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Low-cost Electric Bicycle Designs to Reduce Environmental Pollution

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Abstract

Two major global problems that require attention are the depletion of fossil fuels and the rise in environmental pollution brought on by internal combustion engine cars. Using electric vehicles is one of the most promising ways to address environmental degradation and energy security. Due to its many advantages, electric bicycles are among the electric vehicles that are gaining a lot of attention because of their potential to reduce environmental pollution as a low-cost alternative to internal combustion engine cars. Few review articles exclusively addressed low-cost electric bicycles, despite the fact that several have demonstrated the potential for widespread use in the future as electric vehicles. The development, design, and research of electric bicycles were all explored in this study. Also, an analysis on how electric bicycles are categorized in terms of their parts and designs was also conducted. In order to provide scientists and researchers with useful knowledge to further improve electric bicycles, the electric bicycle research fields were examined based on previous studies. In addition to the aforementioned assessments of electric bicycles, the low-cost parts for widespread manufacturing of electric bicycles at minimal costs were also examined.

Keywords: Electric bicycle, Design, Manufacturing, Environmental pollution, Sustainability, Energy Security.

1. Introduction

One of the transportation market's fastest-growing areas is electric bicycles, or "e-bikes." Research has tracked the expansion in sales of electric bicycles, and this paper offers a summary of the most important designs that have emerged in the past on the rapidly expanding subject of low-cost e-bikes. Research on transportation rather than recreational e-bikes is the main focus, along with the most important research gaps that need to be filled. China is the global leader in e-bike sales, followed by Germany and the Netherlands. E-bikes require less effort to maintain speed. Bicycle utilization has been reported to rise with e-bikes. Although there are unanswered uncertainties regarding their capacity to replace traditional bicycles, e-bikes have the potential to replace conventional motorized (internal combustion) modes (Philips et al., 2022; Tozluoğlu et al., 2024).

It has been demonstrated that e-bikes offer health advantages and emit an order of magnitude less carbon dioxide than a car going the same distance. The quantity of e-bikes is now getting close to the point where sufficient safety data can be gathered, and safety concerns have become a policy concern in a number of countries. E-bike research is still in its early stages. As the use of e-bikes increases, more research will be required to provide the data that business and policymakers need (Cherry & Cervero, 2007; Dill & Rose, 2012). More research into battery and drive technologies and how they work with electric bicycles will be beneficial to the market for electric bicycles. Currently, the most popular uses of electric bicycles in are leisurely rides and quick excursions to food stores. An overview of the current state of the art for low-cost locally produced electric bicycles is included in this article's methodical, thorough classification of electric bicycles. Additionally, the power needs for many common riding scenarios are noted.

Truly, the bicycle has evolved from an antiquated recreational item to a small, incredibly light personal

mobility tool and a less polluting mode of transportation. In this way, electronic bicycles will serve as the foundation for individual public transportation in major cities across the globe. Although they are still uncommon in developing and underdeveloped countries, electric bicycles account for a sizable portion of daily travel in some regions of the world (Chen & Maharjan, 2024). In several developed countries, where cities are designed to support vehicles, e-bikes' tiny sizes and mobility may not be as significant, but their potential as a car substitute make them a crucial component of the conversation about sustainable transportation. The practical features of e-bikes, especially their higher speed and acceleration compared to traditional bicycles with less effort, contribute to a number of beneficial elements of their use, such as making it possible for more people to ride bicycles, more trips to be performed by bicycle, and more enjoyment for their users. For these users, the outcome was a general decline in driving, with some even giving up cars entirely. However, there have been issues with range anxiety, unwieldiness, safety, and security, as well as several misperceptions on the part of non-users that could inhibit their adoption.

The purpose of this study is to provide a review of low-cost locally-manufactured electric bicycles and their constituent parts. The study aims to provide an analysis on how electric bicycles are categorized in terms of their parts and designs. In order to provide scientists and researchers with useful knowledge to further improve electric bicycles, the electric bicycle research fields are examined based on previous studies.

2. Electric Bicycle Designs

Matey et al. (2017) focused on developing a practical and sustainable solution to the growing concerns regarding energy consumption and environmental pollution. The project meticulously details the design and fabrication process of an electric bike, emphasizing its potential as an energy-efficient mode of transportation. The project delves into the mechanical aspects of the bike's construction, including calculations for chain tension, stress analysis of the sprocket, and selection of appropriate materials. It highlights using a battery as the primary power source and explores the possibility of integrating solar panels for auxiliary power.

Bansal et al. (2020) detailed a project that involved designing and building an electric bicycle. The researchers carefully selected and integrated various components, including a 48V, 750W motor powered by four 12V batteries connected in series. This configuration aimed to provide sufficient power and runtime for the e-bike. It emphasizes the environmental benefits of such a mode of transportation. The key takeaway is their advocacy for e-bikes as a sustainable and eco-friendly alternative to traditional fuel-powered vehicles, especially in urban settings.

Figure 1: A conventional bicycle with electrical components mounted on it (Bansal et al., 2020).

Sudhir et al. (2022) focused on creating a sustainable transportation solution by developing a solar-powered electric bicycle. The project involved designing a system that combines solar energy harvesting with a dynamo mechanism to power an electric bicycle. The bicycle utilizes a 24v 250w Geared motor, powered by two 12v Lithium-ion batteries connected in parallel. A 24v solar panel charges these batteries, providing an alternative to traditional electric charging. The system also incorporates a dynamo, allowing for battery charging through pedalling, which is particularly useful in the absence of sunlight.

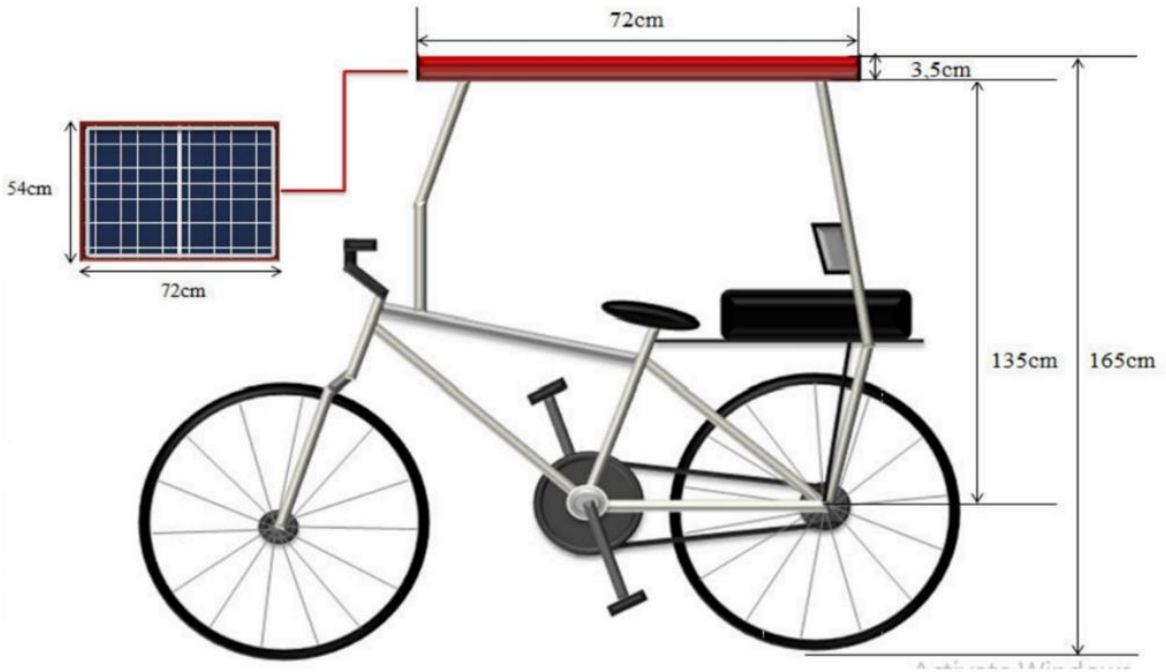

Figure 2: Layout of a solar-powered electric bicycle (Sudhir et al., 2022).

Jadoun and Choudhary (2014) focused on the design and fabrication of a dual-chargeable bicycle as an alternative mode of transportation in response to increasing fuel prices, pollution concerns, and the depletion of non-renewable energy sources. The study aims to address the need for alternative energy sources in vehicles due to environmental and economic factors. By introducing a dual chargeable system in electric bicycles, the research seeks to enhance societal performance and acceptance. The dual chargeable bicycle features a rear-wheel drive system powered by a 0.5 hp motor and a 24V, 5 ampere battery. Charging of the battery is facilitated through both the main power source and an alternator driven by a front-wheel friction drive, making it a dual rechargeable system. The design is suitable for noise-sensitive environments like college campuses and hospitals.

Shashank et al. (2021) revolved around the design and fabrication of a solar-powered bicycle. The main objective is to create a sustainable mode of transportation by incorporating solar energy technology into a conventional bicycle. The solar-powered bicycle is designed to accommodate a single rider and is equipped with a rear-wheel motor powered by solar energy. The system includes a solar panel setup to charge the battery that drives the hub motor. The project draws inspiration from existing research on solar-powered bicycles, highlighting the benefits of reduced pollution and cost savings. Challenges such as terrain limitations due to the reliance on solar power are acknowledged, suggesting the need for further optimization.

Barve and Mishra (2016) discussed the design and development of a Solar Hybrid Bicycle as an alternative mode of transportation in response to increasing fuel prices and environmental concerns. The solar bicycle utilizes solar energy to charge the battery, which powers a hub motor mounted on the front wheel. This concept combines the use of photovoltaic cells to harness solar energy and a dynamo driven by pedalling to charge the battery and run the bicycle. The components of the solar hybrid bicycle include the hub motor, solar panel, lead acid battery, motor controller, accelerator, and dynamo. The study highlights the potential of solar hybrid bicycles in providing a sustainable and cost-effective transportation solution, particularly in regions with ample sunlight like India.

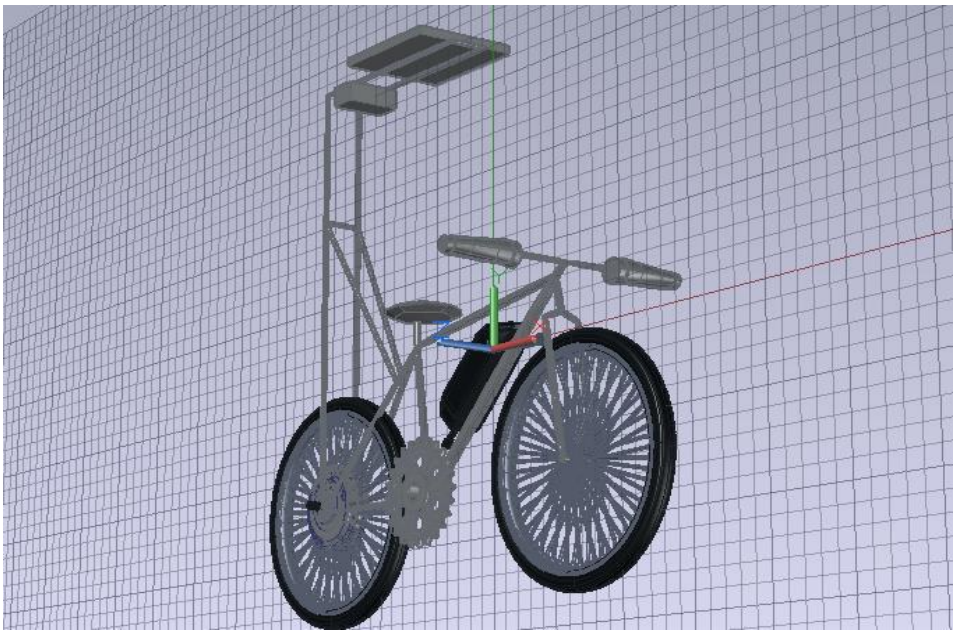

Figure 3: CAD model of a solar-powered electric bicycle (Shashank et al., 2021).

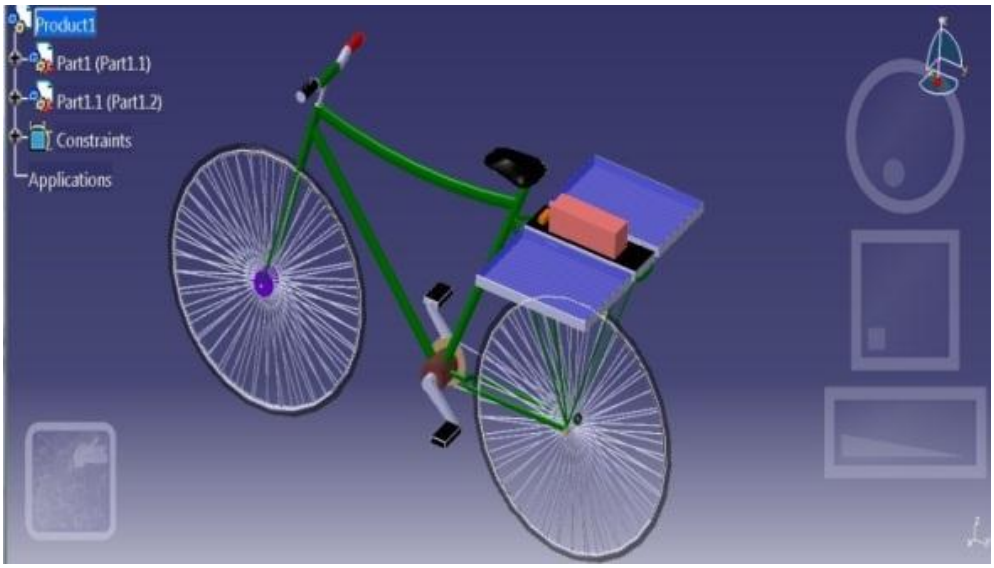

Figure 4: CAD model of solar-powered electric bicycle (Barve & Mishra, 2016).

Randhir et al. (2017) focused on the design and fabrication of an electric bicycle as an alternative mode of transport to reduce fuel consumption and environmental hazards. The electric bicycle utilizes a strong motor and battery power for hill climbing, higher motoring speeds, and free electric transportation. The project highlights the working principle of a DC motor, the role of a speed controller in controlling the motor and serving as a dynamic brake, and the components involved in the Electric Bicycle construction process, including the battery, motor controller circuitry, electric motor, chain and sprocket, and bicycle wheel rotation. The project aims to enhance the efficiency of a normal bicycle by incorporating electric assistance while still allowing manual pedalling for exercise.

AlSabah et al. (2024) focused on the design and mechanical assembly of a Solar Powered Bicycle to address the environmental challenges posed by automobile usage. By integrating a photovoltaic panel with a sun tracker onto the bike, the system maximizes solar energy utilization for prolonged operation. The system architecture and design aim to efficiently capture sunlight, store solar energy in the battery, and power the bike while controlling movement through a relay switch. The project signifies a significant step towards sustainable and eco-friendly transportation, emphasizing the importance of advanced solar technologies and energy storage solutions for enhancing efficiency and usability.

Yashas et al. (2020) discusses the fabrication of a Solar and Dynamo Bike for a two-wheeler, highlighting the use of solar panels, BLDC hub motor, and full twist throttle. When the bicycle is idle or stationary in parking, the solar panel will charge the battery, and a pair of 48-volt dynamo fixed on the rear wheel of the bicycle will charge the battery when the bicycle is running on the road. The technology aims to provide a cost-effective and eco-friendly alternative to traditional fossil fuel vehicles. The system utilizes solar energy captured by solar panels mounted on the bicycle to charge a battery connected to a brushless DC motor, enabling the bike to run on solar power. The design eliminates the need for maintenance, reduces noise, and offers a sustainable mode of transportation.

Figure 5: A solar-powered electric bicycle (AlSabah et al., 2024).

Figure 6: A solar-powered electric bicycle with a dynamo (AlSabah et al., 2024).

Latha (2019) focuses on creating a solar-powered motorbike that utilizes solar panels to continuously charge a 12V battery. The aim is to provide a cost-effective, eco-friendly, and noiseless mode of transportation suitable for various terrains and users, including school children, college students, office goers, villagers, and postmen. The solar-powered bike offers a range of 50 km on a full charge with an average speed of 35 kmph, running for 4 hours. The project emphasizes the reduction of environmental pollution caused by traditional automobile emissions and highlights the advantages of solar power over fossil fuels in terms of availability and sustainability.

Strömberg et al. (2020) conducted in western Sweden focused on investigating the drivers and barriers of using electric bicycles for everyday trips. Participants were lent electric bicycles for 6 months in exchange for replacing at least three days' worth of car journeys with cycling. The study identified various trip components and highlighted how electric bicycles positively and negatively impacted each component. Factors such as ease of cycling, range extension, challenges in mixed traffic, social perceptions, and the need for safe parking and charging facilities were discussed. The study emphasized the importance of understanding user experiences to promote the adoption of electric bicycles and address barriers effectively.

Alanazi (2023) focused on the implementation of electric vehicles (EVs) in cities. It highlights the benefits of EVs, such as lower operating costs, reduced greenhouse gas emissions, and improved air quality. The document also addresses challenges like range anxiety, high costs, and inadequate charging infrastructure. Strategies to promote EV adoption

include government policies, private-sector investment, and public education. The study emphasizes the importance of battery technology, charging infrastructure development, and public awareness in accelerating the transition to a sustainable transportation system.

Apostolou et al. (2018) focused on the experiences and potential of solar-powered e-bikes as a sustainable transportation mode. The research includes a field experiment in the Netherlands to investigate user beliefs and interactions with solar e-bikes. Despite limitations in sample size, the study highlights positive user experiences with solar e-bikes and identifies areas for further research and improvement. Additionally, the project emphasizes the importance of sustainable transportation solutions and the role of solar energy in enhancing e-bike technology.

Asrori et al. (2023) focused on the design and development of a hybrid solar e-bike for sustainable green transportation. Researchers from the State Polytechnic of Malang in Indonesia explored the utilization of solar energy as a renewable power source for electric bicycles. The study involved testing the output parameters of a 100 W photovoltaic module, measuring solar radiation's impact on voltage and current, and assessing the battery's power consumption during operation. The research utilized a minimum microcontroller system to monitor and display real-time data on voltage, current, and power production by the solar cells. Overall, the project aimed to promote eco-friendly transportation solutions by integrating solar technology into electric bicycles.

Bhalshankar and Sutkar (2021) focuses on the application of solar technology in bicycles to create a sustainable mode of transportation. The solar-assisted bicycle is designed to be cost-effective, eco-friendly, and suitable for various road conditions. It aims to provide a practical and efficient means of travel for individuals such as school children, college students, office goers, villagers, and postmen. The solar bicycle is noiseless, pollution-free, and can be recharged using solar energy, making it a viable option for short-distance travel while reducing reliance on fossil fuels. Additionally, the project emphasizes the conservation of energy and the ease of maintenance for users.

Hossain et al. (2022) focused on the integration of electric vehicles (EVs) for sustainable development. It covers various aspects such as technological advancements in EVs, CO_2 emission reduction scenarios, external benefits of EVs, EV adoption hypotheses, and the impacts of EV integration on the grid. The study emphasizes the importance of considering factors like user behavior, policy implications, and technological innovations to promote the widespread adoption of EVs. Additionally, it highlights the need for strategic planning and policy frameworks to support the transition towards a more sustainable transportation sector.

Patoding et al. (2021) focused on the development of electric bicycles with solar panels in Indonesia. By integrating solar panels onto electric bicycles, the batteries can be charged while driving, offering a sustainable and eco-friendly transportation solution. The research included stages such as bicycle preparation, development design, manufacturing of solar panel frames, and component assembly. The electric bicycle uses a 24V, 12Ah battery with a 250-watt DC motor, achieving a maximum speed of 20 km/hour with a range of 16 km and a load capacity of 89 kg. The project aims to promote the use of solar energy in transportation and reduce reliance on traditional electricity sources for charging electric bicycles.

Priya et al. (2021) a research team from SRM Valliammai Engineering College in India developed an innovative electric bicycle that utilizes solar energy for power. The bicycle features a flywheel to capture and reuse kinetic energy lost during braking, a brushless DC motor for efficient propulsion, lead-acid batteries for storage, and a motor controller for power management. This design offers environmental benefits such as reduced emissions and pollution-free operation. The solar bicycle has a speed capability of 40-45 km/hr and a weight capacity of 70 kg, representing a sustainable and efficient mode of transportation. Future enhancements include increasing charging backup, accommodating multiple riders, exploring hybrid bike

options, and incorporating alternator charging for auxiliary functions.

Schepers et al. (2014), the study in the Netherlands compared crash likelihood between electrically assisted bicycles (EBs) and classic bicycles (CBs) to assess road safety. The research emphasized further investigation into the health effects of EBs, considering factors like physical exercise, air pollution reduction, and road safety risks. It highlighted the need for larger studies to develop measures for maximizing health benefits and minimizing risks associated with EB use. The findings are relevant for policymakers in shaping regulations and infrastructure to enhance the safety of electric bicycle users.

Fyhri and Fearnley (2015), the project aimed to analyse the effects of e-bikes on cycling behaviour, specifically looking at the increase in cycling distance and mode share. The study involved participants who were given e-bikes to use for a trial period. Data was collected through surveys and travel diaries at different time points. The results showed that e-bikes led to an increase in cycling activity, with participants cycling more distance and choosing cycling as a mode of transport more frequently. The study highlighted the potential of e-bikes to promote cycling as a sustainable transportation option, especially among women and older cyclists.

3. Components of an Electric Bicycle

Bansal et al. (2020) stated some major components of an electric bicycle such as

i. Motor

The motor provides mechanical force which supports the rider whilst pedalling. These components measure totally different placements for an electrical bike motor, every type has its own benefits; front hub, rear hub, and mid-drive motor. The major function of the motor is to manage force. The more powerful the electrical motor, the more additional force it offers.

Figure 7: A motor.

ii. Battery

The battery powers the motor and will determine the range of your e-bike on a single charge. Batteries are typically rated in volts (V) and amp hours (Ah). Higher voltage provides more power, while higher amp hours provide a longer range. The battery on an electric bike can be located in varying places on the bike, depending on the frame of the bicycle.

Figure 8: A battery pack.

iii. Controller

The controller regulates the power flow from the battery to the motor. It receives signals from the throttle or pedal assist sensor and determines how much power to deliver to the motor.

Figure 9: A controller.

iv. Throttle

This is a handlebar-mounted control that allows you to control the motor speed directly, similar to a motorcycle.

Figure 10: A throttle bar.

v. Battery Charger

This is used to charge the bicycle. For solar-powered bicycles, the solar panels charge the battery with aid of sunlight.

vi. Sensors (Cadence or Torque sensors)

Detect pedalling activity or force applied and sends signals to the controller.

4. Working Principle of an Electric Bicycle

The following steps are the working principle of an electric bicycle:

i. Power Source: The e-bike system starts with a rechargeable battery.

ii. Controller Activation: The rider activates the system, typically by turning on the display unit on the handlebars.

iii. Sensor Input: As the rider begins to pedal, a cadence sensor detects the pedaling motion (rotational speed) or a torque sensor detects the force being applied to the pedals.

iv. Signal Processing: The controller receives the signal from the sensor(s).

v. Motor Activation: Based on the sensor input and pre-programmed settings (pedal-assist level, throttle position), the controller sends electric current to the motor.

vi. Motor Action: The motor utilizes the electricity to generate a magnetic field, causing the motor shaft to rotate.

vii. Wheel Drive: The motor shaft is connected to the drivetrain (chain and cassette) or directly geared to the wheel (hub motor), propelling the bike forward.

viii. Rider Input: The rider can adjust the pedal-assist level or use the throttle (if equipped) to control the amount of motor assistance.

ix. Braking and Stopping: When the rider applies the brakes, the motor may shut off or provide regenerative braking (converting some braking energy back into electricity to recharge the battery - not very effective on e-bikes).

5. Conclusion

Recent research findings reveal a notable gap in understanding the production of electric bicycles that can deliver substantial mileage for the typical commuter at an accessible price point. Hence this research has highlighted some research that offer a vehicle that offers a substantial power supply for daily commuting tasks at a reasonable price point. Therefore, the following recommendations can be made to improve the reviewed designs:

i. Implement a system that captures energy during braking and feeds it back into the battery. This can be done with a regenerative controller, extending the range without significant cost increases.

ii. Consider incorporating used bicycle components like frames and wheels. Reputable bike shops often have good quality used parts at a fraction of the cost of new ones.
iii. Consider integrating a gear-shifting system. This allows riders to choose between electric assist and manual pedaling for different terrains and speeds, potentially extending the range and improving overall performance.
iv. Design the system to use a readily available battery format, like those used in power tools. This allows for easier and potentially cheaper battery replacements.

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