US MDP Vision, Goals, and Structure

2024 update

Version 3 – Nov. 19, 2024 - Soren Prestemon

Vision:

Maintain and strengthen US Leadership in high-field accelerator magnet technology for future HEP colliders

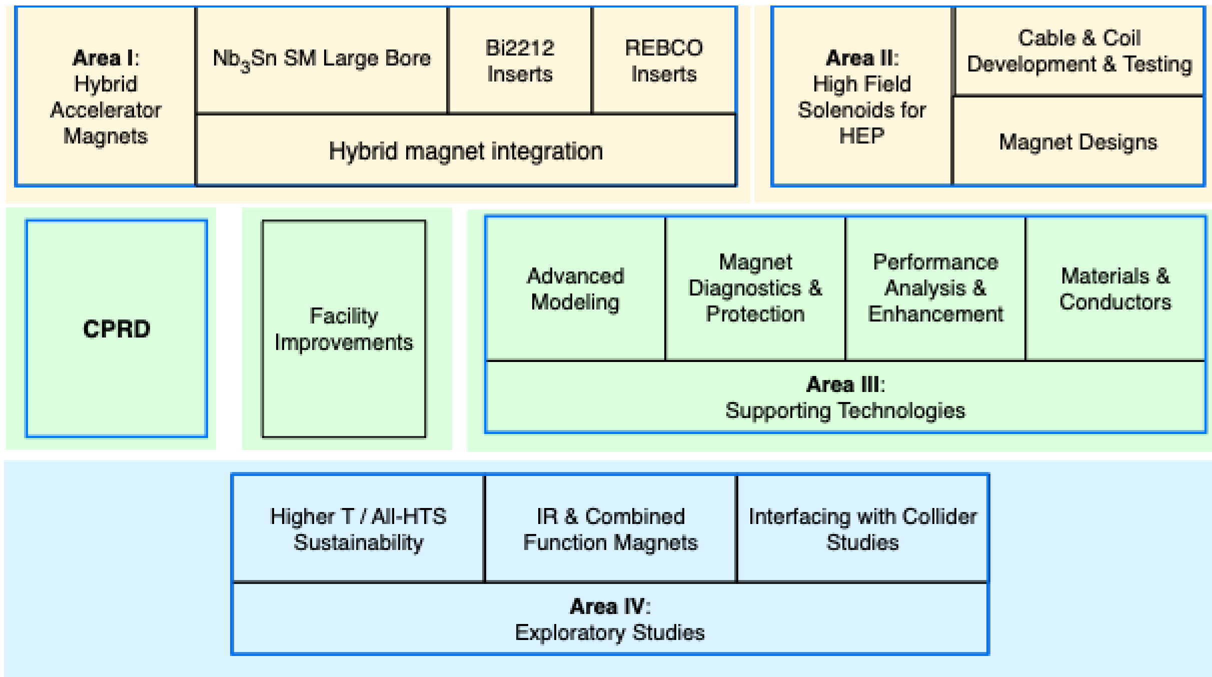
Goals:

- Explore and define the performance limits of superconducting accelerator magnets
- Develop, understand and demonstrate high field HTS magnet technology
- Investigate and understand the fundamental science of magnet design and performance
- Pursue conductor R&D with appropriate properties that enable our accelerator magnet goals
- Support the development of advanced workforce for superconducting magnet technology

Furthermore, MDP serves the mission to:

- Integrate the teams across the partner laboratories and Universities for maximum value and effectiveness to the program
- Identify and nurture HEP and cross-cutting / synergistic activities and opportunities with other programs to more rapidly advance progress towards our common goals.

Program Structure - Synopsis of Areas and sub-Areas:



Area I: Hybrid Accelerator Magnets

Using HTS-based dipoles within the bore of a Nb_3Sn dipole magnet is anticipated to be the most cost-effective means of probing HTS accelerator magnet technology to higher fields. To-date, MDP has focused on developing the core elements of a hybrid magnet: a) stress-managed Nb_3Sn magnet technology, enabling large bore, high field dipoles, exemplified by the SMCT and CCT designs; and b) HTS accelerator magnet technology with REBCO and Bi2212 cables. Our goal now is to integrate these - up until now separate - thrusts in working hybrid accelerator magnets. Thus, we have a twofold ambition: first, to bring the LTS SMCT and CCT magnets to fruition, as they serve both as exceptional demonstrators of 12-14T large-bore dipoles relevant to applications such as a muon collider and as workhorse magnets for developing and demonstrating hybrid magnet technology; and second, to further advance HTS accelerator magnet technology in high magnetic fields.

Near term challenges and driving questions:

Conceptual design and analysis

- Evaluate maximum achievable fields, given the current HTS and LTS conductor properties and coil technology
- Conceptual design of a 20 T hybrid magnet

Comparative analysis of CCT and SMCT designs

Engineering design

- Integrated design of inserts and outserts coils for optimal operation in hybrid configuration
- Compatibility of dimensions, in particular radii and lengths, of LTS and HTS coils
- Location and extension of high field region and of the leads, design of the splices

Mechanics

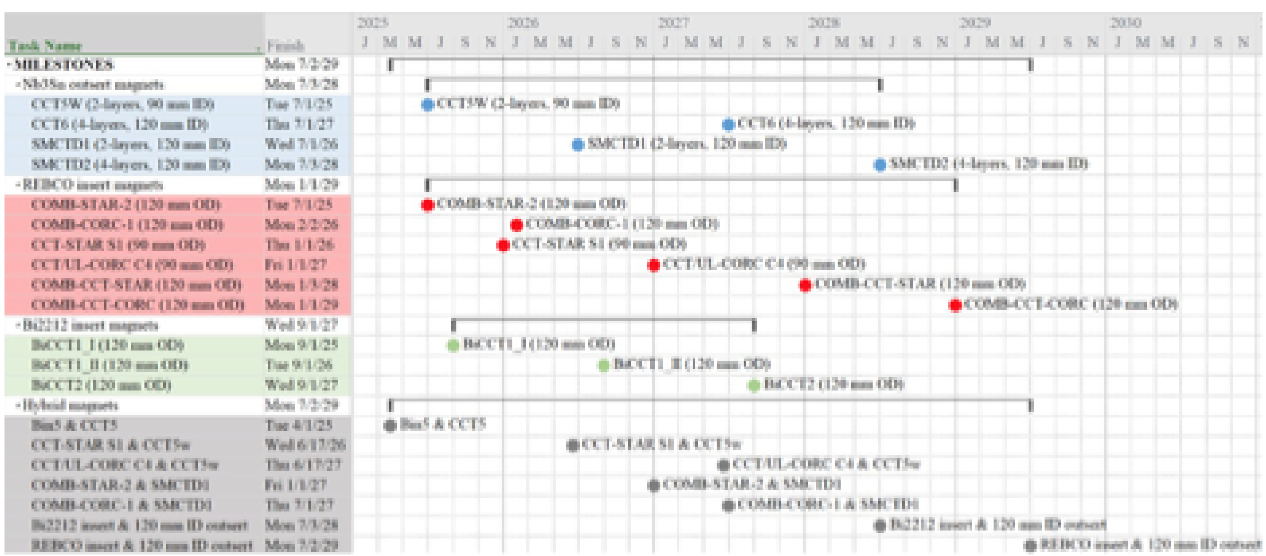
- Mechanical support and assembly process of insert coils inside outsert aperture
- Design of the radial and azimuthal support components to prevent motion and excessive strain both in the insert and in the outsert under the action of the Lorentz forces
- Define tooling and procedures to guarantee mechanical contact between insert and outsert coils, at the same time ensuring reliable assembly and disassembly operations.

Test

- Define test set-ups, powering configurations and protection schemes for hybrid magnets during powering tests

Milestones for Hybrid Accelerator Magnets:

The list of questions and challenges listed above will be addressed by a series of hybrid magnets (see image below, grey markers), which will rely on the Nb3Sn outserts magnets (blue markers), REBCO inserts magnets (red markers) and Bi2212 insert magnets (green markers) fabricated in the respective areas.



Sub-area I.a: Nb_3Sn Stress-Managed Large Bore magnets

The development of stress managed large bore magnets is central to MDPs mission. The large bore challenges conventional cos-theta magnet designs at high field, and hence is an excellent proving ground for the concept of stress-management. Successful demonstration of reliable large-bore (≧120 mm) dipole operation in the 12-14T range, without exhibiting degradation due to strain and operational cycling, is a major milestone for the program. Furthermore, the demonstration will serve as a critical gate for a Muon collider, where high field, large bore dipoles are required to achieve high luminosity while accommodating significant radiation shielding in the bore. Finally, the large bore dipoles will serve as workhorse magnets for the hybrid magnet program, enabling development and testing of HTS dipoles in high magnetic fields.

Near term challenges and driving questions:

- Demonstrate large bore dipoles in the 12-14T range with reliable performance under power and thermal cycling
- Can stress management be used to produce high field magnets with large apertures that can approach the conductor limits without degradation?
- Need to explore stronger materials for > ~16 T magnets. How does this affect fabrication of components (machinability, scale up, 3D printing…)?
- What are the most effective impregnation materials with regard to training, degradation, radiation hardness, … ?
- CCT specific:
    - Can CCT geometries be reasonably be scaled up to long lengths in terms of mandrel fabrication, and magnet assembly?
    - Investigate scalabilty and reversibility of assembly
    - Can training be significantly reduced / eliminated and degradation avoided by using stress management (CCT) with wax based impregnation for large aperture (> ~ 120mm) high field magnets (>~10T)?
    - Challenge: Demonstrate ability to machine mandrels with deep grooves at relatively long lengths (1.5 m)

Sub-area I.b: Bi2212 insert dipoles

The DOE-OHEP has invested significantly in Bi2212, an isotropic, round-wire conductor with built-in current sharing, over the last decade. Bi2212 performance continues to evolve based on deeper understanding of the conductors, which has encouraged and enabled new powder suppliers and wire manufacturers to appear. The accelerator dipole technology has advanced, with multiple magnets demonstrating overcoming of key challenges, e.g. insulation, overall Jc, over-pressure reaction, etc. that encourage advance to the next stages. MDP is poised to perform the first hybrid test using a Bi2212 insert in a 90mm bore Nb_3Sn magnet, and coils have been fabricated in preparation for testing in the flagship 12-14T, 120mm bore dipoles currently under development. The program will now focus on the development and testing of Bi2212 dipoles in high-field, where challenges of quench protection and strain management will need to be addressed.

Near term challenges:

- Understand the industrial process and wire performance relationships to push the industrial wire plateau JE(4.2 K and 5 T) to be consistently greater than 1100 A/mm2. Currently, there are many billets with JE(4.2 K and 5 T) to be in the range of 800 – 1000 A/mm2.
- Understand causes of leakage in the Bi-2212 Rutherford cable based coils, factors that control it, and develop methods to remove it. Some leakages are external and visible after a chemical reaction with insulation materials and some are internal with Bi-2212 leaking into the interface between Ag-0.2wt.Mg% sheaths but nonetheless is harmful to wire performance. Both of them need to be addressed.
- Work with industry to address the recent wire degradation issues that arise from wire twisting. The same wire also had a higher tendency to leak. Note that there are past successes with wire twisting in the CPRD wire billet PMM180211.
- Understand the science and technology of Bi-2212 Rutherford cables and optimize their fabrication.
- Commission the overpressure processing facility RENEGADE furnace to react solenoids relevant for NMR and industry and the 85 cm long canted cosine theta Bi-CCT1 and Bi-CCT2 coils to be tested as insert coils in the 120 mm bore, 12 T CCT6 Nb3Sn dipole magnet.
- Fabricate and test the 85 cm long canted cosine theta Bi-CCT1 and Bi-CCT2 coils. Examine their performance in the standalone situation.
- Explore fabrication of canted-cosine-theta Bi-2212 coils with 3D printed Inconel mandrels to prepare their use in a high stress environment such as a 20 Tesla dipole magnet. Measure materials properties of the Aluminum Bronze 954 (now being used to build canted cosine theta Bi-2212 cols) and Inconel 718, after Bi-2212 heat treatments at low temperatures. It is known that materials would have their yielding stress reduced due to high temperature annealing.
- Integrate Bi-CCT1 and Bi-CCT2 coils as insert coils in the 120 mm bore, 12 T CCT6 Nb3Sn dipole magnet.
- Build prototypes of stress-management cosine-theta Bi-2212 coils to establish fabrication know-hows, establish benchmarked performance, and develop a technology roadmap.

Longer term challenges:

- Understand the industrial process and wire performance relationships to push the industrial wire JE(4.2 K and 5 T) to be consistently greater than 1400 A/mm2. Key to this will be the drive to understand the underlined materials science that underpins the critical current density of the round multifilamentary round wires. This research is being led by NHMFL with support from the US DOE OHEP through GARD university grant.
- Retire magnet challenges from coil fabrication to protection to enable a healthy market for Bi-2212 conductors.

Sub-area I.c: REBCO insert dipoles

The superconductor REBCO has unique challenges but also the highest field and temperature capability which offer strong opportunities for HEP applications. The tape architecture, combined with the intrinsic superconducting and mechanical anisotropy of the material, introduces distinct challenges for both magnet design and manufacture as well as for magnet protection. The opportunity, however, is tremendous due to the strong pull currently underway from the fusion community, where the promise of high-field, compact fusion devices is fueling extraordinary investments in REBCO conductor development.

Our future program will leverage recent MDP developments to focus on cable and magnet design architectures that are compatible with insert magnet geometry constraints while probing REBCO dipole magnet operation in high-fields. Particular focus is placed on addressing potential strain degradation that may occur during magnet fabrication and operation, as well as on developing and demonstrating reliable magnet protection and quench mitigation strategies.

Near term challenges:

- The round CORC-like cables are currently the workhorse for the magnet development, but they have limited operating currents that do not match with that of the LTS conductors
    - Improve the existing conductor performance in terms of the total current and the current density
    - Explore alternative cable designs
        - Flat flexible cables based on twisted tapes
        - Tape-based transposed cables
        - Six-around-one cables
- How do we minimize the critical current degradation during coil and magnet fabrication?
- What is the critical current degradation under the Lorentz forces and due to thermo-cycling?

  - What is the effect of the cycling loads on the magnet performance?

- Are REBCO conductors compatible with the hybrid approach and what needs to be done to improve the compatibility?
- Can REBCO conductors be used for Direct Wind magnets development?
- What magnetic field quality can REBCO magnets achieve and how to improve it?
- Aggressively push the HTS technology and accelerator magnet development:
  - Focus on the bore dipole field as the primary figure of merit
  - but also study and understand other effects and limitations such as ac losses, field quality, stress/strain effects, quench detection and protection.

Area II: High Field Solenoids for HEP

The high energy physics community has identified a number of opportunities for new physics that exploit colliders and experiments that require advanced high field solenoids - prime examples include a muon collider and various axion search experiments. Major advances in high field solenoids over the last decade have been led by the National High Magnetic Field Laboratory, motivated primarily by the provision of >30 T magnets for NHMFL users, culminating in the all-superconducting hybrid LTS/REBCO 32 T magnet. Bruker BioSpin has now sold about 10 28 T/1.2 GHz Nuclear Magnetic Resonance magnets based on similar LTS/REBCO hybrid design. The 2023 P5 report, coupled with the 2024 NAS report, motivated a strong partnership between MDP and the NHMFL to further advance high field solenoid technology tailored to the needs of HEP. This is a new Area within MDP, and the goal is to leverage synergies with the NHMFL and Fusion applications to rapidly develop solenoid technologies tailored to HEP needs.

Sub-area II.a: Cable and Coil Development and Testing

A unique characteristic of HEP applications utilizing solenoids is the diversity of scale of their usage. For muon colliders, solenoid needs range from a few unique, very large bore, high field solenoids for the muon production area, to a kilometer-scale suite of high-field solenoids for the muon-cooling section. For axion searches, a range of field strength and bore sizes are of interest, but generally the search sensitivity scales linearly with field volume and quadratically with field strength, motivating large bore, high field solenoids (we note that some axiom search concepts utilize dipoles, with similar field and bore scaling). Together, these applications motivate the use of scalable conductor architectures, allowing magnet designers to tailor the inductance to optimally address powering and protection considerations in light of the extraordinary amount of magnetic stored energy in the systems. Although scalable conductor architectures are routinely used in the large solenoids of collider detectors, they have not been incorporated in high field NMR, with the (perhaps unique) exception of cable-in-conduit conductor (CICC) usage in the Series-Connected Hybrid magnet currently in operation at the NHMFL. Such architectures are, however, under development by the nascent - but rapidly developing - compact fusion community.

We intend to focus MDP's first experimental efforts in the solenoid field in exploring and developing cable architectures - primarily using HTS materials - in a high-field solenoid background. Major goals are to determine performance boundaries and to develop quench protection methodologies that can be scaled.

Near term challenges:

- Explore cable behavior in solenoid configurations
- High field and stress limits and fatigue resilience
  - Axial forces
- Quench protection of high-inductance HTS-LTS coils connected in series. Test beds for achieving required stress, current, field, stored energy, bending radius, etc.

Driving Questions:

- What kind of test articles will best allow the design and advanced modeling group to decide on both conservative choices for the suite of cooling magnets and an aggressive yet achievable path to the unique magnets?
  - How many cable types should be evaluated further?
  - Should test articles be cables or single and/or dual layer coils?
- What mid-scale testing will de-risk final design and reveal the most unknown-unknowns for the full scale systems?
  - What test beds can we leverage?
  - What is the minimum coil size that addresses mechanics and quench? (~5-10 T, ~10 kA? yy MJ?)
- What synergistic efforts can we learn from, join with, or receive input from to get the most understanding from each test?
  - 32 T magnet efforts, FES (FIRE, …),
  - Instrumentation

Table I: Existing and upcoming test facilities

Location	**Field / configuration**	**Bore**	**Sample current**
ASC/NHMFL	12T / solenoid	160mm	10kA

Location	Field / configuration	Bore	Sample current
CFS/MIT	xxT / toroid	yy	zz
BNL	10T / common coil	30mm	20kA
PSI Sultan	11T / solenoid	580mm	100kA
FRESCA2	13T / dipole	80mm x 100mm	70kA
Soon to be available:			
NHMFL	23T / solenoid	195mm	xx
HFVMTF / FNAL	15T / dipole	144mm x 94mm	16kA (DC) / 100kA (transformer)

Sub-area II.b: Magnet Designs

The unique characteristics of HEP solenoid needs, and in particular the likely use of scalable conductor architectures, motivate a review and adaptation of solenoid magnet design with respect to the high-field solenoid designs that are typically used in high-field solenoid user facilities. Managing the large hoop, radial, and axial stresses in a reliable and cost-effective manner, and designing magnet protection methodologies that are compatible with the scale of field and volume envisioned, are significant challenges that require in depth design and analysis work. Due to the scale of the magnets envisioned, building demonstrations of such magnets is beyond the budget constraints of MDP; this is an area where synergies with other programs may be enabling. What is within MDP capabilities is to build high stress, high field demonstrators that take HTS conductors, still very primitive and evolving rapidly, into domains of field and stress of interest to future HEP uses, so as to identify and retire “unknown Unknown” risks and to set up project driven prototypes.

Near-term challenges:

- Explore the design limitations unique to cable architectures in solenoid configurations.

Driving questions:

- What is the full design space of future HEP solenoid requirements (e.g. size, field, operating temperature, field quality, performance, cost, sustainability), and what should be the local areas for focus exploration?
- What are the gaps in our fundamental understanding of the performance of high-field solenoids (e.g. stress management, screening currents, protection, training, conductor degradation, forces during extraction)?

- What is the ultimate performance of an HTS solenoid based on our current understanding of the material properties of the structure and conductors, as a function of magnet and cable design, and what is the main motivation for a full HTS approach versus a hybrid or LTS concept?
- What magnet subscale designs (that could be built within MDP capabilities) could allow for exploring the design limits in terms of materials, conductors, and design concepts?

Area III: Supporting Technologies

Lasting progress and advances in magnet technology rely on a solid foundation of experimental data coupled with analysis and modeling that together demonstrate an understanding of performance and that can guide the next stage of developments. To provide focus and alignment with MDP goals, four technology arenas have been identified that are critical to support the advance of magnet technology.

Sub-area III.a: Advanced Modeling

The ability to accurately predict magnet performance using modeling techniques is an essential ingredient to demonstrate understanding of the physics and engineering that drive the performance. Most importantly, the models can guide further magnet technology advances, and support the development of design and fabrication specifications and tolerances for applications. Due to the complex interplay between mechanical, electromagnetic, and thermal phenomena, and to the vast range of physical scales involved, a variety of advanced modeling techniques are needed that incorporate multi-physics and that can communicate between each other. To the degree possible, we strive for open-source models to allow broad community usage and to encourage further improvements from collaborators.

The Advanced Modeling working group aims to leverage state-of-the-art computational tools and methodologies to enhance the design, understanding, and performance of superconducting magnets. The working group will focus on three primary areas: development of design tools, fundamental understanding, and performance limitation studies. Each area contains main efforts aligned with the needs and challenges of the other working groups.

Near term challenges:

- Create and refine computational tools that facilitate the design process of superconducting. Magnets.
- Uncover the fundamental principles that dictate performance at the wire, cable or magnet level.
- Weigh in on the definition of experiments performed in other areas, in order to maximize the knowledge extracted from these.
- Understand the eventual limitations encountered during magnet testing; develop strategies to mitigate these issues.

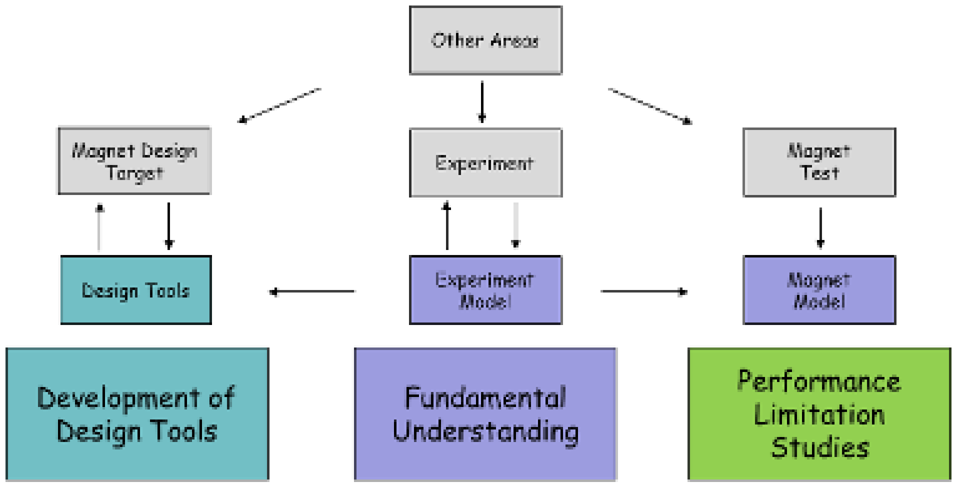


Figure 1. Research structure and interconnections in the Advanced Modeling Area

Sub-area III.b: Magnet Diagnostics and Protection

Diagnostics and instrumentation are the basis for all magnet performance information obtained during magnet fabrication and testing and are central to the MDP mission. Multi-sensor diagnostics data obtained in the R&D magnet tests, coupled with AI/ML processing and advanced models, inform our understanding of magnet performance and guide technology improvements.

Uncovering physical mechanisms responsible for premature quenching and training is critical for overcoming performance degradation and training in high-field LTS magnets that operate close to the conductor's mechanical stress limits. New diagnostics must be developed to probe mechanical energy conversion into heat at these extreme conditions. Well-controlled small-scale experiments can be especially useful in that respect, helping us better understand the transient thermo-mechanical phenomena and guiding our search for new impregnation materials and techniques for future record-field LTS magnets.

For HTS magnets, developing techniques allowing real-time detection and localization of hot spots is of major importance. Non-voltage-based techniques appear promising, especially those based on sensing localized temperature increases within the magnet windings or current re-distribution between superconducting cable elements. Different sensing modalities (ultrasonic, RF-based, Hall sensors, fiber-optics) recently explored by the MDP program must now be scaled up and integrated into prototype magnet coils to compare their efficiency. In connection with this effort, we will also develop diagnostic instrumentation for in-situ localization of HTS conductor defects in magnet coils and quantifying current sharing in complex conductors.

Quench protection is vital for safe and reliable magnet operation, and it fully relies on the early warning signals produced by the quench detection system. Various novel quench protection techniques have been proposed and tested recently, including active current control with cryogenic power electronics, coupling-losses induced heating (CLIQ), smart insulation-based control of current sharing, etc. Variations and combinations of those techniques must be explored further to protect future HTS and hybrid high-field magnets of very large stored energy. Specifically, the interaction between LTS and HTS protection systems is a critical R&D topic for the hybrids. As HTS accelerator magnet technology matures, we expect magnet diagnostics and instrumentation to become fully integrated into magnet design, fabrication, and testing. Providing a robust, reliable, and self-consistent quench detection/protection solution for HTS and hybrid magnets is the ultimate goal of this effort.

Near-term challenges:

- Addressing analysis of big diagnostic data from recent magnet tests with AI/ML. Identifying relevant data connected to magnet behavior and anomalies
- Understanding fundamental mechanisms of transient mechanics and associated heat deposition in LTS conductors and various magnet impregnation materials via small-scale experiments. Providing essential feedback to the MDP design and modeling effort
- Understanding under what conditions can we detect hot spots and safely protect HTS magnets? Developing hardware and software to address this challenge
- Pursuing integration of diagnostic instrumentation into magnets at the early stage of magnet design and construction

Sub-area III.c: Performance Analysis and Enhancement

Data from magnet testing is providing an ever-expanding foundation for analyzing performance correlations as a function of a wide range of factors, including design parameters and coil and magnet training history. Systematically analyzing this data, along with identifying and conducting specific test campaigns to explore causal connections, may yield deeper insights into the factors driving magnet performance and guide future magnet development. Small-scale experiments and targeted developments have the potential to gradually enhance our understanding of key phenomena and aid in building and validating computer models of magnet behavior. These experiments, combined with new techniques and approaches, will lead to faster and more sustainable progress in magnet performance for both LTS and HTS. The cumulative impact of these efforts shapes a sub-area that is closely linked to many other sub-areas, with bidirectional information flow being crucial for advancements across all fields.

Near term challenges:

- Develop and qualify a magnet-conditions emulation device (small scale)
- Measure transient Nb3Sn training dependencies through QCD knobs ("knobs")
- Develop and qualify methods to introduce controlled vibrations with the aim to control friction at relevant interfaces
- Obtain statistical data on the effects of magnet (re-)loading and (re-)assembly on performance through dedicated systematic tests
- Characterize new magnet training and performance data, determine dependencies

Driving questions:

- What are efficient ways to understand underlying mechanisms in magnet performance (training, degradation, limitations)?
- What is the nature of those mechanisms? What are the ultimate performance limits in magnets (LTS/HTS conductors) and how to reach them?
- How to maximize scientific output (given constraints)?
- How to apply new scientific knowledge to quickly boost technology development?

Sub-area III.d: Materials and Conductors

All superconductors beyond Nb-Ti are strain sensitive and brittle in nature; in the case of Nb_3Sn and Bi2212, the conductors are subjected to complex heat-treatments to form the superconducting compounds, and in most cases for accelerator magnets the heat treatments are performed after the coil is wound (i.e. "wind and react") due to the strain sensitivity of the superconductor after heat treatment. To advance accelerator magnet technology, it is essential that we have a thorough understanding of the material properties at all stages of the fabrication process, and that associated magnet materials be selected and applied in a manner that optimizes magnet performance. Developing a robust database of materials properties and a process for materials selection and usage is a critical element of MDP.

Near term challenges:

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Area IV: Exploratory Studies

The 2023 HEP P5 report identified a number of potential collider opportunities over the coming decades that will require advanced accelerator magnet technology to come to fruition. The facilities envisioned are of an extraordinary scale that will require international collaboration beyond the current level and the support from the broader public across many nations. Sustainability – both in the facility construction and in its long-term operation – will be an essential ingredient in getting humanity behind such an endeavor. To optimally prepare for such colliders, it is imperative that we collaborate closely with the accelerator design initiatives and identify the magnet advances that provide optimal value to the accelerator performance. Tradeoffs between field, field quality, aperture, operating temperature, magnet cost, and operational power requirements, for example, are an essential part of future facility design.

Sub-Area IV.a: Higher Temperature / All HTS and Sustainability

Superconductors enable modern colliders by providing the beam's guiding magnetic field without energy loss, i.e. the magnetic field is effectively stored potential energy. Nevertheless, there is energy consumed in the refrigeration power needed to keep the magnets at their operating temperature. The thermodynamic optimal, Carnot efficiency, scales with $Q_c \sim T_{warm}/T_{cold}$, e.g. increasing the operating temperature from 1.9K to 4.2K results in more than a factor 2 reduction in wall-plug power. Operating at 20K would improve Carnot efficiency by a further factor of nearly 5. However, operating at higher temperature limits superconductor options, and comes at a cost of more superconductor due to the Jc(T) dependence. Furthermore, there are complex interrelations, for example related to superconductor magnetization and magnet protection, that can impact the viability of operation at higher temperature. Understanding the field and temperature limitations of each superconductor and associated accelerator magnet technology and the potential implications for collider sustainability is a critical role for MDP.

Near term challenges:

- What's the maximum dipole field a REBCO magnet can achieve as determined by the irreversibility field of the conductor? What's the maximum dipole field a REBCO magnet can achieve at its mechanical limit?
- What would it take to generate a 10 T dipole field at 4.2 K using today's commercial REBCO conductors?
- What's the performance of a 10 T dipole magnet at 4.2 K, including the field quality, quench behavior, magnetization, and ac losses? What does the result imply towards a higher dipole field?
- What's a roadmap and potential collaboration toward testing superconducting magnets in LH2 by 2030?
- What's the impact of elevated temperatures on the magnet performance?
- What's a roadmap toward a dipole field of 20 T at 20 K by 2040?

Sub-Area IV.b: Interaction Region and Combined Function Magnets

While the focus of future collider magnet technology is typically on the ring dipoles due to their dominance in the overall facility cost and performance, there are additional accelerator magnets that drive collider performance, most noticeably the quadrupoles in the detector interaction region that maximize the luminosity of the collider. Advances in accelerator magnet technology can – and must - support the unique challenges of these magnets. Furthermore, innovative magnet designs, such as combined-function magnets that enable unique lattice opportunities, may allow for further collider design paradigms that yield overall improvements in physics capabilities.

Sub-Area IV.c: Interfacing with Collider Studies

Based on the 2023 HEP P5 report, we anticipate the formation of collider design group(s) within the next 2-3 years, and it is essential that there be close collaboration and communication between those groups and MDP. Identifying the primary limitations on magnet performance, e.g. through guidance on achievable fields, field quality, operating parameters, etc. will be important contributions from MDP to enable credible collider designs. Furthermore, close communication can guide MDP developments on those elements of magnet advances that have most impact on collider performance, and/or that address the largest risks in collider operations.

Facilities Improvements

A suite of state-of-the-art facilities is essential to support the magnet tests associated with the Program described above. In particular, the ability to test hybrid magnets is a critical component of the program. This includes separately powered outsert and insert magnets, each requiring unique and flexible quench detection systems. Moreover, power switching and fast energy extraction capabilities are crucial, especially for the protection of the HTS component in hybrid magnets.

Additionally, advanced magnet diagnostics and instrumentation demand specialized data acquisition capabilities, and the test facilities must evolve in step with MDP technology developments. Identifying new enabling technologies, implementing best practices, and sharing magnet test experiences and data are all vital for the success of the MDP mission.

Conductor Procurement and Research and Development (CPRD)

The Magnet Development Program requires access to state-of-the-art superconductors to enable rapid and successive development and testing of accelerator magnets. Furthermore, superconductor performance drives accelerator magnet performance, motivating continued feedback from MDP to the superconductor industry to enable conductor advances that benefit HEP. The mission of CPRD is therefore a) to identify future MDP magnet conductor needs and to procure the requisite conductor in a timely manner, and b) to work with industry to identify possible research opportunities that may lead to significant advances in superconductor performance. The research investments should complement existing funding opportunities such as SBIR, and should support the competitiveness of the US superconductor industry.

Appendix A

Draft 1, Oct. 21, 2024

Table of Coordinators

Area	Sub-Area	Coordinator
I: Hybrid Accelerator Magnets	I.a: Nb3Sn Stress-Managed Large Bore magnets	I. Novitski & D. Arbelaez
	I.b: Bi2212 insert dipoles	T. Shen
	I.c: REBCO insert dipoles	V. Kashikhin
	I.d: Hybrid magnet integration	P. Ferracin
II: High Field Solenoids for HEP	II.a: Cable and Coil Development and Testing	D. Davis
	II.b: Magnet Designs	J. L. Rudeiros, K. Badgley
III: Supporting Technologies	III.a: Advanced Modeling	G. Vallone
	III.b: Magnet Diagnostics and Protection	M. Marchevsky
	III.c: Performance Analysis and Enhancement	S. Stoynev
	III.d: Materials and Conductors	S. Krave & X. Xu
IV: Exploratory Studies	IV.a: Higher Temperature / All HTS and Sustainability	L. Cooley, X. Wang
	IV.b: Interaction Region and Combined Function Magnets	G. Ambrosio & L. Brouwer
	IV.c: Interfacing with Collider Studies	M. Palmer

Critical support	
Facilities Improvements	R. Teyber, P. Joshi, S. Stoynev, D. Davis
Conductor Procurement and R&D	I. Pong