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# Integration of Green Skills in Technology and Vocational Education Curricula: Challenges and Opportunities for SMK Graduates Toward the Green Economy Era

**Rizky Aditya Pratama[1], Putri Indah Lestari[2*], Muhammad Fajar Ramadhan[3]**
[1,2,3] Universitas Pendidikan Indonesia

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***ABSTRACT***

The transition toward a green economy demands a significant transformation of competencies within the vocational education sector to produce an environmentally conscious workforce. This study analyzes the integration of green skills into Indonesia's Vocational High School (SMK) curriculum while identifying structural barriers and labor market opportunities. Employing a systematic literature review (SLR) for the 2015-2025 period using the Synthesis Without Meta-analysis (SWiM) framework, the study synthesized 42 peer-reviewed articles and 5 national policy documents (RPJMN and Bappenas Green Roadmap). The results reveal a distinct competency maturity gap between teachers (scores 2.24-2.91) and students (scores 2.18-2.59) based on harmonized metrics from secondary data. Student scores remain in the low category primarily due to limited school facilities and a lack of direct exposure to green industry standards. Key integration barriers include a curriculum lacking explicit green indicators and low teacher pedagogical readiness. Conversely, labor absorption opportunities are substantial, with a projected need for 1.8 million green workers by 2030 in the renewable energy and waste management sectors, as targeted in the national green workforce roadmap. Managerial solutions suggest curriculum synchronization with circular industry standards. This research recommends that Kemendikdasmen and Bappenas strengthen Project-Based Learning (PjBL) models and Triple Helix collaboration to align vocational education with national low-carbon transformation strategies.

**ABSTRAK**

*Transisi menuju ekonomi hijau menuntut transformasi kompetensi yang signifikan di sektor pendidikan vokasi untuk menghasilkan tenaga kerja yang sadar lingkungan. Penelitian ini menganalisis integrasi green skills (keterampilan hijau) dalam kurikulum Sekolah Menengah Kejuruan (SMK) di Indonesia, mengidentifikasi hambatan struktural, serta memetakan peluang pasar kerja. Menggunakan pendekatan tinjauan literatur sistematis (SLR) periode 2015-2025 dengan kerangka kerja Synthesis Without Meta-analysis (SWiM), studi ini menyintesis 42 artikel jurnal dan 5 dokumen kebijakan nasional (RPJMN dan Peta Jalan Bappenas). Temuan menunjukkan adanya kesenjangan kematangan kompetensi antara guru (skor 2,24-2,91) dan siswa (skor 2,18-2,59) berdasarkan harmonisasi metrik data sekunder. Skor siswa berada pada kategori rendah yang dipicu oleh keterbatasan sarana sekolah dan minimnya paparan industri hijau. Hambatan utama mencakup kurikulum yang belum memuat indikator hijau secara eksplisit serta kesiapan pedagogis guru yang rendah. Di sisi lain, terdapat peluang penyerapan 1,8 juta tenaga kerja hijau pada tahun 2030 di sektor energi terbarukan dan pengelolaan limbah sesuai target peta jalan tenaga kerja hijau nasional. Solusi manajerial yang diusulkan adalah sinkronisasi kurikulum dengan standar industri sirkular. Penelitian ini merekomendasikan agar Kemendikdasmen dan Bappenas memperkuat model pembelajaran berbasis proyek (PjBL) dan kolaborasi Triple Helix untuk menyelaraskan pendidikan vokasi dengan strategi transformasi ekonomi rendah karbon nasional.*



**** Corresponding Author:***

Putri Indah Lestari
*Email*: putri.lestari.project@gmail.com

## INTRODUCTION

The global environmental crisis, characterized by extreme climate change, ecosystem degradation, and resource scarcity, has forced the international community to re-evaluate conventional economic development paradigms. In Indonesia, high greenhouse gas emissions and ecological vulnerability have significantly impacted industrial productivity, compelling companies to adopt low-carbon operational standards for business sustainability. The transition toward sustainable development is no longer merely an ethical choice but an urgent necessity to ensure the survival of future generations amidst tightening planetary ecological boundaries. Governments worldwide are adopting resource efficiency strategies as a primary pillar of national policy to suppress emissions in line with the Paris Agreement targets (Erwinsyah, 2021; Simbolon & Simbolon, 2024).

This global phenomenon creates significant waves of change in industrial structures, where traditional business practices are being replaced by green technological innovations that demand ecoaa-friendly operational standards. Such dynamics require educational institutions to reorient their curricula to align with the demands of a labor market that is increasingly mainstreaming sustainability values in every operational aspect (Fuchs, 2024; Widyakusuma & Hakim, 2024). Consequently, the readiness of human resources adaptive to these changes becomes a primary determinant for the success of this economic transition in the future. Education must bridge the industrial need for a workforce possessing both ecological integrity and proficient technical competence (Chinedu et al., 2023; Maclean et al., 2017).

The green economy in Indonesia is defined as an economic development model to support sustainable development focusing on investment, capital, infrastructure, employment, and skills to achieve social welfare and environmental sustainability. This definition adopts the framework from the United Nations Environment Programme, which prioraitizes improving quality of life while respecting environmental limits. In its application, the green economy in Indonesia has five primary principles encompassing welfare, justice, planetary boundaries, efficiency and sufficiency, as well as integrated governance. Implementing this concept aims to drive economic growth that focuses not only on material gain but also on social inclusivity.

This strategy is expected to be a solution for economic stagnation while addressing climate change challenges that are starting to have a tangible impact on productive sectors in the country. Through this systemic approach, the government seeks to create an economic ecosystem more resilient to global ecological shocks predicted to occur more frequently. The success of this model heavily relies on the synchronization between government macro-policies and micro-readiness at the level of educational units and industry (Isbah et al., 2025). This transformation demands long-term commitment from all stakeholders to shift from exploitative to regenerative practices.

The urgency of the green economy transition in Indonesia is strengthening alongside the establishment of the Indonesia Emas 2045 Vision and the Net Zero Emission (NZE) commitment by 2060 or earlier. The government has placed the green economy as one of the six national economic transformation strategies in the National Medium-Term Development Plan (RPJMN). This policy is supported by various initiatives such as Low Carbon Development (PRK) and the implementation of carbon pricing through carbon tax schemes and carbon caps and trade. This transition is predicted to trigger a major shift in the national labor demand structure.

The renewable energy and circular economy sectors are projected to be primary drivers requiring approximately 1.8 million new green workers by 2030. This figure reflects the massive potential for labor absorption if the education system can adapt quickly to changing industrial competency standards. Indonesia's primary challenge currently is preparing a workforce capable of operating new, more efficient, and low-emission technologies. Therefore, a green workforce development roadmap is crucial to ensure this transition process is fair and does not leave vulnerable groups behind (Mutohhari et al., 2025; Sufiani et al., 2025).

Technology and Vocational Education, particularly Vocational High Schools (SMK), hold a strategic role as the primary supplier of skilled labor for the Business and Industrial World (DUDIKA). As institutions oriented toward mastering practical skills, SMKs are expected to respond to the dynamics of green industry needs by preparing graduates with relevant competencies. However, several studies indicate that the level of green skills literacy among vocational students and teachers in Indonesia is still relatively low and uneven (Jarwopuspito et al., 2023; Saputri & Ediyono, 2022). Furthermore, the integration of green competencies into vocational curricula remains limited and requiraes systematic development and validation (Latif et al., 2025; Suhendra et al., 2025). This condition shows a gap between industrial expectations and the actual readiness of vocational education graduates in supporting the green economy transformation (Lupikawaty et al., 2025; Sari et al., 2025).

Data shows that SMK graduates remain significant contributors to the Open Unemployment Rate (TPT) in Indonesia, recorded at 9.01% as of August 2024. This phenomenon is often caused by a competency mismatch between what is taught in schools and actual modern industry needs. Graduates' unreadiness to face green industry standards is a serious issue hindering labor absorption in future strategic sectors. Critical analysis indicates that this mismatch occurs because vocational curricula often lag behind the rapid pace of low-emission technological innovation adopted by industry (Ahmad et al., 2024; Albertz & Pilz, 2025).

Transforming the SMK curriculum is a necessity so that vocational institutions do not merely produce traditional technical workers but also environmentally conscious agents of change. Competency gaps in green skills remain a major obstacle that must be immediately addressed in Indonesia's vocational education system. Based on research findings, green skill elements and dimensions have not been effectively integrated into current vocational school curricula, resulting in low student competency levels that do not yet meet labor market demands (Mutohhari et al., 2025; Saputri & Ediyono, 2022).

SMK teachers are also reported to have varying levels of understanding regarding green skill concepts, impacting the effectiveness of knowledge transfer in the classroom (Handayani et al., 2020). Green skills integration covers a broad spectrum of knowledge, abilities, values, and professional attitudes aligned with international standards (Ibrahim et al., 2024). Operationally, green skills include the ability to manage waste, improve energy efficiency, and innovate in developing environmentally friendly technologies (Fitriyanto et al., 2021; Haloho et al., 2023). Without clear standardization, this integration process will continue to be fragmented and difficult to measure.

Theoretically, green curriculum development in SMK is grounded in Human Capital Theory, which views education and training as strategic investments to enhance productivity. This perspective is increasingly relevant in the context of green economies, where the accumulation of environmental competencies

contributes directly to sustainable economic growth (Lyu et al., 2025; Pirzada et al., 2023). In this regard, green human capital refers to a set of environmental knowledge and skills enabling the workforce to adapt to clean technologies and sustainable production systems.

By improving human capital quality through green skills integration, Indonesia can compensate for natural resource limitations and ensure long-term global competitiveness. Increasing green competence is not only about mastering new technologies but also about fostering a mindset oriented towards resource efficiency and sustainability values. The Indonesian government has initiated strategic programs such as the SMK Center of Excellence (SMK PK), which aims to strengthen curriculum alignment with industry needs through the link-and-match approach (Ahmad et al., 2024). This effort is expected to reduce the gap between education output and labor market demands.

Other initiatives, such as the development of technoparks and innovation-based learning ecosystems, are also being promoted to support sustainable vocational education transformation (Usman et al., 2024). Additionally, global experiences demonstrate that integrating green technologies into vocational education significantly enhances graduate readiness for sustainable industries (Latif et al., 2025; Li et al., 2023). Despite these developments, previous studies tend to address green skills in a general context without focusing on specific vocational clusters, indicating a gap that requires further investigation.

This study offers novelty through the use of the Synthesis Without Meta-analysis (SWiM) framework to provide a deeper overview of green skills integration in SMK, particularly within technology and engineering clusters. Through this approach, secondary data is systematically synthesized to map teacher and student competency maturity more comprehensively. The focus on these clusters is essential, considering their direct exposure to green industrial transformation and low-carbon technological systems (Pujun, 2025).

Finally, the results of this analysis are expected to generate concrete policy recommendations for strengthening the synergy between vocational education and the green economy. This study is anticipated to contribute to the development of globally competitive human resources with strong environmental awareness. Thus, Indonesia's vision to become a green economy leader in Southeast Asia can be supported by a vocational workforce that is both skilled and sustainability oriented.

## METHOD

This study employs a qualitative approach with a Systematic Literature Review (SLR) design, utilizing descriptive-analytical techniques to explore the integration of green skills in Vocational High Schools (SMK) in depth. This descriptive-analytical design was chosen to provide clear operational boundaries, specifically focusing on the technology and engineering expertise clusters, which are the fields most directly impacted by the green economy transition in Indonesia (Isbah et al., 2025; Kaushiva, 2025). The primary focus of this research is to systematically synthesize data to describe the reality of vocational curriculum implementation amidst the rapidly growing demands of a low-carbon economy. Through this method, the resulting narrative data provides a comprehensive overview of the factors influencing the readiness of SMK graduates compared to circular industry standards (Beducci et al., 2024; Hanna et al., 2024).

The data collection technique was conducted through documentation studies and the synthesis of secondary literature from reputable databases such as Scopus

and Sinta. The literature search was performed systematically via Google Scholar and ResearchGate using specific keywords such as "green skills SMK" and "Indonesia green economy". To ensure validity, the data were strengthened by including national strategic policy documents as primary policy data sources, including the 2020–2024 RPJMN and the Indonesia Green Workforce Development Roadmap from Bappenas. The integration of these various sources aims to ensure the accountability of the data filtration process and provide an up-to-date theoretical foundation (Karyo et al., 2025).

The selection of research materials was based on strict inclusion and exclusion criteria to ensure the accountability of the filtration process. Inclusion criteria encompassed journal articles (2021–2026), books (2016–2026), and national policy documents that explicitly discuss green skills within the context of technology and vocational education. Conversely, articles that only mentioned the term "green economy" rhetorically without supporting data or operational indicators were excluded from the primary analysis. This approach aligns with previous systematic review practices in green vocational education research (Albertz & Pilz, 2025; Pujun, 2025). Based on this filtration procedure, 156 literatures were identified in the initial search stage, of which 42 journal articles and 5 national policy documents were declared eligible for the final synthesis in this study.

The data processing utilized the Synthesis Without Meta-analysis (SWiM) framework to qualitatively map the direction of effects from various curriculum interventions. Structured coding was performed manually using thematic categorization tables to ensure the reliability of the synthesis results without relying on quantitative software. Data were categorized into three primary green skill domains cognitive, interpersonal, and intrapersonal to examine the interconnected patterns of competencies holistically (Pirzada et al., 2023; Trevisan et al., 2025). The researcher applied metric harmonization to compare the maturity levels of green skills between teachers and students to identify gap patterns more objectively, as also highlighted in studies on green skill measurement in vocational education (Mutohhari et al., 2025; Saputri & Ediyono, 2022).

The final stage of this methodology is interactive data analysis, which includes data reduction, data display, and conclusion drawing through a verification process. Data reduction was carried out by summarizing crucial points from the selected literature, focusing on the problematic aspects of vocational education within the technology cluster in Indonesia. Data display was presented in a descriptive narrative and sectoral tables to facilitate the interpretation of green workforce absorption potential. Conclusions were drawn through a verification process by referring back to sustainable development and green workforce theories to ensure the consistency of the research findings (Surono, 2025; Tsironis, 2023). The entire process was conducted while maintaining transparency in the use of source citations to avoid subjective bias and ensure methodological rigor.

## RESULTS AND DISCUSSION

### Green Skills Achievement Profile and Vocational Employment Conditions

The results indicate that the employment condition of SMK graduates in Indonesia faces a significant paradox amidst the green economy transition. Based on the latest data, the Open Unemployment Rate (TPT) for SMK graduates remains the highest among all educational levels, reaching 9.01% as of August 2024. This figure significantly exceeds the national average of 4.91%, indicating a persistent mismatch between graduate competencies and market demands. A critical review

suggests that this mismatch is not merely due to a lack of basic technical skills, but rather a systemic delay in aligning vocational curricula with the rapid adoption of low-carbon technologies by industry (Isbah et al., 2025; Lupikawaty et al., 2025). Therefore, integrating green skills is urgent to enhance the competitiveness of graduates in sustainable sectors (Maclean et al., 2017).

The maturity level of green skills shows a distinct gap between teachers and students in SMK environments. Teachers consistently demonstrate a deeper understanding with scores ranging from 2.242 to 2.917 on a 4-point scale, while students remain in the "low" category with scores between 2.188 and 2.594. This low achievement among students is primarily triggered by internal school factors, such as outdated practical facilities, and external factors like minimal exposure to green industry standards. These findings are consistent with previous studies showing that students' green skill literacy remains relatively low and uneven across vocational institutions (Jarwopuspito et al., 2023; Saputri & Ediyono, 2022). Furthermore, although teachers demonstrate moderate competency levels, their understanding is still insufficient to meet industry expectations, thus limiting effective knowledge transfer (Handayani et al., 2020; Mutohhari et al., 2025).

Analysis of green skill dimensions reveals that the interpersonal (IC) domain has the most consistent and positive influence on student work readiness. The ability to collaborate and communicate regarding sustainable practices proves more prominent than purely cognitive aspects in the SMK environment. This aligns with studies emphasizing that behavioral and collaborative competencies play a crucial role in green workforce readiness (Haloho et al., 2023; Ibrahim et al., 2024). Conversely, the cognitive domain (CC) related to technical environmental knowledge still requires significant strengthening through more applicable and practice-based curricula (Chinedu et al., 2023). Additionally, the positive relationship between religiosity and environmental awareness serves as an important form of social capital in shaping green work ethics (Siti et al., 2024). Balancing cognitive, interpersonal, and intrapersonal dimensions is therefore essential to produce graduates who possess both technical expertise and ecological integrity (Latif et al., 2025).

**Table 1: Comparison of Green Skills Maturity Scores in SMK Environments**

| Respondent Group | Green Skills Score Range (Scale 1-4) | Competency Category |
|---|---|---|
| **SMK Teachers** | 2.242 - 2.917 | Medium |
| **SMK Students** | 2.188 - 2.594 | Low |
| **Industry Target** | > 3.000 | High |

## Green Labor Market Potential and Sectoral Opportunities

The green economy era opens significant new job opportunities for SMK graduates, particularly in renewable energy and environmental management sectors. The government projects the creation of at least 448,000 new green jobs within the next five years, driven by the acceleration of eco-friendly energy infrastructure. This trend is consistent with global findings indicating that low-carbon transitions generate substantial employment opportunities in renewable energy and energy efficiency sectors (Hanna et al., 2024). Specifically, the New and Renewable Energy (EBT) sector requires skilled technicians capable of installation and maintenance to support national energy targets. To respond to this demand, vocational curricula must incorporate applied competencies such as energy auditing and sustainable system optimization (Pujun, 2025; Wibowo et al., 2025).

The waste management and circular economy sectors also represent promising labor markets that remain underutilized by vocational graduates. The development of Waste-to-Energy (PSEL) facilities requires a workforce with specific competencies in emission control and resource efficiency. In this context, SMK graduates have the potential to act as technicians capable of transforming waste into economically valuable products. Strengthening competencies such as waste classification, recycling technology, and eco-efficiency analysis will provide a competitive advantage for graduates (Fitriyanto et al., 2021; Suhendra et al., 2025). Moreover, structured green skills training has been shown to significantly improve sustainable competence among vocational students (Sufiani et al., 2025).

In the manufacturing sector, the demand for a workforce equipped with green industry literacy continues to increase, particularly given the sector's significant contribution to national GDP. Industries increasingly require technicians who can optimize resource use while minimizing carbon emissions. Graduates from mechanical and chemical engineering programs are particularly relevant for green-collar jobs focused on operational efficiency and sustainable production systems. However, without systematic curriculum integration and competency standardization, vocational graduates risk being marginalized in highly competitive industrial environments (Latif et al., 2025; Nurani & Komariah, 2025). Therefore, aligning vocational education with industry remains a strategic priority to reduce graduate unemployment and accelerate green economic transformation.

**Integration Challenges in the Merdeka Curriculum**

Despite these opportunities, implementing green skills within the Merdeka Curriculum in SMK faces complex structural barriers. The current curriculum is considered to lack explicit green indicators integrated into productive and normative subjects. Many schools still emphasize conventional technical competencies while neglecting environmental sustainability aspects. This condition reflects broader findings that green skill integration in vocational education often remains partial and not systematically embedded in curriculum structures ( Fuchs, 2024; Pirzada et al., 2023). The absence of teaching modules that explicitly connect workplace practices with ecological responsibility remains a major challenge. Consequently, Education for Sustainable Development (ESD) is frequently treated as a complementary element rather than a foundational learning principle (Ibrahim et al., 2024). Therefore, a revision of Graduate Competency Standards (SKL) is necessary to incorporate measurable indicators of green work behavior ( Latif et al., 2025).

Teacher readiness emerges as a decisive variable requiring serious attention through continuous professional development. SMK teachers face multiple constraints, including limited time and insufficient training to master emerging green technologies. Low literacy in green skill concepts significantly affects the effectiveness of classroom knowledge transfer (Handayani et al., 2020; Mutohhari et al., 2025). Additionally, teachers are often burdened by administrative demands within the Merdeka Curriculum framework, reducing opportunities for pedagogical innovation. Existing training programs tend to be sporadic and fail to address the specific technical needs of each vocational cluster. Strengthening teacher competence through structured industry collaboration is therefore essential to foster adaptive and forward-looking learning environments (Shamzzuzoha et al., 2022).

Infrastructure limitations in SMK laboratories also hinder the implementation of effective green learning. Many school laboratories still rely on outdated equipment with low energy efficiency, making it difficult to simulate real industrial environments aligned with green standards. Budget constraints further limit opportunities for

upgrading facilities, resulting in a predominance of theoretical learning without practical exposure. To address these limitations, the integration of digital technologies such as virtual laboratories and AI-based simulations presents a cost-effective alternative. Evidence from international vocational institutions shows that technology-enhanced learning environments can significantly support green technology adoption (Li et al., 2023; Lyu et al., 2025). Developing "living laboratories" within schools is therefore a strategic investment to allow students to directly practice circular economy principles.

**Strengthening Pedagogy and Link-and-Match Strategies**

Project-Based Learning (PjBL) is identified as one of the most effective pedagogical approaches to foster green skills among SMK students. Through PjBL, learners actively engage in solving real-world environmental problems, such as designing waste management systems or developing simple renewable energy prototypes. This approach not only enhances technical competencies but also strengthens critical thinking and creativity in addressing sustainability challenges (Fitriyanto et al., 2021). Furthermore, experiential learning activities, such as transforming production waste into economically valuable products, serve as practical indicators of successful green skill integration (Haloho et al., 2023). Thus, vocational education institutions are positioned not only as skill providers but also as incubators of environmentally conscious innovation.

The implementation of the 8+i link-and-match strategy must be optimized by incorporating green industry actors as strategic partners. Curriculum alignment should actively involve practitioners from environmentally responsible industries to ensure relevance with current labor market demands. Guest teacher programs and industrial immersion initiatives can provide updated insights into eco-friendly Standard Operating Procedures (SOPs), benefiting both students and educators. Internationally recognized green competency certifications should become key performance indicators for vocational programs (Pujun, 2025). A Triple Helix collaboration model involving government, industry (DUDIKA), and academia is essential to ensure balanced knowledge transfer and sustainable workforce development (Syafruddin et al., 2025).

The integration of green skills within vocational education represents a concrete effort to prepare the younger generation as agents of change in supporting a just transition toward sustainability. In the long term, SMK graduates equipped with green competencies will play a critical role in achieving Indonesia's Net Zero Emission target by 2060. Their contributions in sectors such as renewable energy systems, smart infrastructure, and circular economy practices will reduce dependence on fossil fuels and enhance national resilience. Strengthening green skills not only improves employability but also shapes a workforce capable of driving sustainable innovation at both local and national levels (Sufiani et al., 2025; Suhendra et al., 2025; Yang & Tao, 2025).

## CONCLUSION

The integration of green skills into the SMK curriculum in Indonesia is a strategic imperative to reduce the Open Unemployment Rate, which reached 9.01% as of August 2024. This study concludes that while there is a potential absorption of 1.8 million green workers by 2030, a significant competency gap persists, as student green skill scores (2.188-2.594) remain far below industry standards (above 3.000). Multidimensional green skills comprising cognitive, interpersonal, and intrapersonal domains serve as the primary foundation for graduates to adapt to low-carbon

technologies. Notably, the interpersonal domain has proven to have the most consistent influence on student work readiness. However, implementation is hindered by a curriculum that lacks explicit green indicators, varying teacher readiness, and limited practical facilities that fail to meet green industry standards. Theoretically, investing in green human capital through vocational education is key to national productivity and the achievement of Indonesia's **2060 Net Zero Emission target**.

To accelerate this integration, the government, through Kemendikdasmen and Bappenas, must immediately establish standardized sustainable learning indicators within the Graduate Competency Standards (SKL) for all SMK majors. Schools should transform learning environments into "living laboratories" using Project-Based Learning (PjBL) models focused on real-world environmental solutions and the circular economy. To overcome budget limitations for such laboratories, schools are encouraged to seek **CSR schemes or equipment grants** from the green industry. Furthermore, teacher-skilling and reskilling programs regarding the latest green technologies are vital to closing the knowledge transfer gap. Strengthening Triple Helix collaboration is also crucial to expanding internship quotas in eco-friendly sectors and encouraging investment in digital infrastructure, such as Artificial Intelligence (AI), to simulate green industrial practices cost-effectively.

**Research Limitations** This study acknowledges certain limitations. As a synthesis of secondary literature, the findings represent a conceptual and meta-analytical overview of the 2015-2025 period. These results require further verification through longitudinal studies or future classroom action research to measure the real-time effectiveness of green skills integration across diverse SMK expertise clusters in Indonesia. Despite these limitations, this research provides a strategic roadmap for creating a competent and globally competitive vocational workforce ready to fill millions of job opportunities in the green economy era.

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