Implementation Principles of Optimal Control Technology for the Reduction of Greenhouse Gases in Semiconductor Industry

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Abstract. Climate change is occurring at a much faster rate than in the past and it cannot be explained solely by natural causes. Humans, specifically the greenhouse gases (GHG) emissions produced by human activity, are the primary cause of the earth's rapidly changing climate today. As one of the most GHG emission industries, semiconductor, at present, there is no clear guideline for the implementation of significant reduction method for many fluorinated compounds (FCs), N2O and NF3 greenhouse gases in the domestic and overseas semiconductor industry. Therefore, this report, implementation principles of optimal control technology for the GHG emissions have been proposed based on the Intergovernmental Panel on Climate Change (IPCC) and old reduction method. This reduction method is suitable for the installation of efficient exhaust gas destruction equipment for the removal of FCs and N2O from Etching, Thin Film, including chemical/physical vapour deposition, and Diffusion processes in the semiconductor industry.

Keywords: Greenhouse Gas (GHG); GHG Emission Reduction; Methodology; Semiconductor Industry; Gas Abatement System

1. Background

In response to the World Semiconductor Council's (WSC) post-2010 voluntary fluorinated greenhouse gas (PFC) emission reduction plan and the global goal of achieving net zero emissions, the Taiwan Semiconductor Industry Association (TSIA) Environmental Safety Committee member companies have been actively engaged in implementing effective strategies. To support these efforts, the WSC has released crucial guidelines and methodologies aimed at reducing PFC emissions in the semiconductor industry.

The WSC has introduced the Methodology for Reduction of Fluorinated and N_2O Greenhouse Gas Emissions from the Semiconductor Industry (TM002) and the Best Practice Guidance for Emission Reduction of Semiconductor Fluorinated Greenhouse Gas (BPGER). These guidelines serve as invaluable references for TSIA Environmental Safety Committee member companies in their F-gas reduction and testing initiatives. Furthermore, the latest IPCC 2019 Emission Guidelines have been incorporated to provide comprehensive guidance for the reduction of greenhouse gas emissions.

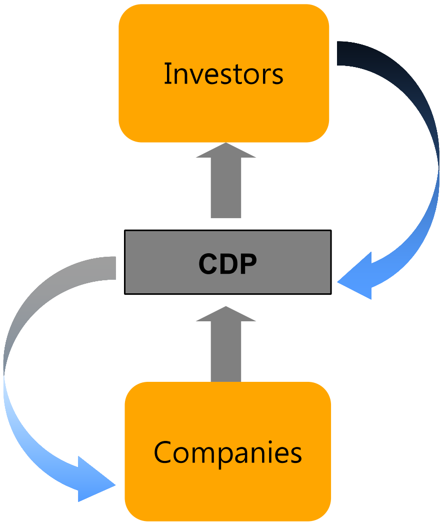

Figure 1. Carbon Disclosure Project (CDP) implemented by international investment institutions in 2003.

The development of these guidelines involved collaborative efforts between the Semiconductor Association member companies and the esteemed Industrial Technology Research Institute (ITRI). Drawing

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upon their collective expertise and knowledge, these organizations have formulated practical standards and recommendations that enable TSIA member companies to effectively mitigate and monitor fluorinated greenhouse gas emissions. Moreover, the Carbon Disclosure Project was also initiated by international investment institutions in 2003 (Figure 1). The CDP survey report mainly provides investors information to understand the status of carbon risk management of an enterprise, and the scale is getting bigger year by year. In the report published recently, a total of 9,331 enterprises disclosed their current situations to CDP, and 219 of which were Taiwanese enterprises. CDP provides five major projects and integrates the information disclosure platform. Carbon disclosure information is integrated from the perspective of Corporate Social Responsibility (CSR).

By adhering to these guidelines and methodologies, TSIA Environmental Safety Committee member companies demonstrate their unwavering commitment to environmental sustainability and their proactive approach to meeting emission reduction targets. Through their collaborative efforts and adherence to international standards, these companies contribute significantly to the semiconductor industry's global endeavors in addressing climate change and working towards a future of net zero emissions.

2. Future GHG Emission Targets

2.1 Standard Emission Rate and 2030 Reduction Target

In line with its dedication to sustainability, the semiconductor industry, under the leadership of the World Semiconductor Council (WSC), is actively pursuing significant reductions in fluorine-gas emissions. The Taiwan Semiconductor Industry Association (TSIA), as a prominent member of the WSC, is committed to implementing the best control technology to achieve a standard emission rate (NER) of 0.22 kg CO_2e/cm^2 by 2020. This ambitious target represents a remarkable 30% reduction in NER compared to the baseline established in 2010. By setting such a challenging objective, TSIA aims to demonstrate its industry leadership in mitigating greenhouse gas emissions. The semiconductor sector recognizes the urgent need for sustainability practices and acknowledges its responsibility in contributing to global emission reduction goals. Through the implementation of cutting-edge control technologies and the adoption of best practices, TSIA is committed to driving significant improvements in emission rates.

Furthermore, TSIA recognizes the importance of long-term sustainability planning. In alignment with the WSC's vision, TSIA will establish its 2030 reduction target to ensure continuous progress towards reducing fluorine-gas emissions. By aligning its goals with the WSC's long-term objectives, TSIA reaffirms its commitment to sustainable practices and acknowledges the global nature of the environmental challenges at hand. The standard emission rate and the 2030 reduction target serve as critical milestones for the semiconductor industry's efforts to combat climate change. By striving to achieve these targets, TSIA aims to make a substantial contribution to global emission reduction efforts and demonstrate its commitment to environmental stewardship. Through collaboration, innovation, and a shared vision, TSIA and the entire semiconductor industry are working towards a more sustainable and environmentally responsible future [4].

2.2 Expansion of Control Techniques

In its pursuit of comprehensive emission reduction, the semiconductor industry recognizes the need to expand the implementation of best control techniques. This expansion encompasses not only emission reporting and new plants but also includes the inclusion of "Rest of the World" plants. While these plants are situated outside the World Semiconductor Council (WSC) region, they are operated by WSC Association member companies, making them an integral part of the industry's efforts to minimize environmental impact. By extending the application of control techniques to "Rest of the World" plants, the semiconductor industry demonstrates its commitment to global environmental sustainability. These plants, although located in different regions, play a crucial role in the overall environmental footprint of semiconductor manufacturing. Recognizing this, the industry seeks to ensure that rigorous control measures are applied consistently across all facilities, regardless of their geographical location.

Through the implementation of best control techniques, the industry aims to minimize the release of fluorine-gas emissions and other related pollutants. This expansion serves as a testament to the industry's collective responsibility in addressing environmental challenges on a global scale. By promoting sustainability practices beyond regional boundaries, the semiconductor industry aims to foster a more cohesive and environmentally responsible approach to semiconductor manufacturing. The inclusion of "Rest of the World" plants within the purview of control techniques highlights the industry's commitment to comprehensive emission reduction and environmental stewardship. It signifies a collective effort to minimize the environmental impact of semiconductor manufacturing operations worldwide. Through collaboration, knowledge sharing, and the adoption of best practices, the industry aspires to create a sustainable future for semiconductor production, one that balances technological advancements with responsible environmental practices [1,4]. Define kilogram carbon equivalent (kg CO_2e/cm^2) per wafer area processed, based on the Global Semiconductor Association's NER as the unit of measure, which will be a WSC target for the global semiconductor industry. This target should not be applied to a single individual region, and companies or facilities that break ground on semiconductor fabs after May 2011 are considered new fabs and must adopt the WSC best execution procedures [5]. This TSIA Semiconductor Fluorine Gas Emission Reduction BAT Implementation Principles will also be used in conjunction with the WSC review and update of the Fluorine Gas Emission Reduction Target.

2.3 Standardized Measurement and Best Execution Procedures

The global semiconductor industry places significant emphasis on standardized measurement as a means to evaluate and mitigate greenhouse gas emissions. Recognizing the need for consistency and comparability, the industry has embraced the kilogram carbon equivalent (kgCO2e/cm2) per wafer area processed as the unit of measure for assessing emissions. This standardized measurement, based on the NER (Normalized Emission Rate) developed by the Global Semiconductor Association, serves as a common target for the entire industry.

It is crucial to highlight that this target is not intended for implementation within a specific region but rather on a global scale. By adopting a unified measurement approach, the industry aims to facilitate meaningful comparisons and benchmarking of greenhouse gas emissions across semiconductor manufacturing facilities worldwide. This global perspective underscores the industry's commitment to addressing environmental challenges holistically and collaborating on sustainable practices. Furthermore, the industry recognizes the significance of best execution procedures in establishing and operating semiconductor fabs. To ensure the highest environmental standards, the World Semiconductor Council (WSC) has mandated that any semiconductor fabs initiated after May 2011 are classified as new fabs. These new fabs must adhere to the WSC's best execution procedures, which encompass a comprehensive set of guidelines and practices for minimizing environmental impact throughout the lifecycle of a facility.

The WSC's best execution procedures encompass various aspects, including site selection, facility design, construction, and ongoing operation. These procedures promote the integration of sustainable technologies and practices into all aspects of semiconductor manufacturing, ranging from energy efficiency and waste management to water conservation and emissions control. By adhering to these procedures, semiconductor fabs are positioned to achieve optimal environmental performance and contribute to the industry's broader sustainability goals. The establishment of standardized measurement and the adoption of best execution procedures reflect the semiconductor industry's proactive approach towards environmental stewardship. By setting global targets and implementing comprehensive guidelines, the industry strives to harmonize its environmental efforts and ensure the highest level of sustainability across semiconductor manufacturing operations. Through continuous improvement and collaboration, the industry aims to advance responsible practices, reduce its environmental footprint, and drive positive change within the semiconductor ecosystem [5].

2.4 TSIA Semiconductor Fluorine Gas Emission Reduction BAT Implementation Principles

The TSIA Semiconductor Fluorine Gas Emission Reduction BAT (Best Available Techniques) Implementation Principles serve as a vital roadmap for the semiconductor industry in achieving the ambitious fluorine gas emission reduction targets set by the World Semiconductor Council (WSC). These principles provide a comprehensive framework that guides industry stakeholders in adopting best practices, implementing advanced control technologies, and fostering collaboration to effectively reduce fluorine gas emissions. By adhering to these implementation principles, semiconductor companies actively embrace cutting-edge techniques and strategies to minimize their environmental impact. The principles outline a range of practices, such as the optimization of process technologies, the utilization of innovative gas abatement systems, and the integration of sustainable design approaches. These measures ensure that semiconductor manufacturing processes are conducted in an environmentally responsible manner. Moreover, the TSIA Semiconductor Fluorine Gas Emission Reduction BAT Implementation Principles work in tandem with the WSC's ongoing review and updates. This collaborative approach ensures that the semiconductor industry remains at the forefront of sustainable practices and continually improves its emission reduction strategies. The principles serve as a dynamic guide, allowing industry stakeholders to adapt to emerging technologies and evolving regulatory requirements while maintaining a strong commitment to environmental stewardship.

The implementation principles also foster collaboration among industry players, academia, and research institutions. By sharing knowledge, expertise, and research findings, the semiconductor industry can collectively address challenges and identify innovative solutions to further reduce fluorine gas emissions. This collaborative approach promotes the exchange of best practices and encourages the adoption of state-of-the-art technologies, ultimately driving continuous improvement within the industry. The TSIA Semiconductor Fluorine Gas Emission Reduction BAT Implementation Principles play a pivotal role in ensuring that the semiconductor industry achieves its emission reduction targets and contributes to a more sustainable future. By aligning with these principles, semiconductor companies demonstrate their commitment to environmental responsibility and their dedication to mitigating the environmental impact of their operations. Through the adoption of best practices and the continuous improvement of emission reduction strategies, the industry strives to minimize its environmental footprint and contribute positively to global sustainability efforts [4].

3. GHG Emission Reduction Program

The GHG Emission Reduction Program encompasses various strategies and methodologies aimed at minimizing greenhouse gas emissions within the semiconductor industry (Figure 2). This section highlights key approaches, including reduction methodology, process optimization, greenhouse gas substitution, advanced abatement methodology, and the implementation of remote plasma cleaning systems.

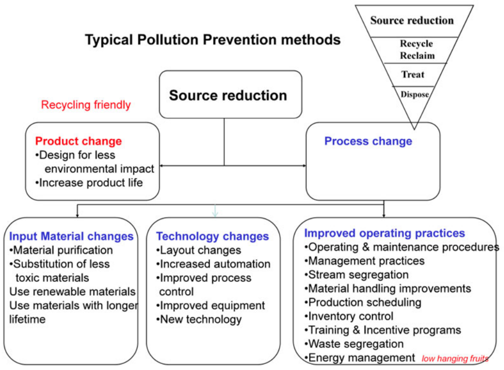

Figure 2. Guideline for sustainable process and prevention of pollution.

3.1 Process Optimization

Process optimization is a key strategy employed in the semiconductor industry to reduce greenhouse gas consumption and minimize fluorinated greenhouse gas emissions. By fine-tuning various process variables, such as chamber pressure, temperature, plasma power, cleaning gas flow rate, gas flow time, and gas mixture ratios, semiconductor companies can achieve significant reductions in carbon emissions [6]. The optimization efforts extend to different processes within semiconductor manufacturing, including chemical vapor deposition (CVD) chamber cleaning and etching procedures. These processes are carefully analyzed and modified to enhance their efficiency and environmental performance. By making adjustments to the process variables, companies can achieve a more sustainable operation while maintaining high-quality production standards.

To support process optimization, advanced inspection systems are employed to monitor changes and gather crucial data. Techniques such as mass spectrometry (MS), infrared (IR) spectroscopy, optical emission spectroscopy (OES), and radio frequency (RF) impedance monitoring are utilized to accurately assess process conditions and identify areas for improvement [7]. These inspection systems provide real-time feedback on gas composition, concentrations, and other relevant parameters, enabling semiconductor companies to make informed decisions in optimizing their processes.

Endpoint inspection, a widely adopted technique for cleaning CVD chambers, can also be applied to other fluorinated greenhouse gas plasma operations, including etching processes. By monitoring the endpoint of these operations, semiconductor companies can determine the optimal timing for terminating the process, minimizing waste and reducing greenhouse gas emissions. Process optimization efforts are driven by the industry's commitment to sustainability and the reduction of environmental impact. By continuously improving process variables and parameters, semiconductor companies can achieve substantial reductions in carbon emissions, contributing to global efforts in mitigating climate change and achieving a more sustainable future.

3.2 Greenhouse Gas Substitution

In the pursuit of reducing net fluorine-gas emissions, the semiconductor industry recognizes the importance of exploring alternative solutions. One approach involves substituting high global warming potential (GWP) gases with lower GWP or non-GWP gases, as well as optimizing the efficiency of gas usage in the plasma process. By adopting these alternative chemical methods, semiconductor companies can significantly decrease greenhouse gas emissions [2]. The substitution of high GWP gases with lower GWP or non-GWP alternatives is a proactive measure to mitigate the environmental impact of semiconductor manufacturing. This strategy involves identifying and implementing gases that have a reduced potential to contribute to global warming. By replacing high GWP gases with more environmentally friendly options, semiconductor companies can make substantial strides in reducing their greenhouse gas emissions.

When evaluating alternative chemicals for substitution, it is essential to consider various factors beyond their environmental impact. Safety and health implications on fab operations, employee protection, and the external environment must be thoroughly assessed. This comprehensive evaluation ensures that the chosen alternative chemicals not only minimize greenhouse gas emissions but also meet stringent safety standards and contribute to the overall well-being of the semiconductor manufacturing ecosystem [8]. By prioritizing greenhouse gas substitution and conducting thorough assessments, the semiconductor industry strives to make sustainable choices that promote environmental stewardship without compromising safety and operational efficiency. These efforts pave the way for a greener and more sustainable future in semiconductor manufacturing.

3.3 Advanced Abatement Methodology

The semiconductor industry has demonstrated its commitment to reducing fluorine gas emissions through the development and implementation of advanced abatement technologies. These innovative solutions prioritize localized emission reduction, recognizing that it is more effective to tackle emissions at the source before they disperse and contaminate the environment further. Through the utilization of advanced abatement methodologies, the industry aims to achieve precise and accurate calculations of Fluorinated Compounds (FCs) emissions by connecting each emission stream to a dedicated local scrubber [9-10].

Table 1. Important features of the advanced abatement methods.

General practice of the Advanced Abatement system	Installation of effective abatement system for the removal of Fluorinated Compound (FCs) and N_2O, such as combustion, electric, or plasma type, etc., for the removal of fluorinated and N_2O GHG from semiconductor manufacturing processes such as Etching process, ThinFilm process, include chemical/physical vapour deposition, and Diffusion processes.
Type of greenhouse gas reduction	Reduce emissions of fluorinated compounds (FCs) and N_2O greenhouse gases. These FCs include CF_4, C_2F_6, C_3F_8, c-C_4F_8, CHF_3, CH_2F_2, CH_3F, NF_3 and SF_6.

Table 1 outlines the important features of these advanced abatement methods, shedding light on their role in the semiconductor manufacturing process. These methods encompass a range of practices aimed at removing fluorinated compounds (FCs) and N2O greenhouse gases from the production system. The installations of effective abatement systems, such as combustion, electric, or plasma-based systems, are instrumental in achieving significant reductions in emissions (Figure 3). These abatement systems target specific fluorinated compounds, CF_4, C_2F_6, C_3F_8, c-C_4F_8, CHF_3, CH_2F_2, CH_3F, NF_3 and SF_6, as well as N_2O greenhouse gases [11-12].

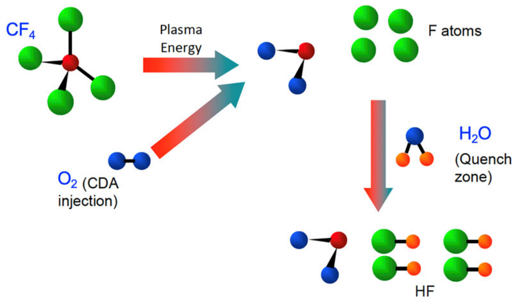

Figure 3. Chemistry of PFCs abatement with proteus.

The effective operation of the abatement systems relies on various factors, including venting equipment and process conditions. Temperature control, fluorinated greenhouse gas inlet concentration, flow rate, and the composition of the total inlet flow all play a crucial role in determining the performance and efficiency of the venting system. By optimizing these parameters and implementing advanced abatement technologies, the semiconductor industry is making significant progress in minimizing its environmental impact and contributing to a greener future [11-12].

The ongoing exploration and evaluation of advanced abatement methodologies highlight the industry's commitment to continuous improvement. As new technologies emerge and are assessed within the framework of the World Semiconductor Council (WSC), the best practices document will be updated to reflect the latest advancements. Furthermore, reliable measurement protocols are essential to accurately assess emissions and evaluate the effectiveness of new technologies, ensuring that the industry maintains a robust and transparent approach to emission reduction [16]. Through collaborative efforts and knowledge-sharing within the WSC, the semiconductor industry is driving advancements in abatement technologies and solidifying its position as a responsible global citizen committed to sustainable manufacturing practices.

3.4 Remote Plasma Cleaning System

The remote plasma cleaning system has emerged as an effective alternative to in-situ CVD chamber cleaning technology, offering a sustainable solution for removing residues left in the chamber after deposition [6]. This innovative technology involves the installation of a plasma generation unit at the front of the CVD chamber. The remote cleaning process typically begins with the introduction of NF3 into the plasma, triggering the generation of fluorine radicals and ions within the remote plasma unit. These reactive species are then directed into the processing chamber, where they chemically react with the deposited material [13]. The by-products of this reaction, including substances like SiF4, are carried away in gaseous form. Remote plasma cleaning has become a widely adopted practice for cleaning CVD chambers, showcasing its effectiveness in reducing fluorine gas emissions [12].

To facilitate the implementation of remote plasma cleaning technology, equipment suppliers have developed and integrated remote plasma systems that can be retrofitted into existing processing tools. These systems replace the original chemistry used for fluorine gas cleaning, enabling semiconductor companies to transition to more environmentally friendly cleaning practices [14].

The semiconductor industry, through collaboration within the World Semiconductor Council (WSC), continually evaluates and shares new technologies and advancements related to fluorine gases [15]. As knowledge and experience grow, the Best Practices document is regularly updated to reflect the latest developments and provide industry stakeholders with comprehensive guidelines for emission reduction. To accurately measure emissions or evaluate the effectiveness of new technologies, companies must adhere to reliable measurement protocols, ensuring consistent and reliable data collection [16].

The adoption of remote plasma cleaning systems represents a significant step forward in the semiconductor industry's commitment to reducing greenhouse gas emissions. By embracing sustainable cleaning technologies and updating best practices, the industry continues to drive innovation and foster a more sustainable manufacturing ecosystem. Through the collective efforts of equipment suppliers, semiconductor manufacturers, and industry organizations like the WSC, the industry is well-positioned to make substantial progress in reducing its environmental impact and promoting a greener future.

4. Basis of Preparation & Monitoring Plan

The Taiwan Environmental Protection Agency (EPA) has established specific objectives and requirements for estimating greenhouse gas (GHG) emissions based on internationally recognized guidelines and values (Figure 4). These objectives and needs align with the "2019 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3, Chapter 6" (IPCC GL) and the Fourth Assessment Report (AR5) Global Warming Potential (GWP) values [7, 17].

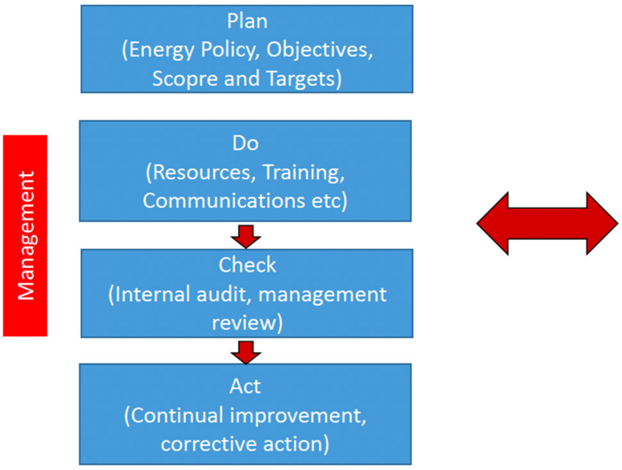

Figure 4. Requirement to achieve the purpose of adopting the standards for basis of preparation.

The EPA's objectives and needs for estimating GHG emissions are as follows:

1. Accuracy and Consistency: The EPA aims to ensure that GHG emissions estimates are accurate and consistent across different sectors and sources. By following the IPCC GL, which provides internationally recognized methodologies and guidance, the EPA can promote consistency in GHG inventories and enhance the accuracy of emissions estimates.
2. Comprehensive Coverage: The EPA seeks to include all relevant GHGs and sectors in its estimation methods. The IPCC GL offers comprehensive guidance on the measurement and estimation of various GHGs, enabling the EPA to account for emissions from different gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases.
3. Transparency and Documentation: The EPA places importance on transparency and documentation of estimation methods to facilitate peer review, enhance credibility, and ensure the reproducibility of results. By relying on the IPCC GL, which provides detailed guidelines and methodologies, the EPA can document its estimation procedures effectively and provide transparent information to stakeholders.
4. Scientific Rigor: The EPA aims to base its estimation methods on scientifically rigorous approaches and the latest scientific findings. The IPCC GL, along with the AR5 GWP values, reflects the most up-to-date scientific knowledge on GHG emissions, their impacts, and the calculation of GWPs. By incorporating these scientific advancements, the EPA ensures that its estimation methods are robust and reliable.
5. Comparability and International Cooperation: The EPA recognizes the importance of comparability and international cooperation in addressing global climate change. By aligning with the IPCC GL and the AR5 GWP values, the EPA's estimation methods can be easily compared and harmonized with those of other countries, promoting international cooperation and facilitating the assessment of global emission trends.

By adhering to the guidelines and values outlined in the IPCC GL and the AR5, the EPA can fulfill its objectives and meet the needs for accurate, comprehensive, transparent, scientifically rigorous, and internationally comparable estimation of GHG emissions. These efforts contribute to the development of effective climate change mitigation strategies and informed decision-making for a more sustainable future.

5. Future Trends and Development of Semiconductor Industry

The semiconductor industry is experiencing significant growth and is poised to play a crucial role in shaping the future. The increasing demand for consumer electronics products and the emergence of transformative technologies like artificial intelligence, machine learning, and the Internet of Things are driving the expansion of the semiconductor market [18]. Factors such as rising household incomes, population growth, digitization, and urbanization are fueling the demand for consumer electronics devices, leading to a rapid market expansion. However, it is important to address the sustainability challenges associated with semiconductor manufacturing. The industry's current capacity may struggle to meet the surging demand in a sustainable manner [19]. To mitigate the environmental impact of semiconductor production and move towards a greener future, companies need to explore and adopt greener alternatives and practices.

One key area of focus is the adoption of greener materials and processes. Semiconductor manufacturers can invest in research and development to find alternatives to hazardous substances and chemicals with high global warming potential. By incorporating eco-friendly materials and implementing cleaner production techniques, the industry can minimize its environmental footprint and reduce greenhouse gas emissions. Additionally, the semiconductor industry can strive to enhance its energy efficiency and transition to renewable energy sources. Investing in energy-efficient technologies and optimizing manufacturing processes can help reduce energy consumption. Moreover, embracing renewable energy sources such as solar and wind power can further reduce the industry's reliance on fossil fuels and contribute to a lower carbon footprint.

Collaboration and knowledge sharing among industry stakeholders are vital for driving sustainable development in the semiconductor sector. Companies can work together to establish best practices, share innovative solutions, and collaborate on research and development projects focused on sustainability. Industry associations and organizations can play a crucial role in facilitating such collaborations and promoting sustainable practices across the semiconductor value chain. Furthermore, policymakers and regulatory bodies can incentivize and support the adoption of sustainable practices in the semiconductor industry through regulations, tax incentives, and funding programs. Encouraging investments in research and development of greener technologies and providing support for renewable energy adoption can accelerate the industry's transition towards sustainability.

Additionally, Taiwan Semiconductor Industry Association (TSIA) and the semiconductor industry in Taiwan have a crucial role to play in driving sustainable development. Taiwan is a major hub for semiconductor manufacturing, hosting some of the world's leading semiconductor companies. As the industry continues to grow, it presents a unique opportunity for TSIA and Taiwanese semiconductor companies to lead by example in implementing sustainable practices. TSIA can take the lead in promoting and coordinating sustainability initiatives within the Taiwanese semiconductor industry. By establishing guidelines, sharing best practices, and facilitating collaboration among member companies, TSIA can drive the adoption of greener alternatives and practices throughout the industry.

Taiwan, with its advanced technology and manufacturing capabilities, can leverage its strengths to develop and deploy innovative solutions that contribute to sustainability. The government and industry stakeholders can work together to invest in research and development of eco-friendly materials, energy-efficient processes, and renewable energy technologies. This collaboration can foster the growth of a sustainable semiconductor ecosystem in Taiwan.

6. Conclusion

In conclusion, the semiconductor industry in Taiwan, supported by TSIA and its member companies, has an opportunity to lead the way in driving sustainability. By embracing greener alternatives, optimizing energy efficiency, and collaborating with stakeholders, Taiwan can contribute to the global goal of achieving net-zero emissions by 2050. Through these collective efforts, the semiconductor industry in Taiwan can continue to thrive while making significant strides towards a more sustainable future.

Competing Interests

All authors declare no Competing Financial or Non-Financial Interests.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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