

OAK RIDGE National Laboratory

2.2 Grain Oriented Electrical Steel (GOES) Alternative for Transformers (GOAST)

DOE OE TRAC Peer Review 2026

Chins Chinnasamy, PhD
Oak Ridge National Laboratory

U.S. DEPARTMENT of ENERGY

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U.S. DEPARTMENT of ENERGY

Project Overview

- **Project Description (high-level)**: (i). Develop low-cost, high saturation, amorphous/hybrid alloy using planar flow casting (PFC) technology to reduce distribution power transformer (DPT) size and cost while decreasing reliance on foreign electrical steel supply chains. (ii). Develop of Fe-3%Si GOES replacement steel for large power transformers.
- **Period of Performance**: 10/01/2025 to 09/30/2028
- **Award Amount: Federal share**: $750,000, cost share: $160,000.
- **Prime Awardee**: Oak Ridge National Laboratory
- **Partners**: Metglas Inc, SC, USA and EERC- University of North Dakota
- **Technology Area**:
  - Advanced Transformers
  - Transformer Materials
- **Alignment/Supports strategic pathway**:
  1. **Stabilize** the grid to address the immediate, acute conditions that strain domestic transformer manufacturing
  2. **Optimize** the grid to enhance performance by minimizing distribution losses and reducing new generation needs, thus strengthening national security
  3. **Grow** the grid by enabling innovation, advancing new technologies, and building capacity for a future-ready electricity system

Problem Statement

Early Replacement Need: 60-80% of the installed U.S. transformers, which typically last around 40 years, will need to be replaced by 2050 as they will reach the end of their functional life.

Import Dependency & Supply Crunch: By 2024, the U.S. relied on imports for 82% of its large power transformers (LPTs). The transformer industry also faced a supply crunch with lead times increasing to 120 weeks.

High-Voltage Transformers Supply Issue: Increased manufacturing lead times, limited production capacity, and shortages of core materials and components have tightened the supply of high-voltage transformers. These transformers are crucial for connecting wind/solar farms and batteries to the grid.

Problem Statement

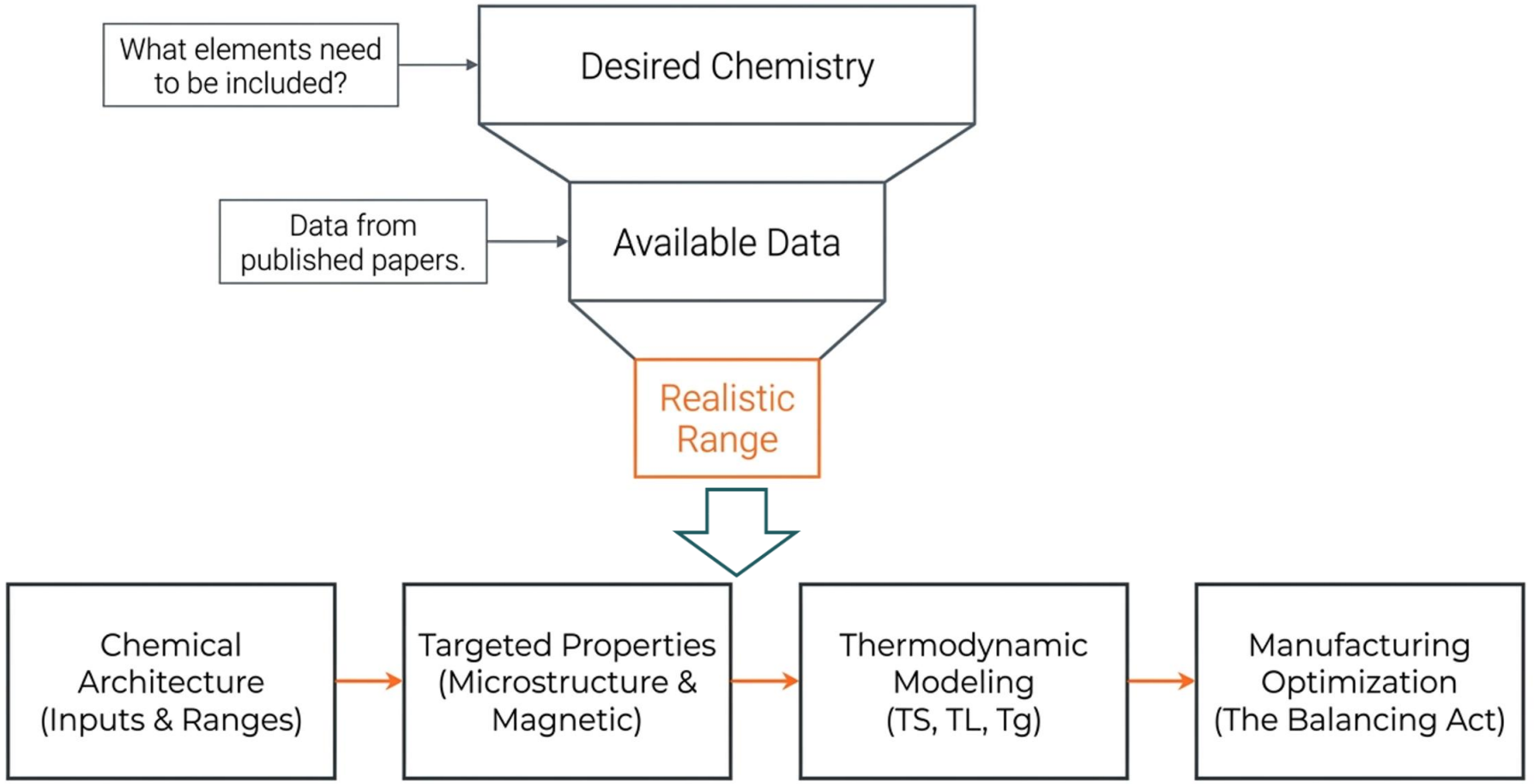
Limited Manufacturing Capacity: In the U.S., there is only one GOES manufacturer, one amorphous steel manufacturer, and six power transformer manufacturing facilities. Together, they can fulfill only about 15% of the country's power transformer demand.

DOE Efficiency Standards: Energy efficiency gains will be achieved with 75% of the transformers on the market being manufactured with grain-oriented electrical steel (GOES) and another 25% with amorphous alloy.

Need more energy efficient transformers with size and weight reduction: Core material with high induction, low losses, and low cost is targeted

Technical Approach

Core Material Innovations

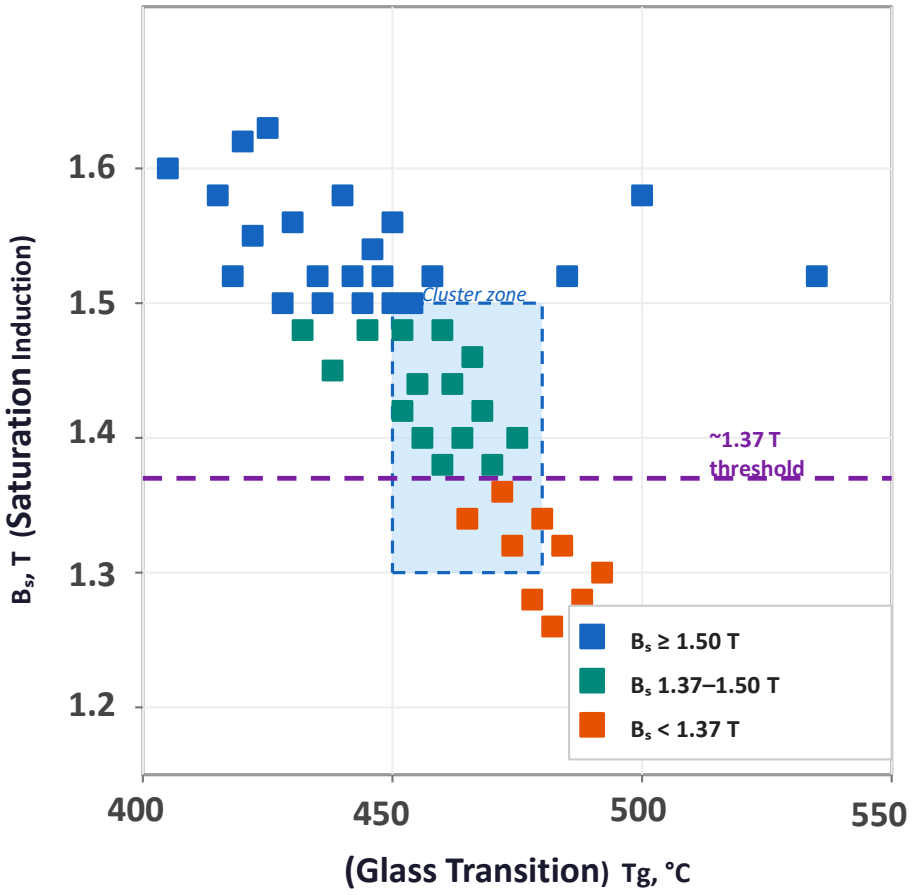


Ts- solidus temperature, TL: Liquidus temperature, Tg: Glass transition temperature

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Data analysis (literature survey) of amorphous alloys

Saturation induction vs Glass transition temperature



B_s values range approximately 1.2–1.6 T

Tg spans ~400–520 °C

Majority cluster near:
Glass Transition Tg ≈ 450–480 °C
B_s ≈ 1.3–1.5 T

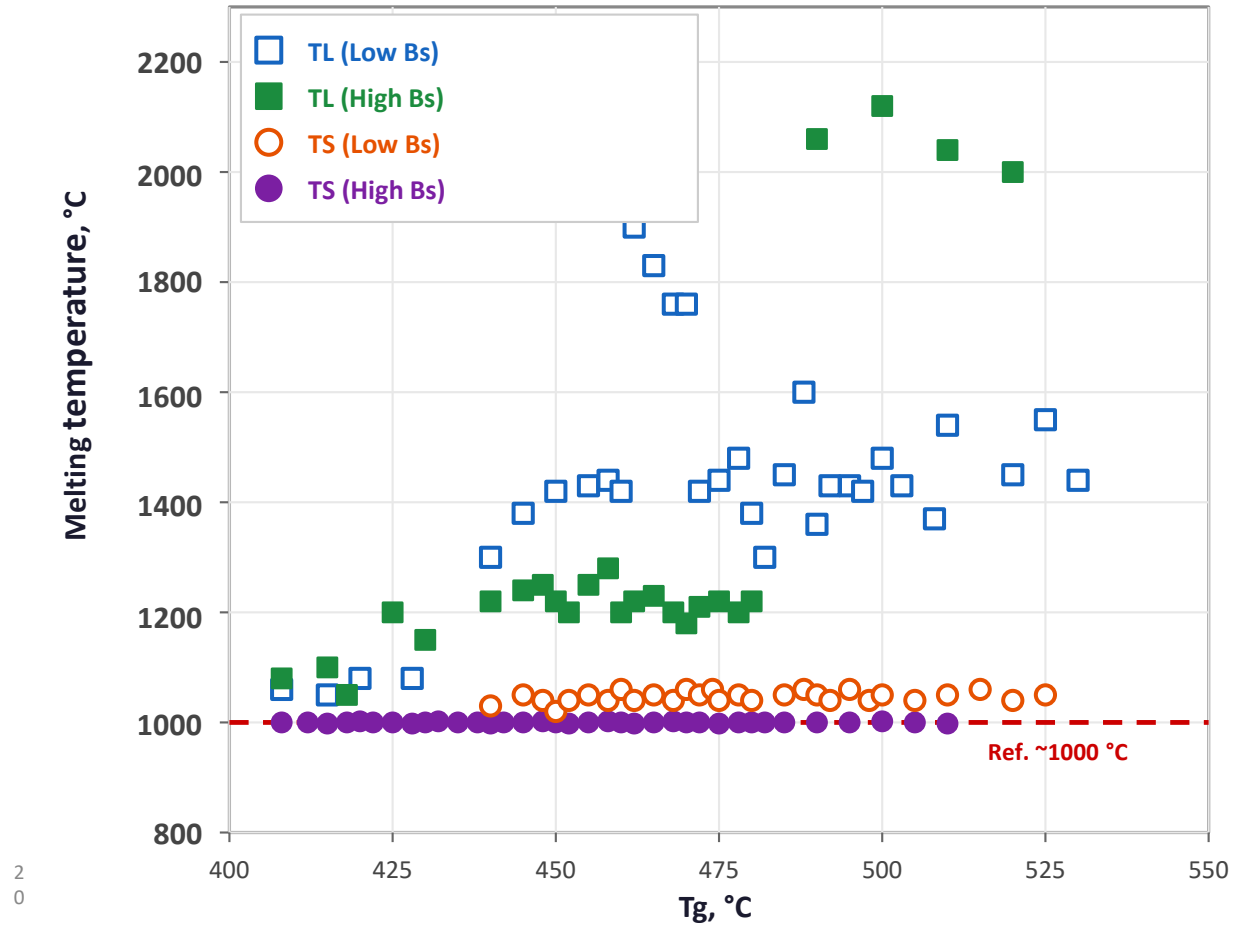
Dashed line (~1.37 T) = target saturation induction threshold

No strong linear correlation observed between Tg and B_s

Magnetic performance can be maintained while tuning thermal stability

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Relationship between glass transition temperature and melting temperature



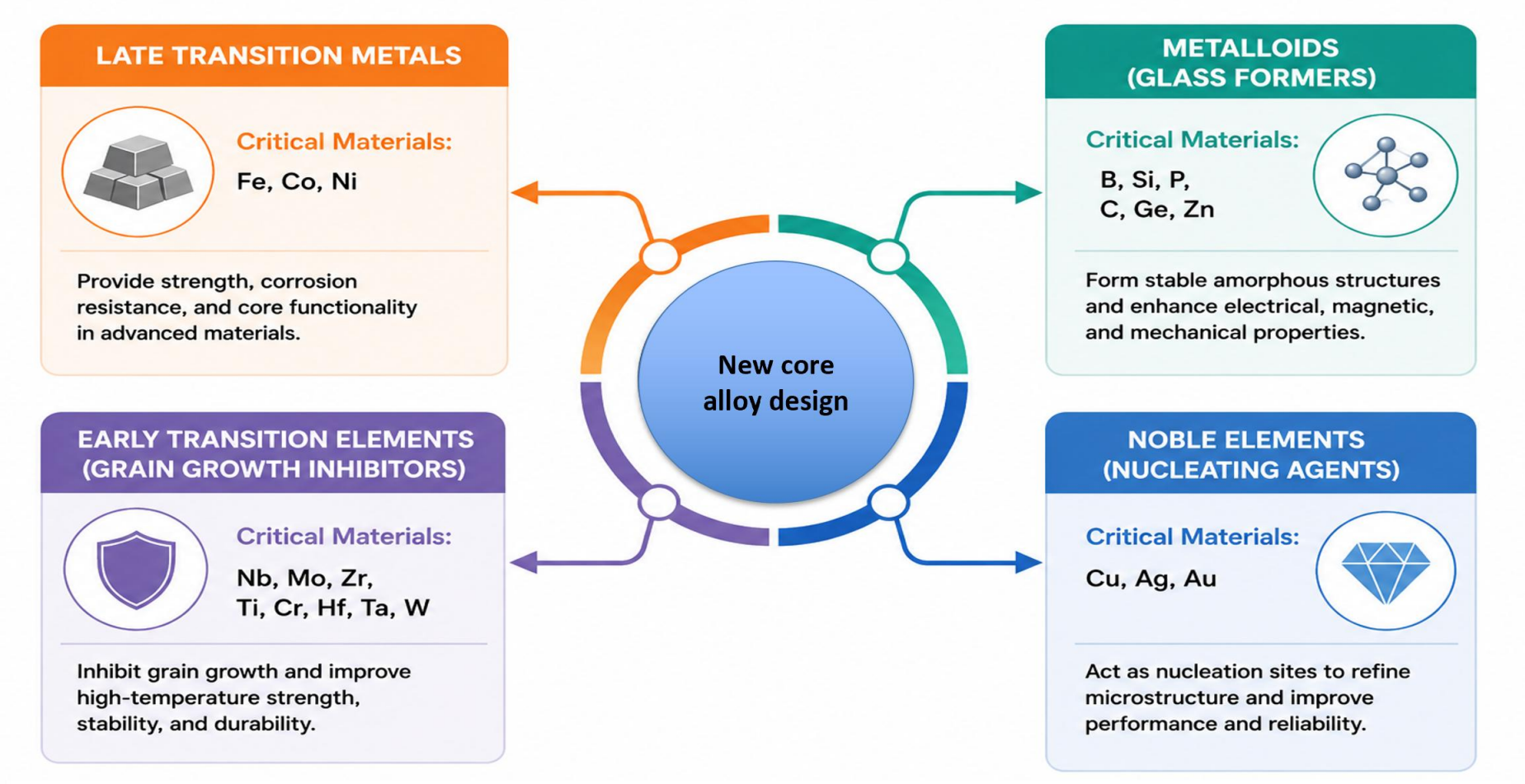
Definitions

Tg	Glass transition temperature
T_L	Liquidus temperature (melting onset)
T_S	Solidus temperature (solidification end)
Bs	Saturation induction (Low Bs vs High Bs)

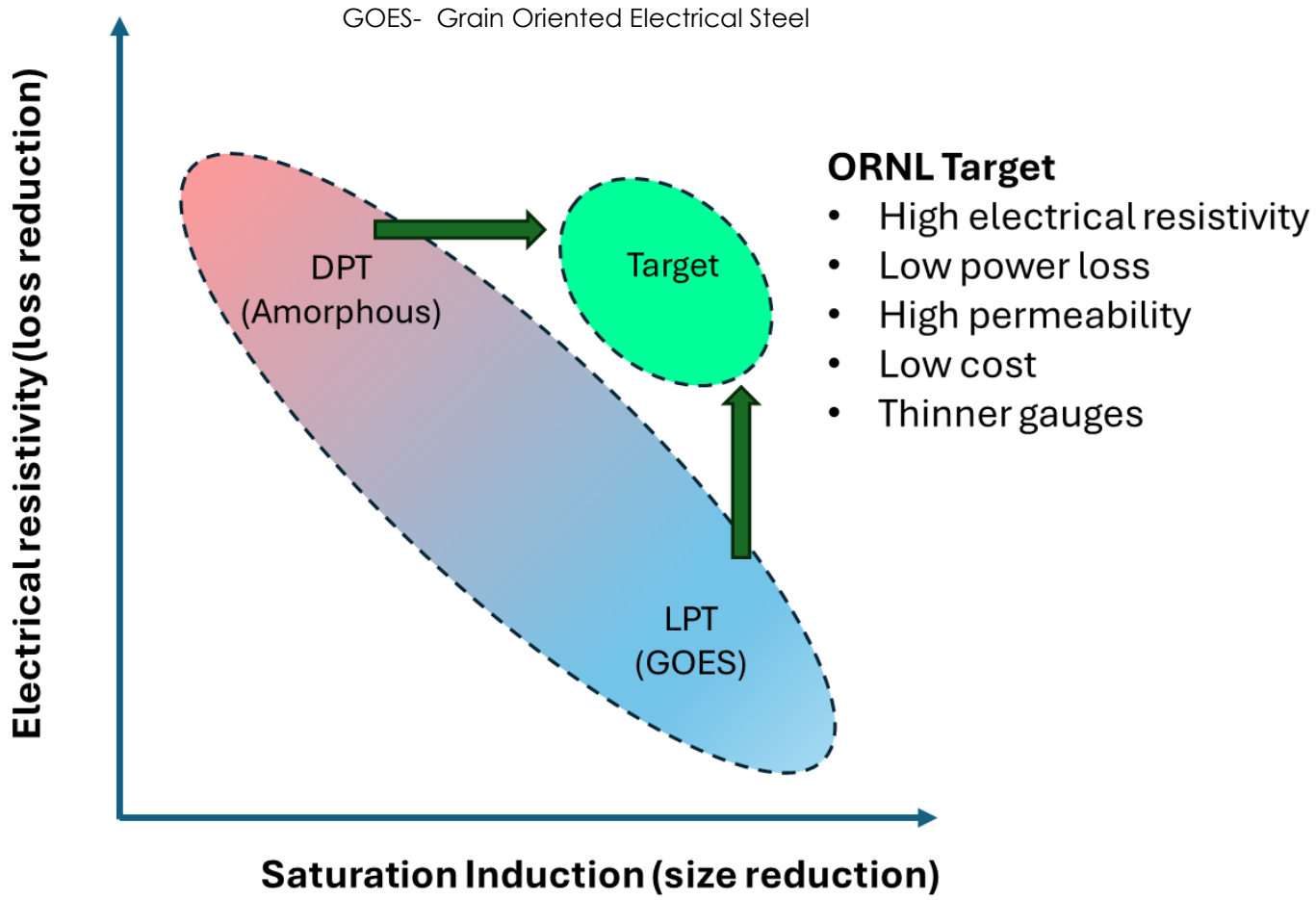
- **T_S remains close to the ~1000 °C reference line across the composition range**, while Tg is mostly within ~440–520 °C, suggesting that the main differentiation among the formulations is driven by liquidus temperature rather than solidus temperature.

Technical Approach / Innovations

New alloy design:



Technical Approach / Innovations



ORNL Target

- High electrical resistivity
- Low power loss
- High permeability
- Low cost
- Thinner gauges

- Low cost -moderate induction
- Moderate cost-high induction



Core/coil assembly determine transformer size and weight

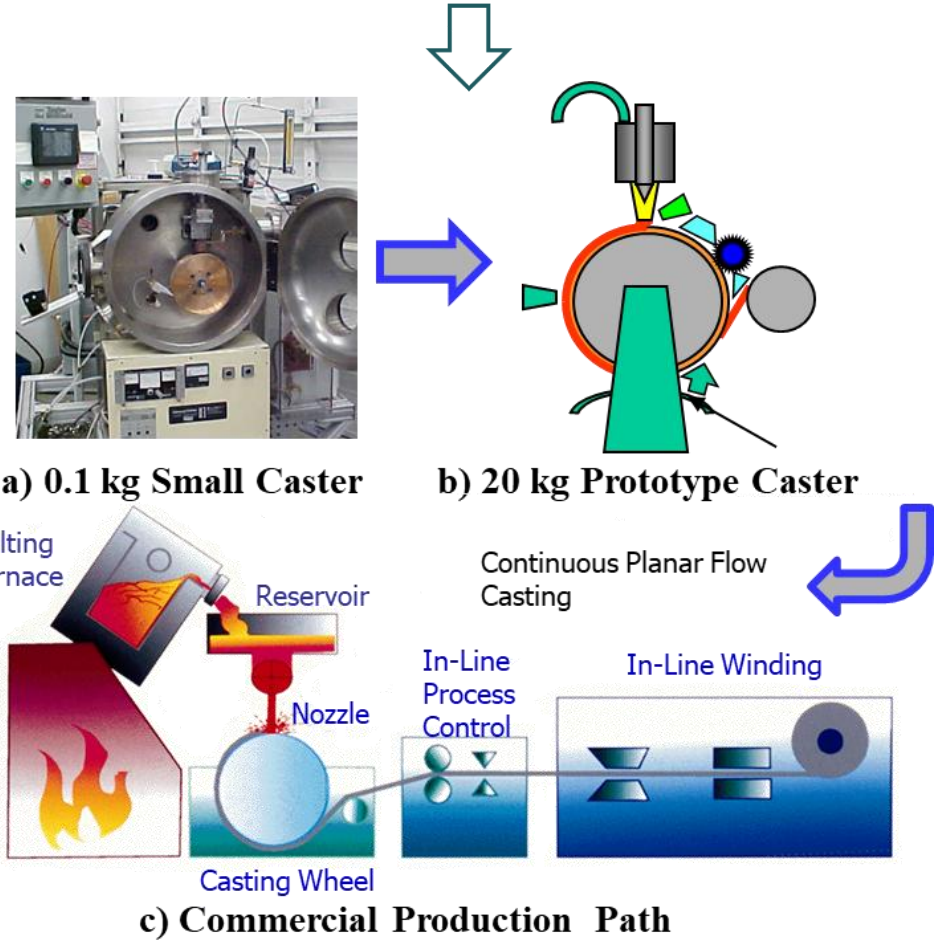
Technical Approach / Innovations

Amorphous alloys for distribution power transformers and high frequency transformers:

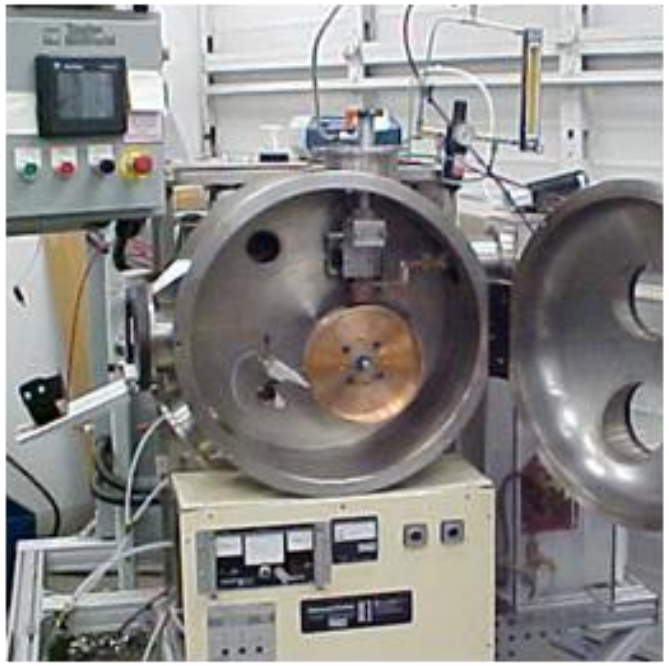
- Develop high induction Fe-Si-B –X-Y-Z alloy to reduce both electrical losses and minimize the overall transformer footprint in terms of size and weight.
- **Cast into a wide (50mm) thin gauge (~25 microns) amorphous steel through planar flow casting methods on a 20kg prototype casting machine that represents commercial production.** (Metglas collaboration)
- Develop a prototype transformer (Metglas collaboration)
- Develop thin gauge amorphous lamination will also be heat treated to a **hybrid amorphous/GOES** structure which has higher saturation induction than amorphous steel and lower losses than conventional GOES laminations.

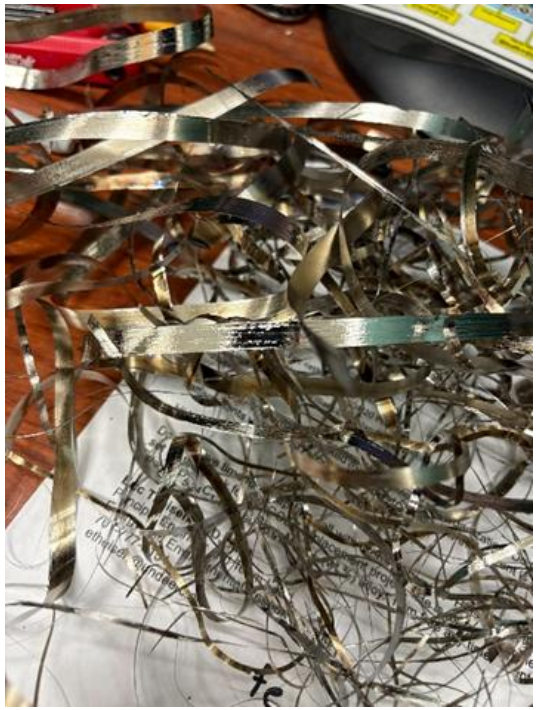
Alloy Development Path

Calphad Thermodynamic modeling



Results: New Amorphous Alloy Development

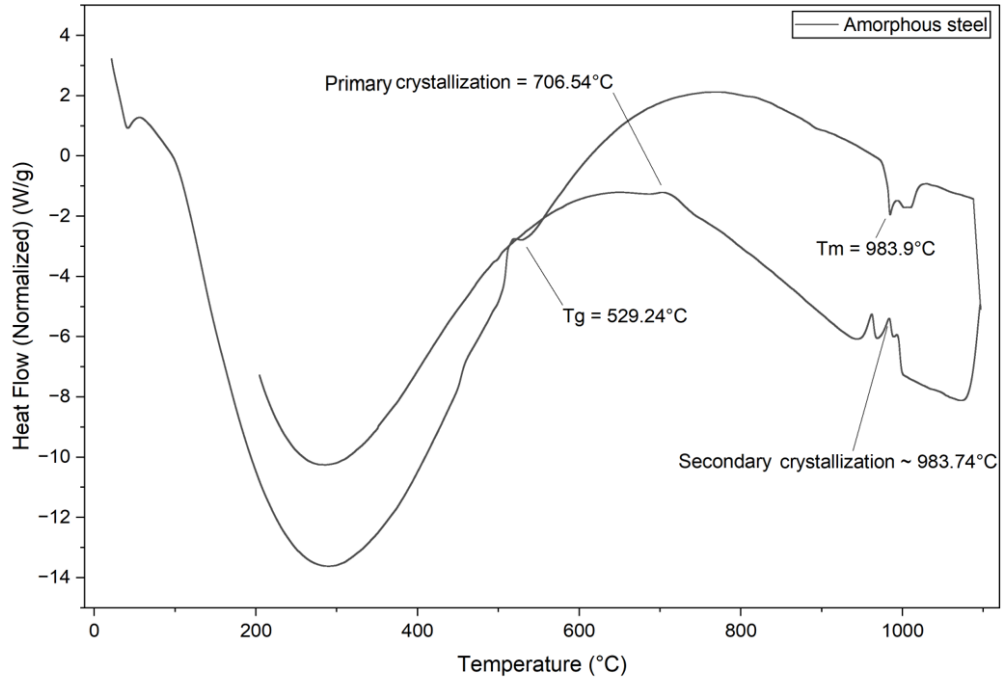






- New amorphous alloy ribbon was successfully prepared at lab scale
- Preliminary characterization is ongoing

Results: Thermodynamic analysis

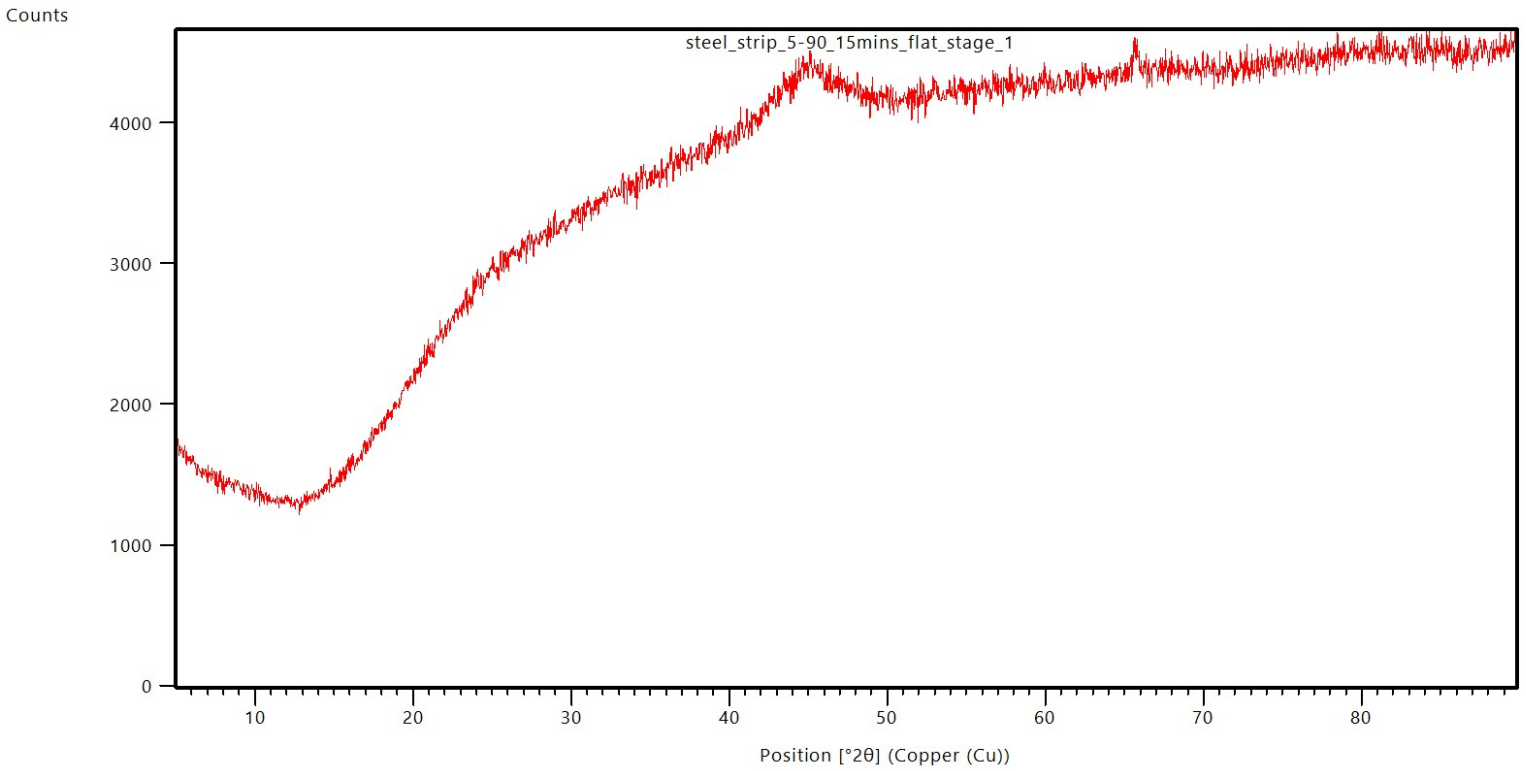


Tg: Glass transition temperature
Tm: melting temperature

Tg: 529 °C

- **Enhanced glass-forming behavior:** The proposed alloy design aims to raise **Tg** and, pending confirmation, widen the **supercooled liquid region, ΔT**, relative to the commercial Fe-based bulk metallic glasses.
- **Improved manufacturability and processing flexibility:** A higher Tg and wider ΔT can support DOE-relevant processing pathways such as **thermoplastic forming** and **bulk-section casting**, reducing reliance on conventional thin-ribbon melt spinning.
- **Greater thermal stability for service conditions:** Increased Tg and a wider processing window can improve the alloy's ability to maintain structural and magnetic performance under elevated-temperature operating environments in transformers

Results: Structural analysis

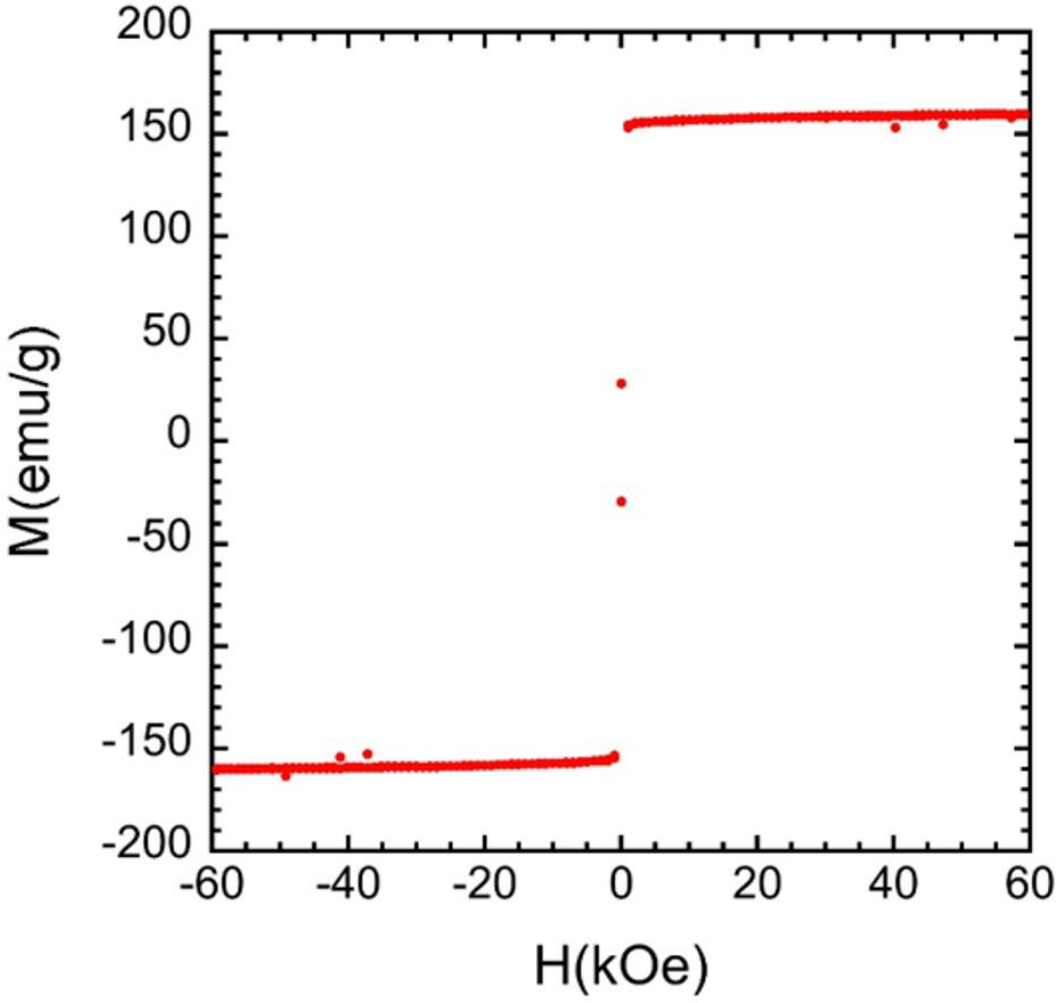


- Amorphous structure

Figure : X-ray diffraction (XRD) analysis of the new amorphous alloy

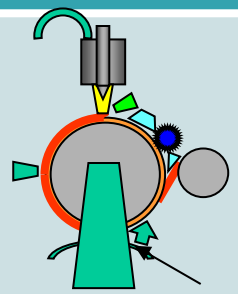
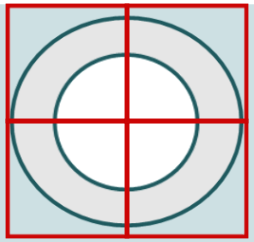
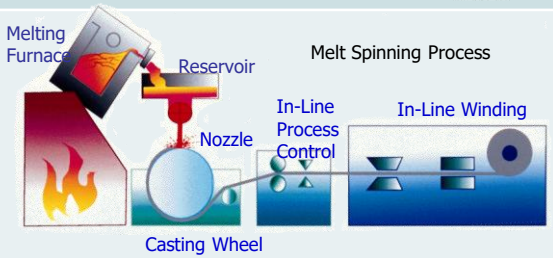
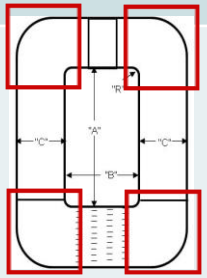
Results: Magnetic Properties of the New Amorphous Alloy

Room-temperature M–H hysteresis loop



- Saturation magnetization of 155 emu/g (equivalent to the saturation induction: 1.44 T)

Next Steps: New Amorphous Alloy Development

Status	PFC Line	Production Size	Component Testing	Schematic
Trials Ongoing		20 kg batch, 2” max width	~ 5 kg Tape Wound Core 	
Future Production		Continuous casting, 10” max width	~ 100 kg Laced Core 	

- 20 kg prototype casting represents commercial production capabilities
- Small tape wound core is a good proxy for a full-size distribution transformer core because radius of curvatures are similar (red squares)

Conclusions

- **CALPHAD-guided alloy compositions were successfully prepared** using the selected elemental ratios
- **Small-scale spin-casting trials produced amorphous samples**, confirmed through visual and structural evaluation.
- **Magnetic performance showed soft magnetic properties with saturation induction of 1.44 T at room temperature.**
- **Thermal behavior was characterized by Differential scanning calorimetry** from ambient temperature to above the alloy melting point to identify key transition temperatures.
- **Overall, the results provide an initial validation of the alloy design strategy** and support continued optimization of Fe-based amorphous alloys for high-performance soft-magnetic applications.

Impact

- The project's success holds the potential to significantly increase the efficiency of the domestic transformer grid while reducing the cost of crystalline and amorphous steels used in LPT and DPT.
- Creating a new opportunity to develop and accelerate the cost-effective fabrication and deployment of the next generation transformers which does not rely on critical GOES materials.
- New amorphous core transformers can lower core loss by 60-70 percent compared to transformers made with conventional GOES cores, resulting in cost avoidance from reduced generation and deferral of generation and transmission capacity expansions.
- The project would also contribute to the nation's energy independence and secure a domestic material source for the transformer supply chain.

Future direction/ Next steps

Strategic pathway: Material development → production scale manufacturing → core validation → prototype transformer demonstration.

- **Scale production** of optimized Fe based amorphous and hybrid alloys in collaboration with Metglas.
- **Validate toroidal core performance**, including core loss, permeability, saturation induction, and coercivity.
- **Design and fabricate a prototype distribution transformer with an industry partner** using the optimized amorphous/hybrid core material to demonstrate efficiency, thermal performance, and size/cost benefits.
- **Develop Fe-3%Si GOES replacement steel** for large power transformer applications and establish the pathway toward prototype core validation.

Acknowledgements

- This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE).