New power electronics to reach next level of energy efficiency in equipment - Results from the IEA 4E PECTA platform's first term

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Abstract

Power electronics (PE) stand as a vital technology to facilitate the green transition and driving the widespread electrification of society. PE play a key role not only in utility scale renewable electricity generation and distribution, in industry applications and e-mobility, but also in home equipment such as power supplies, heat pumps, air conditioners, PV inverters and DC electric vehicle chargers. Efficient power conversion is essential as PE becomes more prevalent.

Wide Band Gap (WBG) is an emerging PE technology that enables energy savings in power conversion and has the potential to further improve energy efficiency for many applications. The IEA's technology collaboration program on energy efficient end-use equipment (IEA 4E) launched the Power Electronic Conversion Technology Platform (PECTA) with the overall goal of collecting and analyzing information about WBG-based devices, coordinating internationally acceptable approaches that promote WBG, and developing greater understanding and action amongst governments and policy makers.

This paper summarizes the first 5-year period of PECTA, focusing on key findings and work conducted. It includes evaluation of energy saving potentials in various applications, supported by real efficiency measurements in laboratory for external power supplies and PV inverters. PECTA addresses the importance of considering environmental aspects and impacts of WBG devices and applications throughout their life cycle. This knowledge is crucial for designing sustainable products and developing holistic regulation. PECTA also examines the drivers and barriers for WBG adoption and implementation. The paper highlights efforts made towards standardization and evaluates potential policy measures to promote WBG in the field of PE. Additionally, PECTA presents its application readiness maps (ARMs), which track the medium and long-term scenarios of WBG adoption using market data, sector trends, and insights from industry and academic experts.

Finally, a concise outlook of the planned work in the next 5-year term of PECTA will be presented.

1. Introduction

Almost every electronic device in homes and offices, from laptops and smartphones to large appliances like refrigerators and air conditioners, incorporates power conversion technology. These devices require specific voltages and current types that are different from the standard AC supply from power outlets. Power conversion ensures that these devices receive the correct voltage and current, optimizing their operation and extending their lifespan. Further, power conversion technology in PV inverters and electric vehicles (EV) DC chargers are essential for the effective use of solar energy and the functionality of electric vehicles. However, continued advancements in power electronics will be critical to improving the performance, efficiency, and integration capabilities of these systems and devices, underscoring their importance in the ongoing energy transition.

In this light, the International Energy Agency's Technology Collaboration Programme on Energy Efficient End-Use Equipment (IEA 4E) has initiated the Power Electronic Conversion Technology Platform (PECTA) with the specific aim of enhancing the global understanding and deployment of energy-efficient power electronics. The platform primarily focuses on the advancement and integration of Wide Band Gap (WBG) technologies, which include materials like silicon carbide (SiC) and gallium nitride (GaN). These materials are pivotal for developing next-generation power electronic devices due to their superior electrical properties compared to traditional silicon-based technologies.

This paper summarizes the first 5-year term of PECTA, starting with introducing WBG technologies and the methodology used in PECTA, then following with a discussion of relevant results and leading to the application readiness map, a tool to understand the expected market penetration and readiness level of WBG. Finally, the conclusions and outline for PECTA´s future work are presented.

2. Wide Band Gap (WBG) technologies

WBG semiconductors are defined by their band gap - the energy difference between the valence band and the conduction band of electronic materials. While silicon, the standard material for semiconductor devices, has a band gap of 1.12 electron volts (eV), WBG materials like SiC and GaN have band gaps of approximately 3.26 eV and 3.4 eV, respectively. All semiconductors with a band gap greater than 3 eV belong to the family of WBG semiconductors. This wider band gap enables devices made from these materials to operate at higher voltages, temperatures, and efficiencies than their silicon counterparts. PECTA identified various advantages and applications of SiC and GaN [1,2].

2.1 Advantages of SiC and GaN

The main advantages can be summarized as follows:

- Higher efficiency: Both SiC and GaN offer superior electrical efficiency compared to traditional silicon devices. This is due to their ability to operate at higher frequencies and voltages with lower losses, which is crucial for reducing energy consumption across various applications.
- Higher operating temperatures: SiC and GaN devices can operate effectively at higher temperatures than silicon. This reduces the need for extensive cooling solutions, which in turn can lower the overall system cost and complexity.
- Faster switching frequencies: GaN reaches very high switching speeds, which allows for smaller power converters. SiC also offers improved switching speeds over silicon, contributing to better performance in applications like electric vehicles and industrial power systems.
- Higher breakdown voltage: SiC devices are known for their high breakdown voltage capabilities, making them suitable for high-voltage applications such as power grid operations and industrial machinery.
- Reduced system size and weight: Due to the high-power density of both, SiC and GaN, the design of more compact and lighter electronic devices and systems is possible and especially beneficial in applications where space and weight are critical factors.
- Improved thermal conductivity: SiC has excellent thermal conductivity, which helps in more effective heat dissipation during operation, enhancing the reliability and longevity of devices.

These advantages position SiC and GaN as key enablers for a range of modern technologies aimed at enhancing energy efficiency and reducing environmental impact.

2.2 Leading Applications using SiC

A (non-exhaustive) list of key applications using SIC was developed:

1. Automotive applications: SiC is already extensively used in PEs for electric vehicle (EV) applications, including traction inverters, onboard chargers, and DC/DC converters. Incorporating SiC results in higher efficiency and power density, contributing to longer driving ranges and faster charging times.

2. Industrial applications: SiC technology can be employed in various industrial applications such as motor drives and servo systems, where high power and efficiency are required.

3. Rail transport: SiC devices can be utilized in traction systems and auxiliary inverters for railways, offering significant advantages in terms of efficiency and compactness compared to traditional systems.

4. Renewable energy systems: In photovoltaic (PV) inverters and wind energy systems, SiC helps achieve higher efficiency levels, thus maximizing the power output from renewable sources.

5. Power supply and grid applications: SiC devices are used in power supplies for data centers and in grid applications including High Voltage Direct Current (HVDC) systems and solid-state transformers, facilitating efficient power management and distribution.

2.3 Leading Applications using GaN

In case of GaN, the following applications were found:

1. Consumer electronics: GaN is predominantly used in lower voltage applications such as laptop adapters, mobile phone chargers, and other consumer electronic power supplies, where it enhances efficiency and enables compact designs with reduced size.

2. Data centers: GaN-based power supplies help achieve higher efficiency and density, crucial for reducing operational costs and energy consumption of data centers.

3. Automotive applications: GaN is used in lower power applications within automotive, such as in DC/DC converters and onboard chargers, particularly in hybrid and electric vehicles.

4. Telecommunications equipment and servers: GaN devices provide high efficiency and fast switching capabilities, significantly improving energy management.

3. Methodology

The overall goal of PECTA includes collecting and analyzing information about new WBG-based power electronic devices, coordinating internationally acceptable approaches that promote WBG-based power electronics, and developing greater understanding and action amongst governments and policy makers.

PECTA was initiated in 2019 as a collaboration of the governments of Austria, Denmark, Sweden and Switzerland, with representatives of these member countries actively engaged in the strategic and decision-making work through their roles in PECTA´s management committee. PECTA established two advisory groups: The Academic Advisory Group and the Industrial Advisory Group, which support PECTA with their knowledge and expertise. PECTA engages with stakeholders along the whole value chain of the semiconductor industry, as shown in Figure 1.

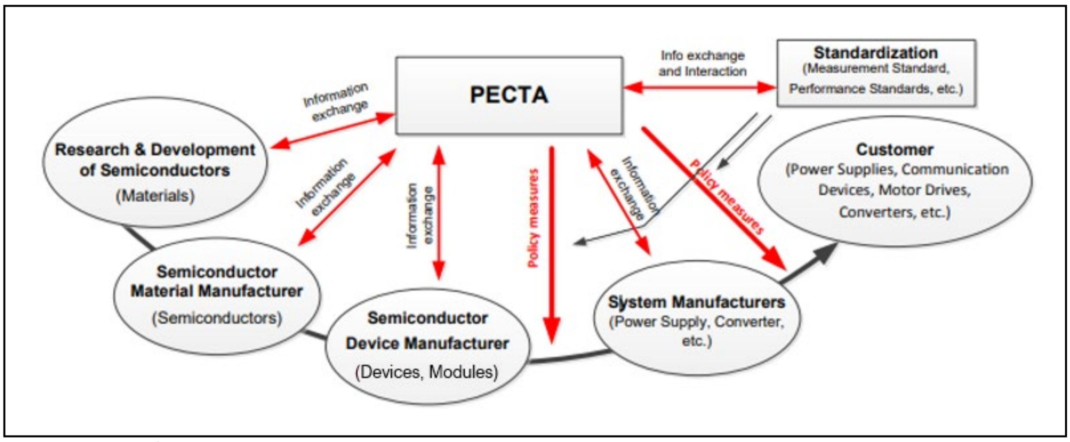

Figure 1 PECTA's role and interaction within the industrial value chain

PECTA carried out an ambitious work plan organized in tasks, each having its own focus and gathering experts engaged to carry out the work. The tasks of the term 2019-2024 of PECTA were [3]:

- Completion and updating available efficiency figures.
- Energy and environmental related Life Cycle Assessment (LCA).
- Revision of elaborated Application Readiness Map (ARM)
- Policy measures and mapping with applications over a timeline
- Standards to support WBG adoption
- Measurement of power supply efficiency
- Optimized SiC PV Inverter.

In addition, preliminary scoping studies were carried out to investigate the topics of Reliability of WBG technology and EV charging stations with WBG technology.

The PECTA management committee, the Academic Advisory Group and the Industrial Advisory Group, jointly engaged and interacted with experts in the conduct of PECTA tasks, and critically reviewed the outputs before disseminating them to broader audiences via publication or papers and reports, as well as presenting at webinars and conferences.

4. Results and Discussion

The first 5 years of PECTA activities brought various and numerous outcomes, which will be presented and discussed next.

4.1 Evaluation of energy saving potentials

The potential energy savings from employing WBG devices over traditional silicon-based systems across various applications were assessed [4]. First, this task involved gathering data on the yearly global energy consumption for selected applications. Then, the efficiencies of existing silicon-based and WBG-based systems were researched through product datasheets and scientific literature. Finally, the global yearly energy saving potential was calculated based on the efficiency differences between silicon and WBG products, factoring in the global annual energy consumption per application, and typical application profiles where possible. The results are shown in Table 1.

Table 1 Potential global annual energy savings from employing WBG for selected applications

Application	Global energy saving potential
Data center / server power supplies (SiC)	4.6 to 6.7 TWh/year
Photovoltaic inverters (SiC)	20.7 TWh/year
Low-voltage motor drives (SiC).	103 TWh/year This value includes HVAC systems: - Fans: 20 TWh/year - Pumps: 20 TWh/year - Compressors: 33 TWh/year
Electric vehicle charging stations (SiC)	0.8 TWh/year
Inverters for grid-connected battery storage systems (SiC)	0.4 TWh/year
Laptop chargers (GaN)	3.2 TWh/year

Adding up the individual saving potentials of the considered applications results in total annual energy saving potential over 120 TWh/year, equivalent to twice the electric energy demand of Switzerland.

This highlights the significant impact that adopting WBG technologies could have on global electricity consumption.

4.2 Measuring the energy efficiency of WBG

To evaluate and compare energy efficiency potential in specific applications, 7 power supplies with different power ratings ranging from 5W to 65W were tested: 3 Si-based and 4 GaN-based [5]. The overall results from the tests are summarized below:

- For power levels up to 30W, the Si-based and GaN-based chargers showed similar energy efficiency performances of around 90% at rated power.
- For higher power levels above 30W, the GaN-based power supplies outperformed the Si-based ones. For example, at 60W, the average efficiency was 92% for GaN and 90% for Si.
- The difference in the efficiency of GaN compared to Si power supplies translates into significant energy savings, especially at higher output powers. For example, it was estimated that charging 6.26 billion smartphones globally using GaN chargers (instead of Si chargers) could result in energy savings up to 2.2 TWh/Year.
- The GaN-based chargers exhibited significantly higher power density in terms of both volume and weight - around two times higher than for Si-based chargers.
- PECTA measurements showed that the GaN chargers generally reached higher energy efficiency. These results also suggest that increasing efficiency regulation requirements (up from average of 88% efficiency for power ratings higher than 49 W) would further promote the adoption of WBG technology in chargers for consumer products (i.e., GaN devices).

In summary, the measurements demonstrated the efficiency and power density advantages of GaN-based chargers, especially at the higher power ratings, which could enable significant energy savings and reductions in size and weight compared to Si-based chargers.

Furthermore, PECTA investigated and compared the efficiency of a commercial Si IGBT-based photovoltaic (PV) inverter with that of a SiC MOSFET inverter under similar conditions.

The results highlighted the advantage of SiC technology in reducing semiconductor losses (over 50% reduction compared to IGBTs in some scenarios) [6]. It was demonstrated that the use of SiC MOSFETs provided efficiency improvements, especially at higher power levels and lower input voltages, resulting in annual efficiency gain estimated up to 2.66% (under Austrian conditions).

4.3 Assessing environmental impacts of WBG

While WBG semiconductors promise significantly higher energy efficiency in the use phase compared to traditional silicon-based devices, a full understanding of their environmental impacts requires looking across the entire life cycle.

By evaluating a range of environmental aspects, from energy and emissions to resource use and end-of-life management, PECTA´s work provides a knowledge base to inform policies and regulations aimed at maximizing the sustainability benefits of WBG technologies as they are more widely deployed. The approach was based on “Life cycle thinking” - examining key energy and environmental aspects across the life cycle phases [7]. Research focused on three areas:

1. Manufacture of WBG devices
2. Design aspects and environmental impacts
3. WBG resources and End-of-Life (EoL) perspectives

4.3.1 Manufacture of WBG devices

The energy demand and material efficiency in the WBG manufacturing for SiC, compared to traditional silicon manufacturing were investigated, following the sequence of processes shown in Figure 2. The distribution and EoL stages were considered separately.

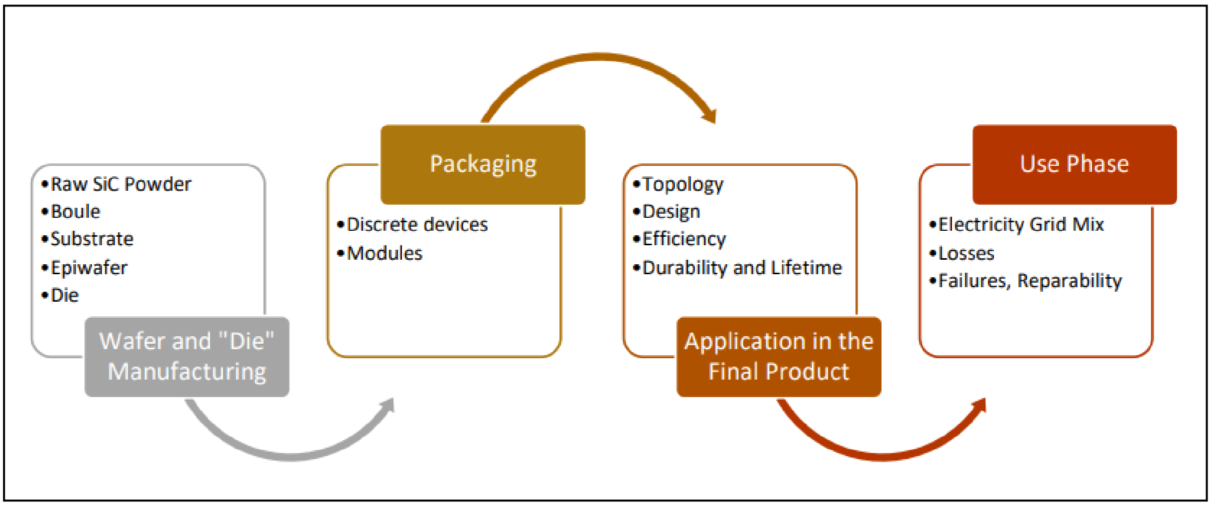

Figure 2 Overview of the life cycle stages of manufacturing and use for SiC-based power semiconductors.

The examination of manufacturing processes for SiC led to various key insights. On the methodology for evaluating environmental impacts these are:

- There is a lack of up-to-date, publicly available life cycle assessments (LCAs) specifically for power semiconductors and WBG technologies.
- No product category rules (PCRs) or environmental product declarations (EPDs) currently exist specifically for WBG semiconductors, making rigorous assessments and comparisons difficult.
- Efforts are underway to develop more relevant PCRs and standards for evaluating electronics and components such as the draft IEC 63366 ED1, which defines product category rules for electronic and electrical products and systems (EEPS).

Correspondingly, the key insights on energy aspects of WBG manufacture are:

- Growing SiC boules is significantly more energy intensive than growing silicon ingots, estimated 20-40 times higher energy demand per usable wafer area.
- More energy is also required for slicing SiC boules into wafers compared to silicon.
- Processing yields for SiC wafers are around 15% lower than silicon due to more defects.
- The SiC manufacturing process currently has a higher “energy burden” than for silicon, but this is expected to improve as technologies mature.
- Higher upfront energy in manufacturing can potentially be offset by increased energy efficiency during the use phase over the product´s lifetime, as shown in the example of a SiC-based photovoltaic inverter.

While WBG manufacturing is currently more energy intensive, the WBG technology efficiency gains justify evaluating the impacts holistically across all life cycle stages.

4.3.2 Design aspects and environmental impacts

The effects of incorporating WBG semiconductors into end-use products were investigated [7], focusing on the case study of 60W laptop chargers with GaN and with silicon, as shown in Figure 3.

Figure 3 Laptop chargers investigated, on the left a 60W Si-based charger (reference), and on the right a 60W GaN-based charger.

The key outcomes of this research in terms of design aspects, energy use and potential environmental impacts are summarized as follows:

- The smaller chip size enabled by WBG materials reduces material usage per chip during manufacturing.
- For the GaN laptop charger case study, die size was around 58% smaller compared to the silicon reference charger.
- Using WBG allows for higher switching frequencies, enabling smaller passive components like transformers and filters.
- The charger size was reduced by around 30% with GaN.
- Achieving design benefits depends on skillfully implementing the topology to leverage WBG's advantages.
- Smaller WBG-based products reduce environmental impacts in manufacturing due to less material usage.
- The impacts in the distribution phase are lower due to reduced product weight for transport.
- Use phase impacts assessed in terms of the global warming potential (GWP), were significantly reduced especially when the GaN-based chargers are operated in carbon-intensive electricity grids. However, efficiency gains may be negligible for already highly efficient products like chargers.

Finally, the effects on the design of end-use products through the application of WBG power semiconductors are very difficult to predict accurately and systematically for a broader spectrum of power converters. Therefore, to assess whether the use of WBG technology is preferable from an environmental point of view, the products should be evaluated along their entire life cycle.

4.3.3 WBG resources and End-of-Life phase

PECTA experts also examined the upstream resource implications of using critical raw materials like gallium and silicon metal in WBG semiconductors [7]. The downstream end-of-life (EoL) challenges and opportunities for recycling, reuse and circularity of these devices were investigated too.

Concerning the use of resources, the following insights were gained:

- Both gallium and silicon metal are rated as critical raw materials by the EU due to high import reliance from a few supplier countries, posing potential supply risks.
- Global demand for these materials is projected to grow significantly as WBG adoption scales up, e.g., 17 times higher gallium demand by 2050.
- Currently, there are no viable substitutes that provide the same performance as GaN and SiC.
- The EU's Critical Raw Materials Act aims to boost domestic sourcing, processing, and recycling of these strategic materials.

On circularity and the End-of-Life phase, the research highlighted the following issues:

- The collection rates for e-waste containing WBG components remain very low globally.
- No industrial-scale recycling processes exist yet to cost-effectively recover gallium and silicon carbide from e-waste.
- The barriers to reusing WBG components include lack of design for circularity, reliability challenges, and complex reverse logistics.
- Some promising recycling concepts exist at pilot scale, like hydrometallurgical processes for gallium recovery.
- Upcoming regulations like the EU's Ecodesign for Sustainable Products Regulation (ESPR) aim to improve circularity through requirements like the Digital Product Passport.

While WBG enables energy efficiency gains, managing the critical material supply and improving the End-of-Life processes will be crucial for the long-term sustainability of WBG as it's adoption increases.

4.4 Barriers and drivers for WBG adoption

Drivers for adoption of WBG were already discussed in this paper, i.e., higher efficiency and energy savings potential, the ability to operate at higher temperatures, the lower cooling demand and more compact designs. The barriers for the adoption of WBG were also investigated in PECTA [1,8]. Important barriers identified include:

- Cost and manufacturing challenges: Currently WBG devices are significantly more expensive than silicon counterparts due to challenges in manufacturing, material quality, and lower volumes.
- Reliability concerns: The evaluation of the long-term reliability of WBG devices, especially at high temperatures and voltages, is ongoing as the technology evolves. More research, dedicated equipment and testing methods, and access to performance data are still needed.
- Lack of standardized components/platforms: Existing power electronic systems are optimized for silicon. Lack of standardized WBG components/modules/packages makes the adoption harder.
- Knowledge gaps on design: Designing with WBG requires different approaches compared to silicon due to their different characteristics. Knowledge gaps still exist.
- High voltage/high current challenges: For high voltage (>1.2kV) and high current applications, SiC solutions are still lacking or are too costly compared to silicon IGBTs.
- Cost pressure in some markets: For cost-sensitive, high-volume markets like industrial drives and PV inverters, the higher cost of WBG is currently a major barrier for adoption.

In summary, while the efficiency and performance benefits are drivers, cost, reliability and lack of standardized ecosystem remain key barriers that still need to be overcome, especially for broader adoption of WBG beyond early markets like automotive into end-use equipment. To address the reliability concerns explained before, PECTA completed a scoping study that will carry on in more detail in the next term [9].

4.5 Standardization and policy measures to support WBG adoption

The measures to support WBG adoption could take many forms, e.g., like support of research and development (R&D), and support to industry e.g. to handle the high manufacturing costs or to improve the workforce capacity. PECTA experts explored in particular product energy efficiency regulations (like EU Ecodesign) and the standards and testing methods.

Existing energy efficiency regulations do not specifically target or promote WBG technologies yet. Introducing stricter minimum energy performance standards (MEPS) or efficiency requirements for products like PV inverters, EV charging stations and/or power supplies (where WBG could enable energy efficiency gains) could drive WBG´s adoption.

Fair comparisons of products are crucial for enabling proper standardization and for promoting WBG technologies. The JEDEC committee is already initiating some standards for WBG devices and PECTA proposed a novel method to accurately measure losses in (WBG) semiconductor devices [10]. Still, there are needs identified with regards to standardization of WBG, which include:

- As discussed before harmonized and robust reliability and durability test methodologies at the device level, but also at the product application level.
- Product Category Rules to support the evaluation of the environmental aspects and impacts of WBG.
- Energy efficiency test methodologies to assess the performance of WBG.
- Specific product architectures of power modules and systems to gain the full benefit from WBG components, especially when not compatible with the existing Si component, module, and package architecture.

The PECTA application readiness map is a relevant tool to examine trends and scenarios of WBG adoption, in support of standardization efforts and development of policy measures. This PECTA tool is discussed next.

5. Application Readiness Maps (ARMs)

The Application Readiness Map (ARM) developed by PECTA experts is a visual guide to understand the expected market penetration and readiness level of a particular technology for different applications over time. Already in the introduction phase of PECTA (2020), the first ARMs were outlined, and successively updated and developed further based on the collective inputs from expert discussions, existing roadmaps, literature studies, conference insights, and the author's own expert judgment [11]. The ARMs focus on the readiness of WBG semiconductor devices across different applications like automotive, renewable energy, industrial drives, and consumer electronics.

Figure 4 shows the WBG ARM for photovoltaic (PV) inverters, wind, grid, and consumer applications (Two additional ARMs are available for other applications). The ARM depicts four key stages or milestones for each application:

- Demonstrator available: A proof-of-concept or prototype using the WBG devices has been demonstrated for that application.
- First product on the market: The first commercial product using WBG devices is available for that application.
- Significant market share: WBG devices have gained a significant (>20%) market share in that application.
- Predominant market share: WBG devices have become the predominant (>50%) choice for that application.

According to Figure 4, first products of consumer power supplies (USB) using GaN and PV inverters using SiC are already on the market and are considered to have a predominant market share now/in near future. Large global saving potential for fans, pumps and compressors was shown in Table 1.

Therefore, it is expected that SiC MOSFETs will be introduced in HVAC (Heating, Ventilation, Air Conditioning) applications. However, due to the uncertainty of the product introduction, HVAC is marked with a dotted line in the WBG ARM.

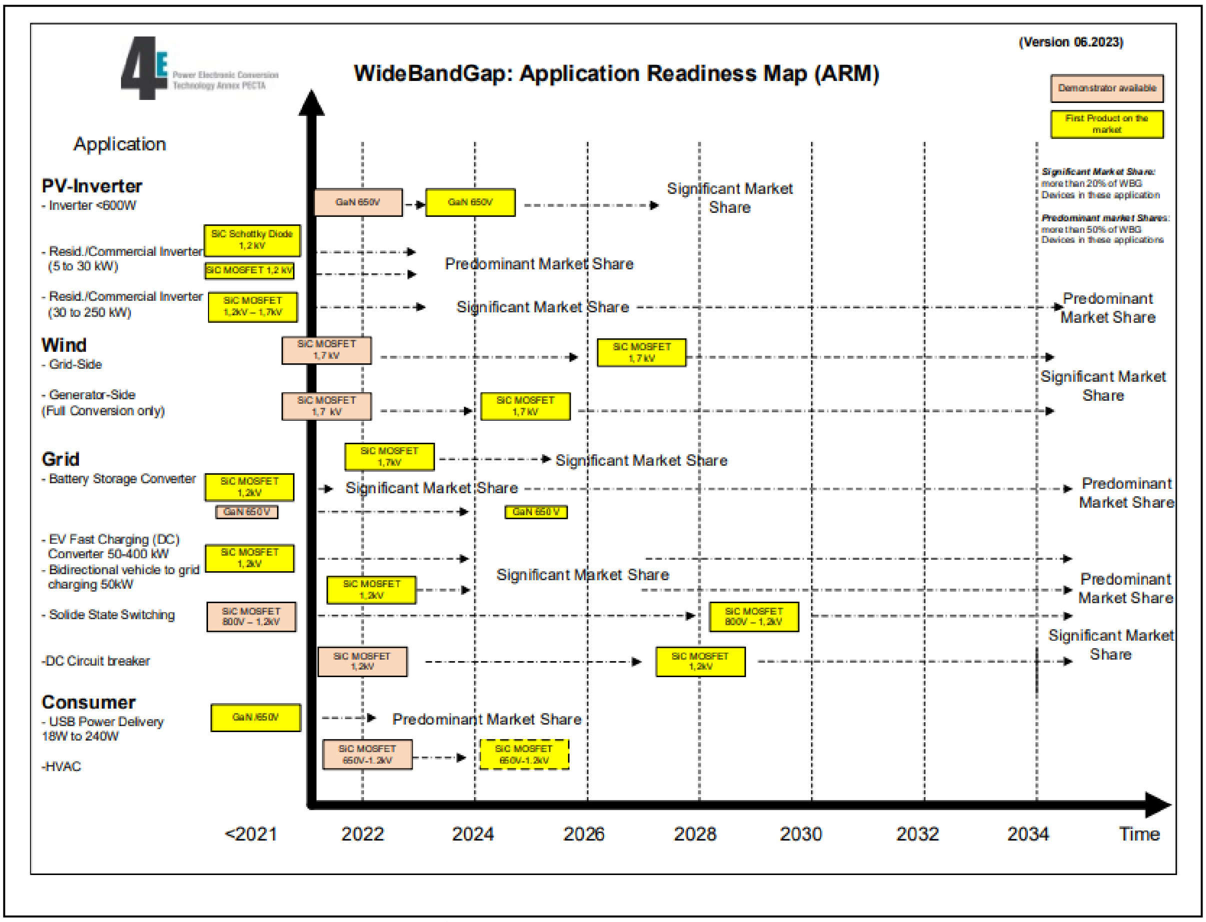

Figure 4 Applications Readiness Map for photovoltaic inverters, wind, grid, and consumer [11].

ARMs can serve as a valuable tool for various stakeholders to make informed decisions, align strategies, develop policies and prepare for the widespread adoption of WBG semiconductors in power electronics applications. The ARM is not a static roadmap. The developments in the WBG market, technology advancements, and application trends must be monitored continuously, and be incorporated into revised ARMs regularly. Accordingly, this work will continue in the next term of PECTA.

6. Summary and conclusions

The activities conducted by the Power Electronic Conversion Technology Platform (PECTA) over the past 5 years have provided valuable insights into the potential of Wide Band Gap (WBG) semiconductor technologies, particularly silicon carbide (SiC) and gallium nitride (GaN), to enhance energy efficiency across various applications. The evaluations revealed significant global annual energy saving potentials exceeding 120 TWh/year by adopting WBG devices in areas like data center power supplies, photovoltaic inverters, motor drives, electric vehicle charging stations, and consumer electronics.

Experimental measurements corroborated the efficiency advantages of WBG-based solutions, with GaN chargers outperforming silicon counterparts by up to 2% at higher power levels, and SiC photovoltaic inverters demonstrating up to 2.66% annual system efficiency improvements compared to traditional silicon IGBTs. While the efficiency gains may seem modest in some applications, the cumulative impact across millions of devices can translate into substantial energy savings.

PECTA´s research also highlighted the importance of considering the entire life cycle when evaluating the environmental impacts of WBG technologies. While the manufacturing processes for WBG materials like SiC are currently more energy-intensive than for silicon, the potential energy savings during the use phase may offset this initial burden. Additionally, the incorporation of WBG semiconductors enables more compact and lightweight product designs, reducing material usage and distribution impacts.

Nonetheless, challenges remain in managing the supply risks associated with critical raw materials like gallium and improving end-of-life processes for recycling and reusing WBG materials. Overcoming barriers such as high costs, reliability concerns, and the lack of standardized WBG components and design knowledge will be crucial for broader adoption beyond early markets like automotive.

To drive wider WBG adoption, PECTA proposed strategies like introducing stricter energy efficiency regulations, developing relevant standards for testing and reliability, and providing policy guidance tailored to specific applications. The Application Readiness Maps (ARMs) offer a valuable tool for tracking the market penetration of WBG devices across various sectors, informing decision-making by industry, policymakers, and other stakeholders.

7. Future work

PECTA has started the second term of 5 years (2024-2029) with the objective of further assessing the efficiency opportunities of using WBG technology. As PECTA will continue focusing on both technical and policy topics as well as target audiences, the proposed activities for the second term are - grouped in the following major areas [12]:

1. Policy research and policy tools
2. Policy supporting activities (analysis, investigations, measurement).
3. Industrial cooperation, communication and dissemination.

7.1 Policy research and policy tools

These activities will contribute directly to policy related results. They cover specifically the information and insights about policy measures and policy making guidance, to further elaborate policy recommendations and tools:

- Fine-tuning policy measures: Building on results from previous tasks, the goal is to develop specific policy measures for appliances and equipment and prepare a policy guide for WBG technology.
- Improving EU regulation on PV converters: Analyze various PV converter topologies to support more precise EU regulations in the second term.
- Policy approaches for motors: Utilize PECTA findings to evaluate WBG efficiency in motor systems, in collaboration with 4E EMSA.
- Efficiency measurement standards: Initiate efficiency standards for WBG devices based on gained insights.

7.2 Policy supporting activities (analysis, investigations, measurement)

These activities will contribute indirectly to policy related results. They cover activities needed as basis for possible policy measures. Most of these activities have a technology-oriented focus:

- Update Application Readiness Maps (ARMs): Based on the groundwork of PECTA, continue refining the ARMs to reflect new semiconductor materials and WBG advancements. The ARMs could potentially be updated every half year or full year.
- GHG emissions and sustainable use: Extend LCA work from the first term to quantify GHG emissions and compare WBG with Si-based devices.

- Electric vehicle charging stations: Monitor developments in charging technology to assess regulatory timing, leveraging advancements in WBG.
- Product reliability and market data: Gather field data on WBG devices to assess reliability. Reliability of the products, and particular the embedded power electronic, is one of the challenges that manufacturers face once a product is on the market.

7.3 Industrial cooperation, communication, and dissemination

PECTA will carry out technology trend analysis with focus on e-mobility's influence on WBG technology, to gain insights and learnings that could be relevant for other end-use appliances/equipment. PECTA is fostering dialogue with European Center for Power Electronics (ECPE) and particular industries about this subject. PECTA will continue to expand a relevant body of data and in-depth knowledge about WBG. The aim is that this know-how continues to be published and disseminated to target audiences.

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