet production needs
Build Digital Foundation	Establish infrastructure for component/simulation models to drive agility and accelerated design cycles
Supporting Efforts	Centralize shared activities across projects to standardize documentation and drive efficient delivery





**Implementation Activities** Identified over three stages: near-term, mid-term, and long-term



**Impact, Output, and Outcomes** Results and products of project delivery



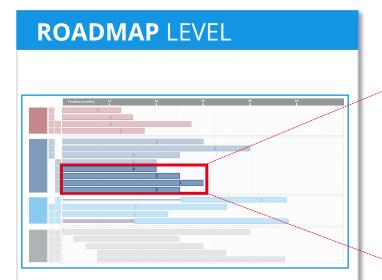
**Interdependencies** Connectivity outlined across projects, lines of effort, and sub-tasks

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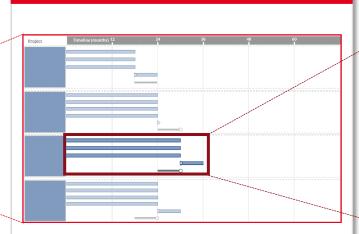


## Navigating the Roadmap



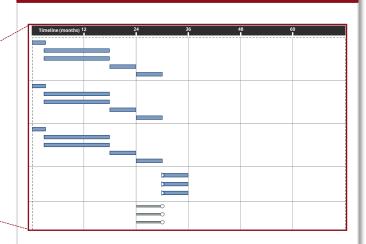
The highest level depicts the multi-year view of all projects, summarizing their attributes and impacts. It provides the framework for down-selecting projects and their activities for funding, organizing the overall projects by applicable ecosystem (casting/forging) and area of focus (swim lane).





The swim lane level organizes projects that aim to achieve similar outcomes, and are delineated along the lines of technology maturity and the digitalphysical nature of AM. This level of the roadmap presents a deeper look into each swim lane and its projects.

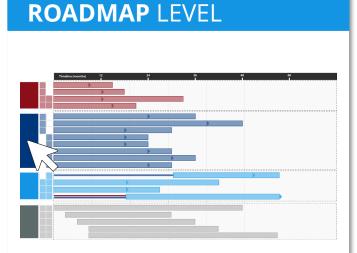
#### **PROJECT** LEVEL



The project level details execution plans that drive individual activities to a specific application domain and outcome. They provide a structured and comprehensive breakdown that describes the attributes of priority, schedule, and results (output, outcomes, and impact).

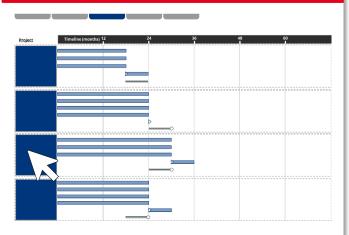


## Navigating the Roadmap Continued



To navigate to a swim lane, click the swim lane title along the left of the slide. To navigate to a particular project, click the project bar within the roadmap.

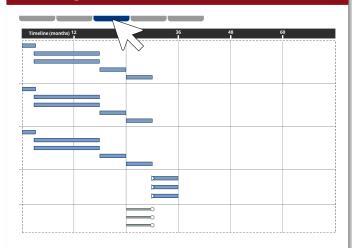
#### SWIM LANE LEVEL



To navigate back to the roadmap or a different swim lane, click the appropriate button at the top of the slide.

To navigate to a particular project, click the project title along the left of the slide.

#### **PROJECT** LEVEL



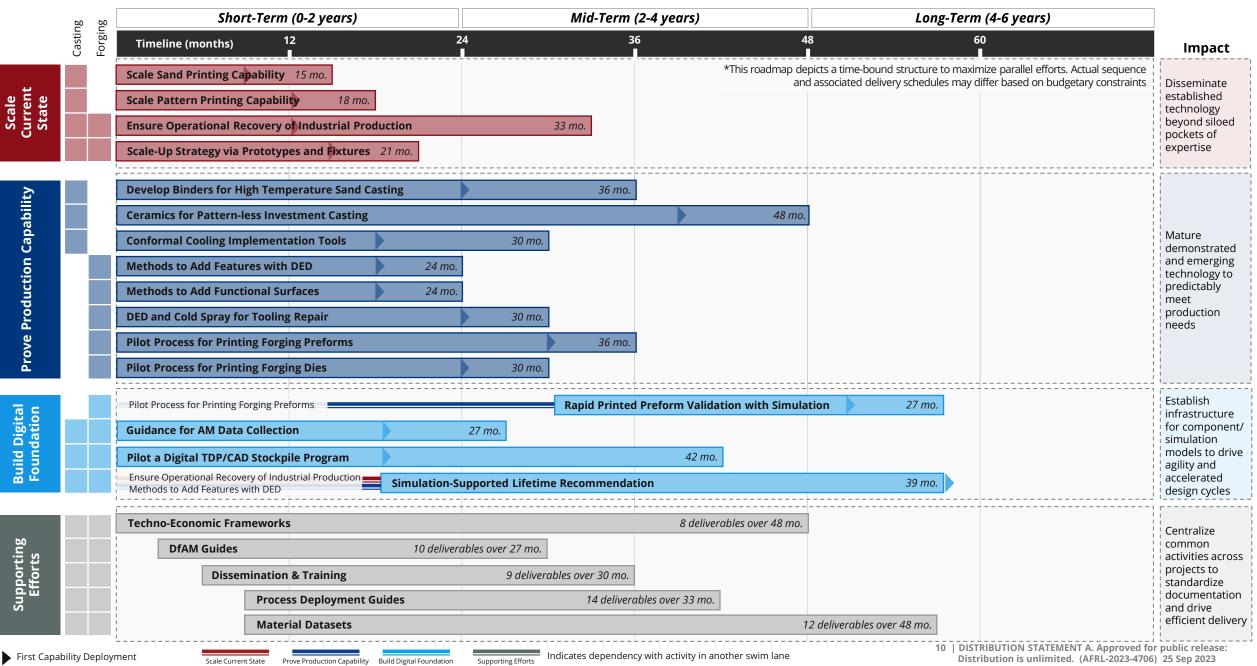
To navigate back to a swim lane or the roadmap, click the appropriate button at the top of the slide.



# Additive Manufacturing Technology Roadmap

#### Additive Manufacturing Technology Roadmap for Castings and Forgings





## **Casting Projects Overview**

# Forging Projects Overview

Scale Sand Printing Capability	Disseminate leading practices and promote adoption of 3D printed sand molds/cores	Methods to Add Features with DED	Established, assess, and demonstrate transferable capability to add complex geometric features to forgings
Scale Pattern Printing Capability	Develop and disseminate leading practices and promote adoption of 3D printed patterns for casting	Methods to Add Functional Surfaces	Established, assess, and demonstrate transferable capability to add functional surfaces to forgings
Develop Binders for High Temperature Sand Casting	Develop enhanced binder materials and strategies to drive processing efficiency of 3D printed sand	DED and Cold Spray for Tooling Repair	Establish methods for planned and unplanned tooling repair and modification applications
Ceramics for Pattern-less Investment Casting	Mature ceramic AM technology to enable rapid pours into integrated shell and cores	Pilot Process for Printing Forging Preforms	Pilot the industrialization of AM preforms to expedite the forging process for low volume components
Conformal Cooling Implementation Tools	Develop and disseminate performance-enhancing tools for implementing AM conformal cooling	Pilot Process for Printing Forging Dies	Pilot the industrialization of AM dies to expedite the forging process for low volume components
Scale Current State	Prove Production Capability Build Digital Foundation Supporting Efforts	Rapid Printed Preform Validation with Simulation	Enable optimized process setups with predictable performance using preforms with heterogenous microstructures

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## **Shared Projects Overview**

Ensure Operational Recovery of Industrial Production	Establish scalable sourcing model for AM industrial equipment replacement parts to keep critical production equipment running	Techno-Economic Frameworks	Drive AM utilization by establishing frameworks that clearly define when, where, and how to print feasibly and economically
Scale-Up Strategy via Prototypes and Fixtures	Define an optimal dissemination strategy for design/deployment guides through prototypes & fixtures	Design for Additive Manufacturing Guides	Enable confident and efficient usage of AM by documenting proven design rules across parts, tooling, and accessories
Guidance for AM Data Collection	Establish data infrastructure and application-based guidance to collect store data spanning AM process flows	Dissemination & Training	Scale the adoption of technical development with focused and strategic communication to build a pipeline of SMMs ready to leverage AM capabilities
Pilot a Digital TDP/CAD Stockpile Program	Accelerate the creation of TDPs and CAD models for legacy components by building a program of record for continued conversion	Process Deployment Guides	Build delivery mechanisms for technical development by documenting clear and tested procedures for implementing and controlling AM processes on the shop floor
Simulation- Supported Lifetime Recommendation	Develop material and geometric performance software solutions to integrate into DoD process flows	Material Datasets	Enable cross-functional sharing with standardized management and storage of material data gathered during development activities





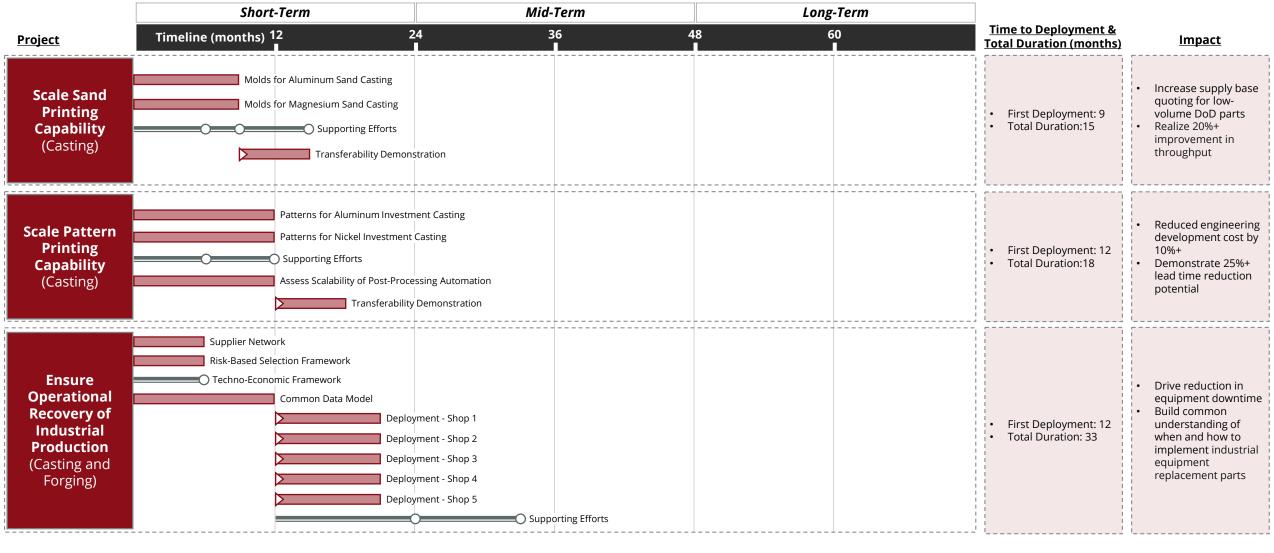
# Scale Current State

apability Build Digital Foundation

Supporting Efforts



#### **Scale Current State**



First Capability Deployment O Deliverable

Scale Current State Prove Production Capability Build Digital Foundation

Supporting Efforts Indicates this activity is interdependent of an activity in another swim lane



#### **Scale Current State**

	Short-Term		Mid-Term		Long-Term		
<u>Project</u>	Timeline (months) 12	24	36 I	48	60 I	<u>Time to Deployment &amp;</u> <u>Total Duration (months)</u>	<u>Impact</u>
Scale-Up	Machining Fixtures						Shorten development
Strategy via Prototypes	Inspection Fixtures Assembly Fixtures					First Danks mark 45	cycles by 10%+ by parallelizing activities
and Fixtures	Prototypes for Parallel Path	Development				<ul><li>First Deployment: 15</li><li>Total Duration: 21</li></ul>	<ul> <li>Build a common training and knowledge</li> </ul>
(Casting and Forging)	Strategy Assessmen						dissemination strategy
; <b></b>	Sup	porting Efforts				L	

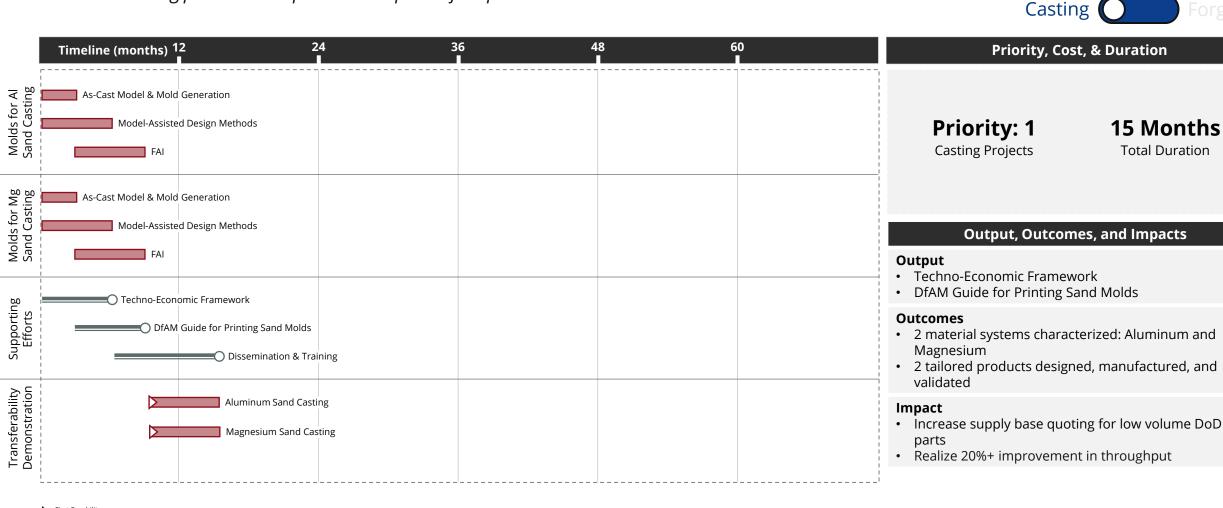
First Capability Deployment	O Deliverable	Scale Current State	Prove Production Capability	Build Digital Foundation	Su
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Supporting Efforts Indicates this activity is interdependent of an activity in another swim lane



#### **Scale Sand Printing Capability**

Disseminate leading practices and promote adoption of 3D printed sand molds/cores



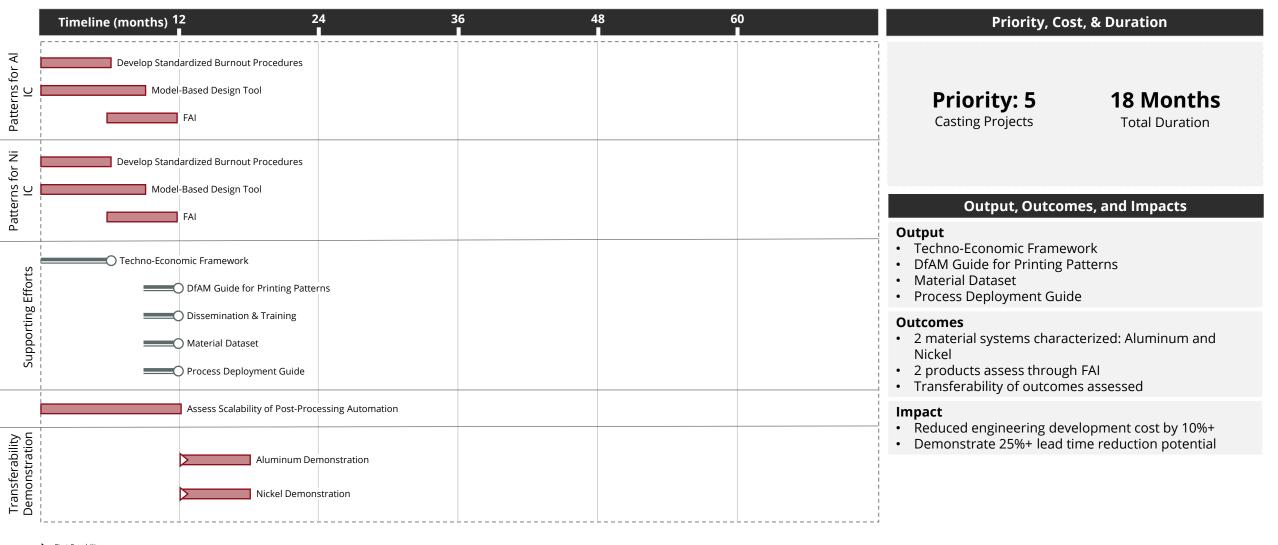


### **Scale Pattern Printing Capability**

Develop and disseminate leading practices and promote adoption of 3D printed patterns for casting



Forging



First Capability Deployment O Deliverable Supporting Efforts Roadmap

**Build Digital Foundation** 

**Supporting Efforts** 



#### **Ensure Operational Recovery of Industrial Production**

Establish scalable sourcing model for AM industrial equipment replacement parts to keep critical production equipment running



	Timeline (months) 12		24	36	48	60	Priority, Cost, & Duration	h	
	O Techno-Econon	tion Framework					Priority: 1 33 Mo Shared Projects Total D	onths uration	
Deploy Shop 1	Z	Produce Replaceme	nt Component duction Trial				Output, Outcomes, and Impa	icts	
Deploy Shop 2	Σ	Produce Replaceme	ent Component luction Trial				<ul> <li>Output</li> <li>Common Data Model for Industrial Equipment Replacement Parts</li> <li>Techno-Economic Framework</li> <li>Process Deployment Guide for Industrial Equipme Replacement Parts (including process selection)</li> </ul>		
Deploy Shop 3		Produce Replacement	ent Component luction Trial						
Deploy Shop 4		Produce Replaceme	ent Component				<ul><li>Outcomes</li><li>Produce and Validate 5 Components</li><li>Deploy to 5 production facilities</li></ul>		
	2	Pro Pro	duction Trial				<ul><li>Impact</li><li>Drive reduction in equipment downtime</li><li>Build common understanding of when an</li></ul>	nd how to	
Deploy Shop 5		Prod	luction Trial				implement industrial equipment replace	ment parts	
Supporting Efforts			Material Dataset     Process Deployment Guide     Dis	semination & Training					
	First Capability Deliverable	pporting Efforts					18   DISTRIBUTION STATEMENT A. Approved Distribution is unlimited. (AFRL-2023-470	for public release: 06) 25 Sep 2023	

Roadmap

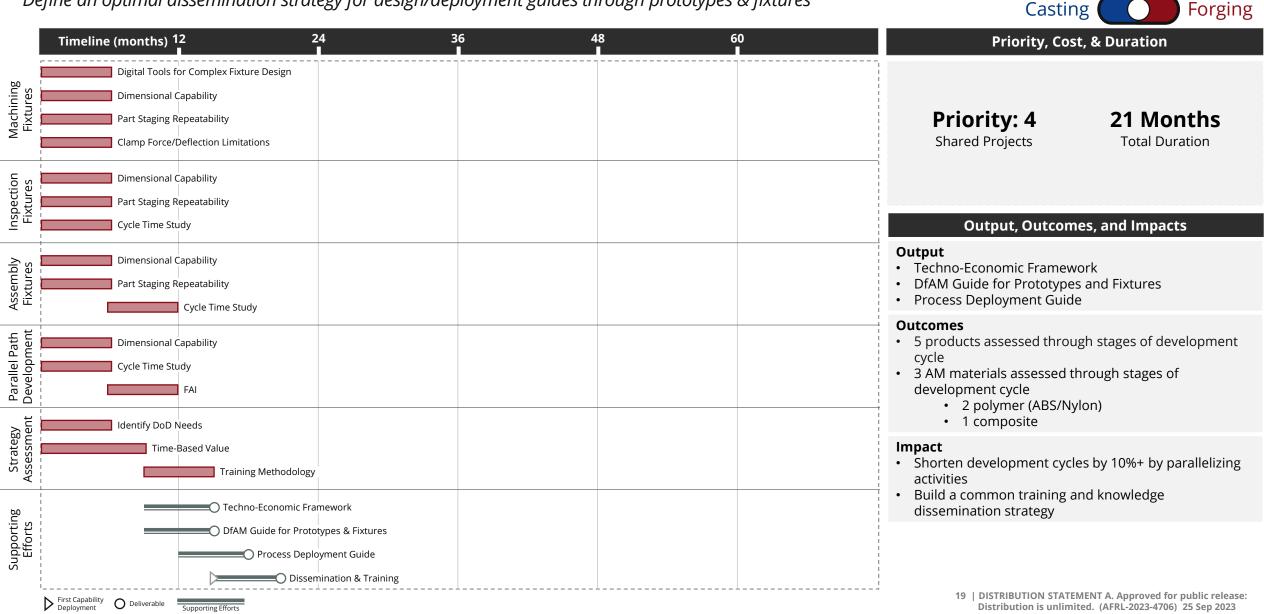
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Supporting Efforts



#### **Scale-Up Strategy via Prototypes and Fixtures**

Define an optimal dissemination strategy for design/deployment guides through prototypes & fixtures





# Prove Production Capability



### **Prove Production Capability**

	Short-Term	Mid-Term		Long-Term		
<u>Project</u>	Timeline (months) <sup>12</sup>	24 36	48	60 I	<u>Time to Deployment &amp;</u> <u>Total Duration (months)</u>	<u>lmpact</u>
Develop Binders for High Temperature Sand Casting (Casting)		Nickel Aluminum Bron Steel Sand Casting	nze Sand Casting orting Efforts		<ul> <li>First Deployment: 24</li> <li>Total Duration: 36</li> </ul>	<ul> <li>Capability to achieve high yield, repeatable Grade C casting performance for high temperature alloys</li> </ul>
Ceramics for Pattern-less Investment Casting (Casting)			Aluminum Investment Castings Nickel Investment Castings Titanium Investment Castings Transferabilit	/ Demonstration fforts	<ul> <li>First Deployment: 39</li> <li>Total Duration: 48</li> </ul>	<ul> <li>Demonstrate 50%+ lead time reduction potential</li> <li>Network of capable suppliers for rapid deployment</li> </ul>
Conformal Cooling Implementation Tools (Casting)	Tooling Te	chniques Aluminum Die Castings Magnesium Die Castings Production Pilot Supporting Efforts			<ul> <li>First Deployment: 18</li> <li>Total Duration: 30</li> </ul>	<ul> <li>Demonstrate 10%+ improvement in die life</li> <li>Demonstrate 30%+ lead time reduction for die casting tools</li> <li>Enable cooling channel optimization without highly specialized labor</li> </ul>
Methods to Add Features with DED (Forging)	Steel Base	e Material Material lase Material Transferability Pilot			<ul> <li>First Deployment: 18</li> <li>Total Duration: 24</li> </ul>	<ul> <li>Enable reduced lead times by adding features over sourcing new components</li> <li>30%+ lead time reduction</li> </ul>



#### **Prove Production Capability**

	Short-Term	Mid-Term	Long-Term		
<u>Project</u>	Timeline (months) 12 2	4 36 4	48 60 I	<u>Time to Deployment &amp;</u> <u>Total Duration (months)</u>	<u>Impact</u>
Methods to Add Functional Surfaces (Forging)	Nickel Base Ma Steel Base Mat Titanium Base	erial		<ul> <li>First Deployment: 18</li> <li>Total Duration: 24</li> </ul>	Improved lifetime of critical components
DED and Cold Spray Repair for Tooling Repair (Forging)		Aluminum Forging Tooling Nickel Aluminum Bronze Forging Tooling Nickel Forging Tooling Steel Forging Tooling Transferability Pilot Supporting Efforts		<ul> <li>First Deployment: 24</li> <li>Total Duration: 30</li> </ul>	<ul> <li>Alleviate tooling production capacity constraints through the increasing material efficiency, tool life, and tool performance</li> </ul>
Pilot Process for Printing Forging Preforms (Forging)		Aluminum Preform Nickel Preform Steel Preform Transferability Pilot O Supporting Efforts		<ul> <li>First Deployment: 30</li> <li>Total Duration: 36</li> </ul>	<ul> <li>Accelerated product development cycle that leverages model- based approaches</li> </ul>
<b>Pilot Process</b> for Printing Forging Dies (Forging)		Aluminum Forging Dies Nickel Aluminum Bronze Forging Dies Nickel Forging Dies Steel Forging Dies Serial Production Pilot Supporting Efforts		<ul> <li>First Deployment: 24</li> <li>Total Duration: 30</li> </ul>	<ul> <li>Demonstrate 50% lead time reduction for short run tooling dies</li> <li>Assess pathway to address no-bid/low volume forgings</li> </ul>

First Capability Deployment O Deliverable

Scale Current State Prove Production Capability Build Digital Foundation

Supporting Efforts Indicates this ac

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24

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Supporting Efforts

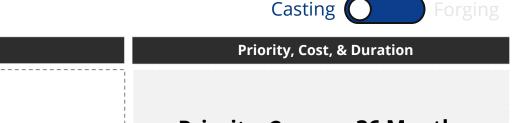
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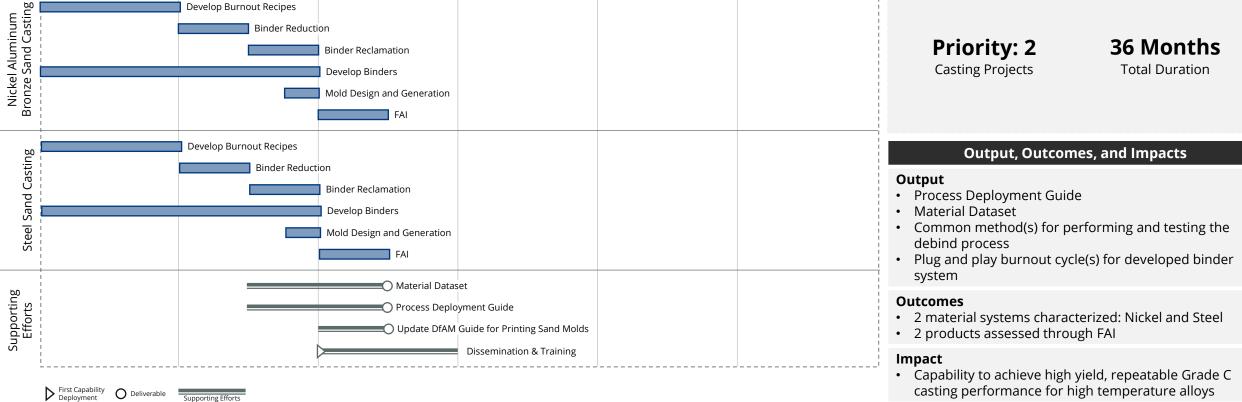


#### **Develop Binders for High Temperature Sand Casting**

36

Develop enhanced binder materials and strategies to drive processing efficiency of 3D printed sand





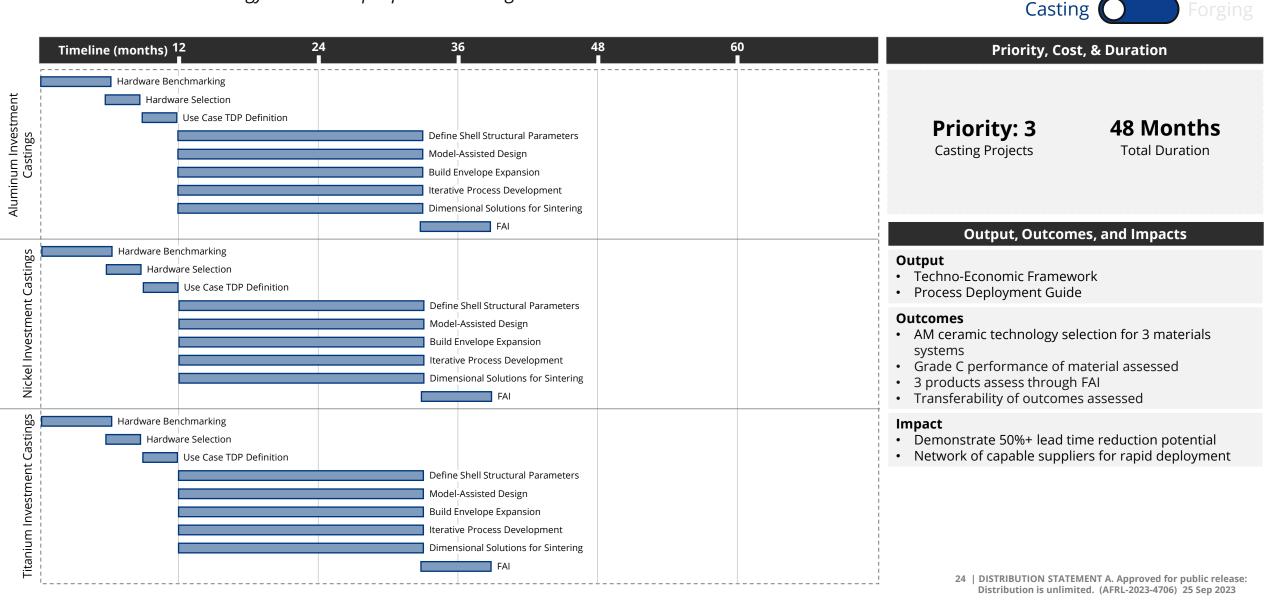
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Roadmap



#### **Ceramics for Pattern-less Investment Casting (1 of 2)**

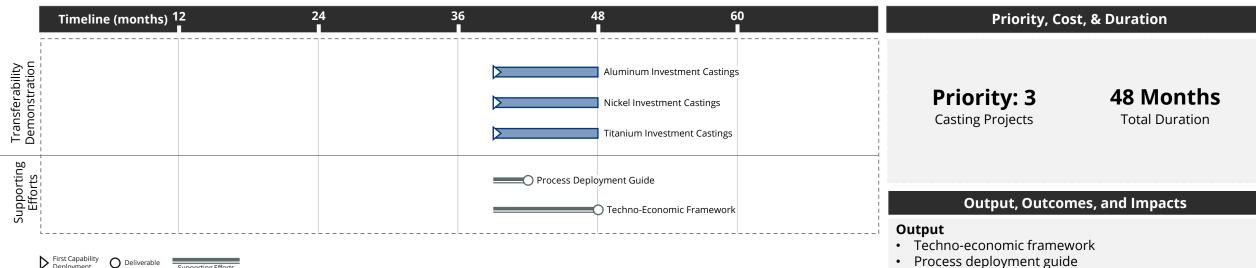
Mature ceramic AM technology to enable rapid pours into integrated shell and cores





#### **Ceramics for Pattern-less Investment Casting (2 of 2)**

Mature ceramic AM technology to enable rapid pours into integrated shell and cores



Supporting Efforts

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Casting

AM ceramic technology selection for 3 materials

• Demonstrate 50%+ lead time reduction potential • Network of capable suppliers for rapid deployment

Grade C performance of material assessed

3 products assess through FAI Transferability of outcomes assessed

Outcomes

Impact

systems

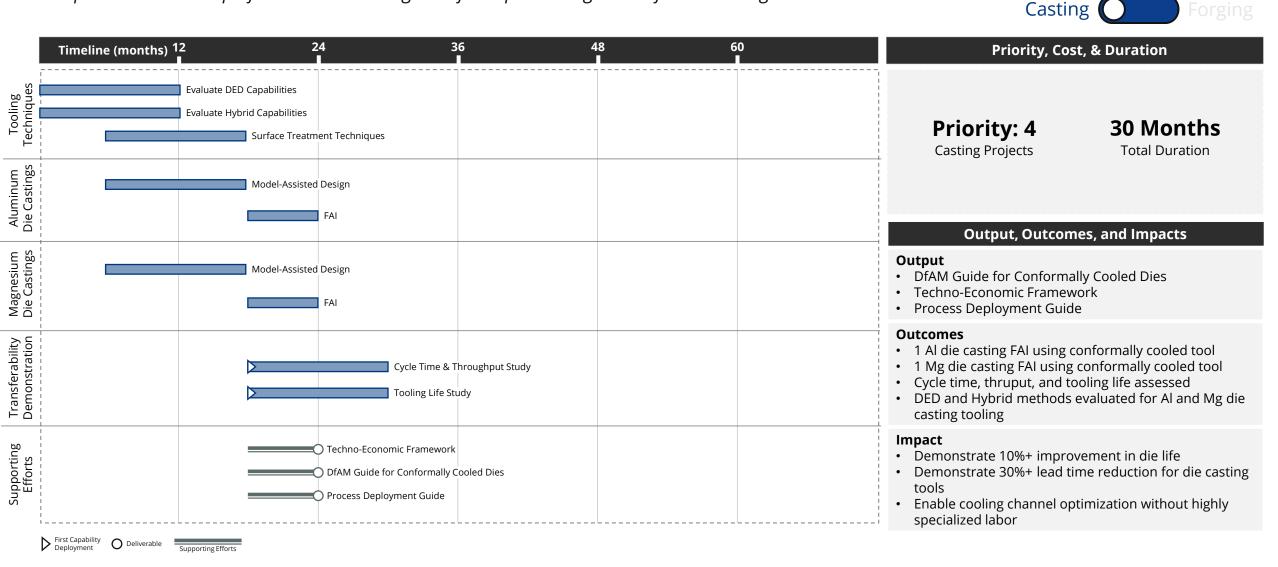
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Supporting Efforts



#### **Conformal Cooling Implementation Tools**

Develop and disseminate performance-enhancing tools for implementing AM conformal cooling



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Roadmap

Deployment

**Build Digital Foundation** 

Supporting Efforts



#### **Methods to Add Features with DED**

Established, assess, and demonstrate transferable capability to add complex geometric features to forgings Forging Priority, Cost, & Duration Timeline (months) 12 24 36 48 60 Repeatable Part Staging Methods Process Parameter Development Nickel Base Material **Priority: 1** 24 Months Material and Feedstock Specifications **Forging Projects Total Duration** Model-Assisted Design Methods FAI Process Parameter Development Steel Base Material **Output, Outcomes, and Impacts** Material and Feedstock Specifications Output Model-Assisted Design Methods DfAM Guide for Adding Features with DED FAI Material Dataset Process Deployment Guide Titanium Base Material **Process Parameter Development** Outcomes Material and Feedstock Specifications • 3 base material systems characterized 3 products assessed through FAI Model-Assisted Design Methods • 3 pilot demonstrations to reproduce outcomes at new FAI supplier Transferability Impact Nickel Transferability Pilot Enable reduced lead times by adding features over Pilot Steel Transferability Pilot sourcing new components • 30%+ lead time reduction Titanium Transferability Pilot Process Deployment Guide Supporting Efforts DfAM Guide for Adding Features with DED Material Dataset Dissemination & Training First Capability O Deliverable Supporting Efforts

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First Capability O Deliverable Supporting Efforts

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Supporting Efforts



#### **Methods to Add Functional Surfaces**

Established, assess, and demonstrate transferable capability to add functional surfaces to forgings



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	Timeline (months) <sup>12</sup>	2 24	4 3	6 -	48 I	60	Priority, Cost, & Duration		
Nickel Base Material		Environmental Degradation Ch Wear Mechanism Characterizat Model-Assisted Design Method FAI	ion				Priority: 224 MonthsForging ProjectsTotal Duration		
Steel Base Material		Environmental Degradation Ch Wear Mechanism Characterizat Model-Assisted Design Method FAI	ion				Output, Outcomes, and Impacts Output		
Titanium Base Material		Environmental Degradation Ch Wear Mechanism Characterizat Model-Assisted Design Method	ion				<ul> <li>DfAM Guide for Adding Functional Surfaces with DED</li> <li>Material Dataset</li> <li>Process Deployment Guidance</li> <li>Dissemination and Training</li> </ul>		
Transferability 7 Pilot			Nickel Transferability Pilot Steel Transferability Pilot Titanium Transferability Pilot				<ul> <li>3 base materials characterized <ul> <li>Environmental degradation and wear</li> <li>mechanism studied for each</li> </ul> </li> <li>3 products assessed through FAI</li> <li>3 pilot demonstrations to reproduce outcomes at new supplier</li> </ul>		
Supporting Efforts			) Process Deployment Guide ) DfAM Guide for Adding Functi ) Material Dataset ) Dissemination & Training	onal Surfaces with DED			<ul> <li>Improved lifetime of critical components</li> </ul>		

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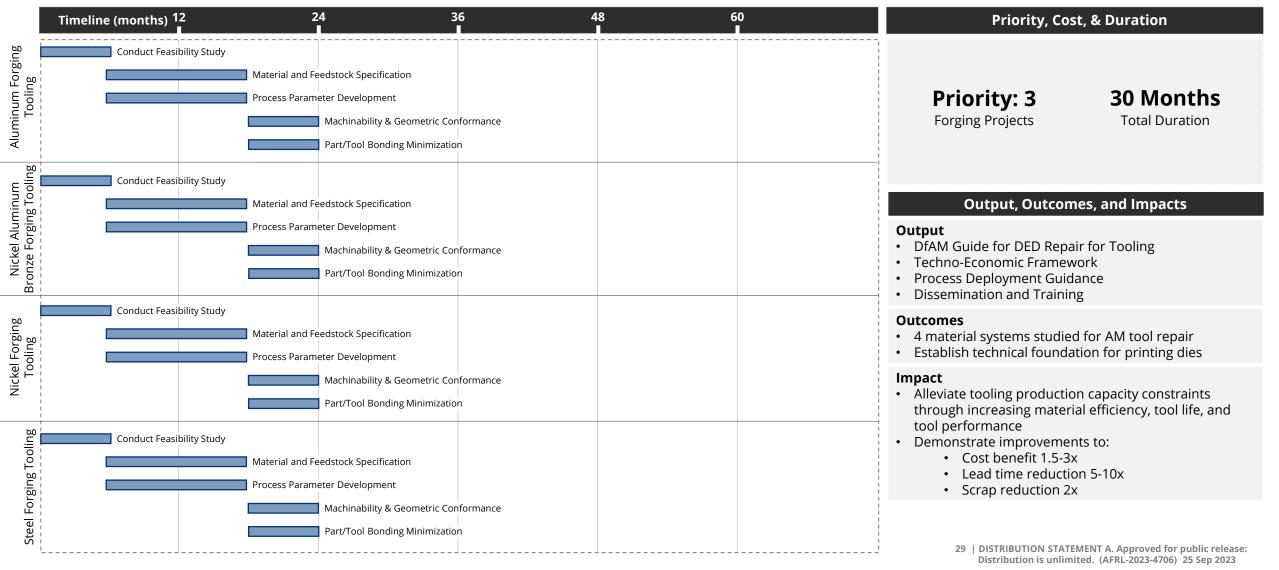
Supporting Efforts



### DED and Cold Spray for Tooling Repair (1 of 2)

Establish methods for planned and unplanned tooling repair and modification applications



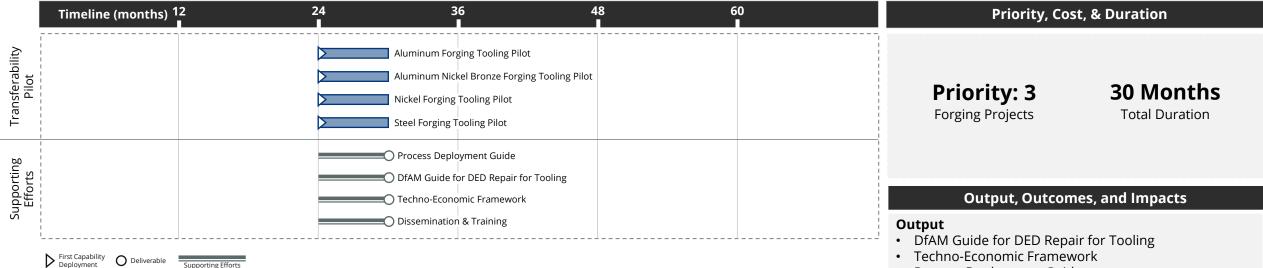




### **DED and Cold Spray for Tooling Repair (2 of 2)**

Establish methods for planned and unplanned tooling repair and modification applications





- Process Deployment Guidance
- **Dissemination and Training**

#### Outcomes

- 4 material systems studied for AM tool repair
- Establish technical foundation for printing dies

#### Impact

- Alleviate tooling production capacity constraints through increasing material efficiency, tool life, and tool performance
- Demonstrate improvements to:
  - Cost benefit 1.5-3x
  - Lead time reduction 5-10x
  - Scrap reduction 2x

First Capability

Deployment

O Deliverable

Supporting Efforts



## **Pilot Process for Printing Forging Preforms**

Pilot the industrialization of AM preforms to expedite the forging process for low volume components Forging 24 36 48 Timeline (months) 12 60 **Priority, Cost, & Duration** Capability Benchmarking Aluminum Preform Process Development Model-Assisted Design Development **Priority: 4** 36 Months Material Testing **Forging Projects Total Duration** FAI Capability Benchmarking Nickel Preform **Process Development Output, Outcomes, and Impacts** Model-Assisted Design Development Output Material Testing DfAM Guide for Printing Forging Preforms FAI Process Deployment Guide Material Dataset Capability Benchmarking Steel Preform Outcomes **Process Development**  3 material systems characterized Model-Assisted Design Development 3 products assessed through FAI Material Testing Transferability of outcomes tested for new part numbers FAI Transferability Pilot Impact Accelerated product development cycle that leverages Aluminum Preforms Pilot model-based approaches Nickel Preforms Pilot Steel Preforms Pilot Supporting Efforts DfAM Guide for Printing Forging Preforms Material Dataset Process Deployment Guide

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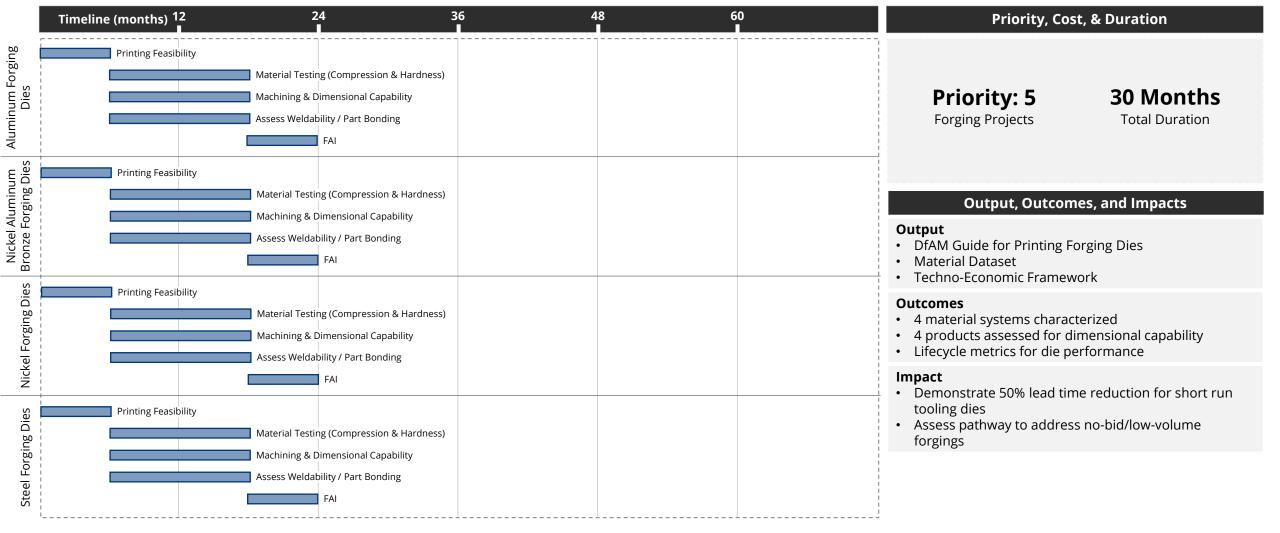
Supporting Efforts



### **Pilot Process for Printing Forging Dies (1 of 2)**

Pilot the industrialization of AM dies to expedite the forging process for low volume components



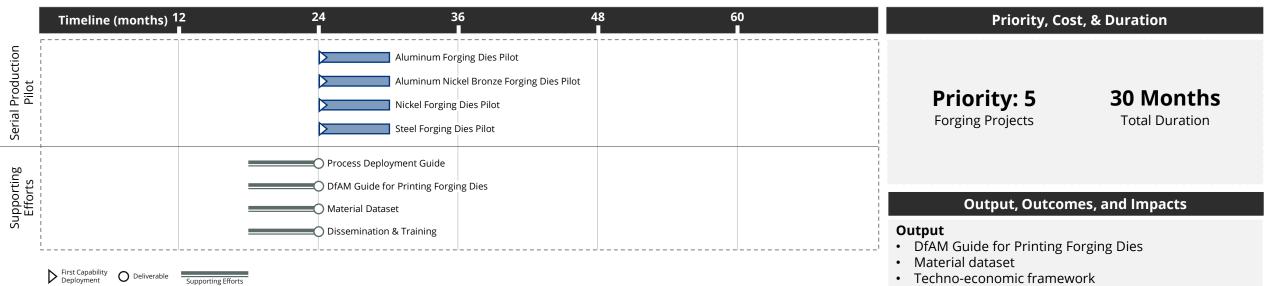




## **Pilot Process for Printing Forging Dies (2 of 2)**

Pilot the industrialization of AM dies to expedite the forging process for low volume components





#### Outcomes

- 4 material systems characterized
- 4 products assessed for dimensional capability
- Lifecycle metrics for die performance

#### Impact

- Demonstrate 50% lead time reduction for short run tooling dies
- Assess pathway to address no-bid/low-volume forgings



# **Build Digital Foundation**



## **Build Digital Foundation**

	Short-Term	Mid-Term	Long-Term		
<u>Project</u>	Timeline (months) <sup>12</sup>	24 36 4	8 60	<u>Time to Deployment &amp;</u> <u>Total Duration (months)</u>	<u>lmpact</u>
Rapid Printed Preform Validation with Simulation (Forging)	<ul> <li>Pilot Process for Printing Forging Preforms</li> </ul>		Additional Material Capability Additional Forging Process Additional Application Existing Model Optimization Model Validation / Pilots Supporting Efforts	<ul> <li>First Deployment: 21</li> <li>Total Duration: 27</li> </ul>	<ul> <li>Enable faster and right-first-time forging of printed preforms</li> <li>Establish framework to reduce number of intermediate forging steps</li> </ul>
<b>Guidance for</b> AM Data Collection (Casting and Forging)	Infrastructure Risk-Base	Data Collection Guidance Technical Guidance Transferability Demonstration		<ul> <li>First Deployment: 18</li> <li>Total Duration: 27</li> </ul>	<ul> <li>Common guidance on what data to gather and store based on application</li> <li>Infrastructure to aggregate data for advanced analysis, analytics, etc.</li> </ul>
Pilot a Digital TDP/CAD Stockpile Program (Casting and Forging)	Create Decision Tree Assess TDP Structure CAD Conve	rsion Process from Drawing CAD Conversion Process from Physical Part Scale-Up Supporting Efforts		<ul> <li>First Deployment: 18</li> <li>Total Duration: 42</li> </ul>	<ul> <li>Remove lead time for legacy CAD model creation</li> <li>Demonstrate reduced sourcing lead time by 25%+</li> </ul>
Simulation- Supported Lifetime Recommendation (Casting and Forging)	Methods to Add Features with DED Ensure Operational Recovery of Industrial Production	Parts with Added Featu Near Net Shape Parts fr Materi		<ul> <li>First Deployment: 39</li> <li>Total Duration: 39</li> </ul>	<ul> <li>Data-driven guidance for lifetime and testing plans for short-term use printed components</li> </ul>
First Capability Deployment	O Deliverable Scale Current State Prove Production Capability Build I	igital Foundation Supporting Efforts Indicates this activity is interde	25   apendent of an activity in another swim lane	DISTRIBUTION STATEMENT A. App Distribution is unlimited. (AFRL-2	

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Supporting Efforts



## **Rapid Printed Preform Validation with Simulation**

Enable optimized process setups with predictable performance using preforms with heterogenous microstructures



	Timeline (months) 12	24	36	48	60	Priority, Cost, & Duration
Additional Material	Pilot Process for Printing Forging Preforms		Baseline Assessment Model Calibration	Phy	sical Testing	Priority: 6 27 Months
Additional Process	Pilot Process for Printing Forging Preforms		Baseline Assessment Model Calibration	Phys	ical Testing	Forging Projects Total Duration
Additional Application	Pilot Process for Printing Forging Preforms		Baseline Assessment Model Calibration	Phys	ical Testing	Output, Outcomes, and Impacts Output • Material Datasets Outcomes
Existing Model Optimization	Pilot Process for Printing Forging Preforms				sical Testing lel Calibration	<ul> <li>1 material system assessed</li> <li>1 forging process assessed</li> <li>1 product assessed</li> <li>Pre-existing model optimized</li> </ul>
Model Exi Validation/ Pilot O	I       I <t< td=""><td></td><td></td><td></td><td>Additional Material Additional Forging Process Additional Application Existing Model</td><td><ul> <li>Impact</li> <li>Enable faster and right-first-time forging of printed preforms</li> <li>Establish a framework to reduce the number of intermediate forging steps</li> </ul></td></t<>				Additional Material Additional Forging Process Additional Application Existing Model	<ul> <li>Impact</li> <li>Enable faster and right-first-time forging of printed preforms</li> <li>Establish a framework to reduce the number of intermediate forging steps</li> </ul>
Supporting Efforts					<ul> <li>Material Dataset-Additional Material Dataset-Additional Proc</li> <li>Material Dataset-Additional Appl</li> <li>Material Dataset-Additional Appl</li> <li>Update Existing Material Dataset</li> </ul>	lication

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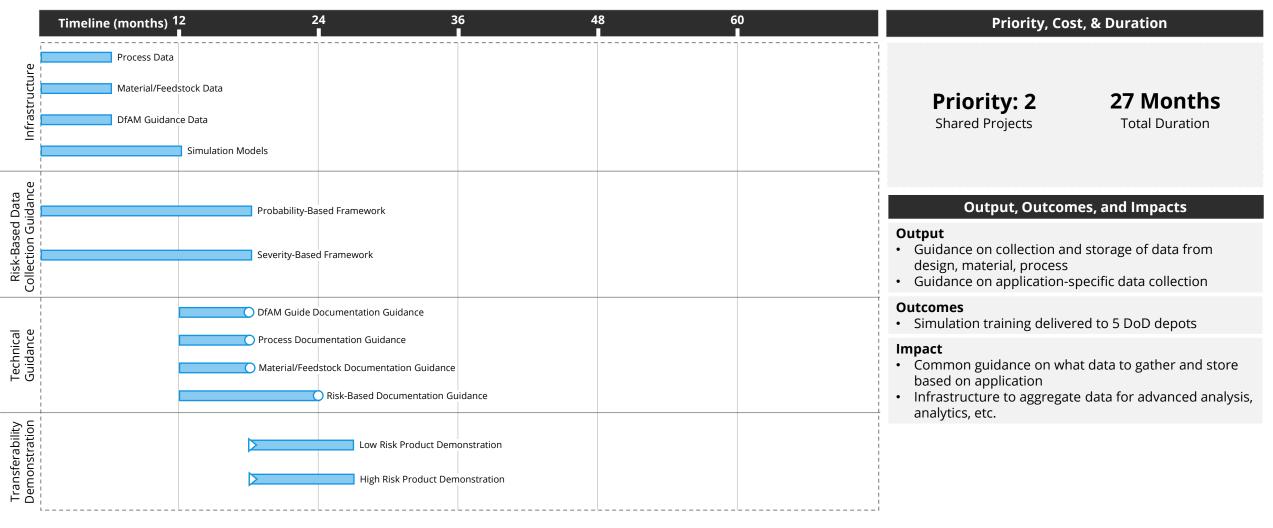
Supporting Efforts



#### **Guidance for AM Data Collection**

Establish data infrastructure and application-based guidance to collect store data spanning AM process flows





Deployment

Supporting Efforts

**Build Digital Foundation Prove Production Capability** 

Supporting Efforts



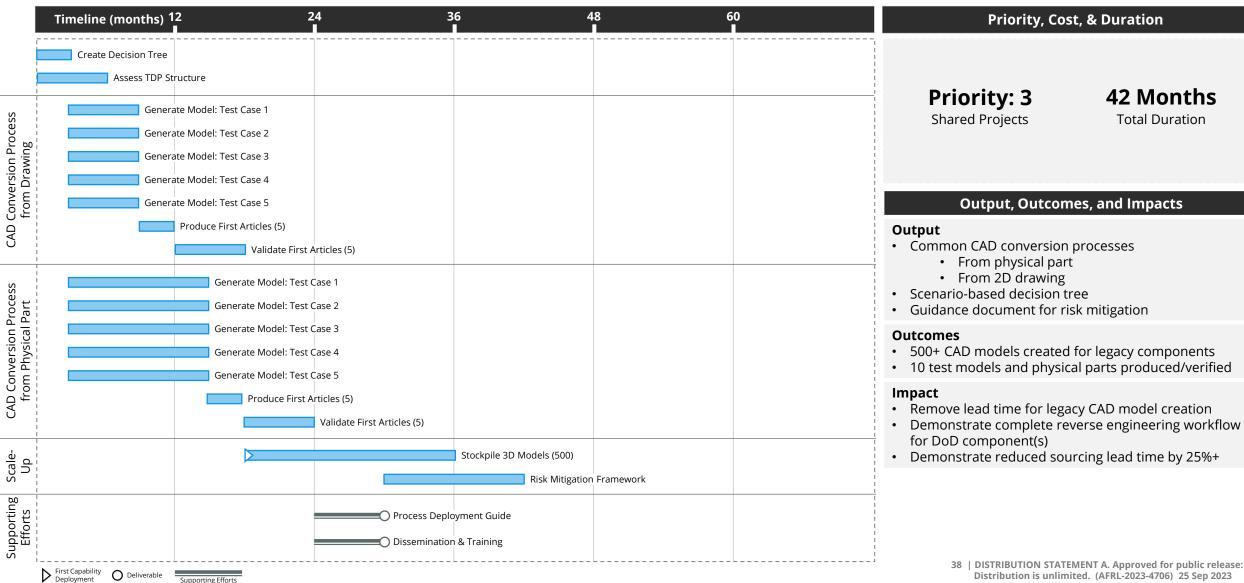
Forging

Casting

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# **Pilot a Digital TDP/CAD Stockpile Program** Accelerate the creation of TDPs and CAD models for legacy components by building a program of record for

continued conversion



Roadmap

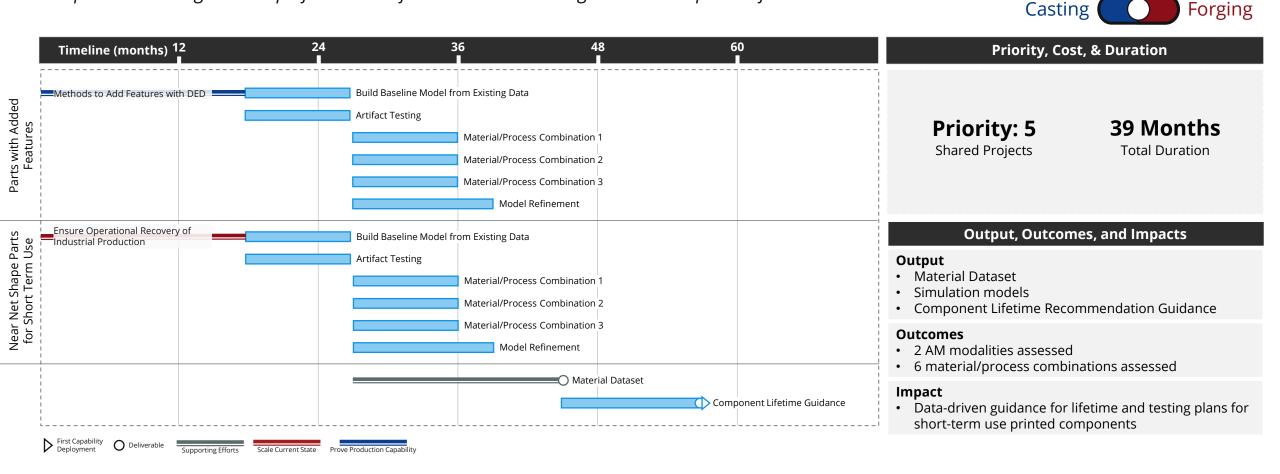
lity Build Digital Foundation

Supporting Efforts



#### **Simulation-Supported Lifetime Recommendation**

Develop material and geometric performance software solutions to integrate into DoD process flows







	Short-Term	Mid-Term	Long	Long-Term		
<u>Project</u>	Timeline (months) 12	24 36	48 0	60 •	<u>Total Deliverables &amp;</u> <u>Total Duration (months)</u>	<u>lmpact</u>
<b>Techno-</b> Economic Frameworks (Casting and Forging)	OTechno-Economic Framework for Printing S     OTechno-Economic Framework for Printing P     OTechno-Economic Framework for Operation     OTechno-Economic Framework for Operation	atterns	of Tooling Techno-Economic Framework	for Printing Ceramics	<ul> <li>Total Deliverables: 8</li> <li>Total Duration: 48</li> </ul>	Drive AM utilization by establishing frameworks that clearly define when, where, and how to print feasibly and economically
Design for Additive Manufacturing Guides (Casting and Forging)	DfAM Guide for Printing Sand Molds DfAM Guide for Printing Patt DfAM Guide for Prot				<ul> <li>Total Deliverables: 10</li> <li>Total Duration: 30</li> </ul>	Enable confident and efficient usage of AM by documenting proven design rules across parts, tooling, and accessories
<b>Dissemination &amp; Training</b> (Casting and Forging)	Dissemination & Training for	emination & Training for Prototypes & Fixtures Dissemination & Training for Adding Features with DED Dissemination & Training for Adding Functional Surfaces with Dissemination & Training for DED Repair for Dissemination & Training for TDP/CAD Stock Dissemination & Training for Operati	ooling bile Program		<ul> <li>Total Deliverables: 9</li> <li>Total Duration: 36</li> </ul>	Scale the adoption of technical development with focused and strategic communication to build a pipeline of SMMs ready to leverage AM capabilities

First Capability Deployment O Deliverable

Scale Current State Prove Production Capability Build Digital Foundation

Supporting Efforts Indicates this activity is interdependent of an activity in another swim lane

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	Short-Term Mid-Te		erm Long-Term			
<u>Project</u>	Timeline (months) <sup>12</sup> 24	a 36 ∎	48	60 I	<u>Total Deliverables &amp;</u> Total Duration (months)	<u>Impact</u>
Process Deployment Guides (Casting and Forging)		ment Guide for Prototypes & Fixtures Process Deployment Guide for Conformally Coole Process Deployment Guide for Adding Features w Process Deployment Guide for Printing Forging Di Process Deployment Guide for Operational Recov OProcess Deployment Guide for Hig OProcess Deployment Guide for TD OProcess Deployment Guide for Printing Forgine Di OProcess Deployment Guide for TD OProcess Deployment Guide for Printing Forgine Di OProcess Deployment Guide for Printine Forgine Di OProcess Deployment Guide for TD OProcess Deployment Guide for Printine Forgine F	ith DED Surfaces with DED ees ery gh Temperature Sand Casting ED Repair for Tooling DP/CAD Stockpile Program	nics for Nickel	<ul> <li>Total Deliverables: 14</li> <li>Total Duration: 42</li> </ul>	Build delivery mechanisms for technical development by documenting clear and tested procedures for implementing and controlling AM processes on the shop floor
<b>Material</b> <b>Datasets</b> (Casting and Forging)		erns Material Dataset for Operational Recovery Material Dataset for Adding Features with DED Material Dataset for Adding Functional Surfaces w Material Dataset for Printing Forging Dies Material Dataset for High Temper Material Dataset for Printing Forging Material Dataset for Printing Forging Material Dataset for Preforms ( Material Dataset for Pr	ature Sand Casting ing Preforms (Additional Material) (Additional Process) ditional Application)	Simulation Supported Lifetime	<ul> <li>Total Deliverables: 12</li> <li>Total Duration: 54</li> </ul>	Enable cross-functional sharing with standardized management and storage of material data gathered during development activities
First Capability Deployment	Deliverable Scale Current State Prove Production Capability Build Digital For	ndation Supporting Efforts Indicates this activity	ty is interdependent of an activity in and		DISTRIBUTION STATEMENT A. Ap Distribution is unlimited. (AFRL-	



# No Regrets Next Steps





No Regrets Next Steps It is imperative to enhance national security by maturing our industrial base with investments that free up CF capacity and streamline throughput





Lower adoption risk by disseminating resources and tools to make informed decisions for when to use AM.

Invest in technology **deployment** by transferring key capabilities and outcomes to the shop floor

Incentivize knowledge **sharing** by early adopters to replicate advanced capabilities at scale across the industrial base

<u></u>	

Incorporate nontechnical solutions to policy and workforce issues that will generate long-term success

To improve our nation's wartime readiness, we must address CF supply chain challenges and build on the momentum generated during roadmap development through continued ecosystem collaboration and targeted investment