ADVANCED MANUFACTURING METHODS ROADMAP FOR THE NUCLEAR ENERGY INDUSTRY

ISSUE STATEMENT

Considerable interest in advanced manufacturing methods (AMMs) is being expressed as the nuclear industry moves to toward new construction and installation of advanced nuclear power plants (NPPs). Multiple new technologies such as additive manufacturing (AM), powder metallurgy-hot isostatic pressing (PM-HIP), diode laser cladding (DLC), and others dictate increased understanding of these technologies before they can be readily applied to new build construction or component replacement. Deployment of many of these AMMs is also complicated by lack of standards, code body acceptance (e.g., ASME) and regulatory approval.

EPRI created the following *Advanced Manufacturing Methods Roadmap* laying out various projects, research and development needs to deploy these and other innovative manufacturing techniques within the nucelar industry.

DRIVERS

- <u>Near-net shaped component production:</u> The ability to produce near-net shaped parts can lead to significant reduction in machining time and raw materials required to produce a part.
- <u>Reduced lead times:</u> New manufacturing methods can often deliver components in weeks or a few months as opposed to conventional manufacturing methods (forging, casting, extrusion, etc.) which can often take years.
- <u>Flexible production of limited quantities of unique shapes:</u> AMMs may enable components to be produced essentially on demand in limited quantities eliminating the need for long term warehousing of parts, alternative supply chains, and replacement of obsolete components.
- <u>Reduced costs:</u> The reduction of lead times, integration of multiple parts without assembly steps, reduction of raw materials required for production, along with storage of those components, will ultimately lead to reduced costs.

RESULTS IMPLEMENTATION

The various projects within this research area focuses on development, deployment and technology transfer for end user implementation by working directly with manufacturers and utilities.

PROJECT PLAN

Research and development with concrete actions and results are necessary to bring forward many of the advanced manufacturing methods (AMMs) for use in the nuclear industry. This roadmap provides a strategic plan for AMM deployment through the following actions:

- Understanding AMMs and Applicability of Each
- Demonstrations of the AMMs at Scale
- Development of ASME Data Packages and Code Cases to Support Implementation of Certain AMMs

Understanding AMMs and Applicability of Each

EPRI is currently reviewing components in ALWRs/SMRs/ARs designs to better understand which AMMs will be most applicable for the manufacture of specific components. Component size often dictates which AMM should be used to produce a component/part and drives manufacturing value. For instance, large components should be produced by PM-HIP, while medium sized components can be produced by directed energy deposition-AM or PM-HIP. Smaller components may rely more heavily on powder bed AM applications. Additionally, alternative methods such as electron beam welding or advanced mechanical connection methods could be used to join specific components. Advanced cladding technologies such as diode laser cladding may be used to reduce the volume of cladding material necessary for a specific application and enable fabrication of improved materials and more reliable components.

Demonstrations of AMMs at Scale

EPRI, US Department of Energy, and a number of industry partners are working to demonstrate several AMMs and fabrication methods at 2/3-scale for the production of major component assemblies of the NuScale Power SMR design. These include: PM-HIP, electron beam welding, diode laser cladding, and directed energy deposition-AM. Through such demonstrations, manufacturers are able to better understand the applicability and advantages/disadvantages of each AMM, as well as the potential of success in implementing the new technologies. Each AMM being investigated will have applicability across the board and will hopefully result in significant cost savings for ALWRs/SMRs/ANLWRs.

Development of ASME Data Packages and Code Cases

ASME data packages and code cases will be necessary to implement any of the AMMs. EPRI has been successful in securing acceptance of multiple PM-HIP code cases and is currently working with ASME to recognize laser powder bed fusion AM. Once recognized, several other Code Cases are planned, particularly as they related to AR construction and implementation.

RISKS

Risks associated with AMMs are often tied to the acceptance of the technologies by Code or Regulatory authorities and the time that it takes to develop and demonstrate a new technology for nuclear use. These risks can be combated by developing novel qualification approaches, demonstrating AMMs in non-safety applications and obtaining valuable operating experience and prove-out.

RECORD OF REVISION

This record of revision will provide a high level summary of the major changes in the document and identify the roadmap owner.

Revision	*Description of Change*
0	Original Issue: August 2021

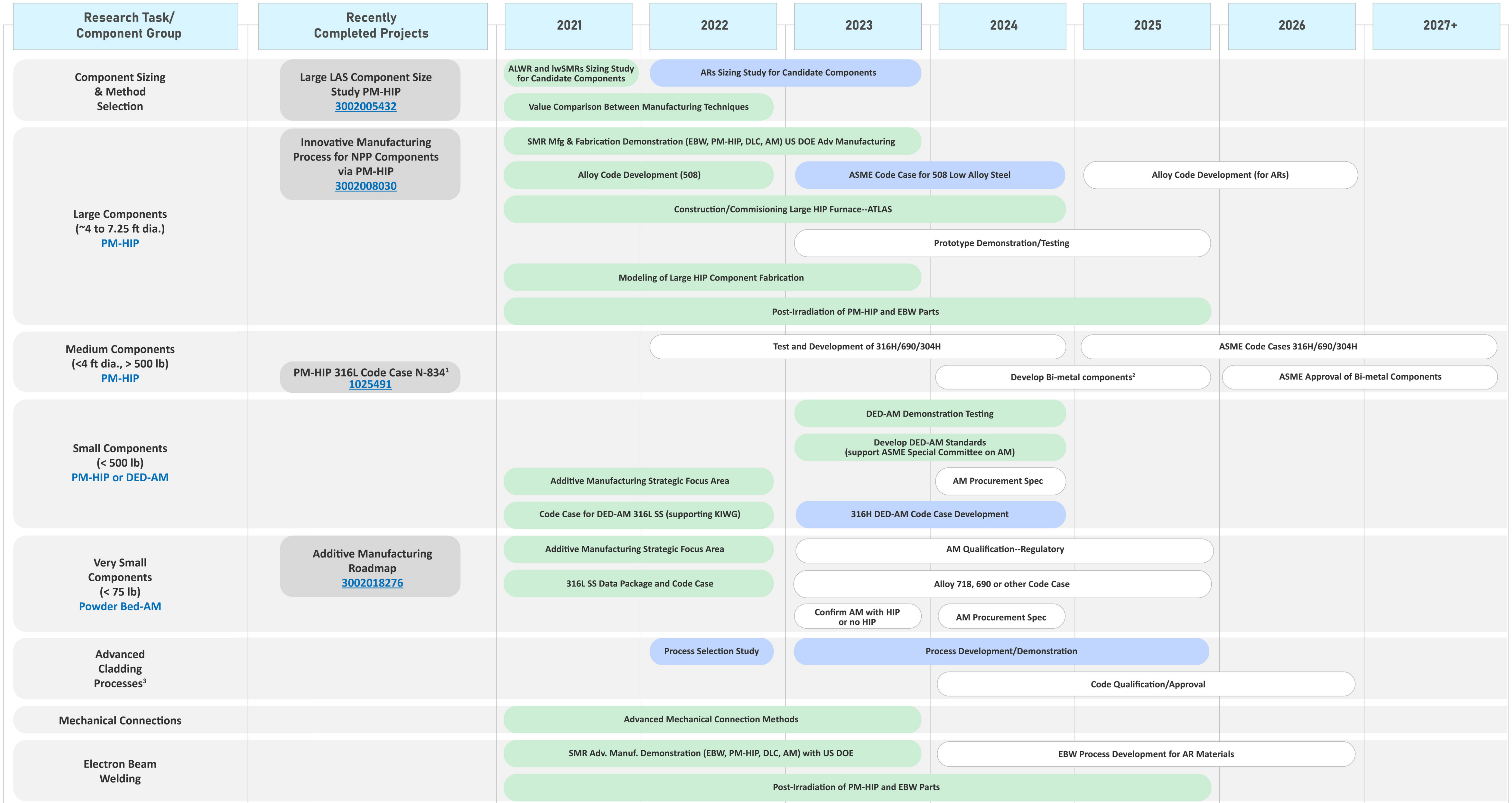
EPRI RESOURCES

David Gandy, Sr. Technical Executive
704.595.2695, davgandy@epri.com

Marc Albert, Sr. Technical Leader
704.595.2187, malbert@epri.com

Reach out to these resources for more information on EPRI's advanced manufacturing research

Advanced Manufacturing Methods – Class 1 Pressure Boundary



Completed Project | Active Project | Scoped Project | Concept

1. Applicable to all PM-HIP component sizes
2. Low Alloy Steel Nozzle / Stainless Steel Safe End
3. Diode Laser Cladding development is part of SMR Adv. Manufacturing Demonstration Project

Advanced Manufacturing Methods – Reactor Internals

EPRI

Research Task/ Component Group	Recently Completed Projects	2021	2022	2023	2024	2025	2026	2027+
Component Sizing & Method Selection	Large LAS Component Size Study PM-HIP 3002005432	ALWR and lwSMRs Sizing Study for Candidate Components Value Comparison Between Manufacturing Techniques	ARs Sizing Study for Candidate Components					
Large Internals (~4 to 7.25 ft dia.) PM-HIP	Note: PM-HIP of Reactor Internals are covered by Class 1 Pressure Boundary Roadmap							
Medium Internals (<4 ft dia., > 500 lb) PM-HIP								
Small Internals (< 500 lb) PM-HIP or DED-AM		DED-AM Demonstration Testing Develop DED-AM Standards (support ASME Special Committee on AM) Additive Manufacturing Strategic Focus Area Code Case for DED-AM 316L SS (supporting KIWG)		316H DED Code Case Development	Procurement Spec			
Fuel Hardware (inc. thin parts) Powder Bed AM[2]	Additive Manufacturing Roadmap 3002018276	Additive Manufacturing Strategic Focus Area 316L SS Data Package and Code Case		Build/Test AM Demonstration Components (Includes X-750/718/725) AM Qualification/Standards Development Confirm AM with HIP or no HIP	AM Procurement Spec			
Control Rod Drive Components				Process Selection Study AM/DED and/or PM-HIP (Includes Co Replacement Alloys)			Process Demonstration/Testing Process Qual/Standards Development	

Completed Project | Active Project | Scoped Project | Concept

1. Applicable to all PM-HIP Internals sizes
2. Powder Bed AM < 75 lb

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3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com