The Building Energy Smart Technologies (BEST) Center

An Industry-University Cooperative Research Center

https://best-iucrc.org/

University of Colorado Boulder

NSF

The City College of New York

The BEST Center is operated using the NSF model for **Industry-University Cooperative Research Centers (IUCRCs)**:

Long-term partnerships are developed among **industry**, **universities**, and **government agencies**

Funds are provided by **NSF** to cover the **operation** and **management costs**

Industry advisory board (IAB) member fees fund **research**, **education**, and **training activities**

https://iucrc.nsf.gov/

BEST Center Mission

The BEST Center seeks to advance energy systems for buildings, cities, and grids to be intelligent, resilient, and efficient.

Research Themes, 2023-2024

Smart Building Materials & Systems

Integrated Energy Generation & Storage Systems

Building Retrofit Applications

Smart Building Energy Systems

Smart Grid Systems

Status of the BEST Center

- NSF IUCRC Phase I Period: 8/1/2021-7/31/2026

- Two university sites: CU Boulder and CCNY

  - Partner site: University at Albany

- Website: https://best-iucrc.org/

- IAB Members: 5 Full, 2 Associate, and 4 Affiliates

- Funded projects typically last one year, beginning in August

  - IAB members are assigned to each funded project to review scope of work and build collaborative relationships with students and faculty

- Two IAB meetings are held per year for center coordination

  - Monthly IAB meetings are held virtually

Fall: IAB Meeting
Faculty & IAB establish annual research topics

Winter: Proposal Preparation
Faculty prepare proposals
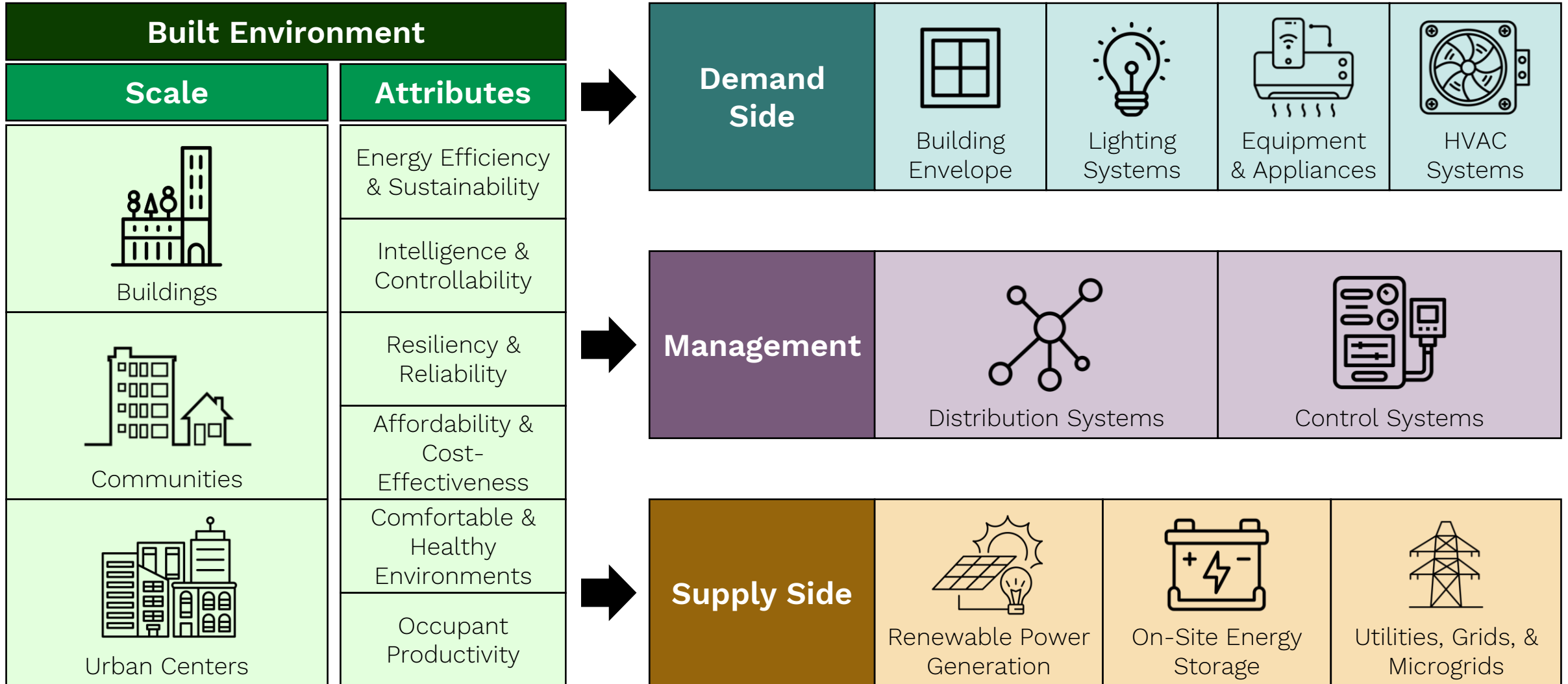
IAB reviews proposals

Spring: IAB Meeting
Faculty/students present proposals & research results

IAB makes funding recommendations

Summer: Research Funding Awarded
Funding is awarded to funded project PIs & research projects start

Scope of BEST Center Projects

Built Environment

Scale	Attributes
Buildings	Energy Efficiency & Sustainability
Communities	Intelligence & Controllability
	Resiliency & Reliability
	Affordability & Cost-Effectiveness
Urban Centers	Comfortable & Healthy Environments
	Occupant Productivity

Demand Side
- Building Envelope
- Lighting Systems
- Equipment & Appliances
- HVAC Systems

Management
- Distribution Systems
- Control Systems

Supply Side
- Renewable Power Generation
- On-Site Energy Storage
- Utilities, Grids, & Microgrids

Research Themes, 2023-2024

Smart Building Materials & Systems
- Simple control systems for smart glazing
- Field-testing protocols for window performance, novel glazing technologies
- Evaluation of condensation risks of high-performance secondary windows
- Peak energy demand reduction for high-performance secondary windows

Smart Building Energy Systems
- Energy efficient and low-cost space heating and cooling systems
- Smart edge devices to control easy-to-install ventilation systems for retrofit applications
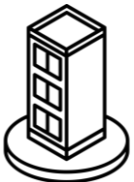- Simplified tools to optimize building shell retrofits and heat pump sizing
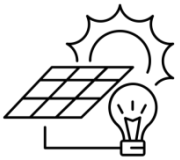
Integrated Energy Generation & Storage Systems
- Energy storage technologies as mitigating options electric peak demand
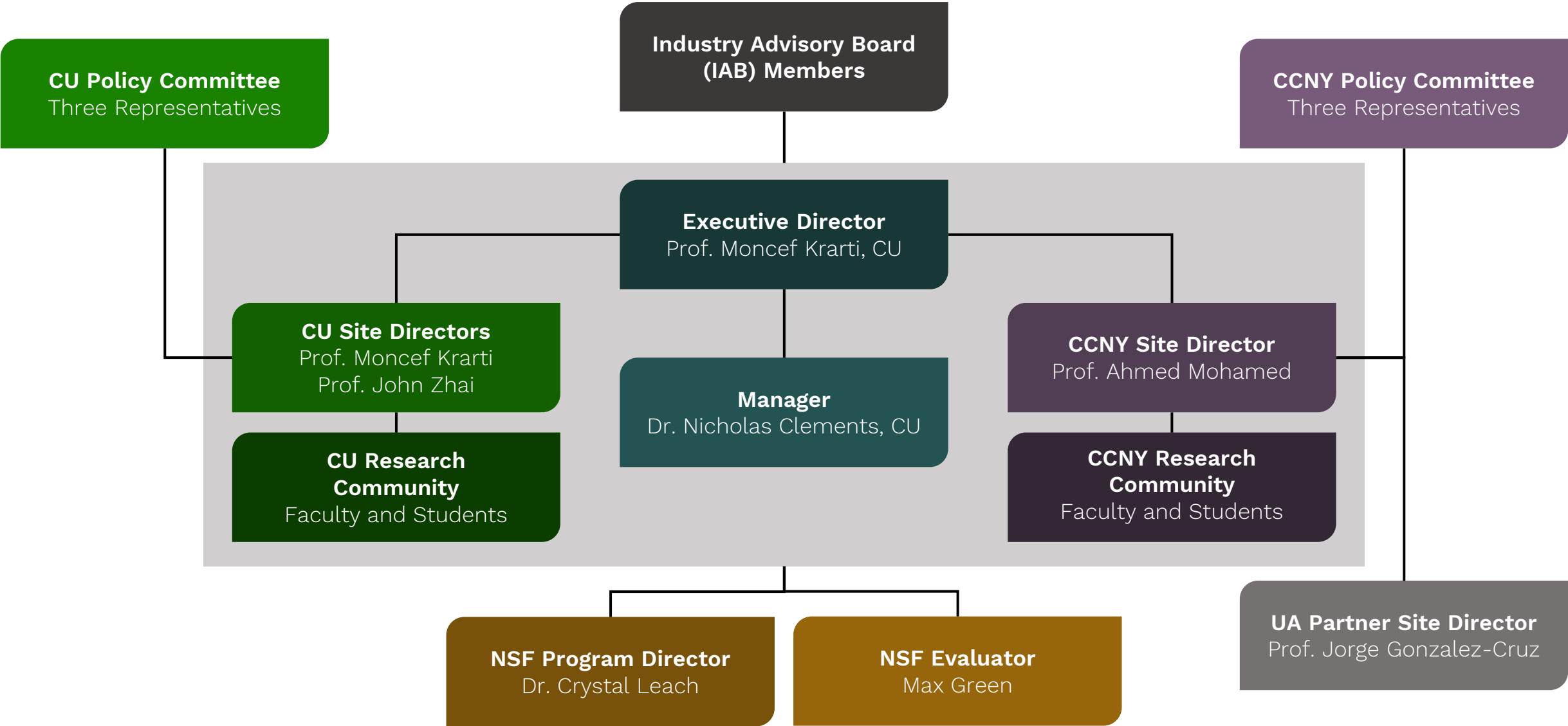- Materials and systems for transparent photovoltaics

Smart Grid Systems
- Peer-to-peer networks to model and operate resources in a grid
- Vehicle-to-home tools for optimizing residential self-sufficient energy systems

Building Retrofit Applications
- Simplified tools to optimize building shell retrofits and heat pump sizing
- Models for building energy systems suitable for performing measured and verification analyses
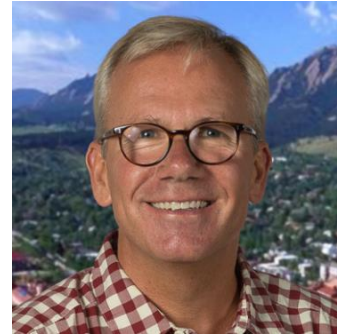
Organizational Structure

Industry Advisory Board (IAB) Members

CU Policy Committee
Three Representatives

CCNY Policy Committee
Three Representatives

Executive Director
Prof. Moncef Krarti, CU

CU Site Directors
Prof. Moncef Krarti
Prof. John Zhai

Manager
Dr. Nicholas Clements, CU

CCNY Site Director
Prof. Ahmed Mohamed

CU Research Community
Faculty and Students

CCNY Research Community
Faculty and Students

NSF Program Director
Dr. Crystal Leach

NSF Evaluator
Max Green

UA Partner Site Director
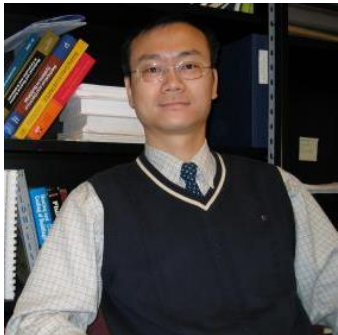Prof. Jorge Gonzalez-Cruz

CU Boulder Faculty

Prof. Moncef Krarti
- Building energy efficiency technologies
- Optimal design & retrofit of buildings
- HVAC & lighting controls
- Benefit analysis of large-scale energy efficiency programs
- Renewable energy system assessment

Prof. John Zhai
- Computational fluid dynamics in buildings
- Thermal comfort & indoor air quality
- HVAC systems & heat transfer
- Building vulnerability & safety
- Renewable energy & sustainable building design

Prof. Kyri Baker
- Power systems
- Smart grids
- Renewable energy
- Building-to-grid optimization
- Energy applications of machine learning

Prof. Gregor Henze
- Building-to-grid integration
- Model-based predictive control of building energy systems and thermal mass
- Model-based building performance benchmarking
- Zero energy buildings

Prof. Wil Srubar
- Biomimetic and living materials science & engineering
- Alternative cement & concrete materials
- Embodied carbon of materials & structures

Prof. Michael McGehee
- Perovskite solar cells
- Dynamic windows with adjustable tinting
- Organic LEDs and light extracting LEDs
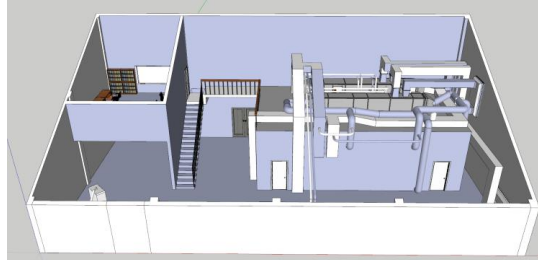- Light trapping in solar cells

CU Boulder Research Capabilities

Larson Lab
(Clements, Zhai, Krarti)

- HVAC system optimization
- Healthcare ventilation design
- Novel building design and envelope benchtop testing
- Air quality control testing
- Larson Lab Website

Building & Electrical Systems Modeling
(Henze, Baker, Zhai, Krarti)

- Machine learning (ML) for energy systems and renewables
- ML-based predictive control and building energy optimization
- Computational fluid dynamics
- Baker Lab Website
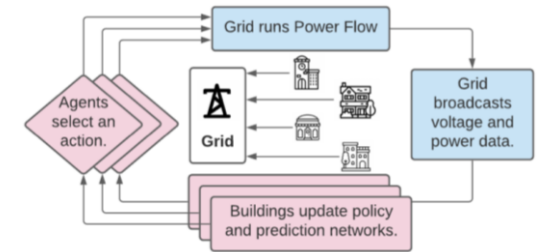
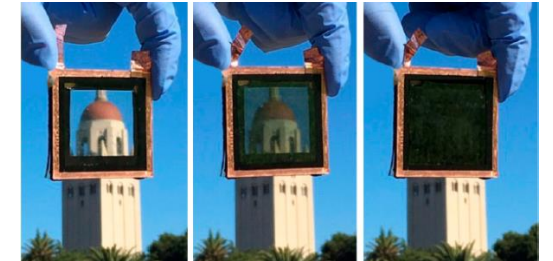## Lighting Lab
(Vasconez, Scheib)

- Dynamic ceiling
- Goniophotometer
- Illumination measurement equipment
- Lighting Lab Website

Solar Cells & Dynamic Windows Lab
(McGehee)

- Perovskite solar cell material properties and efficiency measurements
- Dynamic window tint material properties and design
- McGehee Lab Website

Living Materials Lab
(Srubar)

- Integrates biology with cement chemistry to create sustainable, biomimetic, and living materials
- Structural measurements in lab
- Embodied carbon modeling
- LML Lab Website

Renewable & Sustainable Energy Institute
(RASEI, Baker, Henze, McGehee, Krarti)

- Joint institute between CU and NREL
- Grid innovation research
- Nanoscience for energy capture and conversion
- RASEI Website

RENEWABLE AND SUSTAINABLE ENERGY INSTITUTE

CCNY Faculty

Prof. Ahmed Mohamed
- Power and energy systems
- Smart grids
- Critical infrastructure interdependencies
- Microgrids
- Transportation electrification

Prof. Jorge Gonzalez-Cruz
- Urban energy sustainability
- Urban weather and climate
- Urban remote sensing
- Regional climate modeling and analysis

Prof. Prathap Ramamurthy
- Biosphere-atmosphere interactions over complex terrains
- Boundary layer meteorology
- Urbanization, sustainability and climate change

Dr. Mark Arend
- Lidar and atmospheric modeling systems
- Weather forecasts related to energy usage and energy production in urban regions
- WeatherWatt building energy usage modeling

CUNY Building Performance Lab

Honey Berk
- Executive Director, Building Performance Lab

Michael Bobker
- Director, Building Performance Lab

Duncan Prahl
- Senior Applied Research Scientist, Director Technical Services

CCNY Research Capabilities

Building Performance Lab (BPL)
(Berk, Prahl, Bobker)

- DCAS Energy Data Lab, collaboration to research NYC energy management
- Validated measurement and verification program for energy efficiency and greenhouse gas reduction activities
- Building optimization support and technical services for quantifying energy savings and producing training materials for NYC personnel
- Application development for energy analytics and diagnostics tools (BEMA, BASAT, VII Calculator, AIRC)
- BPL Website

Coastal Urban Environmental Research Group
(Gonzalez-Cruz)

- Observational and modeling research of complex coastal urban areas and their impacts on climate modification
- Integrates the Regional Atmospheric Modeling System (RAMS), Weather Research and Forecasting (WRF) models with building energy models, urban land use data/models, and satellite data
- Social-technical modeling framework for improving resiliency of critical infrastructure for island communities in the event of extreme weather
- CUERG Website

Smart Grid Interdependencies Lab
(Mohamed)

- Interdependent critical infrastructure network modeling for grid resilience
- Smart distribution grid integration with regenerative electric rail braking energy
- Microgrid communication-based control scheme modeling
- Food-water-energy nexus data and modeling framework
- SGIL Website

Advanced Science Research Center

- Promotes interdisciplinary research in five disciplines: env. sciences, nanoscience, neuroscience, photonics, and structural biology
- Next Generation Environmental Sensor Lab (NGENS) with reference instruments for atmospheric gases, particulate matter, noise, and thermal imaging
- Design and fabrication of instrumentation and tools
- Community sensor lab
- ASRC Website

IAB Role in BEST Center Operations

- Assist in the strategic planning of the center
- Voting members (full and associate members) recommend funded research projects during spring IAB meeting
- Monitor progress and execution of funded projects
- Identify industrial internship opportunities
- Help recruiting new IAB members
- Assist in mentoring students and enhance educational activities
- Additional details are specified in center bylaws

IAB Chair, 2023-2024
Sachin Nehete
Rheem

IAB Vice Chair, 2023-2024
Silvia Khurrum
ConEdison

Industry Advisory Board
Membership Levels and Benefits

Full Membership
1. $50,000/yr
2. 1 Vote for Project Funding
3. Royalty-Free IP Access
4. Access to shared research products

Associate Membership
1. $25,000/yr
2. 0.5 Vote for Project Funding
3. Royalty-Free IP Access
4. Access to shared research products

Affiliate Membership
1. <$25,000/yr
2. No Vote for Project Funding
3. No Royalty-Free IP Access
4. Access to shared research products

- Members of all levels attend the semiannual IAB meetings to provide input on research topics and propose case studies
- Overhead of ≤10% is applied to membership fees that are solely used for supporting student-led research
- Members receive bimonthly newsletters containing center updates, project updates, and industry news
- Affiliate Members can establish blocks in their vertical and become Full/Associate Block Leads
- Membership Block leads assist with recruiting/retention and coordination for meetings for their block

Industry Partner Benefits

Recruiting	Research & Development	Networking & Training
Streamline access to students trained in industry verticals	Leverage NSF funds to conduct high risk projects	Stay informed about the state-of-art in smart building technologies
Contribute to BEST center research and education programs as mentors and/or thesis committee members	Access state-of-the-art facilities and research capabilities to develop products and conduct independent testing	Collaborate and interact with other industry partners
Host undergraduate and graduate students as interns	Have non-exclusive rights to the entire BEST center shared research portfolio	Develop custom-made training sessions for employees and provide training to faculty and students

Student Recruiting

All IAB membership levels include additional support from BEST Center staff for student recruiting efforts, including:

Access to an annual resume book of undergraduate and graduate students at CU and CCNY

Advising and recruiting students working on BEST Center-funded projects

Reduced price for booths at career fairs

Coordination of guest lectures and lesson plans related to your company's work with faculty

Industry Advisory Board Members

Full Members

Associate Members

Affiliate Members

Current Industry Advisory Board Verticals

Utilities
Xcel (Full)
ConEdison (Full)

HVAC & Thermal Systems
Rheem (Full)

Windows
Cardinal (Full)
Alpen (Associate)

Municipalities
NYCDCAS (Full)
City of Boulder (Affiliate)

Consulting
RMH Group (Affiliate)
Group14 (Affiliate)

Controls & Sensors
Belimo (Associate)
PassiveLogic (Affiliate)

Target Industry Advisory Board Verticals

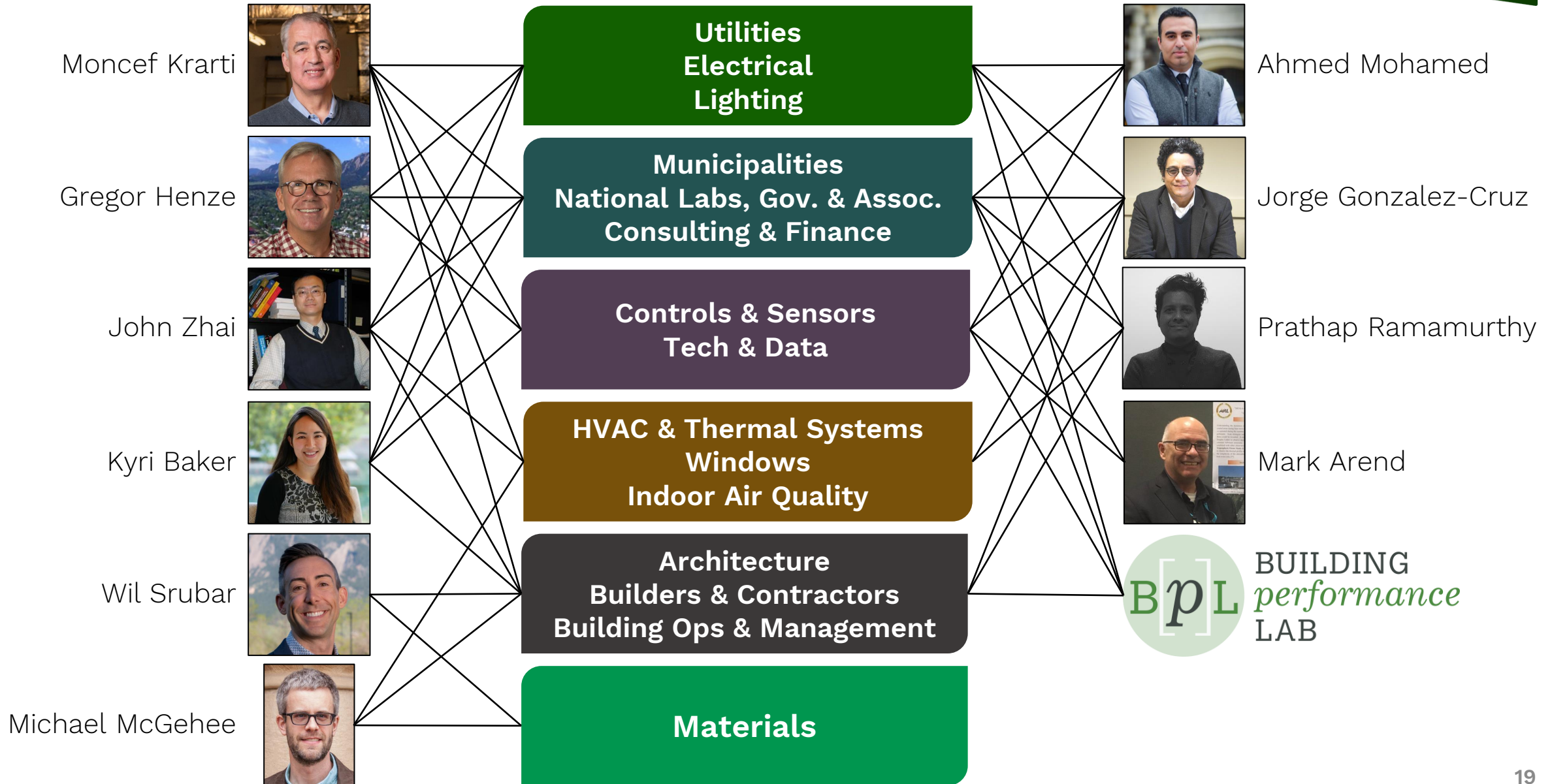|				
Utilities	**HVAC & Thermal Systems**	**Windows**	**Municipalities**	**Controls & Sensors**
Electrical	**Consulting & Finance**	**Lighting**	**Builders & Contractors**	**Materials**
Tech & Data	**Architecture**	**Indoor Air Quality**	**Building Operators & Managers**	**National Labs, Government, & Associations**

# Alignment of Industry-Faculty Research Interests

Funded Research, 2022-2023

1. Evaluation of Field Methods for Assessment of Architectural Window Degradation
PIs: Zhai (CU), Tenent (NREL)

- Assess effectiveness of window thermal measurement techniques and theoretical window deterioration mechanisms
- Relate window durability and thermal performance
- Analyze whole building annual energy implication of window deterioration
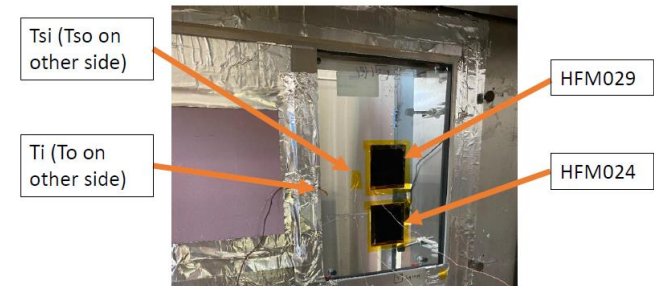
2. Integrated and Smart Controls for Combined Heat Pump and Domestic Water Heater for Residential Buildings
PIs: Krarti, Baker (CU), Jin (NREL)

- Develop a platform for simultaneously designing and controlling heat pumps and water heaters with and without rooftop photovoltaic systems and batteries to enhance energy efficiency and demand response capabilities of electrified residential buildings
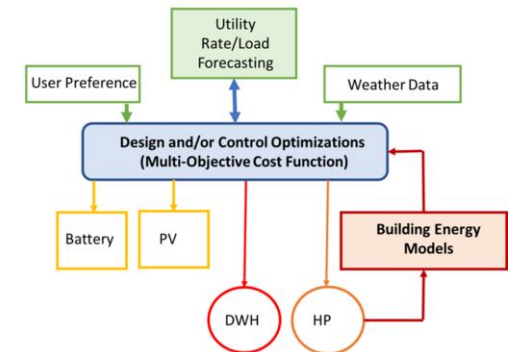
3. Energy-Reduction M&V using Calibrated Simulation (IPMVP Option D)
PIs: Berk, Prahl (CCNY)

- Generate and calibrate BEMs in automated/semi-automated fashion using building data collected for energy audits or other purposes (e.g., geometry, system info, operation schedules, property attributes)
- Produce and evaluate a prototype BEM workflow for a large portfolio of municipal buildings
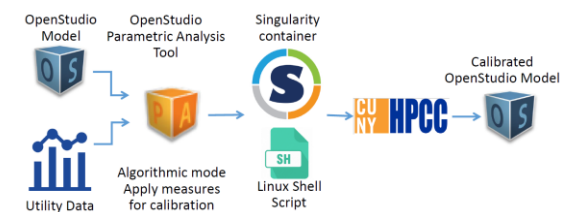
Funded Research, 2022-2023

4. Cost-Effective Way to Forecast Energy use at Building to City Scale using Real-Time Satellite Data
PI: Ramamurthy (CCNY)

- Predict/forecast energy use at multiple scales by exploiting the relationship between urban landcover/land use, urban heat island effect, and building energy consumption
- Couple satellite-derived storage heat flux data to past climate runs to develop an AI/ML based model to predict urban energy consumption
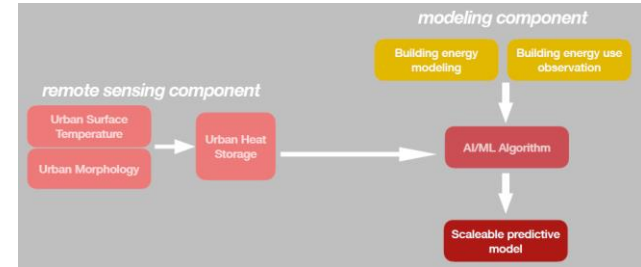
5. Flexible Insulated Panels for Retrofitting Existing Building Envelopes
PIs: Krarti, Roudbari (CU)

- Review literature to understand US market for prefabricated panelized systems for residential deep energy retrofits
- Perform energy modeling to determine optimal design for exterior insulated retrofit wall panels
- Develop a design suitable for retrofit applications
- Construct and test a prototype for an insulated panel

6. Making Reinforcement Learning Practical for Building Control using Surrogate Models
PI: Gregor Henze (CU)

- Use recently completed Advanced Control Test Bed (ACTB) with high fidelity building models that simulate physics and dynamics necessary for controls design and assessment at both supervisory and local loop levels
- Explore techniques that make RL practical and scalable to realistic building scenarios and use of surrogate models and develop recommendations
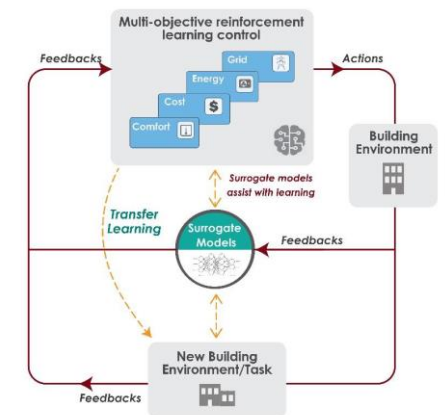
Funded Research Proposals, 2023-2024

Sustainable Air Source Heat Pump Systems for Electrified Transition Markets in the Multi-Family Buildings Sector

- PIs: González-Cruz (AU/CCNY), Ramamurthy (CCNY)
- IAB Collaborators: Rheem, ConEdison, City of Boulder

Development of an Automated Electrification Retrofit Analysis Tool

- PIs: Krarti, Zarske (CU), Prahl (CCNY)
- IAB Collaborators: Belimo, Xcel Energy, City of Boulder

Evaluation of Field Methods for Assessment of Architectural Window Degradation

- PIs: Zhai (CU), Tenent (NREL)
- IAB Collaborators: Cardinal, Alpen

Evaluation of Hygrothermal and Energy Efficiency and Condensation Risk of Secondary Windows

- PIs: Zhai, Krarti (CU), Tenent, Kiatreungwattana (NREL)
- IAB Collaborators: Cardinal, Alpen

Testing and Evaluation of Thermal Energy Storage Panels Integrated with Heat Pumps

- PIs: Krarti (CU), Kishore (NREL)
- IAB Collaborators: Xcel Energy, Belimo, ConEdison

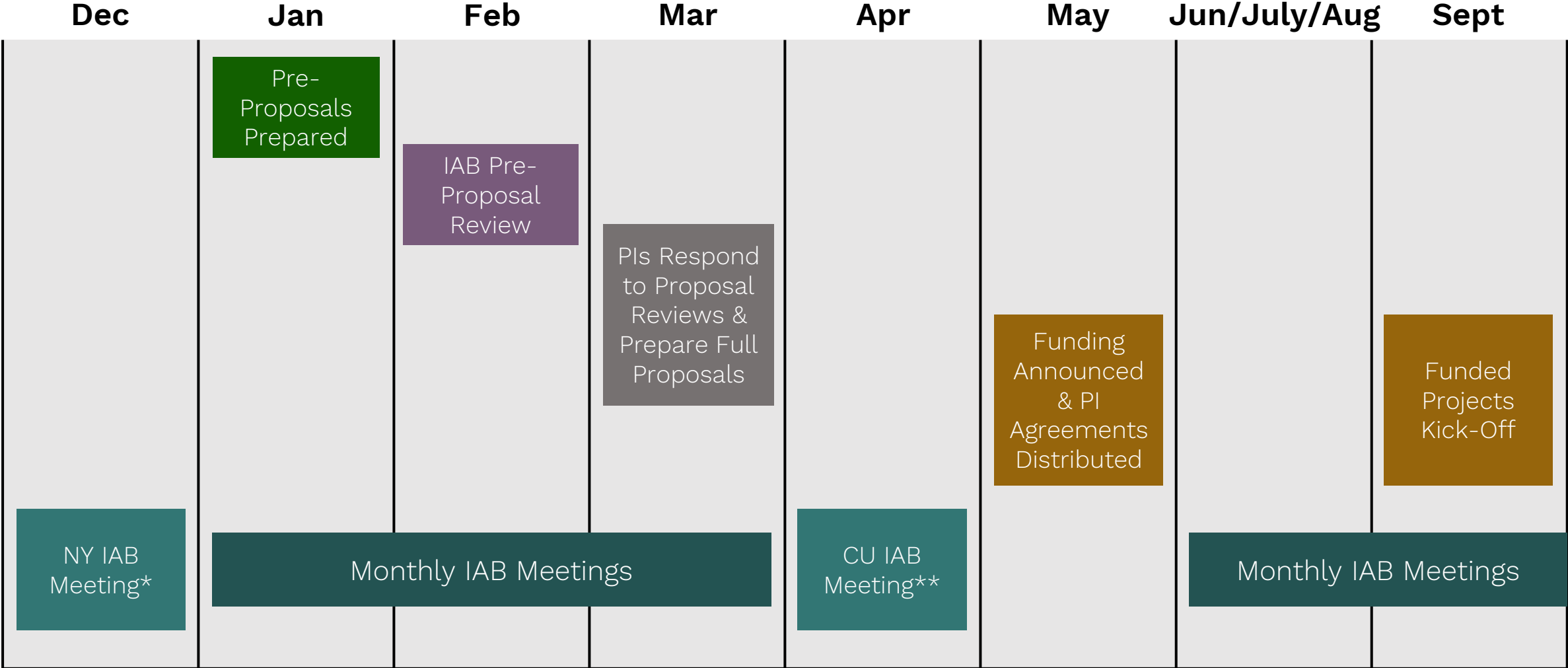## Making Reinforcement Learning Practical for Building Control through Human Feedback

- PI: Gregor Henze (CU)
- IAB Collaborators: Belimo

Research Theme Planning, 2024-2025

May	June	July	Aug	Sept	Oct	Nov	Dec

Monthly IAB Meetings: Presentations from Faculty on Topics of Interest

Bimonthly BEST Center Newsletters Highlight Research Progress and Industry News

2023-2024 Research Projects w/ IAB Advisers

Informal Brainstorming Sessions: Faculty and Aligned Industry Members

Monthly IAB Meetings

NY IAB Meeting*

* 2024-2025 Research Themes voted on during NY IAB meeting

Research Proposal Funding, 2024-2025

Dec	Jan	Feb	Mar	Apr	May	Jun/July/Aug	Sept
	Pre-Proposals Prepared	IAB Pre-Proposal Review	PIs Respond to Proposal Reviews & Prepare Full Proposals		Funding Announced & PI Agreements Distributed		Funded Projects Kick-Off
NY IAB Meeting*	Monthly IAB Meetings			CU IAB Meeting**		Monthly IAB Meetings	

* 2024-2025 Research Themes voted on during NY IAB meeting
** 2024-2025 Proposals presented and funded projects voted on during CU IAB meeting

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University of Colorado **Boulder**

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