The Next Decade Capacitor Requirements

Materials, Reliability and Sustainability/Life Assessment

5th Annual PSMA Capacitor Workshop 19th March 2022, Houston

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www.passive-components.eu

Content Focus

- Introduction
- Electronic Industry – Key Growth Area
- Materials
  - Critical Supply Chain Management
  - New Materials – Next Gen Capacitors
- Reliability, Sustainability and Life Cycle Assessment
- Summary

Introduction – EPCI

PASSIVE COMPONENTS BLOG

AWARDED TOP 40 ELECTRONIC PRODUCTS & COMPONENTS BLOG

ELEKTRA 2016 FINALIST

EPCI European Passive Components Institute

be active with passives !

Passive Components Global Daily News
collection of worldwide passive component news sortable by components and applications
weekly and monthly newsletters

WHO is WHO in Passives
free online database of global passive components manufacturers & suppliers

- **One of few educational and information resources dedicated solely to passive components**
- Established 2015, Elektra 2016 Finalist
- EPCI among the top 15 best rated global component blogs since 2018
- **PCNS Passives Symposium** organiser since 2017

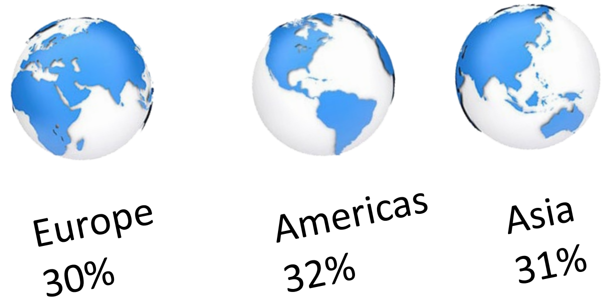
www.PCNS.events

www.epci-academy.com

EPCI Academy
from student level to professional certified online e-learning courses on passive components

www.passive-components.eu

| Passive Components Educational & Information Blog



2021 passive-components.eu web profile:

Active visitors: **>40K/month**
Google Search views: **2.2 million views /month**
Google Search clicks: **35 thousands clicks / month**
Newsletter: > **750** subscribers related to passive components
Top countries: USA, India, Germany, UK, Canada, France, Sweden

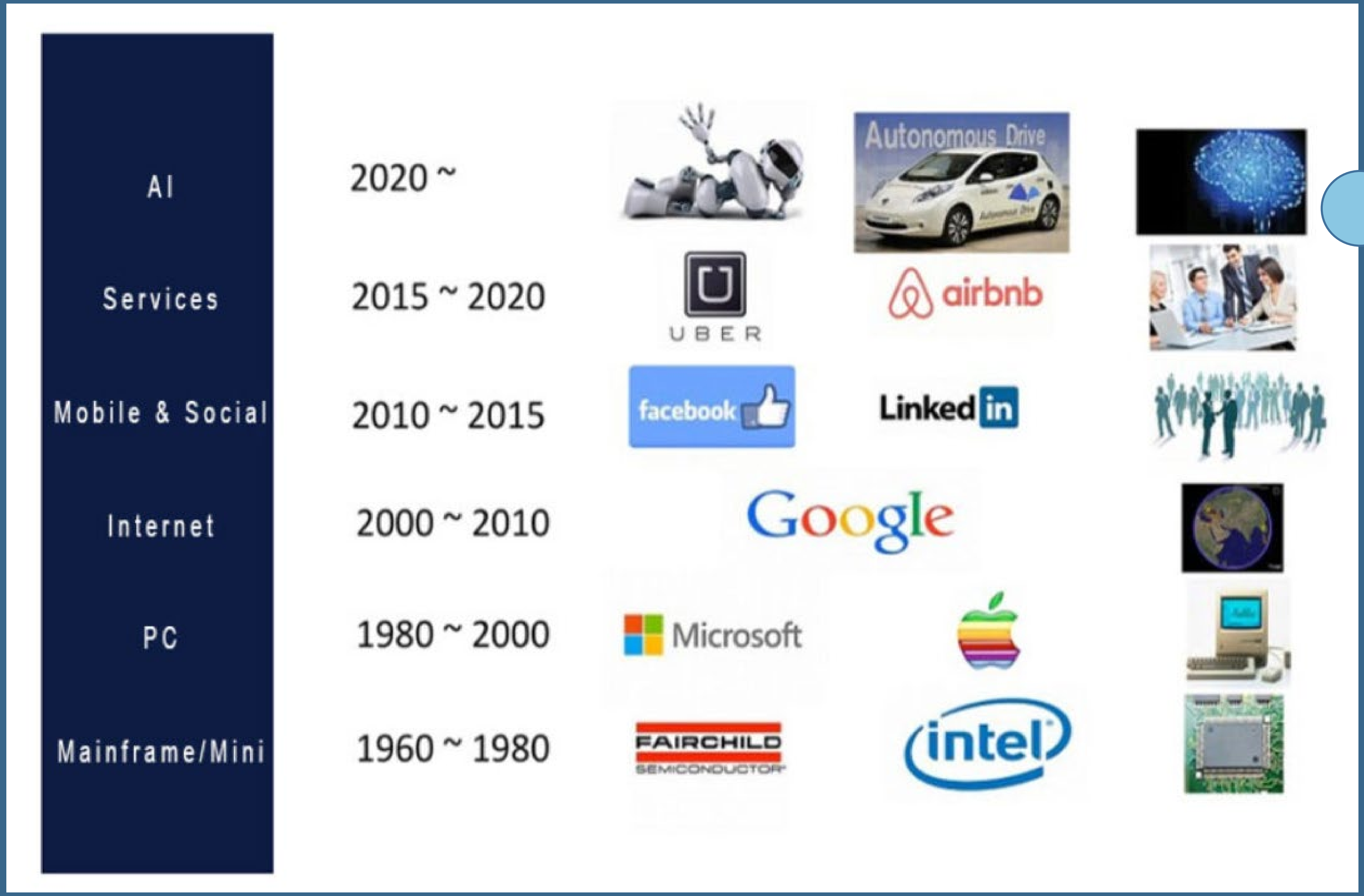
EPCI Gold Members and Supporters:

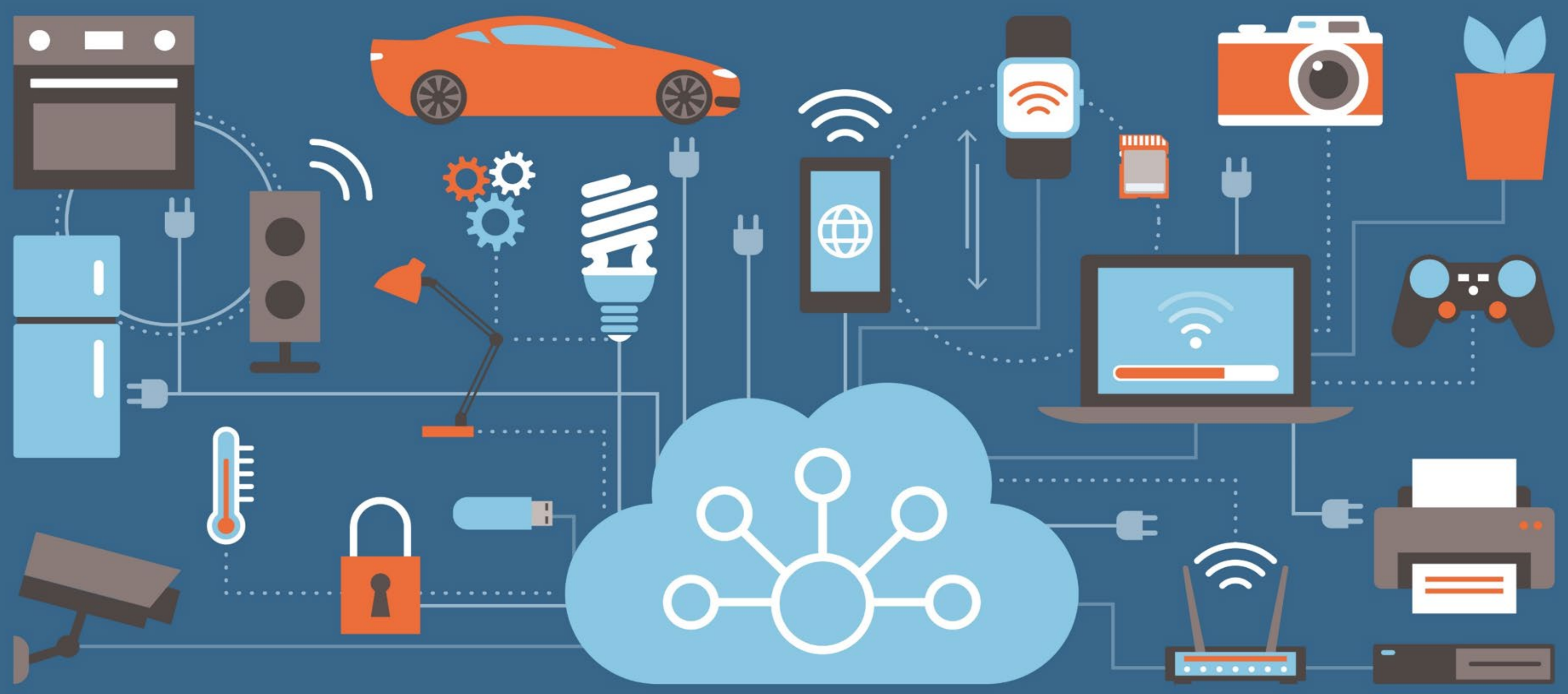
KEMET a YAGEO company · KYOCERA AVX · muRata INNOVATOR IN ELECTRONICS · WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

Electronic Industry – Growth Paradigms

Computing Sector Changing Paradigms

over the past 60 years.





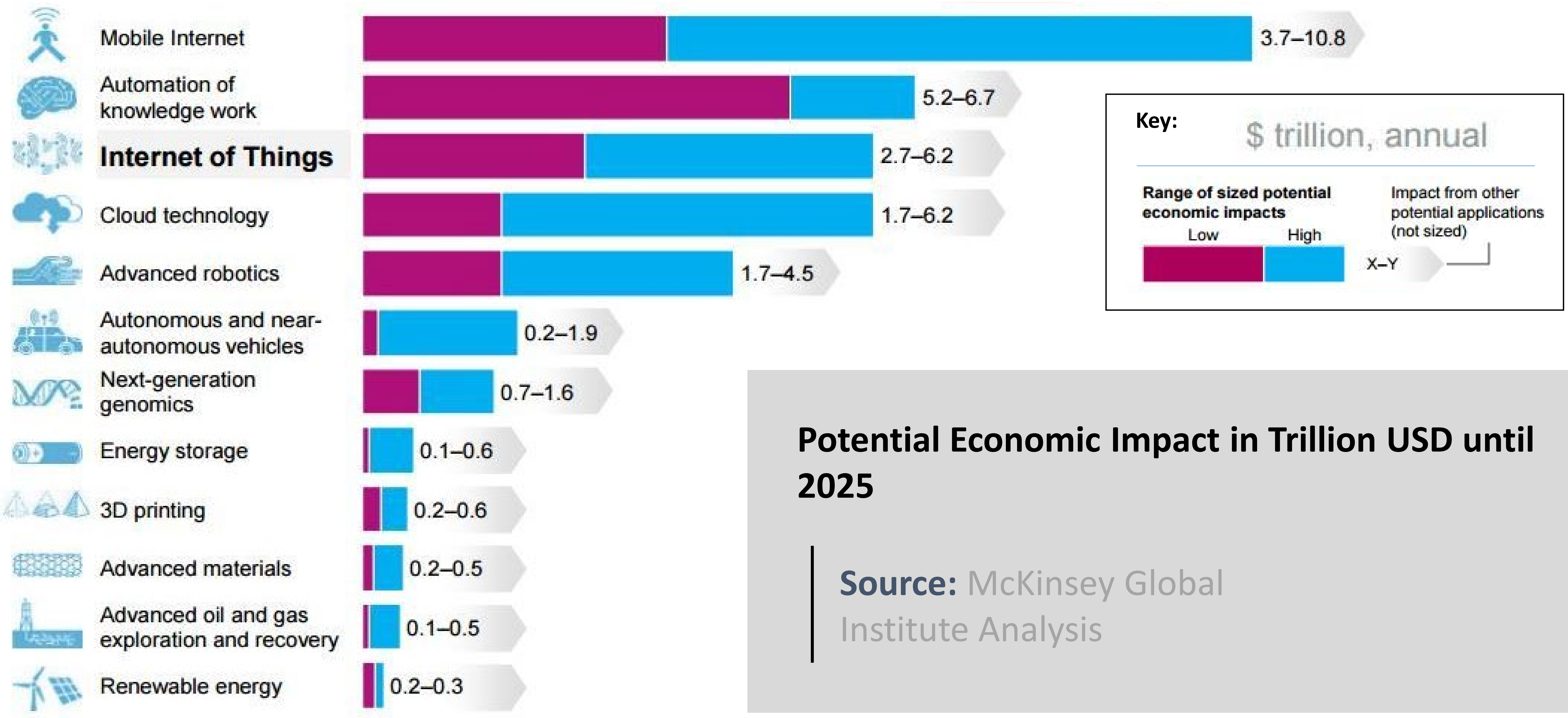
Digitalisation - Enabling Technologies

Electronic Drivers

Key Growth Areas

Economic Impact

The next 10 years will be nothing like anything we have seen



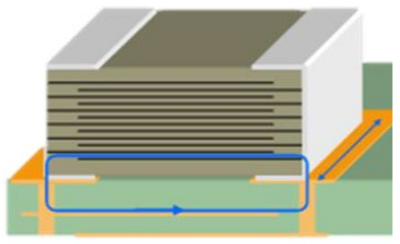
Potential Economic Impact in Trillion USD until 2025

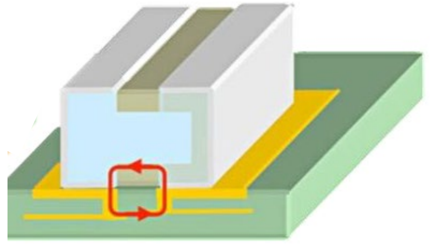
Source: McKinsey Global Institute Analysis

Semiconductor IC Development – Processors

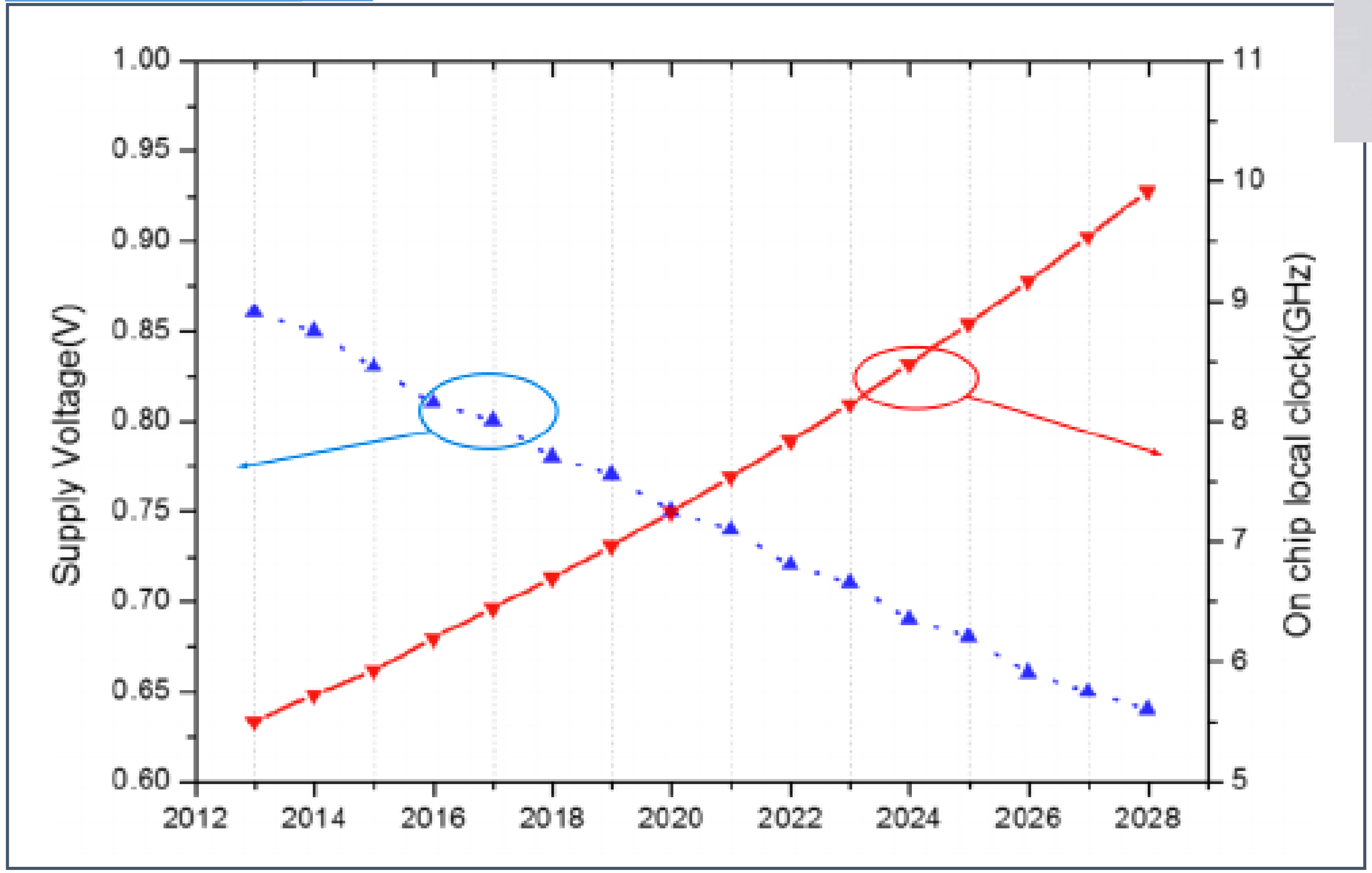
DIE SCALING HAS DROPPED IC SUPPLY VOLTAGE

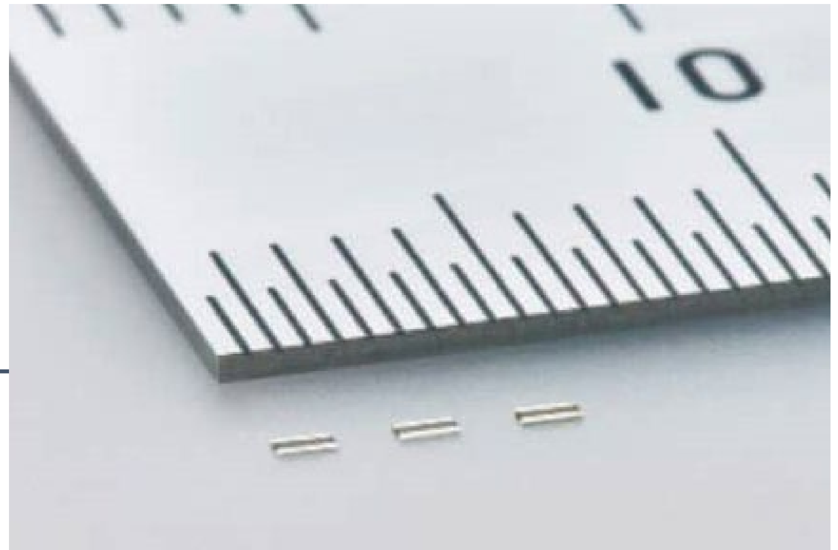
- ***Capacitors job decoupling more critical***
- ***Clock & data speeds making Di/Dt drawn larger***





Source: **ITRS**





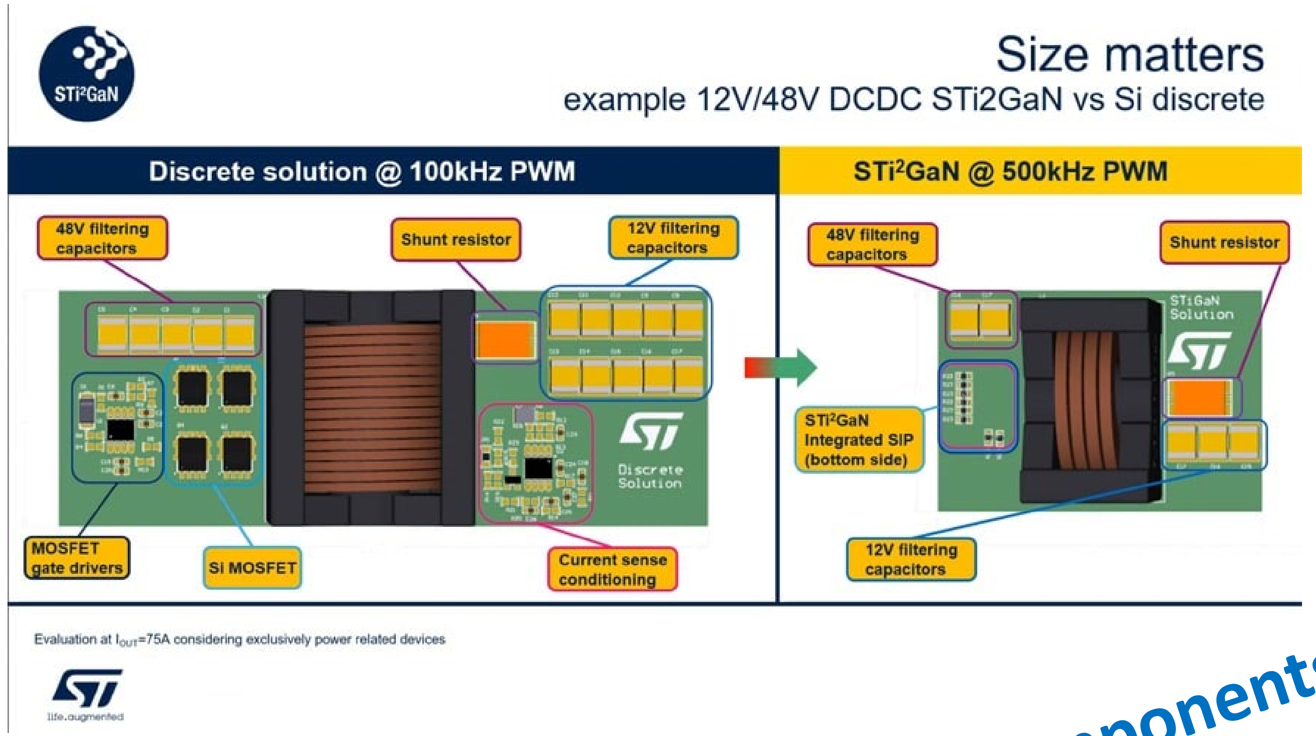
source: Tayo Yuden

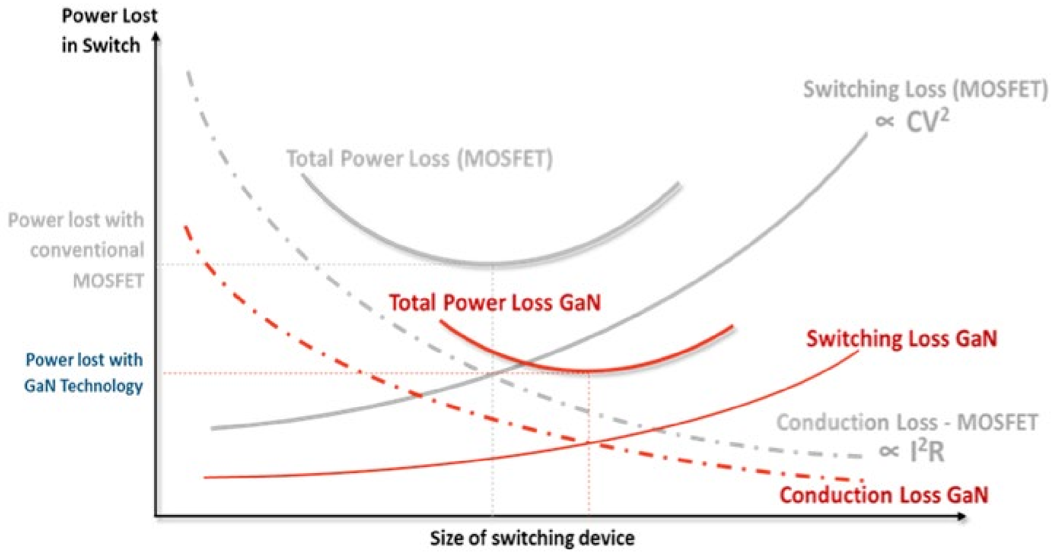
Reverse geometry MLCC 0.47uF 4V size: 0.52 x 1.0 x 0.1 mm

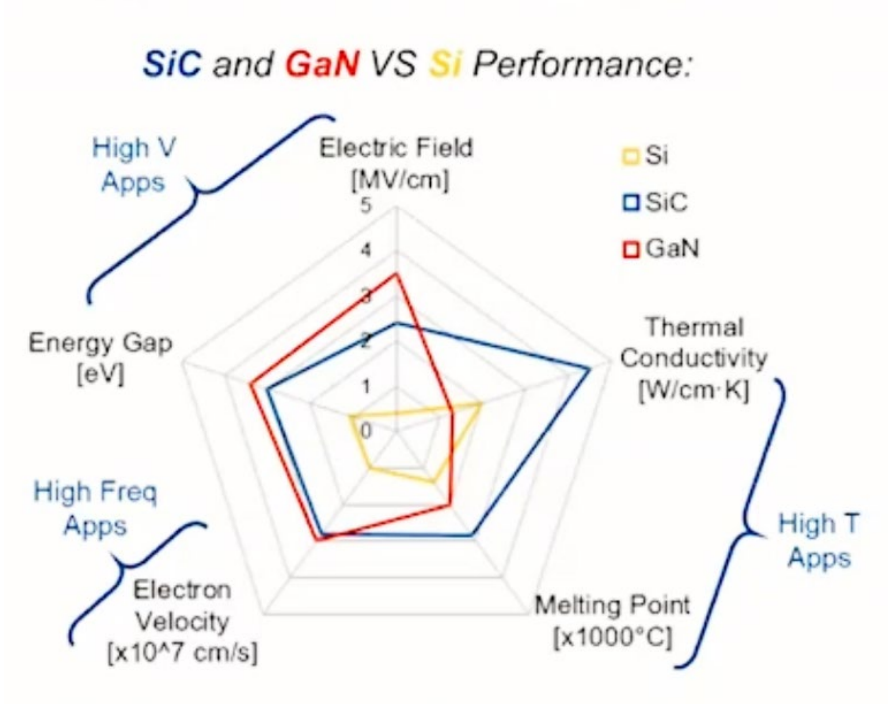
Capacitor Requirements
- Low ESL
- Low ESR
- High power
- Small Size
- Low Profile

High Power Handling & Efficiency

Semiconductor IC Development – Wide Gap GaN/SiC Transistor „Revolution“







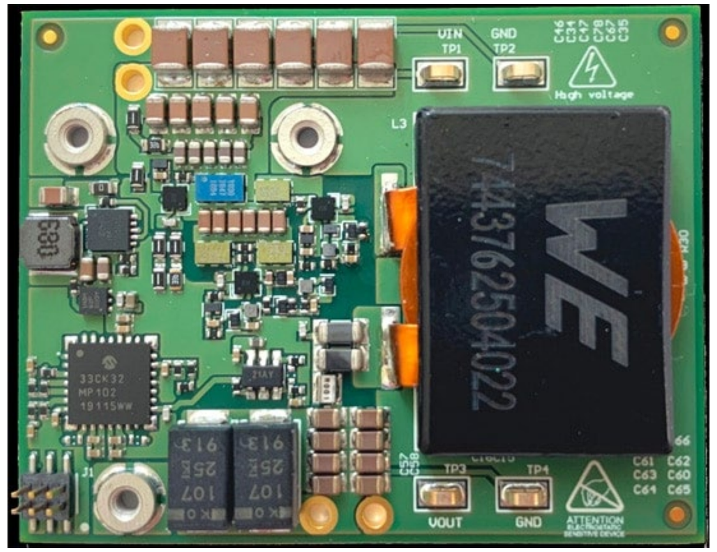
Need for Low Loss, High Power Components

Output Capacitor Changes:

- Lower ESR, High Ripple Current
- Low ESL, Higher Frequency
- Lower Capacitance Needed
- Small & Thin Profile
- Move from electrolytics to MLCC Class II or even Class I on output capacitors

New Requirements:

- Stable Gate Drive Voltage Capacitors (tantalum)
- Output low loss, high power inductors



48 V three-stage synchronous buck converter with GaN technology

Key Growth Areas

Mobile Internet / 5G

5G Key Technology Advancements

- Multiarray Antennas (MIMO) & Beamforming
- Higher Frequency

Low Latency

Low Interference

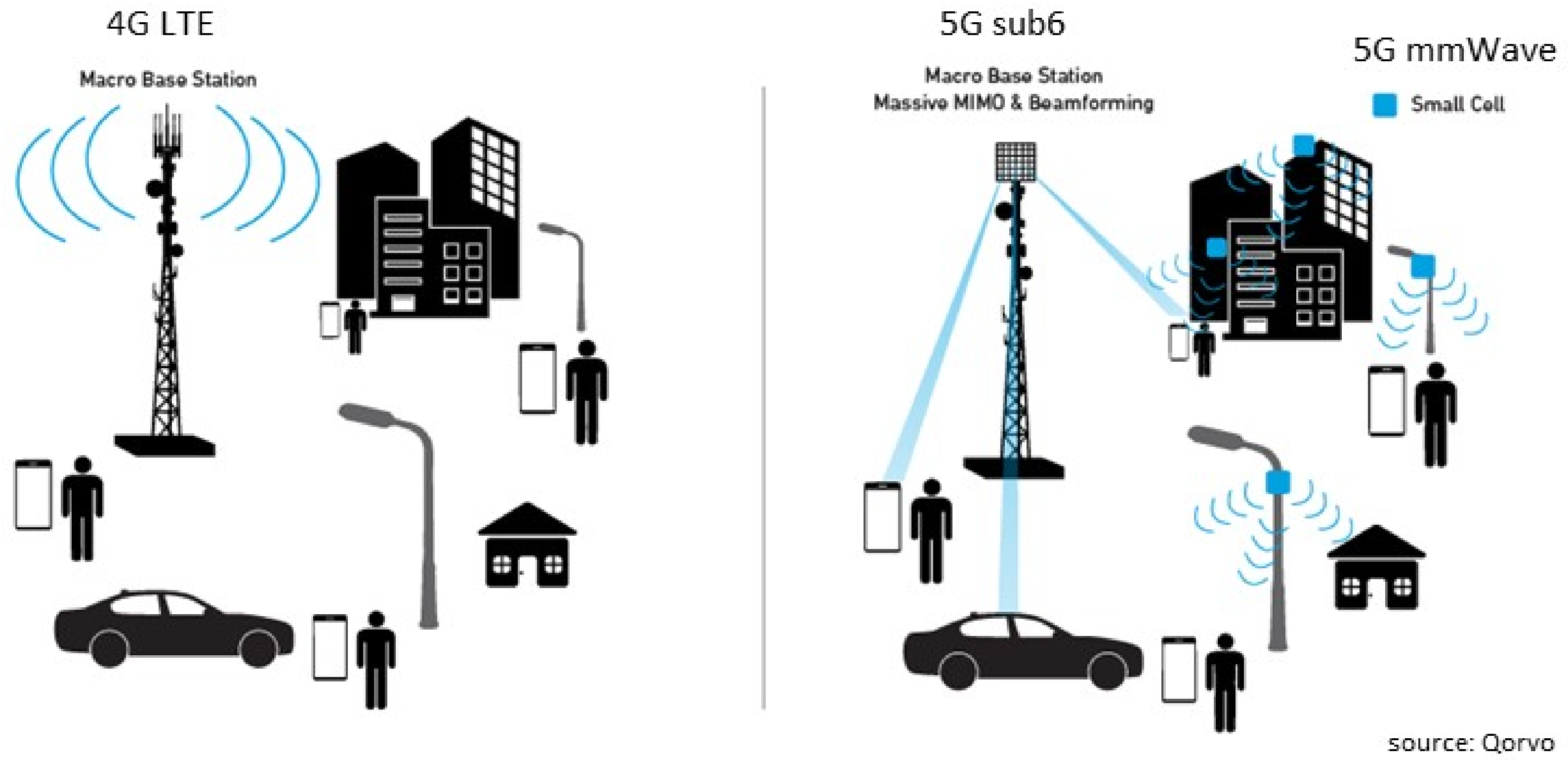
High Downlink Speed

Increase Bandwidth & Device Coverage Density

More Focused Energy & Energy Savings Potential

High Air Attenuation & Short Range

Moisture & Barriers (walls) Attenuation



! 5G Calls for New Infrastructure Architecture !

to use its potential

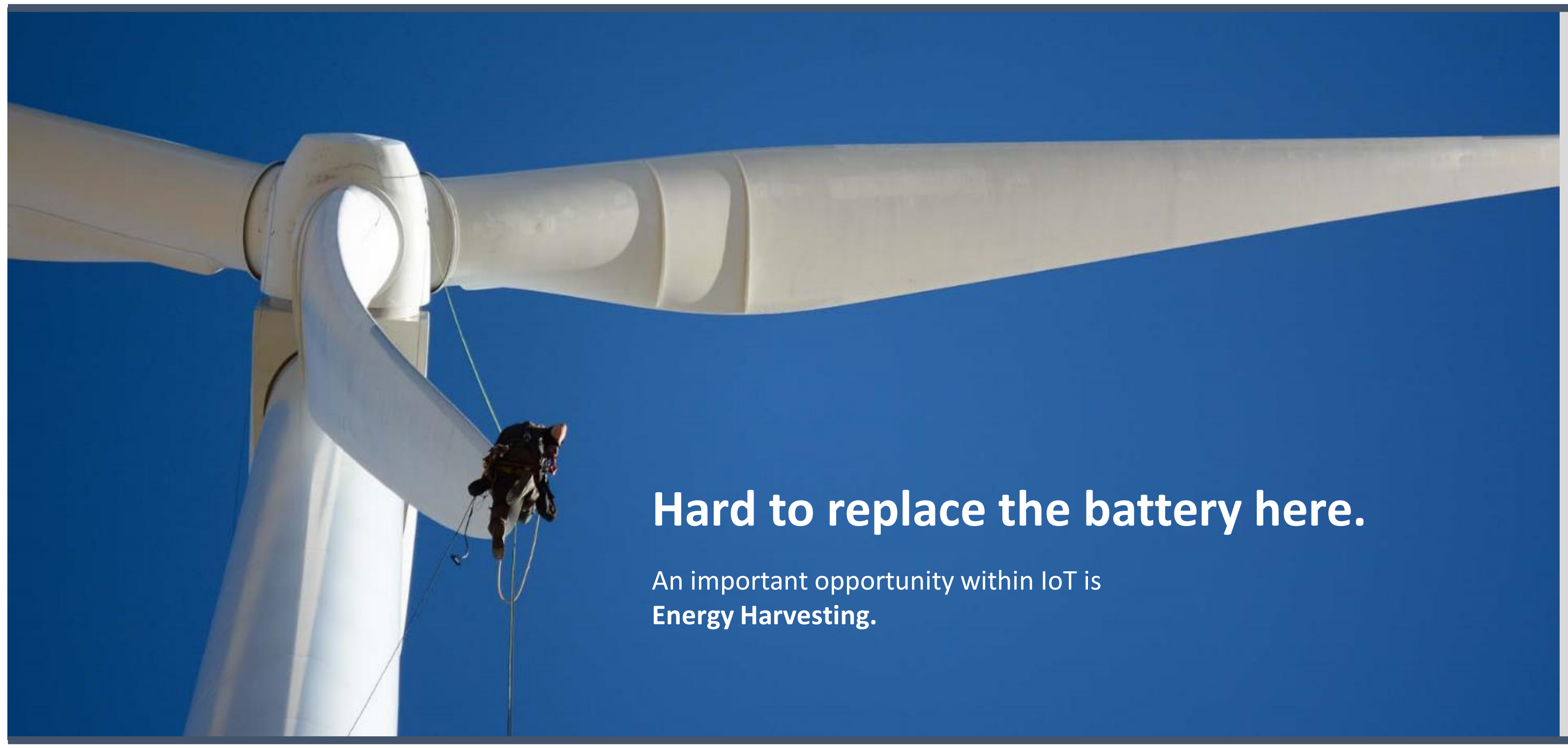
Parameter	4G	5G	
	4G LTE	5G (Sub-6G)	5G (mmWave)
Frequency	2.1GHz	2-6 GHz	6-60GHz
Downlink Speed	1.2 Gbps	6.5 Gbps	18 Gbps
Latency	10-30ms	5-6ms	< 1 ms
Average Range (from a tower)	10km	1-6km	300m
Device Coverage Density	1 million devices per 500km^2	1 million devices per 100km^2	1 million devices per 1km^2
Implementation	Macro Base Stations	Macro Base Stations	Micro Base Stations & Small Cells

5G network will consist macro base station at 5G sub 6GHz (in combination with existing 4G) covering larger areas and 5G mmWave micro base stations and small cells to provide high speed hot spots

Key Growth Areas

IoT

IoT / Industry 4.0 will drive energy harvesting methods, circuits & modules in wide range of applications – consumer, medical, industrial …



IoT Allows:

24/7 remote monitoring of anything

IoT Will Drive Passive Components Volumes

Key Growth Areas

Automotive

Heterogenous Vehicle Connectivity

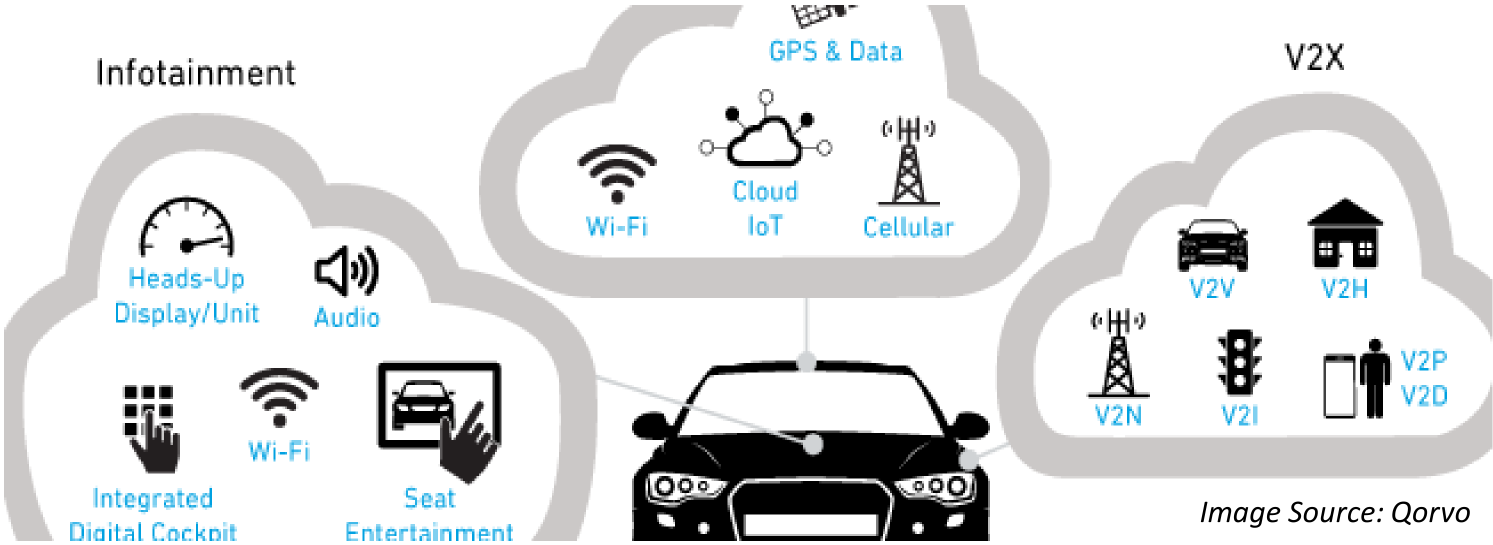
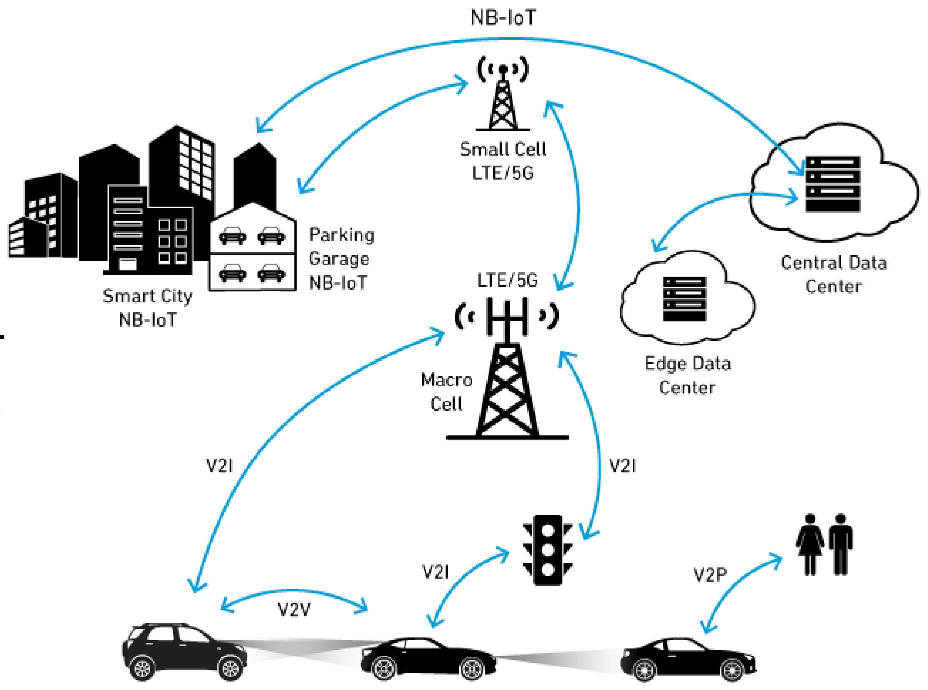


Image Source: Qorvo

V2X Communication

- Fast real time reaction required - can not rely on external network
- Too much latency is intolerable
- 5G etc use as a support in low latency mode
- V2V may become the critical communication



The Amount of Data in an Autonomous Vehicle
> 4,000 GB Per Day

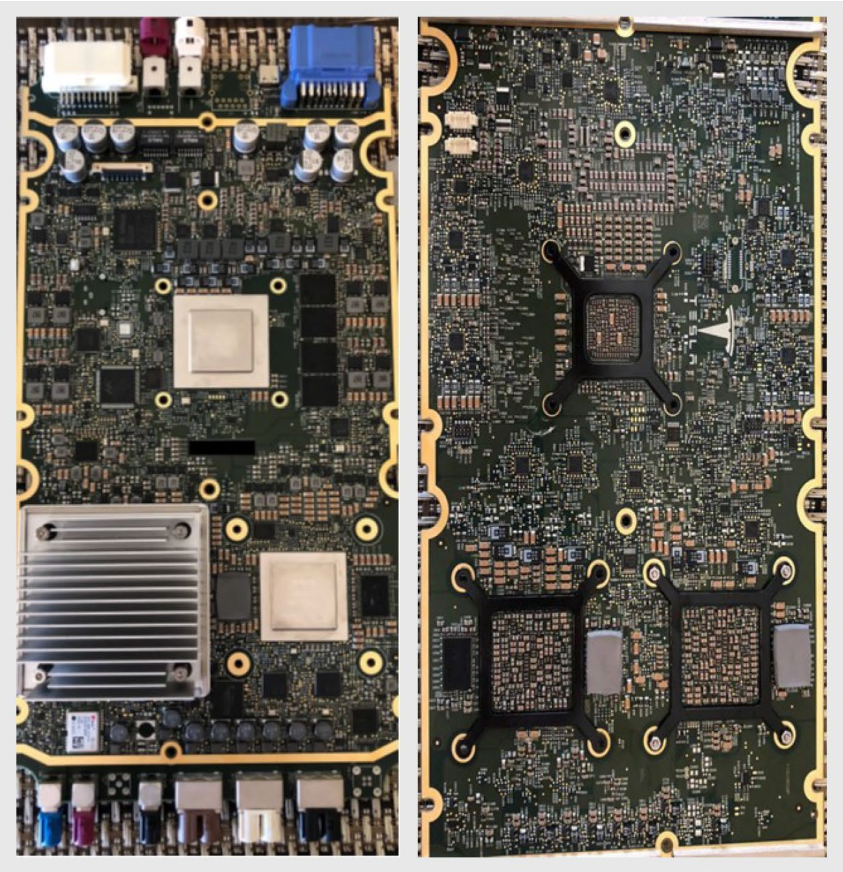
- Connected Car is becoming the prime IoT connected device with higher bit rate then smartphone

Interactive Cabine

- Focal Point of AI and human interface

Each Vehicle is becoming

- It is own cloud
- Large cloud data center
- **High power computing center**



Tesla Autopilot Computer Board Model 3,S,X

Key Growth Areas

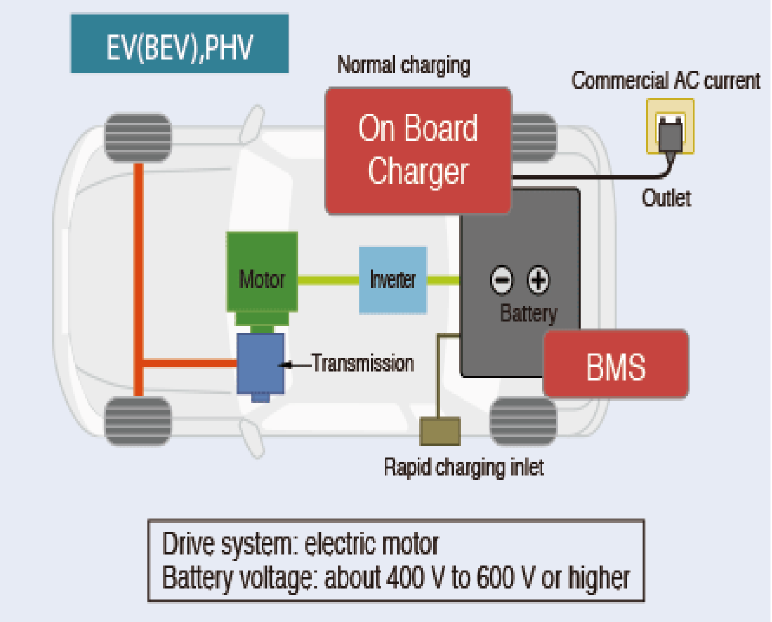
High Power Handling & Efficiency

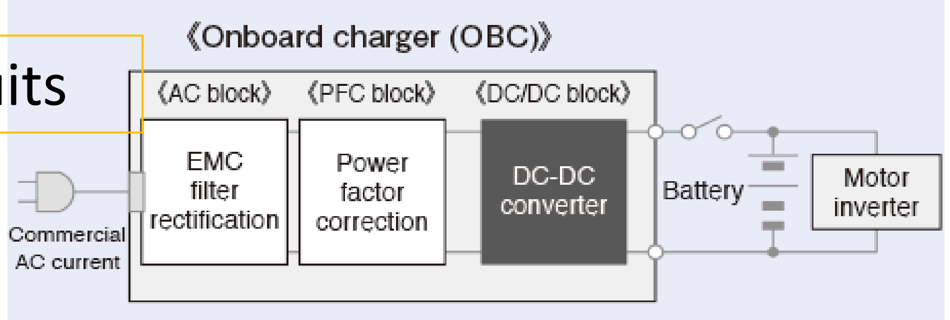
Automotive

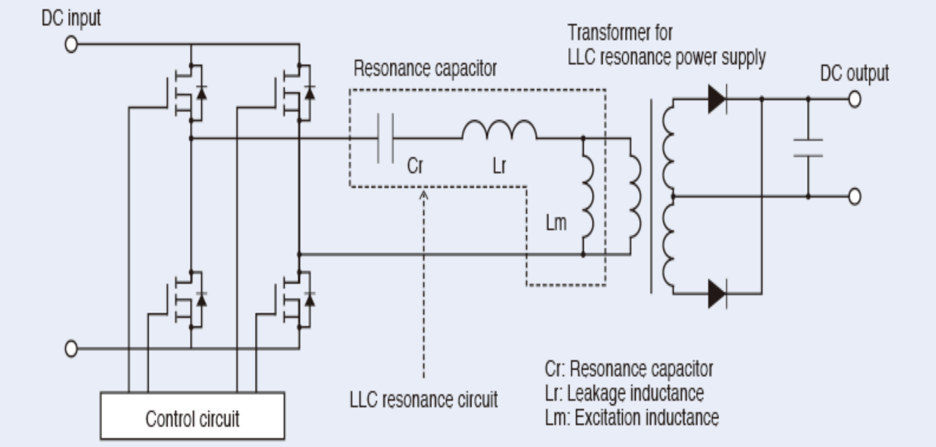
New Arrival Lamborghini Sián
first supercapacitor-based
hybrid V12

Lamborghini supercapacitors Terzo Millennio.
4 electric motors powered by supercapacitors as its energy storage devices located on body panels

LLC Resonant Low Loss Circuits

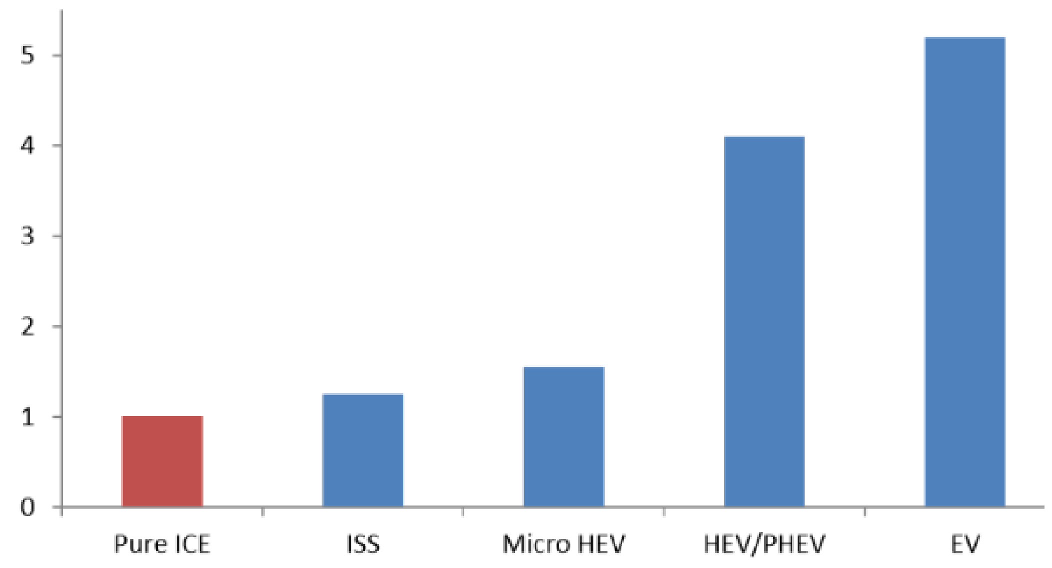




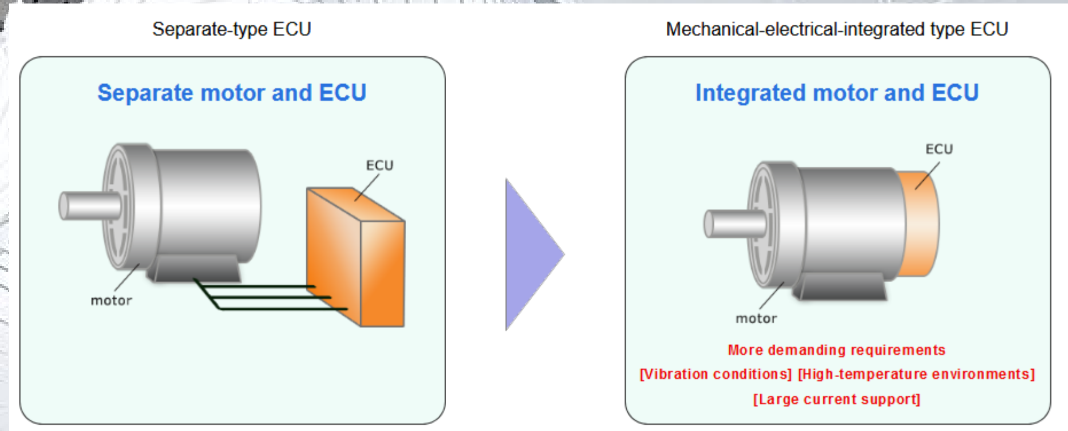


EV/HEV Integrated Power
eMotor, Transmission, Electronics

MLCC content by power train (number of Pure ICE=1)



- More Components
- Smaller & Higher Temperature
- Higher Voltage & Power
- Component Selection Changes
- New Applications
- New Technologies

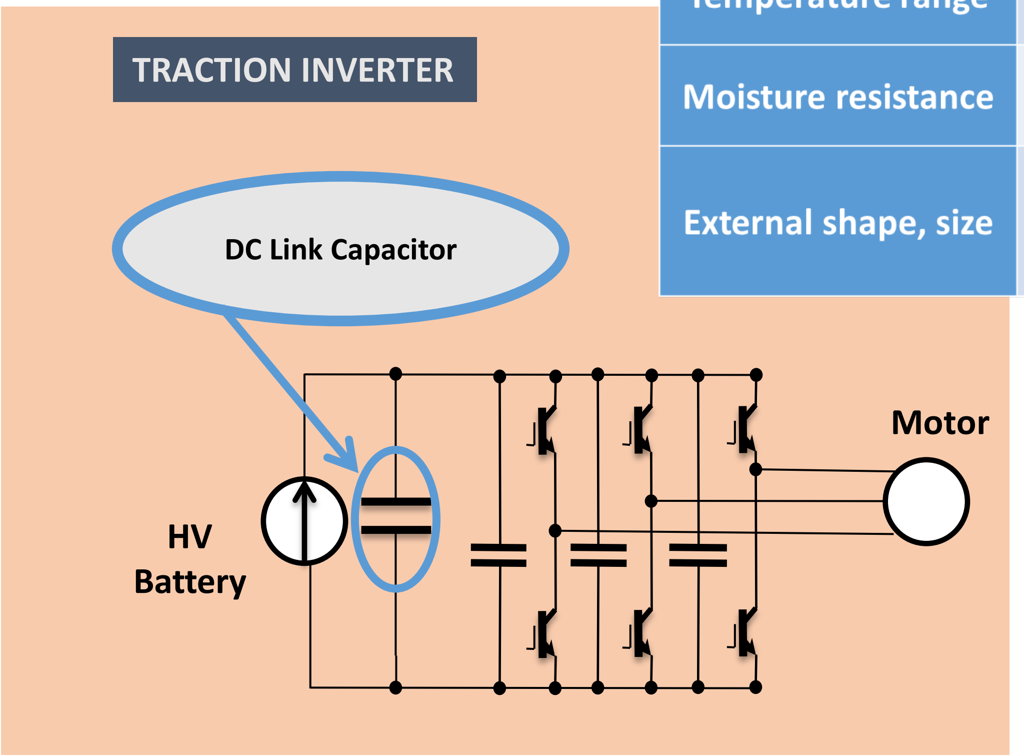


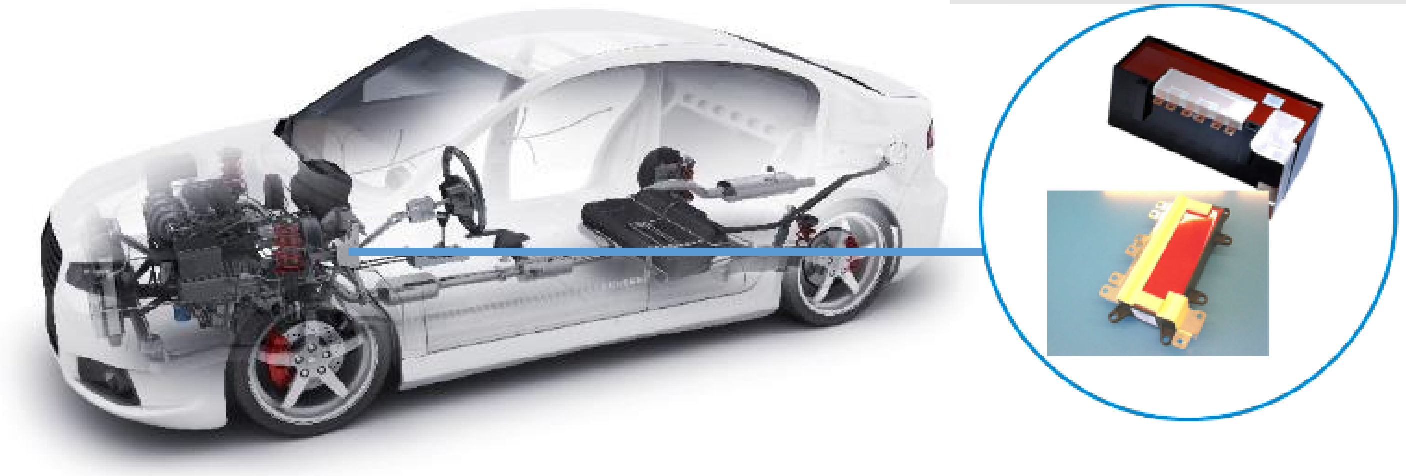
Source: Bosch Mobility Solutions, TTI, TDK, Lamborghini, Panasonic

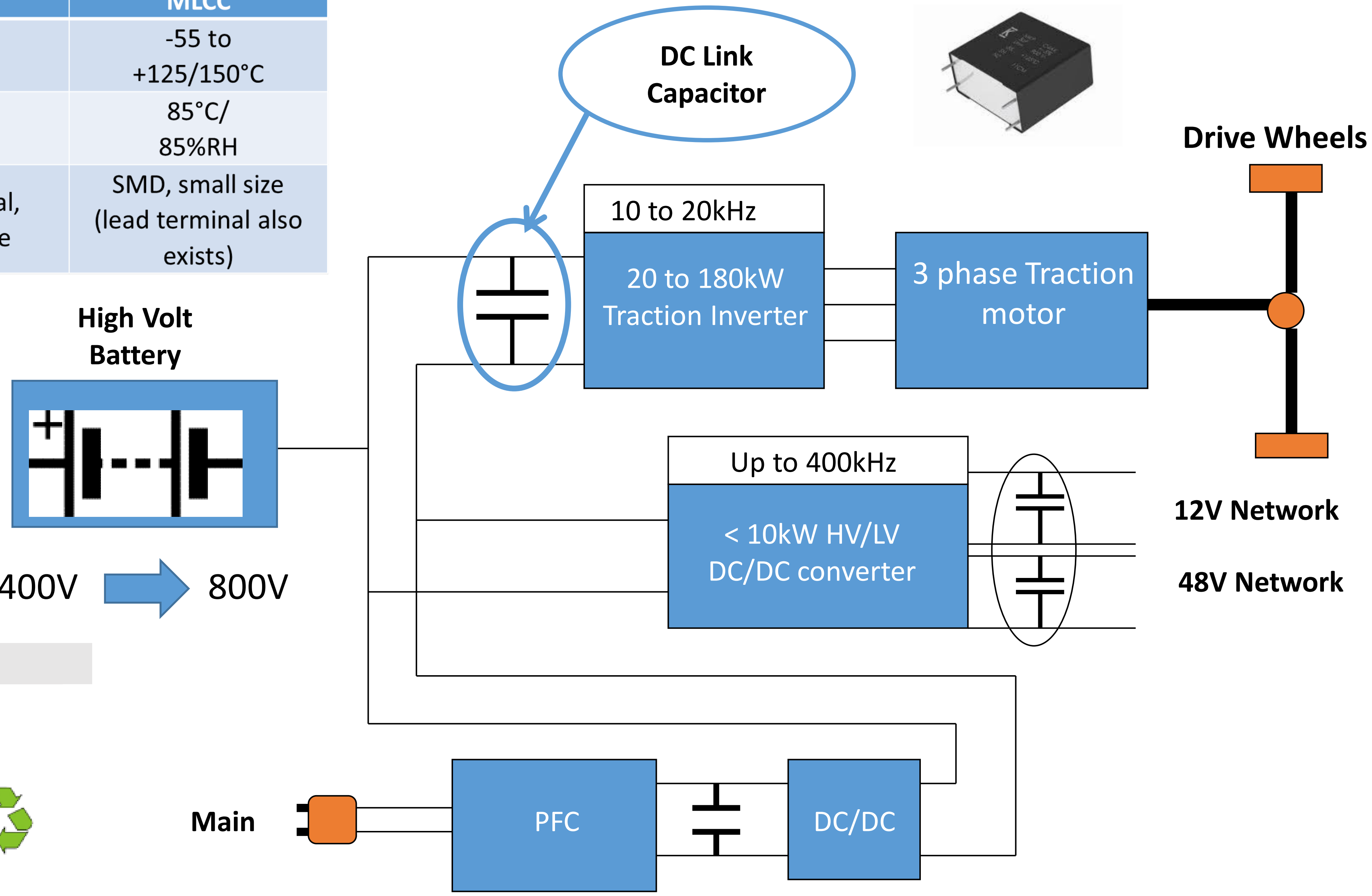
EV/HEV Traction Chain

power film DC-Link capacitor designed for continuous operation up **to 1,000 hours at 135℃**

	Film capacitor A (PP)	Film capacitor B (PP)	C0G / NP0 MLCC
Temperature range	-40 to +105°C	-55 to +135°C	-55 to +125/150°C
Moisture resistance	40°C/ 95%RH	60°C/ 95%RH	85°C/ 85%RH
External shape, size	Lead terminal, large size	Lead terminal, Medium size	SMD, small size (lead terminal also exists)







Key Growth Areas

Automotive

High Power Switching & High Processing Power & Lowering of Processor Voltage

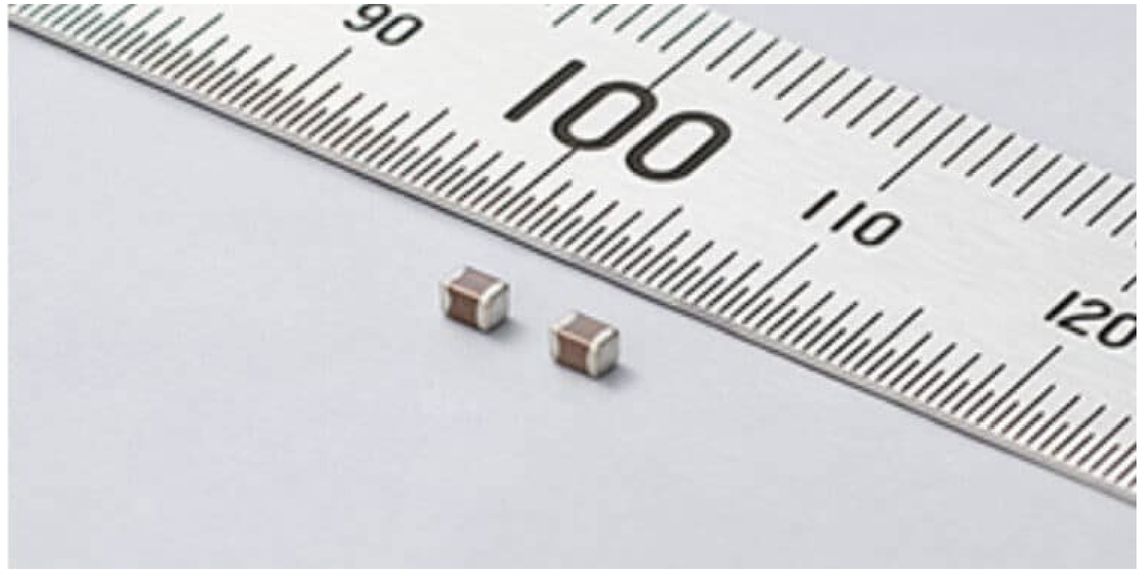
NOISE SUPPRESSION & EMC SHIELDING CHALLENGES

CAN-FD high speed, high accuracy miniature ceramic resonators

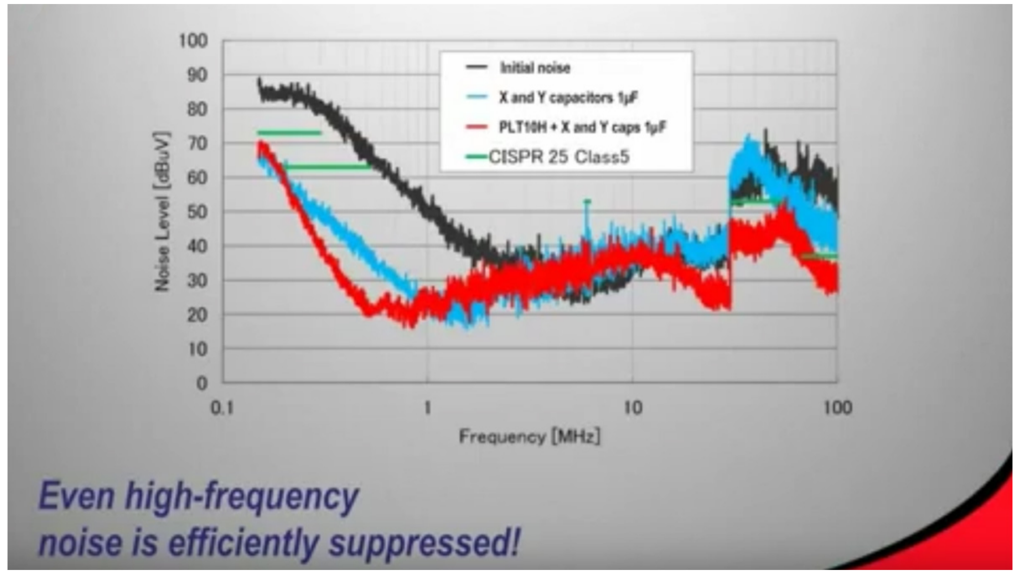
High Speed Data Transmition
- **Integration & Miniaturization** of detection sensors (cameras, LIDAR, radar, etc…)
- **Power Over Coax** for image data transmission combines data and power transmission over a single coaxial line to reduce the amount of cable

Noise suppression by high current common (500mA) mode chokes in miniature 0201 case size

MLCC 10uF/25V in 2012 case size for 12V line smoothing applications in automobiles



Impact of safety capacitors and common mode choke to EMI suppression effectiveness



source: Murata; passive-components.eu

Key Growth Areas – Consequences for Passives Manufacturers

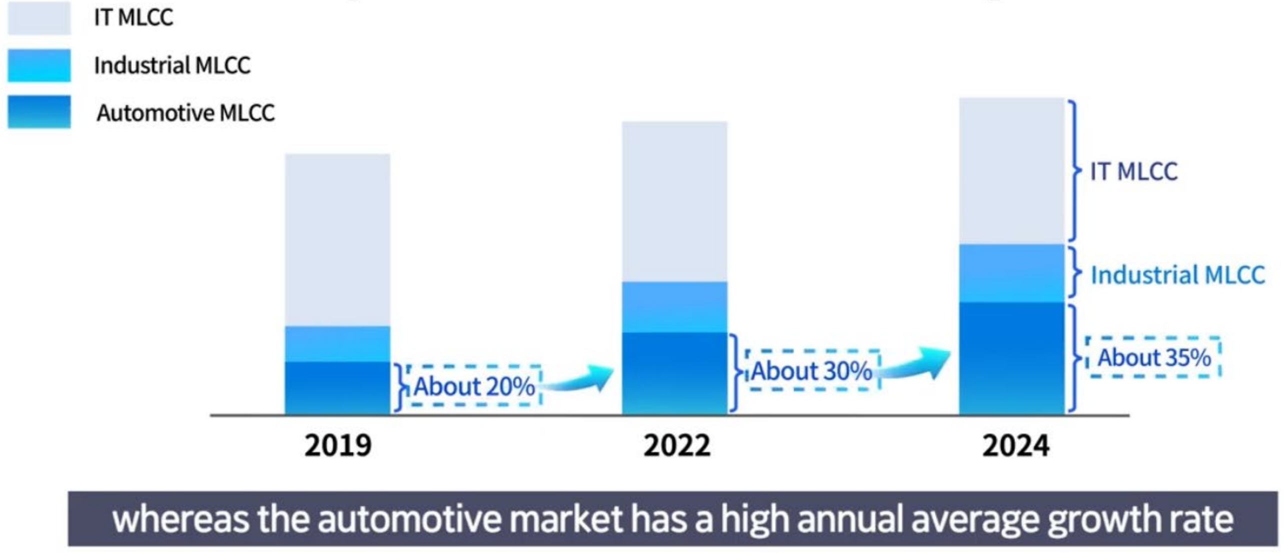
Worldwide Electronic System Production by System Type ($B)

System Type	16	17	17/16 %	18F	18/17 %	19F	19/18 %	17-21 CAGR
Communications	460	490	6.5%	515	5.1%	535	3.9%	4.8%
Computer*	387	404	4.4%	418	3.5%	427	2.2%	3.3%
Ind/Med/Other	210	223	6.2%	236	5.8%	245	3.8%	5.4%
Consumer	174	185	6.3%	197	6.5%	204	3.6%	4.5%
Automotive	131	142	8.4%	152	7.0%	162	6.3%	6.4%
Gov/Military	95	99	4.2%	104	5.1%	107	2.9%	3.8%
Total	1,457	1,543	5.9%	1,622	5.1%	1,680	3.5%	4.6%

*Includes tablet PCs.

Source: IC Insights

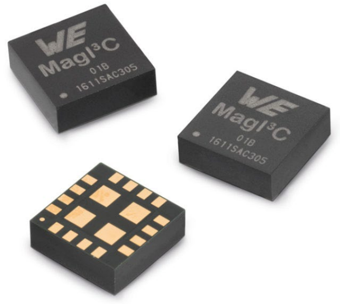
[Outlook for MLCC Market Size]



- Fast growth of digitalisation based services cause an exponential growth of data **communication**
- Need for high speed data processing, computing power, wireless **communication** and storage
- **Automotive** are projected as the fastest growing electronics systems segment

- Passives manufacturers are shifting **focus** from computers, handsets and tablets **to automotive, and telecommunications** as the growths in these new sectors are higher than the traditional consumer electronics markets

- The supply chain management trend is that passive component makers are more and more concentrating on development of **module solutions rather than development of individual components**.



AUTOMOTIVE AEC-Q200 IS BECOMING INDUSTRY „UNIVERSAL“ QUALIFICATION STANDARD

MATERIALS

“The Next Decade on Passive Components will be about Reliability, Sustainability & Materials”

PCNS Passive Components Networking Symposium, September 2021, Milano, Italy
www.pcns.events www.passive-components.eu

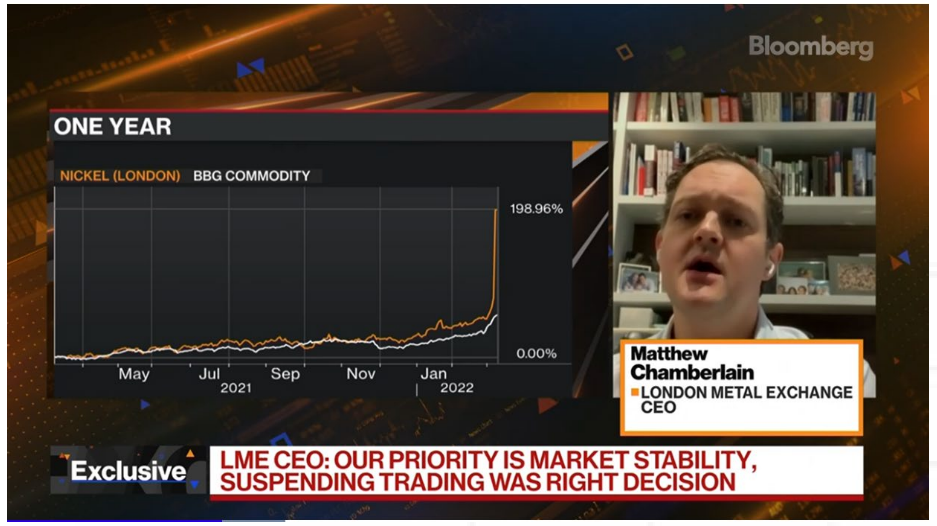
Materials

materials are becoming the central point for many aspects of future component designs

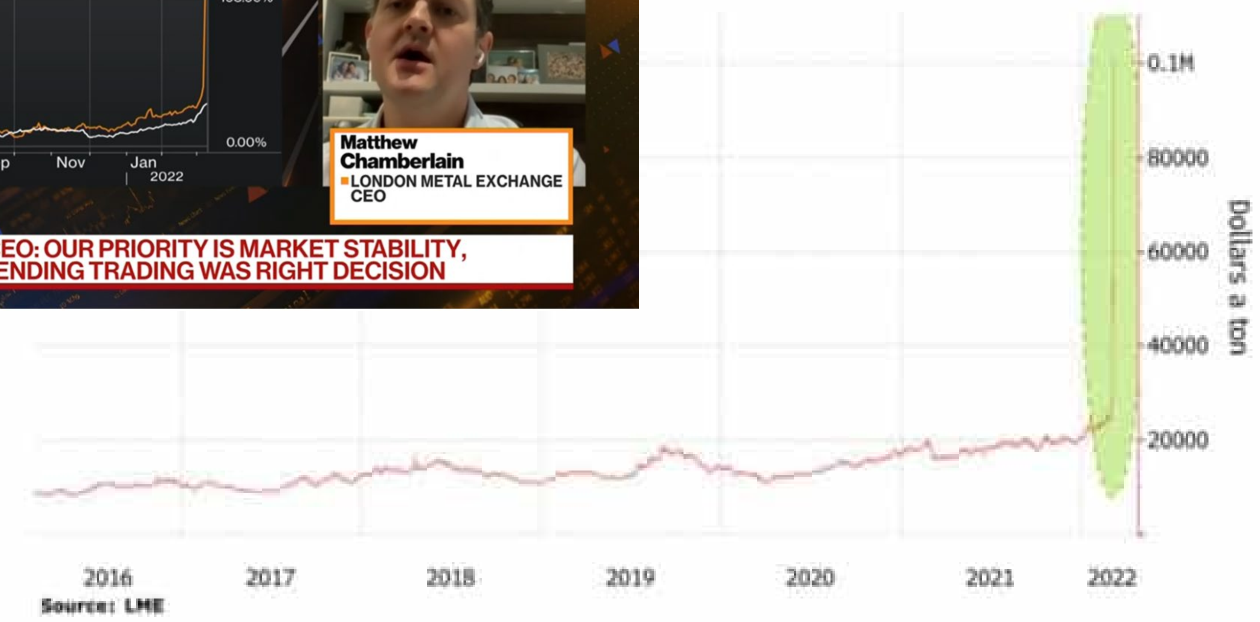
(i) **complete supply chain** and material selection evaluation in order to assess its critical chain, complete life cycle and reduce its environmental footprint.
(ii) understanding of material properties, **its basic physics mechanisms** are the key for failure mechanisms assessment and reliability predictions
(iii) **nano-material science** may yield in development of completely new generation of modern dielectric materials

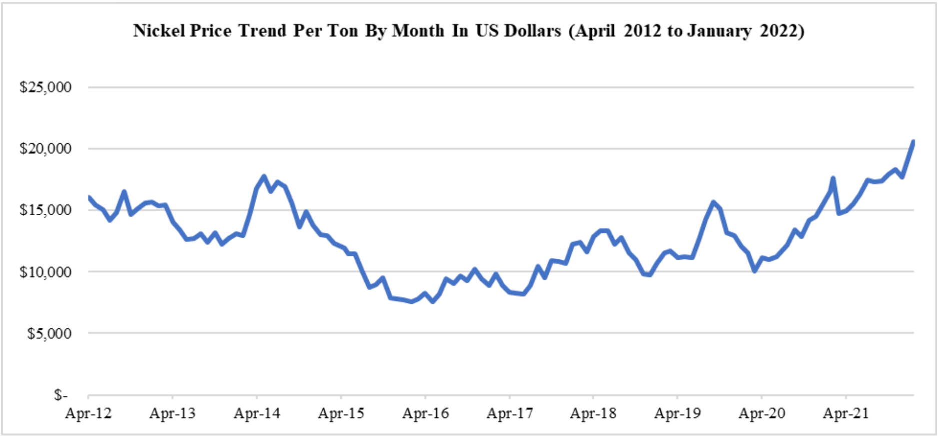
Are We Entering Critical Material Supply Chain Battle Era ?

LME Halts Nickel Trading After Unprecedented 250% Spike



Nickel Price 8th March



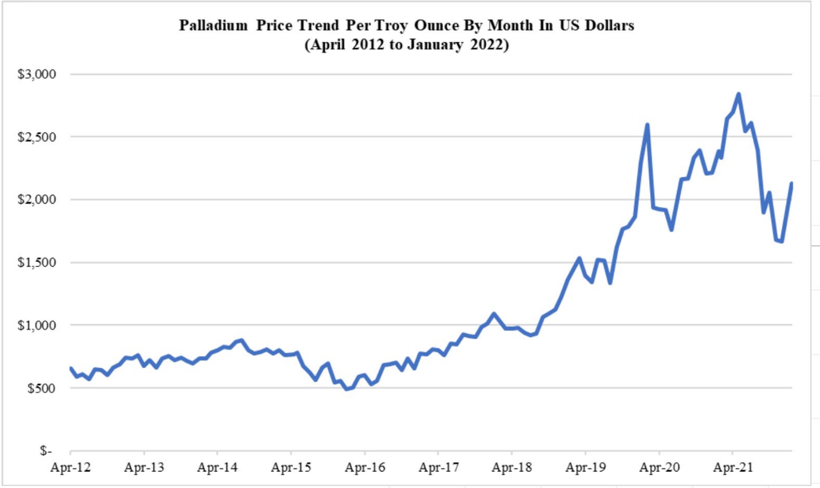


Russia supplies over 40% of the world's supply of palladium and 17% of the world's top-grade nickel.

The price of palladium, has risen over 50% since the invasion, but there are a number of South African suppliers like Impala Platinum, Northam Platinum, Sibanye-Stillwater and Anglo-American Platinum.

Nickel experienced unprecedented spike on March 8th, 2022 as the impact of Russia-Ukrain war and speculations. LME halted its trade for few days.

Palladium Price 9th March



Material Supply Chain Evaluation and Managements Has to Become Critical Element of Component Designs

Source: Paumanok, LME

Electronic Components – Sustainability

17 United Nations´ Sustainable Development Goals

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015

More information: https://sdgs.un.org/goals

Set of Regional Requirements & Standards

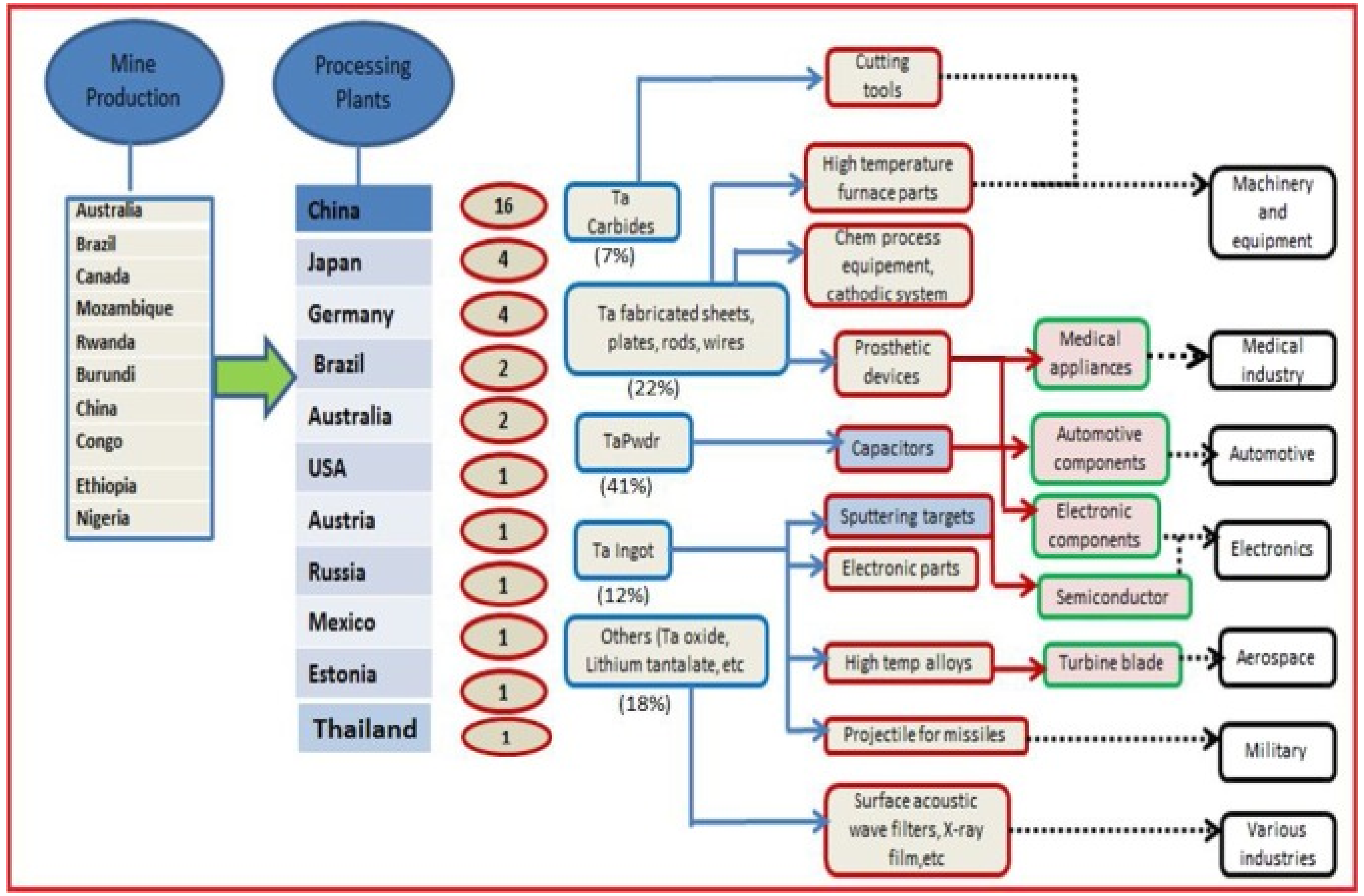
- RoHS
- WEEE
- REACH
- Conflict Minerals
- Environmental Management
- Life-Cycle Assessment
- ….

Sustainability & Conflict-Free Materials

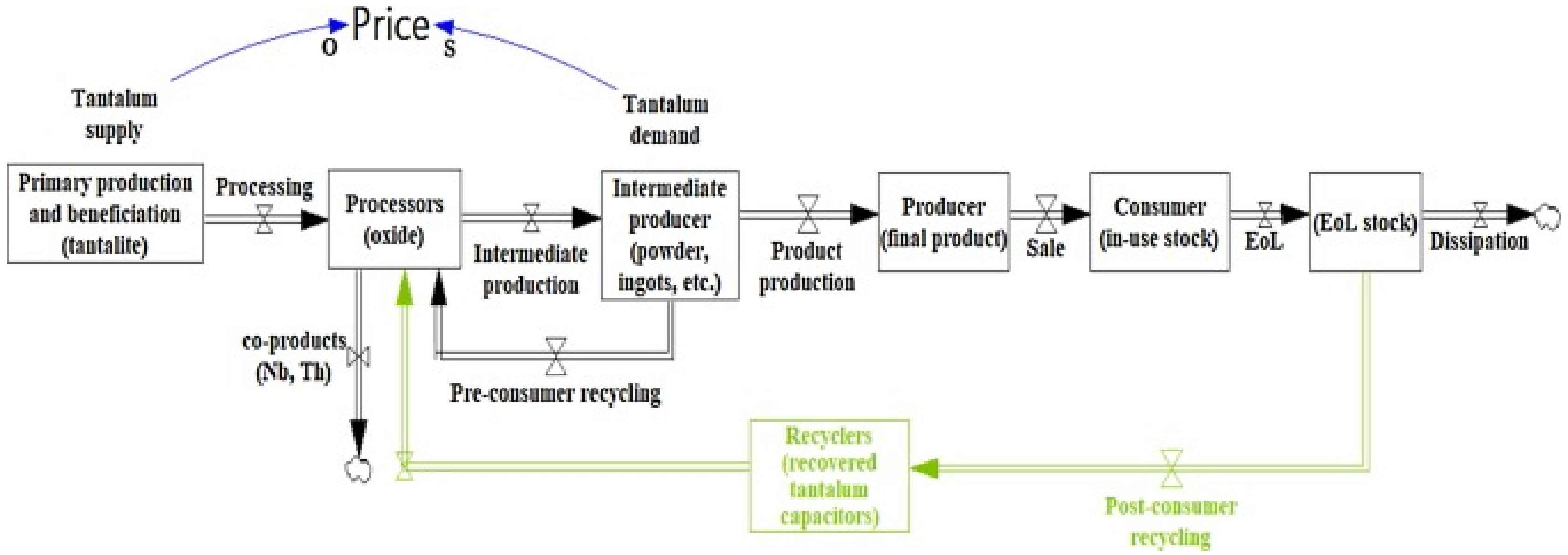
Tantalum Capacitors – Conflict-free Supply Chain Case Study

Gold
Tin
Tungsten
Tantalum

- Tantalum sourced from Congo is listed as a conflict mineral
- Tantalum capacitor manufacturers (AVX, KEMET) actively participated to establish conflict-free supply chain (~ "fair trade coffee") with international authorities including recycling

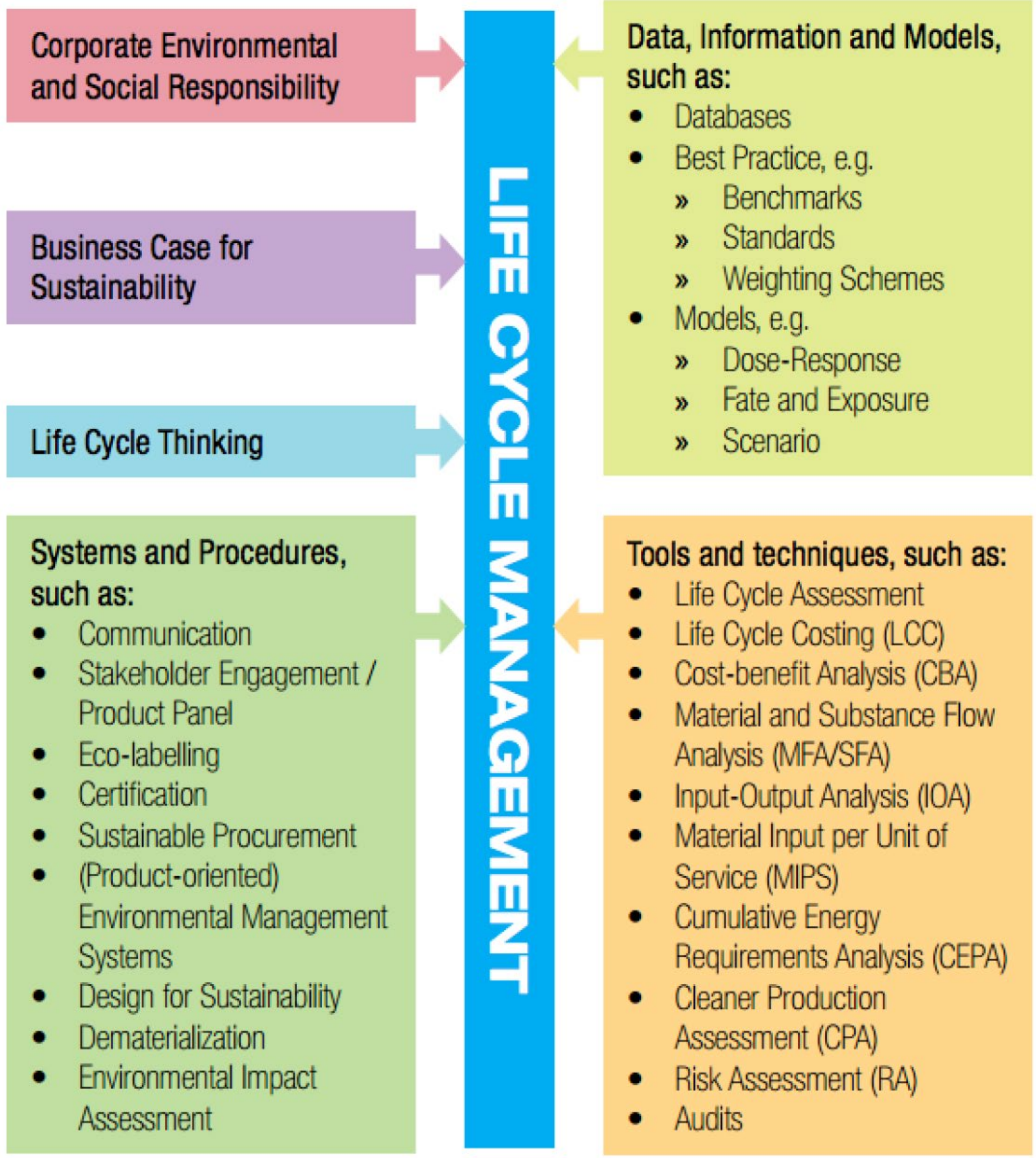


Tantalum supply chain across upstream and downstream industries; source: T.I.C. Tantalum-Niobium International Study Center tanb.org



Tantalum supply chain flow; source: T.I.C.

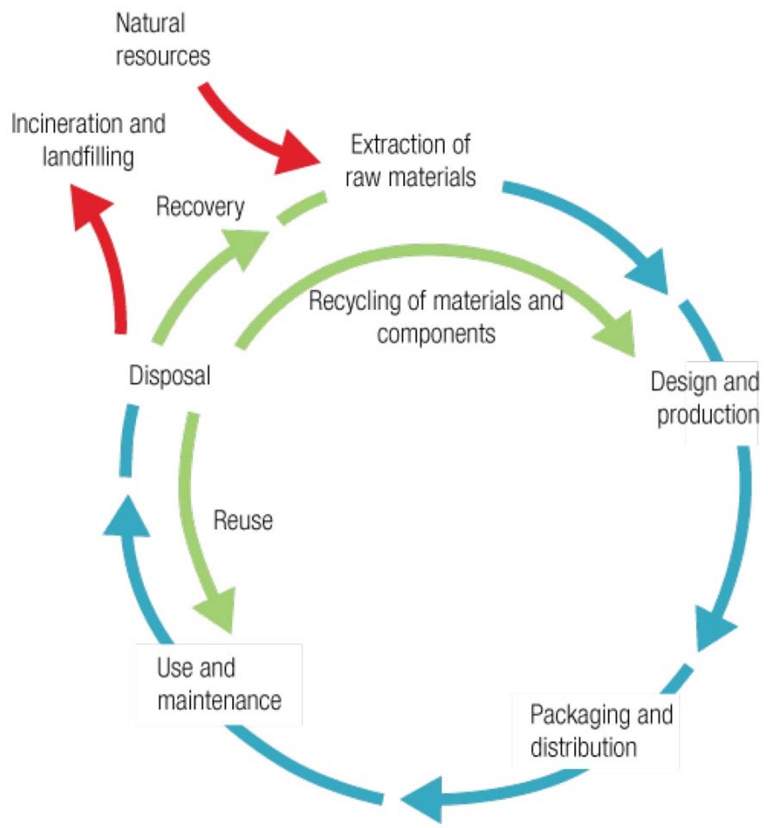
Sustainability & Life Cycle Management



Source: UNEP/SETAC. Life Cycle Management: A Business Guide to Sustainability. Paris, 2007.

Life Cycle Management (LCM) is an integrated concept for managing the total life cycle of goods and services toward a more sustainable production and consumption

…. LCM uses various procedural and analytical tools for different applications and integrates economic, social, and environmental aspects into an institutional context



*Life Cycle Thinking is about going beyond the traditional focus on production site and manufacturing processes to include **environmental, social and economic impacts of a product over its entire life cycle***

Sustainability & Life Cycle Assessment

Pears grown in Argentina, packed in Thailand, sold in USA

Life sustainability – Life Cycle Assessment including environmental fingerprint & recycling may be the next complex challenge that may drive selection of new materials, processes or re-design of current products.

EU Legislation 2019 EN 50693 common rules for:

- life cycle assessment (LCA)
- LCA report
- development of product specific rules

ISO 14001 are an integral part of the European Union's Eco-Management and Audit Scheme (EMAS)

- **ISO 14040:2006** - Environmental Management -Life Cycle Assessment -Principles And Framework
- **ASQ/ANSI/ISO 14044:2006** - Environmental Management -Life Cycle Assessment -Requirements And Guidelines
- **ISO/TS 14071:2014** - Environmental Management -Life Cycle Assessment -Critical Review Processes And Reviewer Competencies: Additional Requirements And Guidelines To ISO 14044:2006
- **ISO/TS 14072:2014** - Environmental Management -Life Cycle Assessment -Requirements And Guidelines For Organizational Life Cycle Assessment

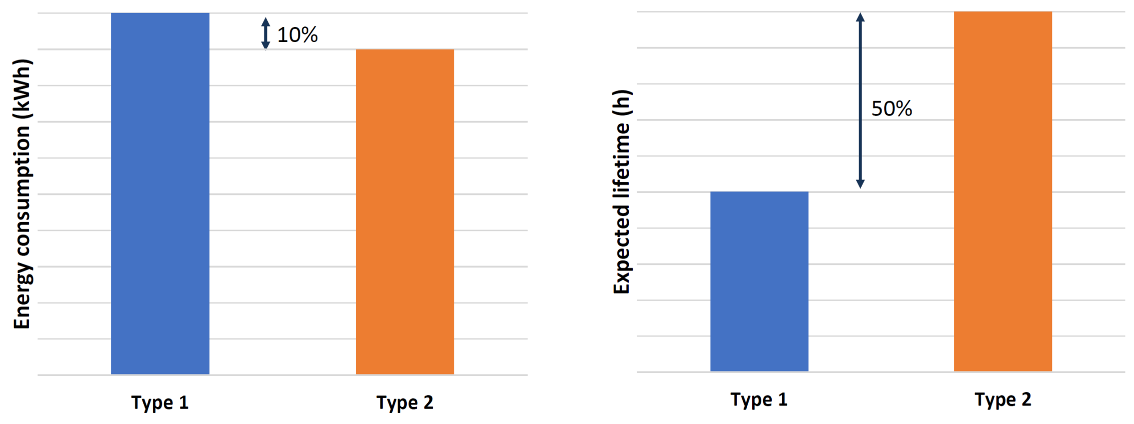
Capacitors Life Assessment Case Study: Aluminum Capacitor Technology

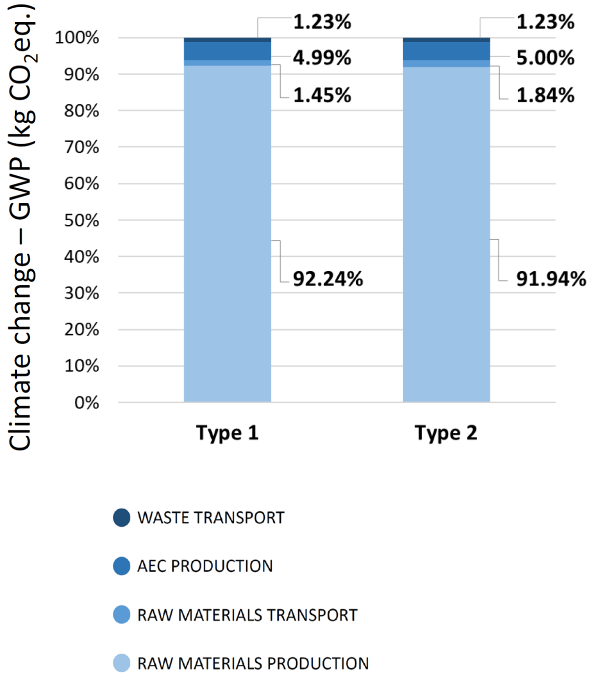
Target: Evaluation of Environmental Impact and Critical Raw Material Usage of Two Aluminum Electrolytic Capacitor with Different Electrolyte Types

EN 50693:2019

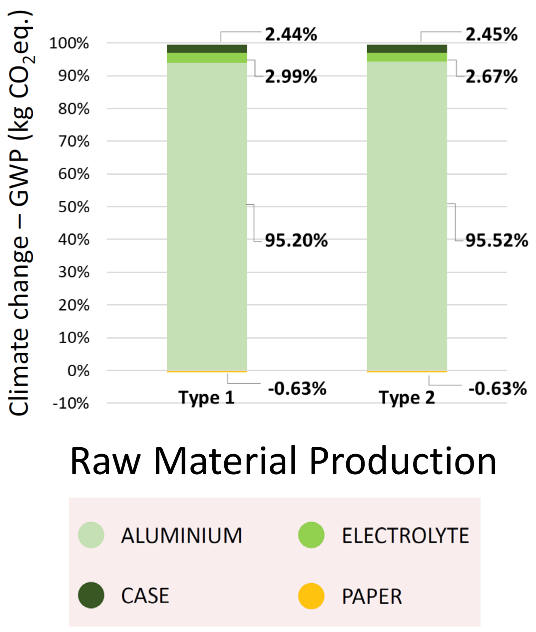
MANUFACTURING STAGE	DISTRIBUTION STAGE	USE STAGE	END-OF-LIFE STAGE
Acquisition of raw materials	Transport	Use	De-installation
Transport of raw materials	**INSTALLATION STAGE**	Maintenance	Collection and transport
Manufacturing and packaging	Installation	Treatment of generated waste	Treatment of generated waste
Treatment of generated waste	Treatment of generated waste		

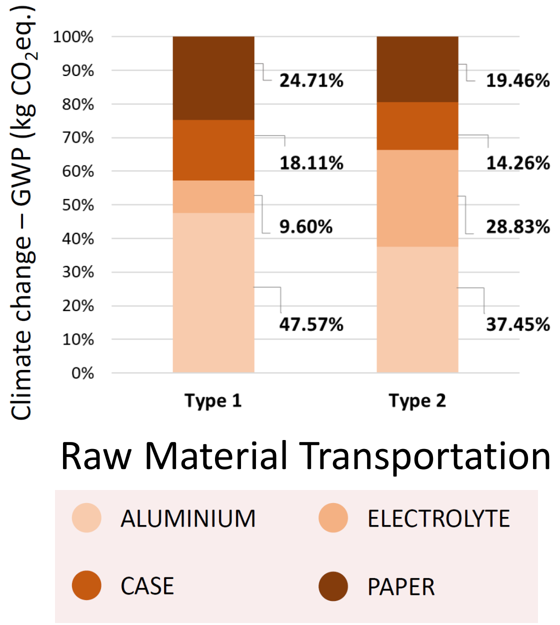
Use Stage





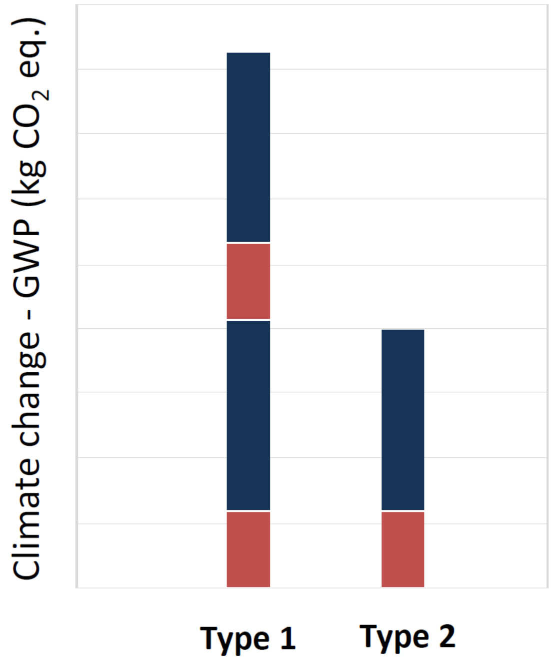
Manufacturing Stage Global Warming Potential





RESULTS

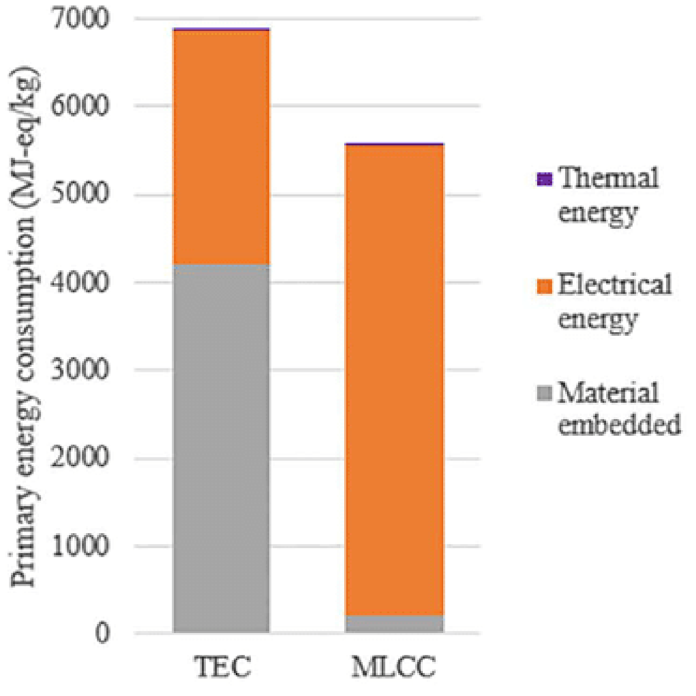
- minor differences in GWP between the electrolyte types
- the environmental impact is then driven by limited lifetime of Type 1
  - two Type 1 capacitors needed to replace Type 2 at given lifetime
  - + replacement / maintenance cost



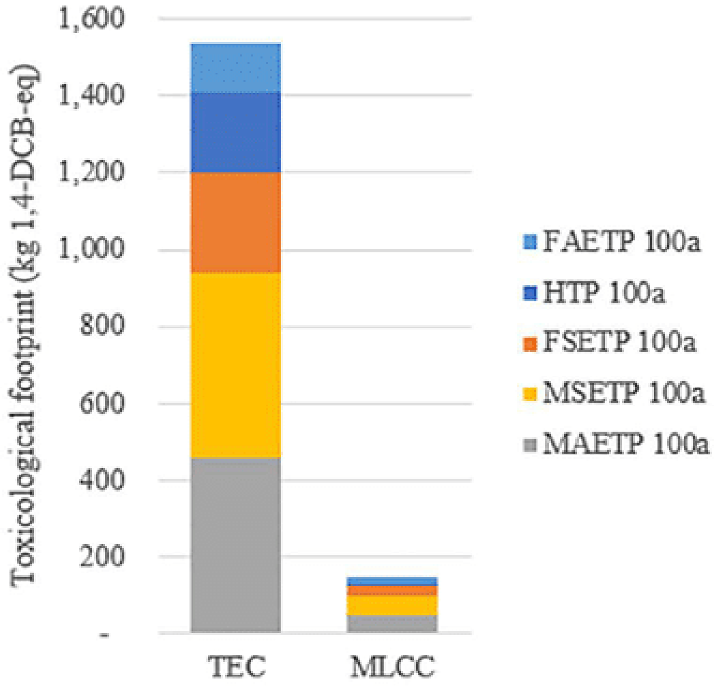
Source: Comparative Life Cycle Assessment of aluminium electrolytic capacitors; Chiara Moletti; Politecnico di Milano; Italy PCNS Symposium 2021
https://passive-components.eu/comparative-life-cycle-assessment-of-aluminum-electrolytic-capacitors/

Capacitors Life Assessment Case Study: Tantalum vs MLCC Capacitors

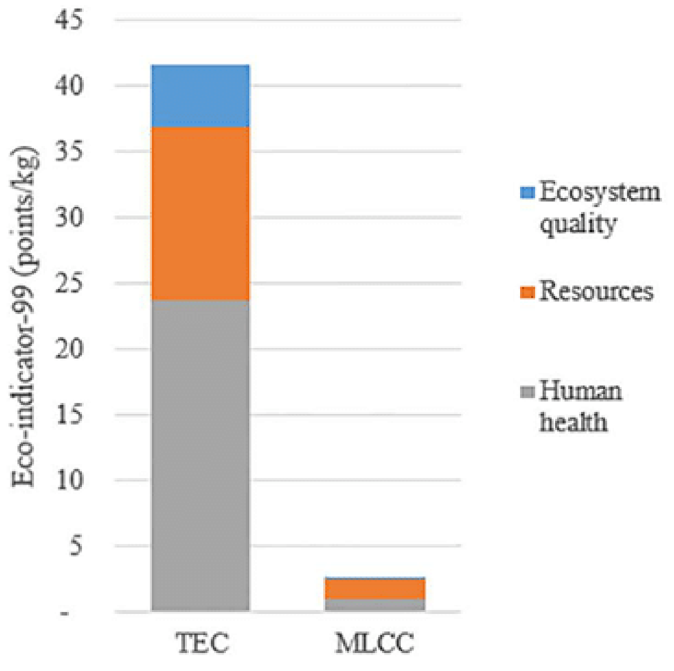
Target: Tantalum Electrolytic Capacitors (TEC) vs MLCC Ceramic Capacitors Environmental Impact Comparison for Automotive Power Supply Design Consideration



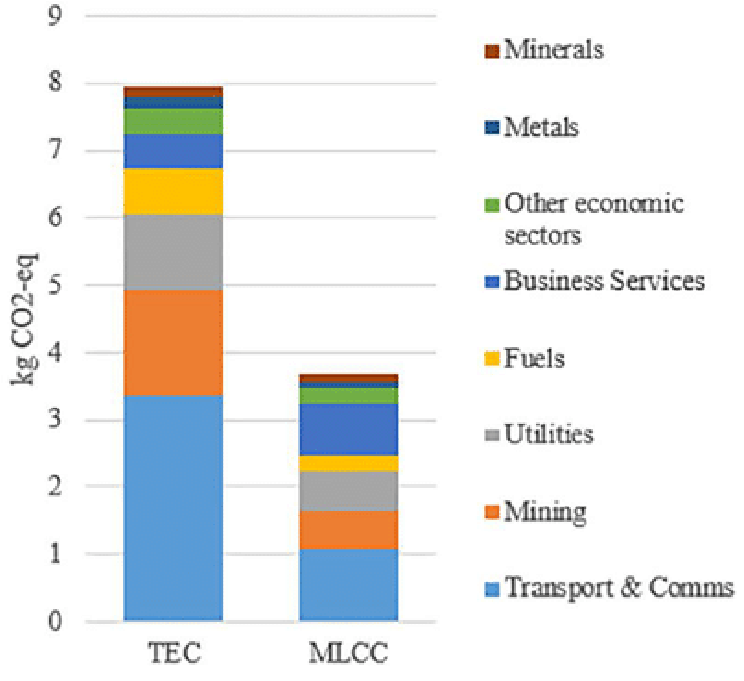
a) Primary energy consumption comparison



b) Toxicological footprint comparison



c) Eco-indicator comparison



d) IO upstream GHG comparison

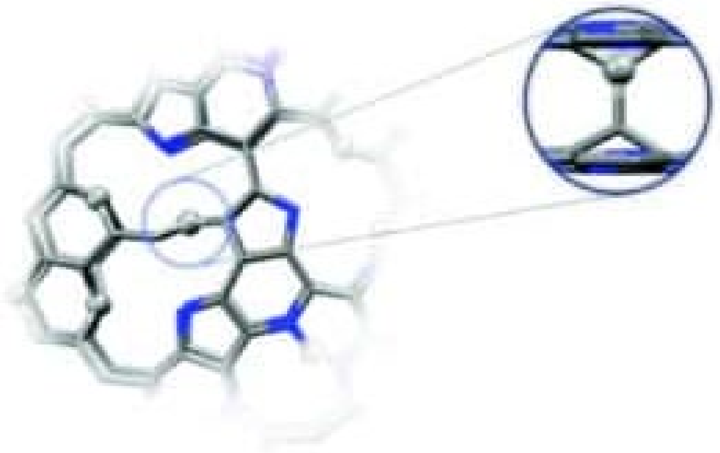
RESULTS

- outcome of the study lead to optimization of high volumetric efficiency capacitor selection for the power supply design based on performance / environmental fingerprint criteria
- target is not to “ban” one of the capacitor technology but prepare a more complex life assessment model of the power supply to evaluate different architecture design options
- the final power supply device can be offered including complete life cycle assessment figures to the automotive end user in order to evaluate its complete vehicle environmental impact

source: Smith, L., Ibn-Mohammed, T., Koh, S.C.L., Reaney, I.M. Life cycle assessment and environmental profile evaluations of high volumetric efficiency capacitors (2018) Applied Energy, 220, pp. 496-513. DOI: 10.1016/j.apenergy.2018.03.067

NEXT GEN CAPACITORS

NEW **HIGH ENERGY DENSITY** MATERIALS & (NANO-)TECHNOLOGIES



High Energy Density Dielectric Materials

THE

Challenge !

Dielectric materials ε_r vs breakdown field benchmark

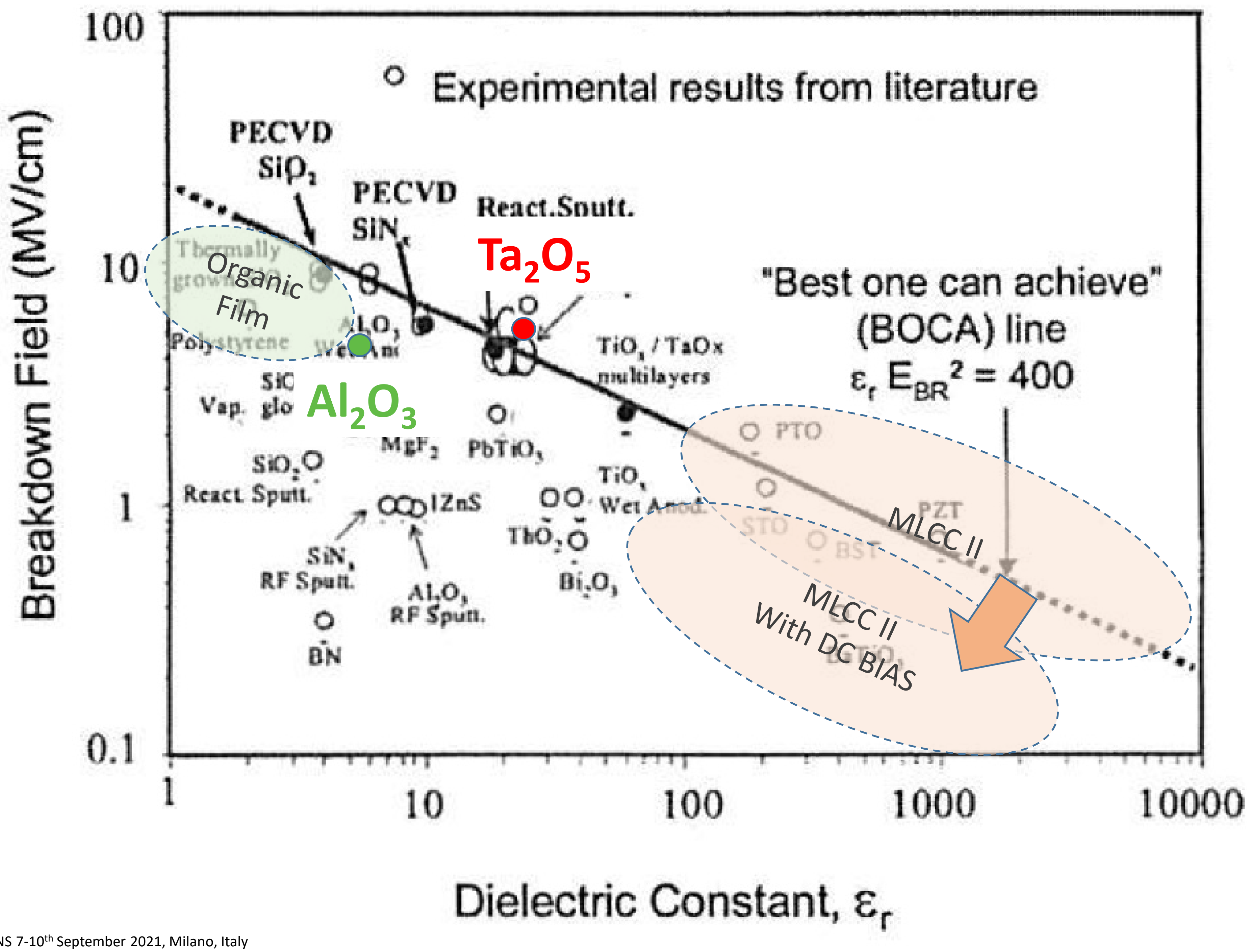


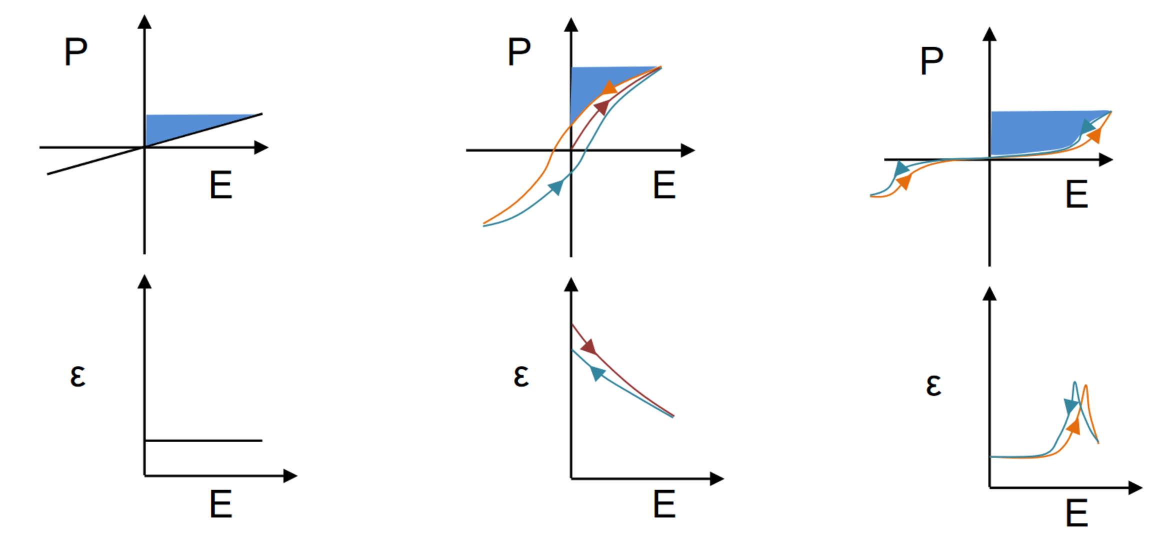
chart source: I.Pushkar, et col. "Thin-Film Capacitors for Packaged Electronics"; Springer book 2004

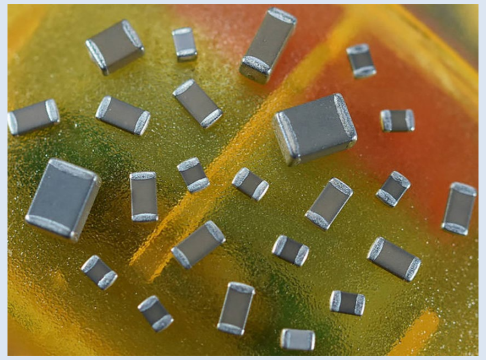
- Tantalum wet capacitors are currently the highest energy density mass manufactured capacitors
  - pure Ta_2O_5 dielectric potential (no electrodes, terminations…) has the highest energy density ~ 16J/cc
  - Real ta capacitors Wet-Hybrid-IDC are **4.5-8J/cc** (but expensive)
  - SMD tantalum solid chips < 1J/cc
- Ceramic class II capacitors max < 1J/cc, high $\varepsilon_{r,}$ low electrical strength; but strong Cap loss with DC BIAS
- Film capacitors typically << 1J/cc, low $\varepsilon_{r,}$ high electrical strength
- Tantalum and Aluminum Capacitors are based on one dielectric types (Ta_2O_5, Al_2O_3)
- Organic film and Ceramic = group of dielectric materials with flexible development potential and modifications (doping, mixing, new processes modifying its internal structure …)

High Energy Density Dielectric Materials – Ceramic Materials

source: TDK

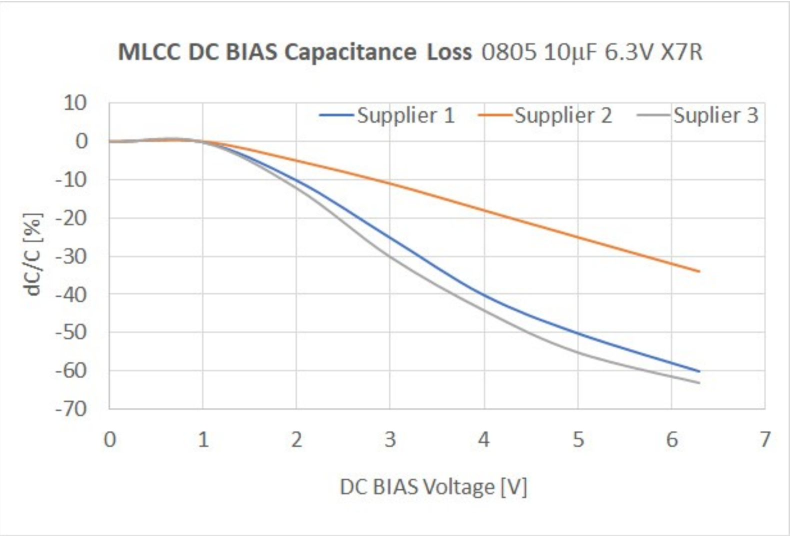
	Linear	Ferroelectric	Antiferroelectric
Nature of electrical polarization	Electronic, ionic	Permanent dipoles form ferroelectric domains	Permanent dipoles form antiparallel zones
Material class	(Ba,Nd)TiO, typ. NP0, C0G	$BaTiO_3$ (BTO), typ. X7R	$(Pb,La)(Zr,Ti)O_3$ (PLZT)
Advantages	ε constant over electric field and temperature	ε up to 10,000 is possible	ε increases with field
Disadvantages	ε < 100	ε decreases strongly with electrical field	ε low at zero bias





P Dielectric polarization
E Electrical field strength
ε Permittivity

Issues: - higher CV ~ worse performance
- process/ manufacturer specific features

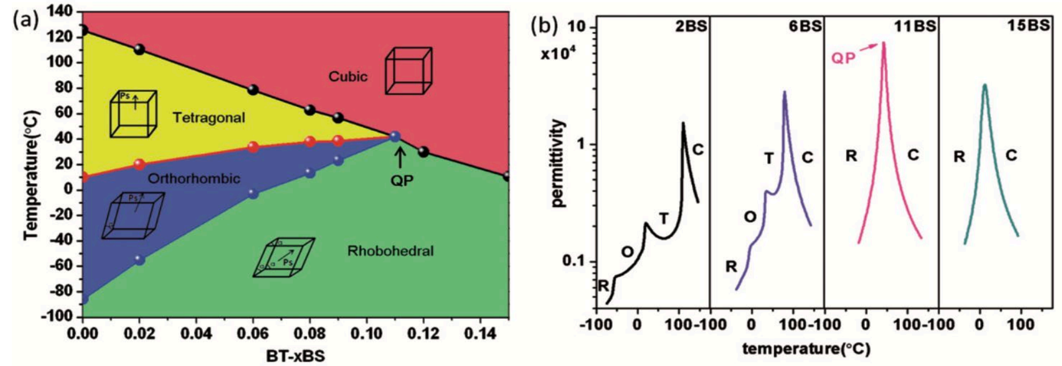


Is there any gain going forward compare to linear ?

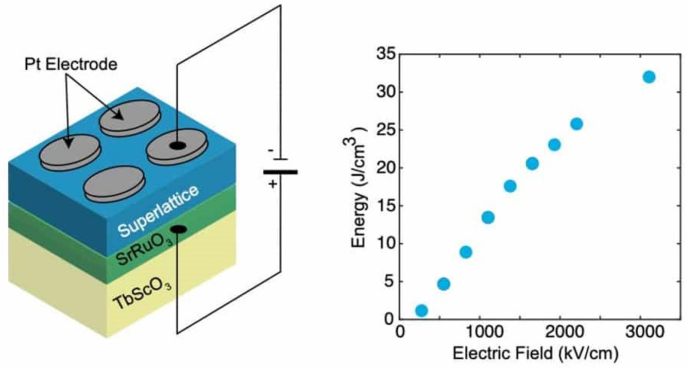
Advantage for high V ~ 1kV Applications
- High energy density at high field (~ 1J/cc)
- Pb content issue
- Limited vendors

New Development

- Semi-linear dielectric materials
  - proprietary dielectric types
- Ferroelectric materials
  - BaTiO3 + dopants
  - Low Curie temperature materials (BaTiO3-11BS)
  - New firing & mixing processes resulting in fine grains – lower permittivity but high electric strength
- Anti-ferroelectric materials
  - Lead-free materials (La1-xBixFeO3/BiFeO3)



example low Curie temp. system **$BaTiO_3$-$xBaSnO_3$** ~4J/cc, E~ 6-9kV/mm

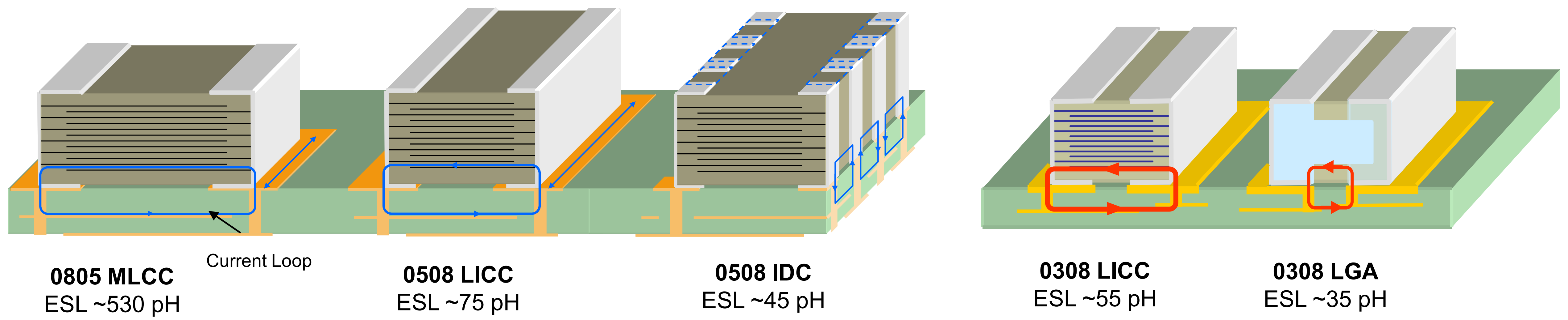


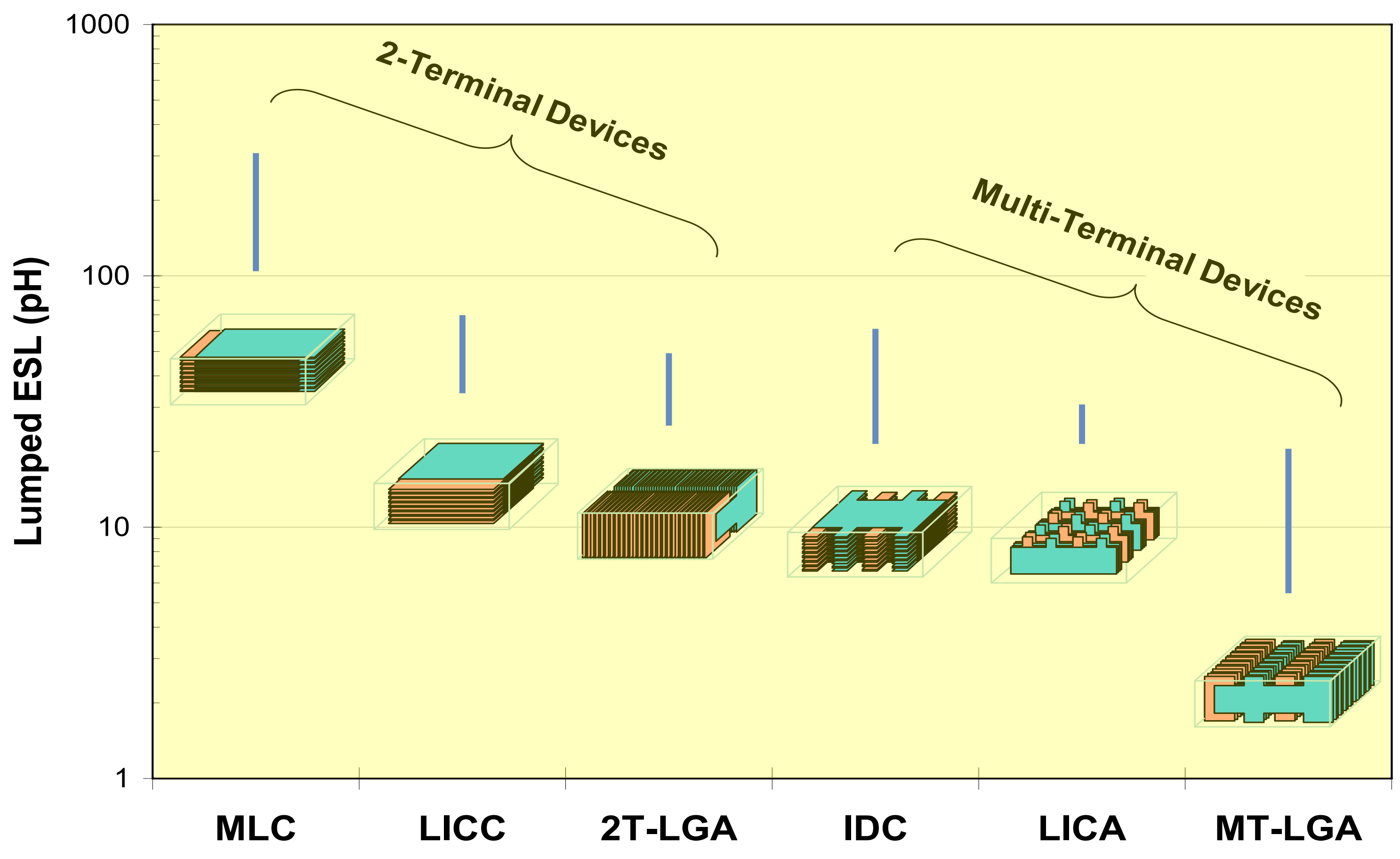
example anti-ferroelectric **La1-xBixFeO3/BiFeO3**

source: passive-components.eu

Capacitors – Ceramic Capacitors, Coupling, RF and High Frequency

Low ESL & miniature MLCCs





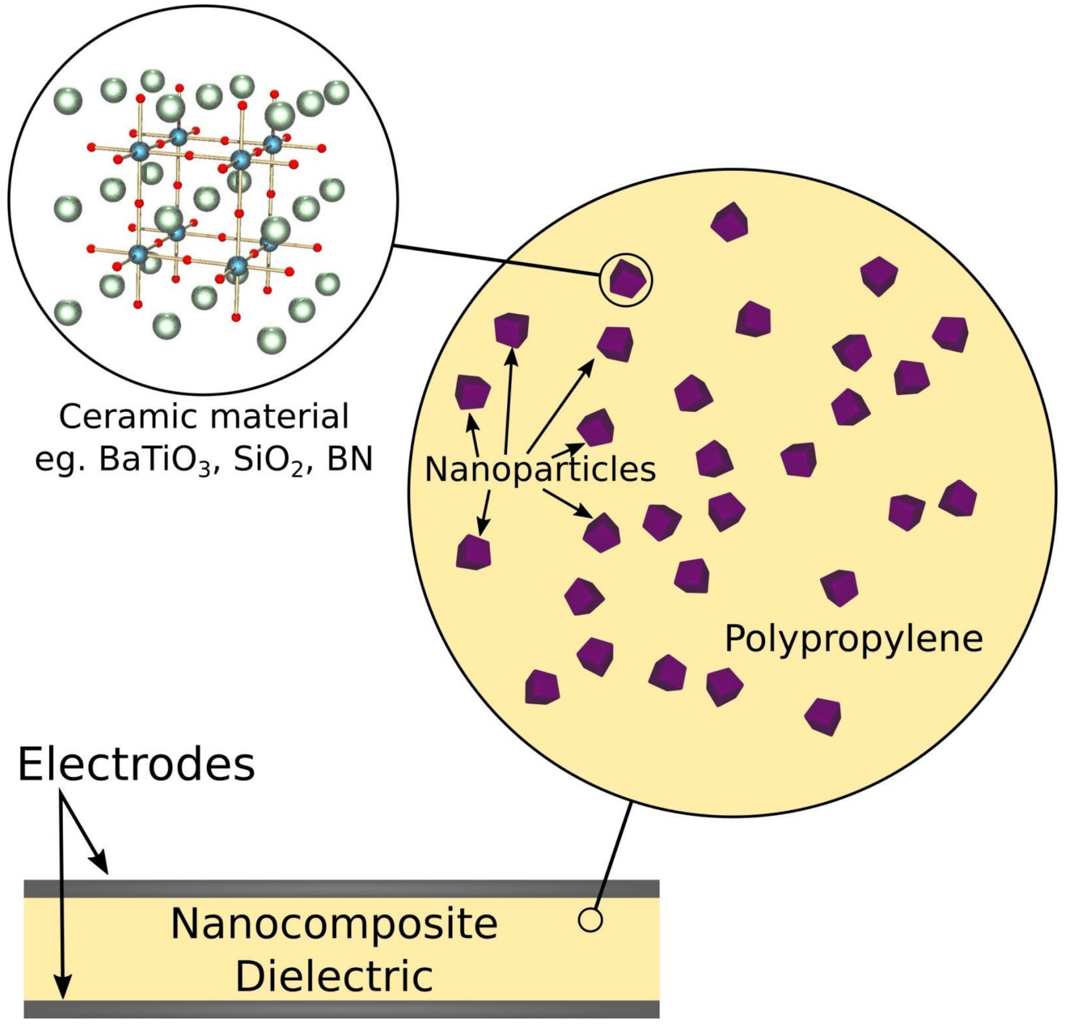
Multilayer Technology

- High Design Flexibility to Meet Target Specifications
- Low ESL Configuration
- Low ESR, High Power Ratings
- Mix Layers C and R – „Z“ chip
- Wide Range of Dielectric / Semiconductor Material Options – Varistors, Diodes, Circuit Protections

source: AVX

New Materials – Nano-materials, Nano-Composites

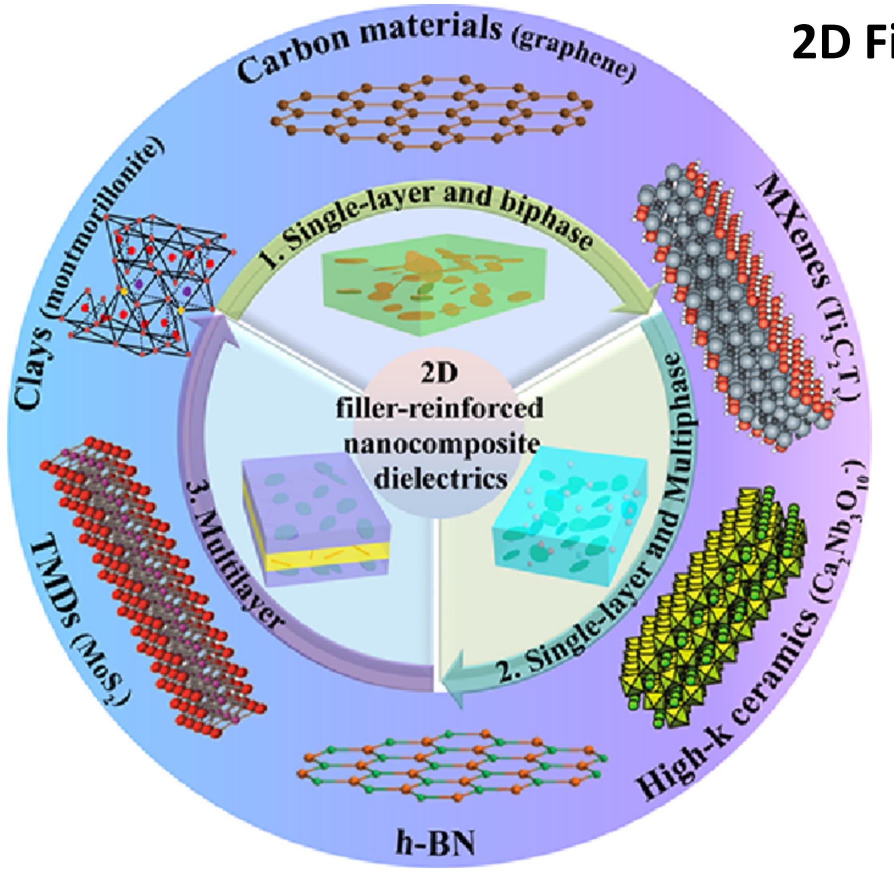
Novel Nanocomposite Dielectric Material



source: W.Greenbank at col., SDU Denmark

Mixed Dielectrics – Nanocomposite Dielectrics

- target to combine best features from different dielectric types
- metal oxide / ceramic material nanoparticles in polymer fillers
- 2D filler-reinforced carbon/graphene material based nanocomposite dielectrics
- not yet commercially successful as capacitor technology
- use of nanomaterials is promising approach to achieve homogenous-like novel dielectric materials



2D Filler-Reinforced Nanocomposite Dielectrics

source: Dalian University of Technology, China

Energy Storage Capacitors – Supercapacitors & Hybrids

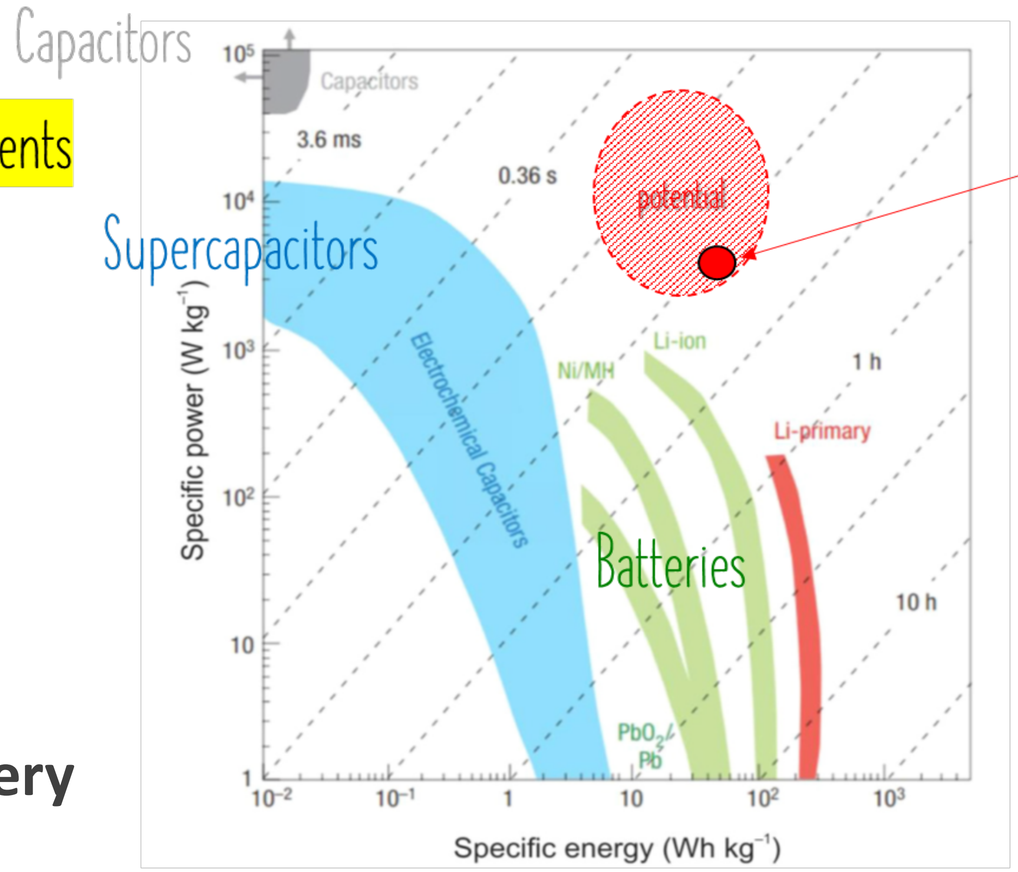
Power Of the Future:

- Small, Light, Cheap
- High Performance
- High Life Cycles
- Reliable
- Billions Made
- Sustainable

Supercapacitors: from (active/nano) Carbon to Graphene

High Power & Energy Density Graphene Based Supercapacitors

Research Achievements

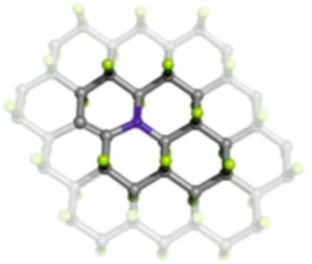


N-Doped 2D Graphene

ED up to 55 Wh/kg at PD 2 kW/kg

Potential:

ED 50-60 Wh/kg at PD 2-50 kW/kg



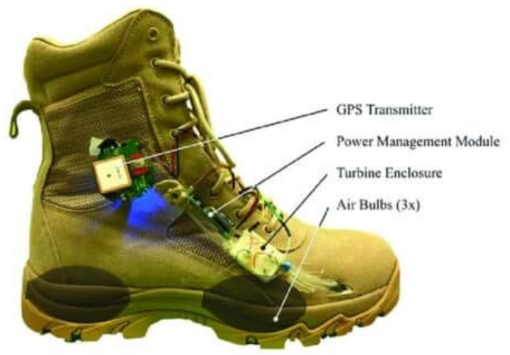
carbon atoms are grey
fluorine green
hydrogen white
nitrogen blue

Source: RCPTM Palacky University Olomouc, Czech Republic

Hybrid Energy Supercapacitor-Battery

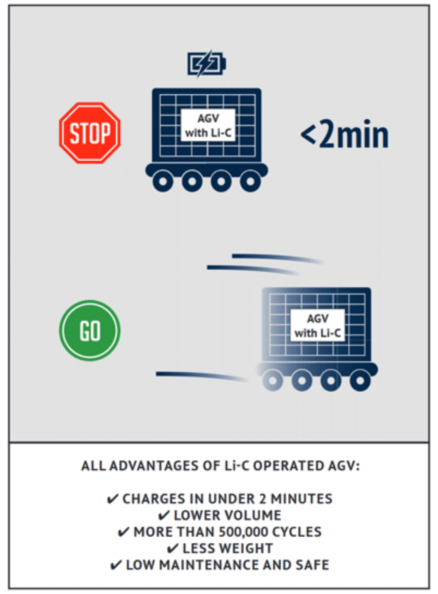
	BATTERIE	ENERGY-C
CONSTRUCTION	2 x 12V 75 Ah in series	6 x 5000F in series
RATED VOLTAGE	24V	24V
EFFECTIVE STORAGE ENERGY	1.800Wh	40Wh
RANGE	6 ~ 8h	700 meters (ca. 12 min)
CHARGE TIME	ca. 4h	<2min
VOLUME	16l	5l
WEIGHT	53kg	4,4kg (in future 2kg)
NUMBER OF CYCLES	~1000 cycles	>500.000 cycles

Flexible Supercapacitors



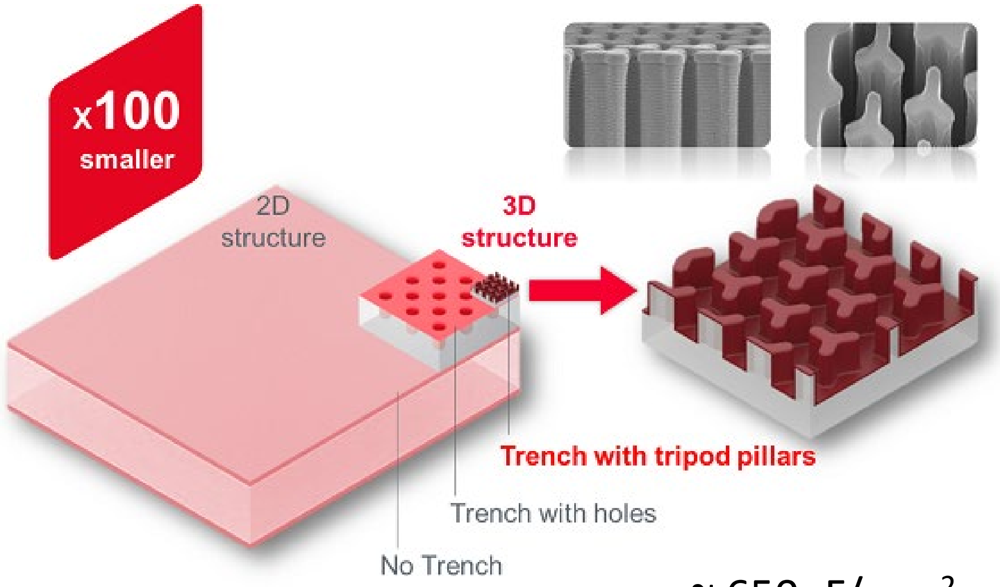
Driverless transport AGV Automated Guided Vehicles

Source: Jianghai-Europe

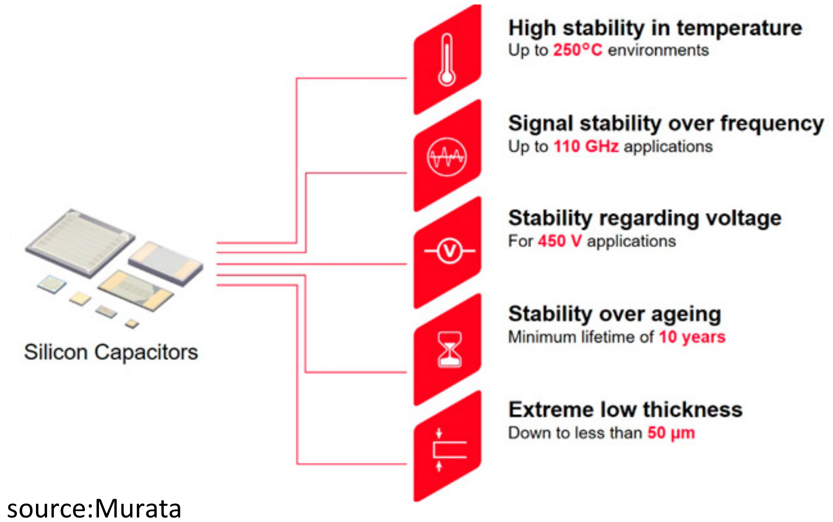


Integrated Capacitors – 3D Silicon, Wafer Based and CMOS Process Compatible

SiO_2 Dielectric Base (mass production stage)



~ 650nF/mm^2



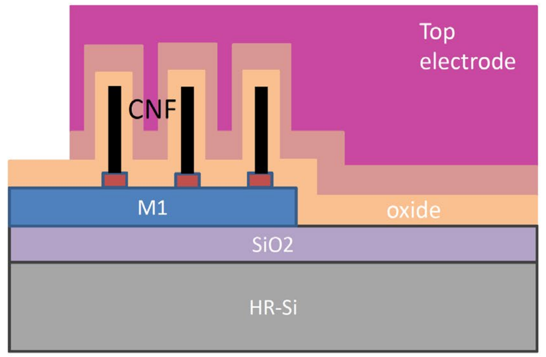
source:Murata

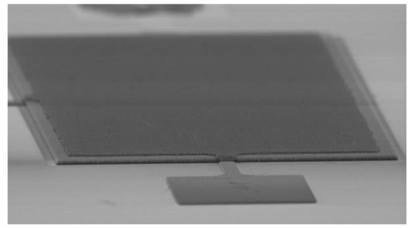
New Semiconductor Process For High Voltage Capacitors (MACOM)

source: Macom

- capable of achieving kilovolt ("KV") operating levels in excess of 1,000 volts
- 200V, 500V and 1,000V, with capacitance values from 2 to 4,700 picofarads

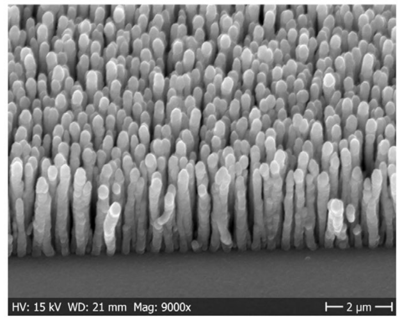
Carbon Nano Tube Base ALD Process Deposition of high K material (pre-production)





Conformal top electrode and bulk metallization

~ 650nF/mm^2

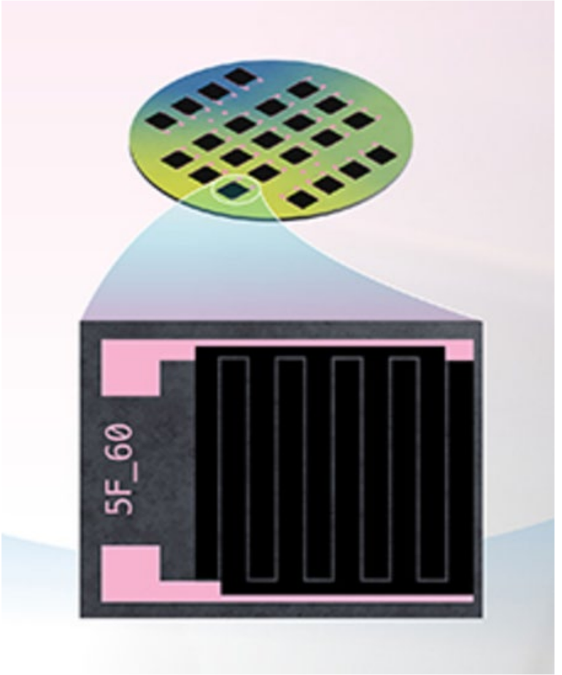


Conformal oxide deposition of HfO_2 and/or Al_2O_3 using ALD (< 250°C)

source: Smoltek, Sweden

Spin-Coated CMOS Compatible Microsupercapacitors for On-Chip Low Power Electronics (research)

~ 1µF/mm^2



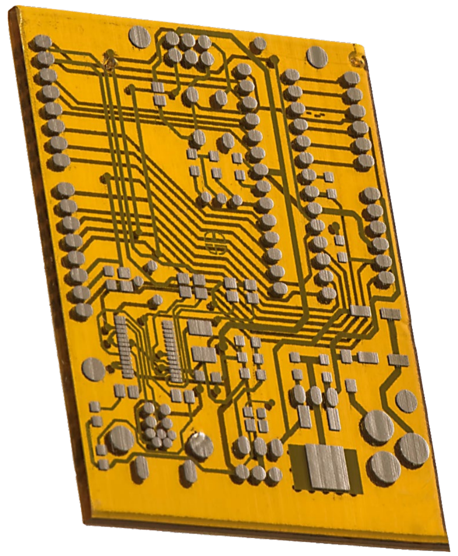
source: Chalmers University, Sweden

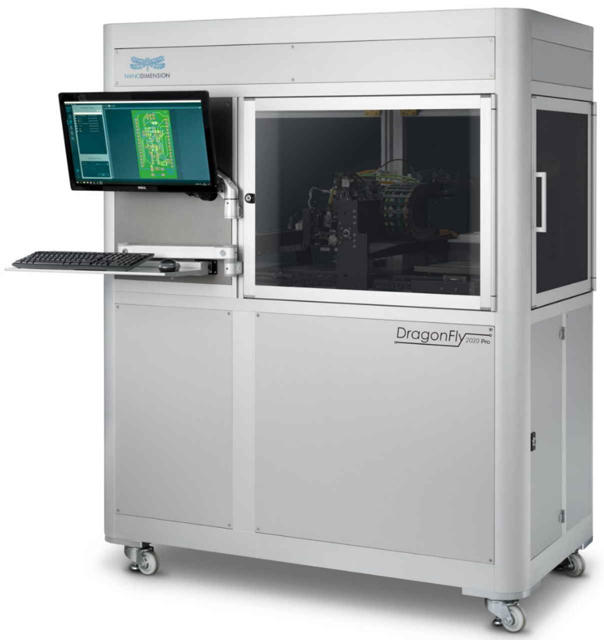
3D Printed Components / Electrodes

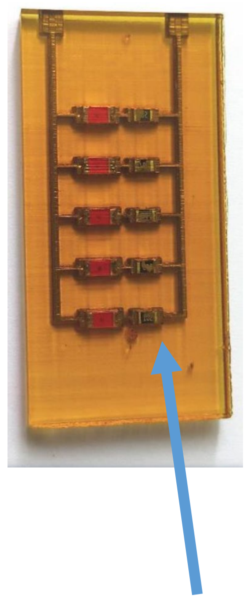
3D PCB Printers

Example parameters (Nano-Dimension DragonFly)

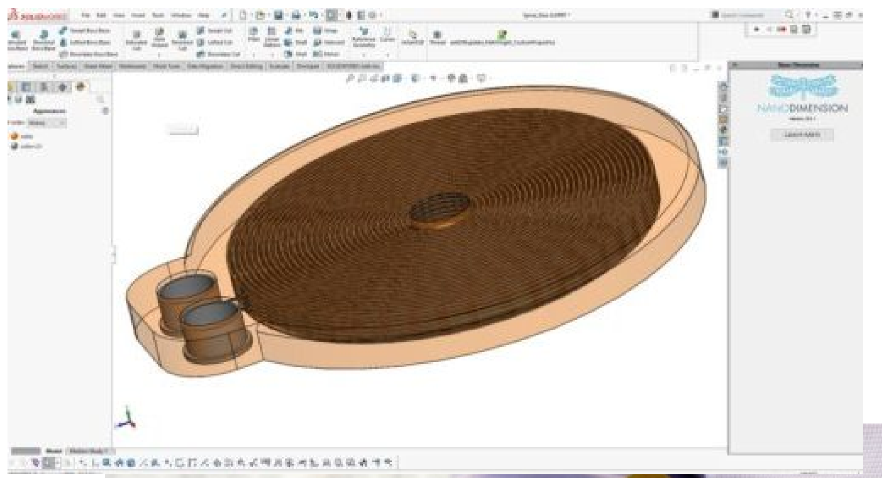
- separate conductive and dielectric inks deposition and curing
- FR4 like dielectric and silver inks available now, further in R&D
- min dimension between conductive path: 125 µm
- layer resolution: 3µm dielectric, 0.3 µm conductive silver ink
- simple capacitor, inductor, antenna printing capability
- **electrode design not possible to make by conventional methods**
- embedding of discrete components as an option
- flexible PCBs possible

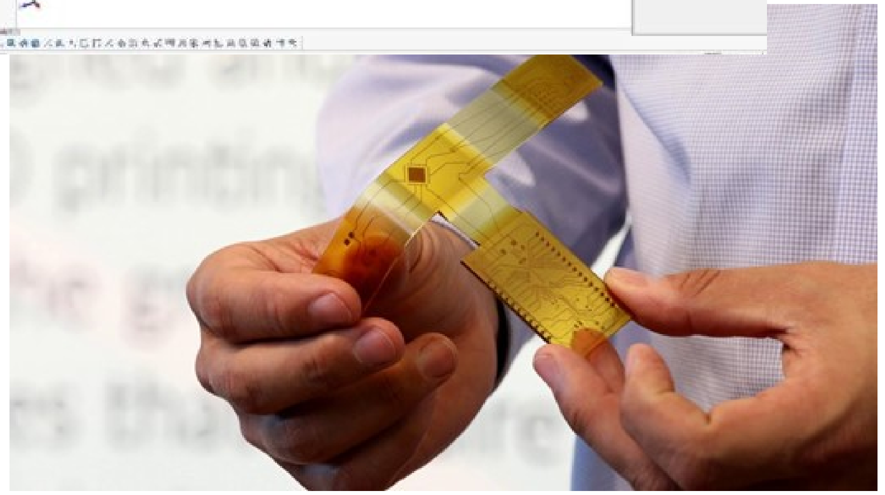




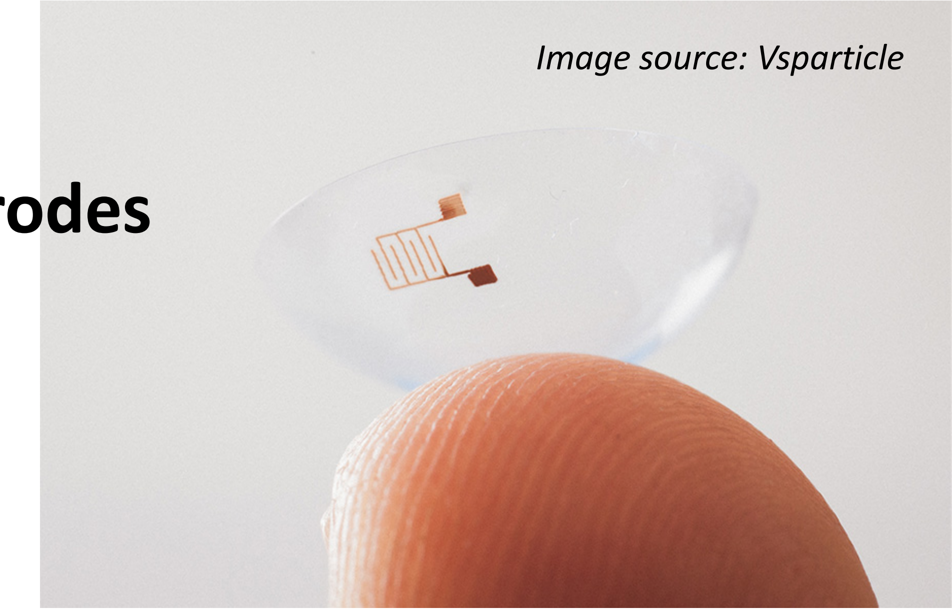


embedded discrete components

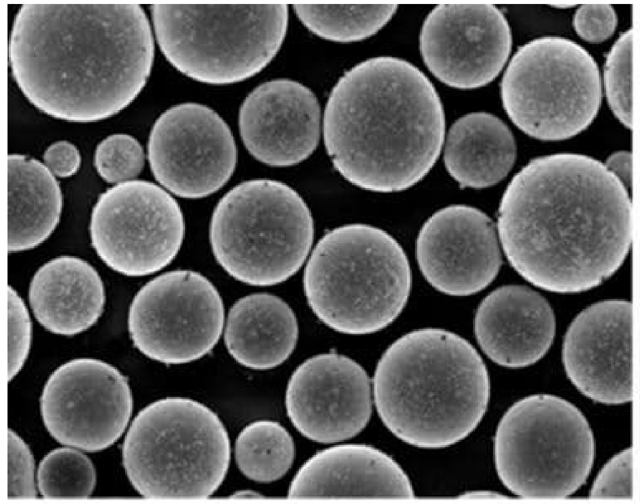




3D Printed Electrodes



- Advances in printing on flexible substrates
- Development of new processes and inks
- 3D metals printing – progress in industrial applications but not yet down to small diameters effective for capacitors
- Cost and economics to be addressed



Tantalum powder for 3D printing and Ta 3D printed cube source: GAM Global Advanced Metals

Source: https://passive-components.eu/when-are-we-going-to-print-pcbs-on-3d-printer-ourselves/

RELIABILITY

COMPLEX RELIABILITY & LIFE-TIME

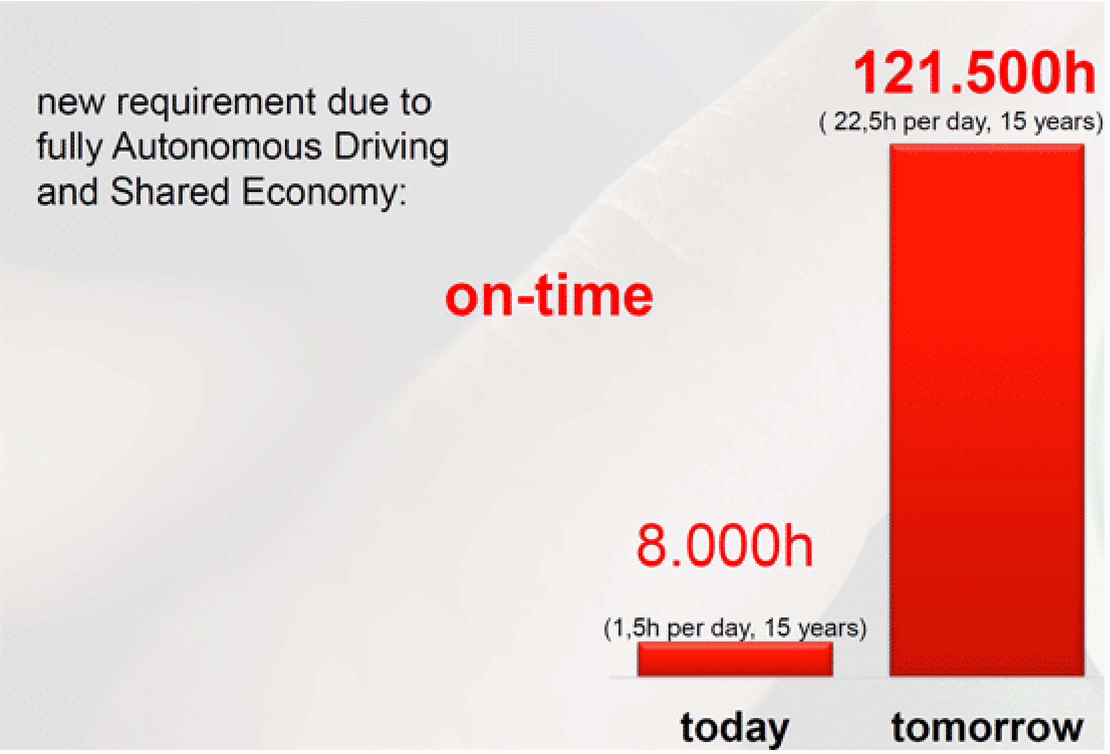
Reliability - Requirements

NEW REQUIREMENTS – SHARED ECONOMY & AUTONOMOUS DRIVING

RELIABILITY CONSIDERATIONS

is AEQ-200 the Sufficient Reliability Reference?

- Automotive AEC-Q200 is becoming ultimate reliability standard even for non-automotive applications
- AEC-Q200 capacitor reference condition requirements – 2000 hrs test at high temperature corner (85C)
- Reliability Calculation – MIL standards and set acceleration factors (Arhenius) to give live prediction at application conditions.

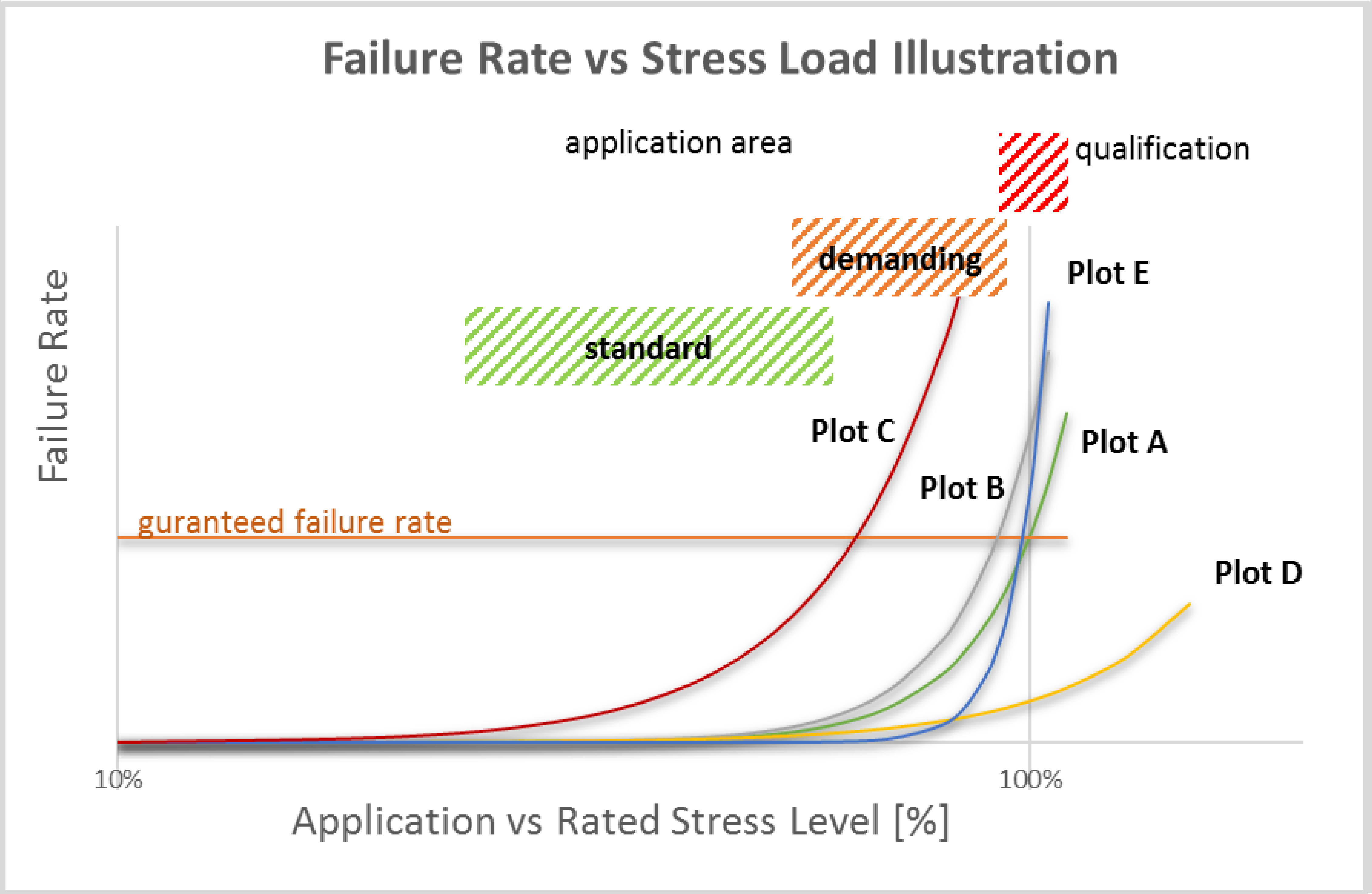


source: Wuerth Elektronik

DISCUSSION

- Typical vehicle is most of its life-time parked in OFF mode, is the guaranteed life-time sufficient
- > 2000 hrs testing is not practical nor economical on manufacturer side
- Can we trust existing “old” reliability calculations / validity of acceleration factors for extended / new products.
- Some industrial applications operating close to real component corner continuous operation (85C) with requirements well exceeding 2000hrs life-time – mostly there is a lack of reliability data beyond 2K hours or physical models from component manufacturers to support life expectations. Users have to rely on their own know-how relevant to the use of components in its specific application conditions.

Reliability – Illustrative Component Failure Rate Scenarios



source: EPCI

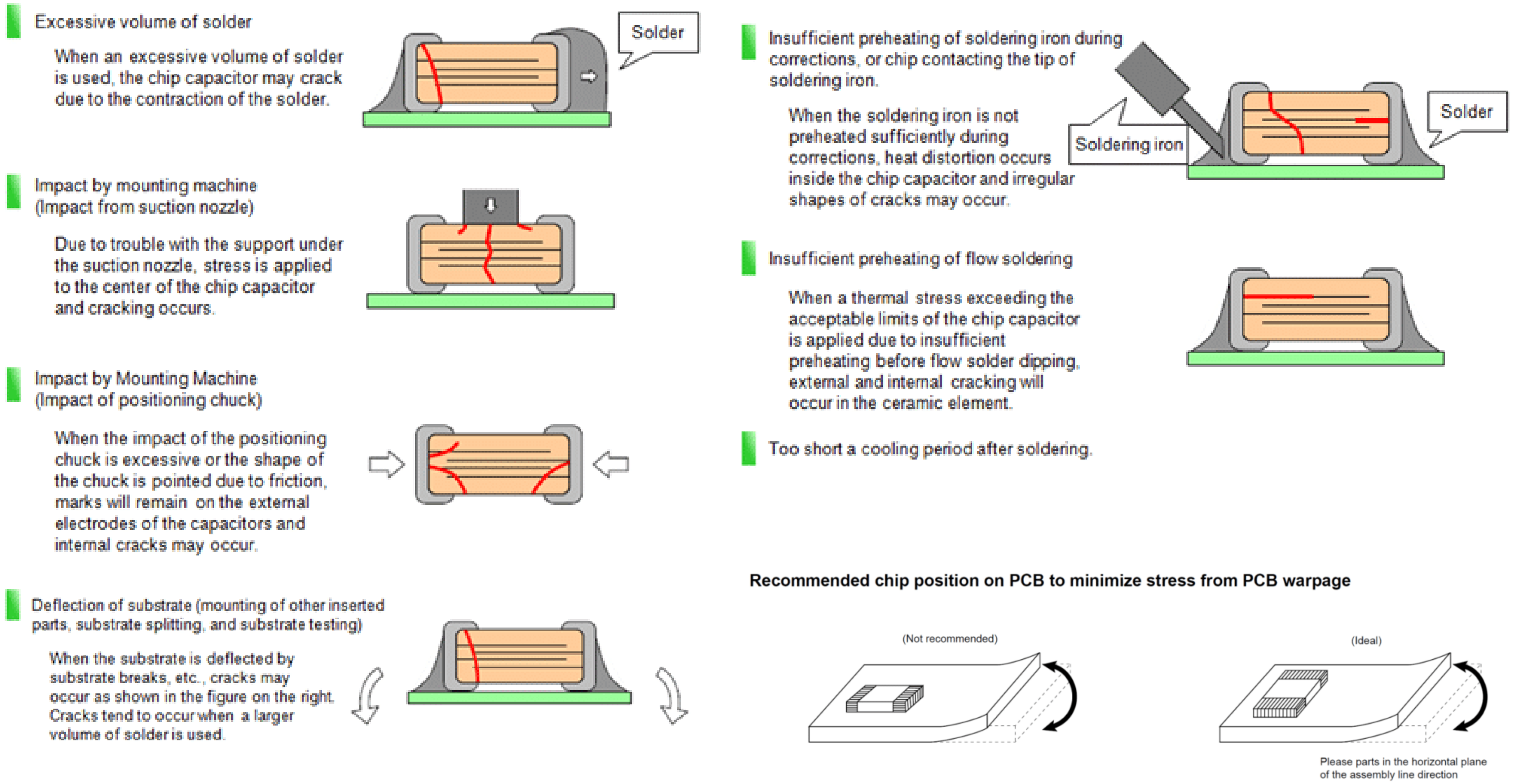
PLOT A **"as per specification"**
PLOT B **"consumer low cost approach"**
PLOT C **"high failure risk – faulty component"**
PLOT D **"high reliability products with safety margins"**
PLOT E **"high field stress capable materials"**

Discussion

- Derating may be the differentiator factor
- Real component failure rate between plots D and E
- New capacitor materials trade-off:
  - improved material purity and structure reduces failure rate and allows operation under higher electrical fields
  - operation at higher fields lead to higher failure rate and its dynamics
- In general, by rule of thumb, failure rate calculations still applies for new materials – BUT not necessary for all materials and component types

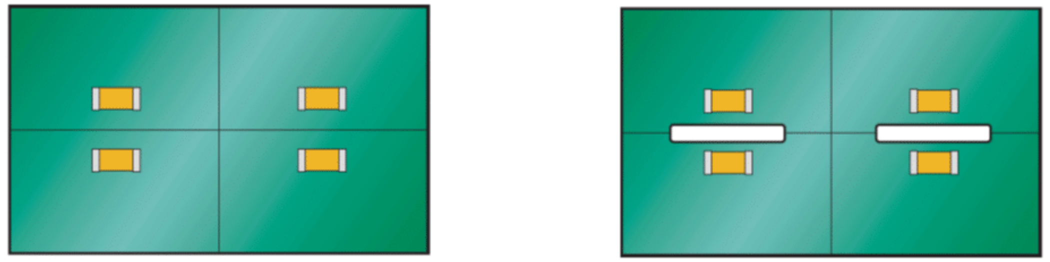
RAISING IMPORTANCE of Material Knowledge Based Physical Modelling and Long-Life Predictions (beyond 2000 hrs)

Complex Reliability



Mounting Induced Capacitor Failures

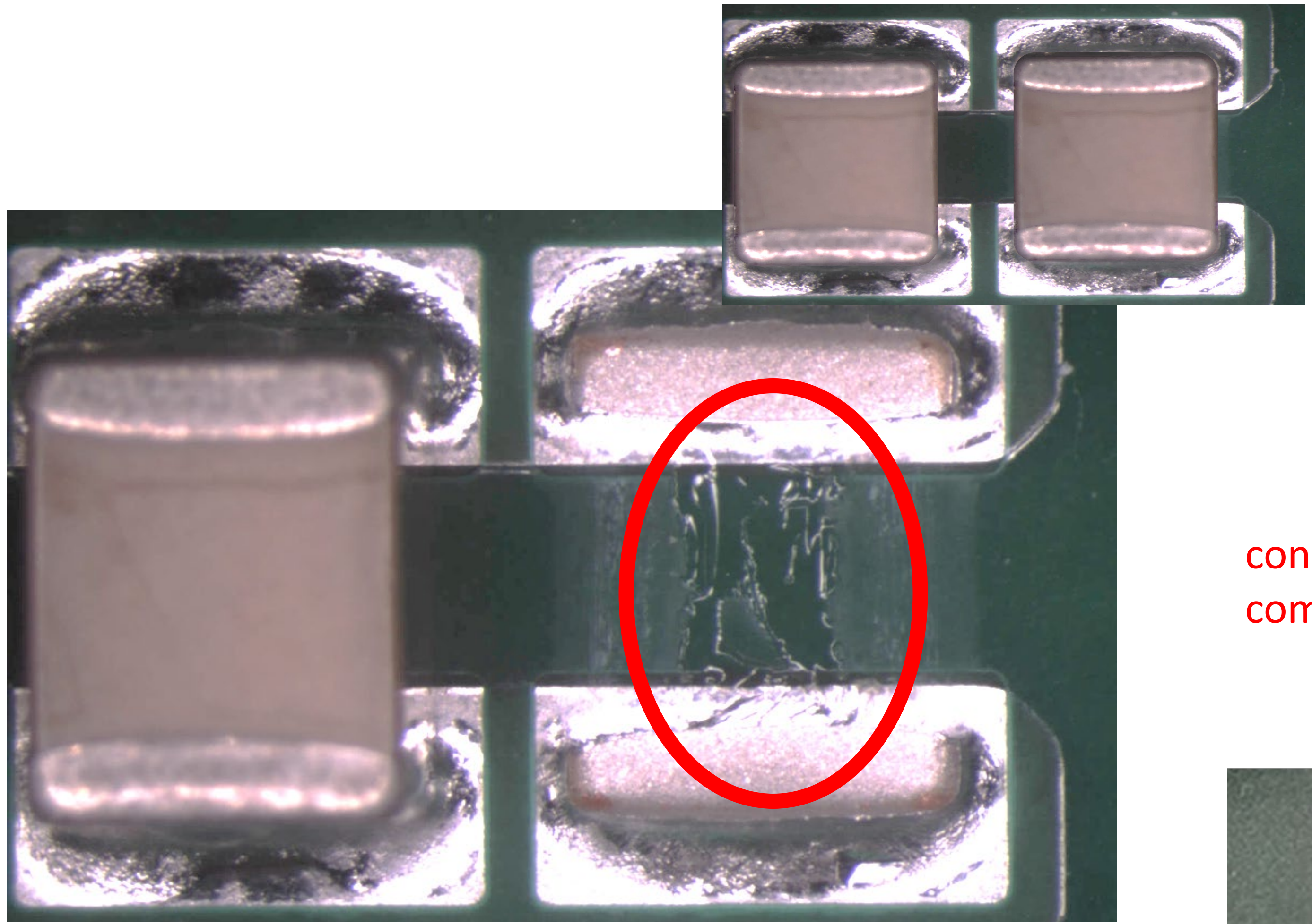
- Dominating capacitor failure cause
- Capacitor technology and application specific
- Driven by MLCC high volume capacitors assembly sensitivity
- Importance of manufacturer mounting recommendations & best practice rules
- New component types may raise new issues to be addressed



No Stress Relief for MLCs   Routed Cut Line Relieves Stress on MLC

source: Murata, EPCI

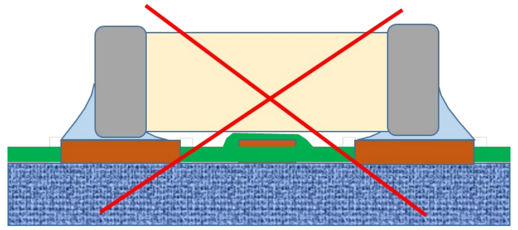
Complex Reliability – PCB Cleaning

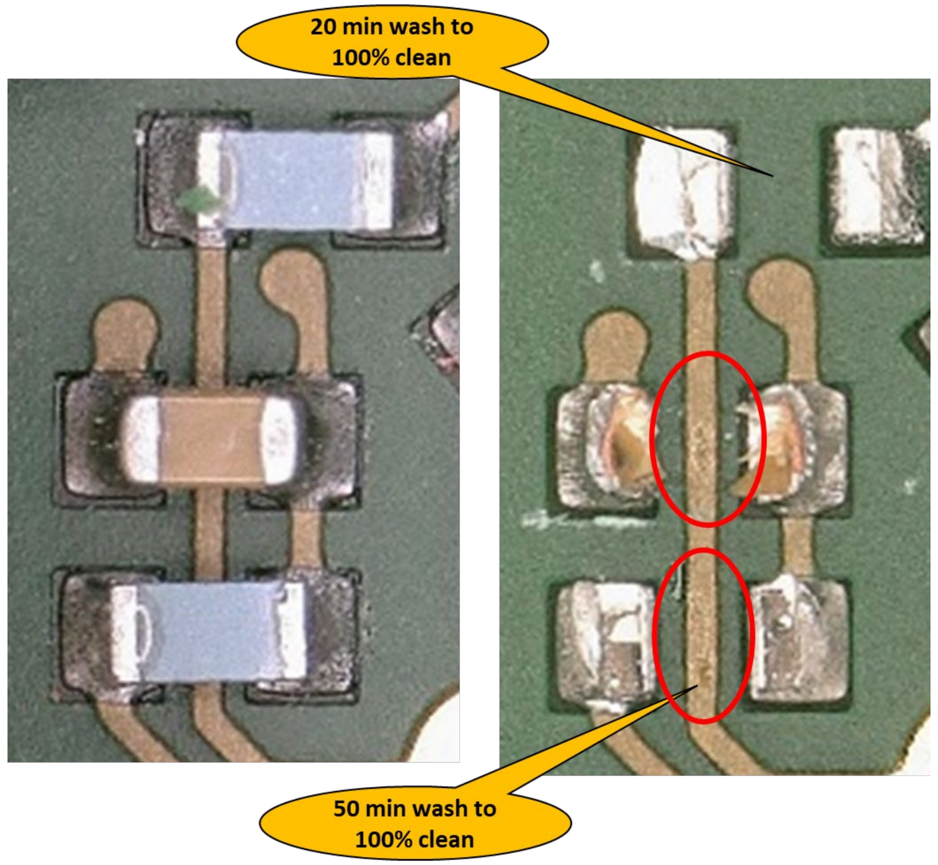


- "no clean" paste does not necessary mean NO CLEAN needed
- Cleaning challenges in thin gaps with limited wash fluid flow
- Length of channels (tunnels) is critical
- Cleaning issues / residual impurity reliability risk increase associated with PCB wrong layout and specific component types

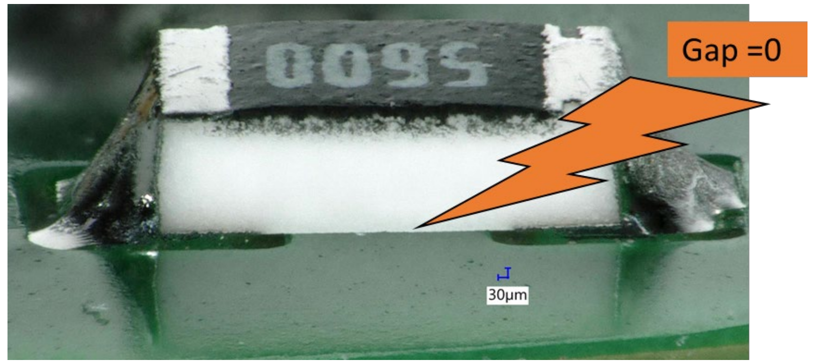
Clean Challenging PCB Pad Design Layout Examples

connection leads under components

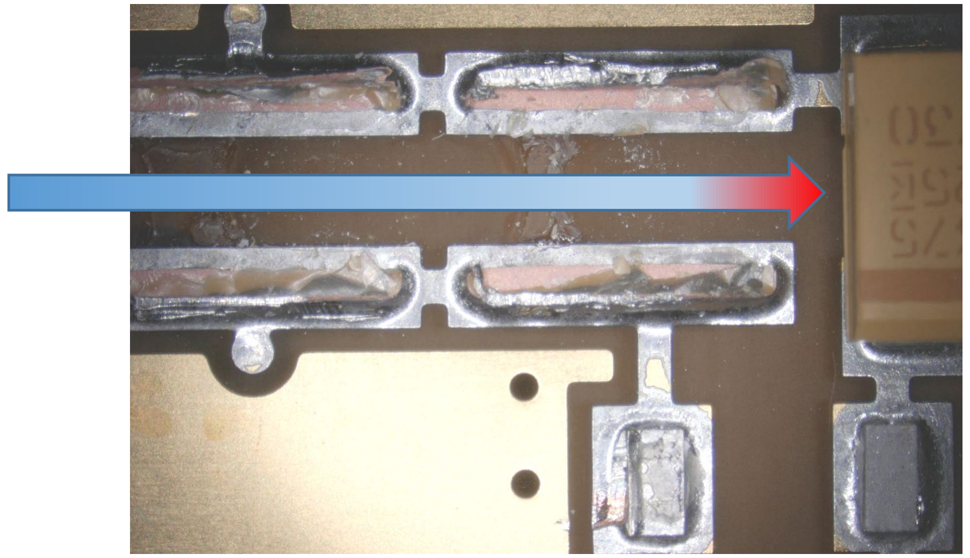


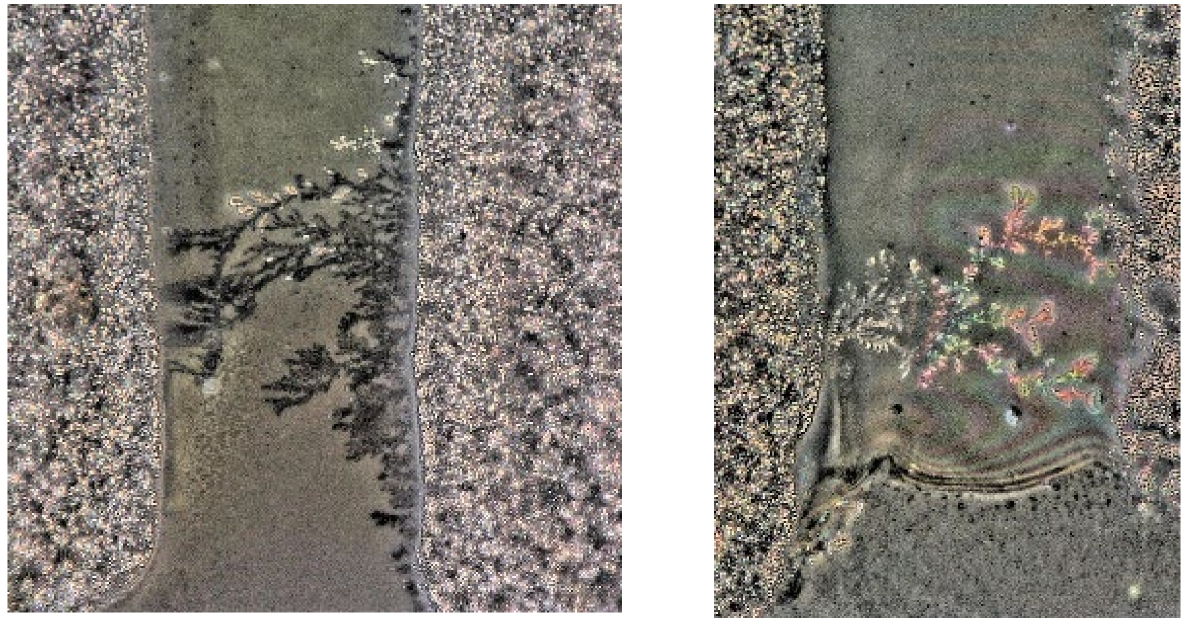


too thick solder mask



"T" blocked cleaning fluid flow



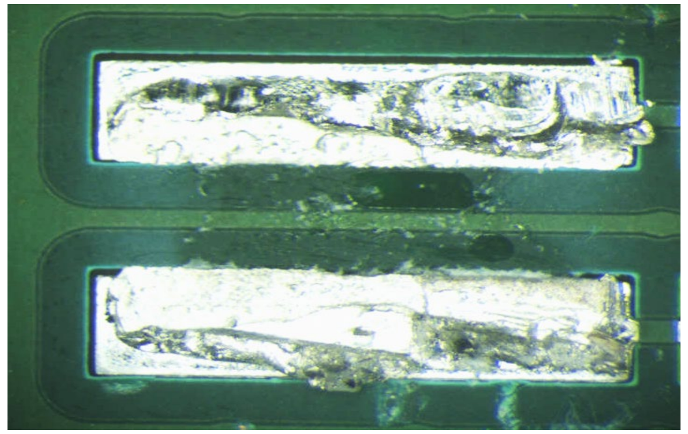


Pad Shortage Caused by Dendride Growth; source: PBT Works www.pbt-works.com

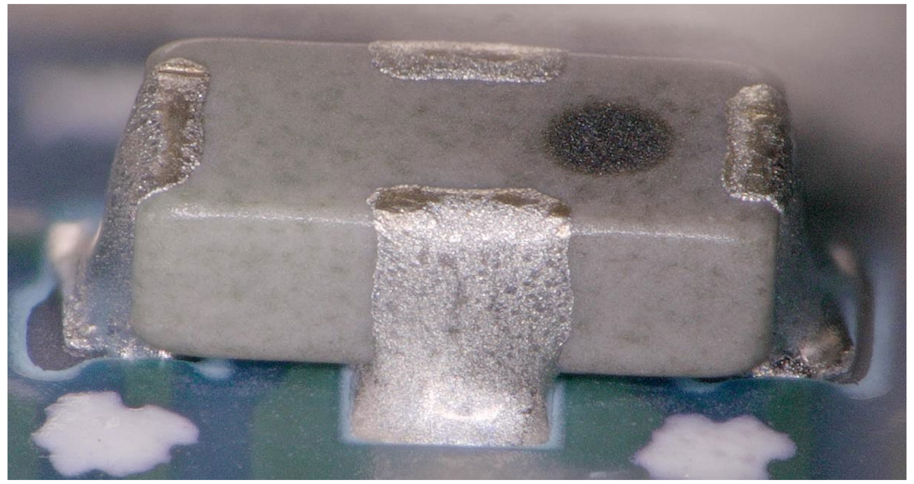
source: PBT Works www.pbt-works.com

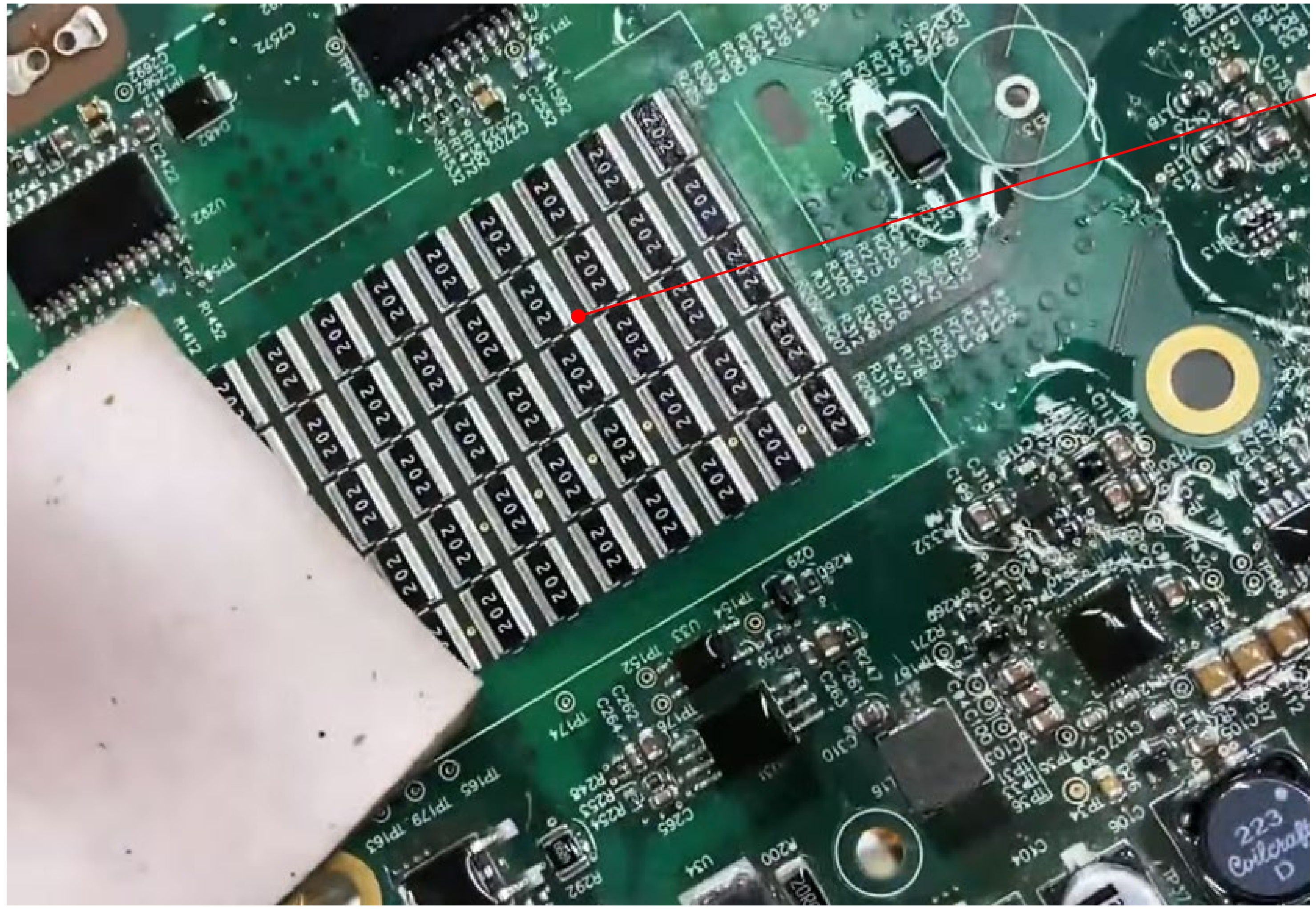
Complex Reliability – PCB Cleaning of Reverse and 3terminal Components

Reverse format Components good for heat dissipation, low ESL, mechanical robustness, but…. present cleaning challenges



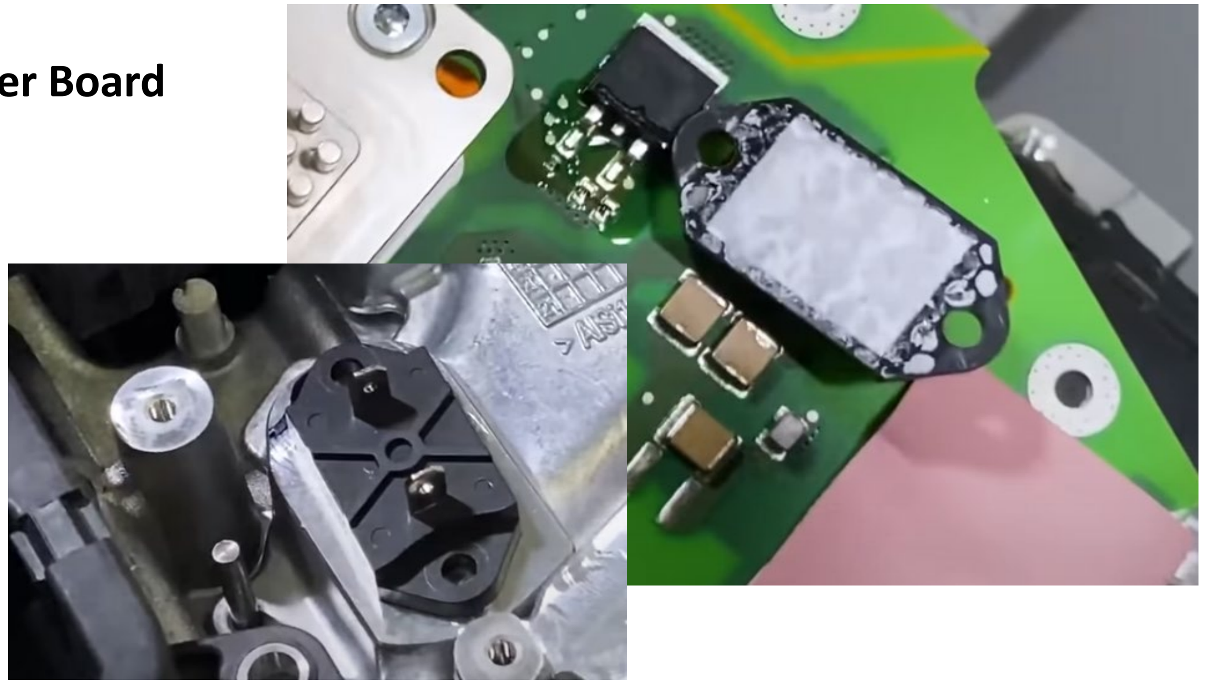
3 terminal MLCC good for noise suppression, high frequency operation, low ESL but….. challenge to clean between 3 terminations

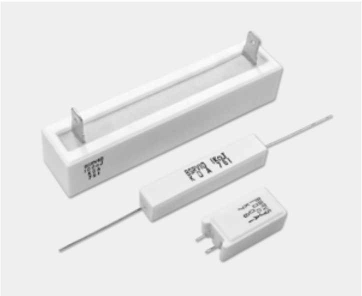




Automotive EV Specialist Inverter Board Bleeder Resistor
Reverse Geometry Resistor Network

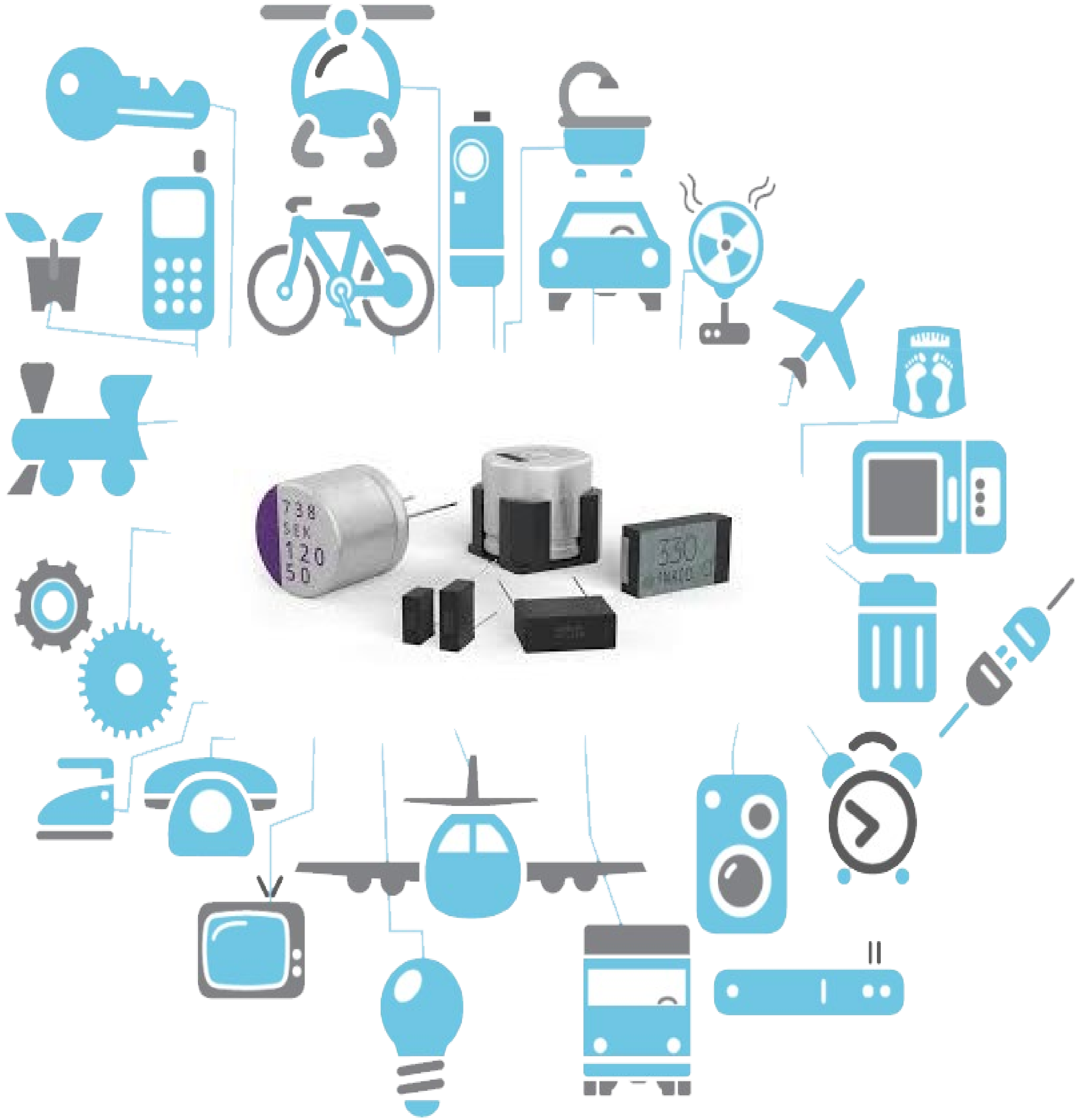
VS.





- conventional EV manufacturer bleeder resistor design
- discrete component with manual assembly
- looks “less advanced” but “more robust”

SUMMARY & CONCLUSION



SUMMARY & CONCLUSION (i)

Materials

materials are becoming the central point for many aspects of future capacitor designs

(i) understanding of material properties, its basic physics mechanisms are the key for failure mechanisms assessment and reliability predictions. Component evaluation based on relatively short testing (such as 2000hrs as per current AEC-Q200) may not be satisfactory for certain applications including automotive segment.

(ii) component design will have to evaluate complete supply chain and material selection in order to assess its complete life cycle and reduce its environmental footprint.

(iii) nano-material science is positioned to bring completely new generation of modern materials / respectively re-design of current existing components to achieve aspects (i) and (ii).

Critical Supply Chain
2022 Material Supply Chain Reset

components supply chain and bottlenecks shall be re-evaluated

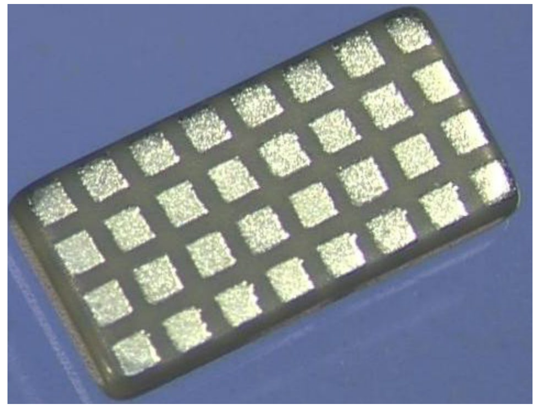
SUMMARY & CONCLUSION (ii)

NEXT GENERATION CAPACITORS

- Evolution is not developing linearly but in step-up strikes
- Current shortages & material supply chain reset may drive design Innovation

Need for efficient components is growing evolution driven by:

1) IC Demands
2) New Applications & Automotive
3) Emerging Active/Passive Technologies & Packages
4) Sustainable Development



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