

# 2<sup>nd</sup> IEEE International Challenge in Design Methods for Power Electronics

## 2025 PELS MagNet Challenge

# MagNet Challenge 2

*“From Steady-State to Transient Models!”*

**Kickoff Meeting, February 13, 2025**

**Shukai Wang, Hyukjae Kwon, Haoran Li, Thomas Guillod,  
Minjie Chen, Charles R. Sullivan**

**MagNet 2025 Organizing Team**  
[pelsmagnet@gmail.com](mailto:pelsmagnet@gmail.com)



# Overview

- **Organizing committee kickoff meeting**
  - Introduce the committee
  - Introduce the new technical challenge
  - Introduce the timeline
  - Collect feedback
  - Finalize everything before APEC
- **Public information session**
  - Feb 26<sup>th</sup> Wednesday at 9am EST
  - Registration Link:  
[https://princeton.zoom.us/webinar/register/WN\\_SKNgzuqBRQKqVYwajY6tJA](https://princeton.zoom.us/webinar/register/WN_SKNgzuqBRQKqVYwajY6tJA)
  - Official launch at APEC 2025

# MagNet 2025 – A Transient Challenge

## MagNet 2025 Organizing Committee:

- **Shukai Wang**, Princeton, USA
- **Hyukjae Kwon**, Princeton, USA
- **Haoran Li**, Princeton, USA
- **Minjie Chen**, Princeton, USA
- **Charles Sullivan**, Dartmouth, USA
- **Thomas Guillod**, Dartmouth, USA

## Judge Committee:

- **Charles Sullivan**, Dartmouth, USA
- **David Perreault**, MIT, USA
- **Jürgen Biela**, ETH Zurich, Switzerland
- **Dragan Maksimovic**, CU Boulder, USA
- **SY Ron Hui**, CUHK, Hongkong

## Liaison Committee:

- **Han Cui**, Tianjin, China
- **Sinan Li**, Sydney, Australia
- **Oliver Wallscheid**, Paderborn, Germany

## Advisory Committee:

- **Gerard Hurley**, National University of Ireland, Ireland
- **Maeve Duffy**, National University of Ireland, Ireland
- **Brad Lehman**, Northeastern University, USA
- **Matt Wilkowski**, Wurth Electronics, USA
- **Mike Ranjram**, Arizona State University, USA
- **Alex Hanson**, UT Austin, USA
- **More ...**



# A Very Successful MagNet Challenge 1



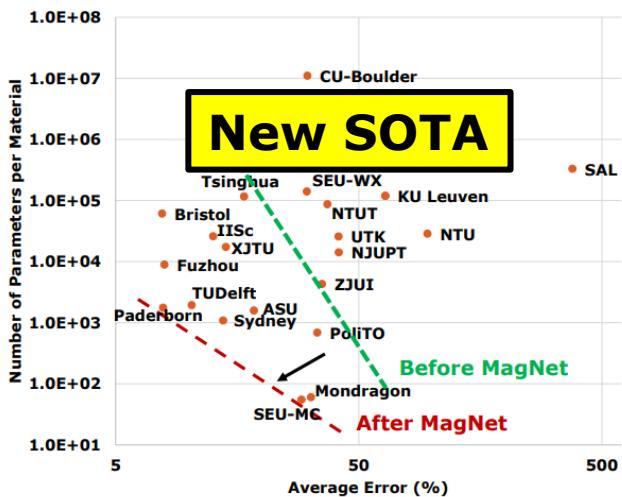
# Charles Steinmetz **S** (1865-1923)



# MagNet Challenge for Data-Driven Power Magnetics Modeling

Minjie Chen<sup>1</sup>, Haoran Li<sup>1</sup>, Shukai Wang<sup>1</sup>, Thomas Guillod<sup>2</sup>, Diego Serrano<sup>1</sup>, Nikolas Förster<sup>3</sup>, Wilhelm Kirchgässner<sup>3</sup>, Till Piepenbrock<sup>3</sup>, Oliver Schweins<sup>3</sup>, Oliver Wallscheid<sup>3</sup>, Qiujiue Huang<sup>4</sup>, Yang Li<sup>20</sup>, Yu Dou<sup>21</sup>, Bo Li<sup>21</sup>, Sinan Li<sup>4</sup>, Emmanuel Havugimana<sup>5</sup>, Vivek Thomas Chacko<sup>6</sup>, Srirathan Radhakrishnan<sup>6</sup>, Mike Ranjram<sup>6</sup>, Bailey Sauter<sup>6</sup>, Skye Reese<sup>6</sup>, Shivangi Sinha<sup>7</sup>, Lihong Zhang<sup>7</sup>, Tom McKeague<sup>7</sup>, Binyu Cui<sup>7</sup>, Navid Rasekh<sup>7</sup>, Jun Wang<sup>7</sup>, Song Liu<sup>7</sup>, Alfonso Martinez<sup>8</sup>, Xinyu Liu<sup>9</sup>, Chaoying Mei<sup>9</sup>, Rui Zhao<sup>9</sup>, Gaoyuan Wu<sup>9</sup>, Hao Wu<sup>9</sup>, Rui Zhang<sup>10</sup>, Hao Song<sup>10</sup>, Lie Zhang<sup>10</sup>, Yibo Lu<sup>10</sup>, Lijun Hang<sup>10</sup>, Neha Rajput<sup>11</sup>, Himanshu Bhushan Sandhibigraha<sup>11</sup>, Neeraj Agrawal<sup>11</sup>, Vishnu Mahadeva Iyer<sup>11</sup>, Xiaobing Shen<sup>12</sup>, Fanghao Tian<sup>12</sup>, Qingcheng Sui<sup>12</sup>, Jiaze Kong<sup>12</sup>, Wilmar Martinez<sup>12</sup>, Asier Arruti<sup>13</sup>, Borja Alberdi<sup>13</sup>, Anartz Agote<sup>13</sup>, Iosu Aizpuru<sup>13</sup>, Minmin Zhang<sup>14</sup>, Xia Chen<sup>14</sup>, Yuchen Dong<sup>14</sup>, Duo Wang<sup>14</sup>, Tianming Shen<sup>14</sup>, Yan Zhou<sup>14</sup>, Yaohua Li<sup>15</sup>, Sicheng Wang<sup>15</sup>, Yue Wu<sup>15</sup>, Yongbin Jiang<sup>15</sup>, Ziheng Xiao<sup>15</sup>, Yi Tang<sup>15</sup>, Yun-Shan Hsieh<sup>16</sup>, Jian-De Li<sup>16</sup>, Li-Chen Guifrida<sup>17</sup>, Nicolo Lo Carlo Stefano Ragusa<sup>18</sup>, Chen<sup>16</sup>, Alessio Luigi Solimene<sup>17</sup>, Xiang Ma<sup>19</sup>, Boyu Zhang<sup>19</sup>, Zheng Wang<sup>19</sup>, Zhongqi Shi<sup>19</sup>, Dixant Bikal Sapkota<sup>22</sup>, Puskar Neupane<sup>22</sup>, Mecon Joshi<sup>22</sup>, Shahabuddin Khan<sup>22</sup>, Bowen Su<sup>20</sup>, Yunhao Xiao<sup>20</sup>, Min Yang<sup>20</sup>, Kai Sun<sup>20</sup>, Zhengzhao Li<sup>23</sup>, Reza Mirzadaran<sup>23</sup>, Ruijun Liu<sup>23</sup>, Lu Wang<sup>23</sup>, Tianming Luo<sup>23</sup>, Dingsihao Lyu<sup>23</sup>, Mohamad Ghaffarian Niasar<sup>23</sup>, Zian Qin<sup>23</sup>, Syed Irfan Ali Meerza<sup>24</sup>, Kody Froehle<sup>24</sup>, Han Helen Cui<sup>24</sup>, Daniel Costinetti<sup>24</sup>, Jian Liu<sup>24</sup>, Zhanlei Liu<sup>25</sup>, Cao Zhao<sup>25</sup>, Yongliang Dang<sup>25</sup>, Yukun Zhang<sup>25</sup>, Na Wang<sup>25</sup>, Yiting Chen<sup>25</sup>, Yiming Zhang<sup>25</sup>, Chushan Li<sup>25</sup>, Yinan Yao<sup>26</sup>, Tianxiang Hu<sup>26</sup>, Lumeng Xu<sup>26</sup>, Yiyi Wang<sup>26</sup>, Sichen Wang<sup>26</sup>, Shuai Jiang<sup>27</sup>, David Shumacher<sup>28</sup>, Dragan Maksimovic<sup>29</sup>, Ron S. Y. Hui<sup>29</sup>, Johanna W. Kolar<sup>30</sup>, David J. Perreault<sup>31</sup> AND Charles R. Sullivan<sup>2</sup>

**133 co-authors**



The figure is a world map with red balloons placed on specific locations to indicate the host cities for the 24 WorldSkills competitions. The balloons are concentrated in North America, Europe, and Asia.

- Arizona, USA
- Fuzhou, China
- Hangzhou, China
- Torino, Italy
- Graz, Austria
- Lalitpur, Nepal

**24**

- Arizona, USA
- Fuzhou, China
- Hangzhou, China
- Bangalore, India
- Leuven, Belgium
- Hernani, Spain
- Nanjing, China
- Cambridge, USA
- Singapore, Singapore
- Taipei, Taiwan
- Hong Kong, China
- Paderborn, Germany
- Princeton, USA
- Hanover, USA
- Piscataway, USA

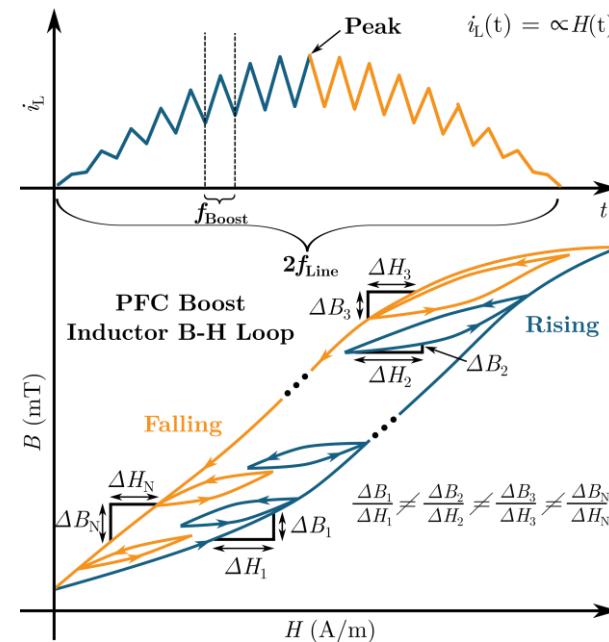
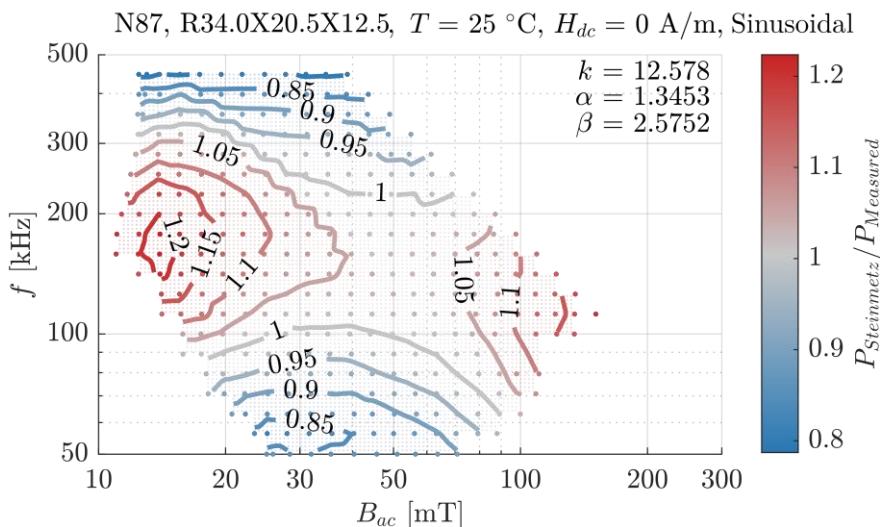
**MagNet 2023 - IEEE International Challenge in  
Design Methods for Power Electronics**

**24 teams**

# Many theses



# MagNet 2025 – A Transient Challenge



Steinmetz Equation  
(1890s)

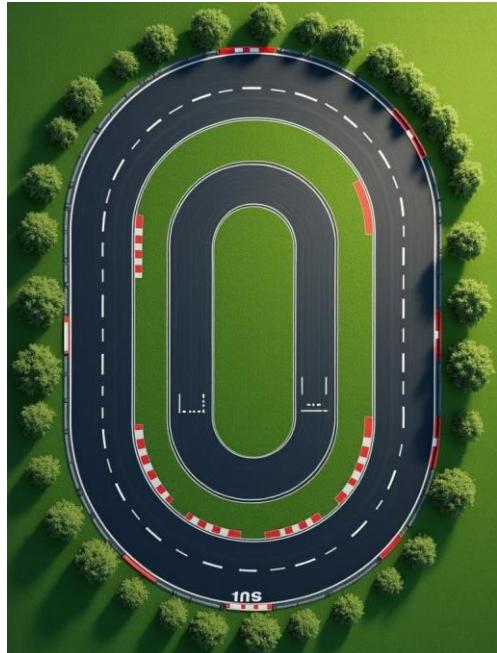
Preisach Model & J-A Model  
(1930s) & (1980s)

# Foundation Model for Power Magnetics

- Motivation:
  - MagNet Challenge 1: find something better than Steinmeitz
  - MagNet Challenge 2: what's the best modeling framework
- Foundation Model for Magnetic Materials?
  - Frequency agnostic (non-steady-state)
  - Universal time step (long- or short-time steps)
  - Hypothesis: impact of initial state has finite time horizon
  - ...
- A Rigorous Mathematical Framework?
  - A compact and efficient, hopefully explainable modeling framework which will converge over time to the material's steady state condition
  - Physics-based, data-driven, or hybrid ...

# 2025: from Racetrack to Open Path

Periodic Steady State Excitations



Non-Periodic Excitations

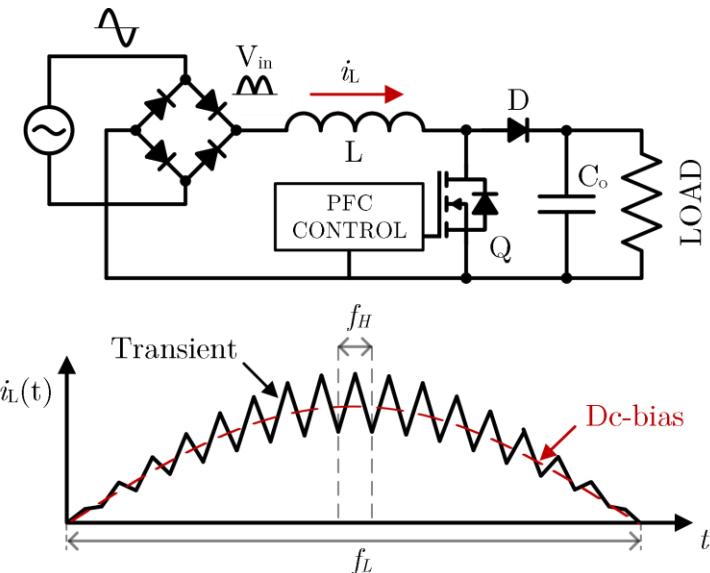


# Motivation for the MagNet Challenge 2

- No good method to design magnetics in transient.
- **Imprecise material  $\leftrightarrow$  imprecise model  $\leftrightarrow$  imprecise design.**
- Unnecessary design margins (thermal,  $B_{sat}$ , batch-to-batch variation, ...).
- Future chips, vehicles, and robotics need miniaturization and precision.
- Opportunities to reduce the size of all magnetics by 20%~50%?
- Need a better way to document, compress, and share information.
- Help the manufacturers to improve repeatability, control the quality, and share better data in better ways.



An example PFC converter

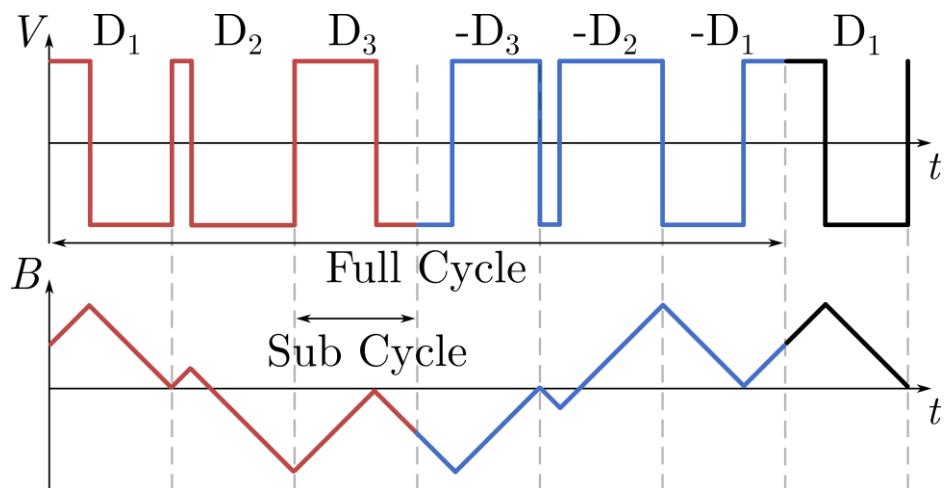


Make every AC-DC adapters 30% smaller?

# New MagNetX Dataset for Transient Dynamics

- Duty cycle step changes  $D = 0.2 \sim 0.8$ , min step size = 0.1
- Fixed subcycle frequency sequences  $f = 50\text{kHz} \sim 800\text{kHz}$ , 7 subcycle frequency levels
- Three temperatures: 25°C, 50°C, 70°C
- ~7 voltage levels
- 100 subcycles per sequence

## Example symmetric magnetizing and demagnetizing sequences



Symmetric magnetizing and demagnetizing sequences  
15 ferrite materials  
>5,000 sequences per material  
Fixed sampling frequency: 16 MHz  
50 kHz: 320 steps per subcycle  
500 kHz: 32 steps per subcycle

- Hyukjae Kwon, Shukai Wang, Haoran Li, et al. "MagNetX: Extending the MagNet Database for Modeling Power Magnetics in Transient," *TechRxiv*. December 11, 2024. Accepted to APEC 2025.

# Data Structure

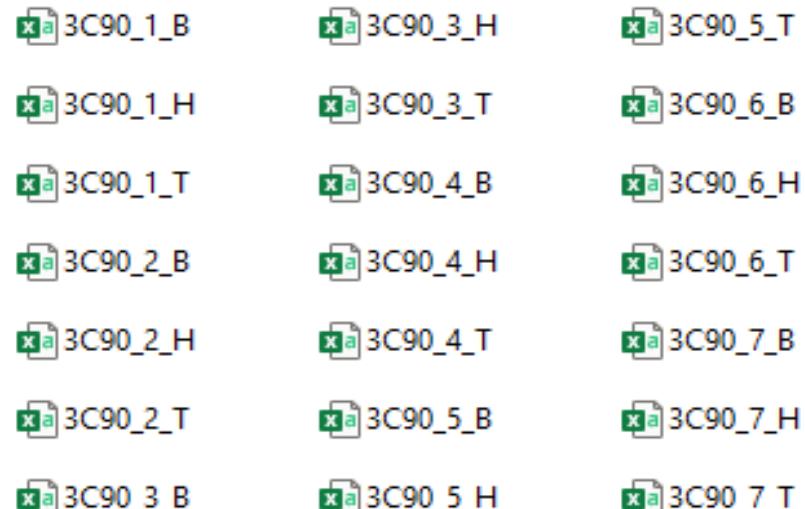
## For Training

- Material format:
  - 7 sets of  $B(t)$ ,  $H(t)$ ,  $T$  for each material
  - Frequency information not provided
- Sampling frequency for all sequences: 16MHz
  - 50kHz: 32016 steps
  - 80kHz: 20016 steps
  - 125kHz: 12816 steps
  - 200kHz: 8015 steps
  - 320kHz: 4975 steps
  - 500kHz: 3216 steps
  - 800kHz: 1967 steps

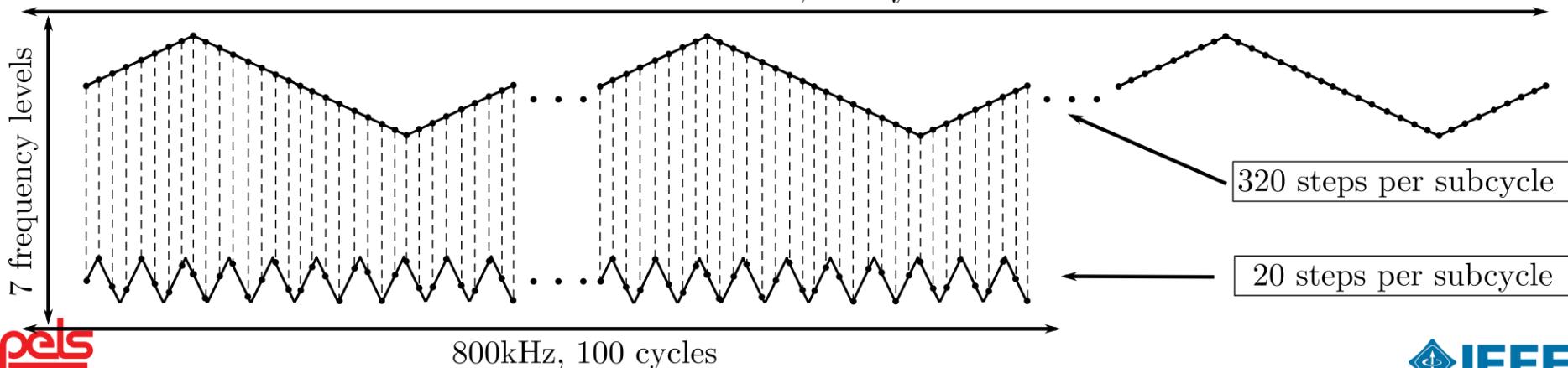
## Testing

- Same length for all sequences (TBA)

Material Folder: 3C90



50kHz, 100 cycles



# Outcome: A Callable Prediction Function

## Training data:

- 10 training materials
- Lots of long  $B(t)$ - $H(t)$  pairs
- Temperature



## Testing data:

- 5 new materials
- Temperature
- Practicing: plenty of long  $B(t)$  and  $H(t)$  pairs
- Testing:

- $B(t)$  and  $H(t)$  pairs from  $t_0$  to  $t_1$
- $B(t)$  from  $t_1$  to  $t_2$

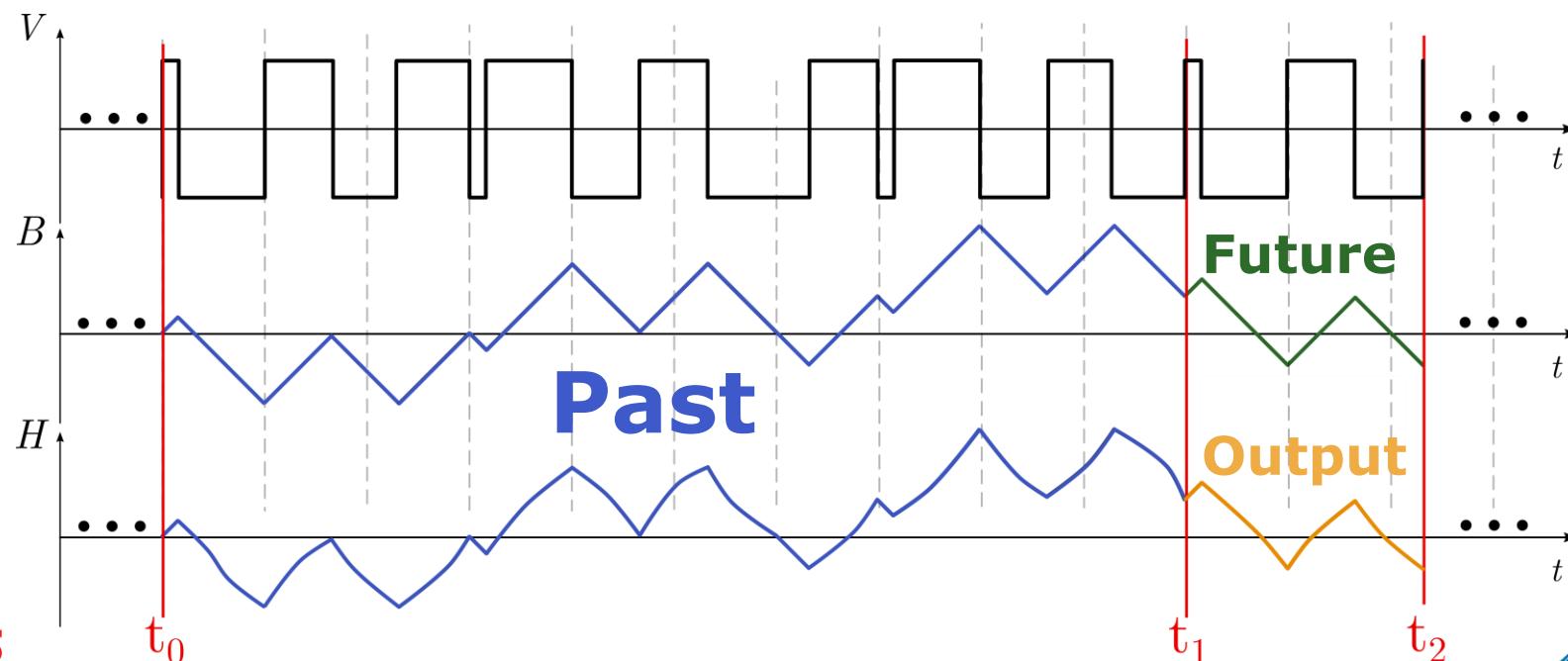
## Output:

- $H(t)$  from  $t_1$  to  $t_2$



## Evaluate:

- Total core loss from  $t_1$  to  $t_2$
- $H(t)$  RMS error from  $t_1$  to  $t_2$
- Model size (# of parameters)



- Hyukjae Kwon, Shukai Wang, Haoran Li, et al. "MagNetX: Extending the MagNet Database for Modeling Power Magnetics in Transient," *TechRxiv*. December 11, 2024. Accepted to APEC 2025.

# Strategies to win the Challenge?

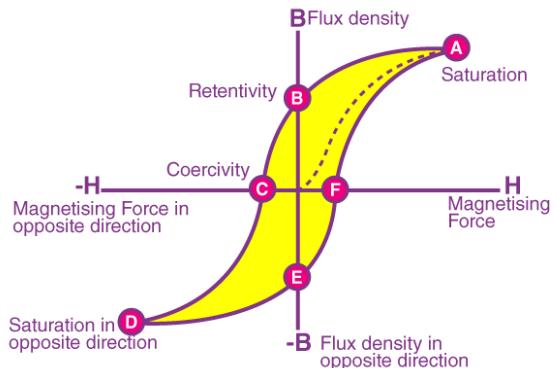
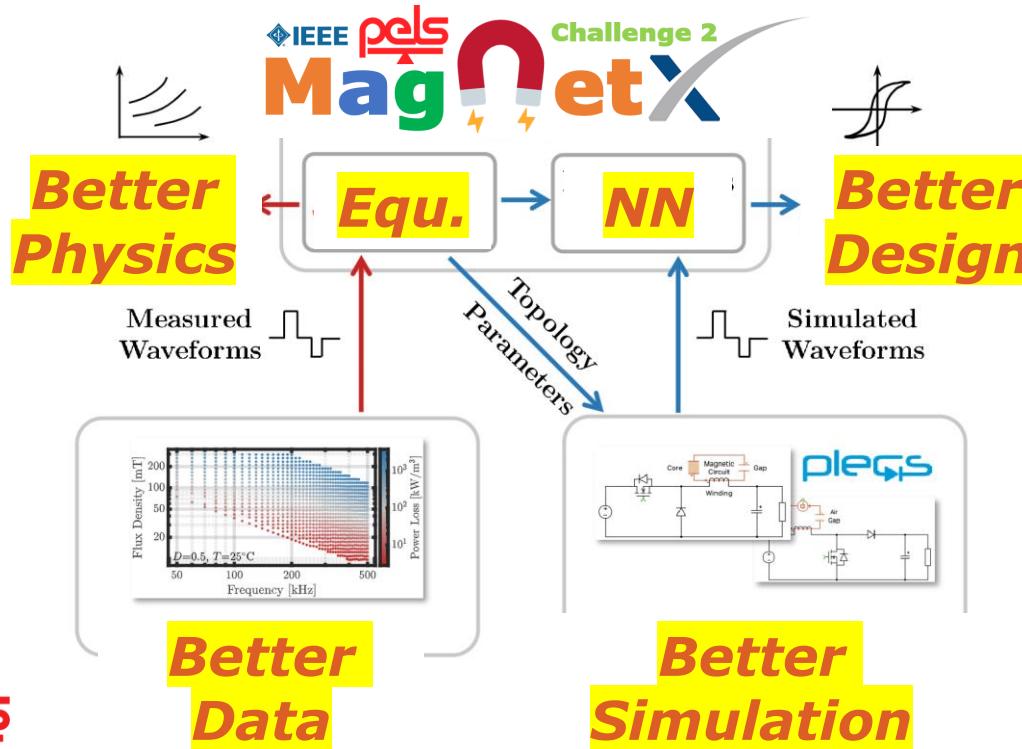
- **Understand physics and understand data**
  - Model / method should be reasonably explainable
  - Balancing model generality and model accuracy
- **Understand materials and understand design**
  - What manufacturers provide? – modeling framework
  - What designers need? – software engineering
- **Respect legacy and challenge legacy**
  - Understand what has been done
  - Challenge existing understanding
  - Leverage modern methods and tools
- **Winning team structure:**

**Power Electronics**  
**Magnetics**

**Data Science**  
**Software Engineering**

# Outcomes of the MagNet Challenge 2

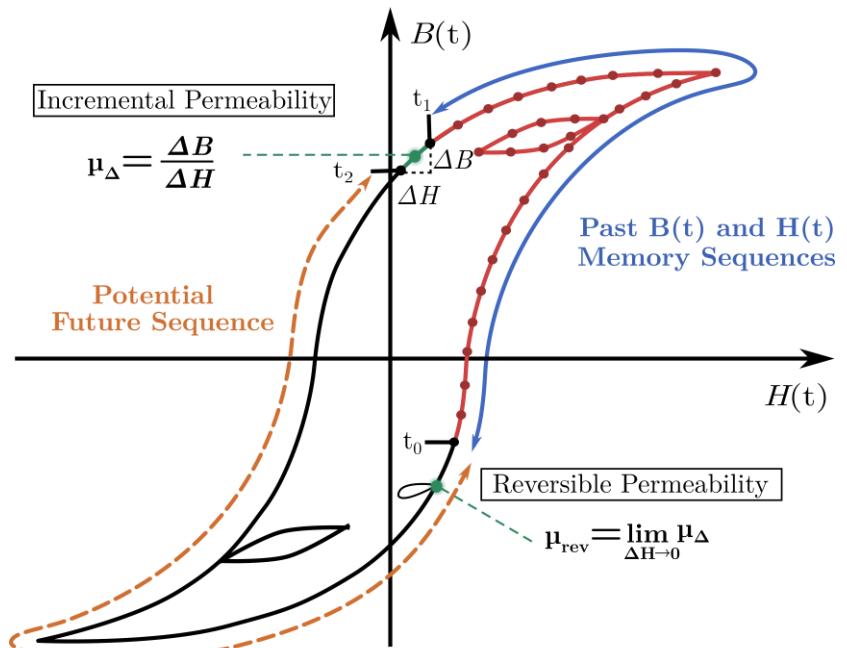
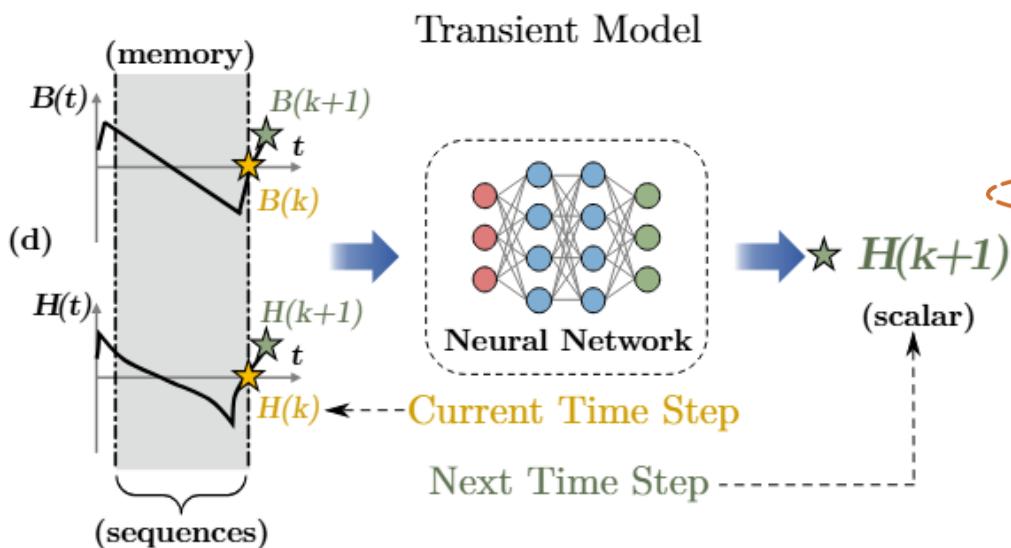
- Better understandings about power magnetics.
- Better tools for power magnetics design.
- Better ways of sharing information (digital/interactive datasheet).
- Cultivate an open-source community.
- Better impact on practical design.



- Hysteresis loop exists for almost all energy materials
- Magnetics, capacitors, piezoelectric, batteries, etc.

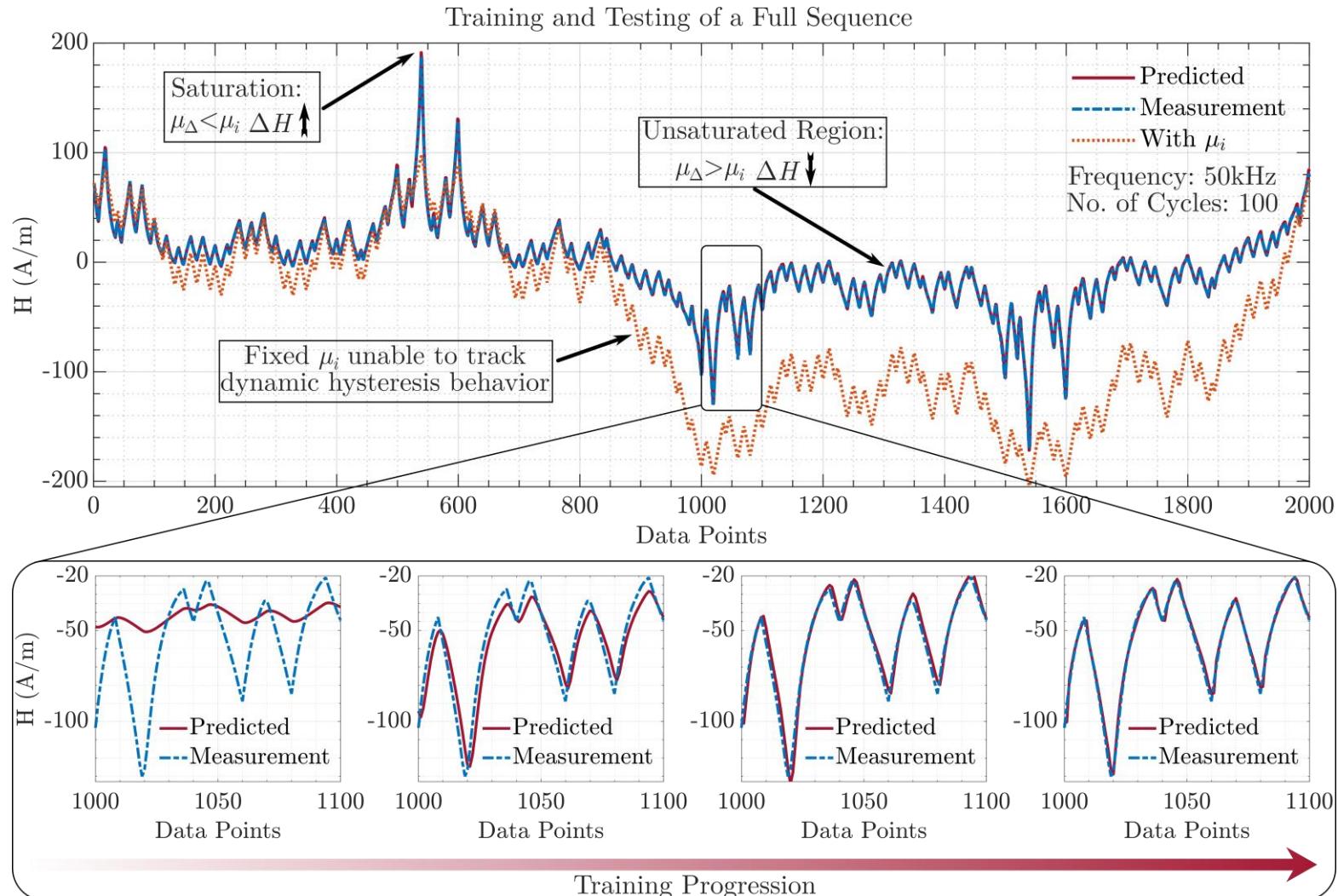
# What we have developed (as tutorials)

Input:  $B(t)$  in the past 80 steps  
 $H(t)$  in the past 80 steps  
future  $B(t)$  from  $t_1$  to  $t_2$   
Output: future  $H(t)$  from  $t_1$  to  $t_2$



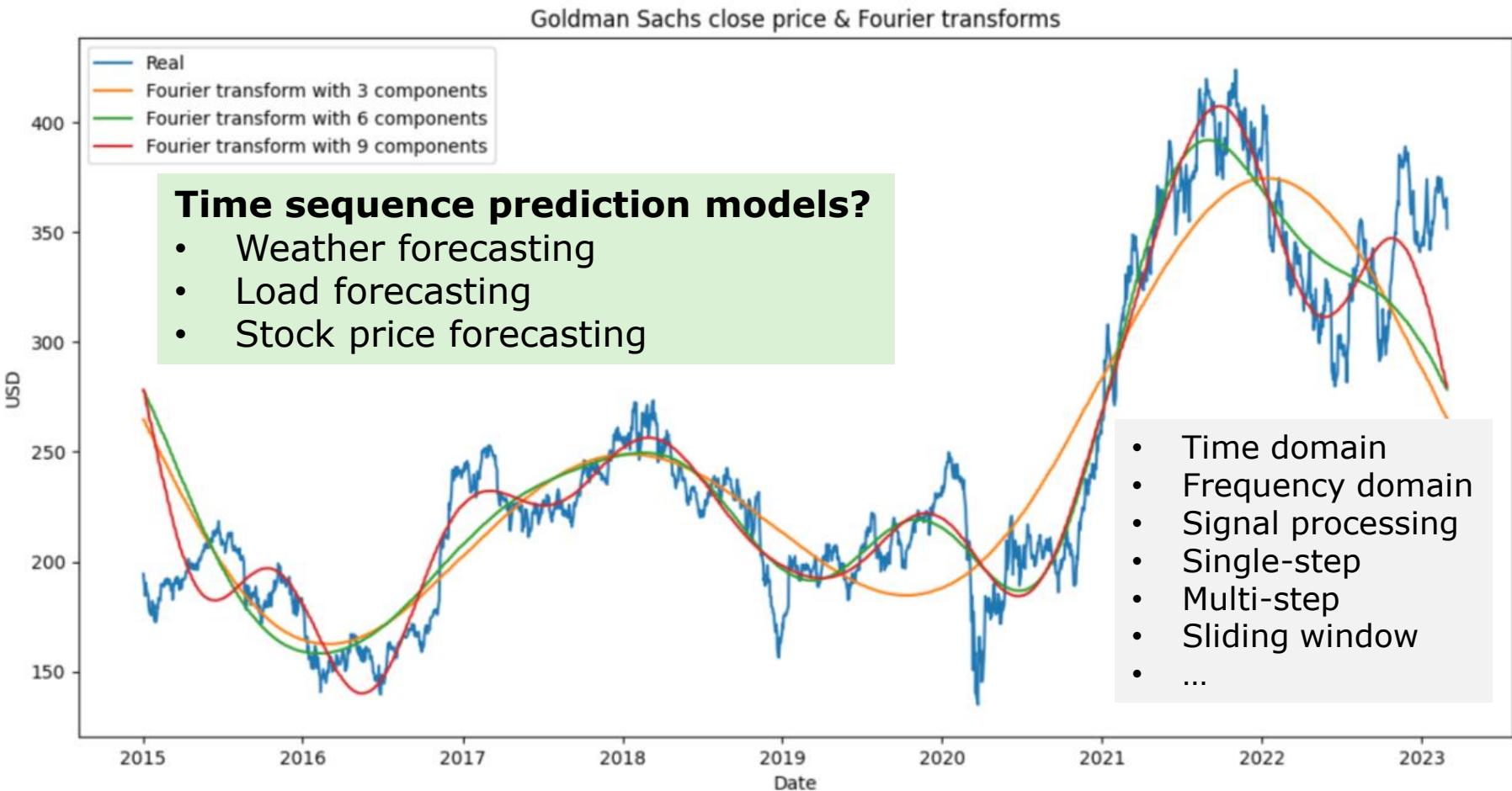
- Shukai Wang, Hyukjae Kwon, Haoran Li, et al. "**MagNetX: Foundation Neural Network Models for Simulating Power Magnetics in Transient.**" *TechRxiv*. December 11, 2024. Accepted to APEC 2025.

# A Large Model for the Long Sequences



Goal: Autoregressive Prediction

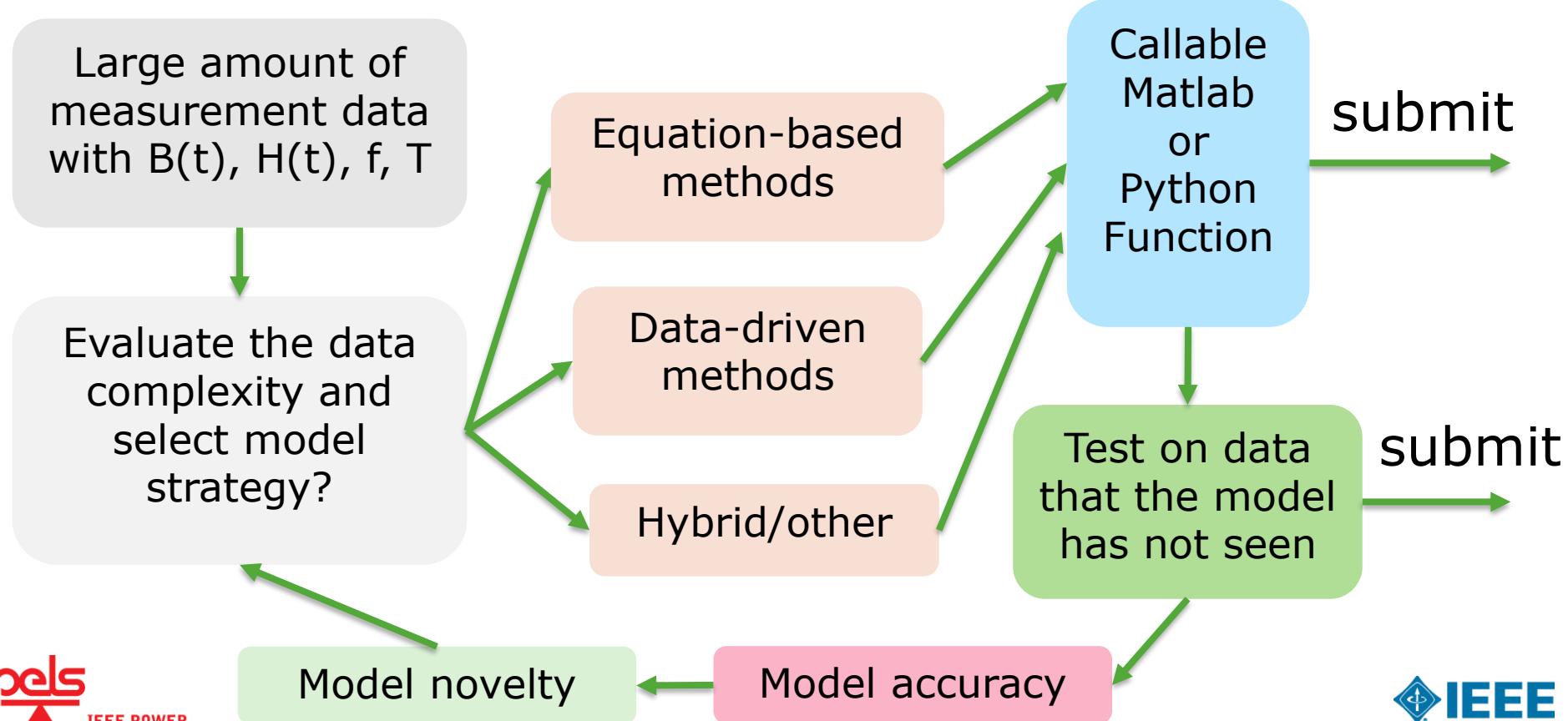
# Separate Fast Details and Slow Trends



# Information Flow of MagNet Challenge 2

**Next step:**  $H_{t+1} = \text{function}(B(t), H(t), B_{t+1}, T)$

**Long cycle:**  $H_{t_1 \rightarrow t_2} = \text{function}(B(t), H(t), B_{t_1 \rightarrow t_2}, T)$



# Evaluation Criteria

- **Winning solution:** a **simple, robust, and trustworthy** method to
  - (1) **accurately predict power magnetic behaviors**
  - (2) **efficiently use the training data**
  - (3) **provide useful design insights**
  - (4) **advance understanding about power magnetics**
  - (5) **other novel contributions to the field**
- **Model performance:** 95<sup>th</sup> percentile error on RMS error in B-H sequence.
- **Model size:** number of material-specific parameters that need to be kept in the model. Jointly evaluated by submitted package size and code review.
- **Model novelty:** new insights and new methods in physical understanding, data processing, model development, and anything else related to power magnetics.
- **Model generality:** extending the developed model to different materials.

## Final Winners selected by the Academic Advisory Committee:

- Charles Sullivan, Dartmouth, USA
- David Perreault, MIT, USA      • Jürgen Biela, ETH Zurich, Switzerland
- SY Ron Hui, CUHK, Hongkong    • Dragan Maksimovic, UC Boulder, USA

# Student Team Eligibility

- **Eligibility:** To confirm eligibility, potential participating schools must submit a Letter of INTENT (attached) by **May 1<sup>st</sup>, 2025**, to [pelsmagnet@gmail.com](mailto:pelsmagnet@gmail.com), for better coordination.
- For each team, the minimum student number is **three (3)** and the maximum student number is **five (5)** to qualify for the competition. Each team should consist of between **one (1) to two (2)** undergraduate students (B.S. or equivalent), between **two (2) to three (3)** graduate students (M.S./Ph.D. or equivalent), and at least **one (1)** faculty advisor and optionally **one (1)** industry mentor. Interdisciplinary and diversified teams are highly encouraged.
- Note: We will try to host as many teams as possible. We can perhaps host **2-3 teams per university** depending on the final total participating team numbers and the quality of the proposals.
- Members of the judging committee will be replaced if there is a conflict from the same university. Student teams will NOT be judged by experts with conflicts of interest.
- We will invite **20-30 prominent researchers** from academia and industry as scientific advisors to student teams.

# Timeline of the MagNet Challenge 2

<b>Feb 10<sup>th</sup>, 2025</b>	Initial Call for Participation Announcement
<b>March 18<sup>th</sup>, 2025</b>	APEC Official Announcement
<b>April 1<sup>st</sup>, 2025</b>	Online Q&A Session
<b>May 1<sup>st</sup>, 2025</b>	1-Page Letter of Intent Due with Signature [Attached]
<b>June 1<sup>st</sup>, 2025</b>	2-Page Proposal Due for Eligibility Check [TPEL Format]
<b>July 1<sup>st</sup>, 2025</b>	Notification of Acceptance [Eligibility Check]
<b>Nov 1<sup>st</sup>, 2025</b>	Preliminary Submission Due, Finalists Selected
<b>Dec 24<sup>th</sup>, 2025</b>	Final Submission Due
<b>March 1<sup>st</sup>, 2026</b>	Winner Announcement and Presentation

April 1<sup>st</sup> - Large amount of data  
for 10 materials released

Nov 1<sup>st</sup> – Callable models  
for 10 materials due

**MagNet Methodology**

- Develop methods on **old** materials
- Test methods on **new** materials
- Train models with **small** datasets
- Test models with **large** datasets

May 1<sup>st</sup> – 1-Page letter of intent due

Nov 1<sup>st</sup> – Release small  
training data for 5 new  
materials

June 1<sup>st</sup> – 2-Page proposal due

July 1<sup>st</sup> – All participating teams confirmed

Dec 24<sup>th</sup> – Callable models and predicted core loss ( $P_v$ )  
for 10+5 materials under a variety of  $\{B(t), f, T\}$   
conditions, and a 5-page TPEL format report due

March 1<sup>st</sup> , 2026 – Winner Announcement

# Award Structure (**TBD**)

Tesla Award for Model Performance 1 <sup>st</sup> Place \$10,000	Google Award for Model Novelty 1 <sup>st</sup> Place \$10,000	Princeton Award for Outstanding Software Engineering \$5,000
PELS Award for Model Performance 2 <sup>nd</sup> Place \$5,000	PELS Award for Model Novelty 2 <sup>nd</sup> Place \$5,000	PELS Honorable Mentions \$1,000 x multiple

- Performance
- Model size
- Novelty
- Model generality
- Software implementation
- Other contributions

## Intellectual Property

- MagNet Challenge 2 has no restrictions on intellectual property.
- We encourage open-source culture and open-source licenses.
- Presenting the models to MagNet team is considered as public disclosure.
- Student teams should take actions before disclosure if IP protection is needed.

# Extended Reading – MagNet Challenge 2

- **J-A Model** – D. Jiles and D. Atherton, “Theory of ferromagnetic hysteresis,” Journal of Magnetism and Magnetic Materials, vol. 61, no. 1, pp. 48–60, 1986.
- **Preisach Model** – F. Preisach, “Uber die magnetische Nachwirkung,” Zeitschrift fur Physik, vol. 94, no. 5-6, pp. 277–302, May 1935.
- **LLG Model** – H. H. Cui, S. Dulal, S. B. Sohid, G. Gu, and L. M. Tolbert, “Unveiling the microworld inside magnetic materials via circuit models,” IEEE Power Electronics Magazine, vol. 10, no. 3, pp. 14–22, 2023.
- **iGSE-PFC** – M. J. Jacoboski, A. de Bastiani Lange and M. L. Heldwein, “Closed-Form Solution for Core Loss Calculation in Single-Phase Bridgeless PFC Rectifiers Based on the iGSE Method,” in IEEE Transactions on Power Electronics, vol. 33, no. 6, pp. 4599-4604, June 2018.
- **Why MagNet** – D. Serrano et al., “Why MagNet: Quantifying the Complexity of Modeling Power Magnetic Material Characteristics,” in IEEE Transactions on Power Electronics, vol. 38, no. 11, pp. 14292-14316, Nov. 2023.
- **How MagNet** – H. Li et al., “How MagNet: Machine Learning Framework for Modeling Power Magnetic Material Characteristics,” in IEEE Transactions on Power Electronics, vol. 38, no. 12, pp. 15829-15853, Dec. 2023.
- **MagNet-AI** – H. Li, D. Serrano, S. Wang and M. Chen, “MagNet-AI: Neural Network as Datasheet for Magnetics Modeling and Material Recommendation,” in IEEE Transactions on Power Electronics, vol. 38, no. 12, pp. 15854-15869, Dec. 2023.
- **MagNet Challenge** – M. Chen et al., “MagNet Challenge for Data-Driven Power Magnetics Modeling,” in IEEE Open Journal of Power Electronics, accepted.

# Extended Reading – MagNet Challenge 2

- **iGSE** - K. Venkatachalam, C. R. Sullivan, T. Abdallah and H. Tacca, "Accurate prediction of ferrite core loss with nonsinusoidal waveforms using only Steinmetz parameters," Proc. IEEE Workshop Comput. Power Electron., pp. 36-41, 2002.
- **iGSE** - Matlab Implementation  
<https://www.mathworks.com/matlabcentral/fileexchange/39995-magnetic-core-loss-evaluation-for-arbitrary-flux-waveforms>
- **i2GSE** - J. Muhlethaler, J. Biela, J. W. Kolar and A. Ecklebe, "Improved Core-Loss Calculation for Magnetic Components Employed in Power Electronic Systems," in IEEE Transactions on Power Electronics, vol. 27, no. 2, pp. 964-973, Feb. 2012.
- **iGSE-CD** - D. Menzi et al., "iGSE-CD—An Electric-/Displacement-Field Related Steinmetz Model for Class II Multilayer Ceramic Capacitors Under Low-Frequency Large-Signal Excitation," in IEEE Open Journal of Power Electronics, vol. 4, pp. 107-116, 2023.
- **Stenglein Model** - E. Stenglein and T. Dürbaum, "Core Loss Model for Arbitrary Excitations With DC Bias Covering a Wide Frequency Range," in IEEE Trans. on Magnetics, vol. 57, no. 6, pp. 1-10, June 2021.
- **IGCC** - T. Guillod, J. S. Lee, H. Li, S. Wang, M. Chen, C. R. Sullivan, "Calculation of Ferrite Core Losses with Arbitrary Waveforms Using the Composite Waveform Hypothesis," IEEE Applied Power Electronics Conference (APEC), 2023.
- **MagNetX Models** - S. Wang, H. Kwon, H. Li, et al. "MagNetX: Foundation Neural Network Models for Simulating Power Magnetics in Transient," TechRxiv. December 11, 2024.
- **MagNetX Database** - H. Kwon, S. Wang, H. Li, et al. "MagNetX: Extending the MagNet Database for Modeling Power Magnetics in Transient," TechRxiv. December 11, 2024.