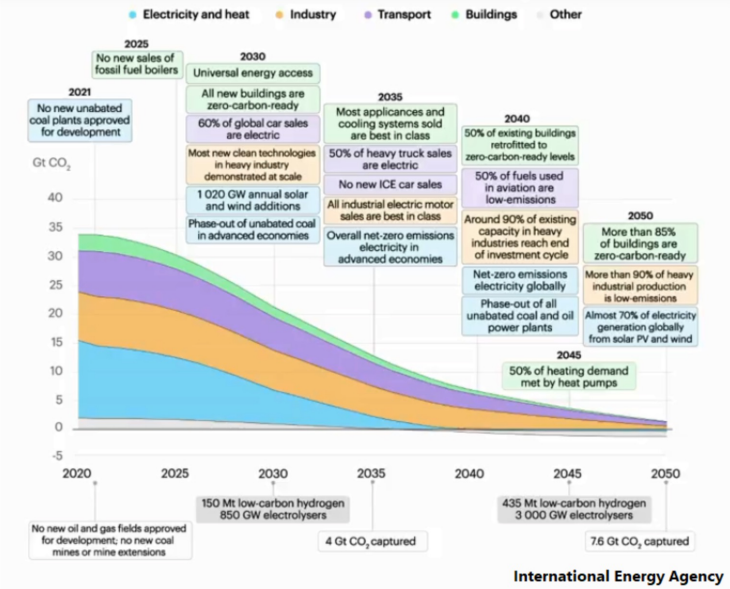
Solving the EMC & thermal issues of driving GaN at high speed

CS International, 17 April 2024

2024

Electrification is essential: Motors are critical

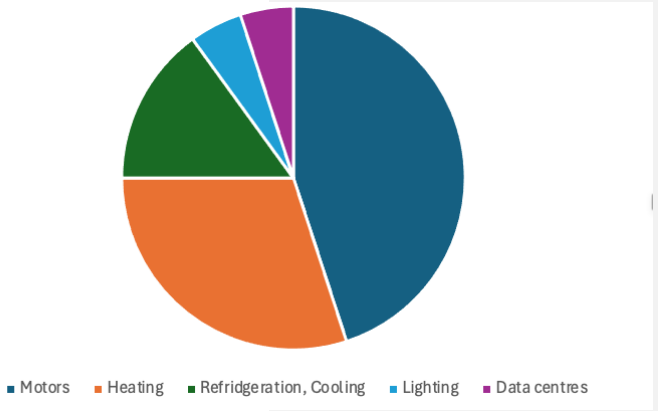
Inevitable move towards electrification: pressure from net zero.



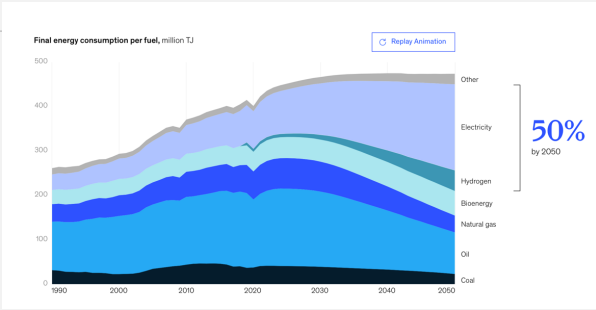
Electric motors are the worlds biggest energy consumers.

~50% of global electricity - more than any other application.

Electric motor today are often shockingly inefficient: scope to reduce waste by 25%



Electric usage will triple by 2050 (83 ExaJ to 252ExaJ) >3x growth in motors



But...

Electric motors are the largest single-energy use with half of global electricity consumption.

There is a huge, untapped potential for energy efficiency in motors: around 25% of electricity use could be saved cost-effectively, which would reduce global electricity demand by 10%.

However, the energy efficiency of motors has been neglected in comparison with other sustainable energy opportunities

- IEA

GaN has great advantages over SiC or Si

- Lower gate capacitance:
  GaN <1 nC-Ω vs 4 nC-Ω for Si*

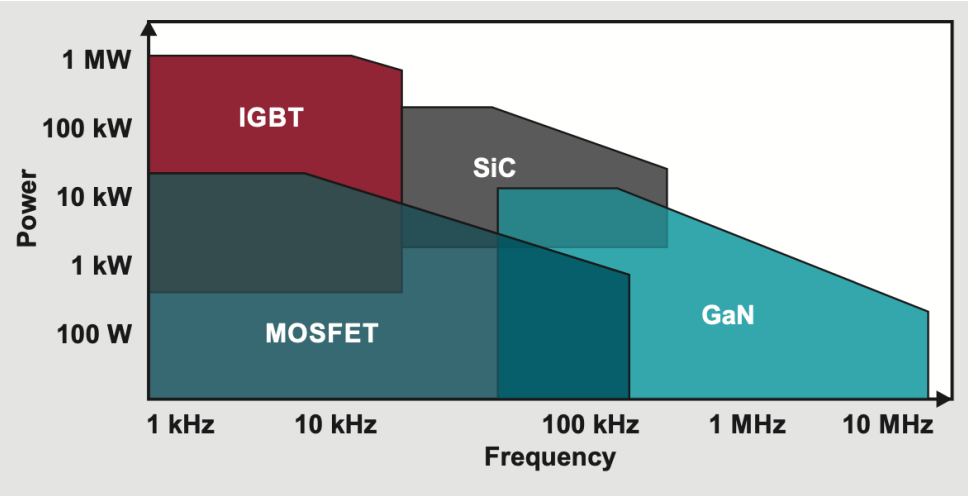
- Lower output capacitance
- GaN output charge <5 nC-Ω vs Si at 25 nC-Ω*

- Zero reverse recovery / no body diode
  No reverse recovery losses
  Typical SiC FET >85 nC of reverse-recovery charge*

- Lower switching energy: half that of SiC

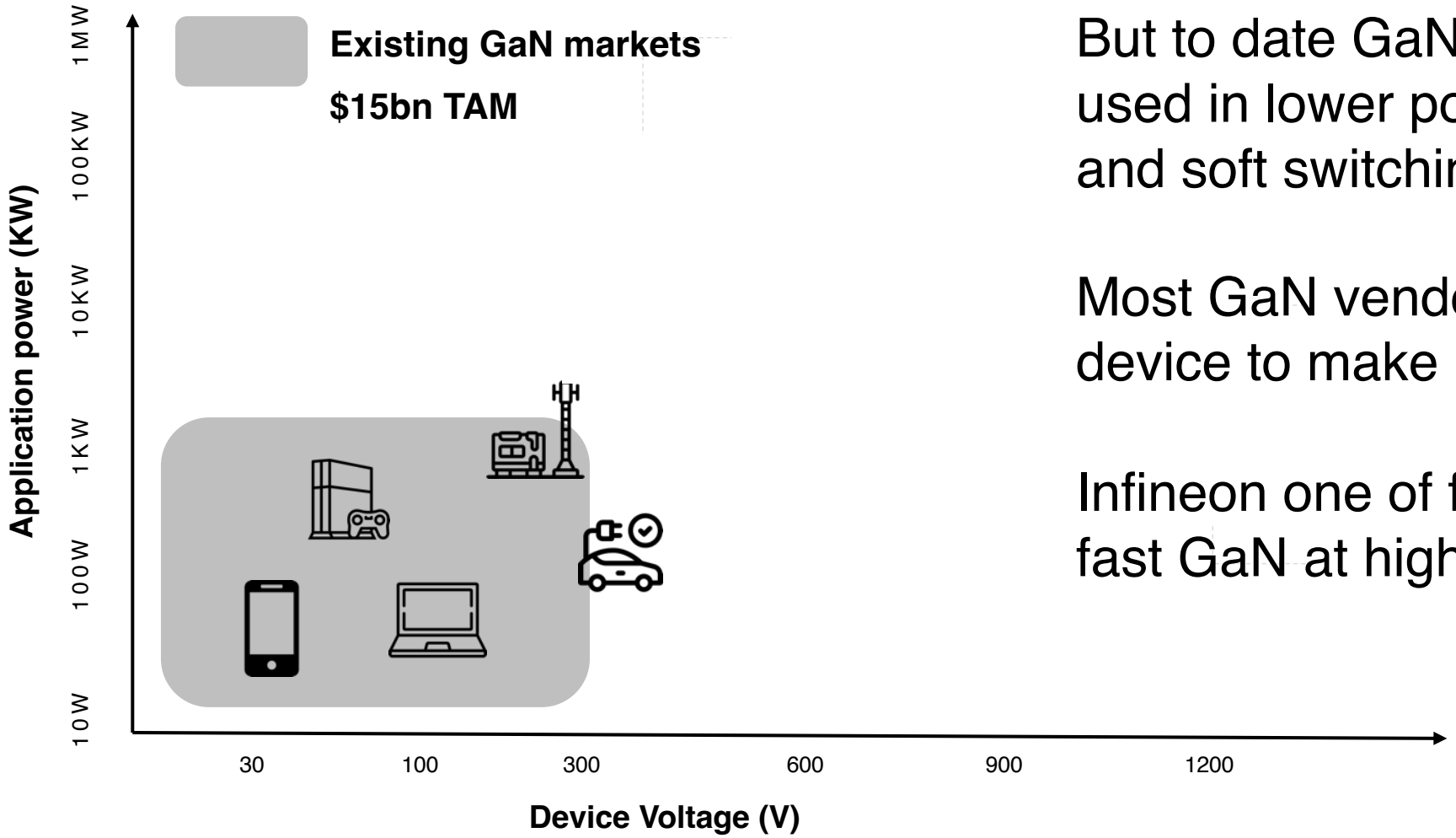
- Faster switching speed: up to 10MHz

- Lower cost: Si substrate, 300m wafer



** These are representative/typical, not for a specific device*

If only GaN could do higher power…

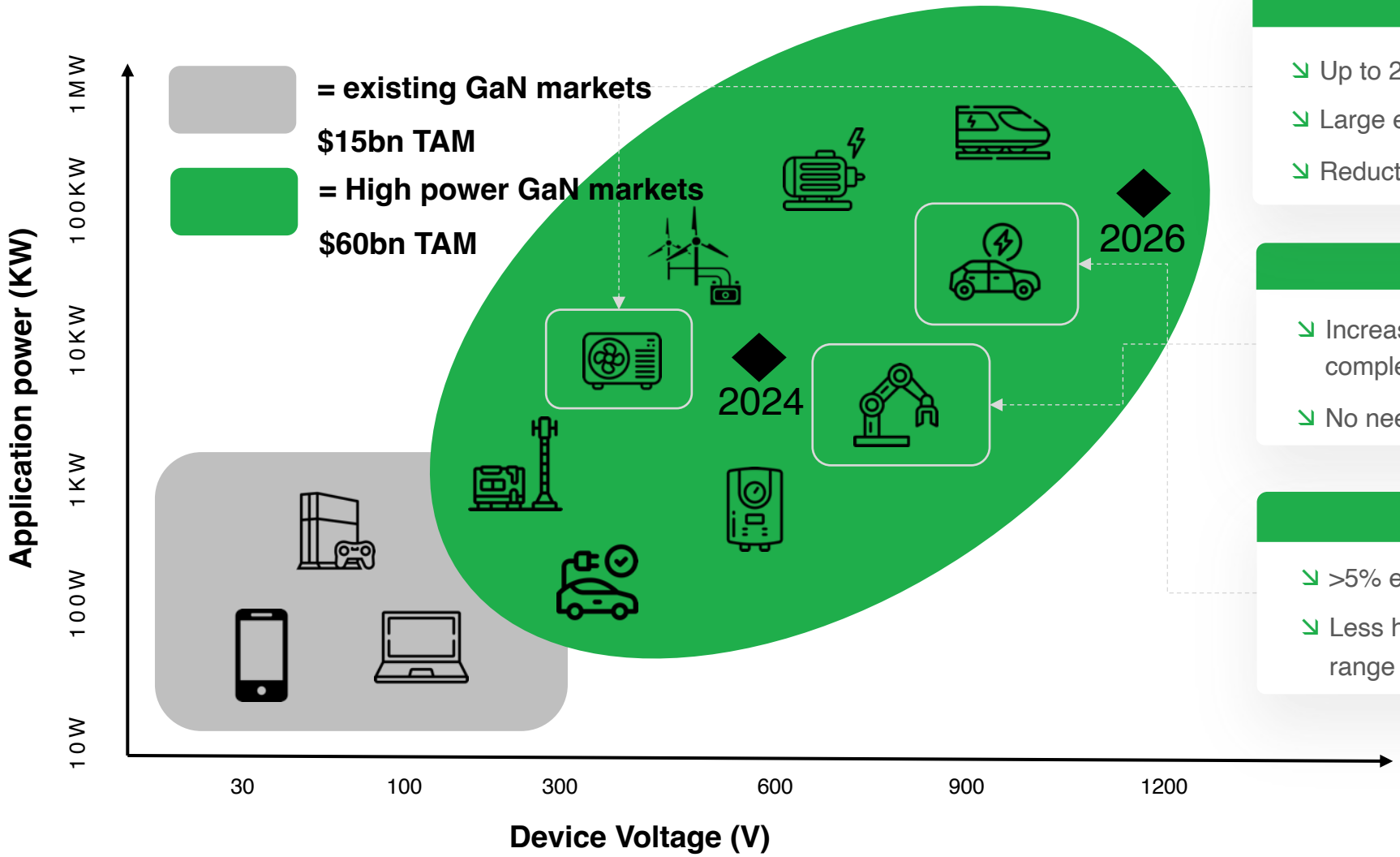


But to date GaN has only been used in lower power applications and soft switching

Most GaN vendors “sandbag” the device to make it “look like” Si

Infineon one of few vendors with fast GaN at high power

… but it can!



HVAC

- Up to 20% efficiency improvement
- Large energy saving for consumers
- Reductions in carbon emissions

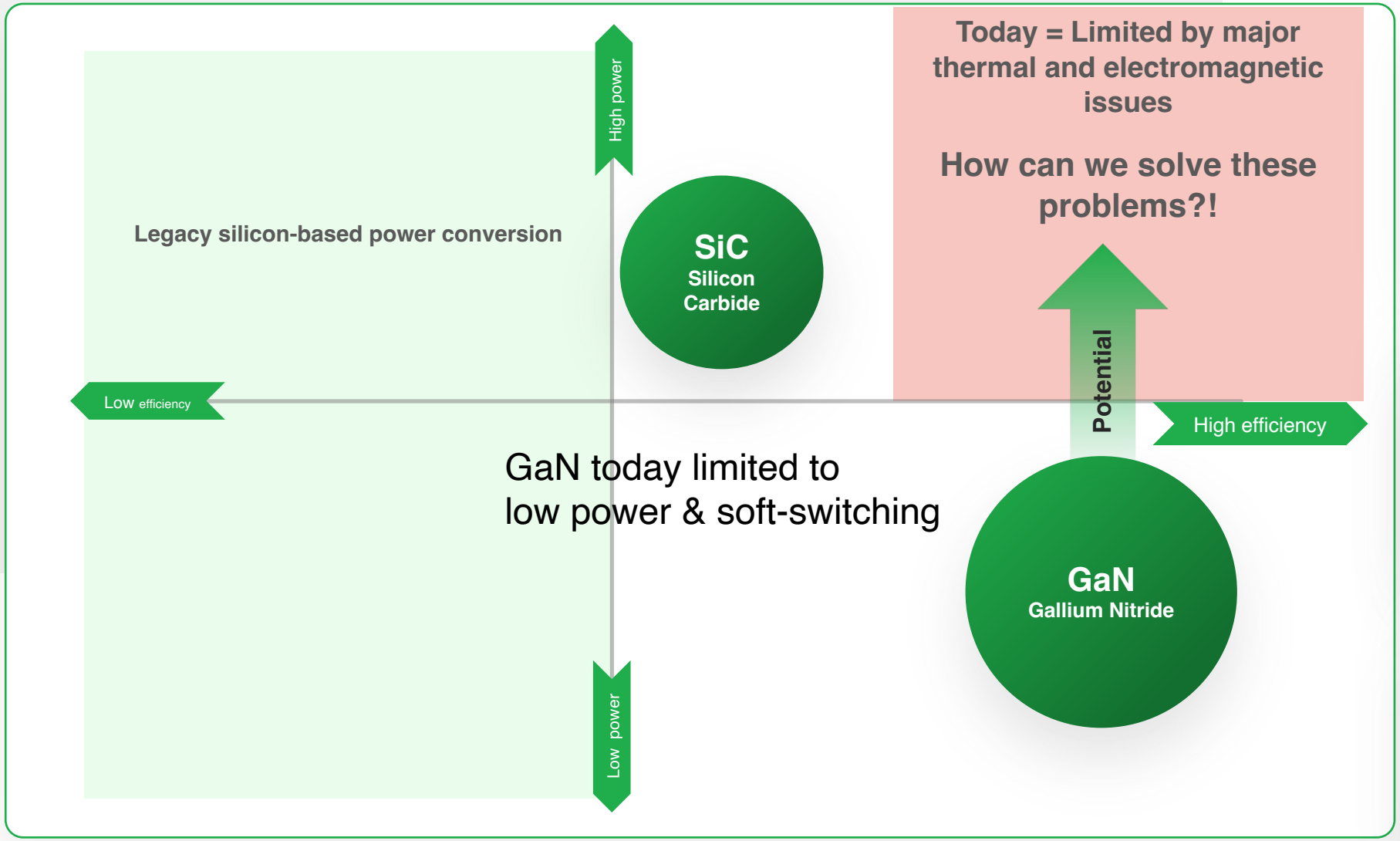
Industrial

- Increased power density to reduce cabling complexities
- No need for screened cables

Electric Vehicles

- >5% efficiency improvement over SiC
- Less heat, reduce weight to further increase range

GaN can replace IGBT & SiC: Higher power at higher efficiency



Unlocking the ultimate efficiency

$66bn
Potential annual energy savings

Unlocking the ultimate efficiency

Industry disruptive

Unlocking the ultimate efficiency

Save 1000TWh and 400m tonnes CO2

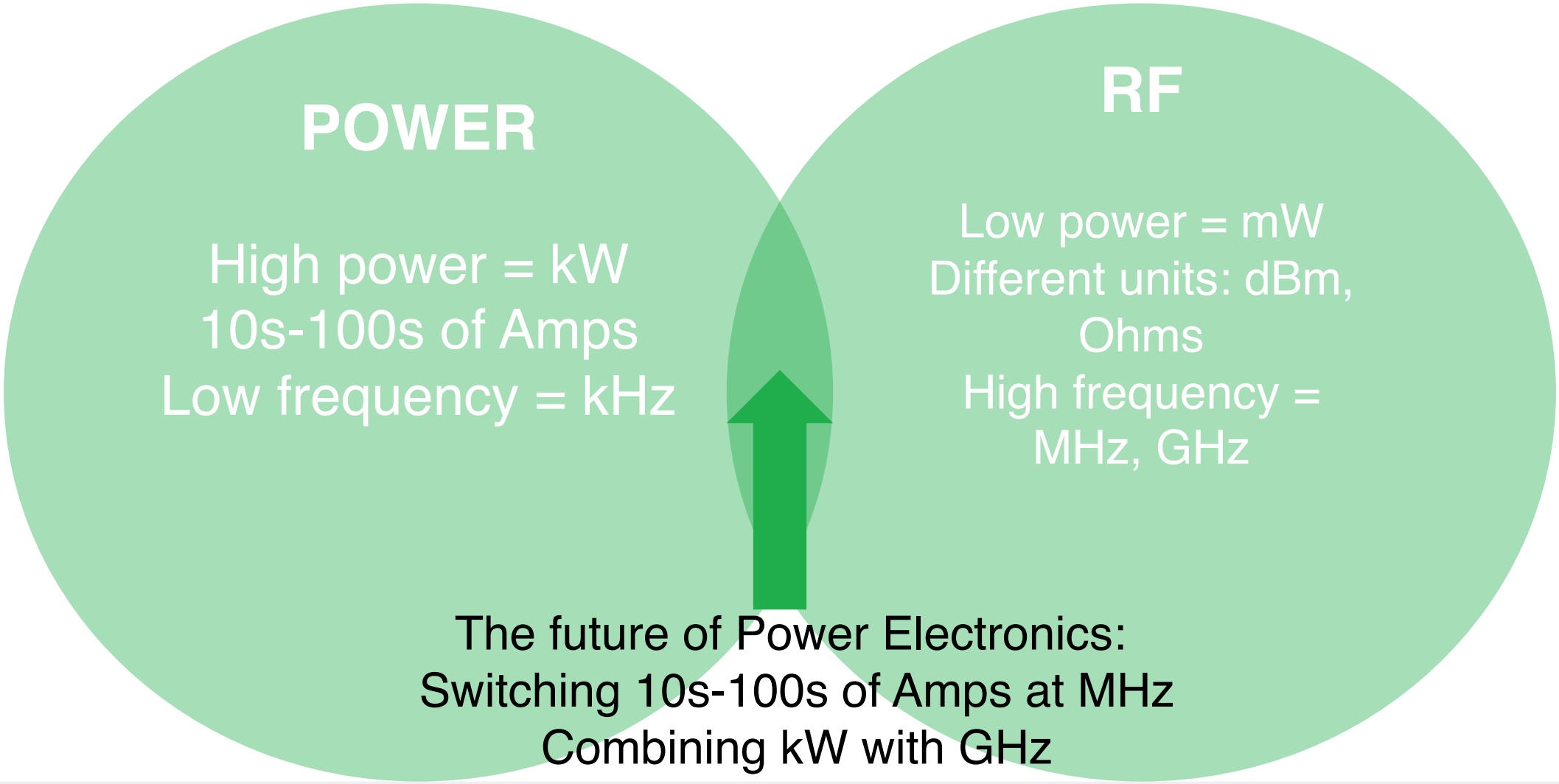
The problem: Why efficient motor drives are critical

- Many motors today are shockingly inefficient. Only 23% use a Variable Frequency Drive (VFD) to control speed, but even those are inefficient
- The faster the transistors in the VFDs can switch, the more energy is saved. Running VFDs at higher frequencies increases power density (reducing size and weight)
- GaN has great advantages over Si IGBT or SiC
- But to completely replace them, new system design is required
- **The worlds of power engineering and RF / microwave engineering have collided: the old approaches no longer work**

Variable Frequency Drive (VFD)

Motor (Speed controlled by VFD)

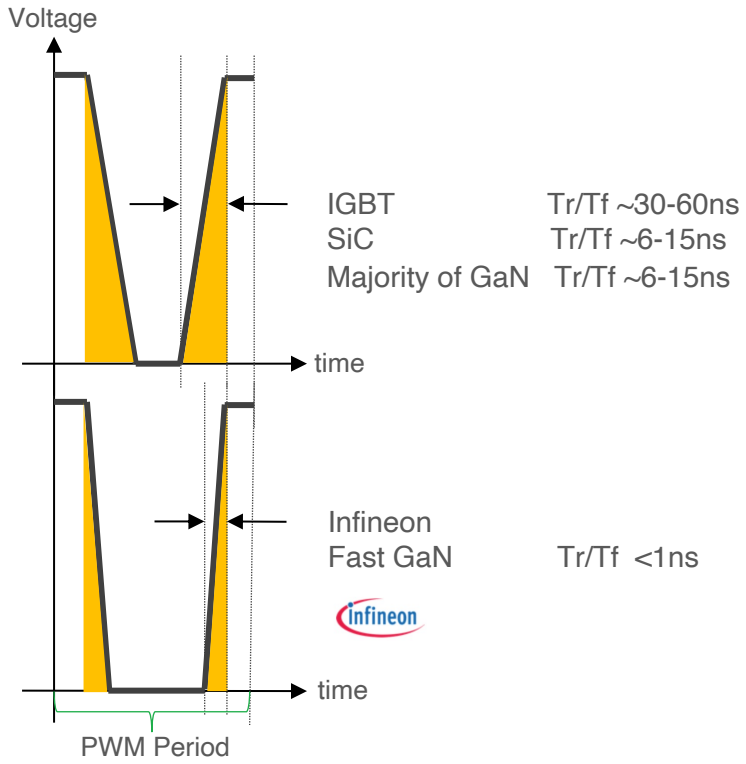
To use GaN = RF Meets Power

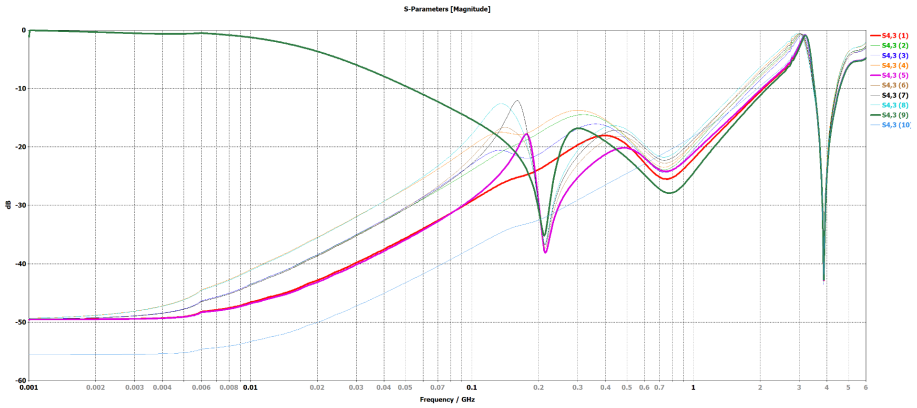


The future of Power Electronics:
Switching 10s-100s of Amps at MHz
Combining kW with GHz

The problem with hard switching…

- Switching the DC bus directly: no ZVS and/or ZCS advantage
- Only way to reduce wasted energy in transitions is by transitioning faster (less time in resistive region = less energy wasted)
- But when we do this, we have a microwave RF power system:
  - Any power path longer than ¼ wave is a transmission line and needs to be terminated or we get highly destructive reflections!
  - ¼ wave in power systems IGBT switching systems is around 1.5m not really an issue in a motor drive!
  - ¼ wave in a fast GaN system is around 5cm (harmonics at 1-2cm): starts to get interesting…
- Most GaN transistors are “sandbagged”
  GaN Systems/Infineon are unusual in supporting high power (650V, 15A) at high frequencies (<1ns switching)

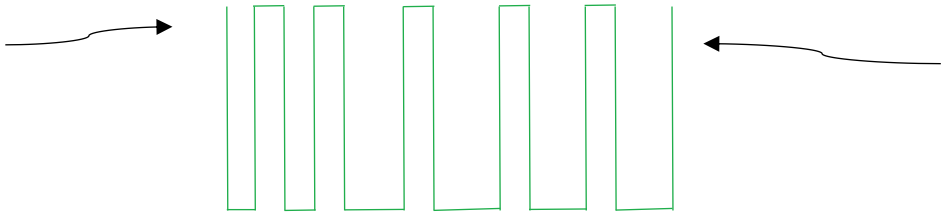




The Benefits and Challenges of Fast Switching

PWM frequency of 1MHz

Makes sinus filter very much smaller, lighter, cheaper



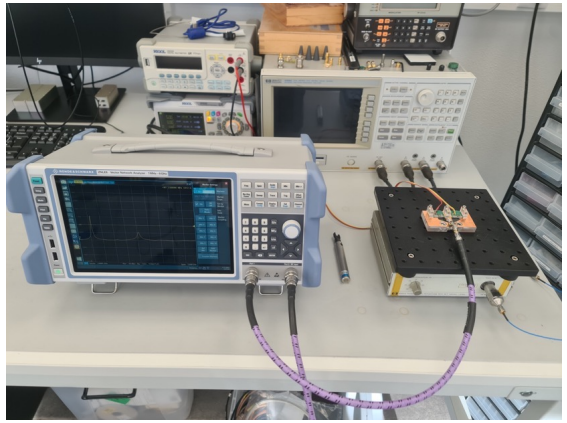
<1ns rise/fall time

Very little time in resistive region = very low losses, less waste heat

But RF challenges: signals into GHz

Benefits

- Sinus filter is is built into the architecture reduced from 36kg to 100g
- All reactive components (L's and C's) are reduced in size (and cost!) by ~100x
- GaN has no body diode: less wasted energy



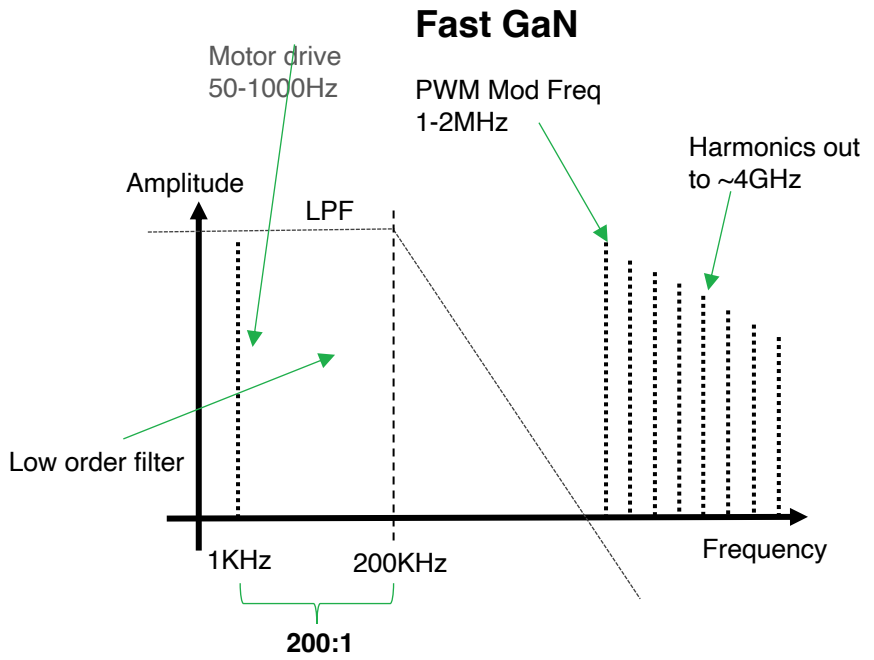
RF output impedance of modules being characterised in our lab.

Challenges

- Complex output impedance of GaN H-Bridge must be terminated
- LC output filter must have a self resonant frequency of several GHz to avoid EMC issues
- Conducted and radiated emissions must be managed

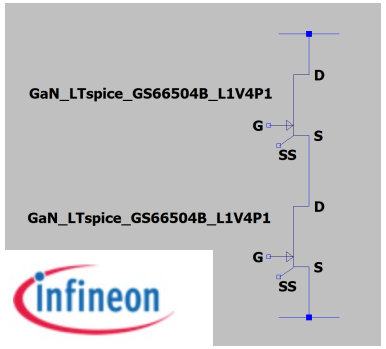
Filtering

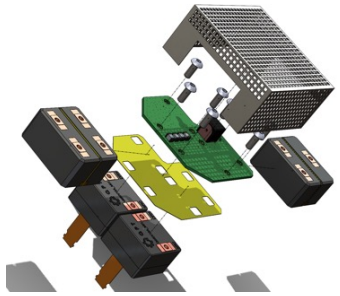
- Higher PWM frequency makes filtering easier: greater separation between motor drive, PWM & harmonics
- High energy and fast rise/fall makes filtering essential – otherwise dV/dt would be unacceptable
- Clean sine (very low THD) has major benefits for motor: less heat, lower eddy currents, less winding stress, less noise/vibration, no common mode or dc path

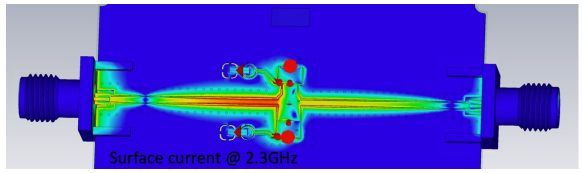


HV GaN Half Bridge driver generates significant power up to 4GHz

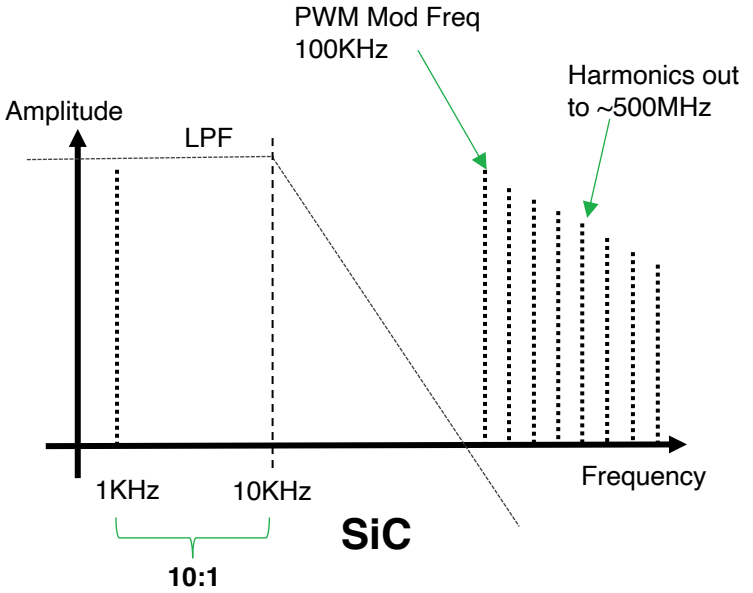
RF impedance match to ~4GHz
LPF for sine output







Output LPF Fc ~200KHz (Sinus Filter)
Harmonics >60dB suppression = clean sine output at Fc

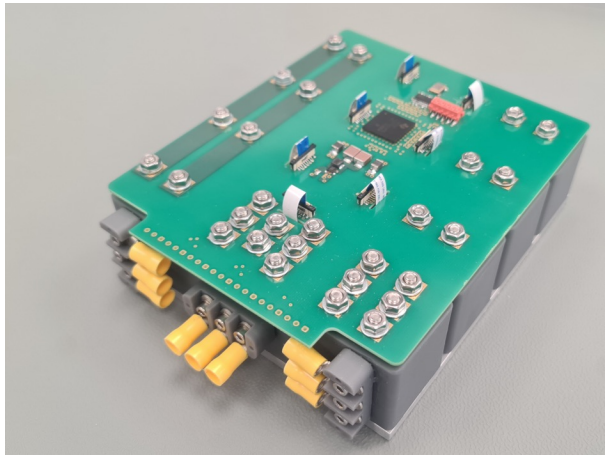


This is real…

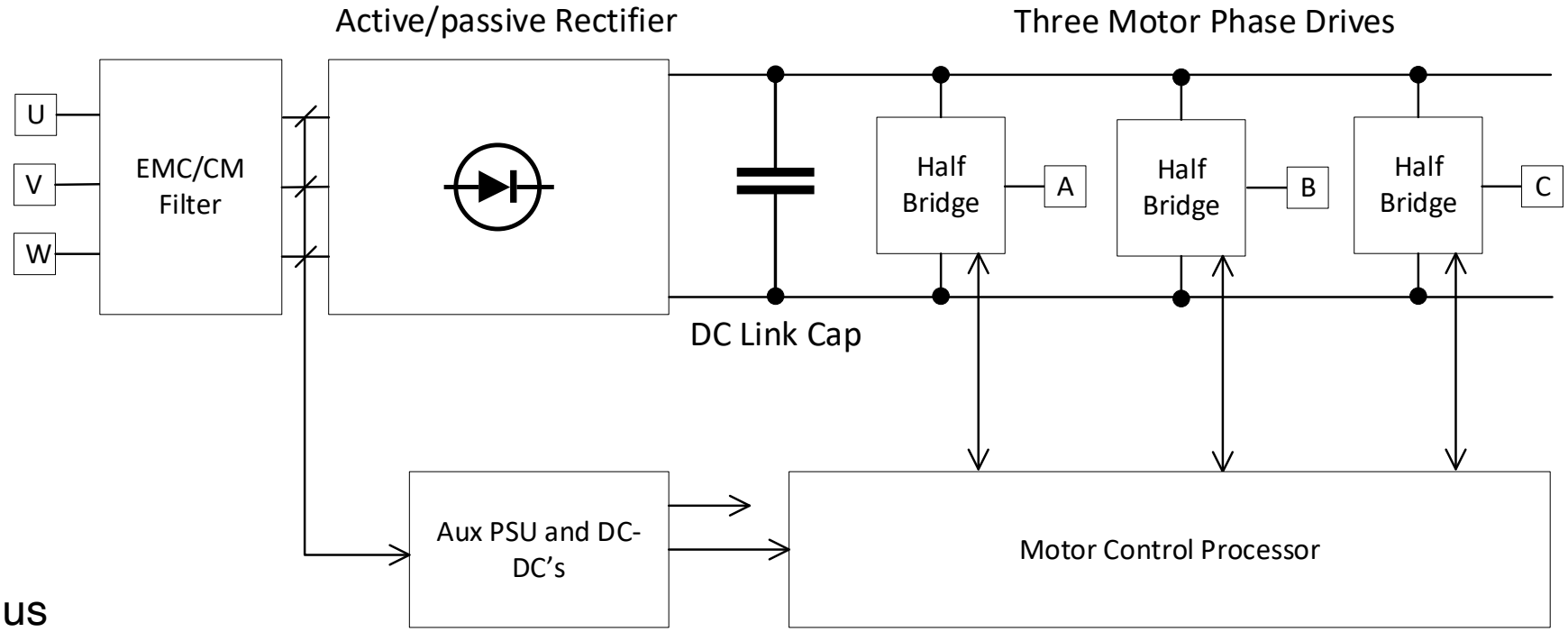
400V (230V 3phase) 7.5kW GaN-based VFD

- Ultra-high efficiency, ultra-compact
- 1MHz internal switching PWM (<1ns switching time)
- Compact integrated sinus filter (no high dV/dt, no dc component)
- 0-500Hz output (0-30,000rpm), pure sine (~0% THD)
- Active rectifier: <5% THD, no electrolytic caps, high MTBF
- GaN transistors: low losses, minimal heat dissipation
- Volume: 1litre (15cm x 16cm x 4cm)

Complete VFD Module (with integrated filter)



- 15cm x 15cm x 4cm
- 1l volume
- 3x Half bridge, rectifier, sinus filter, control processor



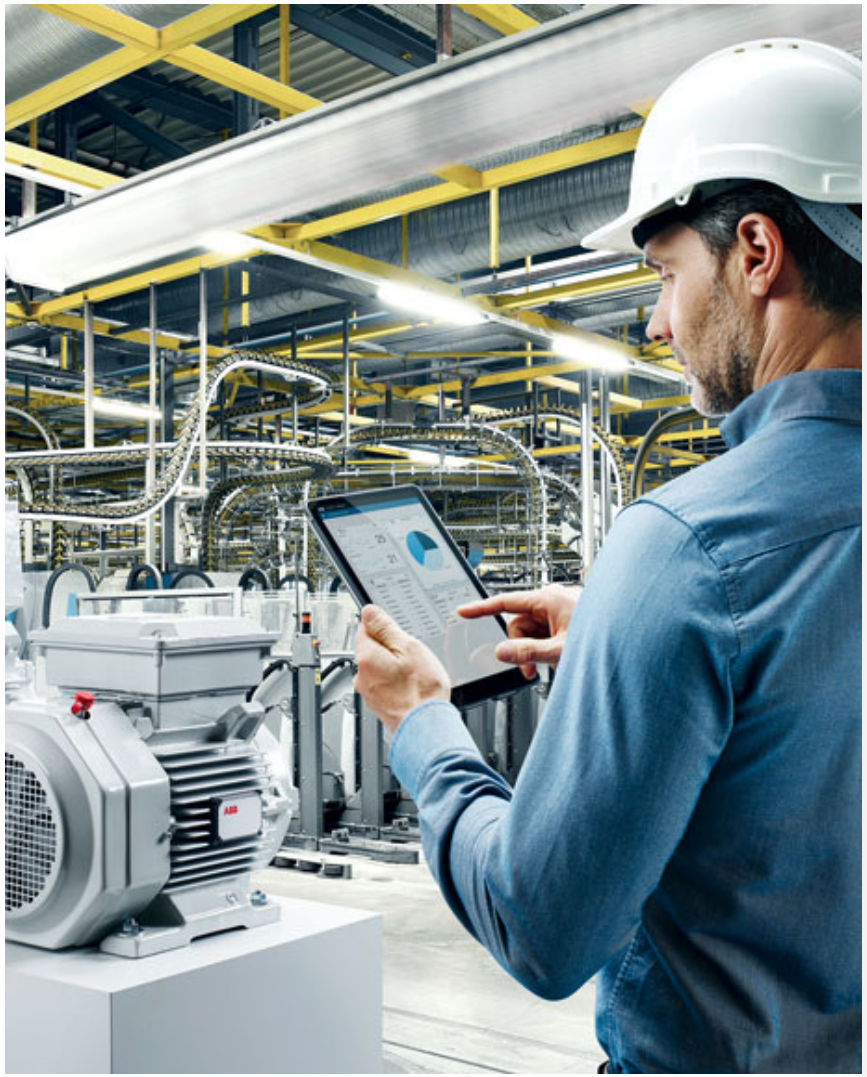
Traction

Winner Open Innovation competition:

Contract to develop next-generation GaN-based VFD for the world's largest supplier of industrial electric motors

"QPT's qGaN technology looks very promising for future power electronics and we can't wait to work with them. ***This innovation can bring several benefits to customers in different applications by addressing energy efficiency and power quality in a compact form factor.*** *QPT's solution is effectively addressing some of the key challenges with the qGaN technology, and this can truly challenge SiC in the future."*

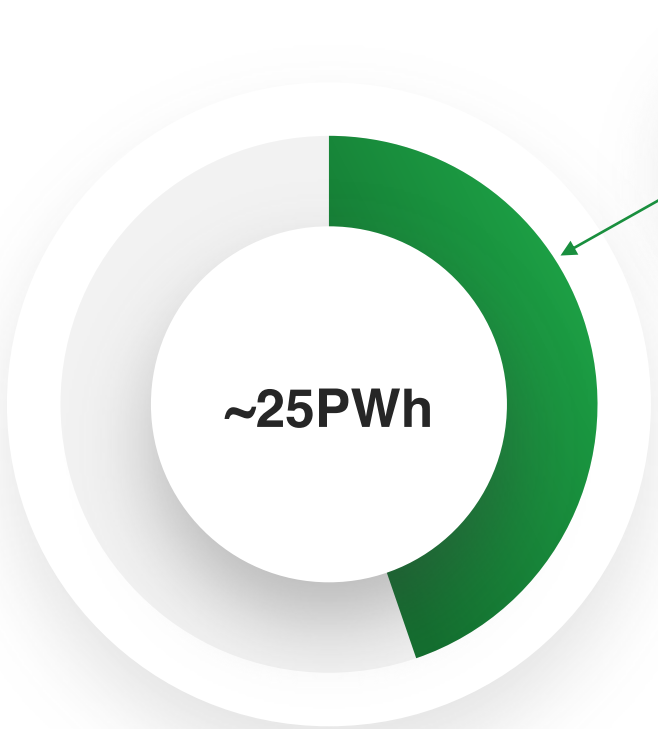
Harri Mustonen, Head of Strategy & Business Development



Benefit

- Faster switching = lower losses
  - Improve VFD efficiency 5-10%
  - Less heat
  - Improved reliability
- Integrated filter = Clean sine into motor
  - Further efficiency saving: another 5+%
  - Reduced eddy currents & winding losses
  - Less strain on motor, improved reliability
  - Reduces noise & vibration
  - No common mode or dc path
- Eliminates EMI/RFI: No need for screened cables
- Dramatically higher power density, smaller lighter VFD / motor systems
  - Enables novel motor designs & integrated VFD

Environmental impact:
Equivalent to removing 50% of the planes from the sky



Electric **Motors** **45%** of global electricity

Current annual global energy consumption*

*projected to increase by 72% to 41PWh by 2050

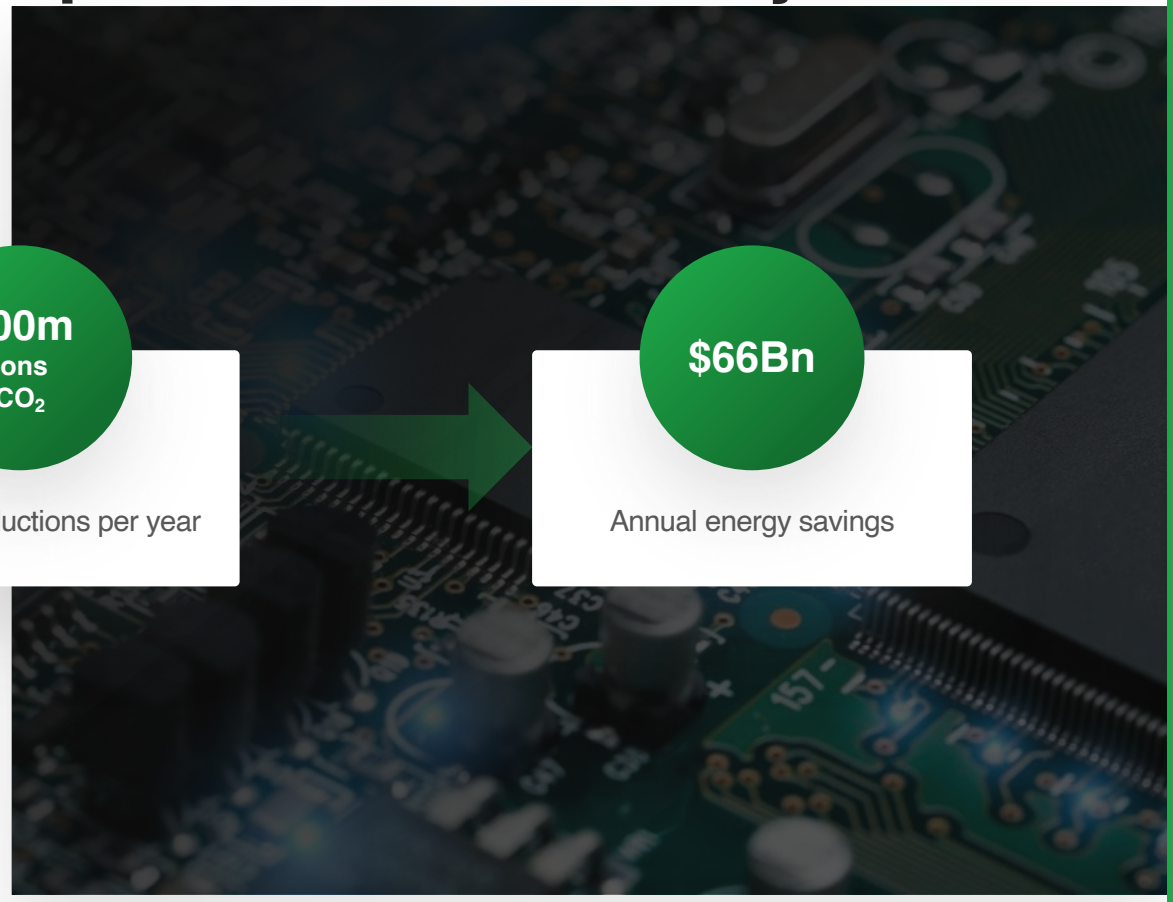
QPT can improve energy efficiency **by at least 5%**

400m tons CO_2

Emission reductions per year

$66Bn

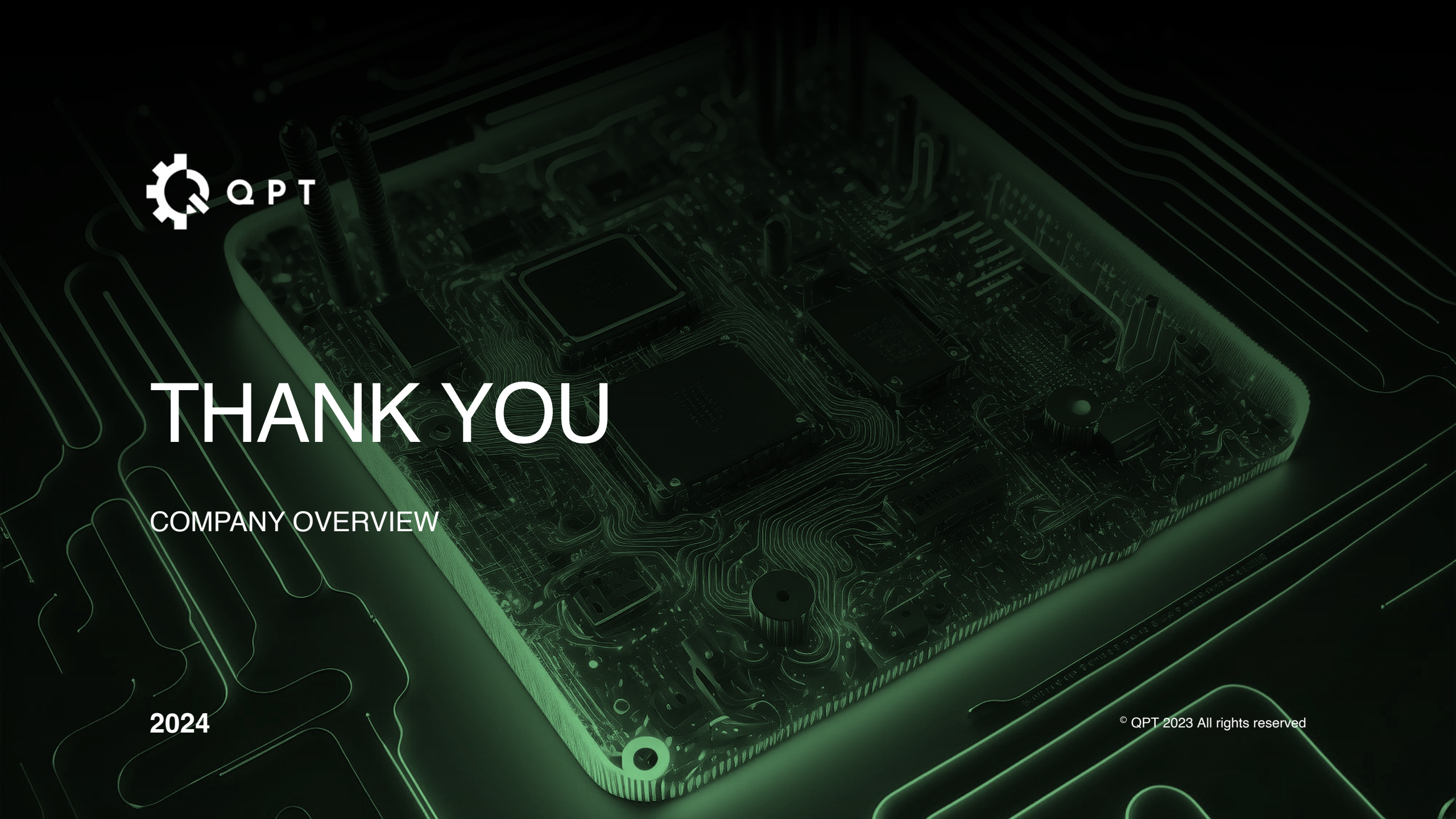
Annual energy savings



Summary

- Electric motors consume ~50%of world electricity, rising quickly with electrification
  But much of this is shockingly wasteful
- Net zero – compelling need to make electric motors more efficient
- GaN is *inherently* a better transistor than Si or SiC: faster, no body diode, lower capacitance
- But it has been hard to use…
- GaN for Power electronics has been limited to low power, soft switching (eg “wall-wart” PSU)
- But good system design allows GaN to be used in higher power & hardswitching

- **QPT + Infineon: unleashing the power of GaN to make electric motors radically better**
- **Save $66bn in energy, 400m tonnes of CO2**



THANK YOU

COMPANY OVERVIEW

2024