HIGH TEMPERATURE MATERIALS FOR POWER ELECTRONIC APPLICATIONS

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TRENDS IN POWER ELECTRONICS R&D

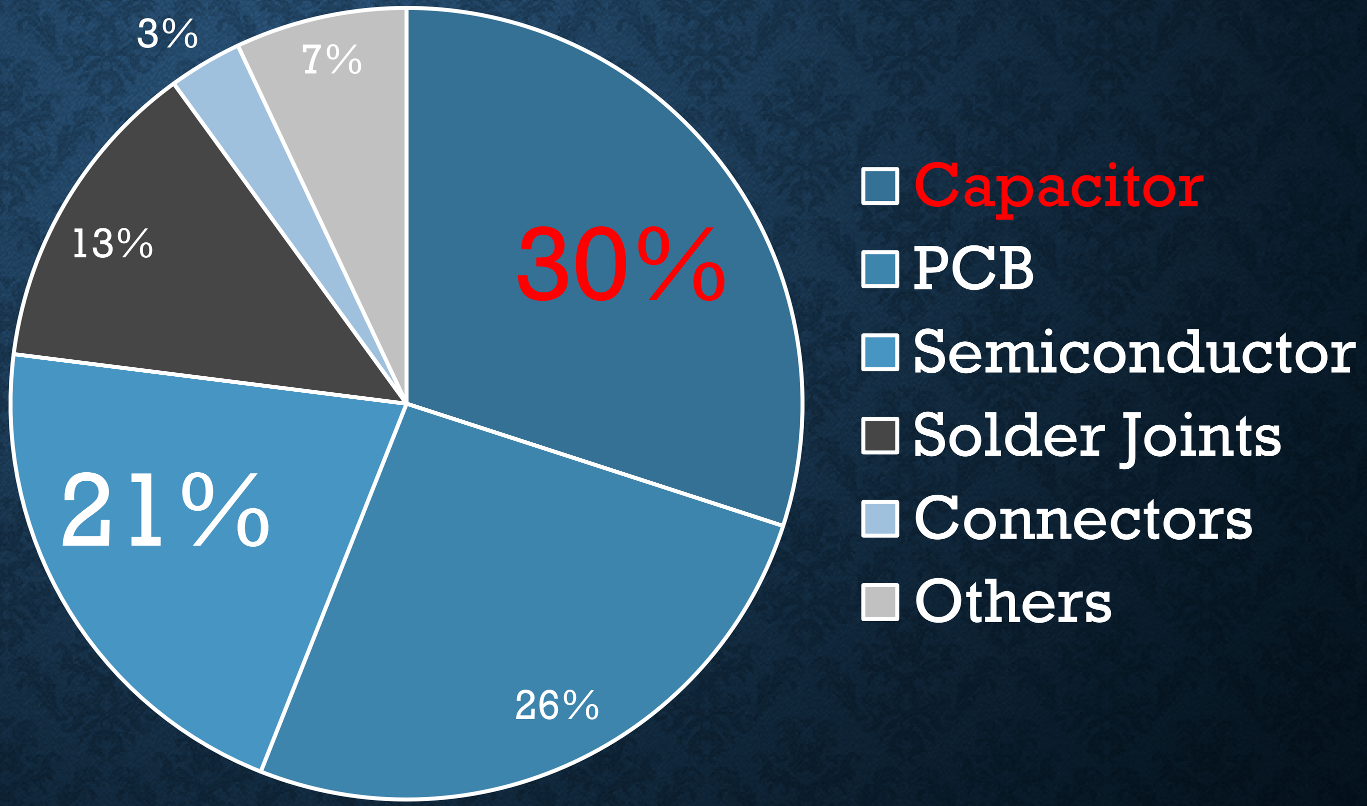
- Wide Band Gap Devices
  - CREE: SiC devices up to 180°C ambient
  - GaN Systems: high frequency switches
- Vehicle Technologies
  - Roadmaps call for SiC switches
  - Capacitors and dielectrics must operate at higher temperature and frequency

50 Amp 1200 V MOSFETS from Cree


All electric vehicles require power capacitors for DC/AC converters
Photo from Toyota

FAILURE DISTRIBUTION AMONG MAJOR POWER ELECTRONIC COMPONENTS

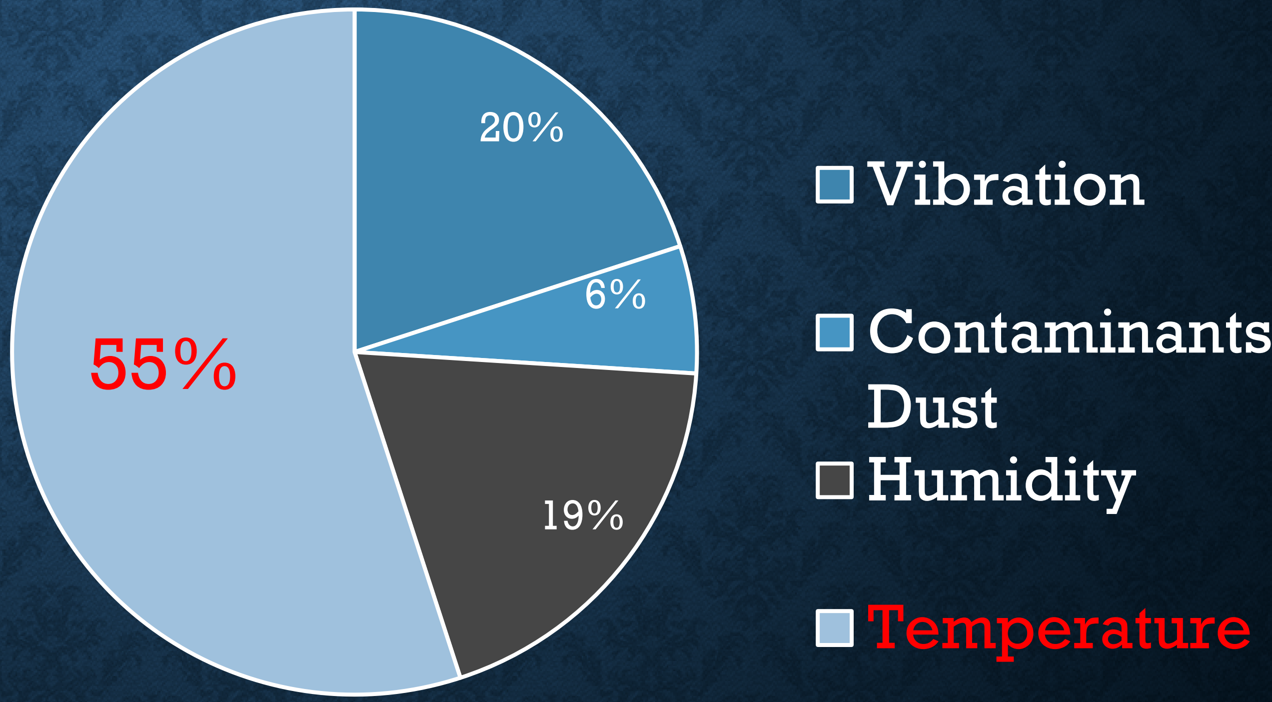
CAPACITORS AND SEMICONDUCTORS ACCOUNT FOR OVER HALF OF POWER ELECTRONIC SYSTEM FAILURES



Wang, Huai, Marco Liserre, and Frede Blaabjerg. "Toward reliable power electronics: Challenges, design tools, and opportunities." *IEEE Industrial Electronics Magazine* 7, no. 2 (2013): 17-26.

ENVIRONMENTAL CONTRIBUTIONS TO POWER ELECTRONICS FAILURE

EXTREME TEMPERATURE IS A LEADING CAUSE OF FAILURE



Wang, Huai, Marco Liserre, and Frede Blaabjerg. "Toward reliable power electronics: Challenges, design tools, and opportunities." *IEEE Industrial Electronics Magazine* 7, no. 2 (2013): 17-26.

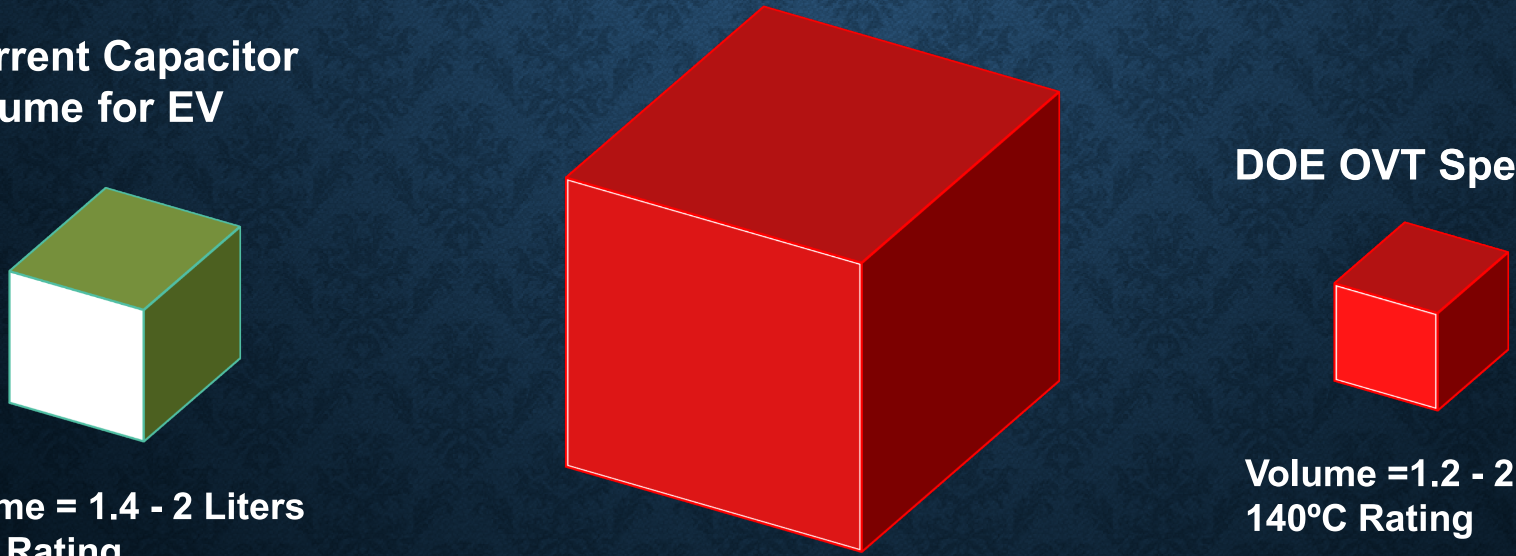
TEMPERATURE AND RELIABILITY DRIVE CAPACITOR DESIGN FOR POWER SYSTEMS

Volume of 1000 µF 600V capacitors in a Hybrid Electric Power Converter

Current Capacitor volume for EV

Present State-of-the-Art High Temperature Commercial Capacitor

DOE OVT Specification



Volume = 1.4 - 2 Liters
85ºC Rating

Volume = 21.6 Liters
125ºC Rating

Volume =1.2 - 2 Liters
140ºC Rating

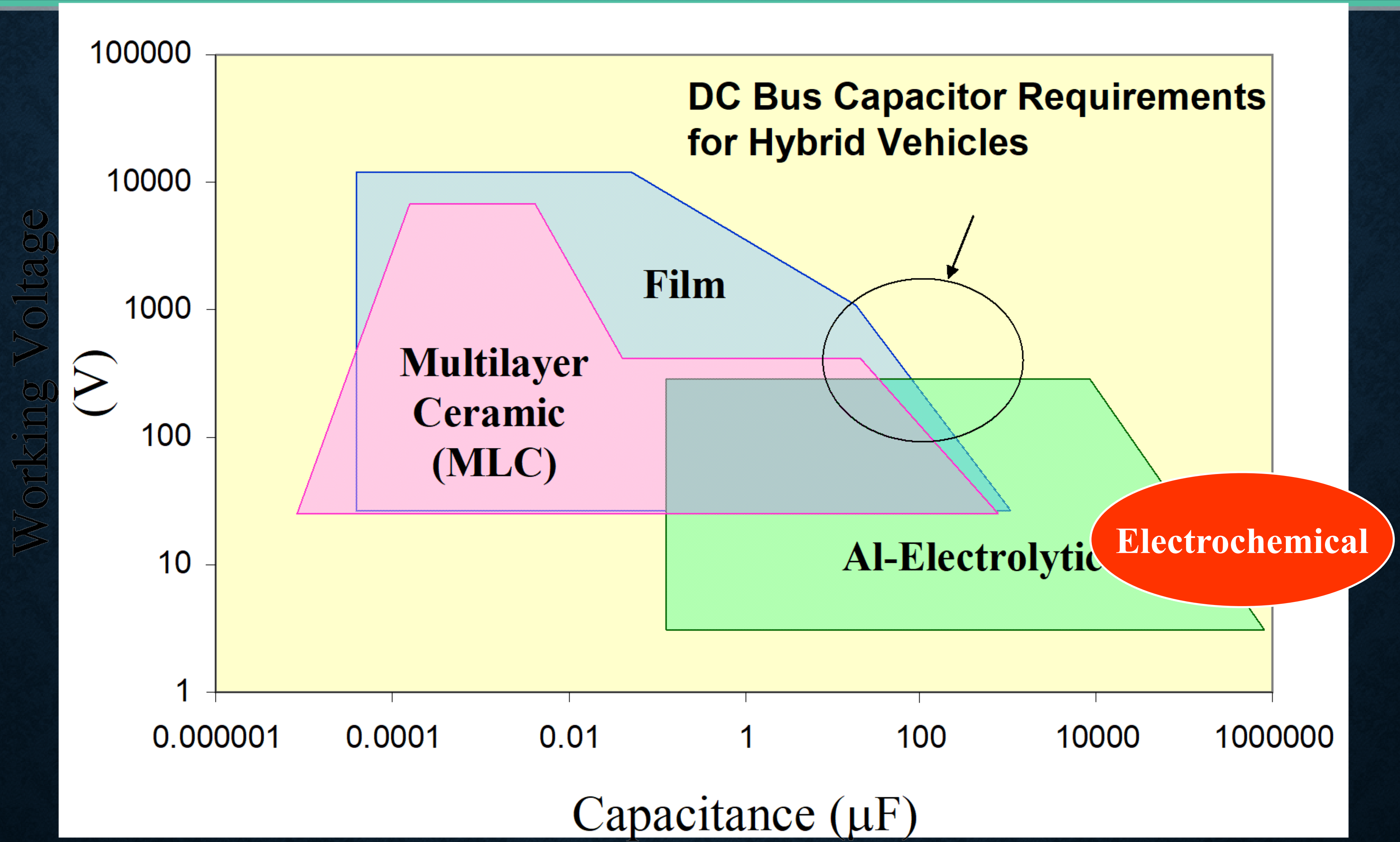
MANY DIFFERENT CAPACITOR TYPES

Glass dielectric used in Leyden Jar (ca. 1750)

Courtesy of Museum Boerhaave

Commercial Capacitors

COMMERCIAL CAPACITOR RANGES



PERFORMANCE OF COMMERCIAL CAPACITORS

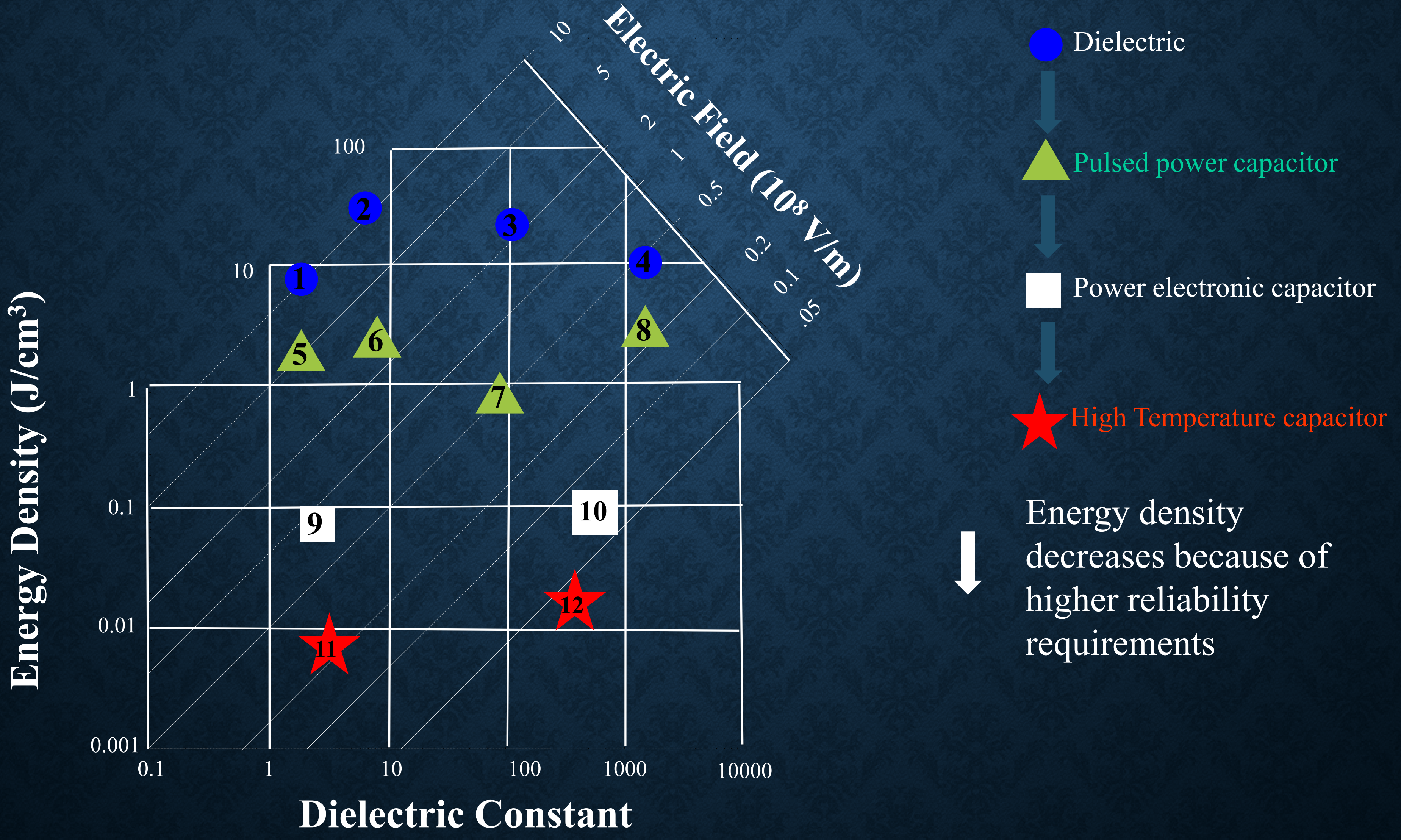
Capacitor	Temp. Range (°C)	Current/ Vol. (A-rms/cm^3)	Energy Density (J/cm^3)	Vol. Eff. (μF/cm^3)	Failure Mode
DOE Specs.	-55 to 105	**0.63**	**0.90**	**5.0**	**Benign**
Ceramic	-55 to 125	**0.67**	**0.20**	**1.7**	**Mechanical**
Polymer film	-55 to 85	**0.05**	**0.10**	**0.21**	**Thermal**
Electrolytic	-40 to 105	**0.05**	**0.80**	**6.42**	**Thermal**

Meets DOE Vehicle technology Goals

Incremental improvement needed to meet Specifications

Significant improvement needed to meet Specifications

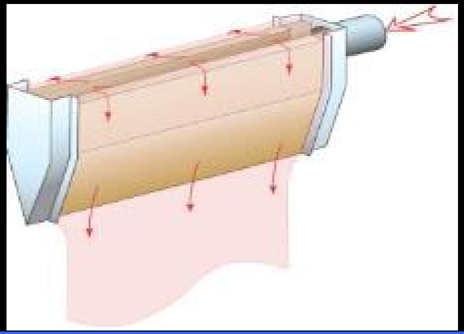
ENERGY DENSITY OF MATERIALS AND CAPACITORS



Energy density decreases because of higher reliability requirements

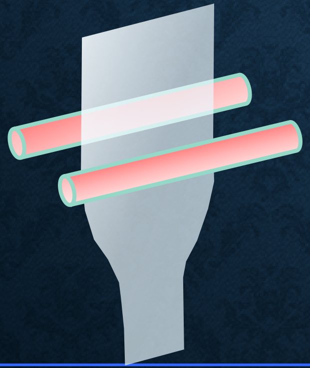
THIN GLASS: A TECHNOLOGY DISRUPTOR FOR CAPACITORS?

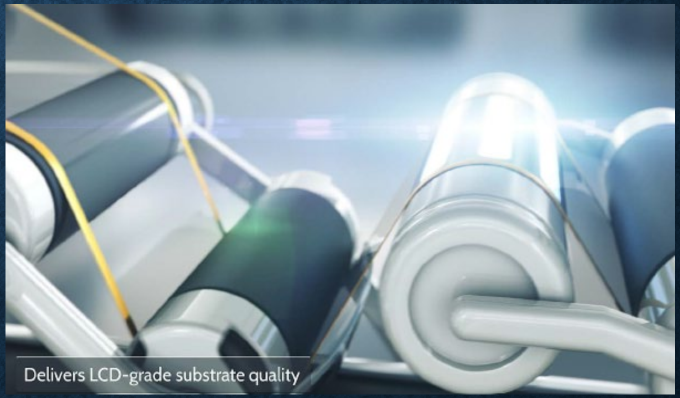
Over flow down draw process



Glass ribbon （4um～）

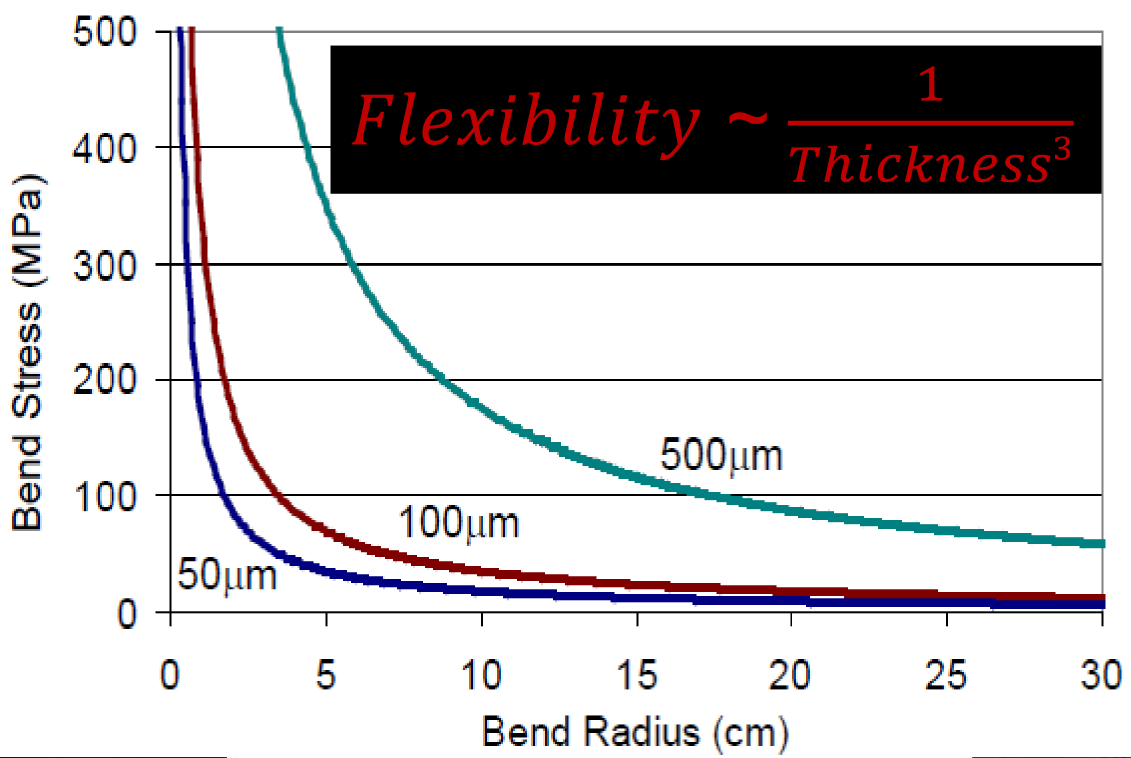
Re-draw process

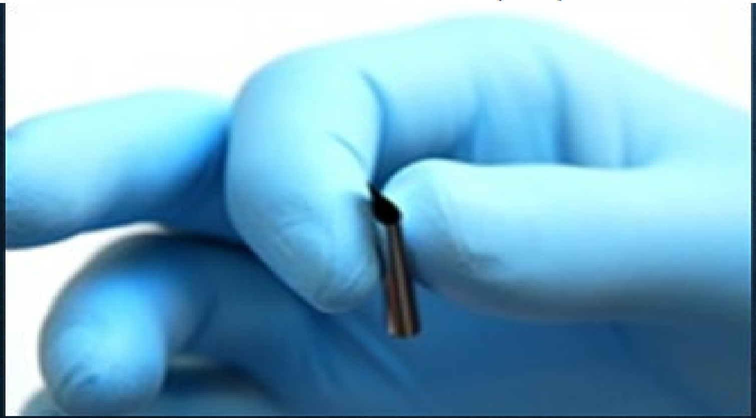




R2R processing of flexible thin glass sheet (© Corning)

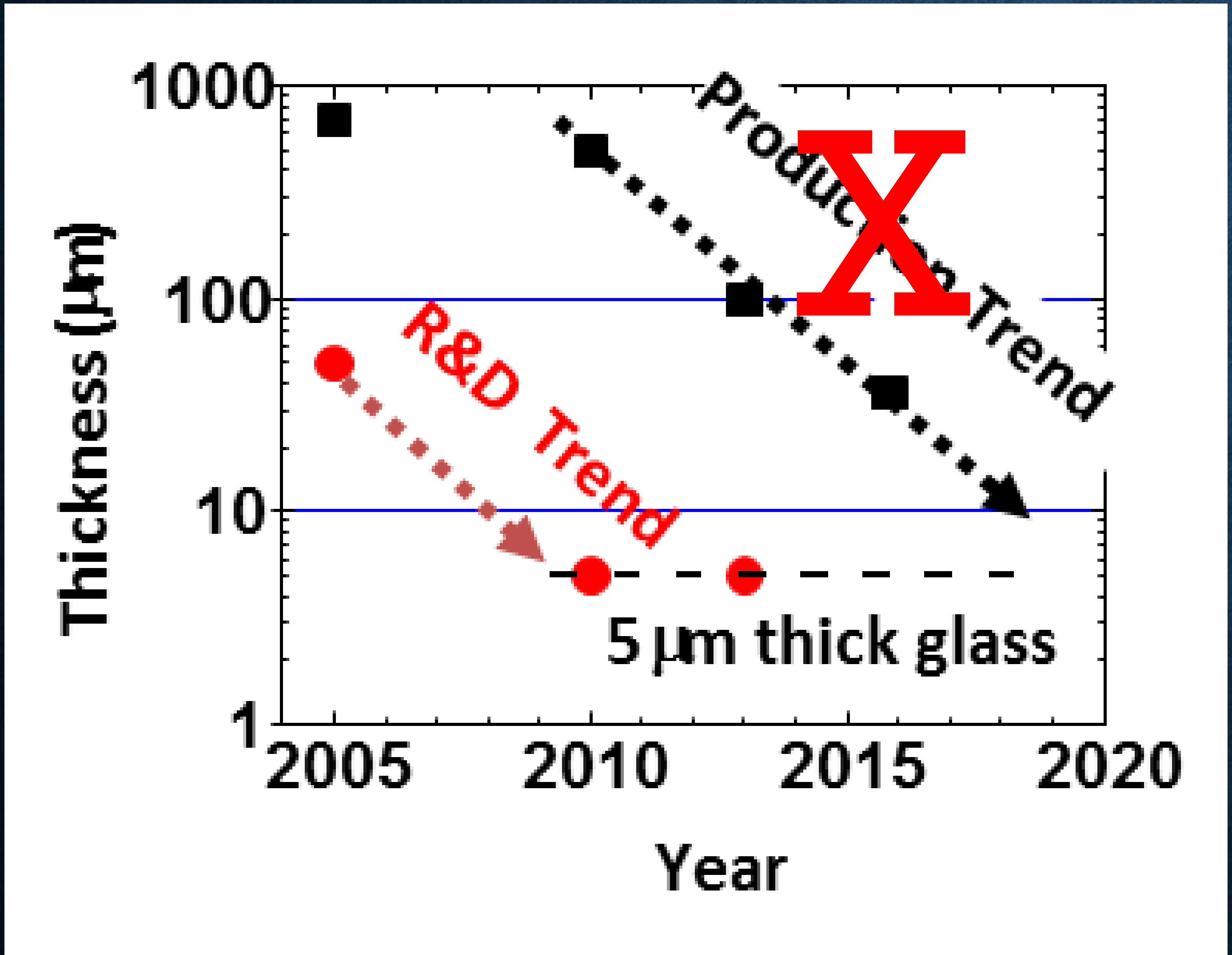
GLASS FLEXIBILITY

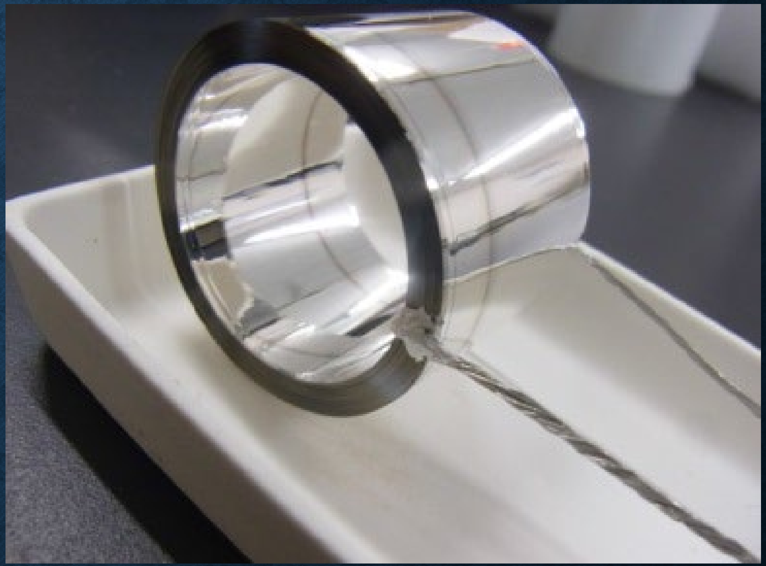




Plot courtesy of Corning Inc. , photo by April Benson (PSU)

PROJECTED GLASS MANUFACTURING TRENDS





Glass film capacitor, photo courtesy of T. Murata NEG Corporation

POLYETHERIMIDE "ULTEM" AS A HIGH TEMPERATURE CAPACITOR DIELECTRIC

Table I. High-temperature polymer dielectrics for capacitor applications

Property	PVDF-CTFE	PC	PPS	PEEK	Siloxane	PEI	PTFE	FPE	PI
Max. use temperature (°C)	125	130	150	150	150	200	260	275	300
Dielectric constant	11	3.0	3.1	3.2	8.6	3.2	2.1	3.3	3.3
Dielectric loss at 1 kHz (10^{-3})	50	1.3	0.5	4	60	2	0.5	2.6	2
Tensile strength (ksi)	7.5	9.5	36	17.4	N/A	14	3	9.5	10.5

Tan, Daniel, Lili Zhang, Qin Chen, and Patricia Irwin. "High-temperature capacitor polymer films." Journal of electronic materials 43 (2014): 4569-4575.

FUTURE R&D DIRECTIONS FOR DIELECTRIC MATERIALS

- Wide bandgap switch technology will drive power electronic circuits to higher temperatures **– high T caps will be needed**
- Polymer film capacitors are the best choice for DC bus applications
  - Benign failure mode, High ripple current capability,
  - New polymer materials are available; however, cost is the issue
- Physics based reliability models, coupled with system design will provide a path for reactive and active component selection.
- Dielectric materials are also important for packaging and have different design criteria.

SUMMARY

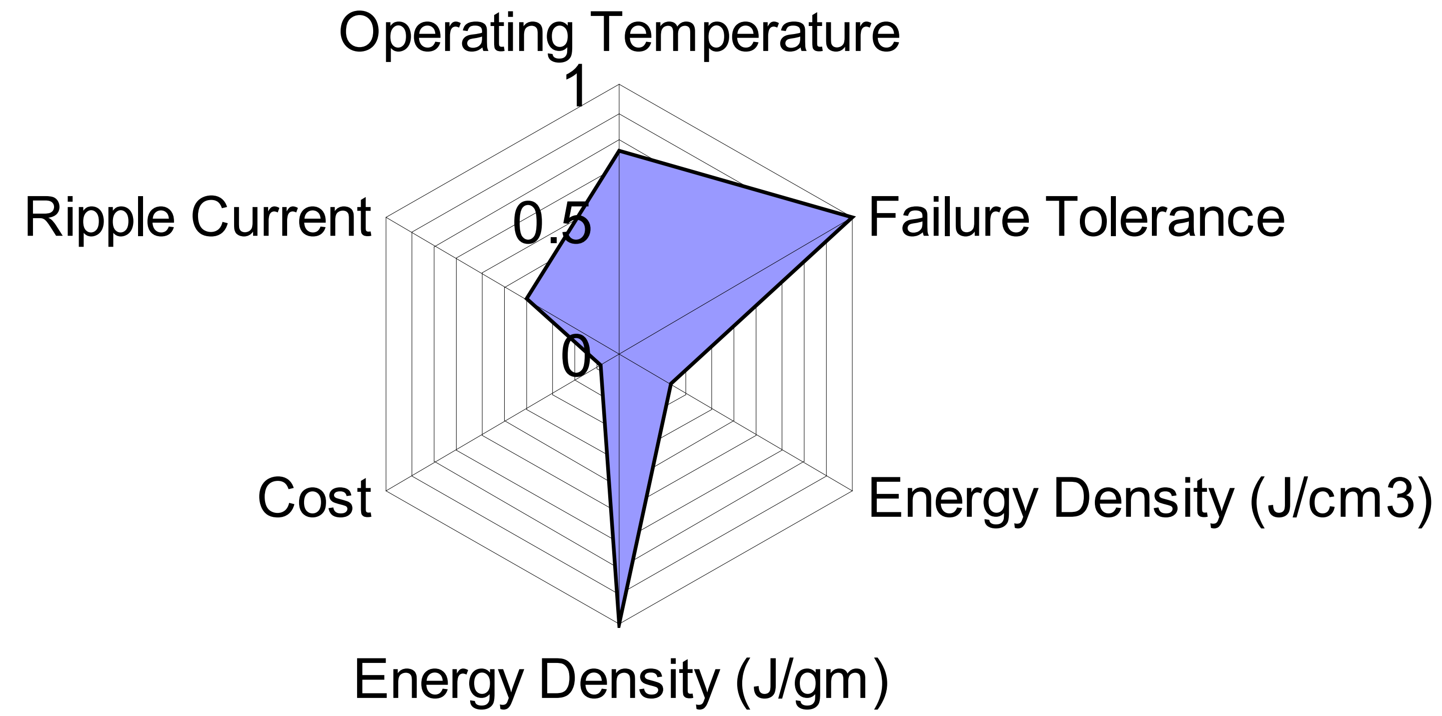
- Assessment shows challenges for all capacitor types.
- Commercial flat panel display glass is an interesting high temperatue capacitor
- Graceful failure mechanisms have been explored for high temperature capacitors.

EXTRA SLIDES

PROJECT RELEVANCE TO THE FREEDOM CAR GOALS

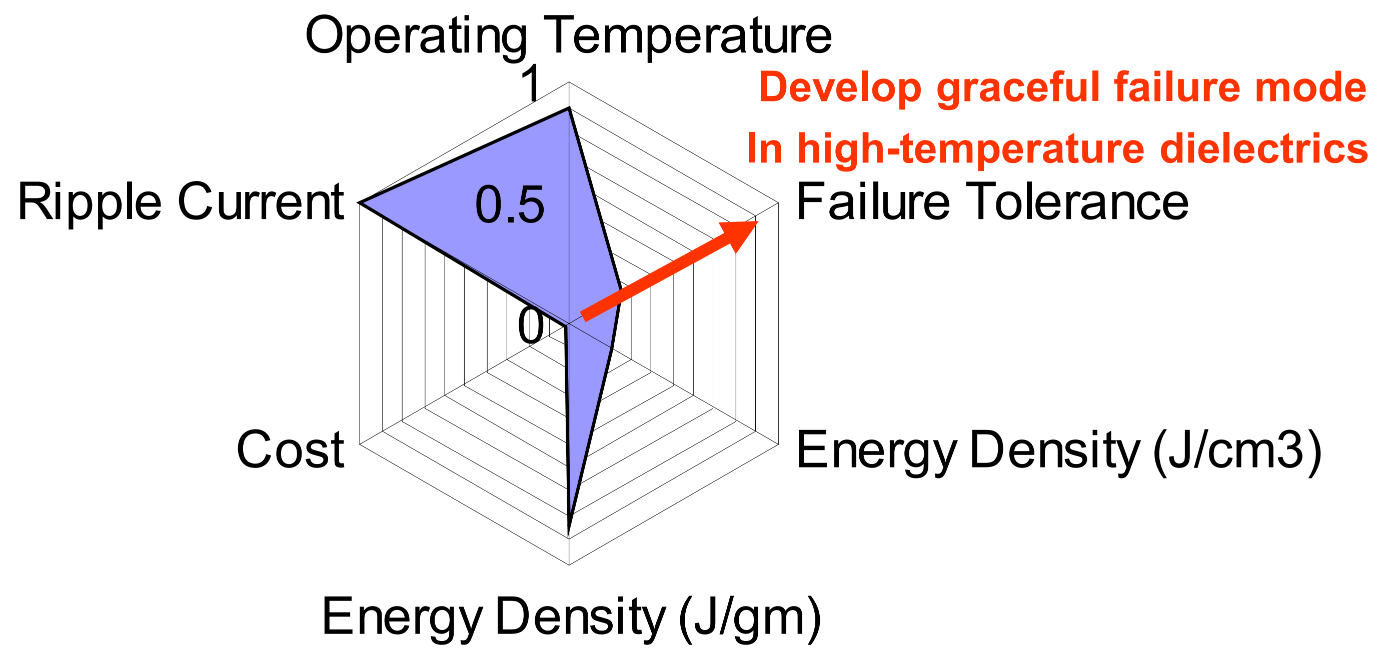
Freedom Car Goals		Penn State Program Contributions
Ambient Temp	105°C	High temp dielectric materials
Ripple Current	250 Amp	Low dielectric loss and ESR, high temperature performance
Failure Mode	Benign	Graceful failure mechanisms
Volume	0.4 liter	High energy density
Cap/Volt	2000 μF/ 600V	High permittivity materials and high breakdown strength
Cost	$30	Low cost materials and processes (i.e. glass)

POLYMER FILM CAPACITORS - GAP ANALYSIS*

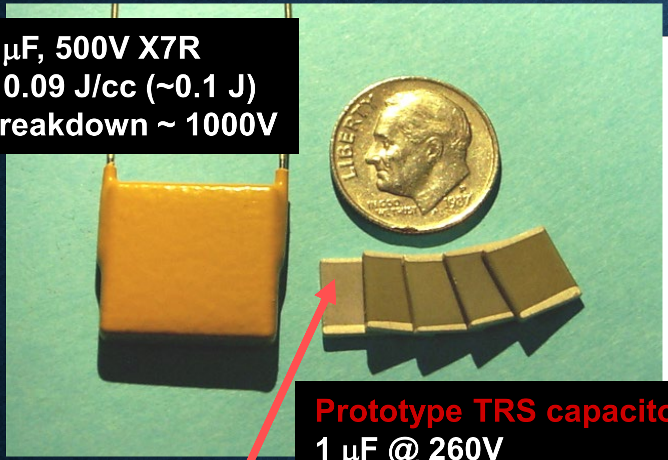


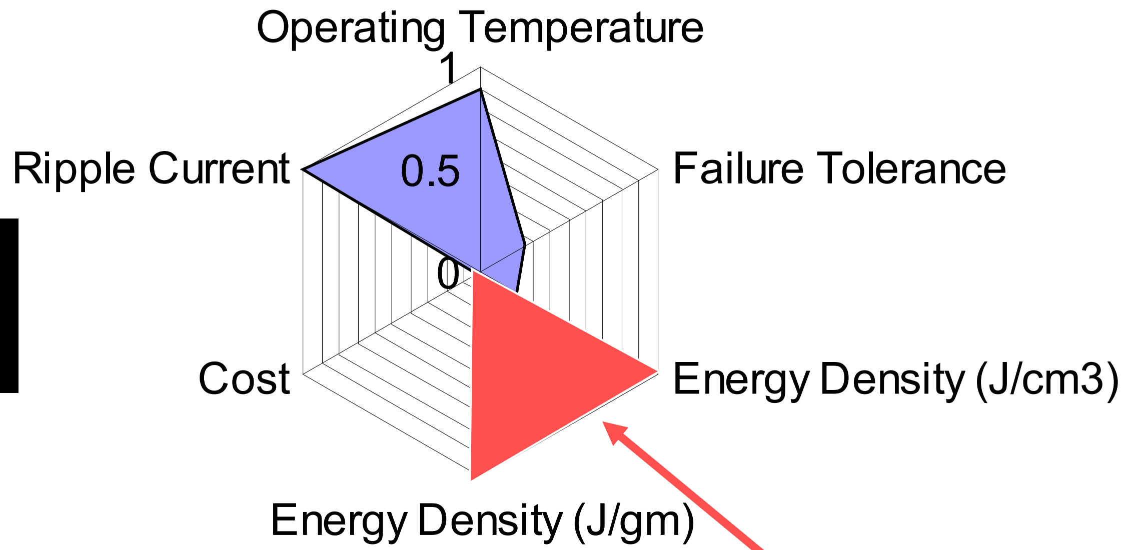
* Results from DOE capacitor assessment (August 2004) (ORNL subcontract to PSU)

COMPARISON OF MLCC CAPACITOR PARAMETERS WITH DOE FREEDOM CAR SPECIFICATIONS.



Past DOE capacitor programs focused on increasing energy density (prior to FY05)





Prototype capacitors are stacked to achieve larger capacitance values

DOE specifications were achieved

HIGHLY ACCELERATED LIFE TESTING (HALT)

- Combine high temperature and high voltage
- No failure was seen after a week at 300°C and 800 V.
- Failure in Schott Glass sample after 5 days at 400°C and 800 V.
- Future work will explore Corning samples

HALT system designed and built at Penn State University