

Green Technology Innovation in Electrical and Mechatronics Engineering Vocational Education Towards Industry 5.0

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Abstrak

The rapid development of technology during the Industrial Revolution significantly impacted the environment, including global warming. This condition has caused anxiety among humans worldwide regarding increasing temperatures in various corners of the world. Various innovative ideas have emerged to develop environmentally friendly green technology. This article examines and explores green technology innovation in Electrical and Mechatronics Engineering vocational education in welcoming the industrial era 5.0. The study of green technology is based on the author's observations and experience developing and applying green technology in learning. Data analysis uses qualitative and quantitative approaches to examine the effectiveness of green technology in the learning process. Implementing green technology in education will increase students' awareness, motivation and competence regarding environmental issues. Vocational higher education is expected to be able to contribute to integrating green technology into the vocational education curriculum to produce a competent and environmentally conscious workforce.

Keyword: Green Technology, innovation, electrical, mechatronic, vocational, industri 5.0.

INTRODUCTION

The Industrial Revolution from 1.0 to 4.0 brought significant changes in various sectors, including the manufacturing industry, information technology, trade, government and education. This revolution has increased the effectiveness and efficiency of production systems in industry (Rainer et al., 2014; M. Ali et al., 2021). The Industrial Revolution 4.0 has had a significant influence on the concept of human and machine collaboration, cyber-physical system integration, and the use of cutting-edge technologies such as artificial intelligence, robotics, big data, machine learning and the Internet of Things (IoT) (Rymarczyk, J., 2020; M. Ali et al., 2022). On the other hand, the Industrial Revolution required machines powered by fossil fuels, which impacted climate change, piles of rubbish, air pollution, land pollution, decreased water quality and reduced biodiversity. Various environmental problems cause global warming, which concerns the world. Increasing earth temperatures trigger the extinction of flora and fauna, sea level rise due to the melting of glaciers at the poles, expansion of desert areas, climate change and various natural disasters (Rajput et al., 2021; Nikoloudakis et al., 2019; Kaliappan, 2021).

Global warming due to environmental damage has triggered various campaigns to increase awareness of the importance of environmental conservation. Scientists from all over the world contributed with their ideas and started introducing various environmentally friendly technologies. Government and non-government organizations, such as the World Wide Foundation (WWF), Green Peace, the Indonesian Forum for the Environment (WALHI), the Indonesian Biodiversity Foundation (KEHATI) and other environmental organizations are starting to form (Ardhian, D et al., 2016),

Sylvianisa, A. W., et al., 2021). Environmental organizations grow and develop to create a healthy environment for a better life.

In the context of education, especially electrical engineering and mechatronics vocational education, adapting to these changes is crucial to prepare graduates to compete in an increasingly complex and dynamic job market (M. Ali, 2020; Ali, M., et al. 2020). Vocational education aims to produce graduates ready to enter the world of work with particular skills. Green technology refers to using environmentally friendly energy production technology, alternative fuels, and environmentally friendly technology (Nikoloudakis et al., Rajput et al., 2021). This condition is attracting much attention due to increasing awareness about the impacts of climate change and the depletion of natural resources. Using environmentally friendly technology will reduce human impact on the natural environment and prevent climate change. The concept of green technology is increasing in various countries, especially Indonesia. Green technology aims to create a clean environment and maintain biodiversity (Wang Q. et al., 2019, Bilal A. et al., 2021). The increasing implications of sustainability have an essential impact on industry, business associations, and society. Therefore, the readiness of the future workforce to face the green economy is challenging for the Vocational Education and Training authorities.

Various efforts have been made to increase environmental awareness, including Karatas, A. et al. (2016), who researched environmental education to increase environmental awareness for vocational students in Turkey. Abbas, M. Y., & Singh, R. (2014) surveyed environmental awareness, behaviour and attitudes of students from various universities towards the environment in India. Meanwhile, in Indonesia, many researchers study environmental issues for education. Purbosari et al. (2021) conducted education on the impact of fertilizers and pesticides for vocational high school students. Rahayu I. et al. (2024) trained and mentored vocational school students to form environmental awareness and social responsibility. Rahman, A. et al. (2021) examined the relationship between environmental knowledge and the behaviour of Vocational High School students. Rakhmawati D. et al. (2016) examined the role of the "Adiwiyata" program in developing the environmentally caring character of vocational school students. Researchers have made various efforts to identify, educate, form awareness, analyze relationships and develop methods for increasing students' awareness of the environment. However, until now, the environment remains one of the biggest problems in improving the Indonesian economy.

Based on the explanation above, the environment is an important aspect to solve. Solving environmental problems will not be effective if it is only carried out partially. Therefore, there is a need for togetherness in solving environmental problems. One crucial aspect is innovating green technology in electrical and mechatronics engineering vocational education. This article discusses green technology innovation in Electrical and Mechatronics engineering education. Hopefully, this article can provide inspiration to students, teachers, lecturers, and vocational education observers, especially in electrical engineering and mechatronics, regarding environmental issues. Apart from that, it can also provide creative ideas for conducting research and development in green technology, both in terms of green technology.

GREEN TECHNOLOGY

Green technology refers to developing and implementing products, services and processes that reduce negative environmental impacts. The main goal of green technology is to minimize pollution, reduce greenhouse gas emissions, increase energy efficiency, and utilize natural resources sustainably (Wicki, S. & Hansen, 2019; Shan, S. et al. 1, 2021). The basic concept of green technology includes sustainability principles that include effective waste management, use of renewable energy, and recyclable product design. The main principle of green technology is to reduce environmental impacts and increase sustainability. These principles include 1) Energy Efficiency, achieved by optimizing energy use in production and consumption processes to reduce waste and costs; 2) Renewable Energy by utilizing renewable energy sources such as sun, wind and biomass to reduce dependence on fossil fuels. 3) Reducing emissions by developing technology that reduces emissions of greenhouse gases and other atmospheric pollutants. 4) Waste management, which is implementing an effective waste

management system to reduce, recycle, and reuse waste. 5) Sustainable Design by designing products and systems that minimize environmental impact throughout their life cycle, from production to disposal.

The application of green technology in various industrial sectors aims to create cleaner and more efficient production processes (Li, X., Huang, 2022, Wang, Q. et al. 1, 2019). Examples of the application of green technology in industry include: 1) Renewable Energy. Solar panels and wind turbines will be installed in production facilities to replace conventional energy sources. 2) Green Buildings, design and construction of buildings that use environmentally friendly materials, efficient heating and cooling systems, and good water management. 3) Environmentally Friendly Manufacturing Process. Use of recyclable raw materials, reduced use of hazardous chemicals, and implementation of clean production technology. 4) Green Transportation: Development of electric and hybrid vehicles and use of cleaner alternative fuels.

Although the implementation of green technology offers many benefits, several challenges need to be overcome, such as: 1) High Initial Costs: Implementation of green technology often requires significant initial investments. 2) Lack of Awareness and Knowledge: Many parties still do not understand the benefits and importance of green technology. 3) Infrastructure Limitations: Existing infrastructure may not support the widespread implementation of green technology. 4) However, this challenge also opens up opportunities for further innovation and development (Bilal et al., 2021). Increasing public awareness and government support provides excellent potential for creating a cleaner and more sustainable environment. This condition is expected to produce a workforce that is ready to face the demands of industry in the future

LANDASAN TEKNOLOGI HIJAU

The legal basis for developing green technology innovation is supported by various international agreements and legislation in each country. Indonesia ratified the Paris Agreement, which requires countries to contribute to global efforts to reduce greenhouse gas emissions and control climate change. This agreement encourages implementing green technology as a national strategy to reduce emissions. Apart from that, Indonesia is also committed to achieving sustainable development (Sustainable Development Goals), which includes clean and affordable energy and action against climate change (Rahayu, I. et al. 2024).

The basis for developing green technology in Indonesia is regulated in Law Number 32 of 2009 concerning Environmental Protection and Management. This law emphasizes the importance of environmental protection and sustainable management. One of the goals is to encourage the use of environmentally friendly technology in various industrial and development activities. Apart from the environmental law, there is Law Number 30 of 2007 concerning Energy. This law regulates national energy policies, including developing and utilizing renewable energy sources. The government encourages the development of clean energy and green technology to achieve national energy security. Detailed guidelines for both environmental and energy laws are clarified through government regulation Number 79 of 2014 concerning National Energy Policy. This regulation supports the development of renewable energy and energy efficiency. This policy targets increasing the contribution of renewable energy in the national energy mix and implementing energy efficiency technology in various sectors. The procedures for developing green technology are regulated in Presidential Regulation Number 22 of 2017 concerning the General National Energy Plan. This draft outlines strategies and measures to achieve renewable energy targets and reduce greenhouse gas emissions. This plan includes the promotion of green technology in national energy management. The utilization of Renewable Energy Sources for Providing Electricity is emphasized in Minister of Energy and Mineral Resources (ESDM) Regulation Number 50 of 2017. This regulation regulates mechanisms and incentives for developing renewable energy-based electric power projects, including solar, wind, biomass and hydropower (Rahman A. et al., 2021; Rakhmawati et al., 2016).

Electrical and Mechatronics Engineering Vocational Education

Electrical and mechatronics engineering vocational education is one of the educational institutions that plays an essential role in preparing skilled workers who are ready to face the challenges of modern industry. Vocational education provides crucial practical experience for students, enabling them to apply theory in real situations. Learners gain the technical skills necessary to work in various industrial sectors, including manufacturing, automotive, and information technology. Vocational education is designed to focus on industry needs and ensure that graduates are ready to enter the world of work with relevant skills immediately. Skills in green technology also make graduates more desirable to companies focused on sustainability (M. Ali, 2020). Pendidikan vokasional teknik elektro mekatronika sangat relevan dalam era industri 4.0, di mana integrasi sistem elektrik dan mekanik menjadi semakin kompleks dan kritis. Pendidikan vokasional yang efektif di bidang ini harus mencakup aspek teoritis dan praktis, serta memfokuskan pada perkembangan teknologi terbaru, termasuk teknologi hijau. Pendidikan vokasional teknik elektro dan mekatronika berfokus pada pengajaran keterampilan yang diperlukan untuk bekerja dengan sistem kelistrikan, instrumentasi dan kontrol proses industri. Pendidikan vokasional teknik elektro mencakup pemahaman tentang dasar-dasar kelistrikan, rangkaian listrik dan elektronika, pembangkitan, transmisi, distribusi dan pemanfaatan tenaga listrik, instrumentasi dan kontrol proses, serta instalasi dan pemeliharaan peralatan listrik. Mahasiswa belajar bagaimana merancang, mengembangkan, memasang, memeriksa, menguji, mengoperasikan dan memelihara berbagai sistem kelistrikan dan kendali yang digunakan di industri dan kehidupan sehari-hari.

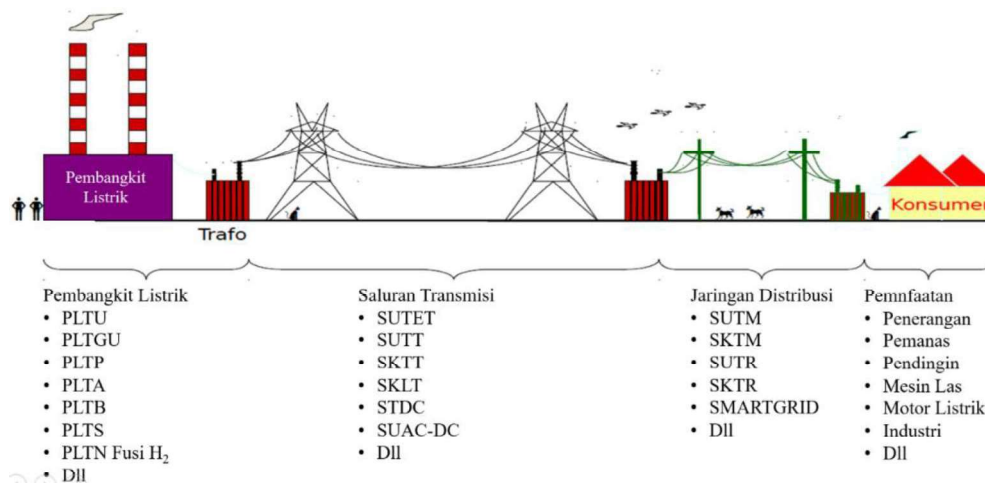


Figure 1. Scope of Electric Power Systems

Source: personal documents, <https://www.youtube.com/channel/UC-1MDHLbE6hmR8UVUWiwX1A>

Mechatronics vocational education combines mechanics, electronics, and computers to design and operate intelligent and automated systems. Mechatronics vocational education aims to equip students with skills in designing, programming and maintaining mechatronic systems used in various industrial applications.

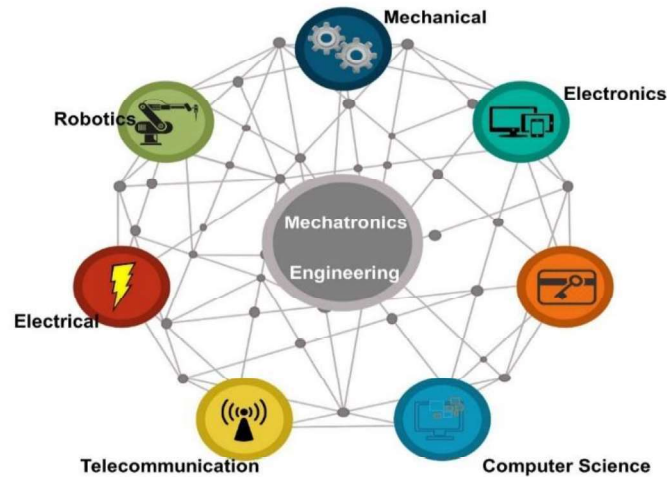


Figure 1. Scope of Mechatronic Engineering

Green technology is vital in electrical and mechatronic engineering vocational education to face global environmental challenges and increase sustainability. This integration includes: 1) Renewable Energy: Solar Panels and Wind Turbines: Students learn about the design and installation of renewable energy systems, such as solar panels and wind turbines, and energy storage technology. 2) Energy Efficiency: Teaches concepts and techniques to improve energy efficiency in electrical and mechatronic systems. 3) Environmentally Friendly Materials and Processes, 4) Recycled Materials: Use of recyclable materials in projects and laboratories. 5) Green Production Processes: Teaches production processes that reduce waste and emissions.

Innovation of Green Technology in Electrical and Mechatronics Engineering Education

1. Renewable Electric Energy Generation

One implementation of green technology can be carried out in the field of generating, transmitting, distributing and utilizing electric power. Power plants that use oil, gas, nuclear and coal fuels cause extraordinary environmental pollution. The migration of power plants using environmentally friendly fuels is starting to become a focus of innovation in the present and future. Renewable power plants are starting to become the prima donna for developing power plants such as solar cells, wind turbines, Geothermal, Biomass, Gas, Hydrogen Fusion, and other renewable power plants.

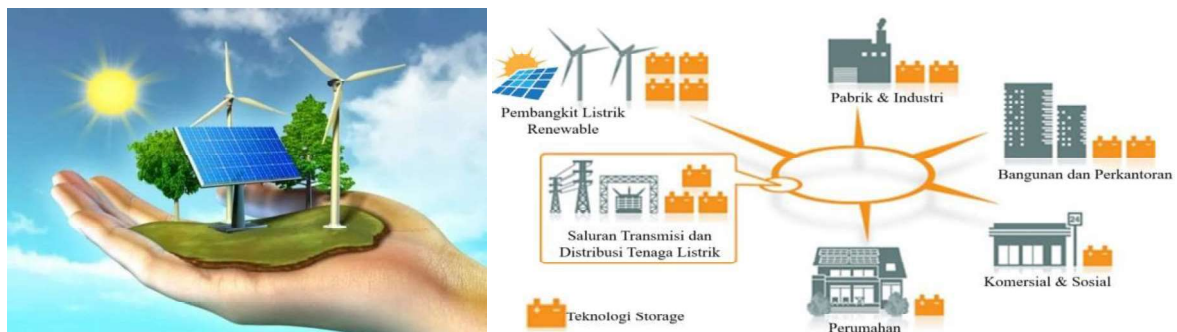


Figure 3. Renewable Electric Energy Generation

2. Smart Grid Technology

One of the weaknesses of renewable power plants is that they are intermittent. Renewable power plants cannot always operate continuously, requiring an electrical energy storage system. One way to

overcome this problem is by developing an innovative electricity network (smart grid). This intelligent grid system can manage various sources of electrical power from both conventional and renewable power plants reasonably and efficiently (Dileep, G. J. R. E., 2020).



Figure 4. Intelligent Electricity Network (Smartgrid)

Source: <https://www.linkedin.com/pulse/smart-grids-comprehensive-overview-aalon-sheikh>

3. Carbon Capture and Storage Technology

The use of electricity from fossil sources is tough to eliminate. Electricity consumption is increasing, and the absence of reliable power plants means that fossil fuel power plants will continue to be used. The direction of development of fossil fuel power plants is cleaner burning, such as coal gasification or carbon capture and storage (CCS) to reduce greenhouse gas emissions.. CCS is a method for reducing CO₂ gas emissions into the atmosphere to mitigate global warming. This technology involves a series of related steps, starting from separating and capturing CO₂ from the source of exhaust emissions, then transporting the captured CO₂ to a storage location, and finally storing the CO₂ safely. The process of separating and capturing CO₂ gas generally uses absorption technology. The captured CO₂ is then transported via pipe or tanker and stored in rock layers below the earth's surface or can be injected into the sea at a certain depth.

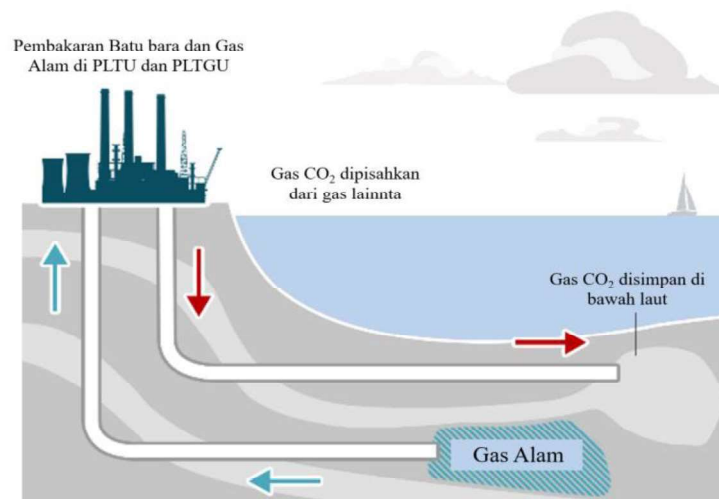


Figure 5. Carbon Capture and Storage Technology

Source: private document

4. Hybrid Technology

Each renewable power plant has advantages and disadvantages. For this reason, various types of power plants need to be combined or mixed. A hybrid approach combining energy sources such as

solar, wind and battery storage will be a trend in the future. This method allows greater flexibility in optimizing energy supply based on environmental conditions and demand.

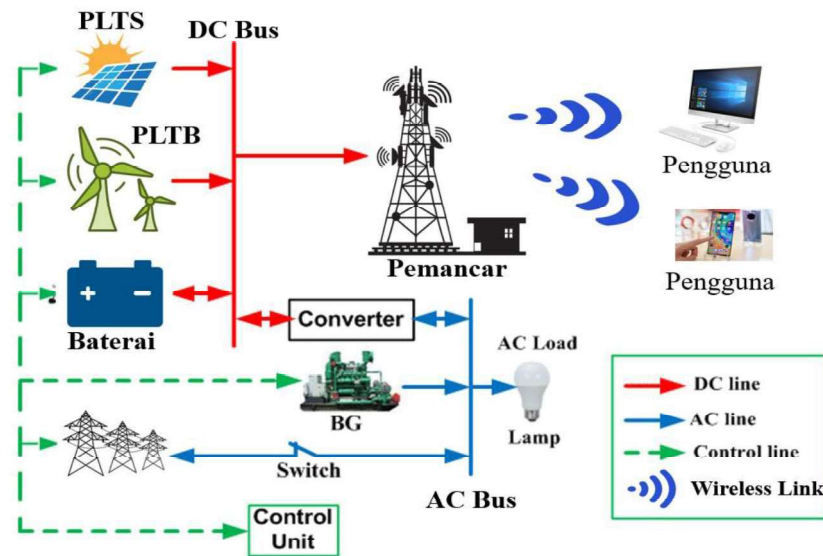


Figure 6. Hybrid Technology of Renewable and Conventional Power Plants
Source: private document

5. Ocean Thermal Energy

One of the energy potentials that is quite large and has not been widely exploited is the sea. Various research is starting to focus on utilizing the potential energy contained in the ocean to become renewable energy. Marine energy potential, such as waves, currents and ocean thermal energy, has become a sustainable and reliable renewable energy source in coastal areas. As an archipelagic country whose territory is dominated by the ocean and is the second largest in the world, Indonesia is crucial for developing electricity generation using marine energy. Sunlight shining on the ocean can be absorbed by seawater effectively. This energy is trapped in the sea surface layer at 35-100 m depth. This energy can be used as an electric power generator, sometimes changing heat in seawater. The difference between seawater at the surface and greater depths can produce electrical voltage.

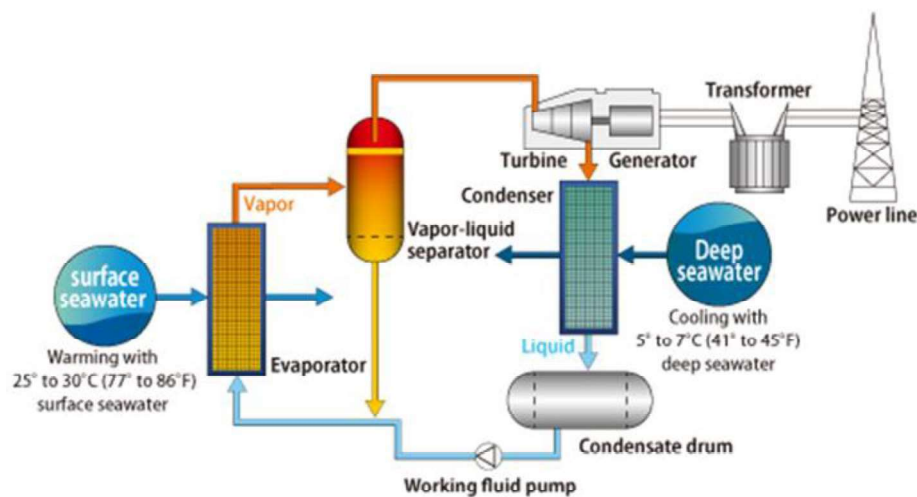


Figure 7. Ocean Thermal Energi Conversion Power Plants
Source: https://www.yokogawa.com/eu/industries/renewable-energy/ocean-thermal-energy-conversion/#Details__OTEC-process

6. Hydrogen Fusion Power Plant

Despite the controversy surrounding nuclear energy, there is ongoing research to develop safer, cleaner, and more efficient nuclear reactors. The Thorium and Nuclear Fusion reactor concepts are part of the potential for future power generation. Hydrogen fusion power plants promise a significant revolution in the world of energy. With the potential to be a clean, safe and limitless energy source, this technology has long been a dream of scientists. Recently, technological advances have brought us closer to realizing this dream. Hydrogen fusion is a nuclear reaction in which the nuclei of hydrogen atoms combine to form helium. In this process, a considerable energy release occurs. Scientists use Tokamak devices and inertial fusion reactors in the laboratory to combine Hydrogen gas into helium. The main advantage of hydrogen fusion power plants is their clean nature. Unlike conventional power plants that produce carbon emissions, hydrogen fusion only produces harmless waste in helium. In addition, the raw materials, namely the hydrogen isotopes deuterium and Tritium, are available in sufficient quantities in nature and can be obtained from water and Lithium.

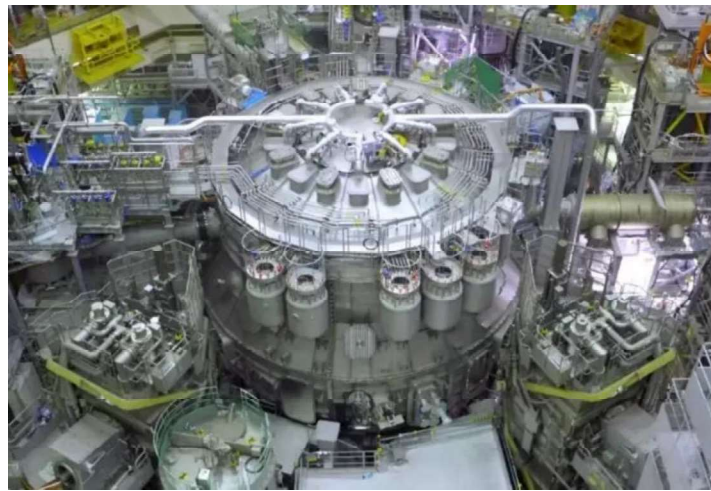


Figure 8. Nuclear Hydrogen Fusion Power Plant

Source: <https://koran-jakarta.com/jepang-resmikan-reaktor-fusi-nuklir-eksperimental-terbesar-di-dunia?page=all>

7. Electric Vehicles

Electric vehicles are one of the main focuses in reducing carbon emissions and dependence on fossil fuels. This technology offers many advantages, including higher energy efficiency, reduced air pollution, and potential integration with renewable energy sources. As battery technology advances and charging infrastructure improves, electric vehicles are expected to play an essential role in a more sustainable future transportation system.



Figure 9. Electric Vehicle Innovation

8. Automation and Robotics

Automation and robotics are critical elements in the Industrial Revolution 4.0 towards 5.0. Automation and robotics technology can increase productivity, effectiveness, efficiency, quality and production speed while reducing costs and waste. Automation plays a significant role in producing and

managing renewable energy, which is the essence of green technology. Thus, robotics can revolutionize the manufacturing industry by increasing efficiency and reducing environmental impact.



Figure 10. Innovation in Automation and Robotics

9. Smart Building

Smart Building is one of the main focuses in the industrial era 4.0. Smart Building refers to buildings equipped with advanced technology to improve energy efficiency, occupant comfort, and operational management through sensors, automation systems, and analytical data. Smart Buildings integrate various systems and technologies to create more efficient and adaptive environments. The basic principles of Smart Building include 1) Connectivity that connects various devices and systems via the Internet of Things (IoT) network to enable efficient communication and data exchange. 2) Automation to control and manage building operations, such as lighting, HVAC (heating, ventilation, and air conditioning), security, and energy systems; 3) Data Analysis by collecting and analyzing data from various sensors to provide insights and make better decisions both related to building operations and maintenance, 4) Interactivity which gives occupants the ability to interact and control their environment via mobile applications, control panels, or voice commands (Aliero, M. S., et al. I., 2022).



Figure 11. Smart Building

Sumber: <https://id.linkedin.com/pulse/perspektif-smart-building>

Green technology innovation in electrical and mechatronics engineering education is inclusive. Various innovations have been carried out by students, lecturers, researchers, industry and education observers to create a more environmentally friendly environment. Many household, office and industrial equipment have been developed. The development of green technology has also penetrated the fields of communication, transportation and other fields.

Technological developments are heading towards Industrial Revolution 5.0 as a new phase in industrial development. The Industrial Revolution 5.0 emphasizes collaboration between humans and intelligent machines to create higher value and more personalized experiences (George, A. S., & George, A. H., 2020; Taj, I., & Zaman, N., 2022). In this context, green technology is essential in ensuring that industrial development can go hand in hand with environmental sustainability. Industry 5.0 utilizes modern technology to increase renewable energy and energy efficiency in various industrial

sectors. Industry 5.0 encourages using environmentally friendly renewable energy sources such as solar power, wind, water, biomass, and hydrogen. Intelligent technologies enable better integration between renewable energy sources and the power grid, ensuring a stable and efficient energy supply. Sensors and the Internet of Things (IoT) monitor and optimize energy consumption in industrial facilities. Intelligent energy management systems can identify areas that waste energy and provide recommendations for improving efficiency (Taj, I., & Zaman, N., 2022). Energy storage technologies, such as batteries and other large-scale energy storage technologies, are essential in ensuring sustainable energy availability.

The integration of green technology in vocational education in Electrical and Mechatronics Engineering is expected to improve students' technical competence and provide relevant skills for a greener and more sustainable industry. This condition is essential in creating environmentally conscious people who can contribute to nature conservation. Integrating green technology in electrical and mechatronics education starts with curriculum design. Course design must pay attention to aspects of environmental sustainability. The next step needs to be to develop learning materials related to electrical and environmental engineering. Learning evaluation also needs to include the environment.

Conclusion

Green Technology innovation in electrical and mechatronics engineering education is essential in creating more efficient and environmentally friendly solutions. Effective and efficient use of renewable energy sources will enable sustainable system development. Green technology helps reduce environmental impacts and encourages the development of more responsible industries. The application of green technology in vocational education is also important to prepare future generations who are ready to face the challenges and opportunities in the era of sustainability.

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