

# Assessing the Export Potential for High-Performance Materials

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U.S. DEPARTMENT OF  
**ENERGY**

# Motivation

- **NETL program benefits typically assessed as**
  - Reduced cost of electricity
  - Reduced emissions
  - Changes in economy - GDP, Jobs supported
- **Rarely are benefits assessed as the potential value and impacts of exports**
  - Measurable net jobs impact
  - Real addition of demand for U.S. goods and services
  - Roughly 11% of the U.S. economy was driven by exports in 2017
- **Large worldwide market for coal-related technologies and materials**
  - 40% of total generation in 2017 (WEO 2018)
  - 25% of total generation in 2040 (WEO 2018)
- **There is substantial opportunity for NETL's knowledge and technology to be exported globally, creating the potential for:**
  - Positive impacts to the United States economy
  - New exports generating new demand for U.S. goods and services

# Study Goals

- Overview of the global market for superalloys
- **Assess export potential related to A-USC/NGCC power plants**
  - Assess the international market for HPMs in A-USC/NGCC power plants
  - Estimate the size of the international market for HPMs in A-USC/NGCC power plants
- **Identify *secondary applications* of technologies within other industries**
  - Overview of applicability of HPMs to non-power sectors
  - Aerospace market emerged as the only candidate for analysis due to data constraints
- **Assess the international market for HPMs in the aerospace industry**
  - Estimate the current and future values of exports in the aerospace industry
  - Estimate the proportion of exports that can be attributed to HPMs

# Global Market for Superalloys

	Sub-segments	Revenue – 2016 (Millions)	Forecast – 2023 (Millions)	CAGR (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%

- In 2016, the global superalloys market was valued at \$4,158 million
- Estimated to reach \$7,677 million by 2023, growing at a CAGR of 8.9% from 2017 to 2023.
  - Fastest growing market region: India (CAGR of 9.8%)
  - High costs are anticipated to hamper market growth
  - Rise in demand from emerging economies
- Superalloys are used in:
  - aerospace
  - gas turbine engines
  - nuclear reactors
  - power generation turbines
  - petrochemical equipment
  - rocket engines
- Leading base material is nickel.
- Largest application is aerospace with nearly 50% of total market share in 2016.
  - Nickel-based superalloys constitute over 50% of the weight of advanced aircraft engines.

Source: Adapted from Doshi and Das (2018)

# NICKEL-BASED SUPERALLOYS MARKET REVENUE, BY REGION

2016 – 2023 (\$MILLION)



Region	2016	2017	2018	2019	2020	2021	2022	2023	CAGR % (2017 – 2023)
North America	1,329	1,467	1,610	1,757	1,907	2,059	2,210	2,359	8.2
Europe	894	993	1,097	1,205	1,316	1,430	1,545	1,660	9.0
Asia-Pacific	772	856	944	1,035	1,128	1,223	1,319	1,415	8.7
LAMEA	227	252	277	304	331	359	386	414	8.6
<b>TOTAL</b>	<b>3,223</b>	<b>3,568</b>	<b>3,928</b>	<b>4,300</b>	<b>4,683</b>	<b>5,071</b>	<b>5,461</b>	<b>5,848</b>	<b>8.6</b>

Source: Adapted from Doshi and Das (2018)

# NICKEL-BASED SUPERALLOYS MARKET VOLUME, BY REGION

2016 – 2023 (KILOTONS)



Region	2016	2017	2018	2019	2020	2021	2022	2023	CAGR % (2017 – 2023)
North America	106	117	129	142	155	168	181	194	8.8
Europe	69	77	77	94	102	112	121	130	9.2
Asia-Pacific	65	72	72	88	96	105	114	123	9.3
LAMEA	19	21	21	25	27	30	32	34	8.9
<b>TOTAL</b>	<b>258</b>	<b>287</b>	<b>287</b>	<b>348</b>	<b>381</b>	<b>414</b>	<b>448</b>	<b>481</b>	<b>9.0</b>

Source: Adapted from Doshi and Das (2018)

# GLOBAL SUPERALLOYS MARKET REVENUE, BY APPLICATION

2016 – 2023 (\$MILLION)



Region	2016	2017	2018	2019	2020	2021	2022	2023	CAGR % (2017 – 2023)
Aerospace	2,155	2,386	2,628	2,879	3,136	3,399	3,662	3,925	8.6
Industrial Gas Turbine	1,143	1,271	1,407	1,549	1,695	1,845	1,997	2,150	9.2
Automotive	226	254	284	316	349	383	418	454	10.2
Oil and Gas	183	205	229	253	279	306	334	361	9.9
Industrial	325	357	391	425	461	496	531	565	7.9
Others	126	139	152	166	180	194	208	221	8.0
<b>TOTAL</b>	<b>4,158</b>	<b>4,613</b>	<b>5,091</b>	<b>5,588</b>	<b>6,100</b>	<b>6,622</b>	<b>7,150</b>	<b>7,677</b>	<b>8.9</b>

Source: Adapted from Doshi and Das (2018)



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- *Identify secondary applications of technologies within other industries*
  - Overview of applicability of HPMs to non-power sectors
  - Aerospace market emerged as the only candidate for analysis due to data constraints
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# High Performance Material Use in Power Plants

Overview



- Advanced Ultra-Supercritical Coal (A-USC)
- Natural Gas Combined Cycle (NGCC)
- Estimated world markets for A-USC and NGCC

# A-USC Timelines



- **2020**
  - A-USC Component Test project
  - A-USC plant materials and fullscale component development
- **2025**
  - Large-scale A-USC demonstration plant (greenfield or retrofit)
- **2035**
  - Commercial operation of fullscale A-USC plant

# Natural Gas Combined Cycle

- Similar to A-USC applications, advanced alloys based on nickel (superalloys) or nickel-iron superalloys can help cope with the high temperature, high pressure steam.

# Potential A-USC Export Market for U.S. HPMs – Current Policies

WEO 2018



## Total New Coal Builds (World)

**397 GW**

Total New Coal Builds (2026 – 2040) outside of North America according to the World Energy Outlook 2018 published by the International Energy Agency

- Estimated percentage new builds that are A-USC: 20%

**Total Potential A-USC Export Market for U.S. Advanced Materials: 79 GW**

# Potential A-USC Export Market for U.S. HPMs – New Policies

WEO 2018



**Total New Coal Builds (World)**

**255 GW**

Total New Coal Builds (2026 – 2040) outside of North America according to the World Energy Outlook 2018 published by the International Energy Agency

- Estimated percentage new builds that are A-USC: 20%

**Total Potential A-USC Export Market for U.S. Advanced Materials: 51 GW**

# Potential NGCC Export Market for U.S. HPMs – Current Policies

WEO 2018



**Total New Natural Gas Builds  
(World)**

**649 GW**

Total New Natural Gas Builds (2026 – 2040) outside of North America according to the World Energy Outlook 2018 published by the International Energy Agency

- All new builds are expected to make use of HPMs, which are assumed to be commercially available for NGCC applications in 2030

**Total Potential NGCC Export Market for U.S. HPMs: 474 GW**

# Potential NGCC Export Market for U.S. HPMs – New Policies

WEO 2018



**Total New Natural Gas Builds  
(World)**

**589 GW**

Total New Natural Gas Builds (2026 – 2040) outside of North America according to the World Energy Outlook 2018 published by the International Energy Agency

- All new builds are expected to make use of HPMs, which are assumed to be commercially available for NGCC applications in 2030

**Total Potential NGCC Export Market for U.S. HPMs: 430 GW**



# Quantifying Economic Impacts for the U.S.



- **Economic Impacts of Interest:**
  - GDP
  - Employment
  - Income
- **Metrics necessary to calculate economic impacts**
  - Annual estimate of the value of A-USC and NGCC HPM exports
  - Specification of the economic sectors that will be impacted
- **Developed a spreadsheet model to estimate U.S. A-USC and NGCC materials exports in different scenarios**

# Equipment Costs (thousands 2009\$)

- **A-USC**

- 550 MWnet
- Total Equipment Costs: \$293,600
- HPM portion of Equipment Costs: \$11,870

- **NGCC**

- 350 MWnet
- Total Equipment Costs: \$65,479
- HPM portion of Equipment Costs: \$6,548

# Additional Assumptions

- **Results capture only the portion of the economic impacts associated with the value of HPMs within the equipment.**
  - HPMs represent approximately 4% of the value of the A-USC boiler equipment (PC Boiler and Accessories, Steam TG and Accessories, and Steam Piping)
  - HPMs are assumed to represent 10% of the value of the NGCC steam turbine equipment
- **Exports of A-USC HPMs begin in 2026**
- **Exports of NGCC HPMs begin in 2030**
- **U.S. captures 50% of the non-U.S. market for HPM parts for both A-USC and NGCC plants**
- **Costs are held constant over the forecast period**

- Designed to estimate the economic impacts of NETL's technology development, deployment, and operation over a corresponding NEMS forecast period
  - Comprehensive and consistent method to quantify NETL's programmatic impacts (employment and income)
- An ECIO model combines the capabilities of econometric (EC) modeling with the strengths of input-output (IO) modeling.
- Two components:
  1. The IO component is used to determine industry supply requirements and in some cases primary factor demands.
  2. The EC component determines final demands, primary factor demands, factor prices, primary factor supplies, and their relationships within the U.S.

# Total Economic Impacts of U.S. Exports for A-USC and NGCC Plants

Results from NETL-WVU ECIO Model



## Current Policies Scenario

- Value of exported products:  
**\$2.811 billion**
- Employment Impact:  
**28,500 job-years**
- Income Impact:  
**\$1.627 billion**
- GDP Impact:  
**\$4.005 billion**

## New Policies Scenario

- Value of exported products:  
**\$2.433 billion**
- Employment Impact:  
**24,600 job-years**
- Income Impact:  
**\$1.407 billion**
- GDP Impact:  
**\$3.465 billion**

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# Alternate Applications for Advanced Materials

*Aerospace – Largest HPA/Superalloy Market*



- **Large Project growth**
  - Current backlog equiv. to 3 years of output (Roskill)
- **Emphasis on improved engine efficiency**
  - Higher temperatures
  - Lighter weight
  - Proportion of “advanced” engines increasing annually
- **Resulting in earlier aircraft retirements and increased new aircraft purchases**
- **Aeroengine market to grow an estimated 3.5% through 2037 (Roskill)**



# Alternate Applications for HPMs

## *Energy & Power*



- **Oil & gas**
  - Deep well tubing, special tools, well heads and valves, pipelines, LNG storage
- **Electricity generation from fossil fuels**
  - Boilers, heat exchangers, steam turbines, electrostatic precipitators, FGD units, coal gasifiers, carbon capture units
- **Nuclear energy**
  - Containers for long-term storage of radioactive materials, nuclear fusion chamber, nuclear service water piping
- **Biofuel production**
  - Acid hydrolysis tanks and other equipment in ethanol production
- **Wind, wave, tidal and hydro power generation**
  - Gearing and generator components, marine corrosion protection
- **Solar energy, geothermal energy, waste-to-energy, fuel cells, energy storage**
  - Molten salt tanks and pipes, saline water pipes, incinerator and gas cleaning components, fuel cell components and catalyst, NiMH battery

## *Other Applications*

- **Medical Applications**
  - Surgical implants, medical tools, health care equipment and fixtures, dental tools and implants
- **Chemical, Pharmaceutical & Petrochemical**
  - Ni-steels, Ni-alloys, Ni-Cr-Mo-alloys, Ni-Cu-alloys, Ni-Ti-alloys
  - Austenitic, Duplex, Precipitation Hardenable stainless steels
  - Ni-irons, cast irons, Ni-plating
- **Pulp & Paper**
  - High wear/corrosive environments,, nickel alloys, and other nickel-containing alloys
- **Electronics**
  - Nickel-irons, stainless steels, high nickel alloys, nickel-containing copper alloys, nickel-plating, nickel-containing solders, nickel chemicals
  - Applications range from very large electronic pieces to nano-scale technology
- **Water**
  - Potable and waste water treatment, desalination
- **Automotive**
  - Light weight/strong structures Ni-alloys, Ni-steels, Ni-Fe alloys, Ni-powders
  - Ni batteries, fuel cells

# Data Availability for Potential Export Markets



- Although multiple potential markets were identified, data were not available to quantitatively analyze the potential benefits of the NETL R&D within many of these markets
- However, data for the aerospace market were identified
  - Projected growth in the global market
  - Current U.S. exports
  - Data to estimate the value of embodied advanced materials within export values

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# Advanced Materials Use in Aerospace Industry

## Overview



- **Background Information**
  - Uses of advanced materials in aerospace industries
  - Projected growth in the aerospace industries
- **Current U.S. exports in the aerospace industry**
  - Value of current exports
  - Percentage of total industry output
- **Estimated future exports in aerospace industries**
- **Economic impacts of aerospace exports**
  - Full value case
  - Advanced material value case

# Uses of Advanced Materials in Aerospace Industries

- Demand for superalloys in aerospace is driven by efforts to improve engine efficiency and efforts to reduce emissions
- **Primary applications for superalloys in aerospace are:**
  - Turbine blades
  - Vanes
  - Combustor cans
  - Turbine discs
  - Aircraft fastener applications
  - Airframe components
  - Rocket engines
- **There are several markets that demand aircraft engines:**
  - Commercial – 80% of superalloy consumption
  - Military – 15% of superalloy consumption
  - Rotary – 5% of superalloy consumption
- **Nickel-based superalloys account for roughly 50% of the weight of the materials used in advanced aircraft engines.**

- **Three sectors of interest within the U.S. economy were chosen to represent aerospace industries for this analysis.**
    - Assume these sectors use superalloys as an input
    - Assume these sectors export their respective outputs for use in the assembly of complete aircraft, space vehicles, and/or guided missiles outside of the U.S.
1. **Aircraft engine and engine parts manufacturing**
  2. **Propulsion units and parts for space vehicles and guided missiles**
  3. **Other aircraft parts and auxiliary equipment manufacturing**



# Projected Growth in Aerospace Industries

- **Output in these industries is assumed to grow by 3.5% per year through 2035 based on estimates in the 2018 Boeing Current Market Outlook**
  - Value of superalloy use in these industries is forecast to grow by 8.6% per year through 2023 based on estimates by Allied Market Research
- **Growth attributable to NETL's advanced materials research is represented by 10% of the year over year growth from 2024 onward**
  - Assumes that 10% of the expected growth will only exist after 2025 if NETL-related HPMs are ready for commercial use

# Projected U.S. Exports in Aerospace Industries



- Exports were assumed to grow by 3.5% per year to satisfy international demand.
- Value of exports for all sectors of interest 2025 - 2040:  
\$ 1.674 trillion
- Value of HPMs embodied in 2025 - 2040 exports:  
\$128 billion
- Value of HPMs embodied in 2025 - 2040 exports attributable to NETL R&D :  
\$3.044 billion

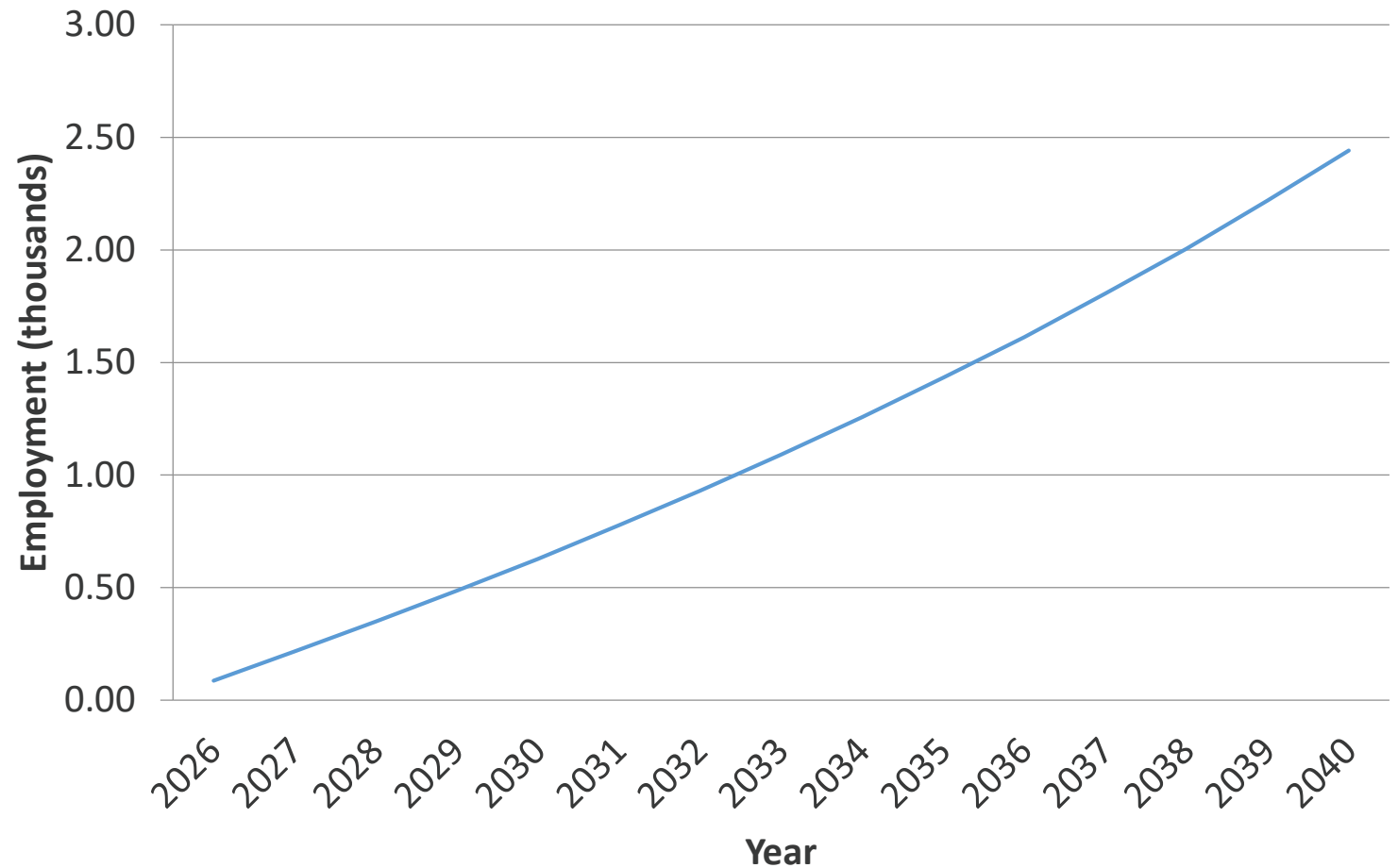
# Total Economic Impacts of U.S. Exports for Aerospace Sectors

Results from NETL-WVU ECIO Model



- Value of exported products:  
**\$1.642 billion**
- Employment Impact:  
**17,300 job-years**
- Income Impact:  
**\$1.059 billion**
- GDP Impact:  
**\$2.549 billion**

Employment Impacts (thousands of jobs)



# Conclusions

## A-USC and NGCC Markets for HPMs



- **Regions that will be likely export markets for U.S. HPMs for A-USC and NGCC plants include:**
  - European Union
  - China
  - India
  - Japan
- **Impacts will depend on the penetration of A-USC and NGCC technology around the world and on how much of each market the U.S. penetrates to provide HPM equipment:**
  - If 20% of global new coal builds after 2026 are A-USC and 100% of global new gas builds after 2026 are NGCC, and the U.S. penetrates 50% of that market:
    - Average annual exports could reach nearly \$3 billion and result in total economic impacts of 28,500 job-years, \$1.627 billion in labor income, and \$4.005 billion in value added or GDP.

# Conclusions

## Aerospace Market for HPMs



- **Regions that will be likely export markets for U.S. HPMs for aerospace include:**
  - Europe
  - Asia
- **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:**
  - If U.S. exports match the assumed growth rate of 3.5% across sectors of interest and 10% of the growth after 2025 is assumed to be attributable to NETL research in HPMs:
    - Average annual exports could reach nearly \$2 billion and result in total economic impacts of 17,300 job-years, \$1.059 billion in labor income, and \$2.549 billion in value added or GDP