

Next Generation Ceramic Processing:

Flash Sintering and Other Technologies

Ceramics UK, 29TH June, 2022

Dr David Pearmain

Changes in Ceramic Manufacturing are coming...

- Custom process development in a flexible **Advanced Ceramic Pilot Line**
- Technology Development & Commercialisation;

Digital

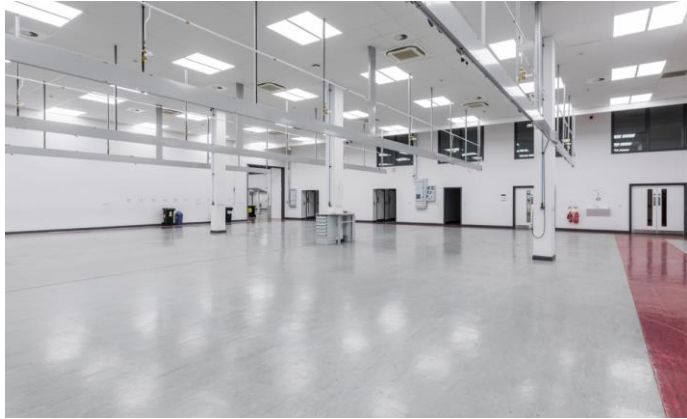
**Hydrogen
Fire**

**Additive
Manufacturing**

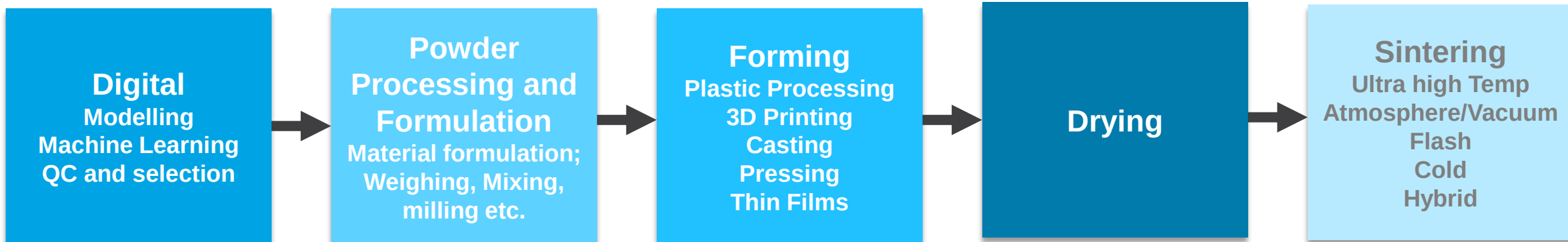
**Flash
Sintering**

Advanced Ceramic Pilot Line – Strength in Places and the MICG

- New facility to specialize in process development and technology scale up

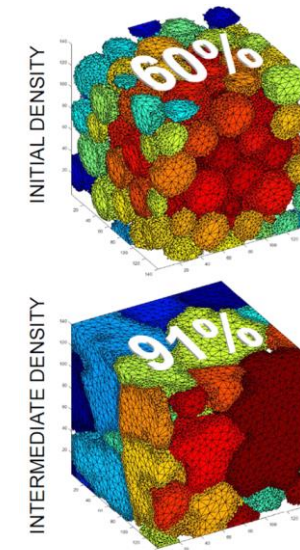
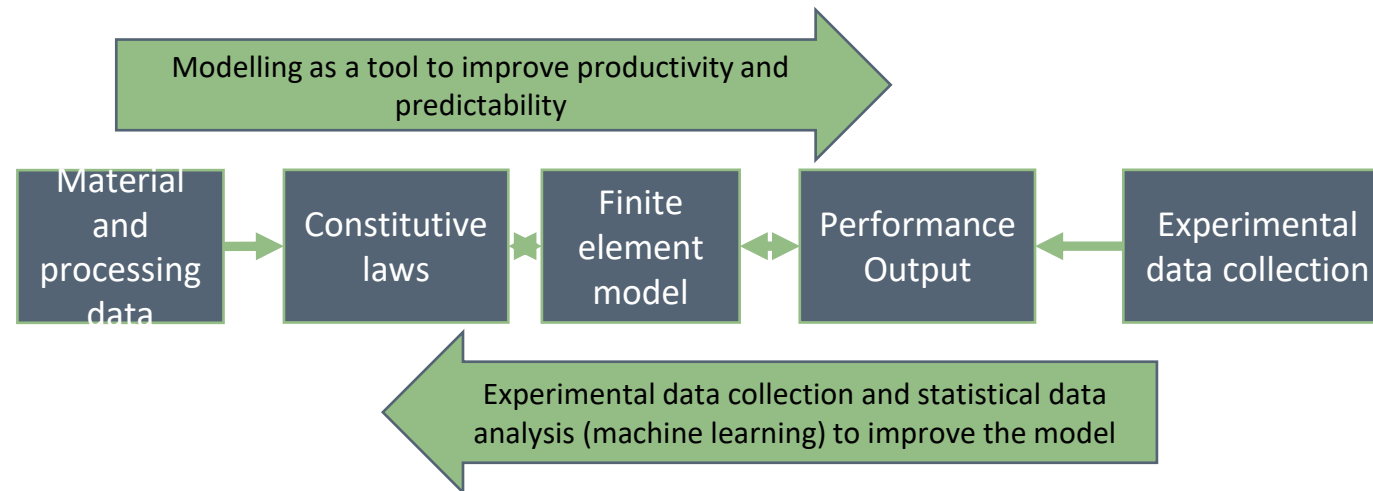


MICG Midlands Industrial Ceramics Group

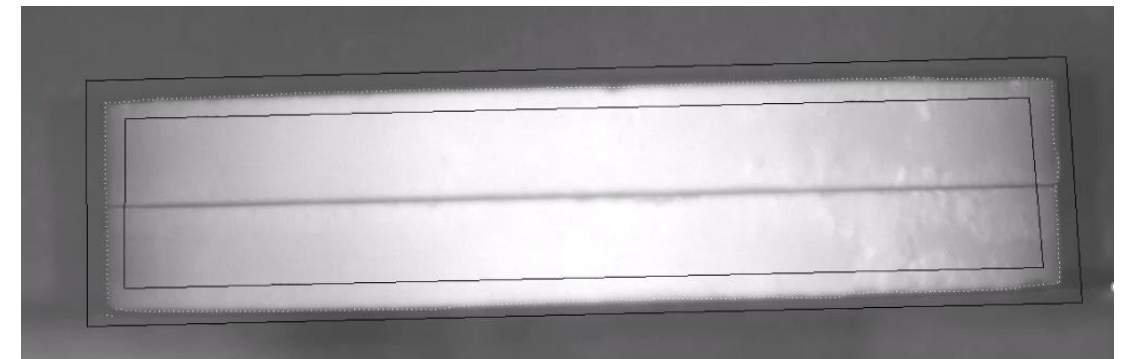


Digital; Modelling and Machine Learning for Ceramic Processes

- Building a Process models e.g., Sintering – reduction in iterative development

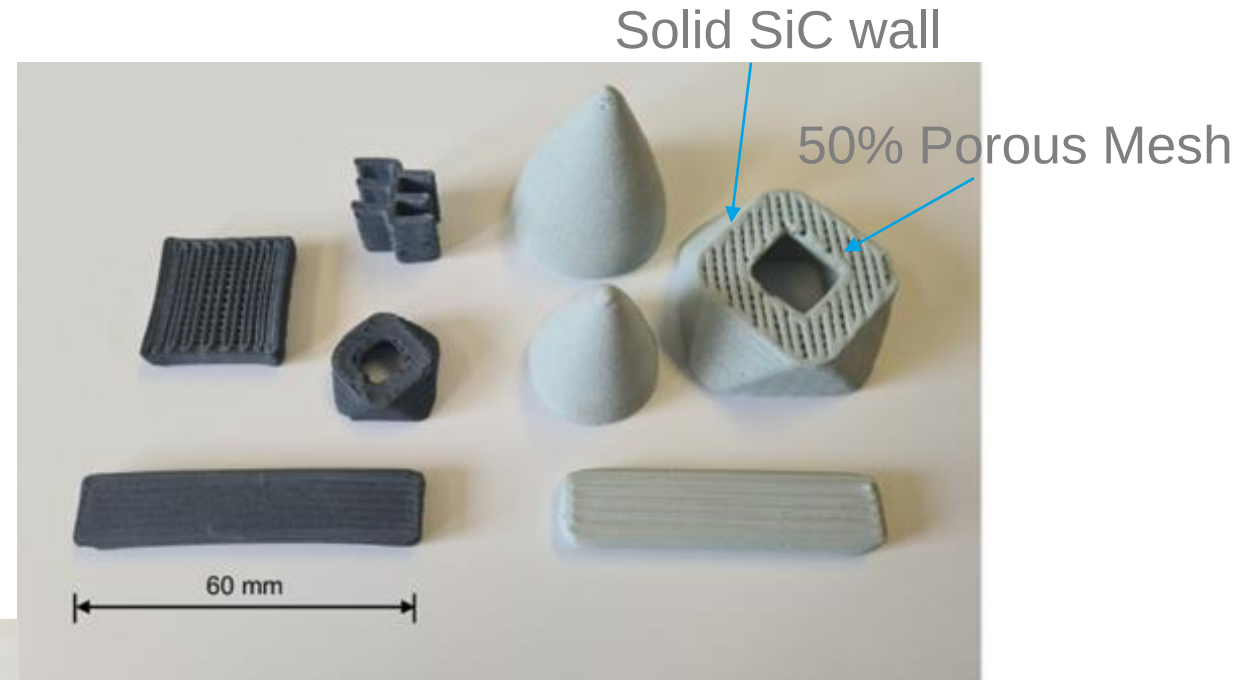
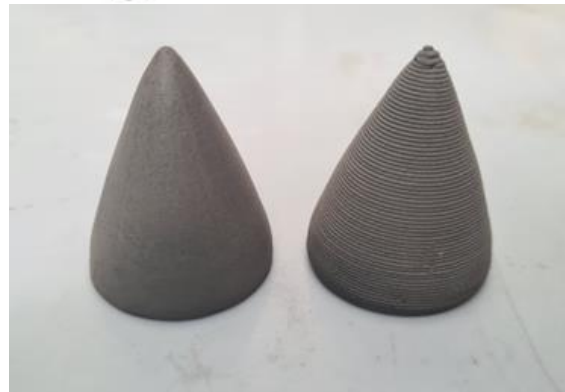
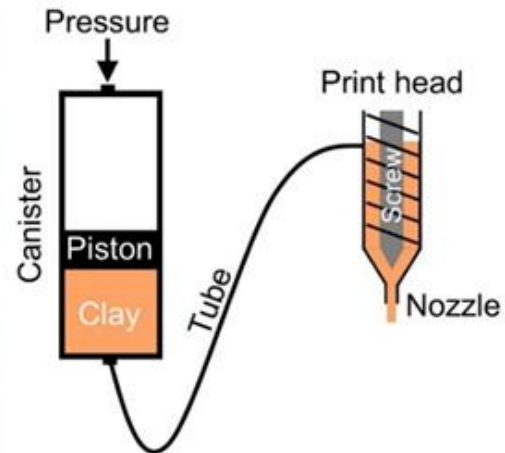


- In-Situ Sintering edge detection
- Deploy Computer Vision Machine Learning
- Feed data into model to better understand sintering, thermal distortion and flash sintering



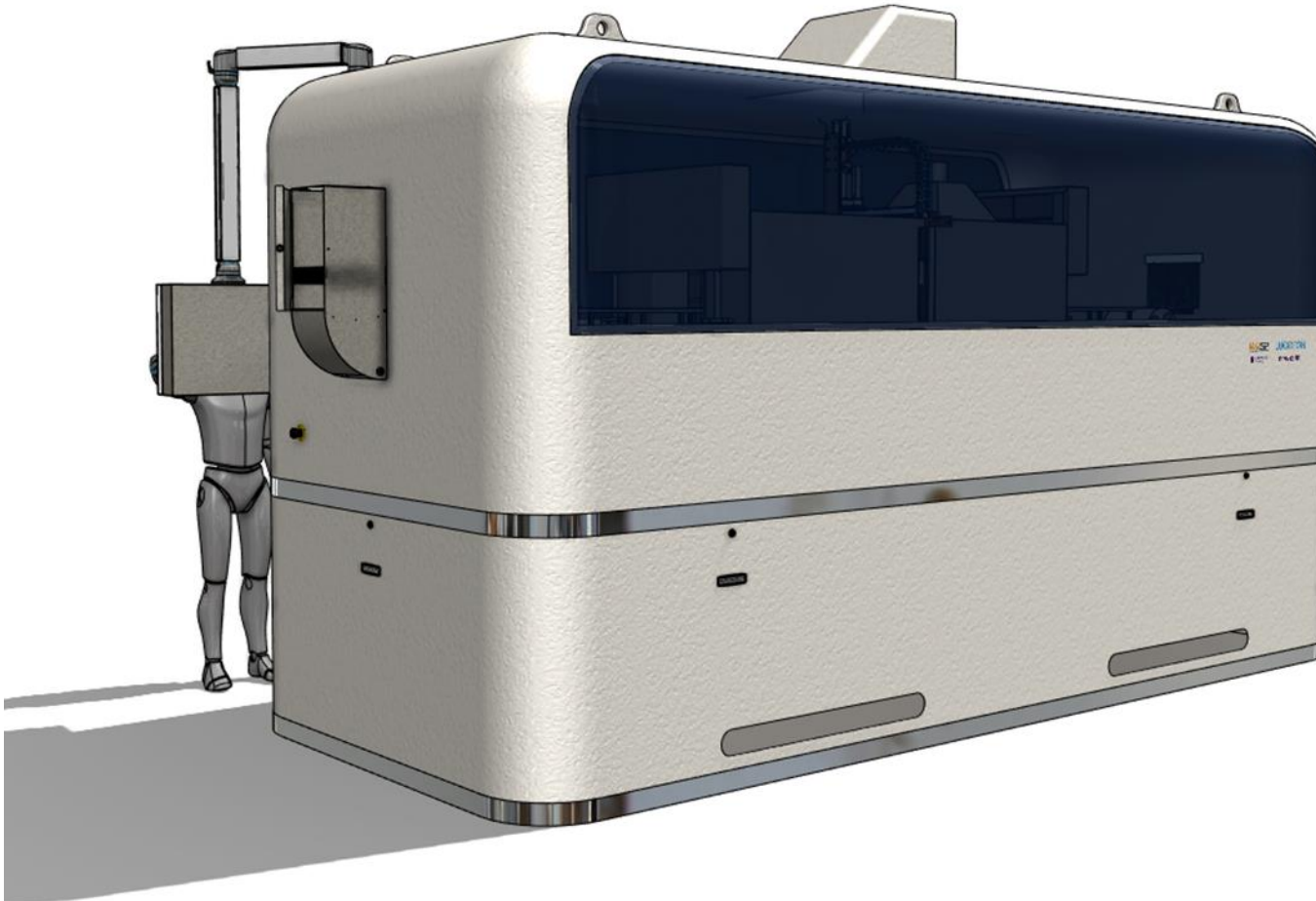
Ceramic AM: Robocasting

- Resolution up to 0.2mm
- Alumina, Liquid phase sintered SiC and Nitride Bonded SiC

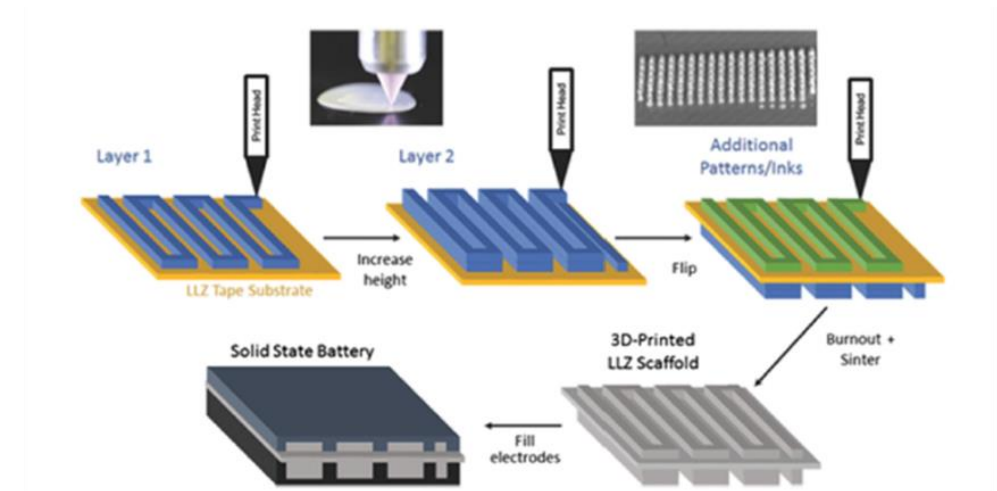


- Rapid low cost one off Kiln furniture development
- Print and Flash Sinter...single unit

Print and Flash Sinter

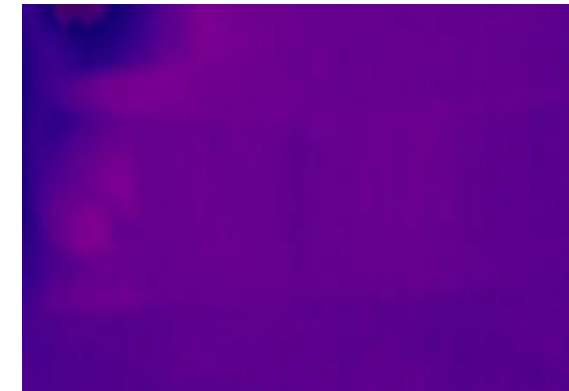
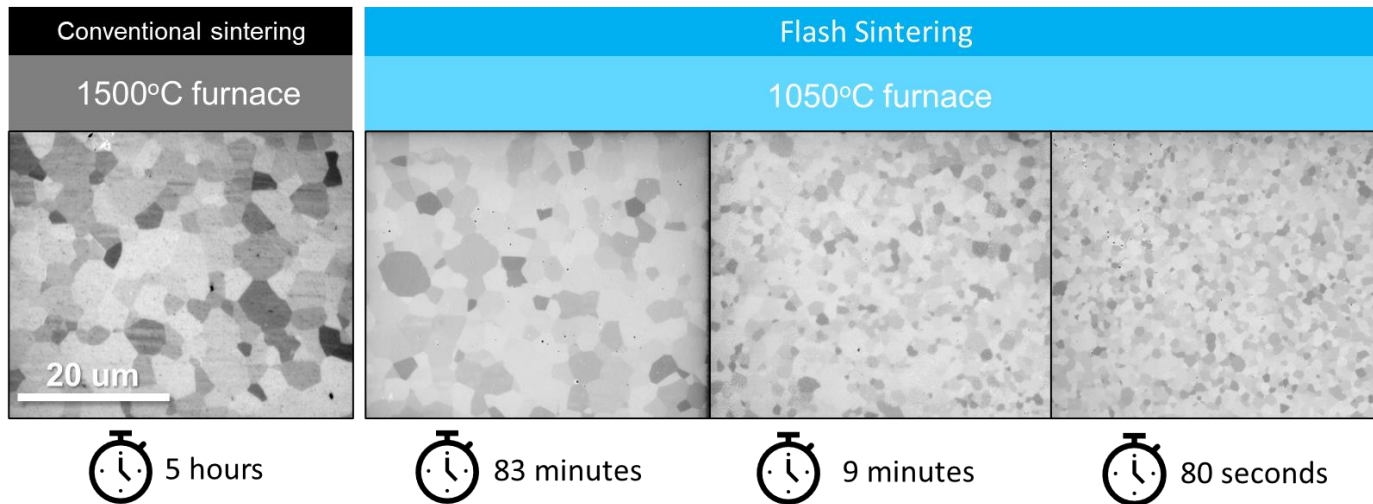
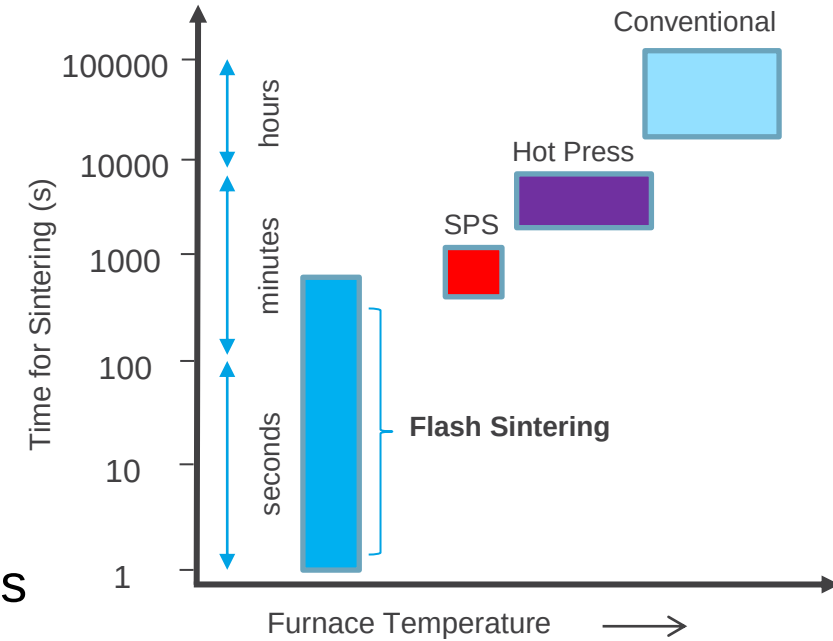


- Scale up designs for print and contactless flash layer by layer...
- One application is Solid State Electrolyte
- Thin Film Development



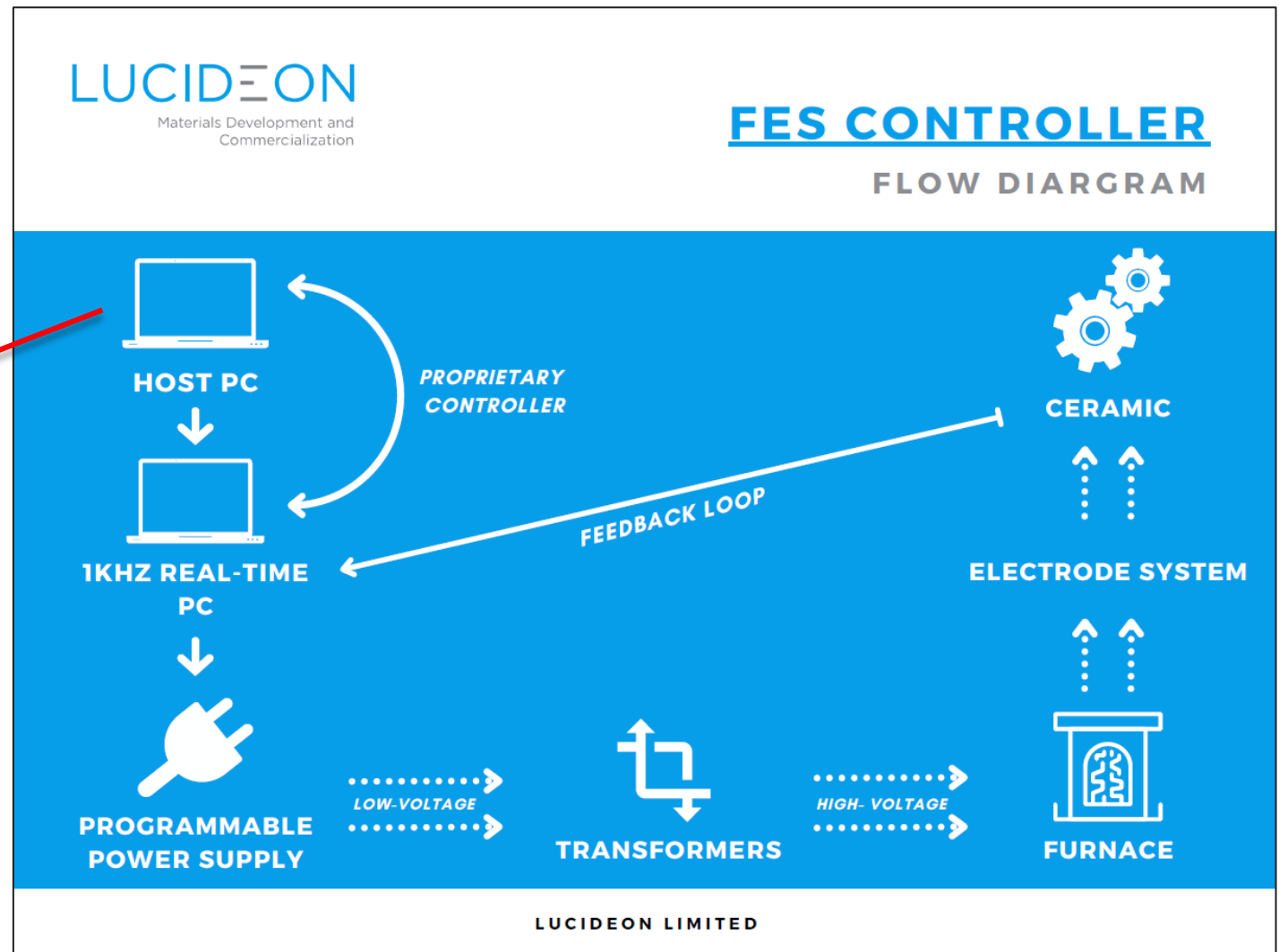
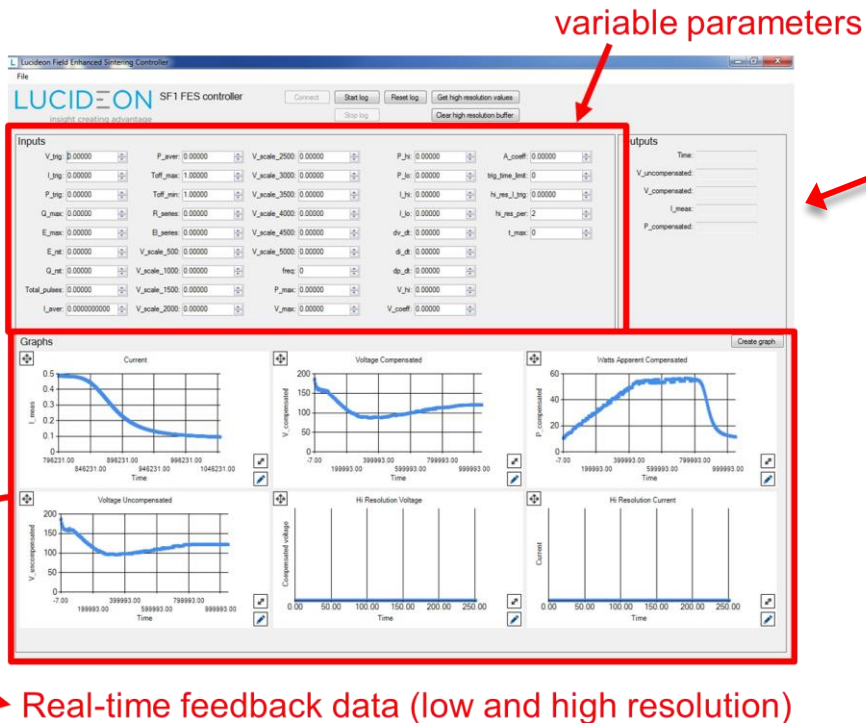
Flash Sintering

- Reduced time
- Reduced ambient temperature
- Enhanced microstructural control
- Monolithic, Composite and Thin Film applications

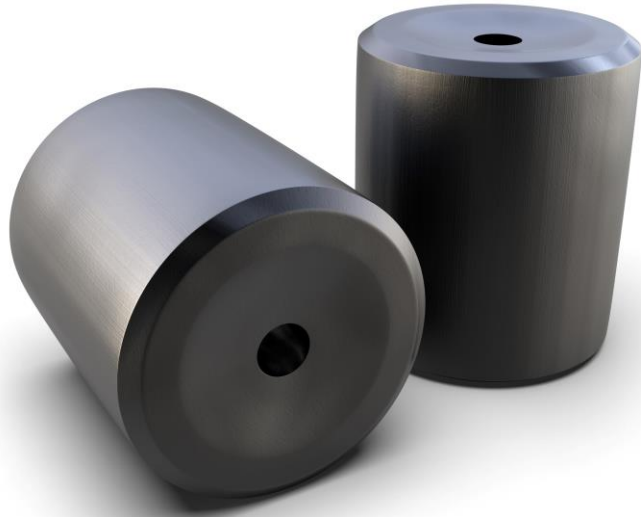


Flash: Controllability and Scalability

- Control and repeatability through software



Flash Sintering for Advance Nuclear Fuel Cycle



- Huge economic benefit via rapid processing
– enhanced Sintering kinetics
- Better incorporate volatiles without species loss and decomposition
- Dense samples with thermal homogeneity produced
- Scale up designs via partnership for manufacturing in place

LUCID Ξ ON

NATIONAL NUCLEAR
LABORATORY

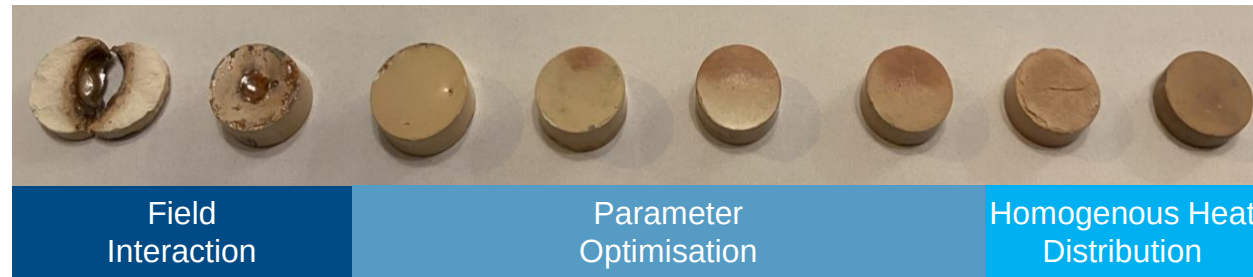


MANCHESTER
1824

The University of Manchester

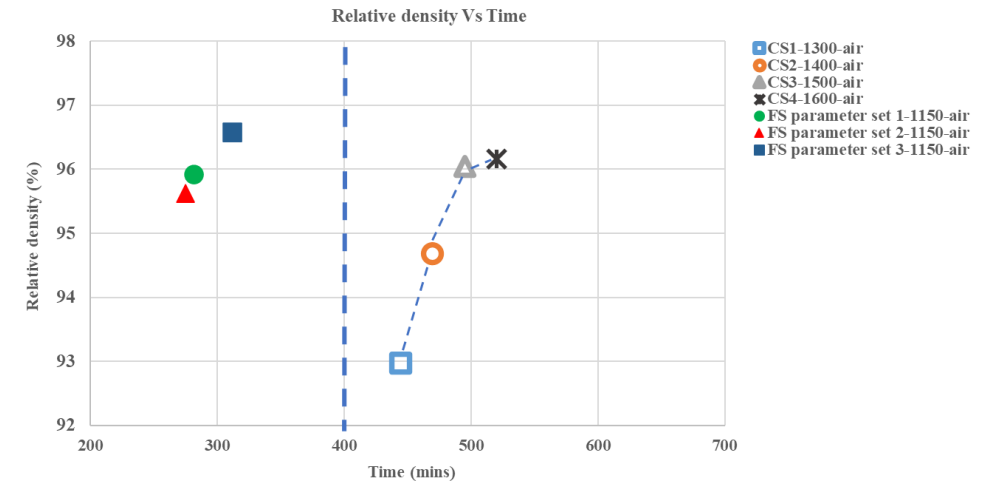
AFCP
Advanced Fuel Cycle
Programme

Process Development: Surrogate Fuel, CeO_2

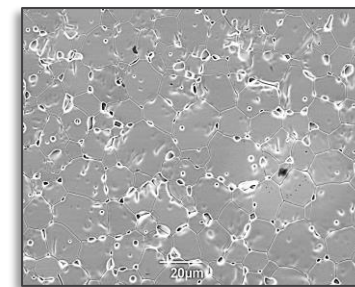


- Optimisation of flash parameters
 - Maximum current density
 - Current ramp rate up/down
 - Holding time at maximum current
- Furnace temperature
 - 1000-1150°C
- Interface of sample / electrode

- >50% reduction in time
- 35% reduction in firing temp

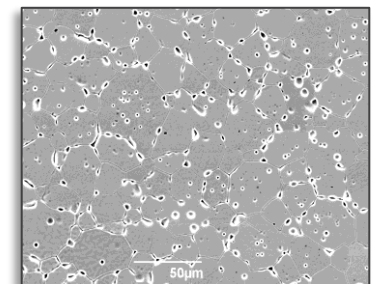


Flash Sintering
1100°C



20µm

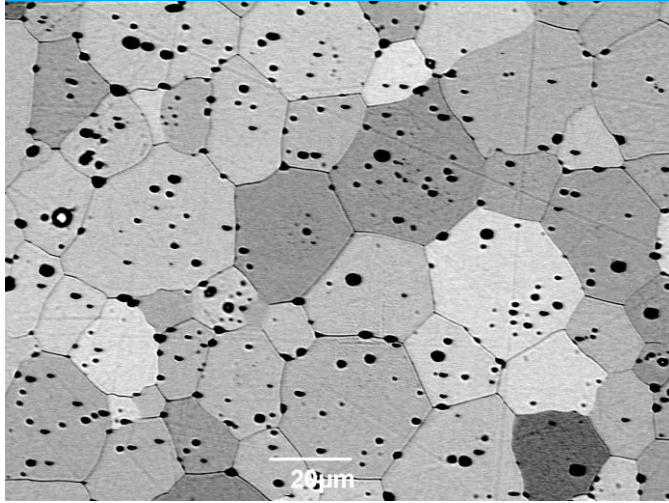
Conventional Sintering
1600°C



50µm

VS

Dv(50): 10 μm Parameter set 3

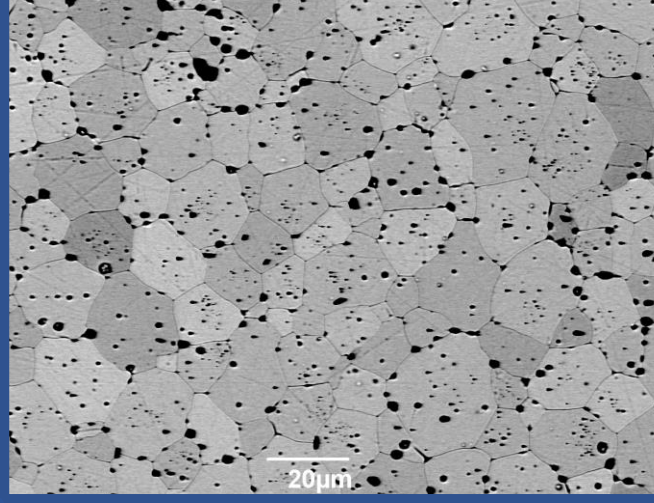


RD: 96.6 % $\pm$ (0.3)
GS: 19 $\pm$ 4 μm

Milling



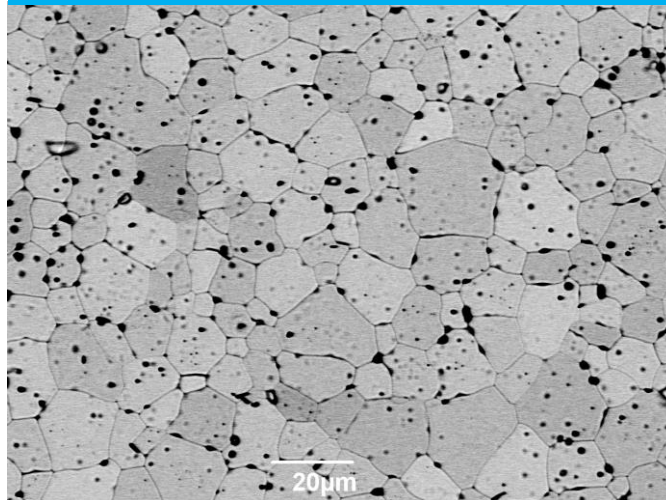
Dv(50): 4 μm Parameter set 3



RD: 97.50% $\pm$ (0.47)
GS: 11 $\pm$ 1 μm

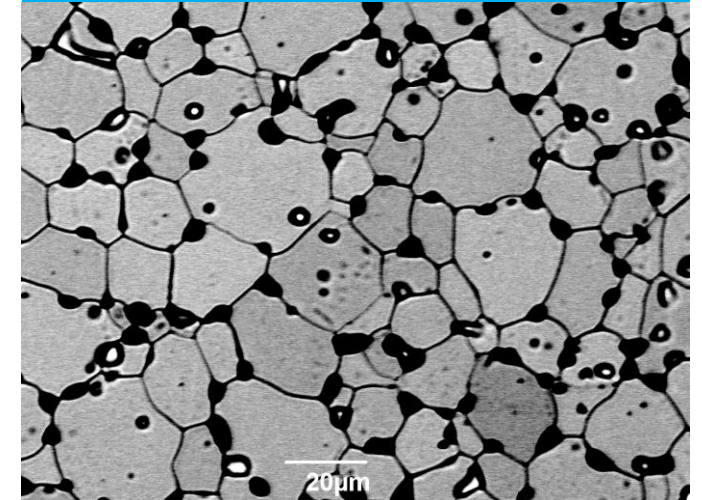
The effect of milling
on density and grain
size of FSeD pellets in
air

20% reduction current density



RD: 96.8 % $\pm$ (0.1)
GS: 10 $\pm$ 1 μm

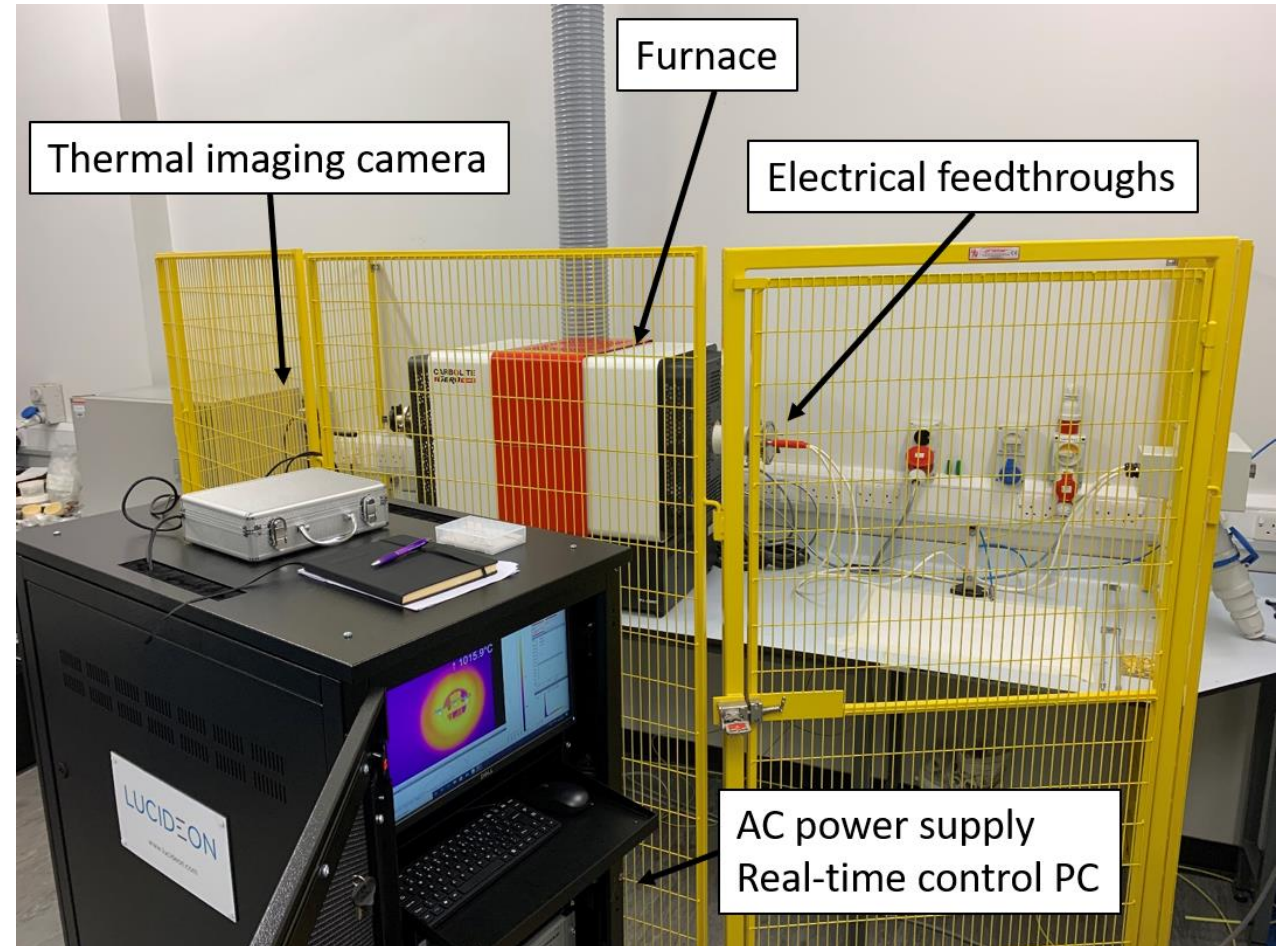
3X increase in holding time



RD: 95.5 % $\pm$ (0.4)
GS: 13 $\pm$ 2 μm

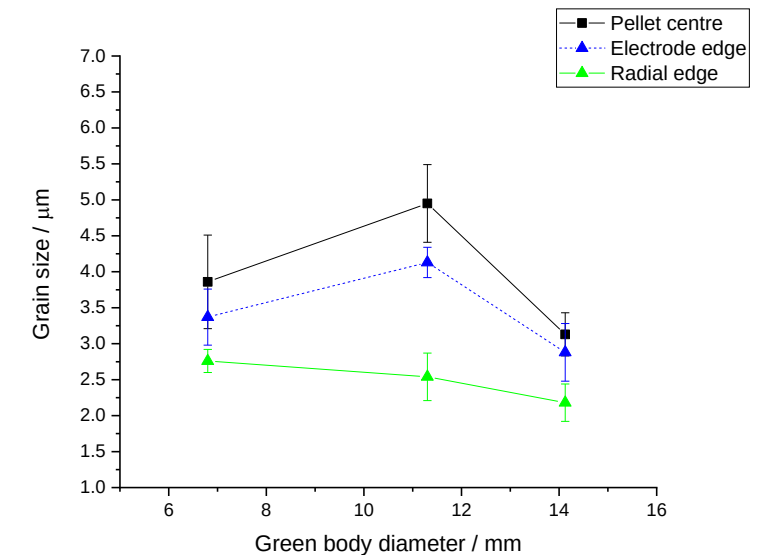
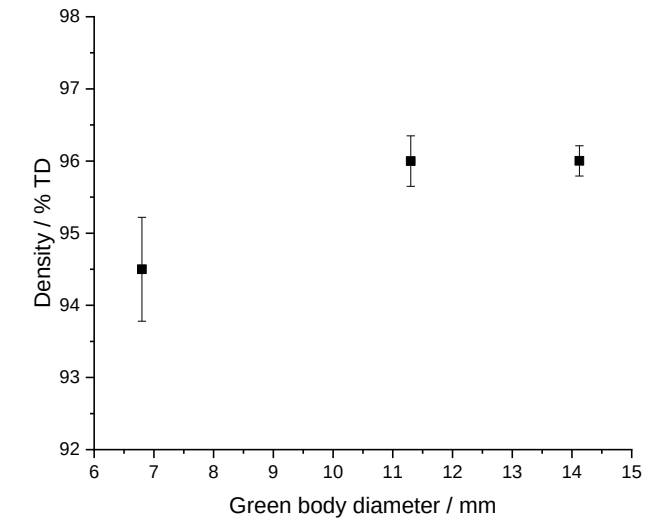
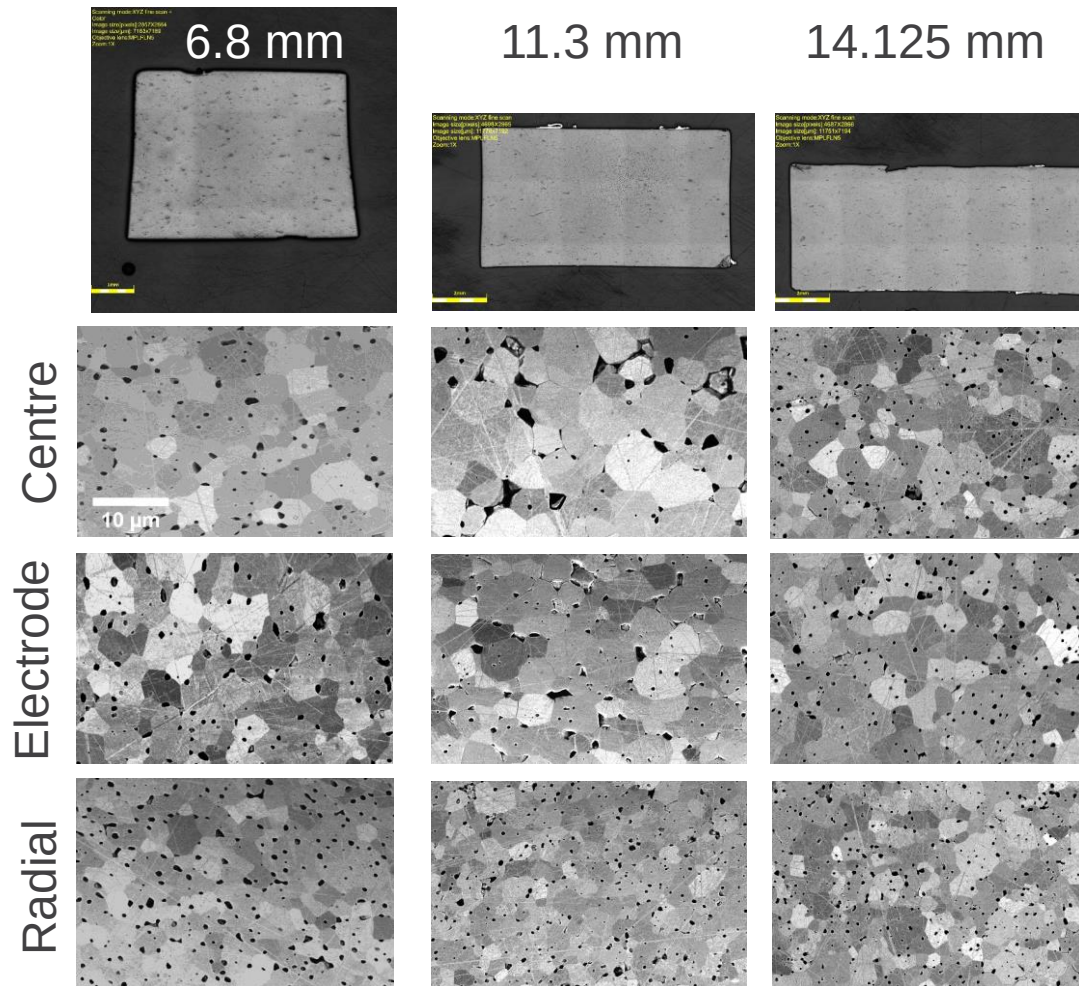
Transition to Active Materials

- Installation and commissioning of FS furnace, developed by Lucideon, in UoM uranium active laboratories
- Sharing Flash parameters with UoM for FS of UO_2
- Collaborative development of homogeneous and reproducible FS on UO_2 between UoM, Lucideon and NNL
- Working closely with Orano to scale up FS of active material

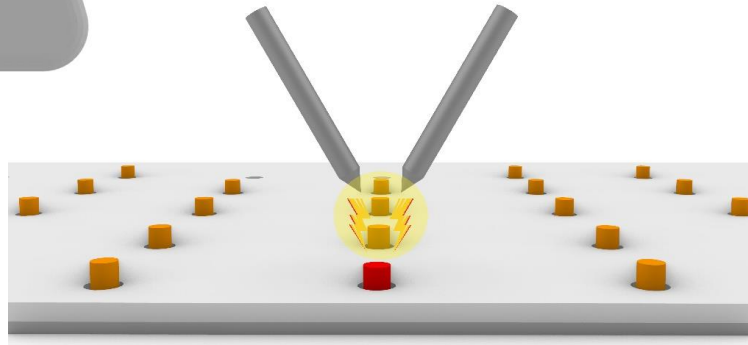
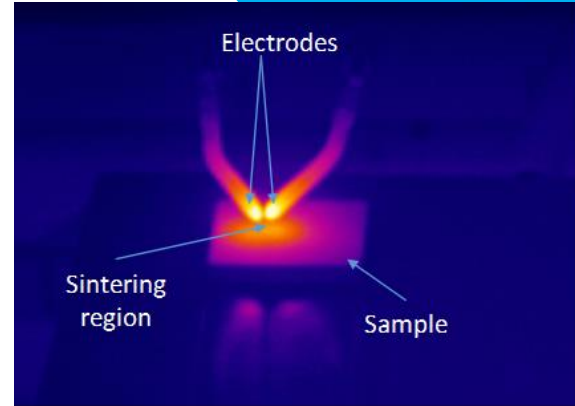
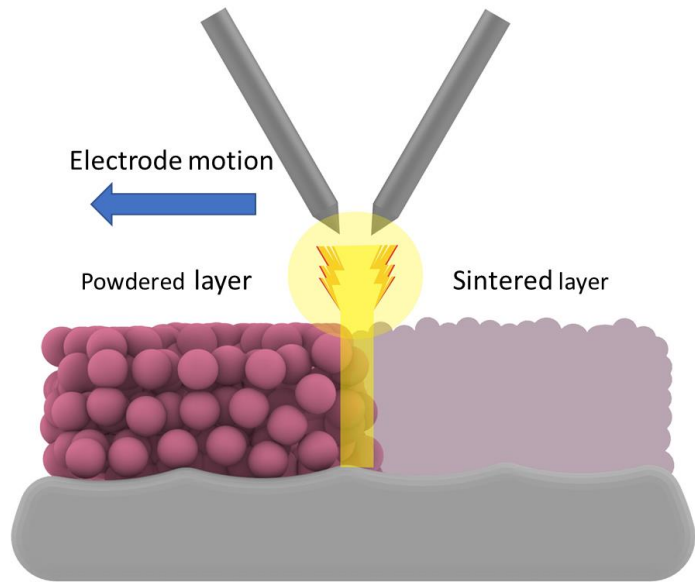


Uranium Dioxide (UO₂) Scale-up trials

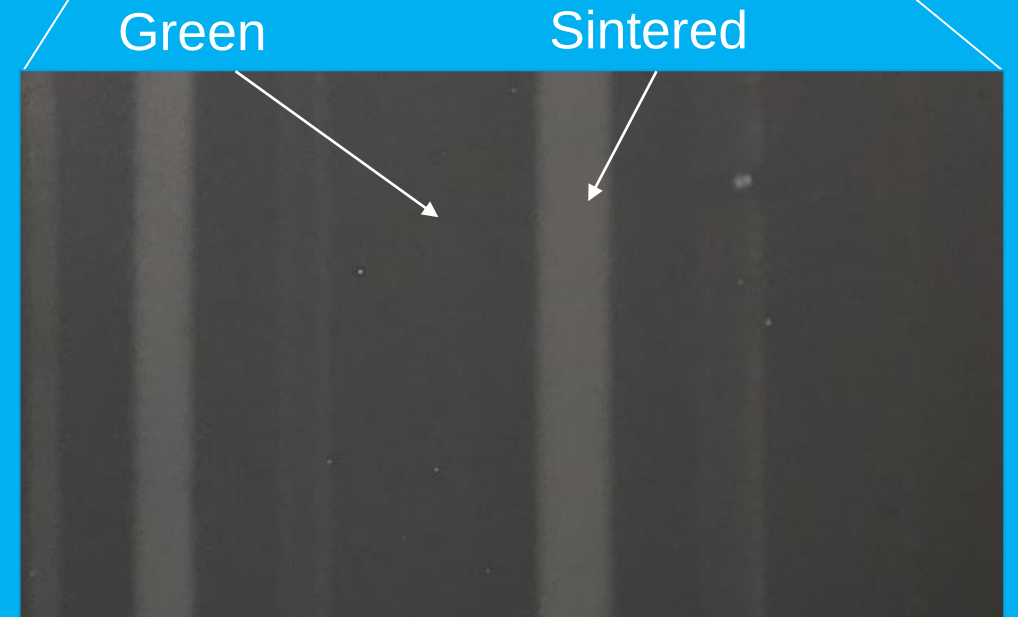
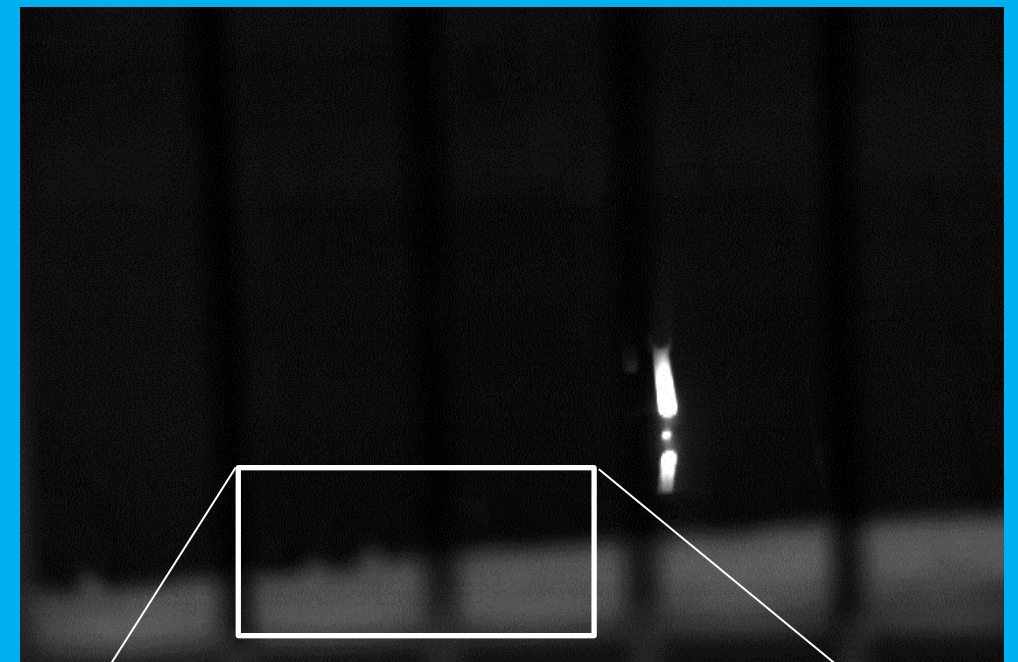
- FS programme used for scale-up trials;
 - Furnace temperature = 900°C, 20 min hold, I_{max} = high A



Contactless Flash Sintering

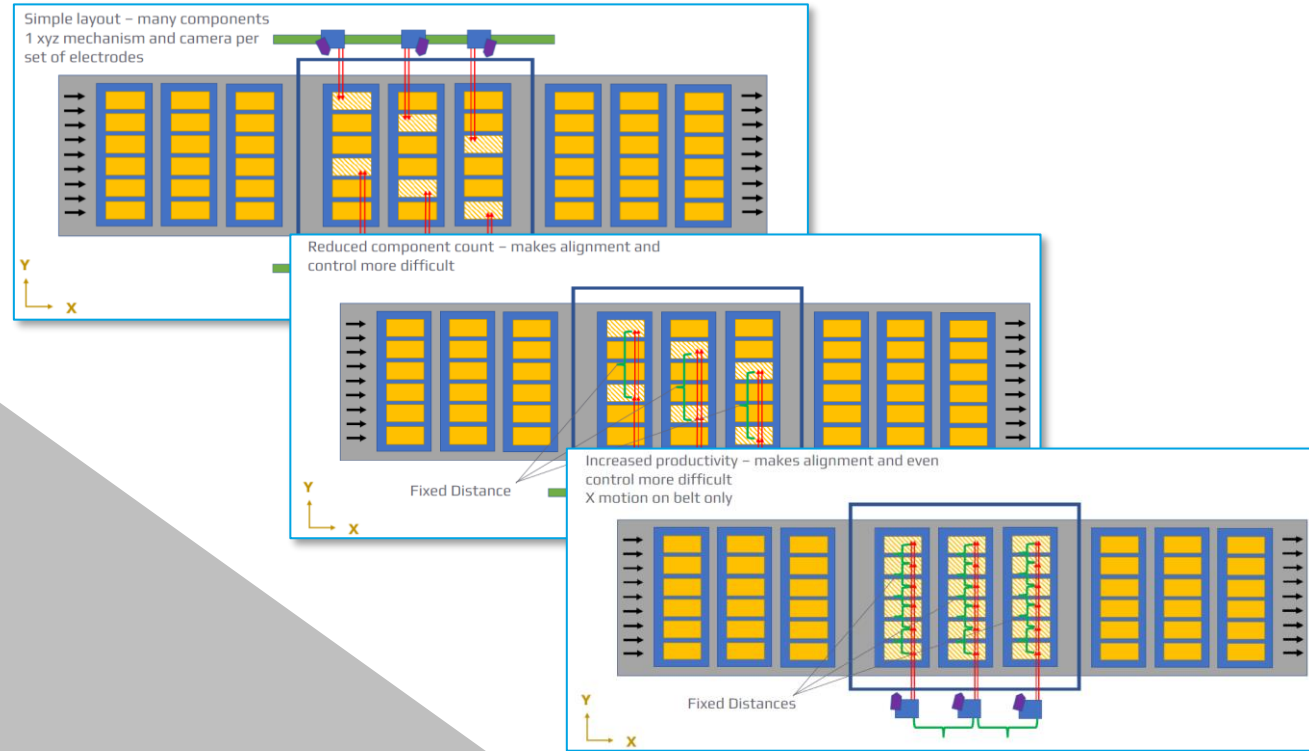


- Coatings: **EBC** work underway
- **Solid State Electrolyte** for EV
- **SOFC**



Control over the degree of sintering

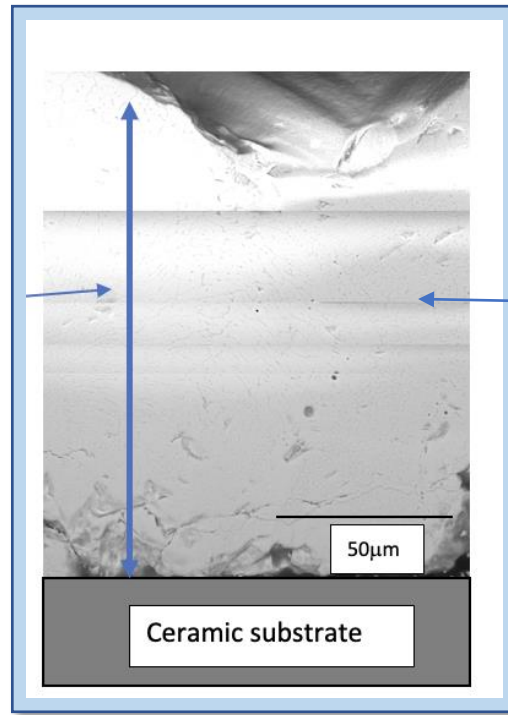
Continuous processing through Contactless Flash Sintering



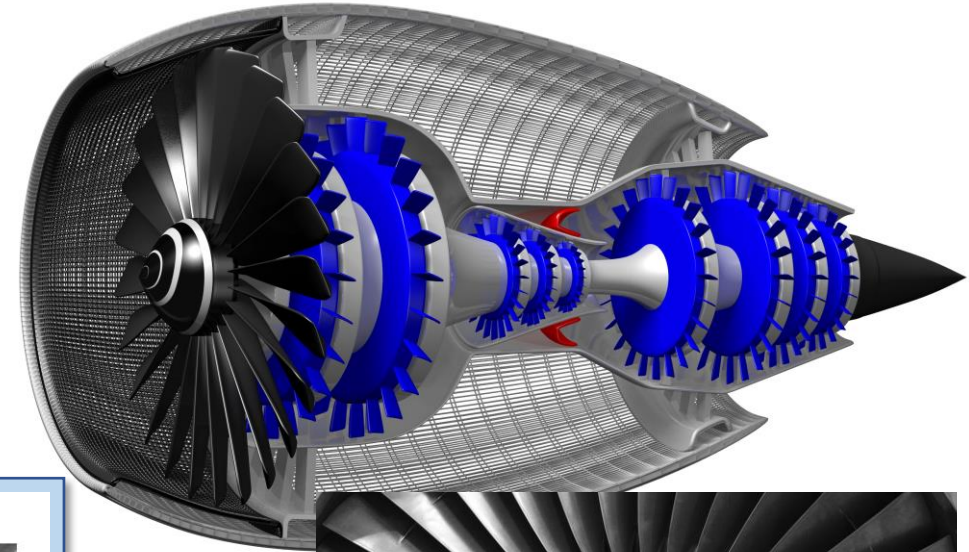
Contactless Flash for Environmental Barrier Coatings (EBC's)

- Contactless Flash sintering for manufacturing EBC 's for aerospace applications
- To produce protective EBCs on ceramic substrates in minutes and seconds, not many hours using flash.
- Collaboration is with Dr Nasrin Al Nasiri at Imperial College London

Preliminary trials shows a **dense and thick coating based on Rare-Earth silicate** 100-150 micron has been successfully produced on silicon-based substrates using **flash sintering**.



RE- silicate coating



Room temperature processing with Hybrid Sintering

Cold Sintering



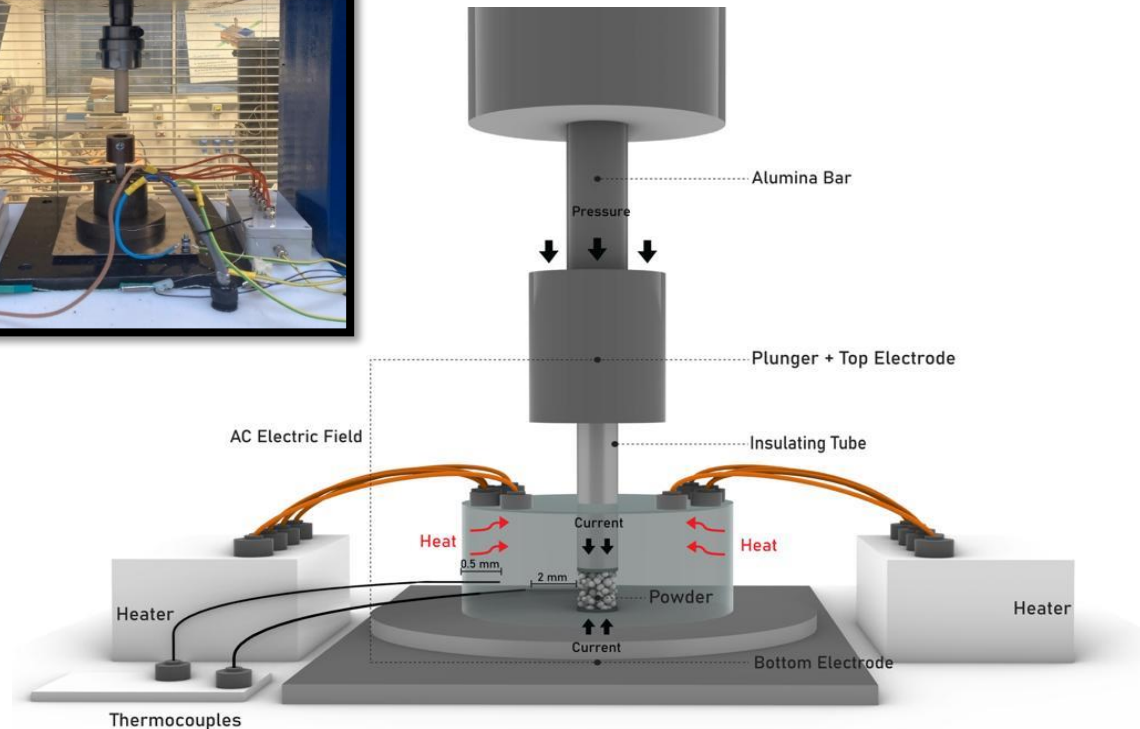
(transient liquid and pressure)



Flash Sintering



(Electric field)



- Refractories to density at 60°C !!!
- Scale up kit under design



Conclusions

Insight into where we see next generation of ceramic process technology, its path to commercialization and its benefits to adoption

Strides in certain sectors for scale up and adoption of these technologies will cascade to more markets.

Rapid processing for high performance materials

Greener processing routes for green technologies – net zero.



Thank you for listening!

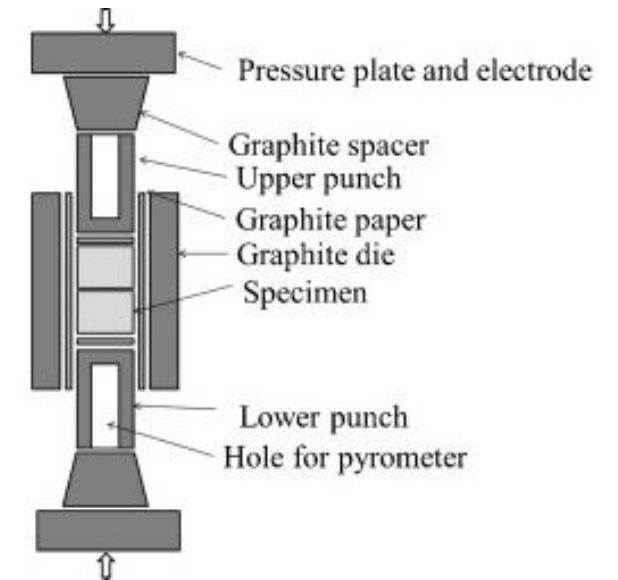
Contact details

T +44 (0)1782 764403
E david.pearmain@lucideon.com
W www.lucideon.com

LUCIDEON

How is FS different from SPS?

- FS is a pressureless technique, SPS under load in a graphite die
- Current flows through the sample in FS, in SPS through the highly conductive die. Sintering mechanism different, and not entirely known....
- Energy consumption lower by an order of magnitude in flash
- Flash has more scalable application given the absence of a die and the utilisation of more continuous processing methods.



Pilot Plant Process Flow

