Materials Innovation Platform for Field-Assisted Synthesis and Processing (FASP)

Accelerating Materials Discovery through Electromagnetic Field-Driven Synthesis

Overview

This proposal establishes a ***national Materials Innovation Platform*** dedicated to harnessing electric and magnetic fields for transformative advancements in materials synthesis and processing. The envisioned platform, named ***Field-Assisted Synthesis and Processing (FASP)***, ***aims to leverage externally applied electric and magnetic fields as active, tunable parameters to enable unprecedented control over the synthesis of complex materials systems***. ***Targeting alloys, advanced composites, and quantum materials, FASP*** will provide innovative synthesis pathways previously unattainable via conventional methods. By seamlessly integrating advanced experimental capabilities with real-time, in situ diagnostics, characterization, computation, and theoretical modeling, ***FASP will empower researchers from academia, national laboratories, and industry to precisely engineer materials from atomic to mesoscale dimensions***.

Intellectual Merit

The intellectual merit of this proposal lies in its ***pioneering approach to materials synthesis by introducing electric and magnetic fields as dynamic tools for controlling phase formation, defect configurations, microstructural evolution, and emergent functionalities.*** By merging cutting-edge experimental methods with real-time characterization and closed-loop feedback, ***FASP*** will significantly accelerate materials discovery and innovation. The resulting scientific advancements will expand fundamental understanding of field-material interactions and catalyze breakthroughs in synthesizing materials critical to energy, aerospace, quantum computing, and numerous other strategic areas. The interdisciplinary nature and technological novelty of the proposed research align closely with NSF's strategic vision, ***filling a critical gap in national research infrastructure***. Notably, the ***FASP*** team has pioneered two transformative and complementary synthesis approaches: the patented ***Field-Tailoring Technology***, which combines magnetic fields with laser heating, and ***Flash Sintering Technology***, which uses electric fields/currents to edit crystal structures. ***With this unique combination of expertise and innovation, the team is exceptionally well positioned to lead this endeavor.***

Broader Impacts

FASP's broader impacts encompass broadening participation, enhancing national competitiveness, and accelerating workforce development in critical technology sectors. The platform is designed as an open-access facility serving an inclusive user base spanning academia, industry, and national labs (***up to 5,500 users in the US***). Through comprehensive user support, targeted outreach initiatives, and structured educational programs -- including workshops, seminars, and hands-on training experiences -- ***FASP*** will foster extensive community engagement and skill development. Additionally, the platform will proactively reduce barriers for emerging researchers and institutions, thereby promoting diversity and inclusivity. Ultimately, the ***FASP*** initiative promises to ***elevate the United States' leadership in materials innovation, addressing major scientific challenges vital to national security, technological leadership, and global sustainability***.

I. Senior/Key Participant List. ***Suggested length: 0.5-1.5 pages***.

Commented [DC1]: 1. Senior/Key Participant List. ***Suggested length: 0.5-1.5 pages***.
-Provide a list of participating Senior/Key Personnel (university faculty and equivalent) by full name, organizational and departmental affiliation, and major roles in the proposed MIP (e.g., in-house research, tool development, user facility operation, knowledge sharing, and/or training).
-Describe briefly the team's expertise with respect to the proposed in-house research, tool development, user facility operation, knowledge sharing, and training.
(It will be helpful to boldface the name of each Senior/Key Personnel wherever it occurs throughout the whole Project Description.)

Gang Cao, *Department of Physics and Materials Science and Engineering, University of Colorado Boulder (CU Boulder)*

Prof. Cao is a leading expert in materials discovery, synthesis, and characterization, with extensive experience in single-crystal growth using flux, floating zone, and electrochemical deposition techniques. He recently pioneered Field-Tailoring Technology (***FTT***), a patented technology that uses magnetic fields to control crystal structure formation during high-temperature synthesis, opening new pathways for directed synthesis of complex materials. Over the past two decades, he has led seminal studies of 4d and 5d transition metal oxides, establishing them as key quantum materials. As ***FASP*** Director, **Cao** will oversee the platform's scientific vision, operations, and strategic coordination.

Longji Cui, *Mechanical Engineering and Materials Science and Engineering, CU Boulder*

Prof. Cui specializes in nanoscale thermal transport, scanning probe microscopy, and energy conversion. He pioneered ultrahigh-resolution thermal imaging techniques that revealed vibrational, quantum thermal transport, and dissipation at atomic and molecular scales. His breakthroughs include single-electron thermal quanta detection, coherent phonon transport in molecules, the first molecular-scale Peltier cooler, and heat transfer across atomic-scale vacuum gaps. Recently, his lab observed destructive phonon interference in a single molecule, establishing the field of molecular thermal phononics. He also advances energy conversion and quantum devices, developing cryogenic memristors, sensors, and machine-learning-driven diagnostics. Cui will lead atomic-scale imaging and diagnostics for field-assisted synthesis.

Dan Dessau, *Department of Physics and Materials Science and Engineering, CU Boulder*

Joel Eaves, *Department of Chemistry, CU Boulder*

Eaves' expertise is in atomistic modeling, in and out of equilibrium, for ground and excited states. He uses and develops techniques in theory and computation including molecular dynamics simulation methodologies and tensor-based algorithms for classical and quantum relaxation dynamics in systems driven from equilibrium. Applications include linear and nonlinear optical, infrared, and magnetic resonance spectroscopies, quantum relaxation, and the development of chemical quantum hardware using organic molecules.

Minhyea Lee, *Department of Physics, CU Boulder*

Rahul Nandkishore, *Department of Physics, University of Colorado Boulder*

Prof. Nandkishore has extensive expertise in theory of quantum materials. He has done seminal work on correlated phases in graphene, on disorder effects in Dirac semimetals and topological insulators, and on correlated electronic phases in Kagome materials. He has also made foundational contributions to our understanding of how new techniques from nonlinear spectroscopy may be used to interrogate quantum materials and reveal information inaccessible to traditional experiments. His work ranges from formal theory to work in close collaboration with experimentalists.

Rishi Raj, *Mechanical Engineering, CU Boulder*

Dimitry Reznik, Department of Physics, University of Colorado Boulder

Prof. Reznik is an internationally recognized expert in Raman scattering with a distinguished record of experiments probing electron-phonon interactions, magnetic dynamics, and nonequilibrium phenomena in quantum materials. He leads a state-of-the-art, NSF-funded time-resolved Raman spectroscopy laboratory at CU Boulder, uniquely capable of ultrafast measurements across a broad spectral range. His group has pioneered a technique that tracks the time evolution of Raman-active phonon modes to directly quantify electron-phonon coupling strength as a rare experimental benchmark for theory. These capabilities have been applied to systems ranging from high-temperature superconductors, spin-orbit coupled iridates and others. In addition to foundational work in correlated electron systems, Professor Reznik has recently made significant contributions to the understanding of the FLASH phenomenon—a process in which electric fields dramatically accelerate densification in ceramics and drastically alter electrical and optical properties of single crystals. His group has provided new insight into the underlying physics using advanced scattering techniques, contributing to the emerging picture of current-assisted breakdown (CAB) and its role in initiating metastable electronic states that alter atomic mobility.

Michael Toney, *Chemical and Biological Engineering/ Materials Science and Engineering, CU Boulder*

Potential collaborators:

Hua Chen, Theorist/DFT, Physics, Colorado State University;
Barry Zink, Experimentalist, Physics, University of Denver;
Jingke Tang, Experimentalist, Physics, University of Wyoming;
TBD, CU Denver

II. Results from Prior NSF Support. Suggested length: 2-4 pages.

Gang Cao (25 years of continuous NSF support): **Current Sole PI Grant:** DMR 2204811, $ 747,878, 5/1/2022-4/30/2026. *Discovery and Control of High-Z Matter – Beyond Topological Materials*. **Intellectual Merit:** The PI has primarily focused on discovery, synthesis, and study of 4d/5d-electron based materials. A primary driver of the unique properties of these materials is a combined effect of strong spin-orbit interactions and electronic correlations. **Broader Impact:** This project has successfully generated three PhDs and numerous publications in prestigious journals, including Nature and Physical Review Letters. Additionally, the PI organized two workshops related to the project's topics in 2023 and 2024, which attracted over 160 participants. Publications during this award period: 15.

***Longji Cui**:* **Current Sole PI Grant:** CAREER CBET-2239004, $544,000, 03/01/2023-02/28/2028. *Fundamental understanding of thermal transport at the single molecule level*. **Intellectual Merit:** This work aims to leverage an advanced variable-temperature from liquid helium to above room temperature, ultra-high vacuum scanning thermal microscope developed by the PI to study the structure-property relationship in thermal transport, energy dissipation, and thermoelectric phenomena at atomic and single molecule scales. **Broader Impact:** This project can enable rational bottom-up design of high performance thermal and thermoelectric materials. This project also focuses on workforce development in nanoengineering through an education program. This project has supported 2 graduate students, resulting in 6 publications so far [1-6] and 4 under review.

Dan Dessau
Joel Eaves
Minhyea Lee
Rahul Nandkishore
Rish Raj

Dmitry Reznik (NSF awards DMR-1709946, DMR-2210126) has advanced the understanding of how external perturbations affect correlated quantum materials. His group demonstrated that magnetic fields during Sr_2IrO_4 growth alter magnetic structures and phonon dynamics, revealing a structural mechanism for field-tuned magnetism. Using time-resolved Raman scattering, they uncovered strong electron-phonon coupling linked to photoinduced superconductivity, and characterized high-quality $YBa_2Cu_3O_{7-x}$ heterostructures for Josephson devices, confirming robust epitaxy and superconductivity above 77 K. Recent studies identified novel electronic excitations in $NiBr_2$, opening new directions in quantum magnetism. **The intellectual merit** lies in revealing fundamental mechanisms for controlling quantum phases. **The broader impacts** include enabling new platforms for superconducting devices and advancing field-assisted synthesis strategies for quantum materials.

Mike Toney

III. Vision, Goals, and Rationale *(of the proposed Platform)* Suggested length: 2-

4 pages

III.1 Vision Statement

This proposal envisions the establishment of ***a critically needed national Materials Innovation Platform for Field-Assisted Synthesis and Processing*** (***FASP***), centered on ***the transformative integration of electric and magnetic fields with laser-based heating to accelerate materials discovery and revolutionize synthesis and processing***. By leveraging externally applied electric and magnetic fields as dynamic, tunable control parameters, ***FASP*** will drastically expand the thermal and electromagnetic degrees of freedom, ***enabling fundamentally new pathways for the design, discovery, and scalable fabrication of complex materials systems*** -- including high-entropy alloys, magnetic alloys, advanced composites, and quantum materials -- that remain largely inaccessible through conventional methods, even those employing simultaneous high-pressure and high temperature conditions [3, 35-36, 89]. ***FASP*** emphasizes the following aspects:

Close-loop Feedback System At the core of ***FASP*** lies a transformative, field-assisted synthesis paradigm that enables precise control over phase formation, defect landscapes, microstructural evolution, and emergent functionalities. By seamlessly integrating advanced experimental capabilities with real-time, in situ diagnostics, characterization, computation, and theoretical modeling, ***FASP*** will implement a robust closed-loop feedback system. This dynamic platform empowers users to tailor materials across atomic to mesoscale dimensions with unprecedented precision, significantly accelerating pathways to the discovery of new materials (see **Fig.1**). ***FASP*** brings together a team of top researchers with diverse, complementary expertise across synthesis, and characterization and theory. Moreover, we have a strong track record of successful collaboration. All team members are strong in materials research, with some recognized as world leaders in their respective fields. Notably, the ***FASP*** team has pioneered two transformative and complementary synthesis approaches: the patented ***Field-Tailoring Technology (Fig.2)***, which combines magnetic fields with laser heating, and ***Flash Sintering Technology (Fig.3)***, which uses electric fields/currents to edit crystal structures. With this unique combination of expertise and innovation, the team is exceptionally well positioned to lead this endeavor.

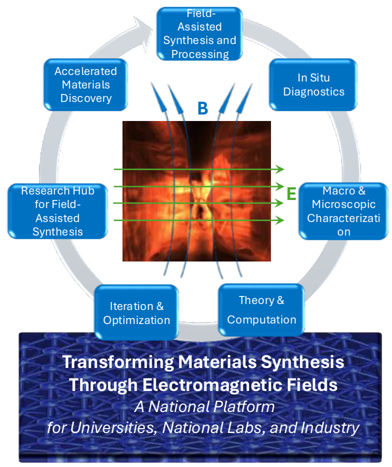

Fig.1. The closed-loop FASP *center on the transformative integration of electric (**E**) and magnetic (**B**) fields with laser-based heating to accelerate materials discovery and revolutionize synthesis and*

Broad and Inclusive User Base ***FASP*** is strategically designed to serve a broad and inclusive user community of approximately ***4,000 –5,500 individuals*** (**Chart 1**), spanning academia, national laboratories, and industry, with transformative applications across energy, aerospace, quantum information science, and beyond. A steadfast commitment to open-access infrastructure, comprehensive user support, and workforce development will cultivate robust community

Commented [DC2]: 3. Vision, Goals, and Rationale.
Suggested length: 2-4 pages.
-Provide a **vision statement** for the proposed entire Platform.
-In separate paragraphs or bullets, state the **major goals** of knowledge sharing, in-house research, tool development, user facility operation, training, and diversity of the proposed Platform.

-Discuss the critical needs of the proposed MIP for
- (a) addressing a grand challenge or challenges of fundamental research and advancing relevant NSF or national priorities,
- (b) a transdisciplinary team to address the grand challenge(s),
- (c) new experimental and computational tools as well as technique development, (d) fostering new modalities of research
through knowledge sharing, and (e) education/training of next-generation instrument developers and users.

engagement. Additionally, targeted outreach initiatives will expand participation, actively reducing barriers for emerging researchers and institutions in the US.

FASP Directly Aligns with NSF's Strategic Priorities by:

- Advancing **field-driven materials synthesis** through integrated scientific discovery and technical innovation,
- Cultivating a **diverse and interdisciplinary user community** through inclusive infrastructure, outreach, and collaboration**;** and
- Addressing **grand challenges** in synthesizing complex, multifunctional materials that are critical to sustaining U.S. leadership in science, technology, and sustainability [NSF].

Important Note: *Despite the immense potential of field-assisted synthesis and processing, there has been no coordinated or systematic national effort to advance this pivotal area of materials research. The proposed FASP platform is both timely and essential, directly addressing a critical gap in the United States' innovation infrastructure.*

III.2. Major Goals of FASP

The overarching goals of ***FASP*** are to fundamentally address the grand materials challenges currently facing the United States, accelerating the design, discovery, and application of functional and quantum materials through:

Seamless Access: Providing streamlined, professionally managed, open-access to state-of-the-art field-assisted synthesis and characterization facilities.

Integrated Tools: Developing and deploying advanced instrumentation that integrates precise electric and magnetic field control with real-time, in situ characterization capabilities (e.g., diffraction, spectroscopy, thermal imaging).

Modular Platforms: Creating flexible, reconfigurable experimental platforms that accommodate both routine and exploratory synthesis workflows, enabling users to customize setups tailored to their specific research needs.

Pioneering Research: Conducting groundbreaking in-house research to push the frontiers of field-assisted synthesis, serving as both a proving ground for novel techniques and an accelerator for external user-driven innovation.

Exemplar Use Cases: Demonstrating impactful applications within targeted classes of materials (e.g., high-entropy alloys, magnetic alloys, topological materials, correlated electron systems, and composite materials) to highlight the unique capabilities and scientific benefits offered by the platform.

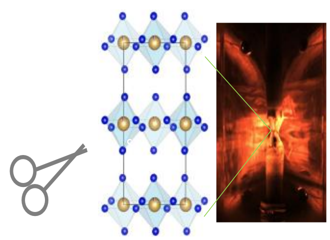

Fig.2. Field-Tailoring Technology (FTT): *Sc… crystal s… growth i…*

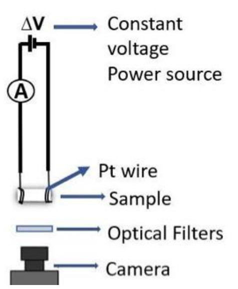

Fig.3. Schematic for Flash Sintering Technology *[91]* *Placeholder. Dmitry*

Broad Dissemination: Facilitating widespread distribution of knowledge generated by platform-enabled research through open-access publications, accessible data repositories, and established best practices in field-assisted synthesis methodologies.

Cross-disciplinary Engagement: Fostering interdisciplinary collaboration and exchange through annual symposia, targeted workshops, and seminar series that engage researchers from academia, national laboratories, and industry.

Comprehensive Training Programs: Offering structured training for users across all career stages through hands-on workshops, online educational modules, and immersive research experiences.

Workforce Development: Equipping the next generation of materials scientists and engineers with the expertise needed to lead future innovations in field-driven materials synthesis by embedding targeted education and skill development into every aspect of the platform's operations.

III.3 Rationale and User Base for FASP

III.3A. Rationale

Materials synthesis and processing lie at the core of technological innovation*,* enabling the development of high-performance structural, functional, and quantum materials. Traditionally, these processes have relied on thermal and mechanical means. However, the grand materials challenges confronting us today strongly indicate that conventional synthesis techniques are no longer sufficient. There is an urgent need for novel synthesis technologies capable of producing new phases and structures [1, 5, 6, 17–19].

Electric and magnetic fields offer powerful levers for transforming the thermodynamic and kinetic landscapes of solid-state reactions [AAA–NNN]. Acting as additional driving forces, these fields can enhance the mobility of charged species and ordered structures, lower activation barriers and temperature fluctuations, and stabilize otherwise inaccessible metastable phases. ***Magnetic fields***, in particular, can ***reshape phase equilibria by altering the Gibbs free energy landscape*** -- enabling, for instance, the stabilization of the ordered $L1_0$ FeNi phase, a promising rare-earth-free permanent magnet and candidate for high-density magnetic storage. ***Electric fields***, on the other hand, can ***accelerate phase formation by promoting ionic transport and defect generation***.

Crucially, these field-driven effects are not simply thermal in origin; rather, they emerge from the intricate coupling between external fields and material-specific parameters such as defect chemistry, grain boundary dynamics, and interfacial energetics. ***The ability to tune phase formation through precise control of field strength and orientation represents a paradigm shift in materials synthesis.*** The key advantages of field-assisted synthesis are summarized in **Table 1.**

Important Note: *$L1_0$ FeNi exhibits high uniaxial magnetic anisotropy, comparable to that of rare-earth magnets. In nature, this phase forms extremely slowly -- over millions of years in meteorites -- due to sluggish atomic diffusion. Laboratory synthesis of bulk or scalable $L1_0$ FeNi has long remained elusive. The* ***FASP*** *platform offers a unique opportunity to access such important, previously unattainable alloys.*

Table 1. Key advantages of field-assisted synthesis and processing

1.	*New phases and structures*
2.	*Highly ordered (micro)structures*
3.	*Acceleration of phase formation*
4.	*Stabilization of non-equilibrium metastable phases*
5.	*Reduction of lattice distortions*
6.	*Spin micromechanics*
7.	*Large magnetic domains*
8.	*Low convection, temperature fluctuations and striations*
9.	*High homogeneity*
10.	*Densification*

In short, the introduction of ***electric and magnetic fields*** into these processes provides unprecedented control over phase formation, microstructure evolution, defect manipulation, and energy efficiency [1-10]. Electromagnetic field-assisted techniques offer novel pathways to design, tailor, and manufacture materials with properties that are unattainable through conventional methods. In particular, ***FASP*** address the following five "**Critical Needs**":

Critical Needs for Addressing Grand Materials Challenges and Advancing National Priorities The grand challenge addressed by this MIP is to transform the way advanced materials (e.g., alloys, composite materials) are synthesized and processed by exploiting *electric and magnetic fields as active control parameters*. Conventional thermal routes are energy-intensive and limited in accessing metastable, non-equilibrium, or compositionally complex phases. In contrast, electromagnetic field-assisted synthesis enables rapid processing with enhanced selectivity, energy efficiency, and microstructural control. This capability is urgently needed to advance national priorities in ***quantum information science (see Fig.4) and critical materials security***. For example, field-assisted synthesis can enable rare-earth-free permanent magnets, metastable battery cathodes, and highly textured thermoelectrics [e.g., 35, 36]- all essential for sustainable technologies and resilient supply chains. Addressing this challenge requires a coordinated national platform to develop the science, tools, and trained workforce necessary to realize this new synthesis paradigm.

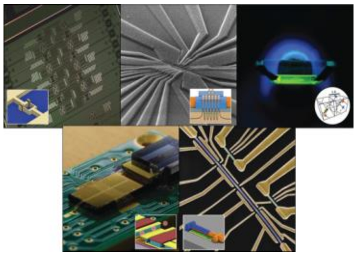

Fig.4. Materials challenges limiting five quantum computing hardware platforms: *Clockwise from top left: superconducting qubit processor, semiconductor quantum dots, color centers in diamond, topologically protected systems, and trapped ions [19].*

Critical Needs for Critical Materials The U.S. is heavily reliant on foreign sources for critical materials, such as ***rare earth elements, cobalt, and lithium.*** Field-assisted methods provide a pathway to **(1)** Stabilize functional phases using earth-abundant elements (e.g., Fe-Ni-based permanent magnets as substitutes for Nd-Fe-B); **(2)** Synthesize previously inaccessible materials, expanding the design space beyond traditional compositional limits; **(3)** Engineer microstructures for enhanced performance, potentially reducing material consumption per device; **(4)** Access to high-strength nanostructures and gradient materials; **(5)** Texture-engineering through magnetic field alignment for directional properties; **(6)** Rapid, low-temperature synthesis of ceramics and intermetallics vital to hypersonics, armor, and propulsion.

Critical Needs for an Interdisciplinary Team to Address Grand Challenges The complexity of field-matter interactions—spanning *solid-state chemistry, electromagnetism, materials physics, thermodynamics, and mechanics*—demands a truly *interdisciplinary team*. Expertise is needed in areas such as high-temperature synthesis, electric/magnetic field control systems, phase-field modeling, in situ diagnostics, and materials informatics. Moreover, integration across scales—from atomistic simulations to mesoscale microstructure design and macroscale device performance—requires ***co-design among theorists, experimentalists, and tool developers***. No single discipline can independently tackle the coupling between field effects and defect dynamics, phase transformations, or anisotropic growth. ***FASP*** will fulfill a critical need by uniting diverse perspectives to co-develop field-driven synthesis science and its technological translation (**Fig.1**).

Critical Needs for New Experimental and Computational Tools and Technique Development Electromagnetic field-assisted processing is still in its infancy in terms of available instrumentation. This is particularly true in the US. Realizing its full potential requires ***custom-built synthesis platforms*** capable of applying tunable electric and magnetic fields at elevated temperatures, under controlled atmospheres, and with integrated in situ diagnostics (e.g., x-ray, X-ray, optical, thermal, spectroscopic). In parallel, there is a critical need for multi-physics modeling tools that simulate field-induced phase transitions, charge migration, and defect evolution in real-time. Data-driven optimization of synthesis protocols will also require automated control systems, machine learning frameworks, and digital twins. ***FASP*** will develop, prototype, and share these tools with the community to enable reproducible, scalable, and high-throughput field-assisted materials processing.

Critical Needs for New Modalities of Research Through Knowledge Sharing ***(see IV)*** Electromagnetic field-assisted synthesis introduces an entirely new modality of materials design, one that depends not only on temperature and time but also on field strength, frequency, and orientation. ***This parameter space remains largely unexplored, and there is currently no central repository for the protocols, results, and techniques emerging in this domain. FASP will meet the critical need to systematize and share new knowledge, including phase maps under field conditions, structure - property databases, open-source simulation tools, and user-friendly experimental workflows.*** This will accelerate the dissemination of best practices and catalyze broad adoption of this paradigm, lowering the barrier for entry and enabling users from diverse institutions to engage in high-impact field-assisted synthesis.

Critical Needs for Education and Training of Next-Generation Instrument Developers and Users There is a severe shortage of researchers and technical staff trained in field-assisted synthesis, particularly at the intersection of ***materials science, applied physics, and advanced instrumentation***. As the U.S. pursues innovation in energy, defense, and quantum technologies, it is essential to build a workforce capable of operating and advancing these novel synthesis platforms. ***FASP will address the critical need for hands-on, interdisciplinary training in field-enabled processing and tool development.*** Programs will span undergraduate, graduate, and postdoctoral levels and include ***instrumentation internships, modular curricula, and workforce***

certification programs. The platform will also engage underrepresented communities and partner institutions to ensure broad, inclusive participation in this next-generation materials revolution.

Important Note: *In light of the urgency to address energy, manufacturing, and critical materials challenges, electromagnetic field-assisted synthesis and processing is not merely a promising alternative -- it is an essential tool for the U.S. to accelerate innovation, secure supply chains, and lead the materials revolution. National investment in this area is critical to ensure competitiveness, resilience, and technological sovereignty in the coming decades.*

III.3B. FASP User Base in the US

There will be a board user base for ***FASP*** in the US (see **Chart 1**). Below is a reasoned estimate based on sectoral analysis:

Academic and National Lab Researchers They include materials scientists, physicists, chemists, and engineers working in universities and national labs with interests in:

Solid-state synthesis
Ceramics and metallurgy
Functional materials (e.g., batteries, catalysts, thermoelectrics, magnets)
Field–matter interaction studies (e.g., flash sintering, magneto-structural effects)
Quantum materials (e.g., 2D materials, topological and correlated materials)

Estimated active users: ~ 800 - 1,000

This estimate is based on faculty and senior researchers across *~100 research universities* and *~15 national labs* with active materials programs.

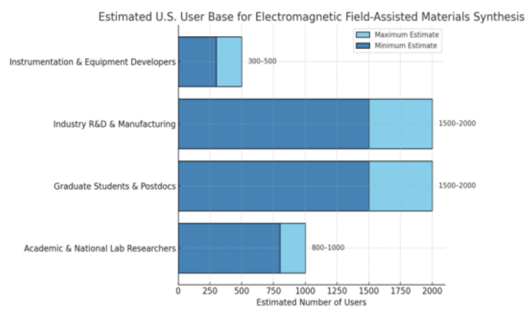

Chart 1. Estimated Total U.S. User Base: *~ 4,000 – 5,500 users.*

Graduate Students and Postdocs A large fraction of users in academia are graduate students and postdocs trained in

Electroceramics
Energy materials
Field-driven materials phenomena
Computational modeling of field effects
Quantum materials (e.g., correlated materials, topological materials, 2D materials)

Estimated users: ~1,500 - 2,000

This estimate is obtained assuming 2 - 3 trainees per faculty member across *the ~ 400 – 500 PIs* in the field. **Industry R&D and Manufacturing** Companies in the following sectors are key users or stakeholders:

Quantum information processing (QIP) (e.g., quantum computing hardware platforms; **Fig.2***)*
Energy storage and conversion (e.g., solid-state battery firms)
Electronics and semiconductors (e.g., microfabrication, capacitor and interconnect materials)
Aerospace and defense (e.g., structural alloys, armor materials, radar-absorbing ceramics)
Advanced manufacturing (e.g., metal forming, additive manufacturing, sintering)

Estimated users: ~ 1,500 – 2,000

This estimate includes engineers, R&D specialists, and technical managers at *~200 - 300 companies* in materials-heavy industries)

Instrumentation and Equipment Developers

These are companies and research facilities that develop or use:

Flash sintering

Magnet annealing systems

Electromagnetic forming setups

In-situ EM field integration for microscopy or spectroscopy

Estimated users: ~ 300 – 500

This estimate Includes instrument designers, materials test engineers, and system integrators.

Estimated Total U.S. User Base:

~ 4,000 - 5,500 individuals

This estimate includes core users and a surrounding group of collaborators, trainees, and developers who actively utilize or benefit from field-assisted synthesis and processing.

Important Note: *The recently established APS Topical Group on Quantum Materials Synthesis (GQMS) founded and chaired by the PI - has already attracted over 500 members and continues to grow rapidly. This figure does not account for researchers working in other classes of materials.*

IV.Knowledge Sharing. **Suggested length: 5-7 pages**

likely challenges in creating a culture of knowledge sharing and **Strategies to overcome these challenges**

(This section needs more work, please help)

A central mission of ***FASP*** is to establish a culture of open, collaborative science through the sharing of tools, data, codes, samples, and expertise. This culture is essential to accelerating the adoption of field-assisted synthesis and processing methods and to ensuring that the benefits of ***FASP*** extend to the broader materials research community. Our goals are to **(1)** Enable transparent, reproducible, and scalable materials synthesis through shared protocols and data infrastructure, **(2)** Foster interdisciplinary training and collaboration by making in-house expertise and advanced instrumentation accessible, **(3)** Build a national repository of data and field-based processing parameters, and **(4)** Provide community-wide access to validated codes and simulators for electric and magnetic field-assisted synthesis.

IV.1. Anticipated Challenges and Mitigation Strategies

Cultural and Structural Barriers: Knowledge sharing can be hindered by disciplinary silos, proprietary research norms, and inconsistent documentation practices.

Strategy: Foster an inclusive and proactive sharing culture through regular joint research meetings, co-authorship models, and training workshops. Develop incentives such as attribution in datasets and digital object identifiers (DOIs) for shared codes and methods.

Commented [DC3]: **4.Knowledge Sharing. Suggested length: 5-7 pages**

-MIPs are designed to foster new modalities of research and education, through sharing of tools, codes, samples, data and know-how.

-In addition, MIPs are expected to incorporate the emerging fields of **data science**, including **artificial intelligence** and/or **machine learning**, as appropriate, in materials research.

-In this section, identify likely **challenges in creating a culture of knowledge sharing** and describe strategies to overcome these challenges.

- Describe **goals** and **proposed mechanisms** for knowledge sharing, the anticipated results, and the expected outcome and impacts.
- Include mechanisms for knowledge sharing within the in-house research team; among external users; and for the whole community of practitioners that the proposed MIP represents (in-house research scientists, external users, and other scientists).
- Different mechanisms could be needed, depending on type of tools, codes, samples, data (including meta data) and know-how to be shared.
- The mechanisms should balance between the need for confidentiality and creation of a culture of knowledge sharing, as well as be consistent with relevant NSF policies (see, for example, PAPPG Chapter XI.D) and FAIR data principles. (The Data Management and Sharing Plan can be used to provide additional details for data access and sharing, as well as discussing other issues such as types and format of data and meta data, data archiving, data security, etc., as appropriate).

Data Standardization and Interoperability: Diverse instrumentation, formats, and metadata standards present hurdles to integration.

Strategy: Adopt community-agreed ontologies and metadata schemas. Collaborate with national data initiatives (e.g., Materials Data Facility, NIST) and use open standards like JSON-LD and HDF5 for extensibility.

Balancing Confidentiality and Openness: User facilities often generate proprietary data in early-stage collaborations.

Strategy: Implement tiered data access (e.g., embargoed, open after 12 months) and non-disclosure protocols. Allow secure, role-based access through a user portal that complies with NSF policies and institutional IRB/ITAR/EAR frameworks.

IV.2. Mechanisms for Knowledge Sharing

Internal Team Sharing

Collaborative digital workspace: A cloud-based environment (e.g., Globus, Materials Commons, or JupyterHub) for sharing protocols, raw data, annotated images, and scripts.

Shared lab notebooks and instrumentation logs: Maintained through an electronic lab notebook (ELN) platform integrated with our data management system.

Weekly team-wide synthesis debriefs: Facilitated via hybrid meetings, focusing on process optimization, anomalies, and reproducibility.

External User Access

User training and onboarding: Including remote modules and hands-on workshops for safe and effective use of field-assisted synthesis tools.

Code repositories and model dissemination: Hosted on GitHub/GitLab with documentation, version control, and example workflows.

Automated logging of synthesis parameters: Each experimental session logs field strength, waveform, temperature, atmosphere, and outcome; this metadata is shared with users and integrated into a searchable knowledgebase.

IV.3. Broader Community Engagement

Publication-linked data packages: All published MIP papers will reference archived data with DOIs for download from open repositories (e.g., Zenodo, Mendeley Data).

Workshops and hackathons: Focused on community use of shared tools and codes, including AI/ML pipelines trained on FASP datasets.

Annual FASP Symposium: To showcase user-led advances, share best practices, and seed new collaborations.

IV.4. Expected Outcomes and Impacts

Broad dissemination of field-dependent synthesis blueprints will lower the entry barrier for institutions with limited infrastructure. Data sharing practices will set new community standards for reproducibility and openness in synthesis science. A digitally connected, cross-disciplinary community will emerge around FASP methods, catalyzing new alliances across academia, national labs, and industry.

V. Background and Proven Advantages of Field-Assisted Synthesis and Processing

Suggested length: 5-8 pages.

Commented [DC4]: 5.In-House Research. Suggested length: 5-8 pages.
-Describe the **scope and targeted scientific outcome** of the MIP and specific in-house research activities.
-The scope of in-house research should be focused, smaller than the scope covered by the whole MIP, and synergistic to the user program.

-This section **must also discuss** how the proposed in-house research closes the loop among materials synthesis/processing, materials characterization, and theory/modeling/ simulation such that it is iterative and synergistic and utilizes a transdisciplinary approach to enhance the scientific impact above and beyond what can be accomplished using conventional approaches.

-If more than one institution is involved in the in-house research, effective mechanisms to prevent the negative impact of distance on the collaborative, interactive "closed loop" nature of the MIP must be clearly described.

This Section presents the **Fundamentals of Field-Assisted Synthesis and Processing** (**V.1**), the **Proven Advantages of Field-Assisted Synthesis and Processing** (**V.2**) and **Scope and Targeted Scientific Outcomes of FASP (V.3).**

V.1. Background of Field-Assisted Synthesis and Processing

A. Magnetic-Field Assisted Synthesis or Magneto-Synthesis

The effect of magnetic fields on synthesis and processing has been documented since 1960's [20-58,77-86]. The early studies primarily focused on semiconductors using various synthesis methods, such as the Bridgman, floating-zone, and Czochralski techniques. Results of these studies demonstrated that application of magnetic field reduces melt convection and temperature fluctuations, and thus improve the microscopic homogeneity in single crystals of investigated semiconductors [20-34]. The key driving force is the ***Lorentz force*** because liquid semiconductors such as silicon have high electrical conductivity [20, 21, 26, 27, 33].

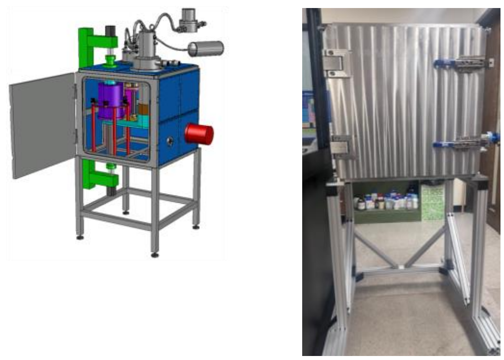

Fig. 5. Left: FTT platform drawing of the high magnetic field molten zone system: *The molten zone consists of the 5-fold laser diode input structure (red), the feed and seed rod mechanics (green) for rotation and translation, and the quartz tube. The superconducting magnet consists of the coils enclosed in the 45K heat radiation shield (purple), the dedicated pulse tube cryocooler (rear quadrant), and the thermal linking bars (pink and yellow). The isolating shields consist of the passive reflectors (gray) from the bottom, the active heat sink shield and linkage (cyan), and the large dedicated cryocooler (front quadrant).* ***Right: The FTT platform under development at UC Boulder****, which is expected to be completed and available to users in early 2026.*

In recent decades, it has become increasingly clear that magnetic energy can also be utilized to enable and accelerate new phase formation, metastable phase stability, structural ordering, and microstructures in a wide range of materials including carbon-steels, which are otherwise unattainable [22, 28, 33-38, 40-49, 77-86]. In essence, since the ***Gibbs free energy*** difference vanishes near phase boundaries, strong magnetic fields can effectively modify the Gibbs free energy such that phase boundaries become a function of the applied magnetic field [36, 44]. Material properties are thus dictated by interactions between applied magnetic fields and electrons/ions/magnetic spins as well as defects, dislocation networks, etc. Our own recent studies indicate that in addition to the Lorentz force and Gibbs free energy, ***a combined effect of strong spin-orbit interactions, magnetoelastic coupling*** and ***near-degeneracies*** plays an essential role in the magneto-synthesis of quantum materials [3, 37] (see **Section V.2**). *The stronger the applied* *magnetic field, the more likely magneto-synthesis will be effective to access novel phases and structures.*

We have developed a novel ***Field-Tailoring Technology (FTT)*** that integrates a laser-heated floating zone furnace and a strong magnetic field superconducting magnet, enabling the synthesis of functional and quantum materials with tailored structures, phases, and properties that are otherwise inaccessible (see **Figs.5** and **6**). This unique instrument is expected to be completed and available to users in early 2026. Two more FTT platforms with stronger magnetic fields and different laser configurations will be built and are expected to be completed and available to users within the first two years of ***FASP***. One of the PIs, Gang Cao, holds a U.S. patent on the FTT platform.

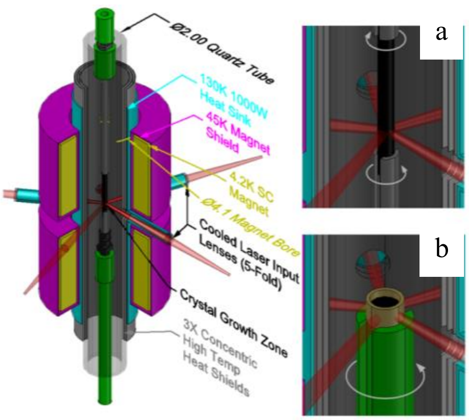

Fig.6. Schematic of the laser furnace with superconducting magnet: *The furnace consists of 5 radial laser diode inputs to supply 1250W. The superconducting magnet consists of a 4K coil and a 45K heat shield. The two devices are separated by passive radiation shields to reduce heat transfer and a 130K radiation shield acting as a heat sink capable of removing over 1250W of power. The magnet bore is 4.1" and the quartz tube enclosing the molten zone is 2.0" in diameter. The red beams represent laser light.* ***Inset a:*** *The enlarged* ***floating-zone setup****; the rotating feed-rod is heated by five laser beams.* ***Inset b:*** *The detailed* ***setup for flux growth****; the metal crucible placed on a rotating holder is heated by five diffused laser beams.*

The novelty of the ***FTT*** platform is that a laser furnace up to 2200 ^{o}C is surrounded by a 5T-superconducting magnet (**Fig.5**). It will permit bulk single-crystal synthesis for ***both floating-zone*** (**Fig.5 inset a**) and ***flux methods*** (**Fig.5 inset b**) in an environment where both the magnetic field and temperature can be tuned up to 5 T and 2200 ^{o}C, respectively, and vacuum or different gases can be applied. This capability will drastically expand the thermal and magnetic degrees of freedom for synthesis and provide access to novel (micro)structures and phases of functional and quantum materials [2, 16] that have proved out of reach to existing synthesis techniques [3, 35-36, 89]. This instrument will enable the synthesis of functional materials for energy conversion and storage [39-43], such as the forementioned high-performance permanent magnets without rare earth elements considering the increasingly worsening shortage of rare earth elements [59, 61].

As illustrated in **Figs. 5-6,** the ***FTT*** platform features an unprecedented combination of **(1)** an array of five 250 W-laser diodes to supply 1250 W of power for a molten zone up to 2200 ^{o}C (**Fig.5**), **(2)** a split 5T-superconducting magnet with five optical windows surrounding the molten zone, **(3)** a series of cryocoolers (e.g., *Cryomech* PT420) to cool the superconducting magnet and provide a thermal shield between the magnet and the molten zone (**Fig.5**), and **(4)** a versatile mechanism enabling both ***floating-zone*** (**Fig.6 Inset a**) and ***flux*** (**Fig.6 Inset b**) growth techniques. ***Note that the rotating molten zone ensures crystal homogeneity*** (**Fig.6 insets a-b**).

The complementary nature of these techniques makes it possible to synthesize single crystals of almost all stable bulk materials in just one instrument. Individual components of the ***FTT*** platform have been explored in different contexts, but ***no one has pursued a laser furnace with a superconducting magnet designed for both floating-zone and flux synthesis.*** The novel combination of capabilities projected for the *FTT* platform has therefore never been attempted.

The significance of the FTT, to a large extent, could parallel that of the floating-zone technology. It was first developed at *Bell Laboratories* and commercialized by *Siemens* in the 1950s. This new technology eventually permitted synthesis of ultrapure silicon single crystals, which was a critical underpinning for the development of many semiconductor devices. More recently, the floating-zone technique was improved by using halogen lamps and ellipsoidal mirrors for crystal growth of a wide range of metals and oxides. The resulting materials have proved to be of great fundamental and technological significance. These early developments open the door to the next-generation synthesis technology, the *FTT* platform that is specially adapted to crystal growth in strong magnetic fields and high temperatures, producing ultra-ordered, field-tailored phases or microstructures that could not be duplicated by other means.

However, the importance and uniqueness of magneto-synthesis have not been widely recognized for materials beyond semiconductors until recent years when material scientists have started to aggressively search for new ways of synthesis to tackle increasingly more materials challenges [35, 38-44].

Important Notes: *Existing thermomagnetic processing technologies commonly used for heat-treatments of carbon steels and other materials are usually constrained by an upper temperature limit of 1100 ^{o}C and a short duration of high-temperature operation [36, 44]. These limits make these technologies inadequate for single-crystal synthesis of most materials, which normally requires much higher temperatures (>1200 ^{o}C) and much longer operation time at high temperatures due to slow cooling [3, 37]. Thermomagnetic processing technologies for steels and Fe-C alloys have been widely used in the manufacturing industry [35-49].*

B. Electric Fields Assisted Synthesis and Processing (EFASP) (Dmitry, please add Flash to this section)

The use of electric fields in materials synthesis and processing dates back to the mid-20th century, with early applications rooted in electrochemical methods. However, it was not until the 1980s that the approach gained substantial scientific momentum. During this period, electric field-assisted sintering began to emerge, utilizing direct current (DC) or pulsed electric fields to enhance the densification of ceramics. By the 2000s, electric fields were increasingly employed to influence grain growth, crystallographic texture, and phase selection during bulk synthesis processes [90].

A major breakthrough came in the 2010s with the advent of ***flash sintering***, ***pioneered by two of the PIs, Rishi Raj and Dmitry Reznik***. This technique involves the application of modest voltages during sintering, enabling ceramics to densify within seconds at significantly lower furnace temperatures. The success of flash sintering has reinvigorated the field, sparking broad interest in electric field-assisted synthesis and processing (see **Fig.7**).

Beyond ceramics, electric fields have been used to stabilize metastable phases, drive ion

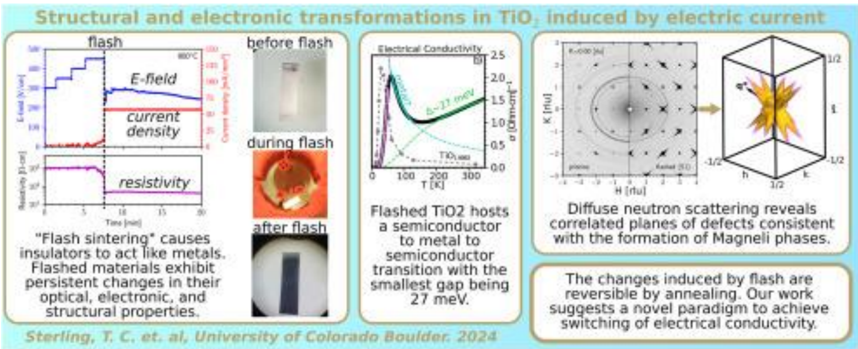

Fig.7. Flash Sintering Place Holder (Dmitry: Please update it)

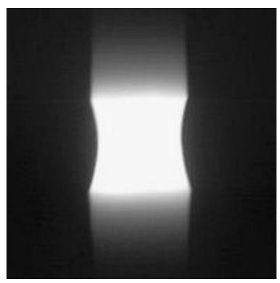

Fig.8. Snapshot of a $La_{1-x}Ca_xMnO_3$ crystal at applied current density of 11.4 A/cm^2 *grown in the molten zone of a laser floating zone furnace [90].*

migration in solid-state batteries, and induce phase transitions in quantum and correlated materials (**Fig.8**). Electric field-assisted synthesis has rapidly accelerated in the past decade through groundbreaking innovations such as ***flash sintering*** and current-induced transformations [e.g.,91, 92].

Electric fields-assisted synthesis can be achieved relatively easily. Electric field can be applied through a voltage generator. For conventional floating zone furnaces (**Fig.9**), the electrodes or wires carrying the voltage can be placed along the metallic shafts. The electrodes can be ~ 1-2 cm apart on the opposite sides of the molten zone. We have developed a setup capable of delivering electric fields up to ***600 V/cm***. For a laser floating zone furnace, we will develop an electric field synthesis platform that enables tuning of field strengths and orientations (**Fig.10**).

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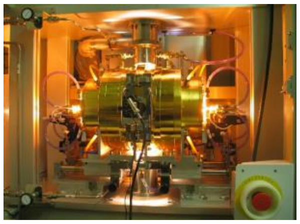

Fig.9. Picture of a conventional floating-zone furnace in Cao's lab. *Note that the electrodes generating electric fields can be readily installed inside the elliptic mirrors.*

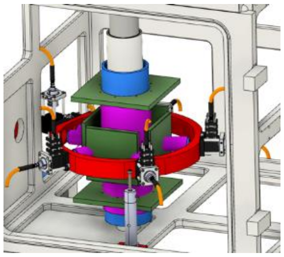

Fig.10. Schematic of FASP laser-based-electric-field assisted synthesis platform. *The dark green plates are electric plates, which apply electric field to the molten zone, either horizontally or vertically.*

V.2. Proven Advantages of Field-Assisted Synthesis and Processing

V.2A Magneto-Synthesis and FTT

The idea of developing the *FTT* originated from our long-time observation and experience that a large body of theoretical work predicting novel phases pertaining novel superconductivity, quantum spin liquid, and other quantum entangled phases [e.g., 2, 7-16] have thus far met with very limited experimental confirmation despite extensive synthesis efforts in recent years [3, 4]. This is particularly true for materials whose ground states are dictated by a highly delicate interplay between spin-orbit and Coulomb interactions chiefly because these materials tend to have multiple nearly degenerate states and are extremely susceptible to even slight magnetic and/or structural distortions and disorder [2-4, 16]; and yet most of these materials are inherently distorted [3, 4]. The *FTT platform* is our response to the long-lasting materials challenges.

It is also important to be pointed out that the ongoing explosion of interest in quantum computing and QIP has produced quantum control schemes and device architectures that address technical challenges such as decoherence, noise, loss, etc. [1]. However, little attention has been given to underlying quantum materials that underpin QIP and, more generally, materials challenges that have inevitably hindered progress in QIP platforms, namely, superconducting circuits, topologically protected systems, quantum dots, trapped ions, and color centers (**Fig. 4**) [17-19]. The current materials challenges evoke those for semiconductor devices in the 1950's and 1960's; tackling them eventually led to new synthesis techniques, such as the floating-zone method, which have ultimately made today's semiconductor technology possible. Clearly, it requires new synthesis approaches to address the materials challenges facing today's technologies [1, 3-6, 17-19].

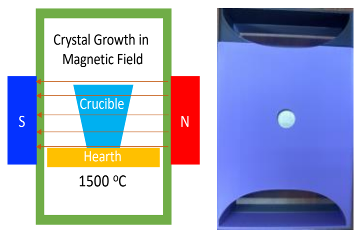

Fig. 11. Left: Schematic of the proof-of-concept setup *for field-tailoring with permanent magnets [3].* ***Right:*** *One of the two 1.4 T magnets inside a specially home-made case (blue)*

The foundation of the *FTT* platform is based on evidence well-established in studies of magneto-synthesis and magneto-processing since the 1960s [e.g., 20-58, 77-86]. These studies clearly indicate that the Lorentz force dampens convection and temperature fluctuations, which in turn improves the crystal homogeneity of semiconductors [20-33]. More recent studies have shown that the magnetic energy also expands the thermal and magnetic degrees of freedom for synthesizing materials with new phases and/or functionalities. It is accomplished via altering phase boundaries, stabilizing metastable phases, tailoring microstructures, accelerating phase formation, enhancing grain growth, etc. [34-58].

The effectiveness of the *FTT* is further confirmed by our preliminary results obtained using a proof-of-concept setup consisting of a conventional muffle or box furnace and permanent magnets of 1.4 T (**Fig. 11**) [3, 37, 58]. The magnetic field inside the furnace chamber is smaller than 0.2 T because the magnetic field decays at a rate of $1/d^3$ and d being the distance between the magnet and the crucible (**Fig.11**). Despite of a small field and other limitations, these results nevertheless demonstrate strong evidence that the magneto-synthesis is particularly effective in altering native states and/or generating new states in high-Z materials with multiple nearly degenerate states (Z = atomic number; spin-orbit interactions ~ Z^2) [3, 4]. This is because magnetic energy can change phase equilibria in general [36, 44] and here, this is also because the applied magnetic field can more effectively align magnetic moments and, through strong spin-orbit interactions and magnetoelastic coupling inherent in these materials, alter or "correct" crystal or magnetic structures at high temperatures, resulting in more desirable behavior [3, 37, 58].

In the following we present several examples ranging from oxides, chalcognides, alloys and steels, which include our recent, unpublished results attained from our proof-of-concept studies (**Fig. 11**), to illustrate *the effectiveness and enormous potential of the FTT for next-generation synthesis when high magnetic fields (up to 5 T) and high temperatures (up to 2200 ^{o}C) are simultaneously available during synthesis*.

We present several representative examples, including ***oxides, chalcogenides, alloys, and steels***, some based on our recent unpublished proof-of-concept results (**Fig.11**), to illustrate the effectiveness and transformative potential of ***FTT*** for next-generation synthesis, enabled by the simultaneous application of high magnetic fields and high temperatures.

Spin-orbit-coupled antiferromagnet $BaIrO_3$. This interesting trimer magnet is extensively studied for its rich physics and is known to be sensitive to lattice properties [e.g., 3, 64-67]. Our most recent data show that the field-treated or field-tailored *$BaIrO_3$ shrinks by astonishing 0.73%* in the unit cell volume V with a less distorted structure (**Fig.12a**) and shifts the Neel temperature T_N from 183 K to 150 K (**Fig.12b**). Even more strikingly, the field-tailored $BaIrO_3$ exhibits a huge entropy removal near T_N = 150 K, indicating a *much more ordered state* than that of the non-treated or non-tailored counterpart (**Fig.12c**). In addition, ***FTT*** also converts the native insulating state to a metallic state (not shown) as a result of the less distorted structure and more ordered magnetic state evidenced in **Fig. 12**.

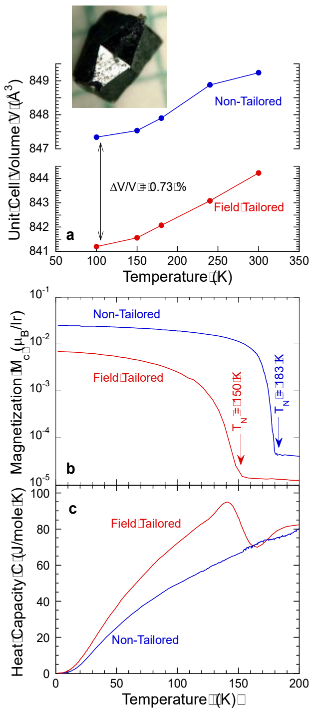

Fig.12. FTT Effect on $BaIrO_3$: a, *The unit-cell V shrinks by 0.73%,* ***b,*** *the magnetic transition T_N drops by 33 K;* ***c,*** *the heat capacity C shows a huge jump at T_N, rare for the iridates. Note the field-tailored and non-tailored data are in red and blue, respectively. Inset: Single crystal $BaIrO_3$ [75].*

Spin-orbit-driven Mott insulator Sr_2IrO_4. This is an archetype of the novel, spin-orbit-driven magnetic insulator that has been extensively studied [e.g., 3, 4, 7, 12-14, 16, 87, 88]. This material is widely anticipated to be a novel superconductor when it is slightly electron-doped [e.g., 10-13]. However, there has been no experimental confirmation of superconductivity, despite many years of experimental efforts [4]. There is strong evidence that the absence of the predicted superconductivity is due mostly to *inherently severe structural distortions* that suppress superconductivity [3, 4]. To address this materials issue, we used the proof-of-concept setup (**Fig.11**) synthesizing the single-crystal Sr_2IrO_4 and electron-doped Sr_2IrO_4. These field-tailored single crystals are either *drastically improved or changed* in terms of the structural and physical properties, compared to those of non-tailored samples [37, 58]. In particular, the abrupt drop in electric resistivity below 20 K in field-tailored, 3% electron-doped Sr_2IrO_4 (**Fig.13**) suggests that the long-elusive superconductivity in the material might be within reach *if/when the sample can be much more strongly field-tailored* (note that the current sample is not yet a superconductor).

Indeed, the field-tailored structure of undoped Sr_2IrO_4 is less distorted (Ir-O-Ir bond angle becomes larger, closer to the ideal 180°) (**Fig.14**), and the antiferromagnetic transition is suppressed by 90 K (**Fig.15a**) and the resistivity is reduced by five orders of magnitude (**Fig.15b**) [37].

The Raman scattering data also reflect the magnetic change. Our earlier study reveals the one-magnon peak, which is prominent in the data of the non-tailored Sr_2IrO_4 at 18 cm^{-1}, is absent in the field-tailored sample [37]. This observation, together with the suppressed Neel temperature (**Fig.15a**) indicates that the magnetic moments are more weakly pinned by the crystal field. The magnon spectrum in the field-tailored and non-tailored samples is vastly different, as indicated by the different lineshapes of the two-magnon scattering peak despite the modest differences in the lattice between the two samples (**Fig. 16**) [37]. Our most recent data further indicate that the field-tailored Sr_2IrO_4 shows a different stacking of weak in-plane ferromagnetic moments and significant softening and broadening of select Raman-active phonons [58].

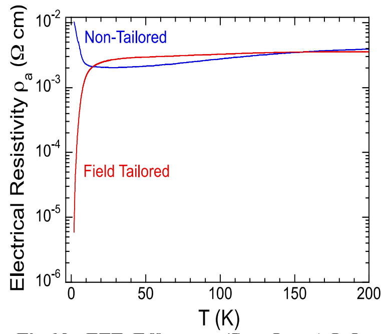

***Fig.13**. **FTT Effect on $(Sr_{0.97}La_{0.03})_2IrO_4$:** The electrical resistivity (red curve) is reduced by 7 orders of magnitude although the current field-tailored iridate is still not a superconductor [75].*

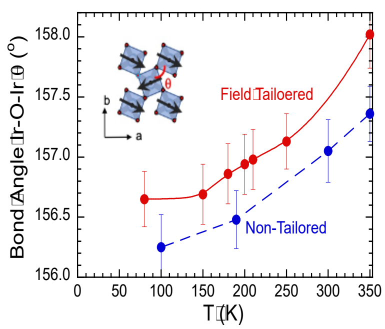

***Fig.14. FTT Effect on Sr_2IrO_4:** The bond angle θ are significantly different between the field-tailored and non-tailored single crystals [37]. Inset: the distorted ab-plane.*

Quantum-spin-liquid $Ba_4Ir_3O_{10}$. We found that this trimer-lattice iridate underpins a quantum spin liquid state that is characterized by a large linear heat capacity C(T) persisting down to 0.2 K (**Fig.17**) [68] and an emergent one-dimensional spinon continuum [69]. However, this spin liquid ground state is readily supplanted by a robust antiferromagnetic state with a Néel temperature at 120 K in the field-tailored sample, which is evidenced in C(T) (**Fig.17**) and the magnetic properties. The drastic change in the ground state is because of the lattice alterations during the magneto-synthesis [37].

Lattice-driven Mott insulator Ca_2RuO_4. The 4d-electron based Ca_2RuO_4 [70] is an extensively investigated Mott insulator for its distinct lattice-driven properties [3]. It is an antiferromagnet with T_N = 110 K [70] but becomes a ferromagnet with a Curie temperature T_C = 140 K (**Fig. 18**) and much more metallic when field-tailored [37].

Paramagnet $CaRuO_3$. $CaRuO_3$ is a paramagnet persisting to 50 mK [3, 74], whereas its sister compound $SrRuO_3$ is a well-studied ferromagnet with T_C = 165 K [74]. The contrasting ground states are a result of the exceptionally high susceptibility of physical properties to lattice distortions which destabilize the ferromagnetic state [3]. The field-tailored $CaRuO_3$ becomes less distorted, compared the non-tailored sample, and consequently, shows a strong tendency to a magnetic order at low temperatures, as shown in **Fig. 19** [75].

Chiral-orbital-current-driven $Mn_3Si_2Te_6$. ***FTT*** is also effective for transition metal chalcogenides, such as $Mn_3Si_2Te_6$, where chiral orbital currents underpin a novel colossal magnetoresistance, as we discovered recently [71]. The field-tailored sample has a larger magnetization than the non-tailored counterpart, resulting in a more magnetically ordered state (**Fig.20**) and the enhanced chiral orbital currents [75].

Functional alloys. It is already established that the magnetic annealing can effectively expand the domain size of magnetic materials (e.g., **Fig.21**) [36], which improves magnetic anisotropy and transport properties [40-43]. Moreover, magnetic annealing can also enhance Goss texture (functional soft magnetic properties) (**Fig. 22)** [36]. Clearly, the magnetic energy as a control parameter can effectively alter microstructures of the functional materials.

Carbon-steels. Application of strong magnetic field B stimulates the martensitic transformation in steels and iron-based alloys because the magnetic susceptibility of martensite is much higher than that of austenite near the transformation temperature. Since B enhances the phase stability of steels, one can control the final microstructures of steel products through the heat-treatment (< 1100 ºC) under B (**Fig.23**) [44]. Magneto-processing of steels has drawn increasing attention in the steel industry over last 20 years [44].

The above proof-of-concept data highlight the extraordinary potential of ***FTT*** to enable the realization of novel materials, ***a distinctive strength of FASP***.

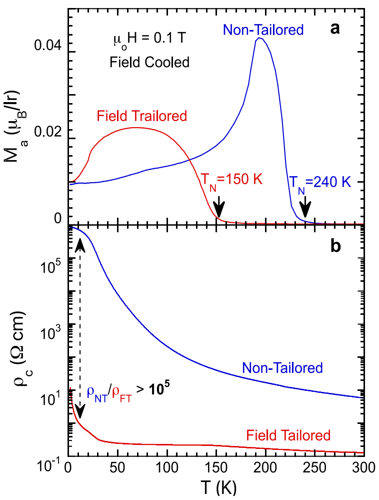

***Fig.15**. **FTT Effect on Sr_2IrO_4: a,** Magnetization and **b,** electrical resistivity changes drastically in the field-tailored single crystals of Sr_2IrO_4 [37].*

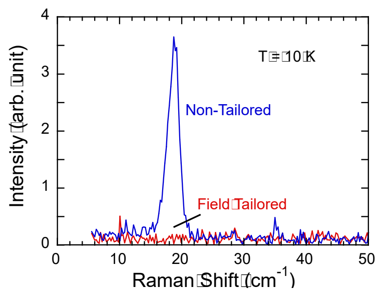

***Fig.16**. **FTT Effect on Sr_2IrO_4:** The magnetic peak and the absence of it in the Raman spectra of Sr_2IrO_4 indicate vast differences magnetically between the non-tailored and field-tailored crystals [37].*

V.2B. Electric-Field Assisted Synthesis and Processing (EFASP) and Flash Sintering

It is well documented that, in the presence of a chemical potential gradient, applied electrical fields act as a second driving force for mobile atoms [93]. The effect of applied electric fields on solid reactions has been studied for various spinels [94-96]. The electric field/current can affect the nature of the resulting phases and their growth rate constant [94, 95]. In general, electric-field assisted synthesis and processing enable realization of materials materials that are extremely difficult to obtain by other methods, for example, ***nanostructured thermoelectrics or composites out of thermodynamical equilibrium*** [97,98].

Above a certain critical electric field, sudden ***densification*** can takes place within a few seconds at temperatures much lower than usually required (up to 500 °C difference) (**Fig.24**) [99]. This flash sintering effect accompanied by a power surge has been observed for different oxide ceramics [100, 101].

Our recent work on flash sintering demonstrates…… (Dmitry, please continue this discussion on flash sintering with a few illustrative figures from your work).

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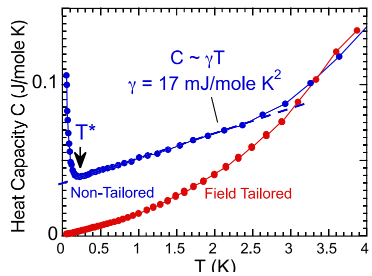

Fig.17 FTT Effect on $Ba_4Ir_3O_{10}$: *The contrasting low-temperature C(T) between the non-tailored and field tailored samples, indicating a drastic change in the ground state [37].*

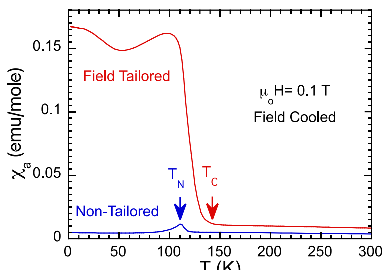

Fig.18. FTT Effect on Ca_2RuO_4: *Magnetic susceptibility of Mott insulator Ca_2RuO_4 that is field-tailored and non-tailored. Note the change of the magnetic state [37].*

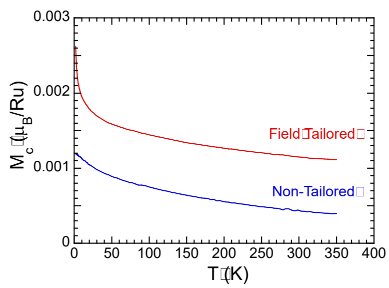

Fig. 19. FTT Effect on $CaRuO_3$: *The strongly enhanced c-axis magnetization Mc is a result of the less distorted lattice, compared to the non-tailored sample [75].*

V.3. Scope, Targeted Scientific Outcomes of *FASP*

The ***FASP*** platform is designed to transform the landscape of materials synthesis by systematically incorporating electric and magnetic fields—as dynamic, tunable parameters—into high-temperature synthesis environments. The scope of FASP encompasses the development of fundamental principles, experimental methodologies, and predictive models for controlling phase formation, defect evolution, microstructure development, and emergent functionalities across a broad range of material classes, including oxides, chalcogenides, intermetallics, high-entropy alloys, and quantum materials.

The targeted scientific outcomes include:

Mechanistic understanding of how electric and magnetic fields influence thermodynamic and kinetic pathways during synthesis.

Discovery of novel materials (e.g., alloys, composites) stabilized only under non-equilibrium field conditions.

Tailoring of defects, textures, and interfaces to achieve properties unattainable via conventional methods.

Real-time feedback-controlled synthesis through integration with in-situ diagnostics and machine learning algorithms.

Quantitative frameworks that bridge experimental data with first-principles calculations and mesoscale modeling to predict field-driven synthesis outcomes.

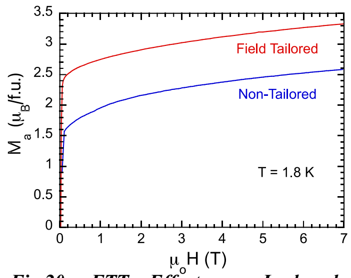

Fig.20. FTT Effect on In-doped $Mn_3Si_2Te_6$: *The increase in the magnetic saturation indicates a more magnetically ordered state [75].*

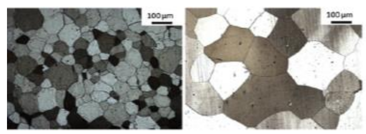

Fig. 21. Expanded domains of Fe-Co alloy: *after 3h annealing below the phase transition at 1223 K and 0 T (left) and 1248 K and 16 T (right) [36].*

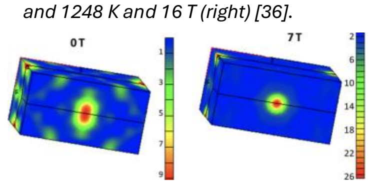

Fig. 22. Goss component of Fe-Co alloy: *The orientation distribution function obtained from backscatter diffraction. The main pole represents the Goss texture component at 0 T (left) and 7 T (right) [36].*

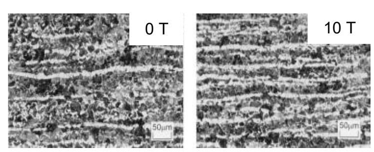

Fig. 23. Carbon-steels. *The ferrite fraction is increased by 10% at B = 10 T (right), compared to that at B = 0 (left) [44].*

VI. In-House Research Activities of FASP

Suggested length: 5-8 pages.

FASP will initiate several integrated in-house research thrusts to serve as testbeds and exemplars of the platform's capabilities.

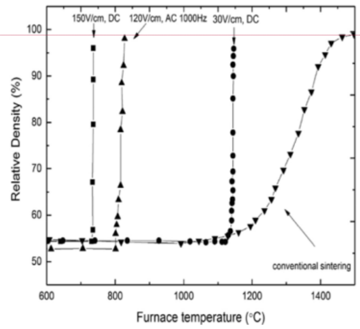

***Fig.24. Electric-Field Effect on densification** of yttria-stabilized zirconia [100].*

VI.1. FTT for Complex Materials

FTT, coupled with our existing research capabilities (Section **XX**), will allow comprehensive studies of the mechanism(s) underpinning magneto-synthesis, which has remained poorly explored. The following three aspects of magneto-synthesis are central to understanding magneto-synthesis: ***Lorentz Force, Gibbs Free Energy and A Combined Effect of Spin-Orbit Interactions and Near-Degeneracies***.

VI.1A. Fundamentals of Magneto-Synthesis

(1) Lorentz Force. Magneto-synthesis and magneto-processing provide an additional, important degree of freedom for materials synthesis and processing. It has been established since the 1960s that control of melt *convection* plays a key role in optimizing semiconductor and oxide (e.g., $CaSO_4$) crystals and can be readily achieved via crucible rotation or application of magnetic field during the crystal formation at high temperatures when melts have a relatively high conductivity or ionic conductivity [20-34, 77-81].

In essence, the conservation of momentum and continuity is dictated by the Navier–Stokes equations for an incompressible fluid in the presence of a magnetic field [33]:

$$\rho\left(\frac{\partial \vec{u}}{\partial t} + (\vec{u}\cdot\nabla)\vec{u}\right) = -\nabla p + \mu\nabla^2\vec{u} - \rho_{ref}\,\vec{g}\,[\beta(T - T_{ref}) + \beta_s(c - c_{ref})] + \vec{F}_L \qquad (1)$$

$$\nabla\cdot\vec{u} = 0$$

where u = velocity, p = pressure, T = temperature, c = molar concentration, t = time, m = viscosity, g = gravity, ρ_{ref} = density at a reference temperature T_{ref} and reference concentration c_{ref}, and F_L = Lorentz force.

In the **Eq. 1**, the Lorentz force F_L = (u x B) x B constitutes the additional, key degree of freedom for magneto-synthesis. It exerts on the fluid and modify its motion. The modified motion in turn affects F_L, which makes the magneto-synthesis highly nonlinear. The application of magnetic field influences melt flow generated by forces, such as buoyancy, Marangoni, etc. Early studies have shown that even modest magnetic fields (< 1 T) can generate a force density (e.g., 150 N/m^2) comparable to a buoyancy force density in a silicon melt [82]. However, much stronger magnetic fields are needed to generate a stronger effect on oxide melts where F_L can be operated on ions as well [83].

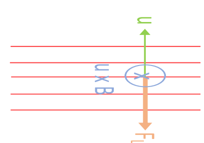

***Fig. 25. The Lorentz force F_L** dampens melt convection.*

The direction of applied magnetic fields can be vertical (**Fig.25)** and transvers (**Fig.11**). ***FTT*** provides a vertical magnetic field. As illustrated

Commented [DC5]: 5.In-House Research. Suggested length: 5-8 pages.
-Describe the **scope and targeted scientific outcome** of the MIP and specific in-house research activities.
-The scope of in-house research should be focused, smaller than the scope covered by the whole MIP, and synergistic to the user program.

-This section **must also discuss** how the proposed in-house research closes the loop among materials synthesis/processing, materials characterization, and theory/modeling/ simulation such that it is iterative and synergistic and utilizes a transdisciplinary approach to enhance the scientific impact above and beyond what can be accomplished using conventional approaches.

-If more than one institution is involved in the in-house research, effective mechanisms to prevent the negative impact of distance on the collaborative, interactive "closed loop" nature of the MIP must be clearly described.

in **Fig.25**, the key effect of F_L is to reduce melt convection. Since melt convection is strongly related to temperature distribution and fluctuations, an adequate control of convention controls the temperature field. Indeed, experimental evidence strongly indicates that *reduced convection due to application of magnetic field leads to the reduction of temperature fluctuations, thus high crystal homogeneity* [84]. These key effects of the magneto-synthesis have been recognized since the 1960's.

(2) Gibbs Free Energy. In recent decades, it has become increasingly clear that magnetic energy can also be utilized to enable and accelerate novel phase formation, structural ordering, and microstructures otherwise unattainable [35, 36, 44].

For magnetic energy to be effective during a phase transformation, it is essential that the magnetic susceptibilities of the native and field-induced phases must be different [35]. Over the last three decades, it has been established, both theoretically and experimentally, that magnetic energy can indeed change phase equilibria and stabilize metastable phases in functional materials, such as ***Fe-Co alloys, $Nd_2Fe_{14}B$, $Nd_2Co_{14}B$, SmCo alloys***, etc., [35, 36, 40-49], and more recently quantum materials such as iridates and ruthenates reported by us [37] (also see **Figs. 12-20**).

Application of magnetic field can modify the Gibbs free energy such that phase boundaries become a function of the applied magnetic field, that is,

$$\mathbf{\Delta G_{Tot} = \Delta G_{Chem} + \Delta G_B} \qquad (2)$$

where ΔG_{Chem} is Gibbs free energy in the absence of applied magnetic field B, and ΔG_B due to B. The magnetic energy is comparable with alloy mixing energies, ordering energies, and defect formation energies. The magnetic field is particularly effective near a phase boundary where the Gibbs free energy difference between neighboring phases vanishes [36, 44]. The total driving force for the transformation ΔG_{Tot} remains unchanged by the application of magnetic field B in the same cooling conditions, that is, ΔG_{Tot} (B=0) = ΔG_{Tot} (B>0) (e.g., **Fig.26** [36]). However, the relative contributions of ΔG_{Chem} and ΔG_B to ΔG_{Tot} (= ΔG_{Chem} + ΔG_B) vary as a function of B: ΔG_{Chem} could be on the order of kJ/mole at room temperature, whereas ΔG_B is only a tiny fraction of ΔG_{Chem}, of the order of J/mole even at 10 T. But for strong magnetic fields or spin-orbit-coupled materials, ΔG_B could be increased up to nearly one percent of ΔG_{Chem}. This relative change could be significant enough to induce a normally inaccessible phase, which has been recognized in previous studies [35-37, 40-52]. This is particularly true for certain types of quantum materials, as our recent studies have demonstrated [3, 37] (discussed below).

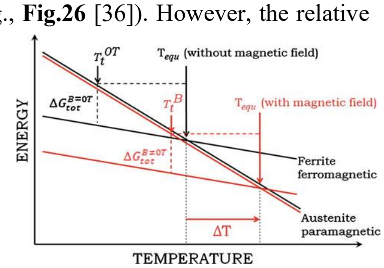

Fig. 26. Gibbs free energy ΔG_{Tot} *as a function of temperature for the ferrite and austenite phases with (red) and without (black) applied B [36].*

*The ratio of ΔG_B to ΔG_{Chem} or **$\Delta G_B/\Delta G_{Chem}$** expresses the importance of a high magnetic field, i.e., the higher magnetic field, the more likely magneto-synthesis will be effective to access novel quantum phases/structures. In brief,*

$$\mathbf{\Delta G_B/\Delta G_{Chem} \propto B.} \qquad (3)$$

(3) Strong Spin-Orbit or Magnetoelastic Couplings and Near-Degeneracies. The two aspects discussed above are applicable to all materials. However, for quantum materials, a combined effect of strong spin-orbit or magnetoelastic couplings and near-degeneracies becomes equally important, according to our own studies [3, 37, 58].

Consider the low-energy theory of magnetic insulators, which can be expressed in terms of effective spin-orbit-coupled spin-1/2 degrees of freedom represented by the Pauli matrices τ^{α}. The interaction among these degrees of freedom can be written schematically as

$$\boldsymbol{H} = \boldsymbol{J}_{r,r'}^{\alpha\alpha'} \sum_{r,r'} \boldsymbol{\tau}_{r}^{\alpha}\, \boldsymbol{\tau}_{r'}^{\alpha'} \tag{4}$$

The coupling of magnetic field to the crystal structure appears in two ways: in the spin-orbital wavefunction content of τ^{α}, and in the magnetoelastic dependence of the interaction *J* on the spatial positions *r* and *r'*.

Such Hamiltonians can exhibit strong magnetic frustration and associated near-degeneracies among exponentially many quantum states. This can occur even when the underlying magnetic lattice has no geometric frustration; the frustration can arise purely from spin-orbit interactions. As a proof-of-concept example, consider the square-lattice, quantum compass model [90],

$$\boldsymbol{H_c} = \boldsymbol{J_r^h} \sum_{\boldsymbol{h-\text{bond}}} \boldsymbol{\tau_r^x}\, \boldsymbol{\tau_{r+x_0}^x} + \boldsymbol{J_r^v} \sum_{\boldsymbol{v-\text{bond}}} \boldsymbol{\tau_r^y}\, \boldsymbol{\tau_{r+y_0}^y} \tag{5}$$

where *h*-bonds and *v*-bonds refer to horizontal and vertical bonds respectively, with the vectors along the bond directions being $\boldsymbol{x_0}$ and $\boldsymbol{y_0}$, respectively.

The Hamiltonian H_c possesses fine-tuned symmetries that give it unusual properties, which also include unusual changes in the crystal and electronic structures [90]. First, every eigenstate of this Hamiltonian, including the ground state, is degenerate with an enormous number of other states. This yields a sequence of degenerate manifolds, each of which is exponentially large in system size (2^L). Second, 1D domain wall defects in the 2D spin system have only a fixed energy cost independent of system size L rather than the usual linear scaling L. However, their entropy still diverges with system size, giving a free energy $\boldsymbol{E - TS}$ that is infinitely negative relative to the ground state, hence a finite density of domain wall defects. The spin-orbit and magnetoelastic couplings imply that each defect in the effective-spin texture also produces a change in the local orbitals and local distortions of the crystal.

Now consider the effect of applied magnetic field. The magnetoelastic coupling requires us to go beyond the spin manifold and include ionic positions. Similarly, the magnetic field will also couple differently to the orbital and spin characters of the effective spins and thus modify the orbitals, again coupling to the crystal structure. Within a model such as the one represented by H_c, the degeneracy of the manifold containing each state implies that even infinitesimally small magnetic fields have a singular and large effect on the free energy landscape. The manifolds with the lowest free energy (and large defect density relative to the ground state) will be split and rearranged so as to favor states with uniform and nonzero magnetization, with those states forming a complicated landscape of free energy barriers reminiscent of spin glasses. If taken literally, this argument would also suggest that the dynamics of the crystal formation can proceed more easily through states with many proliferated defects, and thus are less likely to lead to any state with a particular long-range pattern of distortions.

The full Hamiltonian has many, strongly competing terms beyond any single fine-tuned-frustration term such as H_c. When the full Hamiltonian still results in magnetic frustration, the frustrated system no longer has degenerate manifolds, but instead shows a glass-like landscape of states, some of which lie nearby in energy but have drastically different spin configurations. As the crystal forms, even a small magnetic field can have a large effect on the dynamics of the relaxation of crystal distortions and electronic structure.

Table 2. Key interactions and comparison

Electron	*U(eV)*	*λ_{so}(eV)*	*J_H (eV)*	*Interactions*
3d	*5-7*	*0.01-0.1*	*0.7-0.9*	*$U > J_H > \lambda_{so}$*
4d	*0.5-3*	*0.1-0.3*	*0.5-0.6*	*$U \sim J_H > \lambda_{so}$*
5d	*0.4-2*	*0.1-1*	*~0.5*	*$U \sim J_H \sim \lambda_{so}$*

U = Coulomb correlation; λ_{SO} = Spin-orbit interaction; J_H = Hund's rule coupling [3].

The above three aspects form a starting point of our theoretical pursuit. We will develop models focusing on these three aspects to eventually understand mechanisms that underpin magneto-synthesis.

The ***FASP*** research program will focus on ***three selected areas of single-crystal synthesis using the FTT platform*** and our existing research capabilities/expertise critical to materials synthesis and characterization. The goal is to thoroughly investigate thermodynamics and kinetics of synthesis in the presence of a magnetic field both experimentally and theoretically.

VI.1B. Magneto-Phase-Equilibria and New Phases.

Materials with strong electronic correlations U and spin-orbit interactions λ_{so} are particularly sensitive to even slight changes in $\Delta G_B / \Delta G_{Chem}$ because these materials feature a delicate, unique hierarchy of energy scales and competitions between fundamental interactions (**Table 2**), which renders multiple nearly degenerate ground states [3]. Particularly, the strong spin-orbit interactions λ_{so} intimately couple electronic properties to the crystal structure, as a result, any external stimuli that couple to the lattice, such as magnetic field, can readily tip the balance, generating strong, often disproportional responses [3], as evidenced in our recent study [37, 58] and data in **Figs. 12-20**. This unique characteristic makes *FTT* an effective tool for accessing novel phases and structures unattainable otherwise.

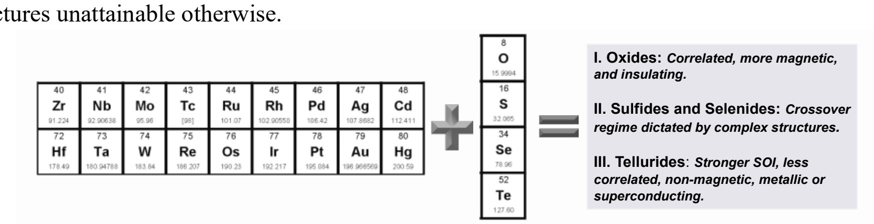

Fig. 27. Targeted transition metal oxides and chalcogenides for magneto-synthesis: *The relative strength of λ_{so} and U varies in the three sub-groups:* ***I.*** *Oxides,* ***II.*** *Sulfides and Selenides and* ***III.***

We will synthesize oxides and chalcogenides (**Fig. 27**). The stark differences in empirical trends between *oxides, sulfides, selenides, and tellurides* stress the significance of the variable relative strength of λ_{so} and U in these materials (**Fig. 27**). The oxides are more electronically correlated, thus more insulating and magnetic, in part, because oxygen has the strongest electronegativity with a tendency to attract electrons, thus the oxides tend to be more ionic. Since the electronegativity decreases following the order of O, S, Se and Te, the ionic bonding is no longer as significant in heavier chalcogenides; instead, strong competition between metal-ligand and ligand-ligand bonding becomes a driver of structural complexity in chalcogenides. Our preliminary results indicate magneto-synthesis can effectively alter structural and physical properties of not only oxides [37] but also tellurides at modest field $B < 0.2$ T (Section **V.2A**). Note that quantum materials/phases mostly occur in this large group of materials where a combined effect of λ_{so} and U underpins an extraordinarily wider range of novel phenomena [2-19].

The key requirement for a material to be affected by the applied magnetic field during a phase transformation is that the magnetic susceptibilities of the parent and product phases are different. Therefore, the impact of magneto-synthesis scales with B, as indicated by the **Eqs. 2-3**. With a wide range of tunability of magnetic field up to 5 T and temperature up to 2200 ºC in *FTT*, we will systematically explore and study these transition metal materials with variable relative strengths of λ_{so} and U. Given the effectiveness of magneto-synthesis of these materials demonstrated in Section **V.2A**, new structures/phases with novel behavior in *strong magnetic fields* will emerge and be tuned via tuning the magnetic field.

The influence of the magnetic field on the equilibrium transition temperature can be predicted and experimentally confirmed. We will develop models and
generate phase diagrams similar to that in **Fig.26** for quantum materials we synthesize. This becomes feasible because real-time monitoring synthesis in the *FTT* platform will allow direct observation and control of phase transitions.

VI.1C. Spin Micromechanics and Lattice Properties

Magnetic energy can alter lattice properties [35-37] because of spin micromechanics in which spins play a role in determining lattice parameters during the formation of crystals [45]. This poses a new pathway to obtain new crystal structures. In fact, the effect of magnetic fields on dislocations or magneto-plasticity has been known for more than three decades [48-55] since the accidental discovery of the magnetic-field effect on NaCl crystals in 1987 by Russian scientists [48]. Magneto-plasticity is precisely a result of spin micromechanics, due chiefly to the depinning of dislocations in a magnetic field and is observed in magnetic fields ranging from 0.1 to 10 T at high temperatures, with changes in the plasticity characteristics by several tens or hundreds of percent in a range of materials [35, 52-54].

Quantum materials driven by a combined effect of λ_{so} and U are extensively studied because their energy landscapes are favorable for a remarkable variety of highly entangled quantum phases of matter extending beyond Landau's paradigms and Fermi liquid theory [e.g., 2, 16]. Examples include quantum spin liquids, novel superconductors, multipolar orders, fractional Chern and fractional topological insulators, symmetry protected topological phases, fracton phases, etc. [2-16]. However, the lack of material realizations of these exotic states despite intense research indicates the extreme susceptibility of these high-Z materials to disorder, distortions, and defects. Indeed, many high-Z materials are inherently distorted or unstable when prepared with existing synthesis techniques [3]. ***FTT*** offers an unprecedented route to produce novel structures in these materials, in part because these materials tend to have a large magnetostriction or strong magnetoelastic coupling [e.g., 71-73]. As pointed out above, our preliminary proof-of-concept studies have shown that application of magnetic field, although weak, can alter lattice properties and reduce distortions and disorder [37] (also **Fig.5a** and **Fig.7**). These lattice changes are significant enough to cause drastic changes in the physical properties of these high-Z materials [37].

Lattice properties of magneto-synthesized materials at *different magnetic fields* will be thoroughly investigated using a wide suite of tools (Section **VII**). In particular, crystal structures, as well as grain boundaries, formed at different fields will be studied, as functions of temperature and electric current. Physical properties of these materials will be also characterized as functions of magnetic field, pressure, and temperature.

We aim to establish correlations between materials properties and applied magnetic fields during magneto-synthesis for high-Z materials. To our best knowledge, no such information has ever been reported for this class of materials.

IV.1D. Magnetic Anisotropy and Domain Size

Application of magnetic field during synthesis can also be used to enhance magnetic anisotropy of a material. When the particle magnetization is not parallel to the applied magnetic field B, the particle (or crystal) orients along the most energetically stable direction under the influence of a magnetic torque, i.e.,

$$\tau = -\, dE_m/d\theta \qquad (6)$$

where E_m is the magnetic energy of the crystal, and θ is the angle between B and the crystal magnetic easy axis. In essence, an applied magnetic field during synthesis or processing at high temperatures renders interactions between magnetic particles in a material, which results in magneto-crystalline anisotropy. Since the total magnetization of a magnet is the vector sum of the individual grains along the direction of the bulk magnetization, the degree of grain alignment plays a significant role in magnetic anisotropy, in other words, the larger the domain size, the stronger magnetic anisotropy. It is well established that magneto-processing expands magnetic domains (e.g., **Fig.21**) and significantly strengthen a magnetic easy axis of magnetization parallel to the field direction [49 and references therein]. Our own preliminary results have also shown that magneto-synthesis is effective in altering the magnetic anisotropy [37].

For functional magnetic materials, magnetic anisotropy is one of the most important characteristics and plays a major role in materials performances. This is particularly true for permanent magnets because magnetic anisotropy is responsible for coercivity.

Moreover, it is now conceivable that magneto-synthesis can open a new avenue to phases and structures otherwise unstable or unattainable using conventional techniques, enabling synthesis of new functional materials such as ***permanent magnets containing only earth abundant elements, which could eventually replace permanent magnets consisting of rare earth elements*** [59]. A good example is $\boldsymbol{(Fe_{0.7}Co_{0.3})_2B}$ [60]. Permanent magnets are essential for energy conversion and storage, more generally, national security, and yet, the shortage of rare earth elements has increasingly worsened in recent years [59, 60, 61].

We plan to work on following *3d* transition metal-based materials to develop high-performance permanent magnets with high density of magnetic elements. These materials are promising [59, 60] but with inherently unfavorable features for high-performance permanent magnets, which are described below:

- ***Fe based magnetic alloys:*** Fe is obviously favored because it has the strongest moment and is the fourth most abundant element in the earth's crust. However, Fe based materials tend to be antiferromagnetic, and adopt a high crystal symmetry with large atomic spacings. These characteristics result in low density magnetic anisotropy that results in weak coercivity.
- ***Mn-based magnetic alloys*** There are two non-Fe-based materials that have shown significant coercivity: MnBi and MnAl [60, 61]. While Mn-containing compounds are typically antiferromagnetic, the moments can be induced to align if the separation of the Mn atoms is greater than 2.96 Å [76]. But the total moments in these Mn-based compounds tend to be low because the large spacing translates to a small volume fraction of magnetic atoms which results in a low energy density. Similar to other magnetic materials, maintaining a fine grain structure is crucial to retaining a desirable coercivity.

The *FTT* can address these issues, stabilizing more favorable, lower-symmetry crystal structures that enable strong anisotropy and coercivity, and expanding the grain size to the single domain particle size limit where the formation of a domain wall inside the grain becomes energetically unfavorable.

Nevertheless, magnetic energy generated by *strong magnetic fields* in synthesis can significantly alter the thermodynamics of the system, shifting phase stability and allowing access to new phases and/or structures unattainable otherwise. Magneto-synthesis is an important and yet largely unexplored field of research, which will have direct implications for all materials [1]. Its interdisciplinary nature demands interdisciplinary investigations covering a wide range of aspects, such as Gibbs free energy, phase transition, phase equilibria, grain size, structural order, mobility, concentration, diffusion, nucleation, magnetoelastic coupling, near-degeneracies, spin-orbit interactions, etc., all of which are essential for advancing our understanding of magneto-synthesis. With the closed-loop feedback approach (**Fig.1**), we are uniquely well positioned to advance the understanding of magnetosynthesis.

VI.2. Electric-Field Synthesis

Flash Sintering (Dmitry)

VI.3. Characterization

VI.3A. In Situ Diagnostics and Real-Time Control.

We will integrate pyrometry and thermal imaging with high-speed data acquisition to enable closed-loop synthesis with real-time feedback….

VI.3 B. Strucutral and Physical Properties (Gang, Minhyea)

VI.3C. Thermal STM (Longji)

VI.3D. ARPES (Dan)

VI.3E. Raman and Neutron Scatting (Dmitry)

VI.3F. In situ x-ray (Mike)

VI.3F. Theory, Modeling (Joel and Rahul)

In-house modeling will focus on field-dependent thermodynamics, transport, and microstructure evolution, providing predictive capabilities that guide experiment and scale-up.

VII. Infrastructure **Suggested length: 5-8 pages (including the table).**

VII.1 Experimental and Computational Capabilities

FASP will leverage extensive existing capabilities while selectively developing new instruments to achieve its scientific mission.

VII.1A. Existing Experimental Capabilities Available to External Users

Materials Synthesis:

- ***FTT*** consisting of 5T superconducting magnet and laser-based heating system (see **Figs.5-6**) for single-crystal growth (*to be available for external users in January 2026*)
- Optical floating zone furnace (up to 2200°C) with pressure and vacuum control for single-crystal growth (**Fig.9**)
- A comprehensive array of furnaces (box, tube, crucible, and zone configurations) for high-temperature materials synthesis and crystal annealing (up to 1700°C) under diverse atmospheres
- Proof-of-concept single-crystal growth systems under magnetic field (0.1 T) for field-assisted synthesis studies (see **Fig.11**)
- Electrochemical deposition setup for single-crystal growth
- Flash sintering (Dmitry, Rishi)
- …

Structural Characterization:

- Hitachi/Oxford MT 3300 Plus SEM with Energy Dispersive X-ray (EDX) analysis
- Bruker ECO QUEST single-crystal X-ray diffractometer, featuring a 90 K–380 K cold stage and electric current application capability
- Rigaku MiniFlex 600 powder X-ray diffractometer
- High-power (17 kW) single-crystal X-ray diffractometer for high-pressure studies
- Polarized light microscopy (Olympus) and various optical microscopes

Commented [DC6]: **6.Infrastructure. Suggested length: 5-8 pages (including the table).**

- Describe the experimental and computational capabilities needed for both the user program and in- house research of the proposed MIP.
- Discuss how the MIP engages and leverages the existing infrastructure and instruments, a detailed description of which is expected in Facilities, Equipment and Other Resources.
- Provide justification (in terms of critical needs in science and/or uniqueness in the United States) for new instrument development and acquisition.
- For tool development, describe the potential technical challenges and bottlenecks, a plan to overcome them, and a **timeline** for development and commissioning.
- If instruments are located at more than one institution, effective mechanisms to minimize the negative impact of distance on user service **must be clearly described.**
- List the major instruments (existing and new) that will be available to external users. The major new instruments acquired through the MIP funding **must devote at least 50% of the instrument operational time to external users.**

Table of Major Instruments that Will be Available to External Users.

Item
Acquisition, Development, or Existing
When Available to External Users
Fraction of Operational Time Available to External Users
Approximate Cost **($K)** for Acquisition or Development

- Please add more
-

Materials Properties Characterization:

- Quantum Design Dynacool Physical Property Measurement System (PPMS) with dilution refrigerator (50 mK - 900 K, up to 14 T)
- Oxford 18 T magnet system with ^{3}He and ^{4}He inserts (300 mK - 350 K) for transport, magnetization, heat capacity, and dielectric measurements
- Quantum Design SQUID Magnetometer (7 T MPMS XL) with a transport probe (1.7 K - 400 K)
- Simultaneous magnetization and resistivity measurements as functions of magnetic field (B) and electric current (I)
- Pressure measurement capabilities: 32 kbar (PPMS) and 40 kbar (MPMS)
- Closed-cycle cryostat (9–900 K) for transport and thermoelectric measurements
- Lakeshore and Linear Research AC resistance bridges
- Dilatometry (5 K - 400 K, up to 14 T)
- QuadTech LCR meter (10 Hz–2 MHz) for frequency-dependent measurements
- Keithley meters (2400/6220 Sourcemeters, 2182/2182A Nanovoltmeters) and Lake Shore temperature controllers
- More ……
-

VII.1B. Computational Capabilities

- First-principles modeling (e.g., DFT) for field-assisted processes
- Thermodynamic and kinetic simulations under electromagnetic fields
- Machine-learning frameworks for materials discovery
- High-performance computing resources accessible through University and National Lab partnerships
- Joel, please help with this section

VII.2. Leverage of Existing University Infrastructure

FASP will **extensively leverage existing facilities and capabilities at UC Boulder** to maximize resource efficiency:

Facility for Electron Microscopy of Materials (FEMM):

- Access to advanced TEM with sub-angstrom resolution across 100 K - 1300 K.
- Enables structural and chemical analysis under electric current and variable temperature conditions.

Nanomaterials Characterization Facility (NCF):

- Instruments including Field Emission Electron Microscope (FE-SEM), Atomic Force Microscope (AFM), X-ray Photoelectron Spectroscopy (XPS), and Electron Backscatter Diffraction (EBSD).

- Directly supports surface and compositional analysis before and after field-assisted synthesis.

JILA Keck Lab and University Shops:

- Supplementary access to nano-characterization equipment similar to NCF.
- Machine Shop, Student Shop, and Wood Shop co-located for sample preparation and customized apparatus fabrication.
- Electronic Shop provides rental equipment, wire bonders, and electronics repair services essential for instrument maintenance.
- These facilities ensure a robust foundation for both the ***user program*** and ***in-house research***, while providing cost-effective and flexible technical support.

VII.3. Justification for New Instrument Developments and Acquisitions

While the current infrastructure is substantial, **critical scientific needs** justify strategic new instrument development and acquisition:

Integrated High-Field Synthesis Platform:

- Custom-built systems that apply high magnetic fields (>5 T) and laser heating during materials synthesis and processing. Built upon the ***FTT*** platform (the first generation ***FTT-I***, to be completed in late 2025), we will develop and build the second generation ***FTT-II*** featuring stronger magnetic fields, higher temperatures and higher homogeneity. We hold the US patent for ***FTT***.
- Custom-built systems that apply high electric fields (>600 V/cm) and laser heating during materials synthesis and processing (see **Fig.10**).
- Flash sintering, Dmitry
- No existing U.S. facility offers programmable, dynamic field-assisted synthesis across these parameters.

High-Throughput Field-Processing Robot:

- An autonomous platform capable of systematic, combinatorial synthesis under electromagnetic fields.

Tools for Materials Characterization:

- Single-crystal and powder x-ray diffractometers with temperature control.
- Scanning electron microscopes (SEM) and energy dispersive x-ray (EDX).
- Instruments for measurements of physical properties as functions of temperature, pressure, magnetic field and electric currents, such as Quantum Design DynoCool PPMS and MPMS.
- More….

These developments and acquisitions are necessary to pioneer new synthesis regimes and position FASP as the national leader in field-assisted materials discovery.

VII.4. Tool Development: Challenges, Mitigation, and Timeline

Technical Challenges:

- Synchronizing applied fields and real-time monitoring of synthesis
- Robust remote operation capability for distributed users
- …

Mitigation Strategies:

- Deployment of modular control and monitoring architectures
- Rigorous phased commissioning with in-house and early external users
- …

Timeline:

- **Year 1-2:** (1) Pilot user program launch: ***FTT-I*** and ***Flash Sintering***
  (2) Design and assembly of new synthesis platforms, i.e., ***FTT-II*** and ***EFASP***
  Year 2: Internal commissioning and in-house research validation of newly built ***FTT-II*** and ***EFSAP***.
- **Year 3:** Full-scale external user access initiated.
- **…**

VII.4 Major Instruments Available to Users

Table 3. FSAP Existing and New Major Instruments

Major Instruments	Description	Status/Timeline	%User Time
Floating Zone Furnace	Single-crystal growth up to 2200°C	Existing	50%
Field Crystal Growth (0.1 T Proof-of-Concept)	Field-assisted single-crystal synthesis up to 1700°C	Existing	50%
Electrochemical Deposition Setup	Single-crystal growth up 5 mA and 1700°C	Existing	50%
Flash Sintering	Materials processing (Dmitry)	Existing	50%
Magnetic-Field Assisted Synthesis **Two FTT-I** Superconducting magnet with laser-based heating	• Variable magnetic field up to 5 T • Variable temperature up 2200 °C (five lasers). • Variable atmospheres. • Suitable for both floating and flux methods. • Suitable for synthesis of single crystals of alloys, oxides, chalcogenides. • Suitable for processing of all materials including alloys, composites, steels, amorphous materials	The 1st FTT-I: January 2026 The 2nd FTT-I: January 2027	50%+
Magnetic-Field Assisted Synthesis **FTT-II** Superconducting magnet with laser-based heating	• Variable magnetic field up to 7 • Variable temperature up 2500 °C (seven lasers). • Variable atmospheres. • Suitable for both floating and flux methods. • Suitable for synthesis of single crystals of alloys, oxides, chalcogenides. • Suitable for processing of all materials	July 2027	50%+

	including alloys, composites, steels, amorphous materials.		
Electric-Field Assisted Synthesis **Optical EFASP-I** Halogen Lamps Heating with Electric Field	• Variable electric field up to 600 V/cm • Variable temperature up 2200 ^{o}C • Variable atmospheres. • Suitable for floating method. • Suitable for synthesis of single crystals of alloys, oxides, chalcogenides. • Suitable for processing of all materials including alloys, composites, steels, amorphous materials	January 2027	50%+
Electric-Field Assisted Synthesis **Laser EFASP-II** Laser-Based Heating with Electric Field	• Variable electric field up to 900 V/cm • Variable temperature up 2200 ^{o}C • Variable atmospheres. • Suitable for both floating and flux methods. • Suitable for synthesis of single crystals of alloys, oxides, chalcogenides. • Suitable for processing of all materials including alloys, composites, steels, amorphous materials	January 2028	50%+
High-Throughput Field-Processing Robot	Combinatorial discovery under fields	January 2028	50%+
SEM-EDX (Hitachi/Oxford MT 3300 Plus)	Surface and compositional analysis	Existing	50%
Bruker ECO QUEST XRD	Single-crystal x-ray diffractometer with temperature and electric current control; 1 kW	Existing	50%
Rigaku XtaLAB Synergy-DW	Single-crystal x-ray diffractometer with dual-wavelength rotating anode, hybrid pixel array detector and kappa goniometer.	July 2026	50%+
Rigaku MiniFlex 600 Powder XRD	Powder x-ray for quick phase scanning	Existing	50%
?? structure tool		Existing	50%
?? structure tool		Existing	50%
Dynacool PPMS with Dilution Refrigerator	Physical property measurements down to 50 mK and up to 14 T.	Existing	50%
Quantum Design MPMS	Magnetic property measurements up to 7 T	Existing	50%
??	Wish list, please.		
??			

How the proposed in-house research closes the loop among materials synthesis/processing, materials characterization, and theory/modeling/ simulation such that it is iterative and synergistic and utilizes a transdisciplinary approach to enhance the scientific impact above and beyond what can be accomplished using conventional approaches.

Effective mechanisms to prevent the negative impact of distance on the collaborative, interactive "closed loop" nature of the MIP *(if more than one institution is involved in the in-house* *research)*

Experimental and Computational Capabilities needed for both the user program and in-house research of the proposed MIP.

1. **User Facility Operation. Suggested length: 2-3 pages.**

The proposed user access modes *(e.g., independent, collaboration, fee for service, sample request, and/or remote access)* **by users and for the in-house research team, the user proposal submission, review and selection process, staffing, instrument time/resource allocation method, user training, safety, and user fee structure.**

Commented [DC7]: **7.User Facility Operation. Suggested length: 2-3 pages.**
-Describe the proposed user access modes (e.g., independent, collaboration, fee for service, sample request, and/or remote access) by users and for the in-house research team, the user proposal submission, review and selection process, staing, instrument time/resource allocation method, user training, safety, and user fee structure.

BROADER IMPACTS (*Note: Must include a separate section header labeled Broader Impacts and the heading must be on its own line with no other text on that line. This section should go between #'s 7 and 8.*)

Commented [DC8]: **BROADER IMPACTS** (*Please note: The Project Description must include a separate section header labeled Broader Impacts and the heading must be on its own line with no other text on that line. This section should go between #'s 7 and 8.*)

8.Training.   Suggested length: 3-5 pages.

Selected Training Activities that integrate strategically with the scientific goals and advance the educational experiences for users, as well as graduate and undergraduate students, postdoctoral researchers, and others associated with the MIP as a unique national resource.

Commented [DC9]: 8. Training.   Suggested length: 3-5 pages.

- Describe a limited number of well-chosen training activities that integrate strategically with the scientific goals and advance the educational experiences for users, as well as graduate and undergraduate students, postdoctoral researchers, and others associated with the MIP as a unique national resource.
- Training of users, especially external users, must be the top priority of the proposed training activities. Potential activities such as hands-on workshops, summer/winter schools, short courses, webinars, and/or online resources such as tutorials may be considered.
- Include outreach plans designed to increase the external user base, to attract users from diverse communities and expertise (from experts to entrants to the field), and to reach potential users in industry, whose work could inform or benefit from instrumentation and technique development activities.

Training of users—including external users:
Potential activities including hands-on workshops, summer/winter schools, short courses, webinars, and/or online resources such as tutorials

Outreach plans designed to increase the external user base, to attract users from diverse communities and expertise (from experts to entrants to the field), and to reach potential users in industry, whose work could inform or benefit from instrumentation and technique development activities.

9.Broadening Participation. Suggested length: 2-3 pages.
CU Boulder's MIP partnership's strategic plan for broadening participation at all levels, the metrics that will be used to measure progress, and the desired outcome for the 6-year award period.

Commented [DC10]: 9.Broadening Participation. Suggested length: 2-3 pages.
- Describe the MIP's strategic plan of broadening participation at all levels, the metrics that will be used to measure progress, and the desired outcome for the 6-year award period.
- MIPs are expected to demonstrate a significant commitment to the involvement of the full spectrum of ~~diverse~~ talent that society has to offer, which includes member of groups from ~~underrepresented and under-served communities~~, as MIP participants (faculty, scientific experts, technicians, postdoctoral researchers, and students) and as users.
- MIP are also expected to reach users from a broad range of academic institutions in the United States (e.g., R1 and non-R1 institutions, institutions from EPSCoR jurisdictions, and institutions described in the section "Broadening Participation in STEM" above).

Our significant commitment to the involvement of the full spectrum of ~~diverse~~ talent that society has to offer, which includes member of groups from ~~underrepresented and under-served communities~~, as MIP participants (faculty, scientific experts, technicians, postdoctoral researchers, and students) and as users.

(Diane's question: how to handle this?)

How our MIP partnership will reach users from a broad range of academic institutions in the United States (e.g., R1 and non-R1 institutions, institutions from EPSCoR jurisdictions, and institutions described in the section "Broadening Participation in STEM" above).

10.Collaboration with industry, national laboratories, and others.

Suggested length: 1-3 pages.

Plans for intellectual and resource exchanges, cooperation, and partnerships with other organizations—including industry, national laboratories, non- profit organizations, and others.

Commented [DC11]: **10.Collaboration with industry, national laboratories, and others.**
Suggested length: 1-3 pages.

- Describe plans for intellectual and resource exchanges, cooperation, and partnerships with other organizations that may involve industry, national laboratories, non- profit organizations, and others, as appropriate.
- MIPs are **encouraged** to make progress towards translation, which may include the generation of new intellectual property, creation of new or broader collaboration with industry, licensing of NSF-funded research, creation of new technology and/or processes adopted by the public and/or philanthropic sector, and the training of future innovation and entrepreneurship leaders.

How our MIP will make <u>Progress Towards Translation</u>—including the generation of new intellectual property, creation of new or broader collaboration with industry, licensing of NSF-funded research, creation of new technology and/or processes adopted by the public and/or philanthropic sector, and the training of future innovation and entrepreneurship leaders.

11.Management Plan. Suggested length: 2-4 pages (including the table).

Organizational Chart: All critical components of the governance structure of our proposed MIP.

Commented [DC12]: 11.Management Plan. Suggested length: 2-4 pages (including the table).

Organizational Chart: Show all critical components of the governance structure of the proposed MIP.

Describe functions of key leadership positions and major committees: the executive committee, the user proposal review committee, the user committee, the external advisory committee (EAC), etc. An EAC is required for all MIPs. However, **potential EAC members should not be approached or identified until the MIP is funded**.

Describe the procedures and criteria used to select, administer, and evaluate in-house research projects. (The procedures for user projects are described in Section 7.)

Highlight the major resources that the organization(s) will provide to the proposed MIP, should it be funded. A detailed description is expected in

Facilities, Equipment and Other Resources. Do not given as dollar equivalents.

· In a tabular form, enter the NSF **budget request (in $K)** for each of the major MIP activities. For each entry in the table, include both direct and indirect costs. Equipment acquisition and development is expected to be mainly in the first few years. User facility operation may begin in year 2, ramp up over time and is expected to reach a steady state by year 4. In-house research and knowledge sharing activities are expected to have a ramp-up period as well. Approximately 50% of the MIP funds provided by NSF, after subtracting instrument acquisition and development costs, should be devoted to the user facility operation when the user facility operation reaches a steady state. Student support is typically not under training, and should be included under appropriate categories depending on what they will do.

Diane's note—relevant to TIMELINE.

Table of NSF Funding Request **(in $K).**

Activity	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Years 1-6
Instrument acquisition and development							
User facility operation							
In-house research							
Training							
Knowledge sharing							
Collaboration with Industry, etc.							
Administration							
Others, if any (please specify)							
Total							

Functions of key leadership positions and major committees

- Executive Committee

- User Proposal Review Committee

- User Committee

- External Advisory Committee (EAC), etc.
  (Note: An EAC is required for all MIPs. However, ***potential EAC members should not be approached or identified until the MIP is funded****.)*

Procedures and Criteria to select, administer, and evaluate in-house research projects.
(Note: The procedures for user projects are described in Section 7.)

Major Resources our Organizations will provide to our MIP
*(Note: A detailed description is expected in **Facilities, Equipment and Other Resources.** Do not give as dollar equivalents.)*

Budget Request (in $K) for each of the Major MIP Activities.

*(Note: For each entry in the table, **include both direct and indirect costs**. Equipment acquisition and development is expected to be mainly in the first few years. User facility operation may begin in year 2, ramp up over time and is expected to reach a steady state by year 4. In-house research and knowledge sharing activities are expected to have a ramp-up period as well. Approximately 50% of the MIP funds provided by NSF, after subtracting instrument acquisition and development costs, should be devoted to the user facility operation when the user facility operation reaches a steady state. Student support is typically not under training, and should be included under appropriate categories depending on what they will do.) Diane's note—relevant to TIMELINE.*

Table of NSF Funding Request **(in $K).**

Activity	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Years 1-6
Instrument acquisition and development							
User facility operation							
In-house research							
Training							
Knowledge sharing							
Collaboration with Industry, etc.							
Administration							
Others, if any (please specify)							
Total							

Commented [DC13]:
Budget and Budget Justification: Provide a budget for each of the six years.
From your Internal Competition Proposal
· **Total: $20,000,000 for six years --** to be requested?
o **Development of new technology for synthesis and processing:** $7,000,000
o **New equipment:** $3,000,000
o **User facility operation:** $3,000,000
o **Personnel:** $3,000,000
o **New space or space renovation:** $2,000,000
o **Research/others:** $2,000,000

· The proposed **budget** should be between **$18,000,000 to $30,000,000 over a six-year perio**d, must be commensurate with the project's scope, and thoroughly justified in the proposal
· The MIP Program will support acquisition and development of instruments, software and databases; service contracts on purchased equipment; professional staing including support for the principal investigators, other senior/key personnel and technicians; and a limited number of students and postdoctoral researchers. Six-year awards totaling $18,000,000 to $30,000,000 for the award period are anticipated. **Approximately 50% of the MIP funds provided by NSF, after subtracting instrument acquisition and development costs, should be devoted to the user facility operation.** *$$$$$$$$$*
· The MIP program **will NOT support** requests for any of the following:
$$$$$$$$$$$$$$$$$
o Construction, renovation or modernization of rooms, buildings or research facilities;
o General purpose and supporting equipment. Supporting equipment refers to basic, durable components of a research facility that are integral to its operation (e.g., fume hoods, elevators, laboratory casework, cryogen storage systems, general-purpose computational or data storage systems);
o Sustaining infrastructure and/or building systems. This category includes (but is not limited to) the installation of or upgrades to infrastructure related to the supply of power, ventilation, water or research gases, routine multi- purpose computer networks, standard safety features, and other general purpose systems (e.g., toxic waste removal systems, and telecommunications equipment); or
o General purpose platforms or environment. This category includes (but is not limited to) general purpose fixed or non-fixed structures, vehicles, and vehicle charging stations.

Facilities, Equipment and Other Resources:

Diane's note: Work with Joe Dragavon on this section.

a.Organizational Resources that will be available to our proposed MIP

- **Dedicated space**

- **Access to existing facilities and instrumentation**

- **New capital equipment**

- **Faculty and staff positions**

- **Faculty release time**

- **Access to programs that assist with technology development, or support of education and training activities, and/or others.**
  (Note that inclusion of voluntary committed cost sharing is prohibited; Do not given as dollar equivalents.)

(b) Technical Description of existing facilities and instrumentation and/or new capital equipment that will be available to users

Commented [DC14]: Facilities, Equipment and Other Resources:
(a) Provide a synopsis of organizational resources that will be available to the proposed MIP (dedicated space, access to existing facilities and instrumentation, new capital equipment, faculty and staff positions, faculty release time, access to programs that assist with technology development, or support of education and training activities, and/or others). Note that inclusion of voluntary committed cost sharing is prohibited; Do not given as dollar equivalents.

(b) If existing facilities and instrumentation and/or new capital equipment will be available to users, provide a technical description.

Supplementary Documents:
Limit: 5 pages (with no more than one letter per page).

(a) No letters of collaboration or support from anticipated users are allowed.

(b) Include only official letter(s) from each of the participating organization(s).

- Such letter(s) should confirm participation, highlight major resources to be provided (no dollar amount), but cannot contain endorsements or evaluation of the proposed project.
- **Details about work to be done under this project should be included within the Project Description**, not in the letter(s) of collaboration.

Commented [DC15]: **Supplementary Documents:**
Limit: 5 pages (with no more than one letter per page).

(a) No letters of collaboration or support from anticipated users are allowed.

(b) Include only official letter(s) from each of the participating organization(s).
· Such letter(s) should confirm participation, highlight major resources to be provided (no dollar amount), but cannot contain endorsements or evaluation of the proposed project.
· Details about work to be done under this project should be included within the Project Description, not in the letter(s) of collaboration.

Required Additional Information:
Immediately after submission of the full proposal, please send an e-mail to mip@nsf.gov:

A Microsoft Excel file with the filename: proposal #_institution_MIP_participants. A spreadsheet of participants designated as Senior/Key Personnel (Principal Investigator/MIP Director, co-PI(s), and other faculty or equivalent). The spreadsheet must have 6 columns. Major MIP roles include in-house research, tool development, user facility operation, training, knowledge sharing, etc.

	Last Name	First Name	Institution	Department	Major MIP Role(s)
PI/MIP Director					
coPI					
coPI					
Sr/Key Personnel					
Sr/Key Personnel					
Sr/Key Personnel					

END OF Diane's proposal form.
Gang, from this point on, I've included the narrative text from the solicitation that describes what NSF is looking for. This following text is no less important than the above specific requirements for the 40-page form. I just separated them to make it easier to see what to put into the proposal form.
Diane

Commented [DC16]: **Required Additional Information:** Immediately after submission of the full proposal, please send an e-mail to mip@nsf.gov:

A Microsoft Excel file with the filename: proposal #_institution_MIP_participants. A spreadsheet of participants designated as Senior/Key Personnel (Principal Investigator/MIP Director, co-PI(s), and other faculty or equivalent). The spreadsheet must have 6 columns. Major MIP roles include in-house research, tool development, user facility operation, training, knowledge sharing, etc.

Last Name
First Name
Institution
Department
Major MIP Role(s)
PI/MIP
Director
coPI

coPI

Sr/Key Personnel

Sr/Key Personnel

Sr/Key Personnel