Wide Bandgap Power to Electrify Our World for a Sustainable Future

By Anthony Schiro, VP Quality & Sustainability, Stephen Oliver, VP Corporate Marketing & Investor Relations, Navitas Semiconductor

From renewables to electric vehicles, how we create, convert and use electricity is critical to meeting Net-Zero CO2 goals

In this article we look at how we can most efficiently 'Electrify our World' to reduce emissions and meet net-zero goals by using wide bandgap semiconductors. Based on 3rd-party verified life-cycle analysis, and sustainability reporting, the article will show how GaN and SiC enable not only enable CO_2 reductions through in-use efficiency but can also support reduced emissions through creation (making the chip) and dematerialization (reducing system size and materials used). We will also illustrate how these technologies not only optimize efficiency but can support increased uptake of electrification thanks to the resulting benefits.

Introduction

While countries have debated how to combat climate change since the late 1980s (see the Montreal Protocol of 1987[1], the UN Framework Convention of Climate Change of 1992[2], the Kyoto Protocol of 2005[3] and the Paris Agreement of 2015[4]), there is a growing sense of urgency to find ways to create sustainable solutions that deliver on the promise of 'Net Zero'. The ultimate aim is to keep increases in average global temperatures to below 2 °C by 2050, as mandated by the Paris Agreement that entered into force on November 4th, 2016.

Today, over 80% of energy sources are based on fossil-fuels[5] and over 80% of our energy requirements are gas- or oil-powered across transportation, heating, cooling, cooking and so many industrial, commercial and consumer applications[5]. Not only do fossil fuels have a limited and finite supply, but their use is damaging our planet with over 36 Gtons of CO2 emitted every year[6]. The required energy transition is shown in Figure 1.

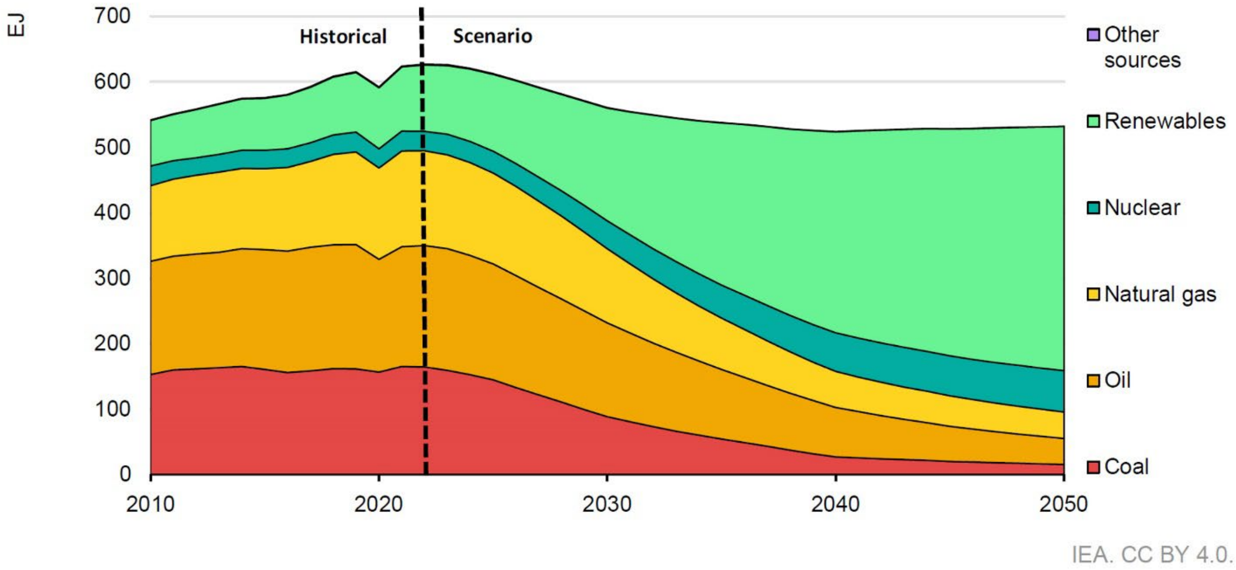


Figure 1: IEA "Energy Technology Perspectives 2023", Renewables and nuclear displace most fossil fuel use in the Net-Zero Emissions Scenario, with the share of fossil fuels plunging from almost 80% in 2021 to less than 20% in 2050.

Increased electrification is the most important way to address this issue. Electricity can be created from renewable sources, of which we have an unlimited supply. It can be used for all energy applications, powering everything from the heating in our homes to the vehicles we drive. And if derived from renewables, using electricity does not result in harmful emissions, making the goal of Net Zero more attainable.

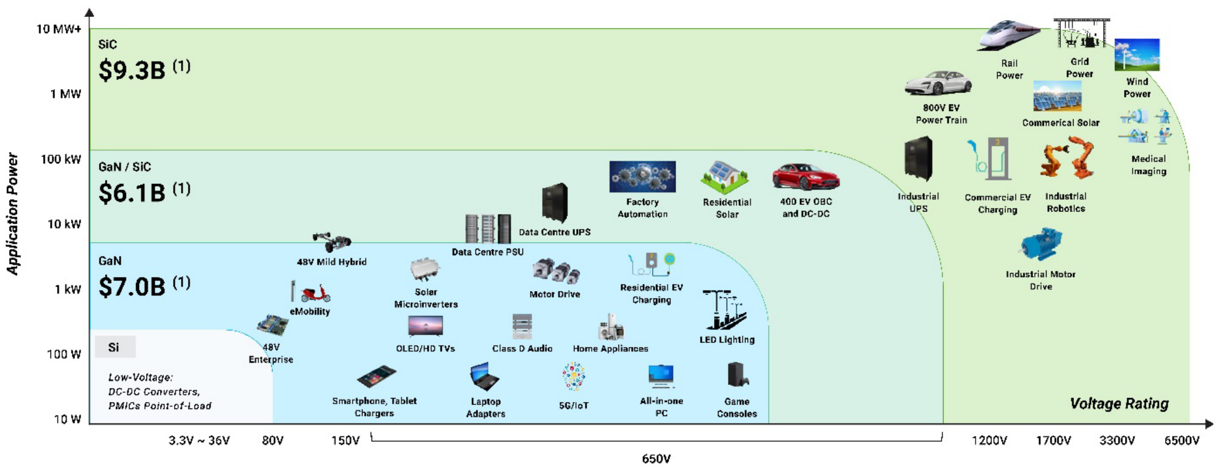
As we move to a more electrified model, it is essential that we generate and convert electricity as efficiently as possible – both to make the best use of the energy available and to support the growing global demand for that energy. New, wide bandgap (WBG) materials – in particular, silicon carbide (SiC) and gallium nitride (GaN) – are critical enablers for delivering this efficiency.

Gallium Nitride and Silicon Carbide

Recent years has seen a significant uptake in the use of GaN and SiC semiconductors in power conversion and battery charging applications - either to improve the performance, efficiency and voltage capabilities of existing applications in which conventional silicon devices have reached their physical limit, or to address challenges of new and emerging applications. This growth will continue, driven by what Frost & Sullivan[7] calls 'transformative Mega Trends' ranging from electric mobility and 5G deployments to renewable electricity and the need for high speed, power, performance, and efficiency across all manner of electronic devices. At Navitas, we estimate the combined market opportunity for GaN and SiC power technologies to be over $22B a year by 2026, as companies look to replace legacy silicon in existing applications and to harness the power of GaN and SiC in emerging designs where silicon cannot compete.

The fundamental benefits that GaN and SiC offer over traditional silicon semiconductor technologies derive from their bandgaps. A bandgap dictates the energy that is needed for electrons to move from the valence band to the conduction band and the bandgaps of silicon, Gan and SiC are 1.1 eV, 3.4 eV and 3.26 eV respectively. Wider bandgaps mean that GaN and SiC can withstand higher electrical fields and, thus, sustain higher voltages. Devices based on WBG technologies can also operate at higher maximum temperatures than legacy silicon counterparts. This is because WBG semiconductors can reach much higher temperatures before the threshold required for the transition of electrons from the valence band to the conduction band is reached.

Of course, there are differences between GaN and SiC – differences that dictate how and where they will be used in terms of voltage and power levels. One key difference lies in electron mobility, or how quickly electrons move through the semiconductor material. At 2,000 cm2/Vs, GaN's electron mobility is 30% faster than that of silicon, while SiC has a slower electron mobility of 650 cm^2/Vs. These differences play a part in what benefits each technology offers a target application (Figure 2).



Notes: Axes not to scale
- Based on internal company estimates, Navitas believes that the potential market opportunity in 2026 is $22B+ for GaN and SiC, replacing certain of the silicon market share

Figure 2: The attributes of GaN and SiC meet the application demands of different voltage and power ratings in a market potentially worth US$22 billion

The higher electron mobility of GaN, for example, makes it much more suitable for high-performance, high-frequency applications up to around 650 V and 20 kW. In addition, as a very small percentage of the chip is consumed by the gate electrode, which ensures very low capacitance - making it even easier to achieve higher frequencies.

SiC, on the other hand, with its higher thermal conductivity and lower frequency operation is more suited for higher power applications (over 1000 V and up to 20 MW), allowing it to address the high-end voltages required in EVs and data centers, some solar-power designs, rail traction, wind turbines, grid distribution and industrial and medical imaging – applications that do not always require high-frequency switching but do demand higher-voltage operation and improved heat dissipation.

Reducing Greenhouse Gas Emissions – Efficiency

The first, and most obvious way that WBG semiconductors can help to reduce global greenhouse gas (GHG) emissions comes from the fact that they are simply more efficient, consuming less energy than their silicon-based counterparts (for the same performance and size). Such efficiency and power density stem from the way the materials are able to reduce losses, both during operation and when switching between states.

The wider bandgap and, thus, higher critical breakdown voltage of the materials enables the development of semiconductors with very short or narrow depletion regions, resulting in device structures with very high carrier densities, which supports much smaller transistors and shorter current paths. This, in turn, results in an on resistance ($R_{DS(on)}$) that is significantly lower than silicon for a given die area and voltage rating and, thus, comparatively lower conduction losses. An additional contribution to reduced conduction loss derives from the improved thermal conductivity and maximum operating temperature, which enables the use of a smaller die while limiting device stress.

When it comes to switching losses, WBG devices offer benefits due to their higher electron saturation velocity and the lower capacitances that are a result of reduced die size. In addition, using lateral structures, such as those deployed in Navitas' GaN devices, ensures low gate capacitance, gate charge, output charge and output capacitance that support both higher switching speeds and reduced switching losses (unlike silicon alternatives where increased frequencies tend to lead to higher switching losses).

Reducing Greenhouse Gas Emissions – Making the Chips

The fact that both GaN and SiC have a die size that is smaller than silicon (for a given power or current capability) translates directly into having more units per wafer during production and, ultimately, a lower-per-chip carbon footprint for the same amount of energy and chemicals used in manufacture. In turn, this means that GHG emissions associated with fabrication are reduced.

In 2020, for example, the reduction in CO2 for a GaN FET was four times that of manufacturing a legacy silicon FET[9]. Now, with leading GaN power ICs offering ever higher levels of integration (including GaN power switch, GaN drive, sensing and protection capabilities) benefits increase, with a forecast of 10x reduction as new generations of GaN ICs are being introduced every 12 to 15 months and as fabrication moves from 150 mm (6 ") to 200 mm (8 ") diameter wafers[8].

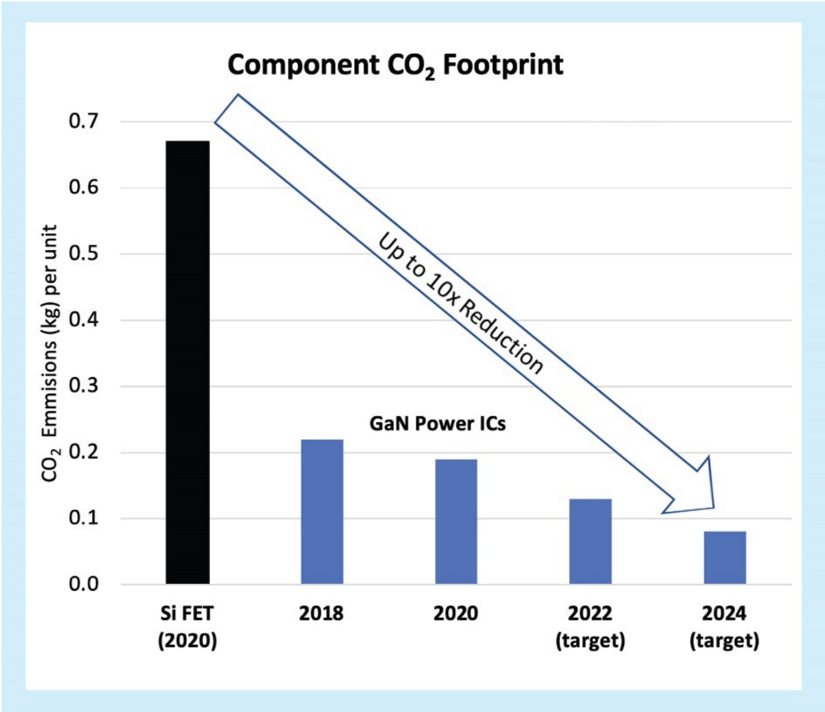


Figure 3: Reducing CO_2 emissions associated with ongoing GaN

In addition to die getting smaller, the wafers on which the die are produced are also getting better, with advances such as epitaxy platforms that combine real-time AI-based image analysis of the wafer surface with hybrid molecular-beam epitaxy (MBE) technology leading to higher yields and further driving down effective CO_2 emissions[8].

At this stage it is also worth making some comments regarding the creation or extraction of raw materials. While elemental gallium does not occur naturally, it is typically derived as a free by-product from the smelting of bauxite ore into aluminum and from the processing of sphalerite ore for zinc. As a result, it has a very low extraction and refinement carbon footprint.

While the production of silicon carbide raw wafers is more energy intensive, there are a number of interesting advances and projects focused specifically on making SiC production more sustainable. These include a novel, low-cost sustainable process funded by the U.S. National Science Foundation (NSF) that aims to convert low-cost natural gas and industrial silicon waste powder into a high-purity SiC powder, while producing hydrogen (H_2) as a clean by-product[10]. Similarly, researchers at the Fraunhofer Institute for Ceramic Technologies and Systems have developed an especially environmentally friendly recycling process[11] that turns by-products and waste products from SiC production back into high-quality silicon carbide, improving yields and reducing dependency on raw materials.

Reducing Greenhouse Gas Emissions – De-materialization

The third way that WBG semiconductors contribute to GHG reduction is by facilitating the use of fewer, smaller and lighter passive components in a power supply or power converter design. Such 'de-materialization' derives from the fact that, in addition to reducing conduction losses, increased operating frequencies with decreased periods between turn-on and turn-off means energy can be more frequently stored and voltage ripple is reduced.

The impact of this for the circuit designer is two-fold (Figure 5):

1. Magnetic components used as energy storage devices in switched mode power devices to ensure current flow is maintained during 'off periods' can be made progressively smaller as switching frequency increases.

2. The capacitors used at the input and output of a power supply to filter out AC noise, suppress rapid voltage changes, and improve feedback loop characteristics can also be made progressively smaller as switching frequency increases.

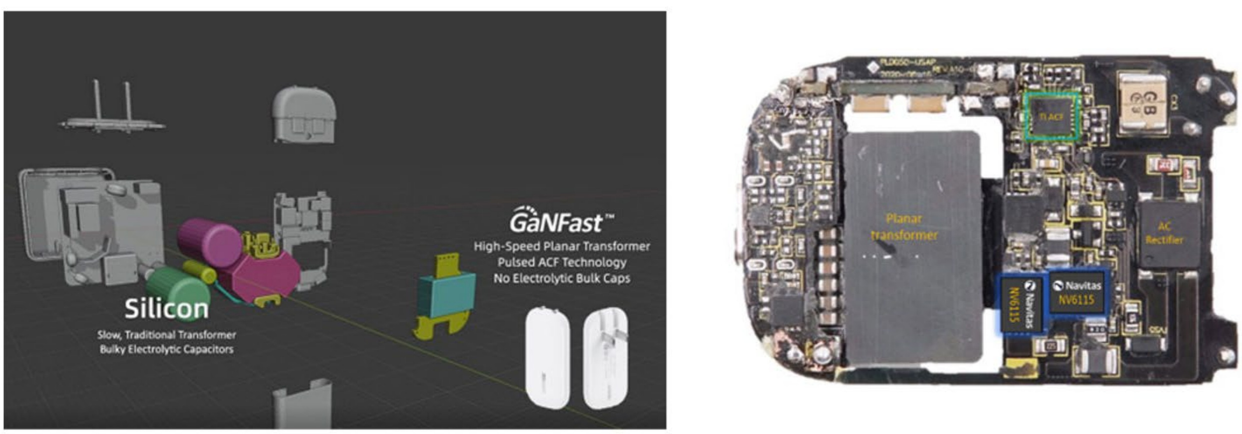


Figure 4: Reducing magnetic and passive component overhead in a fast charger

Finally, with improved efficiency comes reduced waste energy in the form of heat, which, at a system level, allows higher power densities, smaller form factors and less need for thermal management.

In consumer devices the latter may mean a smaller - or even no - heatsink and simplified housing and PCB layout – all of which has an impact on carbon emissions in terms of the 'end-to-end' cycle of manufacture, shipping to the OEM and, subsequently, transport of the final product or system to the end customer.

In larger, higher performance and higher power applications that demand active forced air or, increasingly, liquid cooling, all of the above benefits apply along with an associated reduction in the energy required to deliver that cooling.

Sustainability Examples

So, what do all of these benefits mean when it comes to improving the sustainability of practical, real-world applications?

Let's consider fast chargers for mobile phones. Here GaN power ICs enable power and charging systems to operate at up to 20x higher frequency than legacy silicon, which means up to three-fold higher power or three times faster charging in half the size and weight, and 'in use' energy savings of up to 40%. These benefits – which have enabled the creation of compact, multi-port fast chargers – bring competitive advantage to OEMs and usability benefits to end users which, in turn, has accelerated consumer uptake of more sustainable charging products.

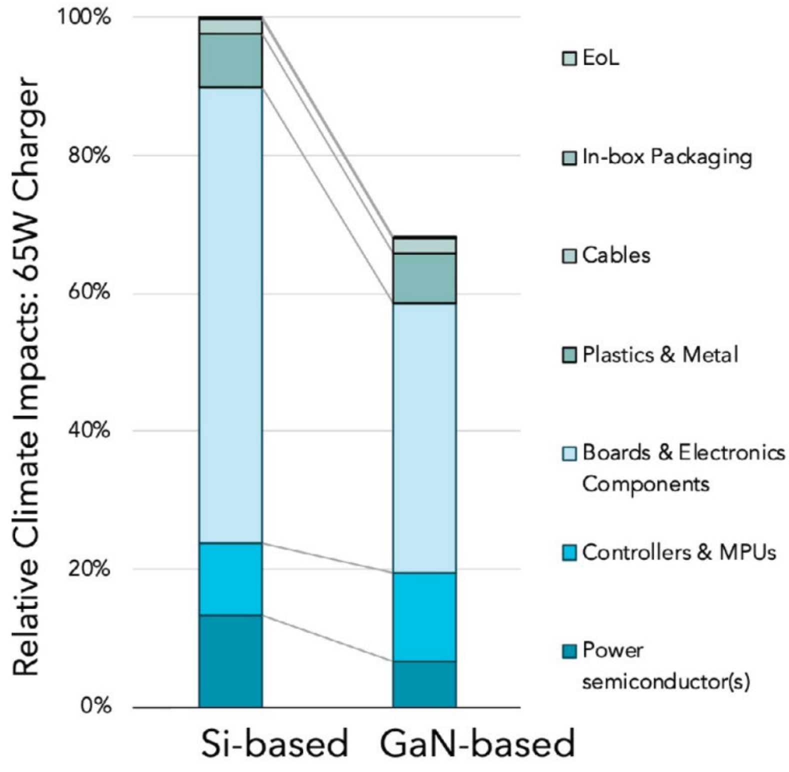


Figure 5: Lifecycle climate impact of Si- and GaN-based 65 W chargers

Figure 6 shows a lifecycle analysis comparison of the relative climate impact of 65 W chargers built around silicon and GaN semiconductors. Extrapolating this type of data, it is estimated that applying GaN to every mobile application would save over 9 billion kWh with an equivalent reduction of 6 billion kg of CO_2 by 2025, or the equivalent of eliminating 1.3 million fossil-fuel passenger vehicles being driven for one year[8].

Similar calculations can be made for potential emission reductions for electric vehicles, where there are three major power applications that can benefit from GaN and SiC: on-board charging (OBC), DC-DC conversion and traction drives. While there is some crossover, the first two are largely the preserve of GaN, with the latter has traditionally delivered the robust, high-power operation demanded by the latter. However, the EV world is evolving rapidly and, increasingly, SiC is needed to support a transition from 400 V to 800 V batteries that cut charging time in half. Higher voltages not only support increased power, but also reduce transmission power losses, lower heat dissipation and reduce weight and cost in the power cables – all factors that make a major contribution to sustainability.

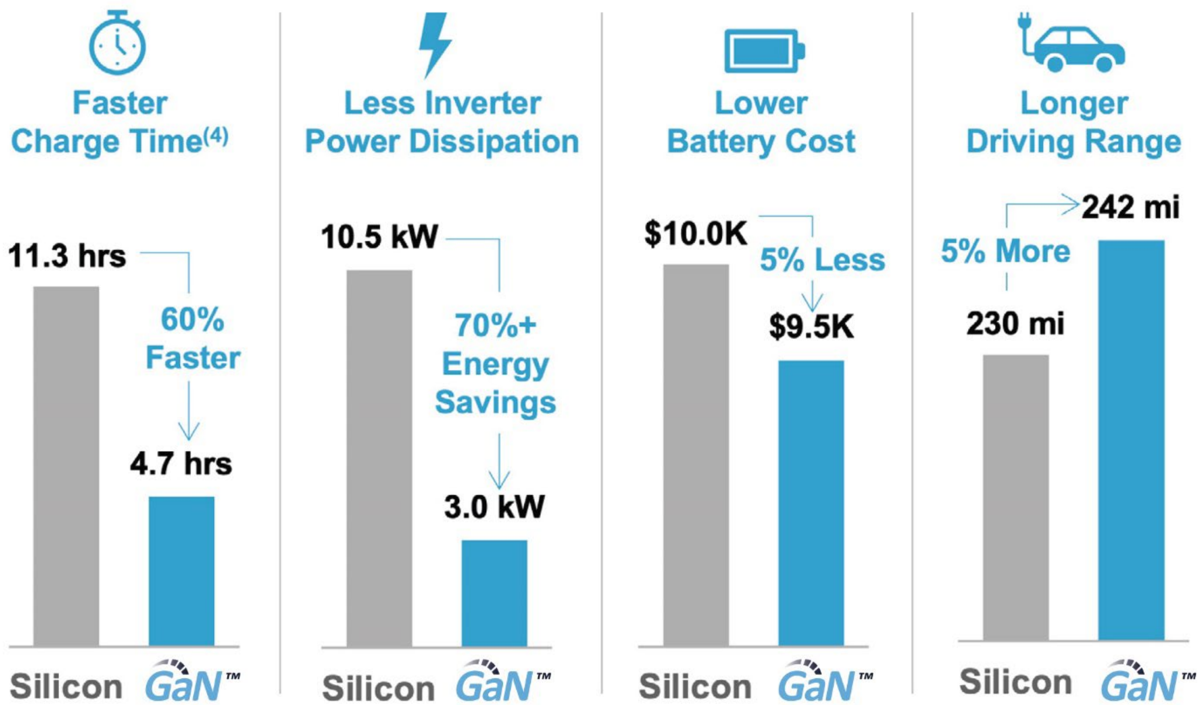


Figure 6: The Benefits of Deploying GaN in EVs

Even by only considering the GaN potential in a modern EV, we can see the potential for life-cycle system emission reductions that result from lower inverter power dissipation, smaller and lighter batteries and extended range per charge (Figure 7). As well as contributing to a vehicle's sustainability in its own right, these changes have a much bigger impact in that they address the key barriers to EV adoption – charging time, driving range and cost. Even before considering the significant benefits that the latest SiC technologies offer, Navitas had calculated that a transition from silicon to GaN power ICs could accelerate world-wide adoption of EVs by three years and reduce road-sector emissions by 20%/year by 2050[11].

And let's not forget data centers. The emergence of generative AI, the use of social media, online gaming and streaming and the move of more business applications to the cloud is creating unprecedented demand for high-power processors operating at 500 W - or much more in the case of NVIDIA's DGX GH200 'Grace Hopper', which can demand as much as 1,600 W.

WBG semiconductors will be essential to addressing this demand without increasing – and, ideally, while continuing to drive down – emissions. Indeed, WBG devices will have to become a de-facto standard to meet emerging legislation such as the European Union's Directive 2009/125/EC, 2019 Annex that states that new data center power supplies must meet extreme 80 Plus 'Titanium' efficiency standards from January 1st, 2023 and Similarly in the U.S. New Energy Act, which covers a broad range of energy efficiency initiatives, some of which specifically target the data center industry.

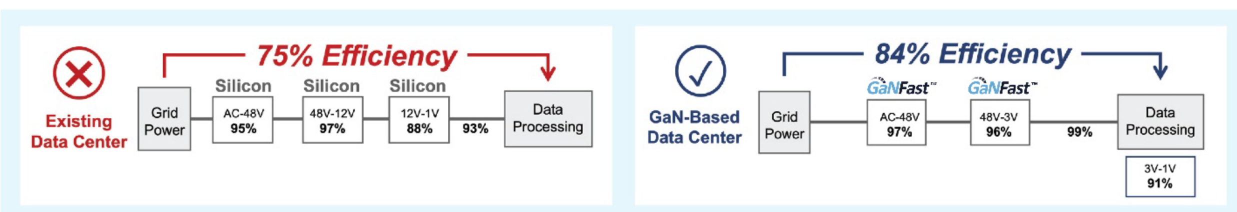


Figure 7: Efficiency improvements will support emerging sustainability legislation for data centers

As Figure 8 shows, upgrading from legacy silicon to high-efficiency GaN in the data center industry has the potential to reduce electricity use by up to 10% - an improvement that if applied across all data centers could reduce energy demand by over 15 TWh, save $1.9B in annual electricity costs and reduce CO2 by 10 Mtons – or the equivalent annual emissions of over 2 million gas- based passenger vehicles[13],[14].

Conclusion

As we electrify our world it is clear that replacing legacy silicon with GaN and SiC semiconductors and deploying these WBG devices in new and emerging applications for which silicon could never have been a candidate will help us on the journey to Net Zero.

Opportunities for such deployments – which have the potential to unlock emission reductions of 6 Gtons/year in CO_2 – include high-frequency SMPS and DC-DC converters, solar inverters and EVs where the technologies address demands for higher efficiency, improved performance, smaller form factors and reduced cost.

Considering the greatly-reduced manufacturing and transportation footprint, and the significant savings both to manufacture downstream products, and 'in-use' efficiency benefits, we can present a per-unit net-benefit of upgrading from silicon to GaN and SiC power ICs. Based on 2020 figures, for example, every GaN power IC shipped by Navitas reduced CO_2 emissions by over 4 kg versus legacy silicon chips. To date that's a total saving of (update at time of publication based on https://navitassemi.com/quality/).

Finally, as well as the benefits delivered by the products it is also critical that semiconductor companies themselves work to achieve their own carbon neutrality. In May 2022, for example, Navitas announced that it is the world's first semiconductor company to achieve CarbonNeutral®-company certification from the leading experts on carbon-neutrality and climate finance, Climate Impact Partners (formerly Natural Capital Partners).

References

1. https://treaties.un.org/doc/publication/unts/volume%201522/volume-1522-i-26369-english.pdf
2. https://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf
3. https://unfccc.int/resource/docs/convkp/kpeng.pdf
4. https://sustainabledevelopment.un.org/frameworks/parisagreement
5. https://www.eesi.org/topics/fossil-fuels/description#:~:text=Fossil%20fuels%E2%80%94including%20coal%2C%20oil,percent%20of%20the%20world's%20energy
6. Source: Global carbon budget. Friedlingstein et al. Earth System Science Data, 2022
7. https://store.frost.com/global-wide-bandgap-semiconductor-growth-opportunities.html
8. Navitas Sustainability Report
9. https://www.powerelectronictips.com/how-much-can-gan-improve-sustainability-and-reduce-co2-emissions-faq/
10. https://www.aiche.org/sites/default/files/cep/20221013.pdf
11. https://www.fraunhofer.de/en/press/research-news/2023/june-2023/energy-efficient-and-low-in-emissions-silicon-carbide-recycling-with-recosic.html
12. DNV estimate for 75%-adoption milestone pull-in, total road sector benefit
13. Navitas estimate based on a) Navitas server/datacom forecast & AAAS data, b) $0.12/ kWhr, c) Si vs. GaN $/W and d) data centre loading profile.
14. Per EPA equivalencies calculator: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator