SAND2023-07812C

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HYBRID METALIZED POLYMER CORE (HMPC) INITIAL RESULTS OF PROTOTYPE MASS OPTIMIZED PULSED POWER HARDWARE

Presented by Charles Rose

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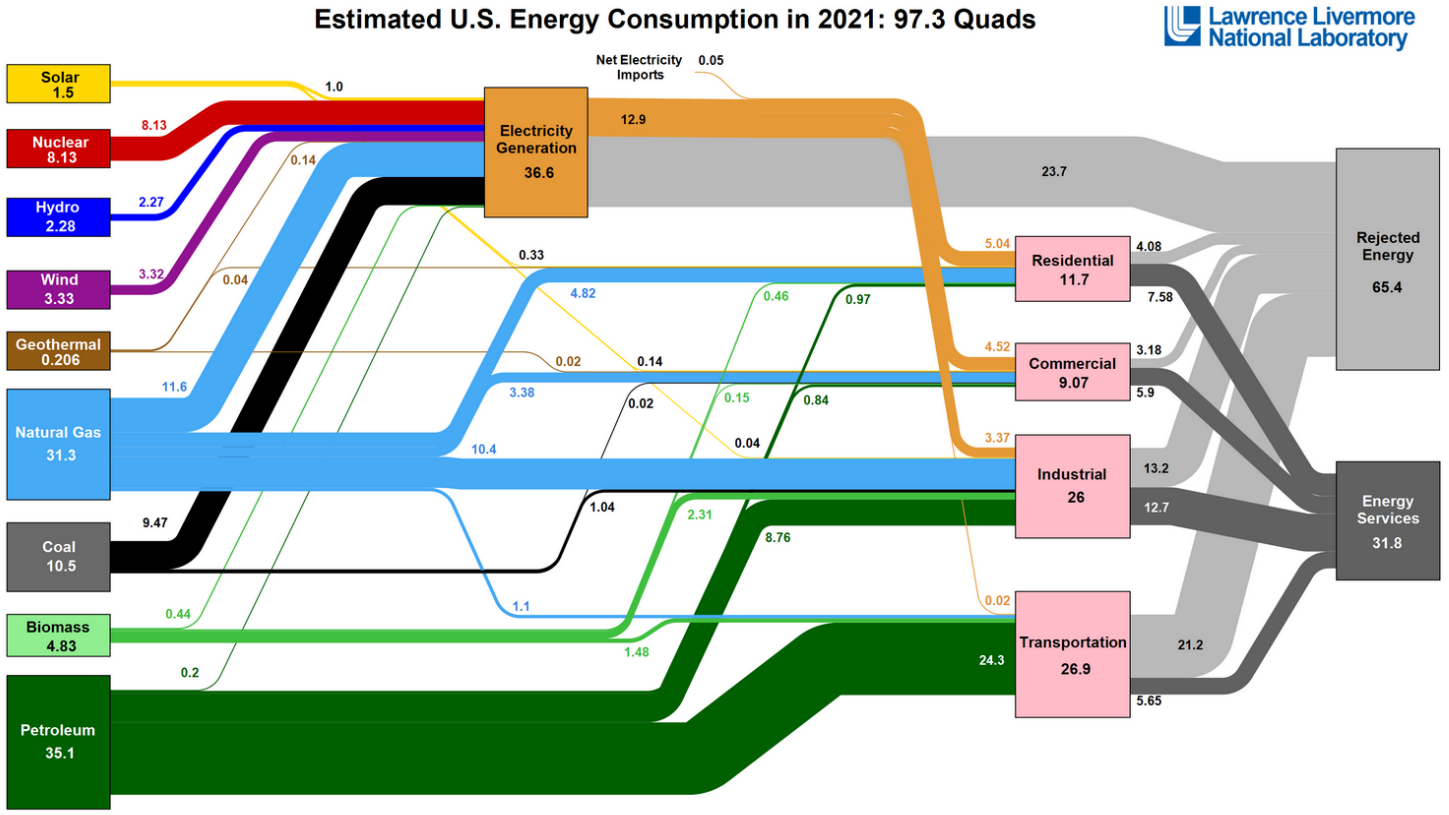
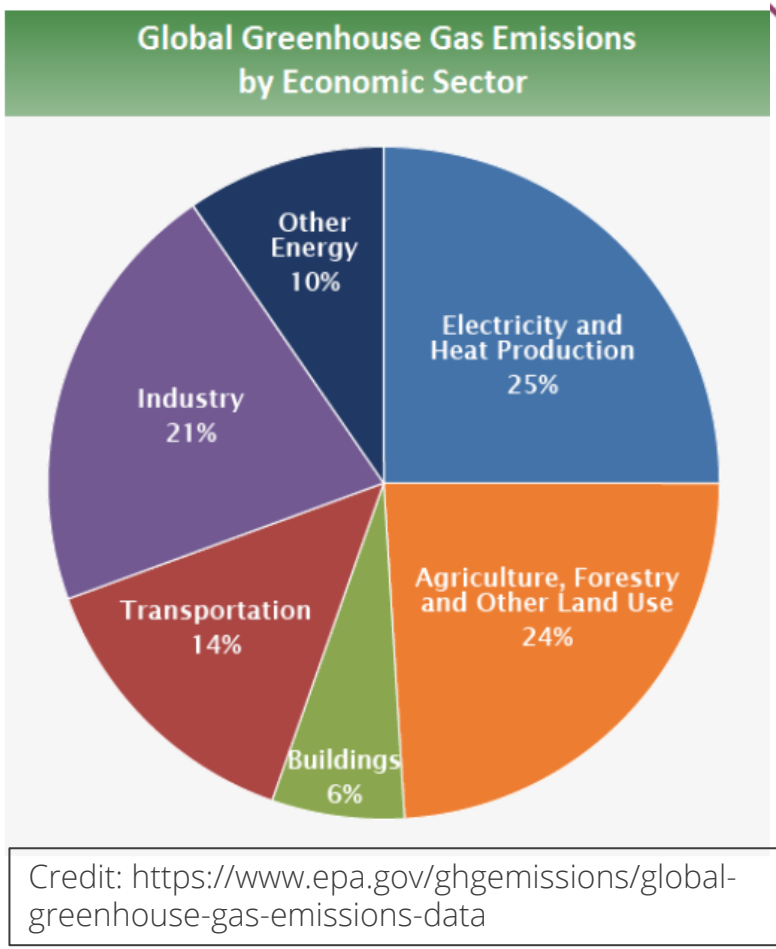
August 14 2023, 4:00-4:20 Room 404

Solid Freeform Fabrication Symposium

Austin Texas, USA

WHY SHOULD YOU CARE ABOUT PULSED POWER?





Credit: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

Take away: To mitigate the worst aspects of global warming we must take rapid action to remove natural gas, coal and petroleum from the energy equation. While sources like wind, solar, hydro etc. seem to be viable future solutions classical (fission) nuclear energy generation is a proven, safe, scalable, solution today with pulsed power as the vehicle for long term fusion based nuclear energy generation.

FISSION VS. FUSION AND WHY WE NEED FUSION

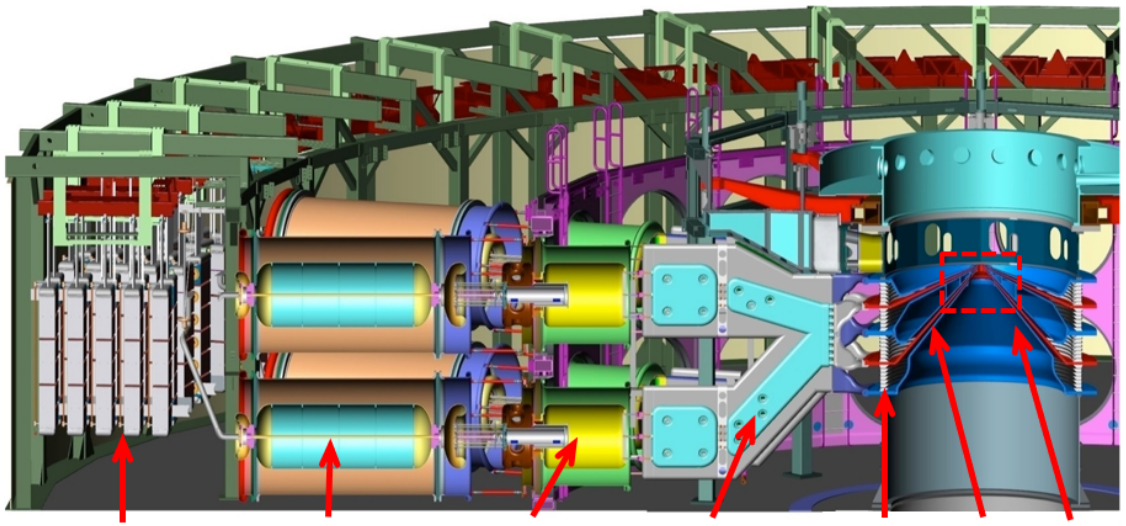
- Fission➔ Energy today: break heavy elements apart producing energy and nuclear waste
  - Good "**short term**" solution especially if you want less nuclear proliferation
  - See "Megatons to Megawatts Program" essentially decommission nuclear weapons and mix highly enriched material with low-level material to produce energy generation grade fuel
  - ~ 20,000 bombs decommissioned and used as fuel [1]
- Fusion ➔ STAR POWER: smash together lighter elements creating energy and … essentially* energy
  - Excellent **long term** solution when commercially viable… ideally soon
  - **No generation of long lived radioactive waste** [2]
  - For all intents and purposes an infinite source of energy generation as this process does not require refined or rare elements.

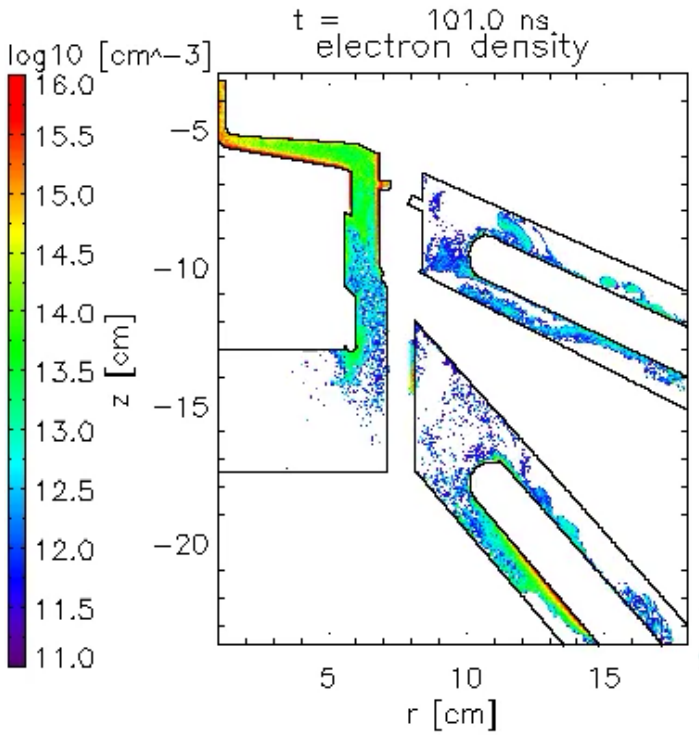
* Glossing over nuance here see me after talk for more explanation

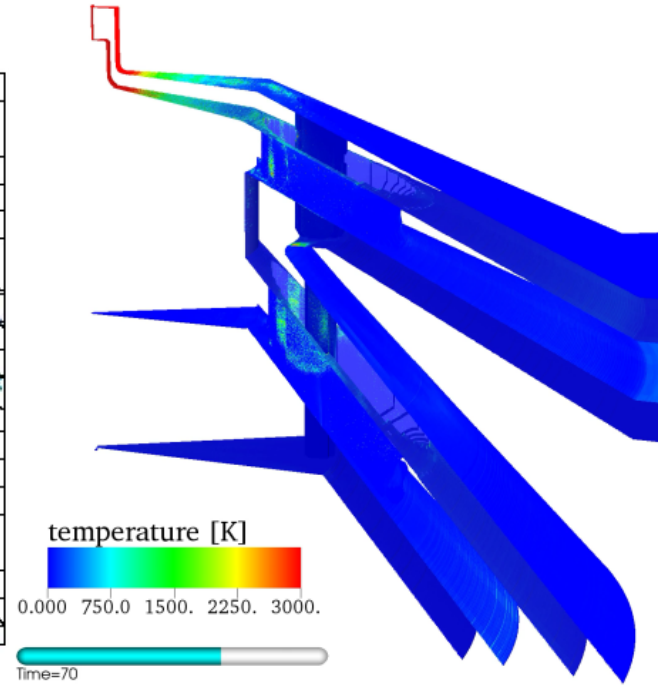
[1] http://large.stanford.edu/courses/2017/ph241/martelaro2/
[2] https://www.iaea.org/topics/energy/fusion/faqs

FUSION RESEARCH NEEDS FUSION TEST-BEDS

Traditional power flow hardware design/manufacture does not meet requirements for next generation pulsed power (**NGPP**). To meet mission requirements we must design for operation at considerably harsher conditions than Z-today (>2X capability) which delivers on the order of ~ 20 MA over ~ 100 ns, at ~ 80 TW of electrical power.

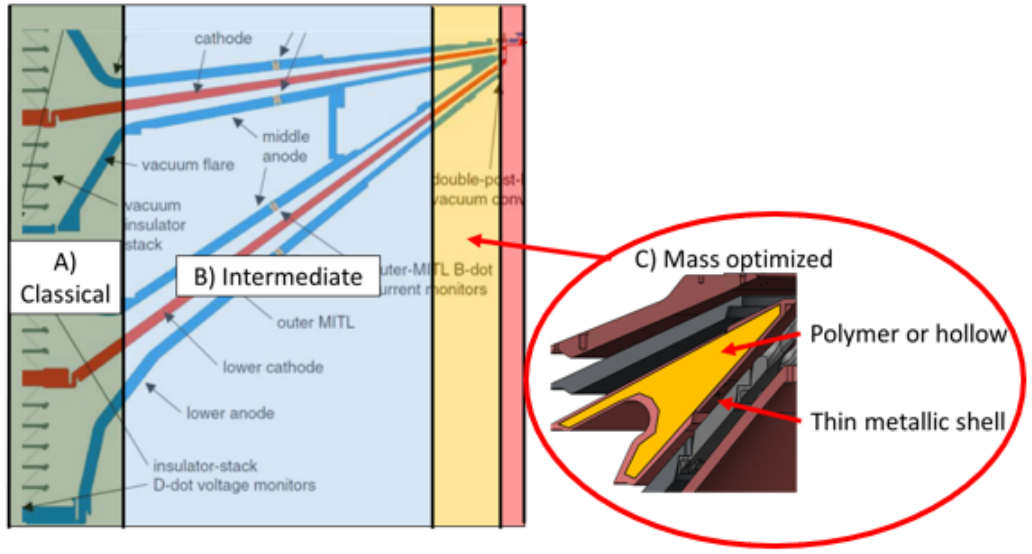






Images/simulation credit: Nichelle Bennett

DEBRIS MITIGATION IS A MAJOR LIMITATION FOR NGPP



Pre-shot photo of MagLIF load hardware

Post-shot photo of damage

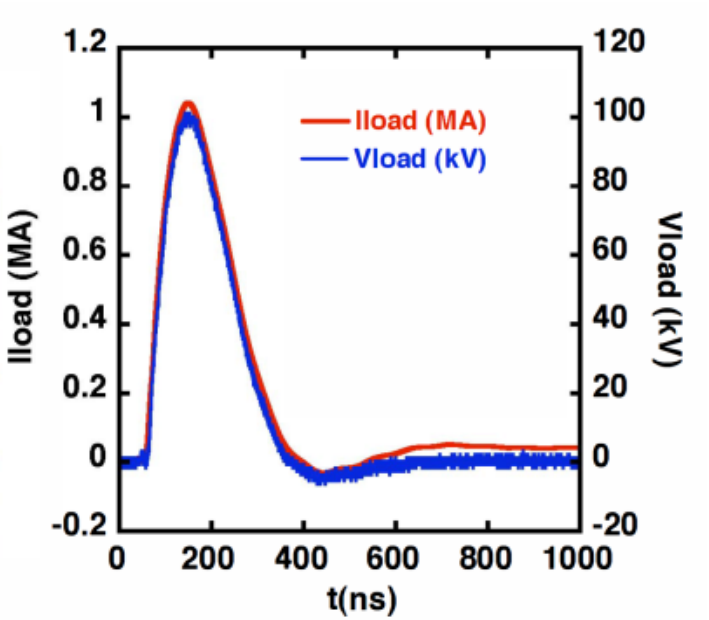
Images credit: SAND2016-9145PE

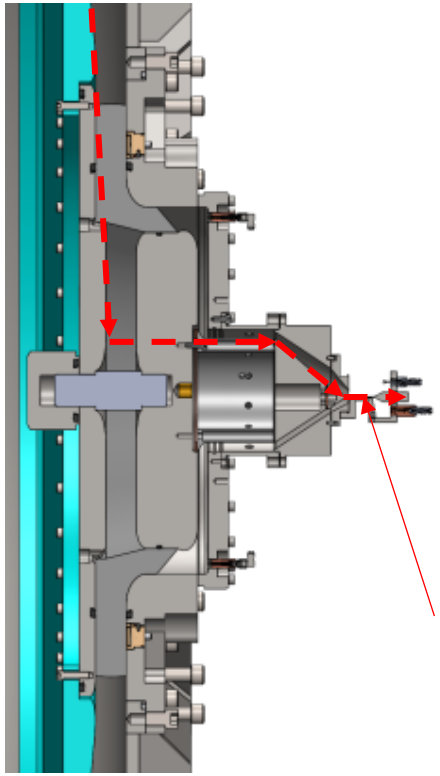
Large amounts of debris are generated every shot. Given NGPP will be greater than 2X current delivery the anticipated "explosion" radius is expected to double generating potentially untenable volumes of debris.

➔ **Solution direction is to dramatically mass optimize hardware**

EXPERIMETNAL TEST-BED: MYKONOS LTD

Mykonos is a Linear Transformer Driver (LTD) at Sandia National Laboratories in Albuquerque New Mexico capable of delivering ~ **1 MA** into a matched load. Practically, load inductance is always higher and delivered currents are on the order of 0.5 - 0.9 MA



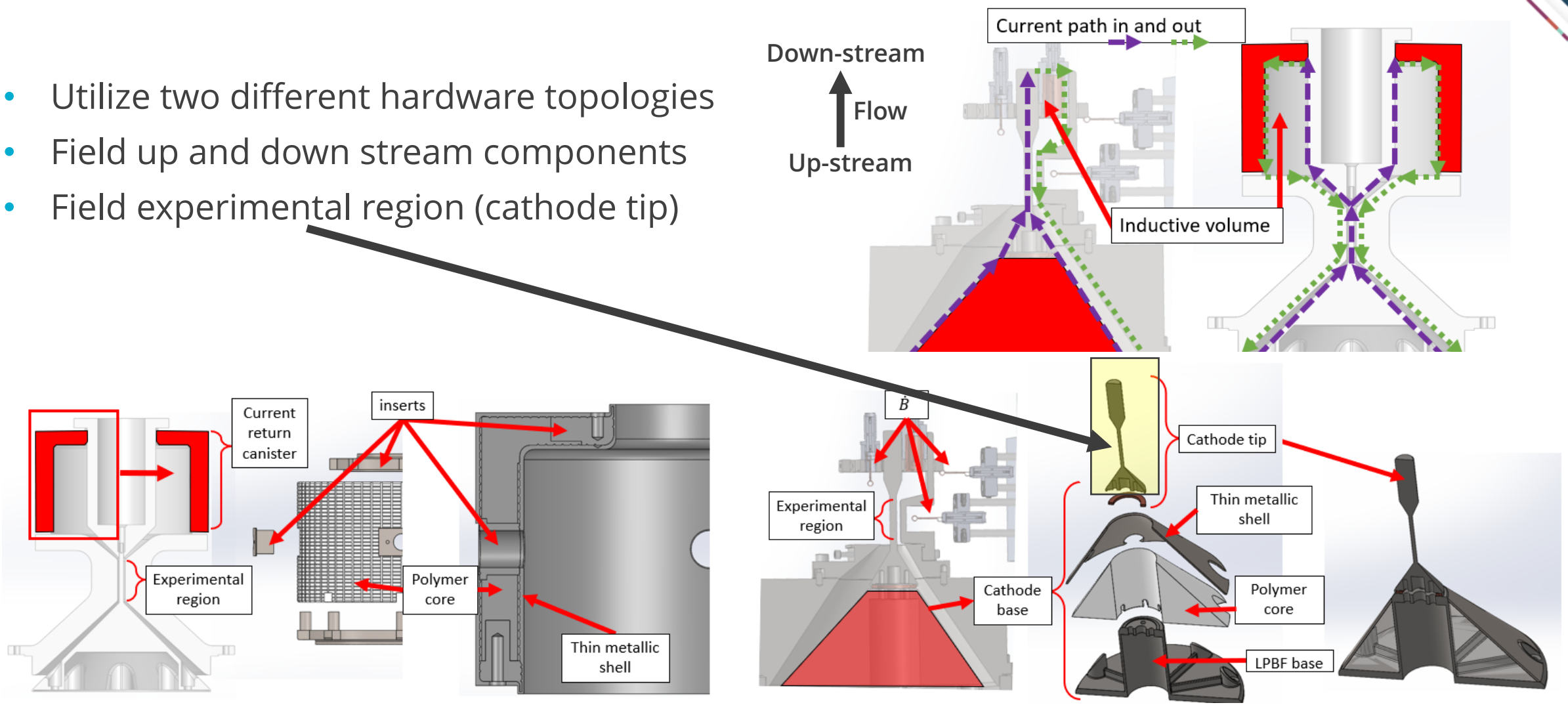


Experiment happens here

Image and waveform credit:
M. G. Mazarakis *et al*., "Experimental validation of the first 1-MA water-insulated MYKONOS LTD voltage adder," *2011 IEEE Pulsed Power Conference*, Chicago, IL, USA, 2011, pp. 625-628, doi: 10.1109/PPC.2011.6191552.

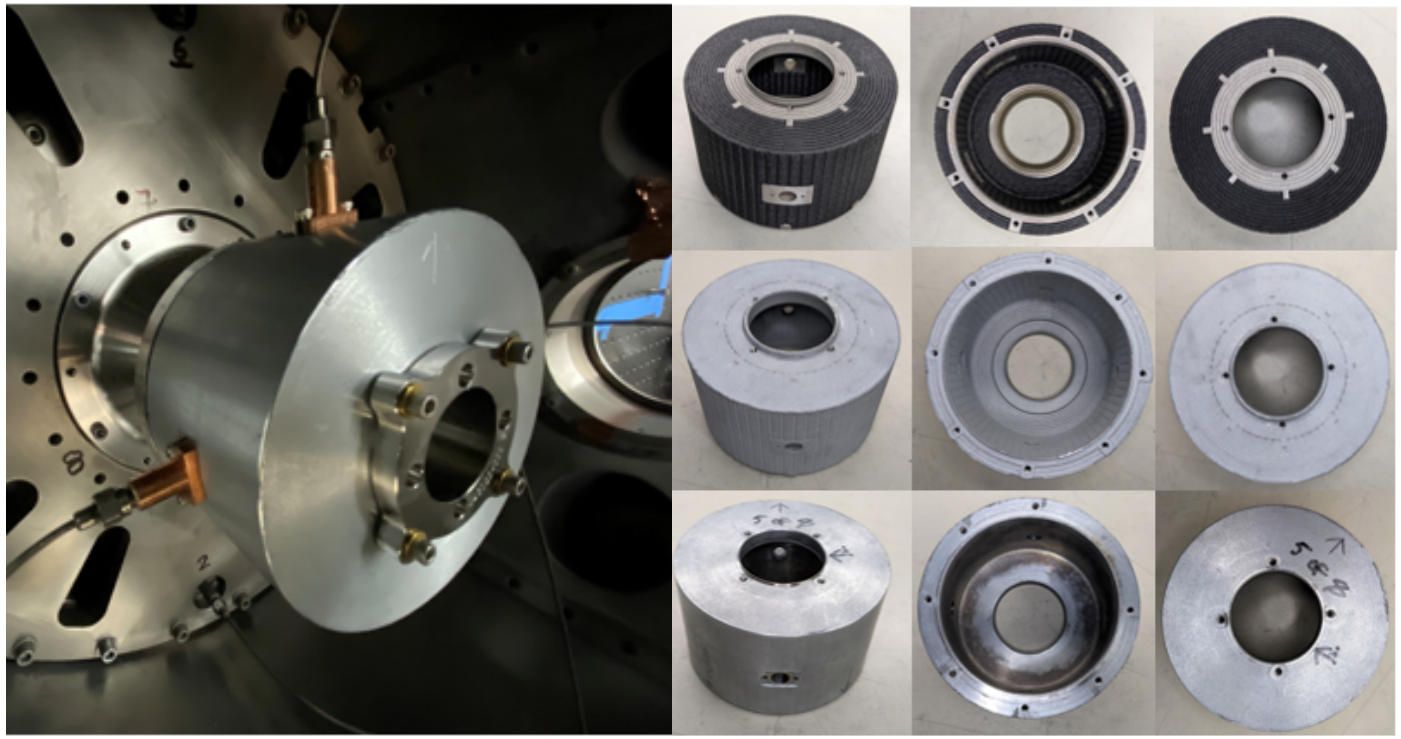
INVESTIGATE HMPC OVER 3 SHOT SERIES

- Utilize two different hardware topologies
- Field up and down stream components
- Field experimental region (cathode tip)



1ST SERIES: DOWNSTREAM CURRENT RETURN CANISTER

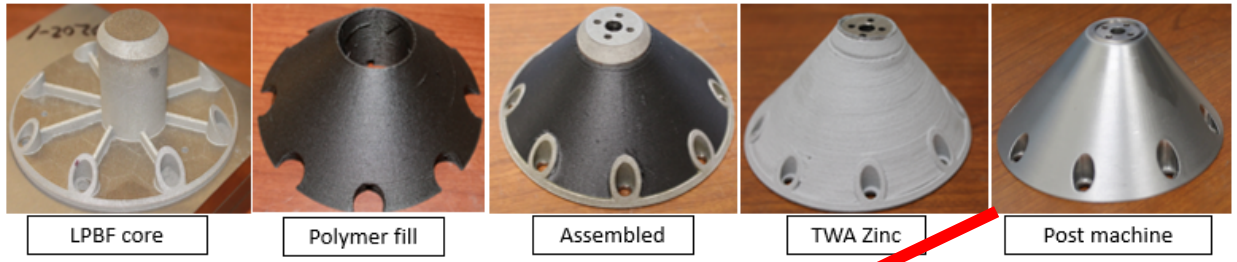
- Redesign current return canister based off of Brian Hutsel's previous work*
- HMPC polymer core requires low-melt bond coat (often zinc) before stainless can be sprayed via TWA.
- Intent was for external shell to be TWA 304L (~ 1 mm), but machine failed during run forcing us to run with a zinc power flow surface!

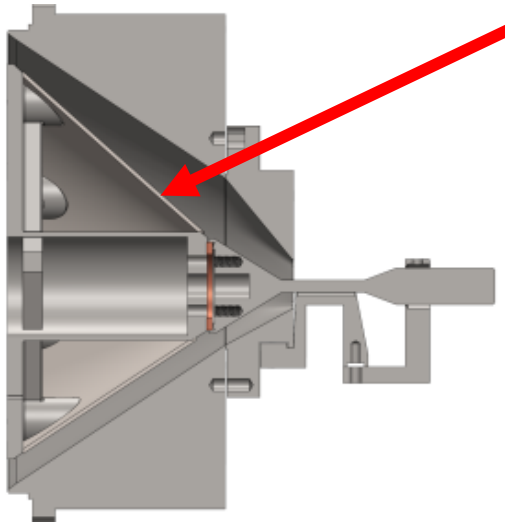


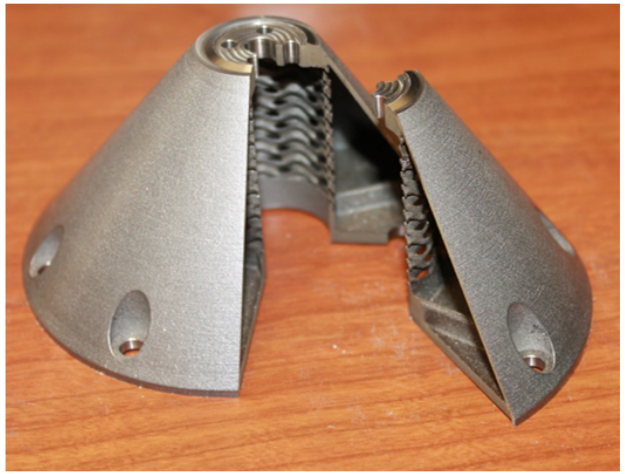
* B. T. Hutsel *et al*., "Millimeter-gap magnetically insulated transmission line power flow experiments," *2015 IEEE Pulsed Power Conference (PPC)*, Austin, TX, USA, 2015, pp. 1-5, doi: 10.1109/PPC.2015.7296902.

2ND SERIES: UPSTREAM CATHODE BASE

- Redesign cathode base based off of Derek Lamppa's previous work.
- Hybridize FDM + LPBF + TWA and CS.
  - ➔ intermediate machine step between TWA CS
- Also produce fully LPBF "thick" (~1 mm) and "thin" (200 um) versions to test hollow core complications



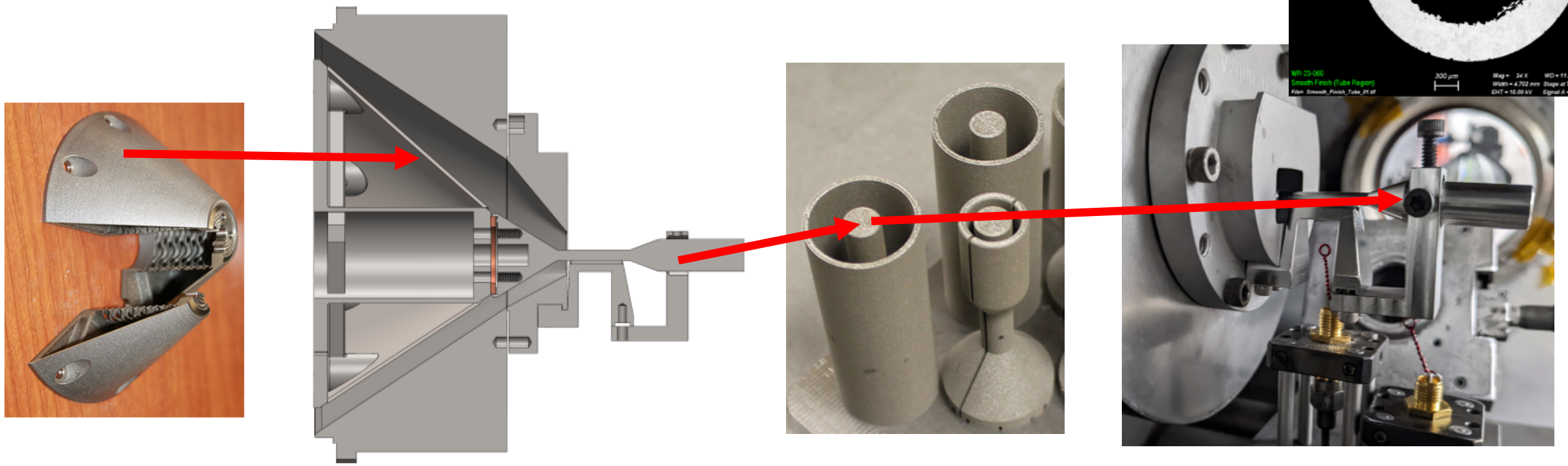




3RD SERIES: EXPERIMENTAL HIGH FIELD REGION

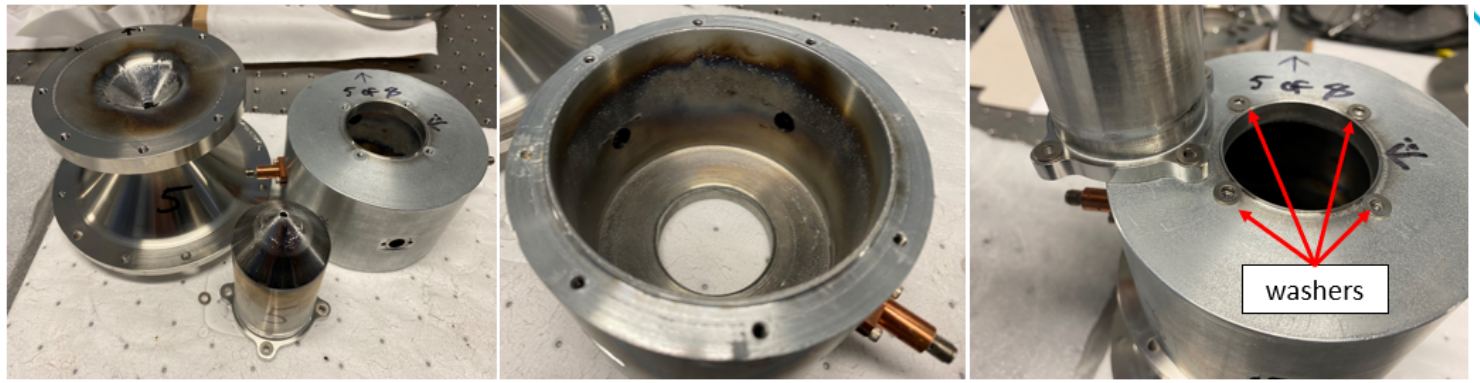
- 3D print both cathode base and tip (experimental region) with LPBF
- Cathode tip printed both solid and hollow
  - Hollow cathode simulates HMPC where core is etched out

We believe this is the first fully additive powerflow cathode with Z-like current densities

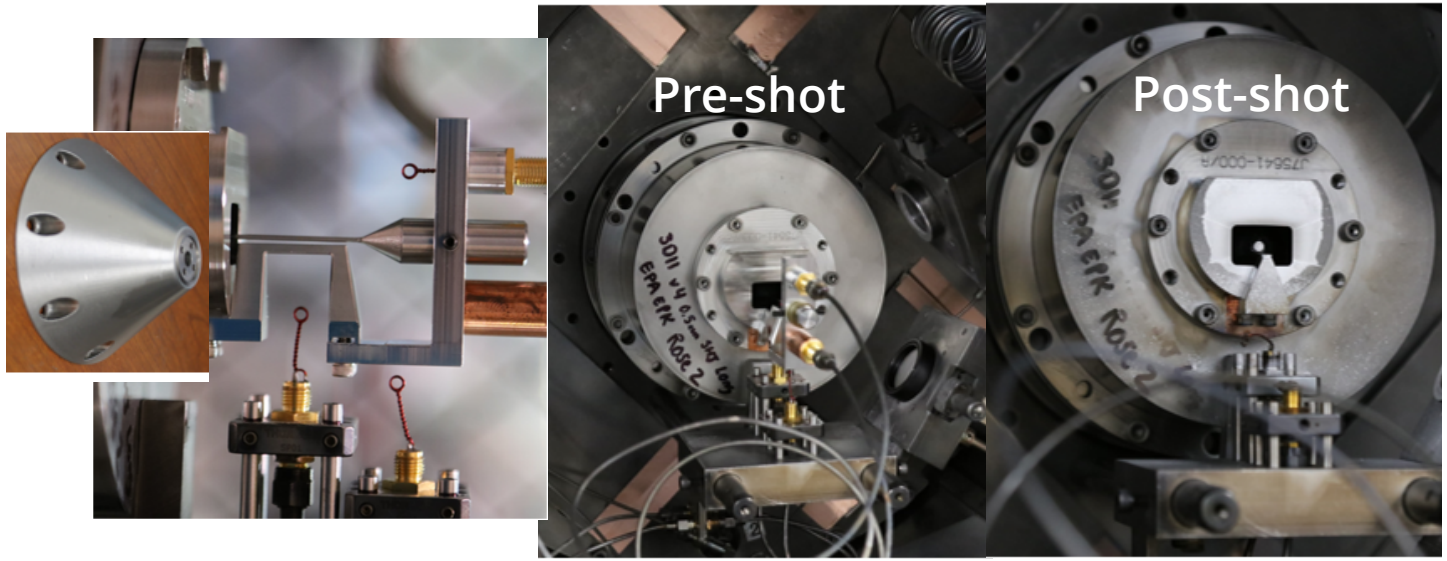


RESULTS: POST SHOT HARDWARE

Return canister survived ~ 600 kA shots at ~ 1 mm of zinc. Part was/is reusable.



Cathode base survived ~ 700 kA shots with ~ 1 mm zinc on surface and part is/was reusable.

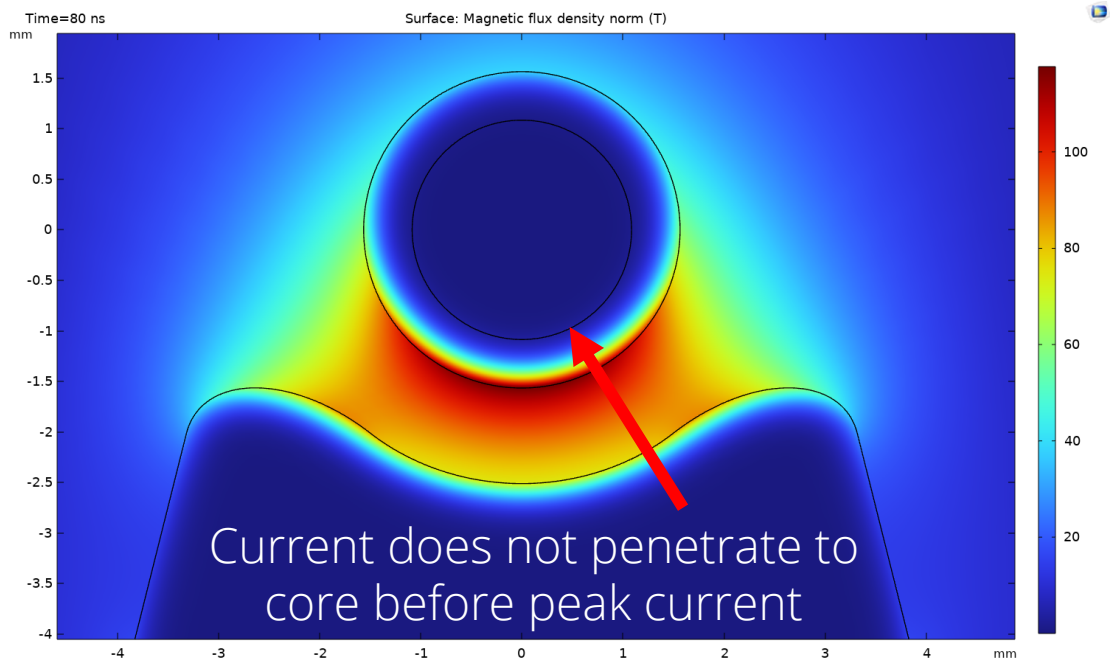


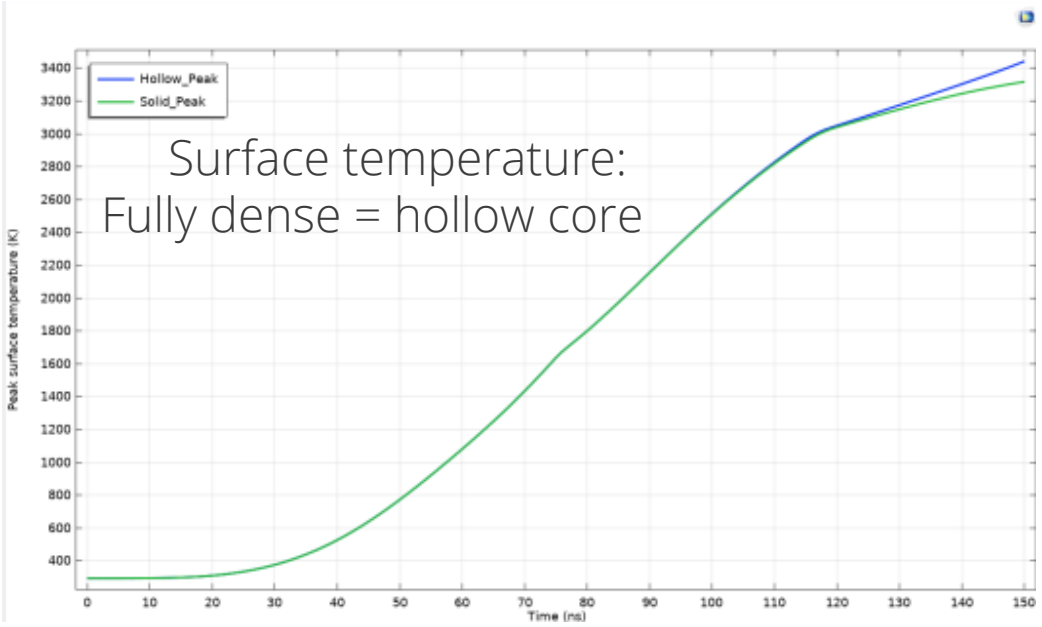
Cathode tip transmit ~ 800 kA essentially non perturbative for both solid and hollow core with 500 μm of 316L SS

WHY DID SOLID BEHAVE SAME AS HOLLOW?

Current does not diffuse deep enough to reach the central hollow region before peak current

➔ solid will behave same as hollow ➔ **This is how we mass optimize**



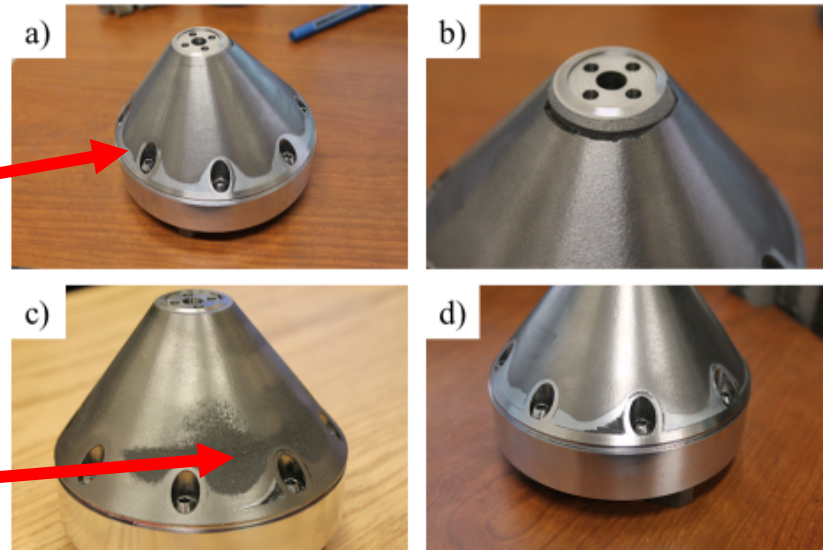


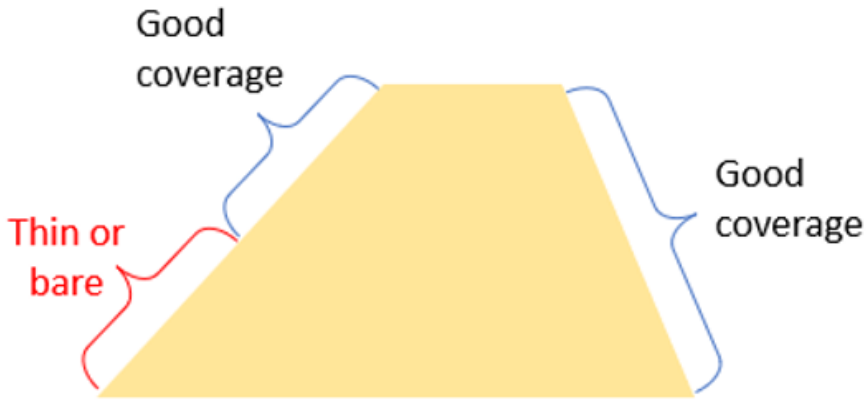
PITFALLS AND LIMITATIONS OF HMPC

HMPC hardware for powerflow is currently difficult to manufacture. Given this, a re-design with this process at the heart should greatly reduce complexity and costs

Bond coat limiting progress (zinc or aluminum intermediate etc.), need to find high-temp polymer to directly coat higher temp metallics (304L)

A-symmetry and high aspect ratio holes are very difficult, but mitigated with clever use of inserts





KEY TAKE AWAY: HMPC IS NON-PERTURBATIVE AND MASS SAVINGS ARE EXCELLENT

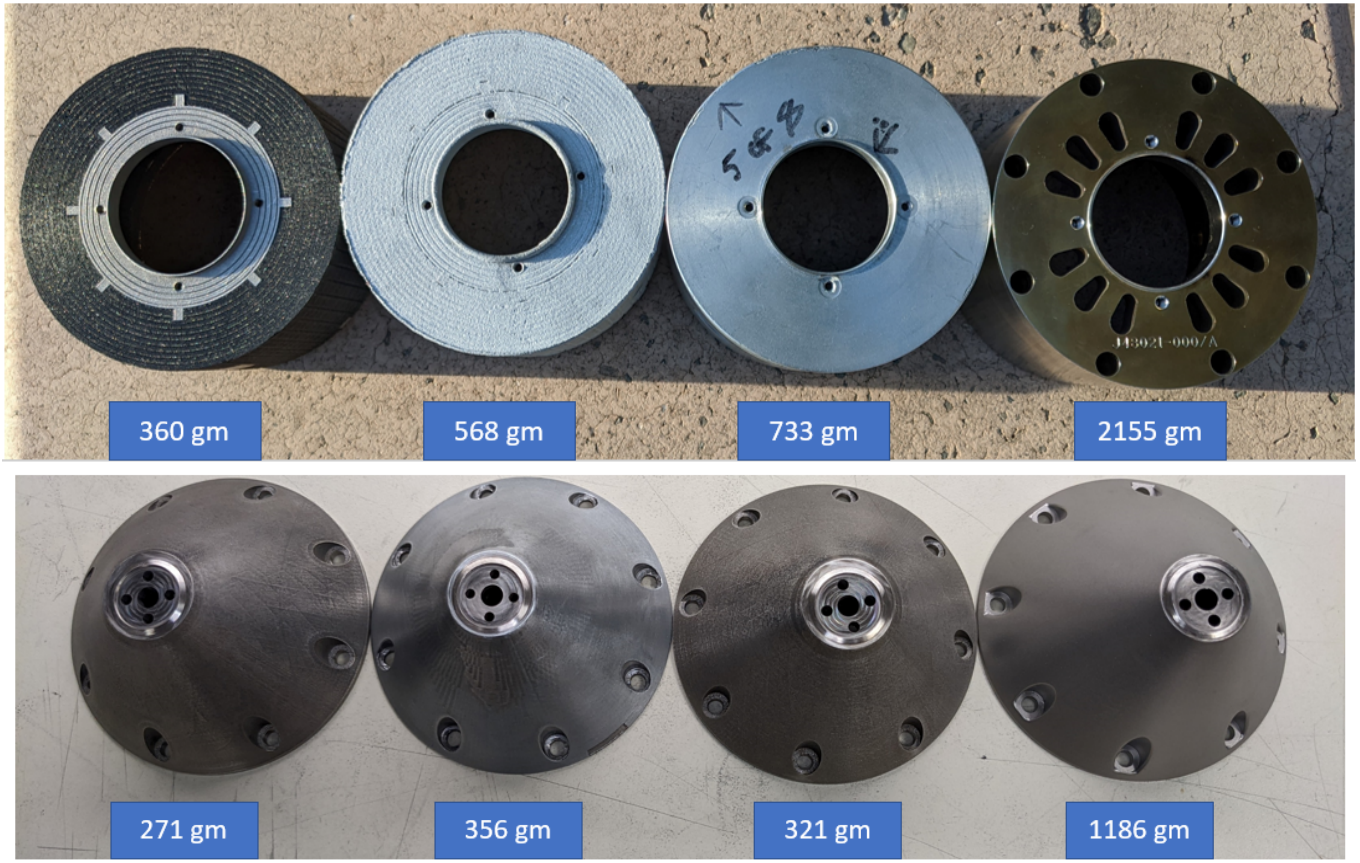
HMPC ~ 3X mass savings accomplished. Further mass optimization could be done.

Components were noticeably easier to work with and install

Machine was essentially none-the-wiser for any case. Polymer core, hollow core, zinc vs stainless etc.

HMPC survived all up/down-stream shots with essentially no observable differences.

Process appears viable for debris mitigation on NGPP

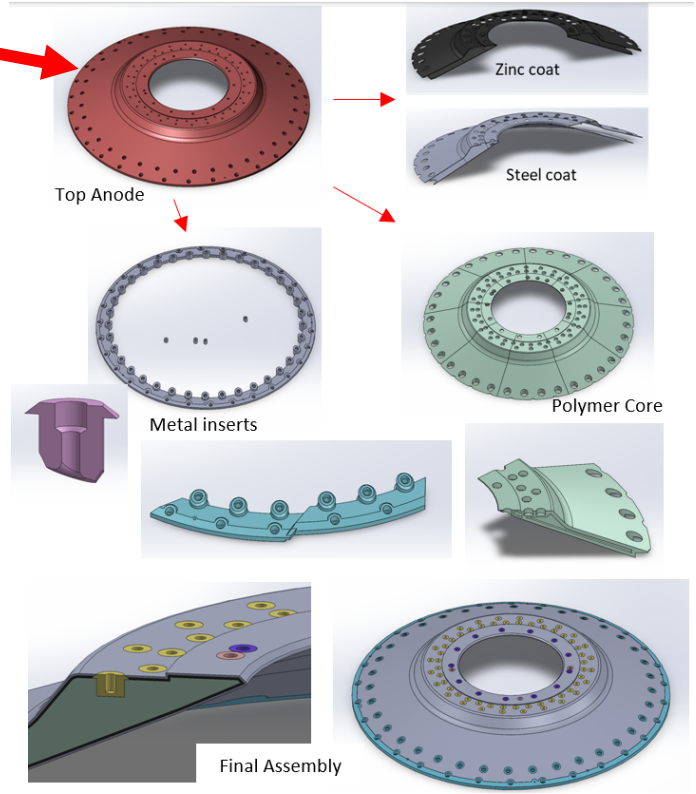


NEXT STEPS FOR HMPC

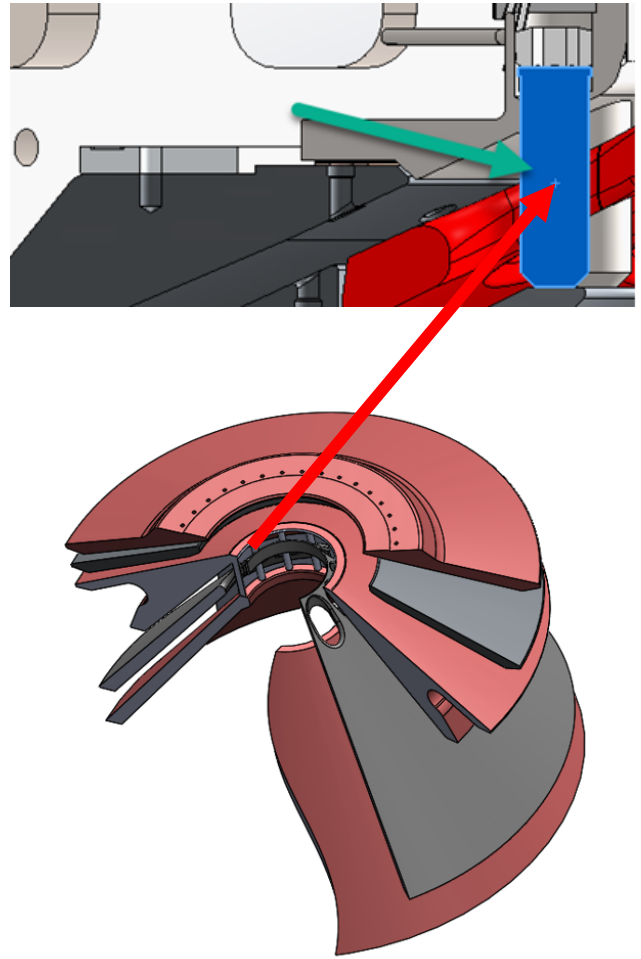
Flesh out scalability by developing and fielding full-scale Z convolute.

Flesh out Z-like conditions by building upper/lower Z anode post(s) ➔ Ideally garnering a ride along shot

Collaborate with external partner to define early goals/gaps etc. necessary to pivot into industrial fabrication space, ideally capitalizing on economy of scale and recent advancements in additive manufacturing.



Upper anode post



QUESTIONS?

We are activity recruiting. For more information please see:
https://www.sandia.gov/careers/career-possibilities