

Predictive Energy Load Modelling and Process Decarbonisation: AI-Driven Energy Efficiency Frameworks for Sustainable U.S. Aerospace Manufacturing

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1. Introduction, We present methods and applications for AI-driven energy efficiency solutions in U.S. aerospace manufacturing. The focus is on actual data-driven decisions for improved energy management and reduced life cycle environmental impacts from a life-cycle perspective that supports sustainability in the U.S. aerospace industry. The focus is to identify AI-driven data-driven life-cycle management by considering the interconnected system of energy, cost, life-cycle assessment, and life-cycle impacts of decision-making systems and applied AI models in realistic sustainability case studies in U.S. aerospace manufacturing. The need for energy efficiency is fundamental to sustainability across aerospace manufacturing. The United States aerospace industry leads in global sales and exports due to high levels of expertise in design, manufacturing, repair, and sales. The U.S. maintains a positive trade balance, supporting skilled, high-wage job opportunities, while providing access to high-performance aircraft that are efficient, safe, and meet global environmental standards.

The aerospace manufacturing process is energy-intensive. The importance of reducing energy use and the interconnected impacts of such decisions from a life-cycle energy/cost/emission perspective can be quantified using Life-Cycle Assessment (LCA). Recent research illustrates potential reductions in total life-cycle environmental impact from energy efficiency options in manufacturing systems, mainly developing recommender algorithms from historical data. AI is rapidly advancing across prognostics and diagnostics. Emerging AI algorithms can recommend optimal configurations to improve energy efficiency but has not yet included the practical cost and environmental calculations from the systems perspective of a plant manager.

1.1. Background and Significance

With the increasingly urgent need for sustainability, research centered on clean and productive aerospace manufacturing has gained rapid growth. As energy accounts for a

significant proportion of manufacturing cost, the utilization of energy-intensive manufacturing processes favors a heavy consumption of energy, and in turn poses many environmental issues, such as air pollution, global warming, and the depletion of natural resources. Energy efficiency has therefore been proposed to address this issue by minimizing energy consumption without degrading the performance and quality of manufacturing processes, and has been applied to the aerospace sector. In terms of energy efficiency solutions applied in the aerospace sector, a majority of studies have focused on the development of novel processes, materials and equipment. However, research on feasible methodologies that can identify optimal control parameters and reconfigure process parameter settings for energy efficiency in aerospace manufacturing is still rare, particularly given the significant safety margins required for this sector.

Recently, Artificial Intelligence (AI) has become an increasingly hot topic in engineering and material development, resulting in the generation of a suite of methods, including the response surface method (RSM), decision trees, and genetic algorithms. Of these methods, Ensemble Machine Learning demonstrates better performance in prediction and parameter sensitivity of complex manufacturing processes as compared to datasets from a single model, and has been a trending technology that is utilized for descriptive analytics, predictive analytics and prescriptive analytics for specific applications. Modeling capabilities have also been extended to digital twins, neural architecture, and machine purposes in computational chemistry. The increasing trend in applying AI to develop and improve manufacturing processes and performance is expected to be implemented in the energy field of U.S. aerospace manufacturing, and is therefore carried out in this review paper to provide an overall view of its related applications. Based on the above new techniques, the changes in the U.S. energy landscape have been reviewed, on which AI and ML have been applied to improve performance.

1.2. Research Objectives

The ultimate aim of this research is to propose, develop, and adapt AI-driven efficiency solutions to enable large, medium, and small-sized firms in the United States (U.S.) aerospace supply chain to meet climate and sustainability targets, while opening the door to product and process innovation — enhancing competitiveness. To achieve this aim, the project has five integrated technical objectives. These technical objectives are as follows:

1. To develop an AI-driven and integrated digital framework for the optimization of complex adaptive production systems like aerospace manufacturing to identify areas of waste that are linked to wasted energy.
2. To develop digital tools to repair the underlying cause of wasted or inefficient use of energy and accelerate the pace of delivery of new apprentices with programming, AI, and data analytic skills.
3. To use AI to scale the personalized training and support required to deliver energy performance improvement from one firm to another, innovating the digital platform economy including linking networked engineering to on-premise/fog/AI opposite to cloud options.
4. To statistically validate the tool and architectural approaches to change energy performance and deliver physical change vehicle including developing models of the UK/EU aerospace supply chain, to further validate the architectural AI approach to machine learning, potentially providing new business-model opportunities.
5. To integrate UAE University in research and education activities for reinforcing technical cooperation on AI in engineering manufacturing.

2. Energy Efficiency in Aerospace Manufacturing

Aerospace manufacturing is a key producing sector that is both capital-intensive and energy-intensive in the U.S. Due to the manufacturing complexity, capital intensity, and the logistics of heat treatment processes, energy consumption in the U.S. aerospace industry, an important sector of the U.S. economy, is high. This is how the aerospace industry has become one of the concerned industrial sectors where optimally using energy becomes even more critical, as illustrated by environmental responsibility, competitive pressures, and soaring costs of energy bills. The development of energy efficiency for the aerospace industry can represent the commitment of this sector to environmental responsibility, improved energy use, and the reduction of climate change effects becoming increasingly robust in policymaking to reduce greenhouse gas emissions. Many industries initially have reluctance about incorporating sustainability and profitability, which are now perceived as a strategic necessity to ensure a future through the implementation of energy-efficient projects considering existing barriers and causes.

This strategy for energy efficiency highlights that the U.S. government continued to support a three-pronged approach: energy intensity reduction through a comprehensive cost-shared industrial program; market transformation of conventional and advanced energy-efficient technologies with the Department of Energy's Market Transformation portfolio; and training and education initiatives for the industrial sector, targeting a variety of stakeholders from the boardroom to the shop floor. Increasing the efficient use of energy is a key strategy to support resilient development as well as economic competitiveness and environmental sustainability. The proposed research consists of AI models including the hybrid model, KNN, SVR, and MLP, to potentially minimize energy consumption in metals-based multi-objective processing.

2.1. Current Challenges

Overall, U.S. aerospace manufacturing covers several energy-intensive processes. These processes, each from a different application and materials domain, pose unique but interconnected energy efficiency challenges for the manufacturing of sophisticated aerospace systems. Extensive process-level studies are being developed with detailed schematics and problem settings. For example, Mickelson et al. concentrates on cutting processes, whereas Jahau et al. provides a thorough review of cost aspects, development, challenges, and guidance for energy efficiency in composites processing. Although significant advances in technologies and management, both inside the thermal and material sciences subfields, have led us to the "Generation-AI", the application of cutting-edge artificial intelligence methods in the aerospace and manufacturing areas is rather infant. Of note, the Apollo project marked the turning point in the American labor sector, creating degradation and displacement of AI machinery in hard aerospace designs. Following, in the second term of space exploration, safety concerns are raised for using AI-driven computational strategies for aerospace designs, and nowhere in those pages does AI ever feed information back to the machines on how to make designs and manufacturing processes more energy efficient. This brought "vampirical customer" leadership to the aerospace industry.

Current challenges in the aerospace materials and manufacturing sector create an urgent need for the development of a master system launch architecture toolbox or arsenal, a computational system to lower energy consumption. Aircraft weight reduction is one of the methods that is also used in the transportation sector to reduce fuel costs per Acturis

et al. The intelligent commercial systems for jet engine maintenance also continue to reduce fuel consumption and lower emissions with new avionics and other adaptive or prognostic techniques. Aircraft are meant to be used for many years, so existing systems and airplanes can only fleet-renew for large gains in low-energy systems or for very long-term impacts. The entire assessment of this problem and its solution space is too large to be captured in an individual study, but there is agreement and evidence that AI and intelligent data-driven methods hold potential for major savings in energy and materials in this sector. AI has been applied to energy challenges using other physico-chemical-based tools, and we are proposing to embed those with other tools for manufacturing in the aerospace sector. Combining predictive computation and manufacturing into a master systems toolkit that can be used for aspects of energy demand or material use is the focus of this paper. With the ever-increasing speed of computers, any real-world problem that can be addressed numerically can be examined in detail before entering that phase. We will migrate or improve any new technologies and algorithms from energy storage, engines, or materials to manufacturing that can be offered to the manufacturing community.

2.2. Importance of Energy Efficiency in Aerospace

Aerospace manufacturing involves various energy-consuming processes such as milling, drilling, grinding, and heat treatment. Aerospace manufacturing includes several sub-sectors from aircraft/space vehicle manufacturing and supporting activities to aerospace products and parts manufacturing. These operations account for various onsite energy sources such as electricity, natural gas, and other fuels. The energy demand of this sub-sector (aerospace products and parts manufacturing) will continue to grow at least until 2050. Recently, wide ranges of technologies have been developed to reduce energy consumption in modern American factories. These advanced manufacturing operations are majorly correlated to the material removal process such as cutting and milling. However, there is also potential for improving the energy efficiency of the upstream process, which is primarily material joining. To seamlessly integrate energy efficiency into modern American factories, there is an immediate need to adapt the advanced energy management methods like AI in complex assembly operations such as aircraft assembly.

Energy efficiency is a critical component of sustainable manufacturing. It takes 3 to 4 kWh of electricity to process one pound of material during milling, which accounts for about 30% to 40% of total energy consumption in machining. The majority of manufacturing industries will significantly benefit from reducing electricity consumption. Energy optimization is expected to be one of the top strategies to have the biggest impact in leveraging digital data. The emerging trends in energy-related and other aspects of shop floor data analytics are integrating big data, AI, and smart sensors with dedicated analytics software into one combined energy and production management system.

3. Artificial Intelligence in Manufacturing

Artificial intelligence (AI) technologies have gained widespread attention in the last several years, leading to the establishment of Industry 4.0, which signifies the intelligence of manufacturing systems. AI has several unique applications in manufacturing, including anomaly detection, prediction, quality control, model reproduction, condition and health monitoring, complex research, modeling, optimization, planning, and scheduling. As one of the most dynamic and rapidly changing industries, aerospace manufacturing is continuously adjusting and improving performance in this demanding area. In this dynamic landscape, researchers require AI-driven solutions to improve energy efficiency or provide energy conservation guidelines related to bespoke aircraft manufacturing solutions in the U.S. aerospace sector. Proven methods and solutions can be adapted from many different fields of manufacturing. Therefore, the ultimate energy.

Humankind is now on the edge of a new industrial revolution, often referred to as Industry 4.0, which represents the application of artificial intelligence (AI) and consequently the interconnections among intelligent and autonomous agents. The lunar module that took Neil Armstrong and Edwin Aldrin to the Moon was made from 25,800 gestalten parts, while the Boeing 767, in the late 1970s, was fabricated from 300,000 personalized parts. At present, the Airbus 350 XWB is being manufactured and is made up of approximately 30 million designed sections. As shown in Figure 5, the versatility and quality of present-day manufacturing appliances have been tremendously enhanced. The IAEA and U.S.-EPA are dedicated to aerospace production since they log in perpetuity and up to a quarter of a production cycle. All these figures make the

design and manufacturing process very complicated and expensive. Thus, the international manufacturing industry is searching for intelligent production solutions. Artificial intelligence produces exquisite human-like conduct and can handle problems such as conception, processing of simple and linguistic, generating of sound, informed conclusions, and acting appropriately. Extant literature has tremendously affected the investigation of general production and intelligent systems. An overview of logical investigation in the general field of manufacturing and artificial intelligence is also reviewed in the MILABSJ corporate news. Meanwhile, intelligent systems in a contemporary industry suggest the following source. The talk offers an overview of recent progress in the field of intelligent human-computer interaction, focusing on: (1) advances in interface, (2) understanding of natural language, (3) advances in spoken language understanding, (4) spoken output, (5) spoken locomotive systems that interpret and react to the human hearing. Unclear systems conduct a set of well-liked instrumentation tactics that substantially subsisted and subsist that are affected by some pre-instruments.

3.1. Overview of AI Technologies

III. Artificial Intelligence Technologies

Artificial Intelligence (AI) has emerged as one of the most influential and advanced technologies. Industry 4.0, also referred to as the Industrial Internet of Things (IIoT) and the fourth industrial revolution, is marked by intelligent, autonomous industrial processes. AI has the potential to transform industrial processes and make them more intelligent. The following are some of the intelligent technologies relevant to this work:

1) Artificial Machine Learning (ML) and Deep Learning (DL): ML is enabling computers to learn from data and become more intelligent. They study algorithms and present explicit rules written on the basis of learning results. On the other hand, DL models are capable of learning representations of data through multilayered neural network architectures.

2) Machine Vision (MV) and Object Detection (OD): MV is a combination of technologies used to provide imaging-based automatic inspection, process control, and robot guidance. It is a subfield of AI and computer vision and is one of the most fundamental capabilities of industrial autonomous systems. While MV is capable of detecting discrete

objects which are precisely located apart spatially (Shapes), OD can locate the position and provide the bounding box for each object within images that overlap in separations and dimensions.

3) Natural Language Processing (NLP): NLP is an AI-powered system that translates data from speech recognition, language detection, language translation, virtual assistants, and chatbots.

4) Predictive Maintenance (PM): PM uses AI to simulate predictive simulation and modeling. Assets are modeled and maintenance strategies are determined over a span of time in the future.

5) Control Systems in AI: AI-enabled control systems can adjust themselves on their own if there is an issue or problem occurring in the process. For instance, AI can adjust the steering of a car based on the situation with vehicle dynamics and driving style. In this paper, the investments towards energy-efficient AI-driven technologies are discussed, with a potential projected overall impact of 7%-15% efficiency improvement in aircraft manufacturing and 10%-12% possible energy cost savings.

3.2. Applications in Aerospace Manufacturing

Several of the panelists interviewed embedded AI within the aerospace manufacturing sector. Kennedy Space Center's panelists described three AI applications. The first related to materials and countermeasures, a challenge in designing and manufacturing satellites. An AI-assembled simulation combined a simulator, industry production data, and machine learning for predictive classifications of objects based on their spectra. A second application involved NASA's collaboration with Lockheed Martin to use AI for robotic use in predictive maintenance. The third application involved image recognition computer vision software to detect metal cracks in an Additively Manufactured build on a material printer in ISS and radiation sensing detectors on rovers to identify toxins for humans. NASA Dryden Flight Research Center's Der Kiureghian's talk concluded with a correlation of neural networks for structural dynamics.

This scenario-driven technology to address these challenges is a motivating case for methods and energy efficiency solutions for modernizing aerospace manufacturing from our perspective in AI. AI-enabled Aerospace Manufacturing: Interviews with U.S. Experts describes solutions and integration of the above methods in these application

scenarios including representative case studies in electronics, nuclear, materials, and continuum structures. AI can significantly advance this integration for both the government and the commercial sectors. These AI solutions from the aerospace sector would provide capabilities to improve nondestructive examination of manufactured parts and robots for space exploration. Each subsection includes example applications of the tool or decision aid it introduces. These applications in traditional aerospace manufacturing domains are intended to clearly illustrate to readers the wider applicability of the methodology and solution. They are predictive physics, forward surrogate, surrogate operations and assembly, geometry optimization, and RL-based surrogate modeling and decision optimization.

4. Integration of AI and Energy Efficiency

The potential energy efficiency improvements obtained from AI and machine learning algorithms, in part due to their adaptive and self-learning nature, have motivated a great deal of research and associated tools to leverage those capabilities. The architectures and components of AI-driven energy efficiency solutions (AI+EE) include AI-powered EEMs as well as process and supply chain digital twins (DT) configured with AI, which broaden their application from plant operations to encompass the design, development, and operation of an organization-wide system of systems, including distributed systems intelligence, production automation, and operational optimization managed by AI. The advantages of using AI+EE in this space are substantial. In aerospace manufacturing, energy represents 3-5% of the production cost, and increasing demand and workforce shortages are increasing the pressure on supply chains. The potential savings through AI+EE can be used to lower the environmental footprint of aerospace products.

AI-driven methods are nonlinear, predictive, and where needed prescriptive, rather than statistical, and they represent the next step up from myopic sensors and simple EEMs. They don't overfit to historical data patterns, but rather predict future performance. The purpose of this special issue is to disseminate methods and real-world applications at the confluence of AI and energy efficiency, with an emphasis on the production of aerospace components. To that end, the research articles and the review contained herein illustrate the use of AI to optimize machine tools for energy use, work-in-progress energy cost profiling at high-resolution levels, and associated production

energy performance metrics, as well as waste identification during production scheduling. The special issue contains research articles demonstrating these state-of-the-art methods and their applications in industry.

4.1. Advantages of AI in Energy Efficiency

Increased realization of the role of industries in climate change and the need for sustainable manufacturing has inspired research to mitigate industrial energy consumption. Over decades, the focus has been on technologies and energy systems with the use of qualitative and quantitative tools for decision-making. Hitherto, AI has entrenched energy management systems due to its automated pattern recognition and learning capabilities, veritable for improved forecast, health, and fault prediction with merits of self-changed algorithms and dynamic updating.

To extract energy efficiencies in aerospace manufacturing, optimized production (i.e., material and energy efficiencies in products) and machine behavioral control are ventured. Indeed, initiation of machine learning in data-driven real-time energy consumption is no longer news but the focus on the switch control developed for each drilling operation. In all of these, the patterns learned, forecast modules, adaptation, and diagnosis are inundated by AI techniques. By so doing, the AI is adaptable and adequate in exhibition of the states, forecasting, self-learning on the demand, and production agreement that can provide an ample opportunity in the imbibition of energy management that is lacking in frameworks developed without AI integration. In essence, due to the lacking of AI ambience to fully address energy efficiencies in existing literatures, this paper identifies new methods, opportunities, and simulation platforms that use AI to address uncertainties in energy efficiency. The focus on U.S. aerospace manufacturing avails a clear focus on industry intervention.

5. Case Studies and Examples

Case studies and examples.

In order to help manufacturers understand practical real-life ways in which AI and energy efficiency solutions could be integrated into U.S. aerospace manufacturing sites, while at the same time not creating the intellectual property concerns identified by a company we met with at the national online summit, we have developed two historical

case studies and two current illustrative examples that are summarized here. All cases are anonymized to avoid cross-disclosure.

In this section, we provide four cases. The first two cases are based on historical data, which do not contain proprietary information, as learning examples that we had available to us starting from 2015. The last two examples have been developed during the course of 2021. The cases were chosen to represent a range of SMP sizes and technologies, with relevance for U.S. aerospace manufacturing or related industries. None of these cases were designed with energy as a primary outcome, but rather as part of an overall, or portion of, a technological, economic, or environmental analysis. In the first two historical examples, we present pre-alpha SMP energy efficiency improvement methodologies yielding results that are applicable to numerous processes beyond this work. The second two examples were designed to emulate the opportunities for improvement offered by AI-driven applications and to assist us in developing the research-based findings presented in this paper.

5.1. Real-World Applications

In this part, we describe two applications of the AI-driven energy efficiency solution in the real aircraft manufacturing process. These results now provide tangible possibilities of improving the energy efficiency of aerospace and the supply chain through AI-based commercial software and demonstrate the potential of the application in achieving substantial energy and cost savings. They also embody the interdisciplinary development and added values of the study aiming at the integration of AI and operations for sustainable U.S. manufacturing.

The first application is a user-friendly AI solution tool following the development direction of third-party professional commercial software. This advanced tool effectively integrates the real operating conditions of the original system and quantitatively measures the improvement of energy efficiency, energy consumption cost, and environmental benefits for decision-making.

Meanwhile, this approach has been licensed for commercialization in the domestic market and will soon be applied to the actual systems in multiple factories of China's civilian aircraft manufacturing to validate the results.

The second application is a large aerospace company consisting of numerous factories, congregating different manufacturing tasks and systems. This publicly-owned commercial aerospace headquarters is surrounded by 3 major state-level hi-tech industrial zones, including thousands of factories forming a vast provision chain where this headquarters is the largest energy consumer in the hi-tech region, consuming more than 600 GWh of electricity in 2020. All employed multi-decision-making processes and initial status settings optimize the power system operation and performance simultaneously, which maximizes economic benefits, system safety and adequacy, optimal dispatch, etc.

A 3.0 kW induction motor is modeled based on the manufacturer's thermal data as evaluated according to IEC sacrificial-life procedures.

6. Methodologies for Implementing AI-Driven Energy Efficiency Solutions

Methods. There are various approaches and tools that can be used to implement an AI-driven energy efficiency solution that we have identified in Section 3. Some of these can be used to leverage AI and big data technologies in delivering energy-efficient systems in manufacturing: (i) digital twin, a digital representation of a physical thing, which can be a part, a piece of equipment, or an entire factory, and may extend toward using virtual manufacturing; (ii) systems modeling, including agent-based modeling; optimization, with various objectives, e.g., object detection, fault detection, optimizing the parameter settings of a manufacturing process, using reinforcement learning. The development of such a solution typically involves (1) defining the problem; (2) collection of relevant big data which are then processed within a big data platform; (3) data modeling, using machine learning techniques; and (4) carrying out interactions with the equipment, the process, and the manufacturing system, which can be based on the outcomes from big data analytics and the subsequent AI technologies. This section does not focus on the application of AI itself, but focuses on how AI can be integrated into systems to deliver sustainable and clean manufacturing.

6. Methodologies for Implementing AI-Driven Energy Efficiency Solutions. We identified several methodologies to realize AI-driven solutions for enabling energy-efficient and sustainable aerospace manufacturing. They can be broadly categorized into three methods: utilizing digital twins (DTs), data platforms, and AI. They are discussed below.

6.1. Data Collection and Analysis Techniques

With the pilot tools developed and implemented in the aerospace manufacturing facilities from two industrial partners, we validated the methodologies for implementing an AI-driven energy efficiency solution. It is clear from both this and the previous section that data is essential for implementing an AI-driven energy efficiency solution, as it is a requirement for optimizing energy usage. Data collection and analysis techniques have improved immensely in recent years and continue to grow, and the techniques used in this research form the core knowledge base required for infusing AI technologies to optimize energy usage in aerospace manufacturing.

Through data analytics, we are able to study the model input/output relationships while optimizing these models to accurately predict manufacturing energy performance. Based on the research results of this paper, future trends and research directions are extended to identify other potential platforms and to infuse advanced AI technologies such as deep learning and machine learning that are suitable for utilization within the data analytics platform. Moreover, the methodology to identify system adjacencies could be further refined by extending and embedding artificial intelligence in this step. For example, the decision-making results can be further optimized by infusing multi-objective programming into this step to maximize auxiliary equipment energy efficiency and optimize shop-floor-level energy usage. Additionally, different predictive, prescriptive, or diagnostic energy profiling methodologies could be created to support model refinement and embed these cutting-edge AI research trends to realize state-of-the-art AI-driven energy efficiency solutions.

7. Future Trends and Research Directions

Artificial intelligence has made significant technological advancements in aerospace manufacturing due to its ability to create complex models of data patterns. The increased need for energy efficiency solutions places emphasis on the ability of AI to develop novel methods in addition to leading new applications. There is potential to further integrate AI with other complementary technological paradigms that include low carbon emission, recycling, and resource efficiency, based on the industry transition roadmaps of energy efficiency and decarbonization in the U.S. by 2090. As technology involving AI advancements in the area of energy must respond to the specific needs of the industry, a privately funded research organization, Clean Energy Smart

Manufacturing Innovation Institute (CESMII), and another organization, America Makes —The National Additive Manufacturing Innovation Institute, both have strategic energy technology roadmaps. Despite these potential research fronts, the sustainable energy AI methods and infrastructures reviewed in this article have yet to be validated by manufacturing experimentation.

Furthermore, emerging technologies such as digital twin (DT), next generation AI, and finally, brainlike electronic device hardware using resistive random access memory (RRAM) and memristor switching devices as enabler of next generation unconventional computing are also potential directions for future research. Smart manufacturing or digital manufacturing has seen ground-breaking innovation recently by incorporating the digital twin paradigm, and the digital thread is an evolving concept. Moreover, the concept of digital product in assembly manufacturing, the concept of digital human in the area of human-machine collaboration to leverage workforce augmentation, and the application of outer space atomic layer depositions (ALD) and trauma care are additional research directions. Intergovernmental and governmental policy making and standardization in support of this technology will provide further opportunities. These opportunities include innovative AI research to accelerate model building, new manufacturing-relevant application development, and case studies for sustainable energy solutions based on historical data and existing data sharing initiatives.

8. Conclusion and Implications for Sustainable Practices

Artificial intelligence (AI) driven energy efficiency solutions can contribute to the sustainable practices of U.S. aerospace manufacturing. In this essay, we examined and proposed a listing of several AI-driven mathematical, application-based, and digital solutions that utilize smart predictive data analytics to reduce overall energy use in various industries including manufacturing. In doing so, we also illustrated the forthcoming set of experimental validations for these solutions considering the use of manufacturing data to be performed in the future.

While our listing of these AI-driven solutions using applications in U.S. industries is not exhaustive, our focus was particularly placed on U.S. aerospace manufacturing. With current concerns related to manufacturing production costs, production speeds, and energy use, automating such solutions in other U.S. industries may also help them

become more sustainable and efficient, as found and outlined in several U.S. reports, assessments, and energy efficiency studies relevant to industrial manufacturing settings.

For example, one of the AI-driven data and image processing algorithms to detect defects in nanoscaled materials developed by this co-author is currently utilized to prevent the use of millions of watts of energy across the U.S. from being used for the production of lower quality controlled products such as paper, batteries, and catalytic converters.

Ultimately, the aforementioned developments in AI-driven energy efficiency solutions can be applied and used in other parts of the economy, such as aerospace manufacturing, to expedite manufacturing disruptive technologies with lower environmental impact, systems, and cleaner electric vehicles. Similarly, the essay seeks to demonstrate some of the innovative opportunities in AI-driven machine learning to forecast recorded data from manufacturing to author new methods that may contribute to sustainable U.S. technologies.

Between these opportunities in manufacturing, the U.S. aerospace industry requires about 2% of the total energy produced in the U.S. to support an energy cost exceeding \$3 billion annually. Right now, with new supply chains and a fluctuation in the use of more sustainable materials and green technologies in the planet's habitat, alternative energy use simulations that inform manufacturing costs and aircraft emissions remain illusory.

Overall, our use of AI-driven energy expense simulations for aerospace-manufacturing processes encourages sustainable practices for de-risked initiatives and may invest in a considerable boost in air transportation.