NATIONAL ENERGY TECHNOLOGY LABORATORY

ASSESSING THE EXPORT POTENTIAL FOR HIGH-PERFORMANCE MATERIALS

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ACRONYMS AND ABBREVIATIONS

A-USC	Advanced ultra-supercritical
AEO	Annual Energy Outlook
BEA	Bureau of Economic Analysis
CAGR	Compound annual growth rate
CCS	Carbon capture and storage
CO_2	Carbon dioxide
DOE	Department of Energy
ECIO	Econometric input-output
EEM	Extreme Environment Materials
ETA	Name of Greek symbol (η)
FE	Fossil energy
GDP	Gross domestic product
GW	Gigawatt
HPM	High-performance materials
ICME	Integrated computational materials engineering
LAMEA	Latin America, Middle East, and Africa
LHV	Lower heating value
MESA	Mission Execution and Strategic Analysis
NAICS	North American Industry Classification System
NEMS	National Energy Modeling System
NETL	National Energy Technology Laboratory
NGCC	Natural gas combined cycle
Ni	Nickel
R&D	Research and development
RD&D	Research, development, and demonstration
SEA	Systems Engineering and Analysis
U.S.	United States
USD	U.S. dollar
WVU	West Virginia University
°C	Degrees Celsius
°F	Degrees Fahrenheit

1 INTRODUCTION

The Energy Markets Analysis Team (EMAT), one team within the United States (U.S.) Department of Energy's (DOE) National Energy Technology Laboratory (NETL) Systems Engineering and Analysis (SEA) Directorate, develops and evaluates advanced energy systems to assist prioritization of research and development (R&D) resources. NETL program benefits are typically assessed by examining potential impacts that result from energy technology deployments within the U.S. Typical impacts investigated include, but are not limited to, changes in the cost of electricity, changes in emissions associated with electricity generation, and economic impacts that result from research expenditures or technology deployment including changes to U.S. gross domestic product (GDP) and employment. There is also substantial opportunity for NETL's knowledge and technology to be exported globally for deployment in other countries, creating the need to investigate the potential impacts to the U.S. economy of exporting goods or services reliant on NETL technologies.

The Advanced Energy Materials program[a] within NETL's Crosscutting Research Portfolio is funding R&D in high-performance materials (HPM) including high-temperature alloys, materials with better corrosion resistance, and materials with better high-temperature creep strength, all of which focus on lowering the cost and improving the performance of fossil-based power generation systems. These materials have the potential to withstand extremely high temperatures and pressures and to operate in environments with exposure to various corrosive slags and gases. Many of these materials will also be able to resist fatigue, which is caused by fluctuating pressures and temperatures, and creep, which is caused by prolonged exposure to high temperatures. Although the primary goal of NETL research is to develop and deploy these materials for use in advanced power systems, the attributes of the HPMs being developed at NETL make them potential candidates for use in other markets as well including, but not limited to, aerospace, mining, electronics, and medical equipment.

This report presents the results from analyses designed to assess the export potential and economic impacts resulting from the primary and potential secondary applications of NETL HPM R&D. Specifically, this report assesses the potential demand within international markets for HPMs in advanced ultra-supercritical (A-USC) and natural gas combined cycle (NGCC) power plants as well as the aerospace sector and estimates the potential economic impacts for the U.S. associated with the estimated HPM exports in each market.

Section 2 presents details on the global market for superalloys. Section 3 reviews relevant projects in the Advanced Energy Materials program within the Crosscutting Research Portfolio and assesses the export potential for HPMs and HPM products in both the A-USC and NGCC markets and others. Section 4 presents the assumptions and results of analyses that estimate the potential economic impacts of scenarios representing the export of products containing HPMs and related services for use in A-USC, NGCC, and aerospace applications; Section 5 concludes and offers directions for future research.

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[a] The Advanced Energy Materials program within the Crosscutting Research Portfolio focuses on material discovery and development that will lower the cost and improve the performance of fossil-based power-generation systems. For more information on NETL's HPM research, visit https://netl.doe.gov/coal/program124.

2 GLOBAL MARKET FOR SUPERALLOYS

The global metals market can be divided into the following categories:

- **Crude Steel**: typical low carbon steels
- **Stainless & Other Alloy Steel**: alloys typically with chromium or nickel (Ni) to enhance corrosion resistance and strength
- **High Strength Low Alloy**: alloys designed to provide high strength characteristics
- **Bearing & Tool Steel**: alloys designed to provide high strength and abrasion resistance
- **Superalloys**: alloys that exhibit several key characteristics: excellent mechanical strength, resistance to thermal creep deformation, good surface stability, and resistance to corrosion or oxidation (includes nickel-, cobalt-, iron-, and titanium-based alloys)

Superalloys represent only a small portion of the world metals market. Exhibit 2-1 displays the categorical breakdown of the global market for superalloys in 2016 as well as a forecast for 2023. [1]

Exhibit 2-1. Global market for superalloys

Segment	Sub-segment	Revenue – 2016	Forecast – 2023	CAGR
		(Millions)	(Millions)	(2017 – 2023)
Base-material	Nickel-based	$3,223	$5,848	8.6%
	Iron-based	$72	$112	6.3%
	Cobalt-based	$863	$1,717	10.0%
Application	Aerospace	$2,155	$3,925	8.6%
	Industrial Gas Turbine	$1,143	$2,150	9.2%
	Automotive	$226	$454	10.2%
	Oil and Gas	$183	$361	9.9%
	Industrial	$325	$565	7.9%
	Others	$126	$221	8.0%
Region	North America	$1,709	$3,062	8.4%
	Europe	$1,150	$2,148	9.0%
	Asia-Pacific	$1,006	$1,930	9.5%
	LAMEA	$293	$537	8.7%

Superalloys are nickel-, iron-, and cobalt-based alloys with a face-centered cubic structure, generally used at temperatures above 540°C (1,000°F). Exhibit 2-2 displays the breakdown of the superalloy market by base-metal.

Exhibit 2-2. Superalloy global market distribution, by base material

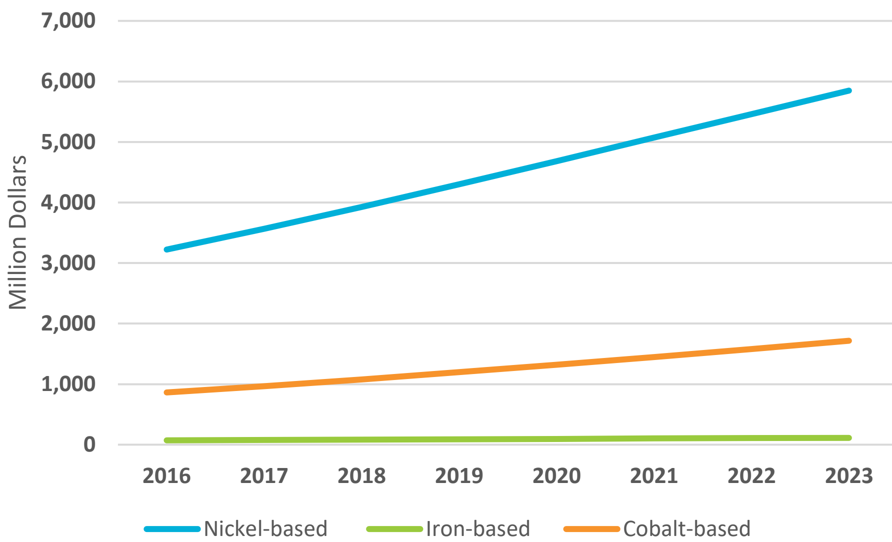
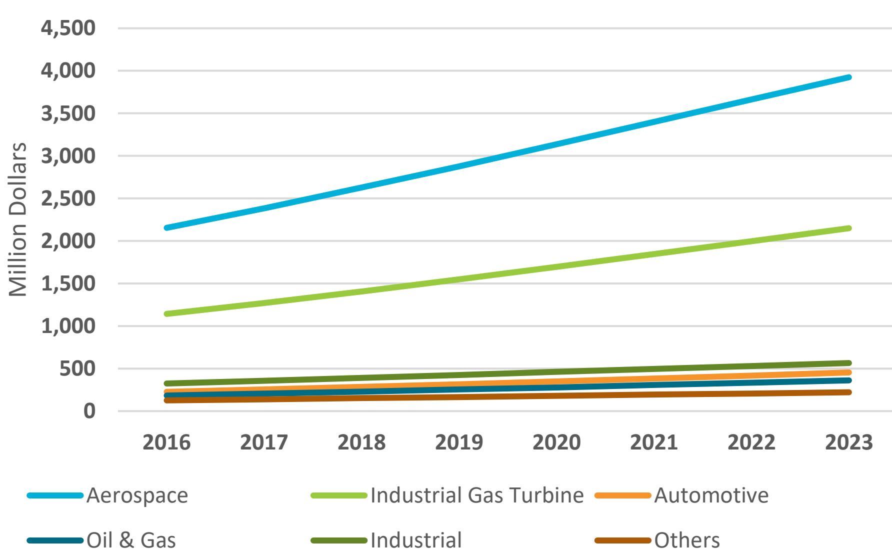


Exhibit 2-2 emphasizes that the majority of the superalloys are nickel-based. [1]

Exhibit 2-3 shows the distribution of the superalloy market across industrial sectors. A majority (52%) of superalloys are used in aerospace applications. Other uses include gas turbines, industrial applications, automotive applications, and applications in the oil and gas industry. Materials from the Crosscutting Research HPM Portfolio are considered high-performance alloys, a subset of the superalloys category.

Exhibit 2-3. Superalloy global market distribution, by application



3 Export Potential for High-Performance Materials and Products

To develop an estimate of export potential of HPMs for both the power generation market and other markets, NETL first needed to determine the primary and secondary markets of interest based on the current NETL research portfolio. This portfolio analysis and an assessment of data availability focused the analyses on the use of HPMs in the global markets for A-USC and NGCC power plants and aerospace applications. Results of the portfolio assessment as well as the estimates of export potential in each market are presented below.

3.1 Relevant Projects on Advanced Energy Materials

The FE portfolio of HPM research and development efforts include a diverse set of relevant projects encompassing a variety of topics including advanced manufacturing, computational materials, materials testing, and functional and structural materials development as shown in Exhibit 3-1.

Exhibit 3-1. Relevant NETL HPM development projects

Project Topic	Secondary Topic	Agreement Number	Project Title
Advanced Manufacturing	Advanced Manufacturing	SC0018856	Large Parts Additive Manufacturing
	Advanced Manufacturing	FEAA119	Demonstrate feasibility of additive manufacturing of high nickel alloys for FE components
	Advanced Manufacturing	FE0031637	Integrated Computational Materials and Mechanical Modeling for Additive Manufacturing of Alloys with Graded Structure used in Fossil Fuel Power Plants
	Advanced Manufacturing	FE0031631	ICME for Advanced Manufacturing of Nickel (Ni) Superalloy Heat Exchangers with High Temperature Creep + Oxidation Resistance for Supercritical CO_2
	Advanced Manufacturing	FEAA127	Additive Manufacturing of High Gamma Prime Alloys
Computational Materials	Computational Materials	FE0030585	The Novel Hybrid Start-off Model of High-Performance Structural Alloys Design for Fossil Energy Power Plants
	Computational Materials	FE0031554	Multi-modal Approach to Modeling Creep Deformation In Ni-Base Superalloys
	Computational Materials	FE0031553	High Throughput Computational Framework of Materials Properties for Extreme Environments

Project Topic	Secondary Topic	Agreement Number	Project Title
	Computational Materials	N/L	Advanced Computational Approaches to Nickel-based Superalloys
	Creep	FE0027822	Development of a Physically-Based Creep Model Incorporating ETA Phase Evolution for Nickel-Base Superalloys
	Creep	FE0030331	An Accelerated Creep Testing Program for Advanced Creep Resistant Alloys for High Temperature Fossil Energy Applications
	Creep	FE0027581	A Guideline for the Assessment of Uniaxial Creep and Creep-Fatigue Data and Models
	Creep	FEAA125	Long term creep and fatigue data on large H282 forgings and castings, and on H282 and Inc740 weldments for AUSC Comtest component design and fabrication processes and provide data for computational based mechanical performance prediction models
	Creep	FEAA116	Corrosion issues of Extreme Environment Materials (EEMs) in advanced coal fired boilers
	Creep	FEAA118	Weldability of Creep Resistant Alloys for Advanced Power Plants
	HPC4Materials	N/L	Understanding Complex, Coupled Mechanisms of Oxidation and Hot Corrosion Degradation with Computational Models
	HPC4Materials	N/L	High Performance Particle Based Modeling of Damage Nucleation from Forging Flaws in Fossil Power Generation Rotor Components
Structural	Structural	FE0025064	Advanced Ultra-Supercritical Component Testing
	Structural	FEAA125	Properties of Advanced Ni- based Alloys for AUSC Steam Turbines
Structural Alloys	Systems Analysis	FEAA128	Modeling Advanced Manufacturing of Nickel-based Alloys

N/L = Not listed

As can be seen in Exhibit 3-1, these efforts encompass not only HPM development but also include significant related work such as materials modeling, manufacturing, and testing.

The analysis team evaluated primarily the high-temperature superalloy projects from NETL's HPM project portfolio and their applicability to non-power generating sectors (all projects are assumed to be applicable to fossil-based power generation systems since that is the primary goal of NETL research in this area) as well as their commercial viability.

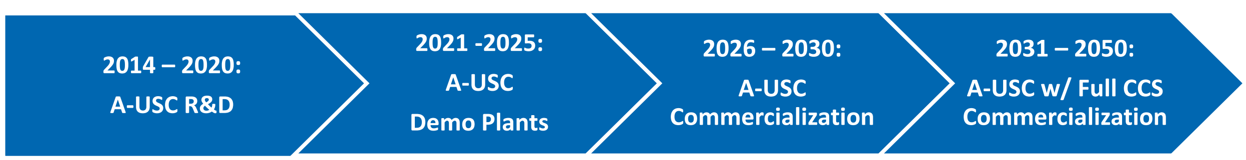
3.2 Export Potential in the A-USC and NGCC Markets

3.2.1 Export Potential in the A-USC Market

Although there are no planned new builds of coal-fired power generation capacity in the U.S., there are still large markets for coal-related technologies and materials in certain regions of the world. The materials and methods described above in Section 3.1 are being developed for advanced power systems such as A-USC coal-fired power generation plants. A-USC plants are high-temperature, high-pressure coal-powered electricity generation systems that will increase the efficiency of generation and reduce CO_2 emissions. The exact definition of A-USC varies. In the U.S., A-USC refers to systems capable of operating at or above 760°C (1,400°F), whereas in the European Union, Japan, China, and India, A-USC refers to systems capable of operating at or above 700°C (1,300°F). Nevertheless, all countries involved in A-USC research, development, and demonstration (RD&D) efforts are using advanced alloys based on nickel (superalloys) or nickel-iron superalloys to cope with the high-temperature, high-pressure steam conditions within these advanced power systems.

Exhibit 3-2 displays the estimated timeline for A-USC technology development and deployment that has been developed by the International Energy Agency after reviewing the RD&D efforts underway worldwide. [2]

Exhibit 3-2. Timeline for A-USC technology development and deployment [3]



Source: Adapted from International Energy Agency, "Technology Roadmap: High Efficiency, Low Emissions Coal-Fired Power Generation," International Energy Agency, 2012.

Technological leadership is a major advantage of being first to market. Through successful R&D and the patent process, the U.S. has the potential to become a first mover in the A-USC materials market and provide expertise worldwide. The U.S. could then maintain technology leadership via a learning curve effect, which could provide cost savings if learning can be kept proprietary.

Though participation in the A-USC materials export market has the potential for net increases in U.S. GDP as well as net domestic job creation, the extent of these impacts will depend on:

1. How the A-USC market develops around the world, and
2. What portion of the global market the U.S. is able to penetrate

3.2.2 Potential A-USC Market

The World Energy Outlook 2018 estimates that there will be 397 GW of new coal-fired power generation capacity built outside of North America within the A-USC commercialization period of 2026 to 2040. [4] Using the fact that roughly 20 percent of current global coal-fired power generation capacity is either supercritical or ultra-supercritical, it is assumed that 20 percent, or 84 GW, of the estimated new coal-fired power generation capacity built between 2026 and 2040 will be A-USC.

3.2.3 Market Penetration of U.S. A-USC Materials and Expertise

There are a number of other countries or regions that have fully functional RD&D programs in the area of A-USC materials and technologies and have the potential to become competitors in the global marketplace. Exhibit 3-3 contains a list of countries and regions with active A-USC RD&D programs, details on these programs, and details on their expected outcomes. [2, 5, 6]

Exhibit 3-3. Details on Active A-USC research programs around the world

Country/Region	Program Title(s)	Focus Areas	Expected Outcomes
China	U.S. China Clean Energy Research Center – Advanced Coal Technology Consortium	Joint RD&D efforts with the U.S. Research combustion, heat transfer, and ash deposition characteristics of large-capacity A-USC boilers	Computational models related to HPMs and A-USC power system components
India	National Thermal Power Corporation; Bharat Heavy Electricals Limited; Indira Ghandi Centre for Nuclear Research	Public utilities and research centers have begun work on developing and demonstrating A-USC technology for the power sector	A-USC demonstration facility by 2020
European Union	AD700 Programme COMTES700	HPM development Design, fabrication, and evaluation of A-USC boiler, turbine, and other components	Demonstration facility is operational and used for evaluating new materials and components A-USC commercialization in Europe is ultimate goal
Japan	METI Cool Earth	HPM development Evaluation of A-USC boiler, turbine, and valve components	Long duration field testing of boiler components was initiated in May 2015 Commercialization at 48% (LHV basis) efficiency is expected around 2020

The U.S. has defined a higher temperature threshold for HPMs to meet to operate within A-USC power plants and is actively supporting development of HPMs for this application, even though A-USC power plants might not be widely deployed domestically. However, competition from the countries or regions mentioned in Exhibit 3-3 within the market for HPMs and A-USC components fabricated from these materials could limit the global market penetration of U.S. technologies. After careful examination of the research programs and consideration of the policy environments around the world, the assumption that the U.S. could potentially capture 50 percent of the global market for A-USC builds was adopted for this analysis.

3.2.4 Export Potential in the NGCC Market

The World Energy Outlook 2018 estimates that there will be 589–649 GW of new natural gas-fired power generation capacity built outside of North America in the New Policies and Current Policies scenarios respectively, within the NGCC commercialization period of 2030 and 2040. [4] This analysis assumed that all of the estimated new natural gas-fired power generation capacity built between 2030 and 2040 will use gas turbines that contain HPMs.

3.3 Export Potential in Other Markets

3.3.1 Data Constraints

Although multiple potential markets were identified, the types of data necessary to quantitatively analyze the potential size of the market for NETL's HPMs and the economic impacts that could be attributed to the NETL RD&D on these HPMs are not available in many cases. Required industry-specific data include but are not limited to

- Projected growth in the global market for the application of interest
- Value of current U.S. exports
- Data to estimate the value of embodied HPMs within export values

The only industrial sector for which usable data are available is the aerospace sector. Since aerospace applications have the potential to be one of the largest markets for HPMs, secondary to NETL's primary targets of developing materials for electric power generation applications, this sector provides a good candidate to explore the economic implications of marketing HPMs developed at NETL to non-power generation markets.

3.3.2 Export Potential in the Aerospace Market

Demand for superalloys in aerospace applications is largely driven by efforts to improve engine efficiency and reduce emissions. According to Roskill, superalloys account for roughly 20 percent of the value of the materials used in aircraft annually. [5] Superalloys are used for a variety of aircraft types including commercial aircraft (80 percent of aerospace industry superalloy consumption), military aircraft (15 percent of aerospace industry superalloy consumption), and rotary aircraft or helicopters (5 percent of aerospace industry superalloy consumption). Although a large portion of the superalloys used in aerospace applications are used in aircraft engines, they are used in many other applications as well. Applications within the aerospace industry include:

- Turbine blades
- Vanes
- Combustor cans

- Turbine discs
- Aircraft fastener applications
- Airframe components
- Rocket engines

Three sectors of interest within publicly available economic data for the U.S. (available from the Bureau of Economic Analysis [BEA]) were identified to represent aerospace industries that use HPMs. [6] These sectors and their associated North American Industry Classification System (NAICS) codes are:

- Aircraft engine and engine parts manufacturing (336412)
- Propulsion units and parts for space vehicles and guided missiles (33641A)
- Other aircraft parts and auxiliary equipment manufacturing (336413)

Based on forecasts published by Boeing, total commodity output in these industries is assumed to grow by 3.5 percent per year from 2012 through 2040. [7]The percentage of total commodity output that is exported in each of these industries is assumed to remain constant at the 2017 level through 2040. Assuming that growth will only continue for U.S. aerospace exports after 2025 if HPMs are commercially available and used, scenarios assume 5–10 percent of the year-over-year growth in exports from 2026 onward to be attributable to NETL's HPM RD&D efforts. This method suggests that the HPM value within cumulative potential exports from 2026 to 2040 could be worth over $142 billion in 2018 USD, $3.5 billion of which can potentially be attributed to NETL RD&D.

4 Economic Impacts of Potential Exports

The NETL/West Virginia University (WVU) econometric input-output (ECIO) model was used to estimate U.S. economic impacts that could result from the export of A-USC, NGCC, and aerospace products that contain HPMs. The NETL/WVU ECIO model is a time-series enabled hybrid ECIO model that combines the capabilities of econometric modeling with the strengths of IO modeling. It was designed to facilitate the estimation of economic impacts of energy technology development, deployment, and operation over a forecast period consistent with the National Energy Modeling System (NEMS), providing a consistent and comprehensive method for quantifying NETL's programmatic impacts. However, this model can also be used to estimate the economic impacts that might result from increases in final demand driven by NETL RD&D, such as foreign exports of products related to HPMs. For these analyses, standard input data were altered to reflect export scenarios rather than domestic deployment of technologies. Specific assumptions and details related to each model run are detailed below.

HPMs are assumed to be commercially available in 2026 for A-USC and aerospace applications and are assumed to be commercially available in 2030 for NGCC applications, consistent with NETL HPM program goals. Market-specific details associated with all scenarios are provided within the subsections below. Employment, income, and GDP impacts were calculated for each case.

4.1 A-USC and NGCC Export Impacts

Representative costs for a 550 MW A-USC power plant were used to estimate the HPM value of the exported A-USC products and representative costs for a 350 MW NGCC power plant were used to estimate the HPM value of the exported NGCC products. Representative costs are shown in Exhibit 4-1 and were assumed to remain constant over the 15-year forecast period.

Exhibit 4-1. Cost assumptions for 550 MWnet A-USC and 350 MWnet NGCC reference plants

Item/Description	Equipment Cost (Million Dollars)	Value Attributable to HPMs (Million Dollars)	% Attributable to HPMs
A-USC Equipment	$341.24	$13.80	4%
NGCC Equipment	$76.10	$7.61	10%

Note: Values are in 2018 USD. Sums and calculated values might vary slightly due to rounding.

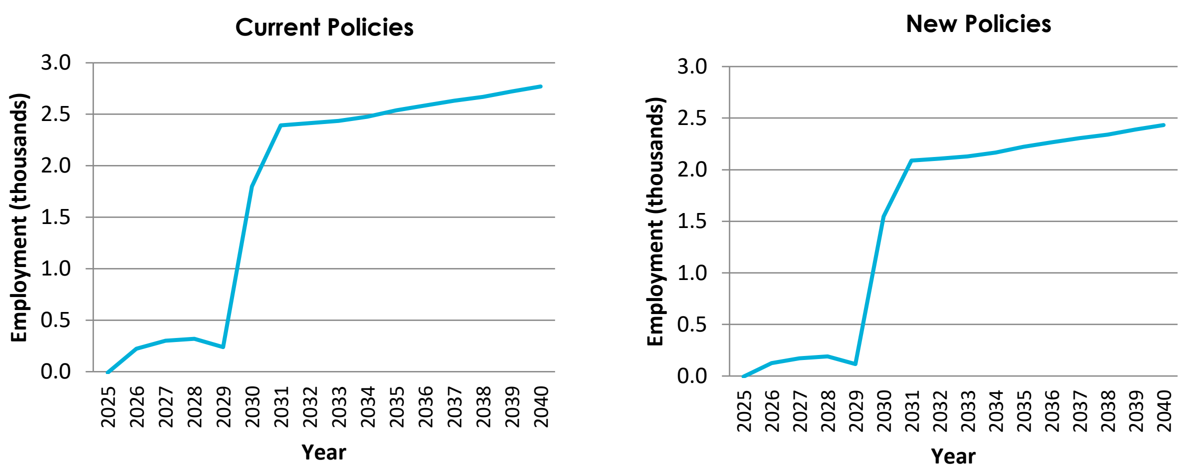
These costs and the size of the potential market for U.S. A-USC and NGCC products were used to calculate the total value of the products and services forecasted to be exported between 2026 and 2040. These values were then assigned to the appropriate economic sectors using publicly available data on industry specific production functions from the BEA Annual Input-Output Accounts for Fabricated Metal Product Manufacturing (NAICS 332). [8] Data on sector-specific increases in export final demand and energy-related data consistent with the NEMS Annual Energy Outlook (AEO) 2018 Reference Case were then entered into the NETL/WVU ECIO model to estimate the economic impacts of the potential A-USC and NGCC related exports. Results from the NETL/WVU ECIO model are displayed in Exhibit 4-2 and Exhibit 4-3.

Exhibit 4-2. Potential economic impacts of A-USC and NGCC exports

World Energy Outlook Scenario	HPM Value in Products Exported (2026 – 2040)	Cumulative Employment Impact in job-years (2026 – 2040)	Cumulative Income Impact (2026 – 2040)	Cumulative GDP Impact (2026 – 2040)
Current Policies	$3.228 billion	28,500	$1.868 billion	$4.599 billion
New Policies	$2.794 billion	24,600	$1.616 billion	$3.979 billion

Note: Dollar values are in 2018 USD.

Exhibit 4-3. Temporal distribution of potential employment impacts of A-USC and NGCC exports



Though the exact value of the impacts will depend on the commercial penetration of A-USC and NGCC technology around the world and on how much of each international market the U.S. captures to provide HPM parts, if 20 percent of global non-U.S. new builds are A-USC and 100 percent of global non-U.S. new natural gas builds are NGCC with turbines containing HPMs, and the U.S. captures 50 percent of those markets, then the HPM value in cumulative exports could reach more than $3.2 billion over the 15-year span (2026-2040). These exports could cumulatively create more than 28,000 job-years, over $1.8 billion in income, and over $4.5 billion in GDP over the 15-year span (2026-2040).

4.2 Aerospace Export Impacts

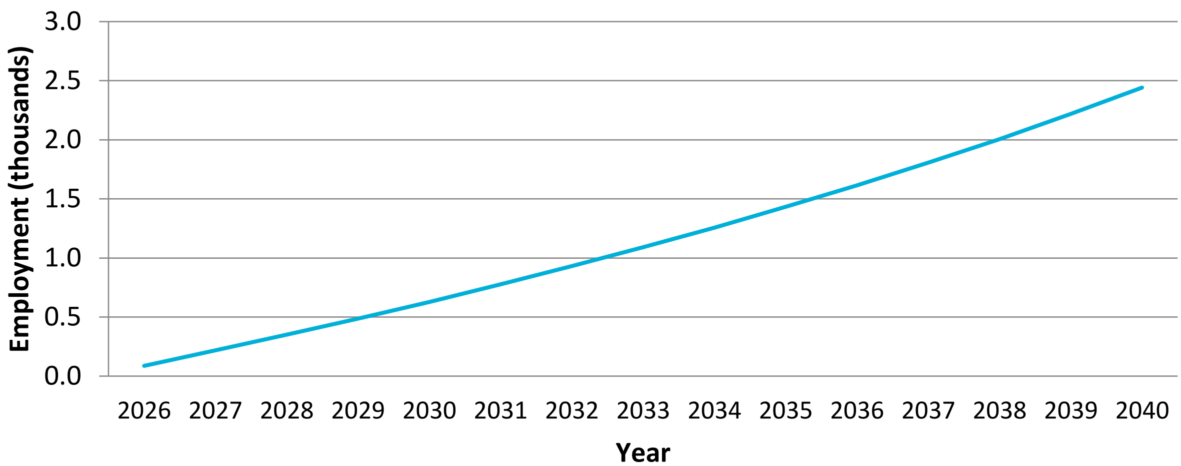
Publicly available data from the BEA Annual Input-Output accounts were used to estimate the value of U.S. exports in 2017 for the three aerospace-related sectors of interest that were identified in Section 3.3.2. [6] Detailed data from the 2007 Benchmark Input-Output accounts were used to disaggregate the sectors of interest within the 2017 Annual Input-Output data. The values for exports attributable to NETL were then assigned to the appropriate economic sectors using publicly available data on industry specific production functions from the BEA Benchmark Input-Output accounts for aerospace industries. Similar to the A-USC/NGCC analyses, data on sector-specific increases in export final demand and energy-related data consistent with the NEMS AEO 2018 Reference Case were then entered into the NETL/WVU ECIO model to estimate the economic impacts of the potential aerospace related exports. Results from the NETL/WVU ECIO model are displayed in Exhibit 4-4 and Exhibit 4-5.

Exhibit 4-4. Potential economic impacts of aerospace sector exports

% of Aerospace Exports Attributable to NETL RD&D	HPM Value of Products Exported (2026 – 2040)	Cumulative Employment Impact in job-years (2026 – 2040)	Cumulative Income Impact (2026 – 2040)	Cumulative GDP Impact (2026 – 2040)
5%	$0.943 billion	8,650	$0.609 billion	$1.464 billion
10%	$1.886 billion	17,300	$1.216 billion	$2.927 billion

Note: Dollar values are in 2018 USD.

Exhibit 4-5. Potential Annual Economic Impacts of aerospace sector exports, 10% scenario



Impacts will depend on the actual penetration of U.S. aerospace parts for aircraft and rocket assembly around the world and on the actual growth pattern of the global air fleet. However, if U.S. exports match the assumed annual growth rate of 3.5 percent across the identified sectors of interest and 10 percent of growth after 2024 is attributable to NETL RD&D in HPMs, then the HPM value in cumulative exports could total over $1.8 billion over the 15-year span (2026-2040). These exports could cumulatively create more than 17,000 job-years, over $1.2 billion in income, and $2.9 billion in GDP through 2040.

5 Conclusions

Although NETL typically focuses on the benefits of domestic deployments of its advanced power generation technologies, there is substantial opportunity for NETL's knowledge and technologies to be exported globally, creating the potential for real addition of demand for U.S. goods and services and positive impacts to the U.S. economy. Results from analyses designed to assess the export potential and economic impacts of potential exports of HPMs for use in A-USC and NGCC power plants and the aerospace sector suggest that these potential markets are quite large and could support a significant number of jobs and a significant amount of income should the U.S. be successful in becoming a global leader in HPMs and products that contain them.

The European Union, China, India, and Japan are all regions that will likely see deployment of A-USC power plants. Though the exact value of the impacts will depend on the commercial penetration of A-USC technology around the world and on how much of each international market the U.S. captures to provide parts that contain HPMs. If 20 percent of non-U.S. new coal builds after 2025 are A-USC and 100 percent of non-U.S. new natural gas builds in 2030 and beyond use turbines that contain HPMs, and the U.S. captures 50 percent of that market, then the HPM value in cumulative exports could reach more than $3.2 billion over the 15-year span (2026-2040), creating more than 28,000 job-years, over $1.8 billion in income, and over $4.5 billion in GDP through 2040.

Europe and Asia are also likely to be large export markets for aerospace products made with U.S. HPMs. Once again, the exact impacts will depend on the penetration of U.S. aerospace parts for aircraft and rocket assembly around the world and on the actual growth pattern of the global air fleet. However, if U.S. exports match the assumed annual growth rate of 3.5 percent across the identified sectors of interest, and 10 percent of growth after 2024 is assumed to be attributable to NETL research in HPMs, then then the HPM value in cumulative exports could total over $1.8 billion over the 15-year span (2026-2040), creating more than 17,000 job-years, over $1.2 billion in income, and $2.9 billion in GDP through 2040.

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