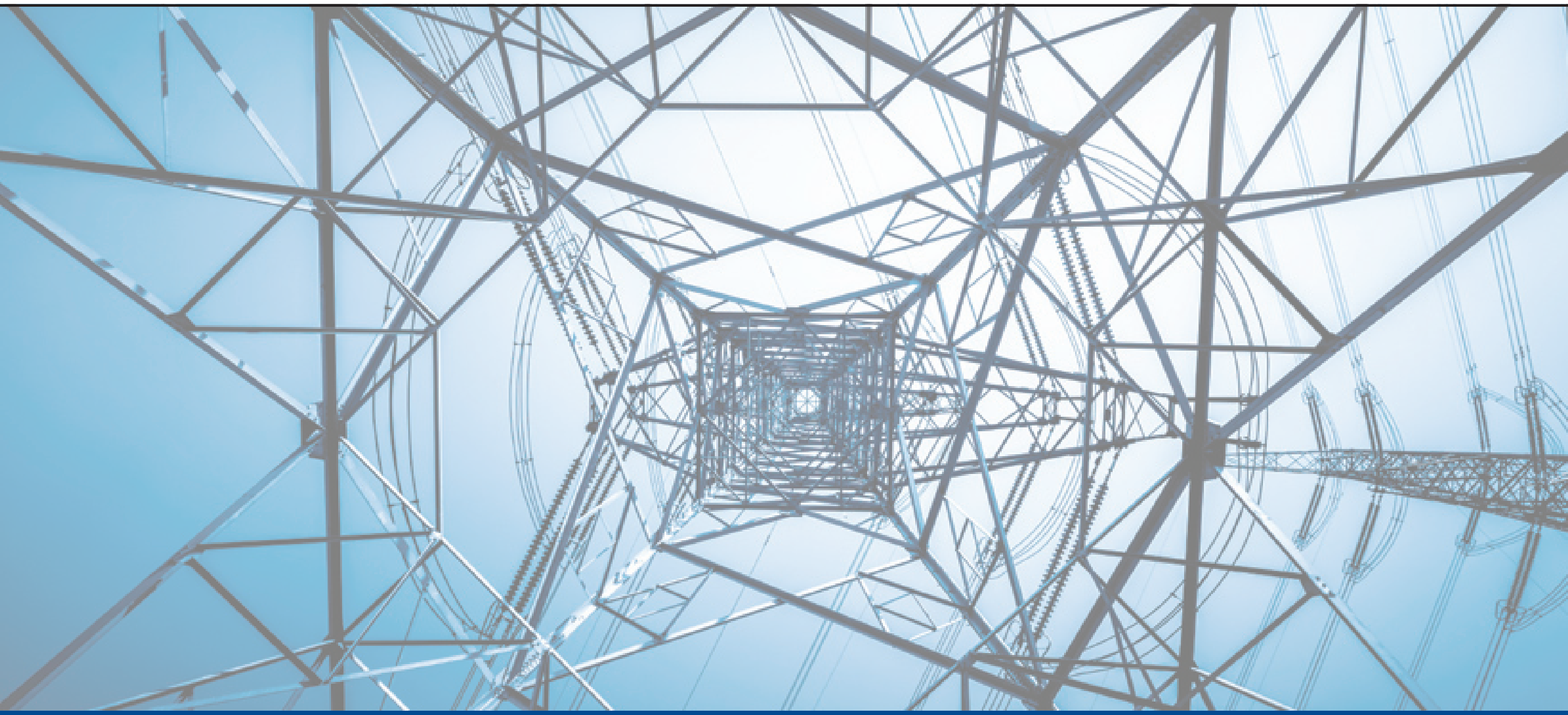
THE MIT Utility of the Future STUDY



Prospectus for an Interdisciplinary MIT Energy Initiative Consortium

This research study seeks to determine the defining characteristics of the electric utility of 2025, identifying successful business models, regulatory trends, and transformative technologies.

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The Team

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Professor Christopher R. Knittel

Christopher Knittel is the William Barton Rogers Professor of Energy Economics in the Sloan School of Management and the Director of the Center for Energy and Environmental Policy Research at the Massachusetts Institute of Technology. He joined the faculty at MIT in 2011. Professor Knittel received his BA in economics and political science from the California State University, Stanislaus in 1994, an MA in economics from UC Davis in 1996, and a PhD in economics from UC Berkeley in 1999. His research focuses on environmental economics, industrial organization, and applied econometrics. He is a Research Associate at the National Bureau of Economic Research in the Productivity, Industrial Organization, and Energy and Environmental Economics groups.

Professor Richard Lester

Professor Richard Lester is Japan Steel Industry Professor and Head of the Department of Nuclear Science and Engineering at the Massachusetts Institute of Technology, where he is also the faculty co-chair and founding Director of the MIT Industrial Performance Center. His research focuses on innovation management and policy, with an emphasis on the energy and manufacturing sectors. As director of the Industrial Performance Center, Dr. Lester has led several major studies of national and regional competitiveness and innovation performance commissioned by governments and industrial groups around the world. In the Local Innovation Systems Project, he directed a study about the technological transformation of industries in regional economies and the role of universities in that process. He currently serves as faculty advisor to the MIT President's Council on Regional Engagement.

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Overview

The MIT Energy Initiative (MITEI) has a long history of identifying research topics that lend themselves to a consortium approach. Such topics benefit from aggregating a diverse set of perspectives on a set of critical issues facing the industry at large. This "commons" approach benefits all of the partners, while enabling each member to individually benefit from an increased understanding of the unique implications to their organization.

The Utility of the Future brings together a diverse consortium of leading international companies to address emerging issues in the electric power sector, and provides a neutral framework within which to evaluate the economic, regulatory, and technological impacts of the ongoing evolution of the power sector world-wide. The study team from MIT and IIT-Comillas combines a breadth of skills in quantitative economic and engineering modeling, with a sophisticated understanding of the complex interactions in the electric power industry. The team includes faculty with decades of experience in advising governments, corporations, and institutions on regulation and market design. The consortium partners — industrial and other market participants — bring valuable real-world expertise and experience to the study.

The electric power sector is poised for transformative change. Improvements in the cost and performance of a range of **distributed energy generation** (DG) technologies and the potential for breakthroughs in **distributed energy storage** (DS) are creating new options for on-site power generation and storage, driving increasing adoption and impacting utility distribution system operations. In addition, **changing uses and use patterns for electricity** — from plug-in **electric vehicles** (EV) to **demand response** (DR) — are altering demands on the electric power system. Finally, the infusion of new **information and communications technology** (ICT) into the electric system and its markets is enabling the collection of immense volumes of data on power sector operations and use; unprecedented control of generation, networks, and loads; and new opportunities for the delivery of energy services.

The combination of ICTs and various **distributed energy resources** (DER) — including DG, DS, EVs, and DR — will allow the creation and proliferation of new **distributed energy systems** (DES), from microgrids and virtual power plants to remotely aggregated controllable loads and smart charging systems for EV fleets. DESs are systems combining one or more DERs, including DG, DS, and/or demand response, with ICTs. These DESs will spawn a range of new **business models** capable of providing value to end-use energy consumers and upstream electricity market actors alike. The nature and penetration of these business models will be heavily influenced by policy and regulation, and the combination of novel DESs, regulation, and business models will shape the utilities of the future.

Approach, Key Questions, and Outcomes

The Utility of the Future, an interdisciplinary MITEI consortium, will seek to answer the question: what will be the defining characteristics of the electric utility of 2025?

This fundamental question encompasses many sub-questions and areas of research. In particular, **The *Utility of the Future* will develop and analyze scenarios of DES technologies, business models, and regulatory environments to understand how the electricity system will change over the coming decade.** This analysis will include identifying potential business models that may emerge and identifying the factors — policy, regulatory, economic, financial, or technical — that will drive a model's success or failure. The potential for these business models to disrupt or complement the activities of incumbent utilities will be assessed. Opportunities for incumbent utilities and new market actors — including those from sectors ranging from natural gas and transportation to ITC and buildings — to capitalize on these changes will be highlighted. Furthermore, scenarios will consider the development of DESs under a range of public policy and regulatory frameworks. **The study will analyze the ability of current policy and regulation to provide a neutral playing field for all existing and emerging technologies and business models and, where necessary, will propose new regulatory schemes and policy paradigms.** *The Utility of the Future* team will utilize existing analytical tools and relevant literature and develop new models where needed to address the questions posed above.

In a style that is the hallmark of MITEI's *Future of…* series, *The Utility of the Future* will be a benchmark academic study of the evolving electric power sector. The study will identify and assess candidate technologies and business models and evaluate their impact from a systems perspective. Plausible visions of the electric utility sector of the future will be developed. Finally, the study will provide findings and actionable recommendations for various market actors and stakeholders in an industry undergoing dramatic change, including incumbent utilities, regulators, policy makers, the private sector, and electricity consumers.

RESEARCH QUESTIONS

The following questions will be central to defining the characteristics of the utility industry of 2025:

- What new business models will succeed in the electric power industry of the future?
- What factors — be they technological, economic regulatory, or otherwise — will determine the magnitude of the impact or the penetration rates of the identified business models and technologies?
- How will the identified business models complement or compete with the services provided by the incumbent utilities and other incumbent market actors?
- How must regulatory frameworks evolve to allow for an economically and environmentally sustainable electric power industry to develop?
- How can other sectors (i.e., gas, ICT, buildings, transportation, etc.) influence, be affected by, or participate in the transformation that is underway in the electric power industry?
- What is the range of plausible scenarios for the evolution of the electric power system in the United States, Europe, and elsewhere?

EXPECTED OUTCOMES

The Utility of the Future will:

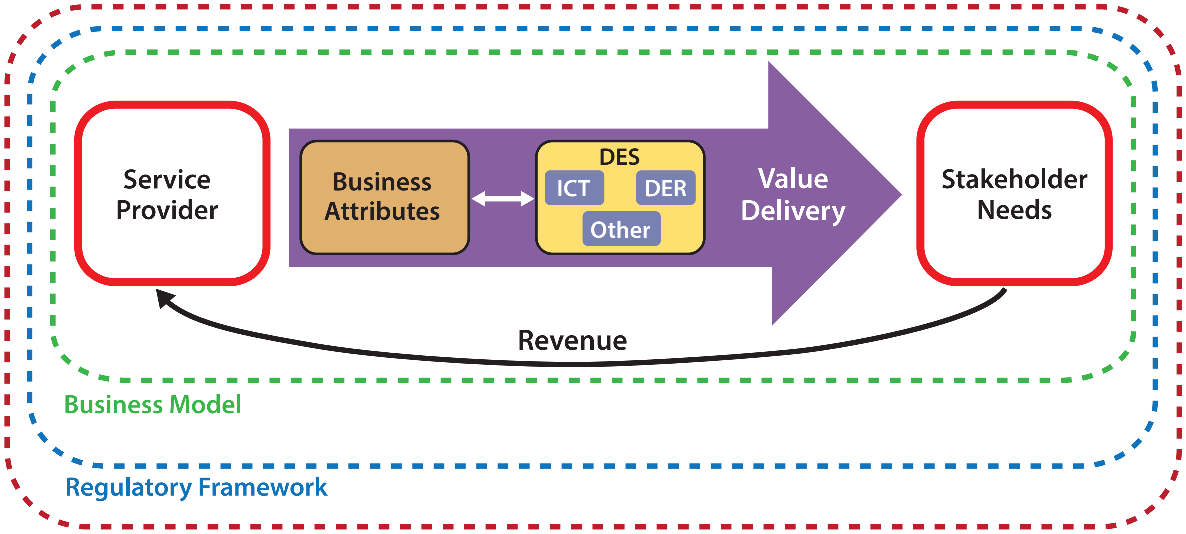
- Identify and assess the characteristics and magnitude of the impact of candidate DES technologies and business models on the system, new and incumbent market actors, and policy and regulatory decision makers.
- Identify the impact of current regulation on the development of the electric power system and suggest improvements to existing regulation as well as novel regulatory frameworks.
- Develop and present multiple plausible scenarios for the electric power system of the future.
- Provide findings and actionable recommendations for incumbent utilities, new market entrants, regulators, policy makers, the private sector, and consumers.

Conceptual Framework – System of Systems

A hallmark of *The Utility of the Future* study is an integrated systems view of the electric power sector. Analysis of the technologies driving change in the power sector, emergent business models, and key regulatory questions will culminate into holistic assessment of systems-level scenarios. These scenarios will capture the complex interactions between the multiple components of the power system to enhance our understanding of the plausible shape of the next decade's electric utility sector.

In order to evaluate the roles of and interactions between the diverse sets of stakeholders in the power system, we take a **system of systems** approach as illustrated in Figure 1 on page 4. DESs comprised of DERs and ICTs are integrated with business models to deliver value to stakeholders. These transactions of value between system agents take place within a regulatory framework. The regulatory framework, in turn, is a component of the broader socio-technical system called "the electric power system," which is characterized by a range of possible technological, economic, geographic, and political contexts. From bottom-up assessments of each subsystem of the power sector, we will build a set of scenarios of future power systems and a set of possible visions of the utility of the future.

Figure 1 A System of Systems Perspective



Structure and Methodology

The Utility of the Future research initiative can be split into four distinct layers as shown in Figure 2 on page 6: (1) candidates and tools; (2) evaluation; (3) implications; and (4) outcomes. While each layer has a unique thrust and focus, they are all interrelated. The final outcome of one layer is critical to the development and completion of the next. The four layers of the study each touch upon various parts of the research questions posed in the "Approach, Key Questions, and Outcomes" section of this prospectus. The primary thrust of each layer is described below.

LAYER 1: CANDIDATES AND TOOLS

1. Identify and classify new value propositions stemming from DES business models and their component technologies.

    - Screen energy industry news sources to understand and summarize state of play and potential future developments.
    - Scan MIT and IIT research activities and knowledge base for evidence of cutting-edge developments.
    - Consider "game changing" technologies, including "leapfrogging" in emerging economies.

2. Develop and adapt analytical models for simulation, optimization, and techno-economic-regulatory evaluation of DES business models and systems interaction effects.

   - Candidate models include Reference Network Models, Optimization Models (DER-CAM), Optimal Power Flow models, and others.

3. Characterize key features of existing regulatory frameworks and develop novel regulatory proposals that will allow for the development of an environmentally and economically sustainable electric power system.

LAYER 2: EVALUATION

4. Perform technical, economic, and regulatory assessment of candidate business models and system interaction effects using the inputs from Layer 1.

   - Employ analytical tools identified and developed in Layer 1 to evaluate candidate value propositions.
   - Develop "test systems" representative of a broad range of system/regulatory/market conditions in the United States, Europe, and elsewhere.
   - Use the output of the models to identify and inform new regulations and business models to analyze.

LAYER 3: IMPLICATIONS

5. Analyze the direct challenges to the status quo for system operators, regulators, markets, industry structure, and new market actors.

6. Analyze how the power sector will be influenced by other key interacting sectors, including natural gas, transportation, ITCs, buildings, etc.

7. Propose alternative strategies for incumbent utilities and other major players in the evolving market.

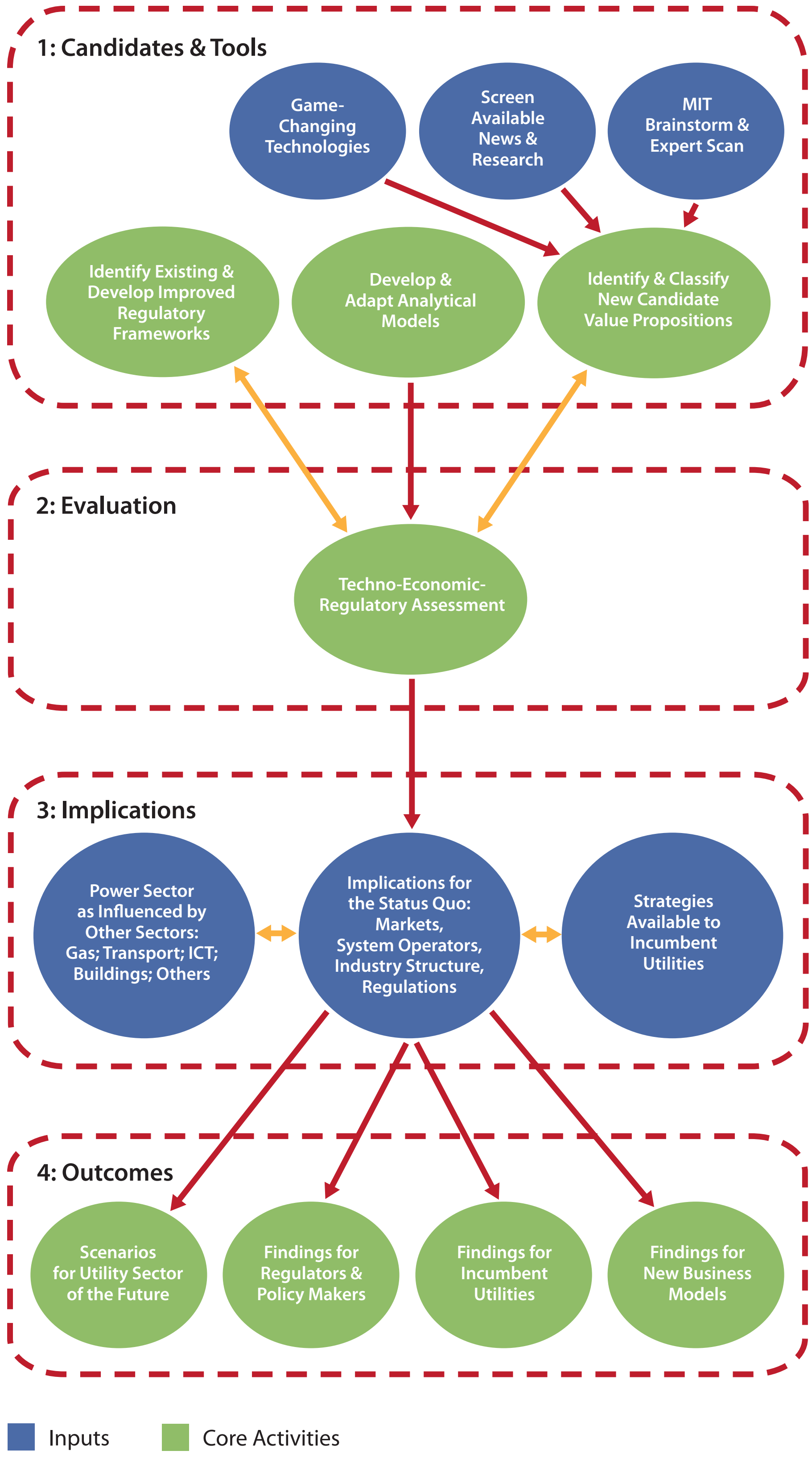
   - Analyze strengths, weaknesses, opportunities and threats for key market actors.

LAYER 4: OUTCOMES

8. Synthesize and report the findings for incumbent utilities and other major market players, new DES-related business models, and regulators and policy makers.

9. Develop and present detailed scenarios that capture the range of likely outcomes of the utility sector of the future.

Figure 2 ***The Utility of the Future*** **Study Structure**



Initial Framing

In preparation for this consortium study, the MIT team has performed an initial assessment of technologies, business models, and regulatory issues that will underpin the analysis to be undertaken by this two-year research effort. The outcome of this initial assessment is summarized below.

Technology Assessment

Improvements in the performance and cost characteristics of DERs — including DG, DS, and DR — underpin the potential for the growth of DESs. Innovation in information and communication technologies — such as advanced sensing and control devices and communication protocols — are also critical to transforming the electricity distribution sector into a more adaptive, responsive system.

What is a Distributed Energy System?

A DES system combines one or more DERs, including DG, DS, and/or DR, with ICTs to enable a business model that provides valued services to energy end users or upstream electricity market actors. Such systems will be distributed throughout the electricity distribution network and adjacent customer properties in a number of different topologies (see Figure 3). Some DESs will be owned or operated by traditional regulated distribution utilities while others will be owned, managed, and operated by end-use electricity consumers and/or by third parties operating in competitive market environments. DESs may enable the provision of a variety of different services, from end-use energy services such as lighting, heating, and cooling to upstream electricity market services such as capacity or ancillary services. DESs can be further described with the three-layer framework illustrated in Figure 4 on page 8.

Figure 3 Illustrative DES Topologies

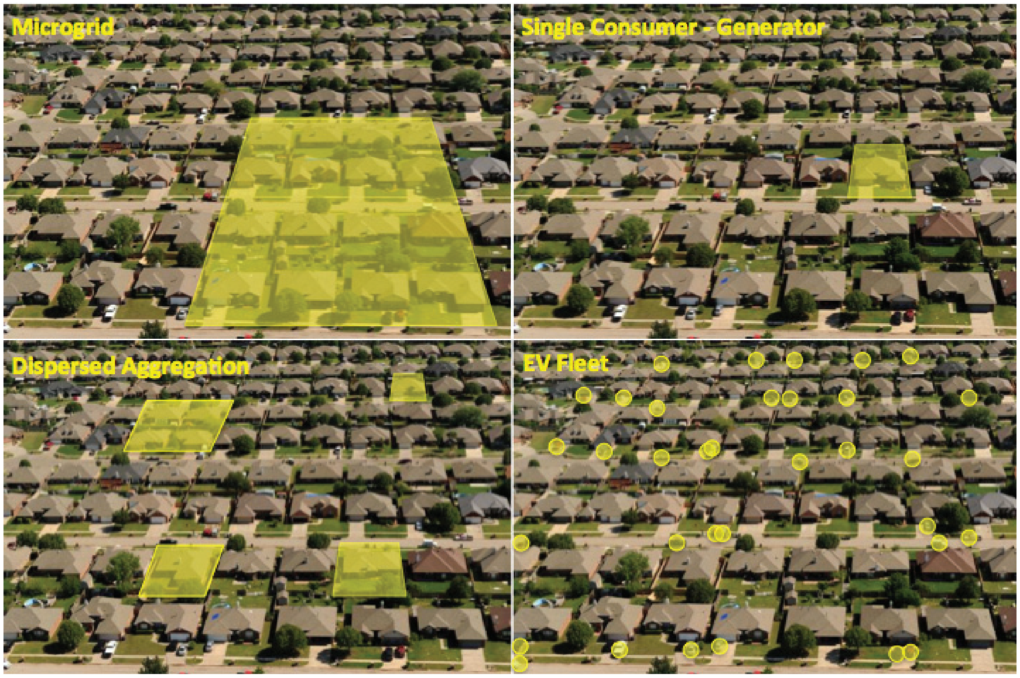
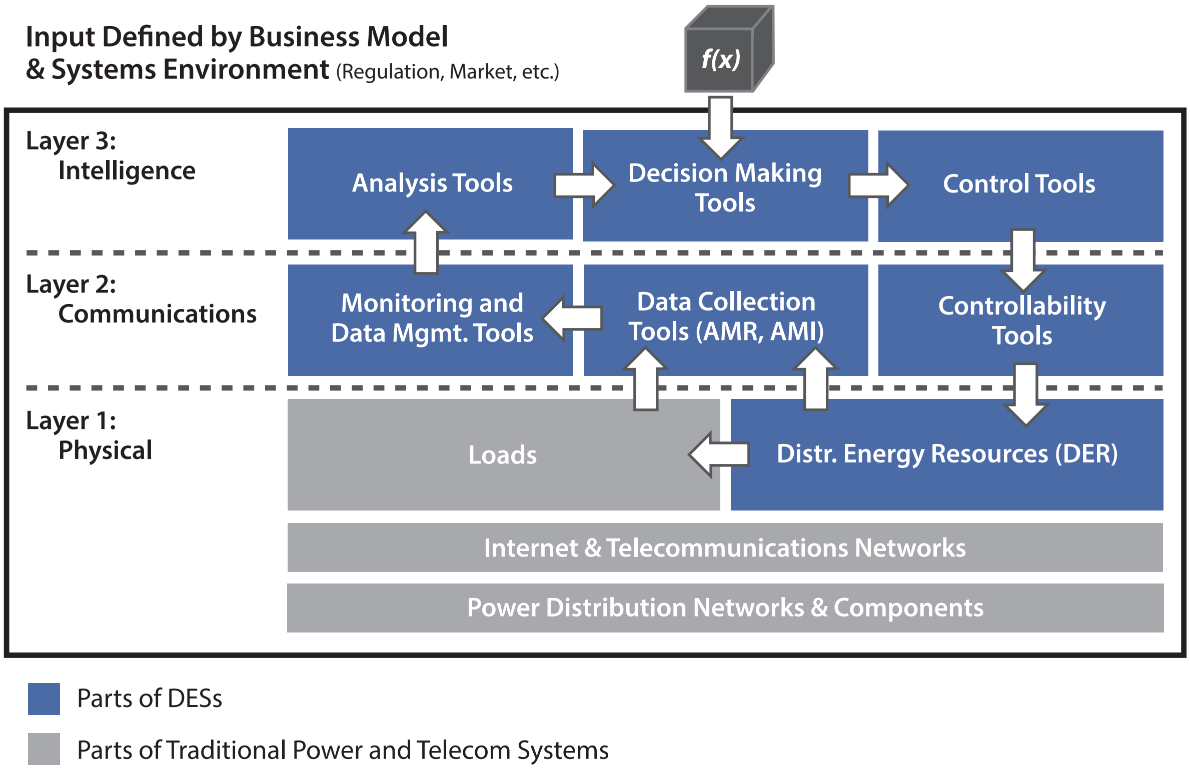


Figure 4 Technology Building Blocks of DESs

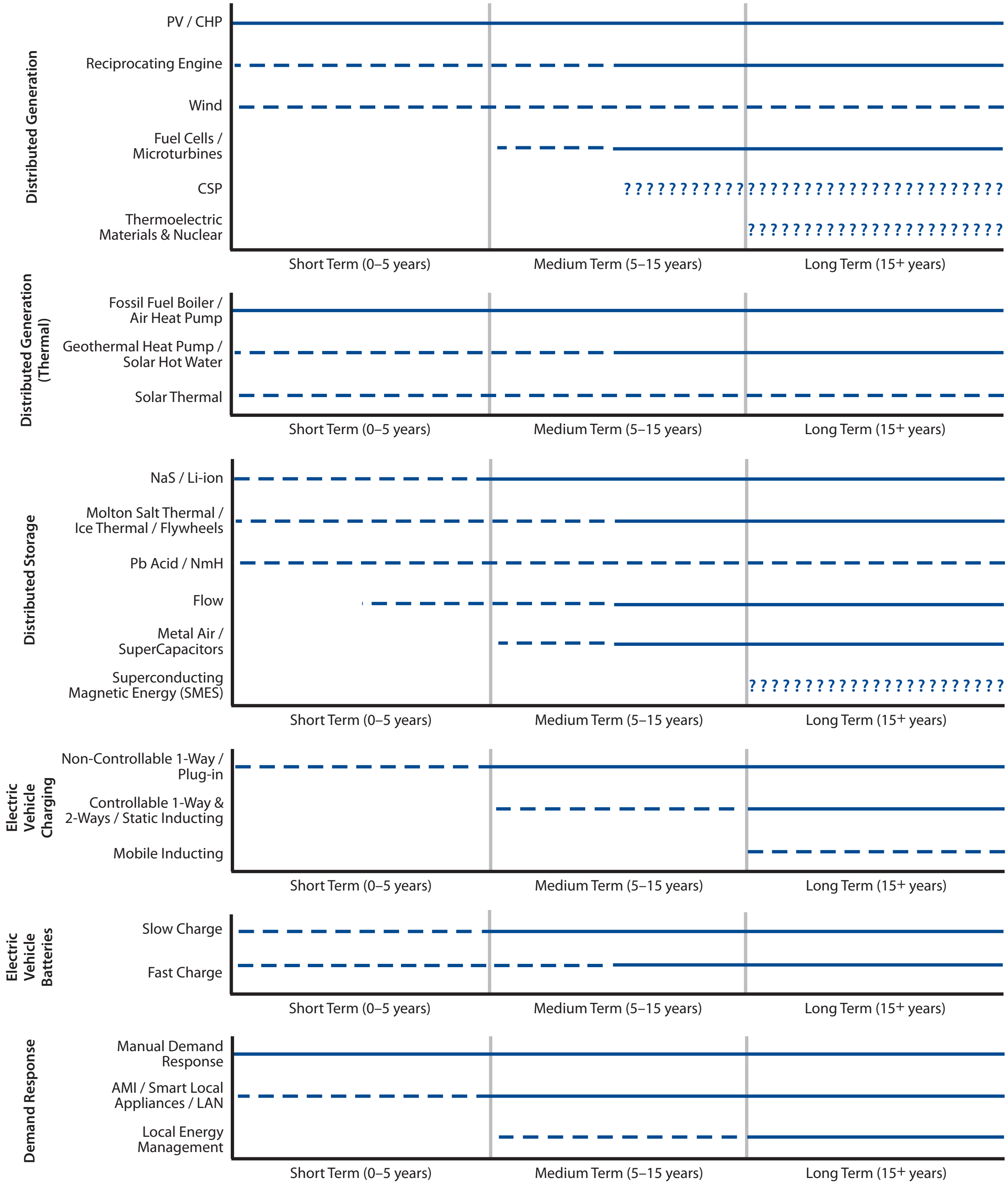


Distributed Energy Resources: a "Disruptive Threat"?

The first step toward evaluating potential futures that may emerge for electric utilities is identifying and understanding the technologies likely to play a significant role in the evolution of the electric power sector. This includes both technologies likely to drive the shift toward a more distributed paradigm and technologies likely to emerge in response to new needs created by regulatory or business model evolution in the power sector, such as the need for increased system flexibility in response to the increasing penetration of intermittent renewables.

Figure 5 depicts an initial qualitative assessment of the potential for key DER technologies to prove disruptive to power system operations, business models, and regulation. Within each technology category, the prospective impact of DERs is indicated with a solid or dashed line in the short, medium, and long terms. Solid lines indicate high impact and thus greater potential for disruptiveness and dashed lines indicate lower impact and thus limited disruptiveness. Question marks indicate insufficient data to determine the likely impact at this time.

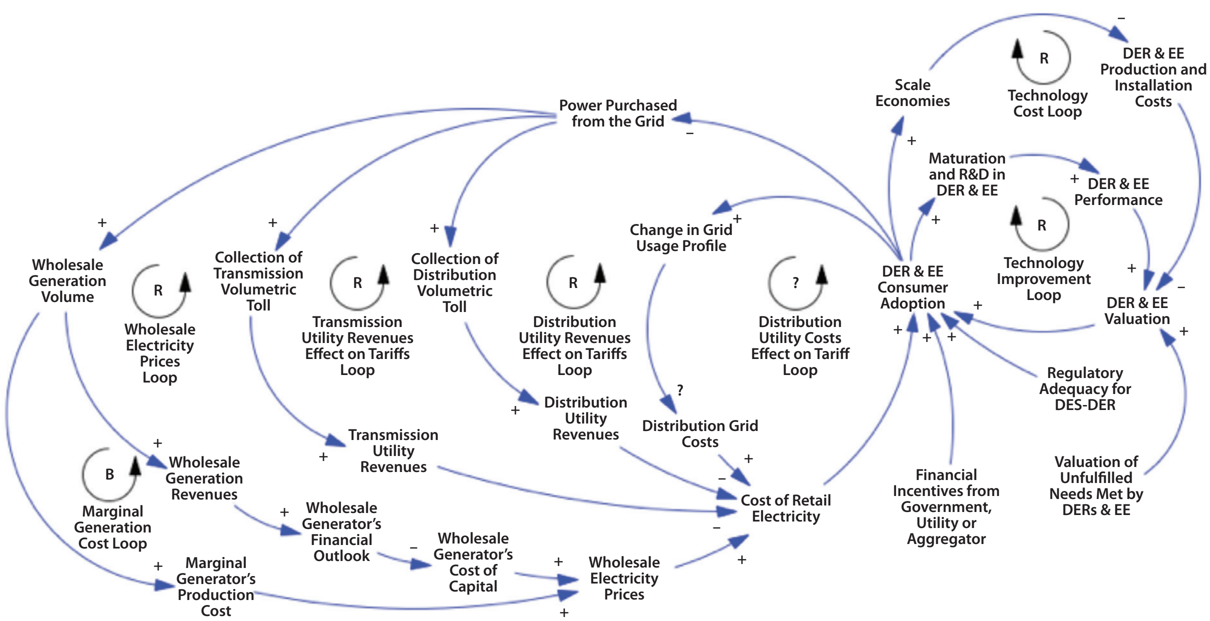
Figure 5 Projected Potential for Disruptiveness of Key DES Component Technologies



Faced with the wide range of emerging DERs cataloged here, many electric utilities and industry observers have worried that these new technology trends will prove massively disruptive to the age-old utility business model. Analogies have been drawn to the deregulation of the airline industries or the overthrow of the landline telephone business by wireless cellular technology. **Some observers predict a "death spiral" that could see DER adoption become a self-reinforcing cycle that decimates the incumbent utility's core business.** In this cycle, improvement in the price and performance of DERs (and end-use energy efficiency) spurs customer adoption, which reduces utility revenues. Reduced revenues then require a rate increase to cover the utility's fixed costs. Higher rates in turn drive even more adoption of DERs and efficiency.

The growing use of DERs clearly represents a paradigm shift in the operation of the electric power sector. Business models and regulation of incumbent utilities will both need to evolve to keep pace with the changing nature of network uses and end-use customer needs. At the same time, the system dynamics or feedback loops associated with adoption of a DER are much more nuanced and complicated than the simple "death spiral" described above (see Figure 6). **Our research indicates that, while a self-reinforcing feedback loop for DER adoption is *possible*, it is *not* pre-ordained. Careful examination and analysis of the potential system dynamics at play as DER adoption increases will be essential to determine the ultimate impact on incumbent distribution utilities and others across the value chain.**

Figure 6 System Dynamics of DER Adoption



Business Models

The business models of electric utilities have co-evolved over more than a century alongside a changing regulatory environment. Over the last two decades, an era of industry and regulatory restructuring saw electric utilities evolve from protected franchise electricity suppliers to a diverse blend of regulated integrated utilities, monopoly network companies, and competitive generators, retailers, and other service providers. Today, the growth of DESs is further accelerating business model innovation in the power sector, as incumbents evolve and new entrants emerge to respond to and take advantage of the new characteristics and services offered by these systems.

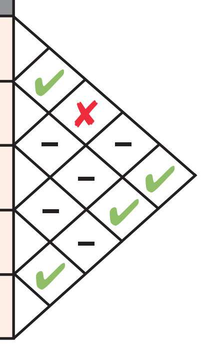
In order to understand the potential business models that might arise in the evolving electricity sector, we present a framework that helps explore and understand the logic of business models and identify the most suitable business opportunities in the context of DESs. Based on the economic activities that exist in electric power systems, **we have defined five core "attributes" of DES-related business models.** At the highest level, the attributes of the business model can be characterized by the primary activities of the business. Specifically, the business may:

- **Own** assets;
- **Operate** assets and/or systems of assets;
- **Fund** the acquisition or the operation of assets;
- **Provide information** and related services to asset owners or operators; or
- **Build** or manufacture assets.

The matrix shown in Figure 7 illustrates the multiple DER-related business opportunities (horizontal axis) that would be best suited to a given business model attribute, as well as the core business attributes (vertical axis) that are most commonly linked together in specific business models (the half matrix on the right-hand side). Within the matrix, a green check in a cell indicates a *likely* DES opportunity for a business

Figure 7 Core DES Business Model Attributes and Associated Opportunities

Technologies (DES) / Business Models Attributes	Distributed Generation	Distributed Storage	Electric Vehicle Infrastructure	Demand Response	Information and Communic. Technologies	Technologies (DES) / Business Models Attributes
Own	✔	✔	✔	✘	?	Own
Operate	✔	✔	✔	✔	✔	Operate
Fund	✔	✔	✔	✘	✘	Fund
Provide Information	✔	✔	✔	✔	✘	Provide Information
Build	✔	✔	✔	?	✔	Build



model characterized by a specific attribute. A red "X" in a cell indicates an *unlikely* opportunity for a business model structured around a given attribute. A black question mark indicates a possible but not particularly strong opportunity. The green check on the half matrix on the right side identifies pairs of business model attributes that have high potential for synergy as opposed to those with a black "–" that are neutral or to those with a red "X" that are judged to conflict.

This business model framework can be applied to decompose, understand, and characterize real-world examples of existing DES-related business models (see Figure 8) as well as prospective new business models that might arise to accompany various DESs (see Figure 9).

Figure 8 DES Business Model Attributes: EnerNOC (Real-World Demand Response)

Technologies (DES) / Business Models Attributes	Distributed Generation	Distributed Storage	Electric Vehicle Infrastructure	Demand Response	Information and Communic. Technologies	Technologies (DES) / Business Models Attributes
Own	✔	✔	✔	✘	?	Own
Operate	✔	✔	✔	✔	✔	Operate
Fund	✔	✔	✔	✘	✘	Fund
Provide Information	✔	✔	✔	✔	✘	Provide Information
Build	✔	✔	✔	?	✔	Build

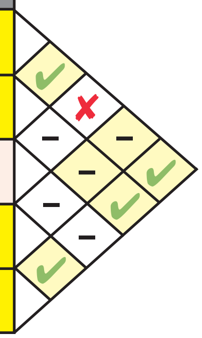
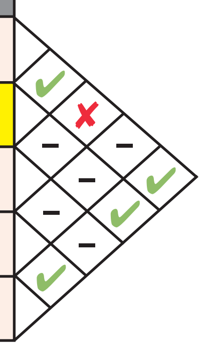


Figure 9 DES Business Model Attributes: Hypothetical Institutional Microgrid

Technologies (DES) / Business Models Attributes	Distributed Generation	Distributed Storage	Electric Vehicle Infrastructure	Demand Response	Information and Communic. Technologies	Technologies (DES) / Business Models Attributes
Own	✔	✔	✔	✘	?	Own
Operate	✔	✔	✔	✔	✔	Operate
Fund	✔	✔	✔	✘	✘	Fund
Provide Information	✔	✔	✔	✔	✘	Provide Information
Build	✔	✔	✔	?	✔	Build



Emerging DESs may give birth to a range of new business models. Many of these DES business models will be active in competitive, unregulated markets. These models may represent either new opportunities or new competitors for non-regulated utility businesses, including generators, retailers, and energy services companies. But what will the growth of DESs entail for the business model of the regulated distribution utility?

As the utility business landscape rapidly evolves, the challenge for incumbent utilities is to find innovative ways to retain the value proposition of their assets while capturing the opportunities presented by new DESs and their component technologies. The business model for the regulated network utility of the future is likely to be quite different than today.

In particular, the regulated distribution utility business model of the future will need to:

- Find a way to turn DER from a threat into an opportunity — e.g., as a new source of network use charges and as a tool to improve system operation efficiencies or reliability;
- Master new and evolving technologies;
- Become more customer-facing and respond adroitly to evolving customer needs and uses of the system;
- Develop new products and services that deliver value to network users and utility stakeholders; and
- Comply efficiently with a changing regulatory and policy environment.

Regulatory Issues

The regulation of the electric power sector has historically co-evolved with the underlying technical and economic characteristics of the electricity system. Today, a new era of technological innovation, in particular at the distribution network level, requires a corresponding anticipative response of the regulatory institutions.

In particular, regulation of distribution utilities must be proactively assessed (Figure 10 on page 14) and, whenever appropriate, reformed in order to:

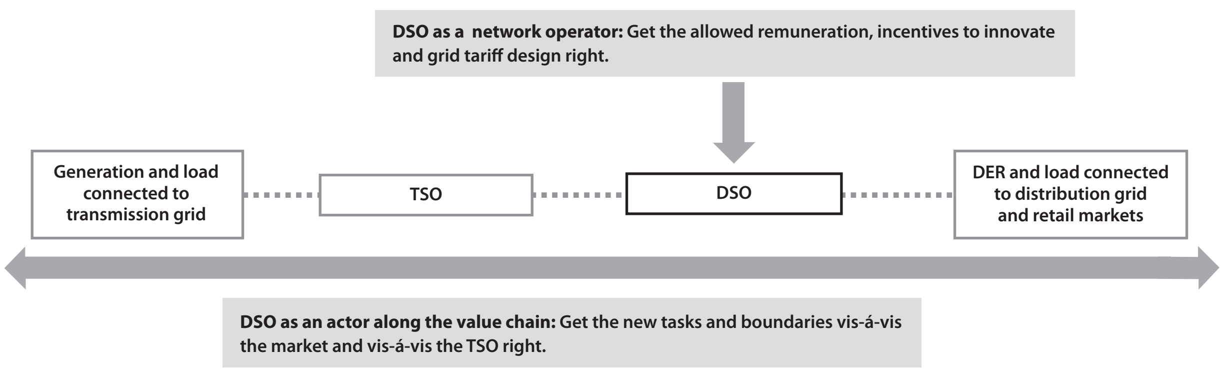
1. **Enable the utility to more rapidly evolve to meet the changing needs of network users.** This requires updating remuneration schemes for regulated distribution utilities to better align the incentives facing the utility and enable the evolution of the utility's business model. Distribution utilities must be adequately compensated for investments required to accommodate new DERs and DESs and incentivized to make efficient use of these same resources to improve system reliability, reduce losses, and defray unnecessary capital expenditures. Incentives to innovate may also be considered to allow distribution utilities to take on the long-term challenges of developing and adopting novel technologies and services necessary to accomplish their evolving role as a dynamic system operator.

2. **Provide efficient price signals for an increasingly diverse range of system users.** Regulators must rethink the design of network charges to ensure that allowed distribution costs are remunerated despite changing cost structures and that appropriate price signals incentivize the efficient location and use of new DERs. Network tariffs should provide incentives for network users to evolve business models and practices that add value to the system and prevent users from arbitraging weaknesses in market or regulatory design.

3. **Define the proper industry structure and responsibilities of the distribution utility.** The roles and responsibilities of distribution utilities are very diverse in restructured power sectors around the world. As a general rule — to be adapted to each particular situation — transparency requirements regarding commercial data availability and switching procedures should be adopted, and the functions assigned to the network operator and the level of separation with other activities must be revisited.

4. **Clarify the ways in which the distribution utility will interact with adjacent market actors, including the Transmission System Operator (TSO), Distribution System Operator (DSO), and new DES businesses.** This also includes defining the way these market actors will interact and coordinate to dispatch DERs and DESs.

Figure 10 Relevant Areas of Regulatory Reform



Source: Pérez-Arriaga, Ruester, Schwenen, Batlle, and Glachant 2013.

Who Can Benefit from the Study?

Utilities that want to understand and develop actionable strategies to manage the opportunities and threats posed by the rapid changes facing the electric power industry, including their fundamental relationships to other market participants and industrial sectors.

Technology & Service Providers that want to enhance their understanding of new market opportunities and future customer needs with respect to the changing electric utility industry.

Electricity End Users that would like to benefit from new combinations of new distributed energy systems that can provide them with new services, lower-costs, and enhanced autonomy.

Regulators that seek to understand how to meet the changing needs of system users; define the proper industry structure and responsibilities of the distribution utility; and clarify the ways in which the distribution utility will interact with adjacent market actors, including the TSO and new DES businesses.

System Operators who can make use of services offered by multiple actors and must cope with a more uncertain environment, as well as estimate the impact of distributed energy systems on their businesses.

Policy Makers who desire to understand how changes in the power sector will influence policy objectives.

How to Join

The Utility of the Future at the MIT Energy Initiative is structured around the participation of corporate and institutional sponsors that participate in providing financial support as well as industry and business knowledge to the effort. The study is anticipated to be of a two-year duration beginning in the spring of 2014.

Corporate and institutional participation is available at two levels: Sponsors and Participants. All commitments are for a period of two years. Sponsors and Participants will each receive advance copies of written materials throughout the study period and will have the opportunity to provide feedback and submit written comments. MIT will retain editorial authority. Additionally, Sponsors and Participants will take part in interactive workshops where the findings will be presented and discussed among consortium members.

Sponsors ($125,000 per year for 2 years)

Sponsors are expected to be an integral part of *The Utility of the Future* study. Through their participation on the Advisory Committee, Sponsors will participate in shaping the research questions, scenario development, and the determination of critical issues and constraints. Sponsors will also be requested, where appropriate, to provide assistance in the research activity, mostly via technical information and discussions. They will be asked to appoint a single representative to serve on the Advisory Committee to the study.

Participants ($62,500 per year for 2 years)

Participants will be active members of the study. They will be asked to provide input and contribute to discussions through ongoing engagement, attendance at the workshops, and the opportunity to provide feedback.

Consortium Activities and Deliverables

Kick-off Call: One-on-one call with each new member to review scope and discuss key issues.

Bi-annual Workshops: One-day workshops for Sponsors and Participants focused on presentation and review of the latest study findings.

Bi-annual Advisory Committee Meetings: Half-day consortium Advisory Committee meeting for Sponsors to have the opportunity to shape the direction of the study.

Early Access to Report and Findings: Advanced access to report and findings allowing each member to provide input to the final report.

MITEI Fall Research Conference and Spring Symposium: All Members of *The Utility of the Future* consortium will be invited to participate in these invitation-only MITEI events.

***The Utility of the Future* Final Report:** The final study report will be a substantial multidisciplinary academic report in the tradition of MIT's *Future of…* series.

For additional information or to join the consortium please contact:

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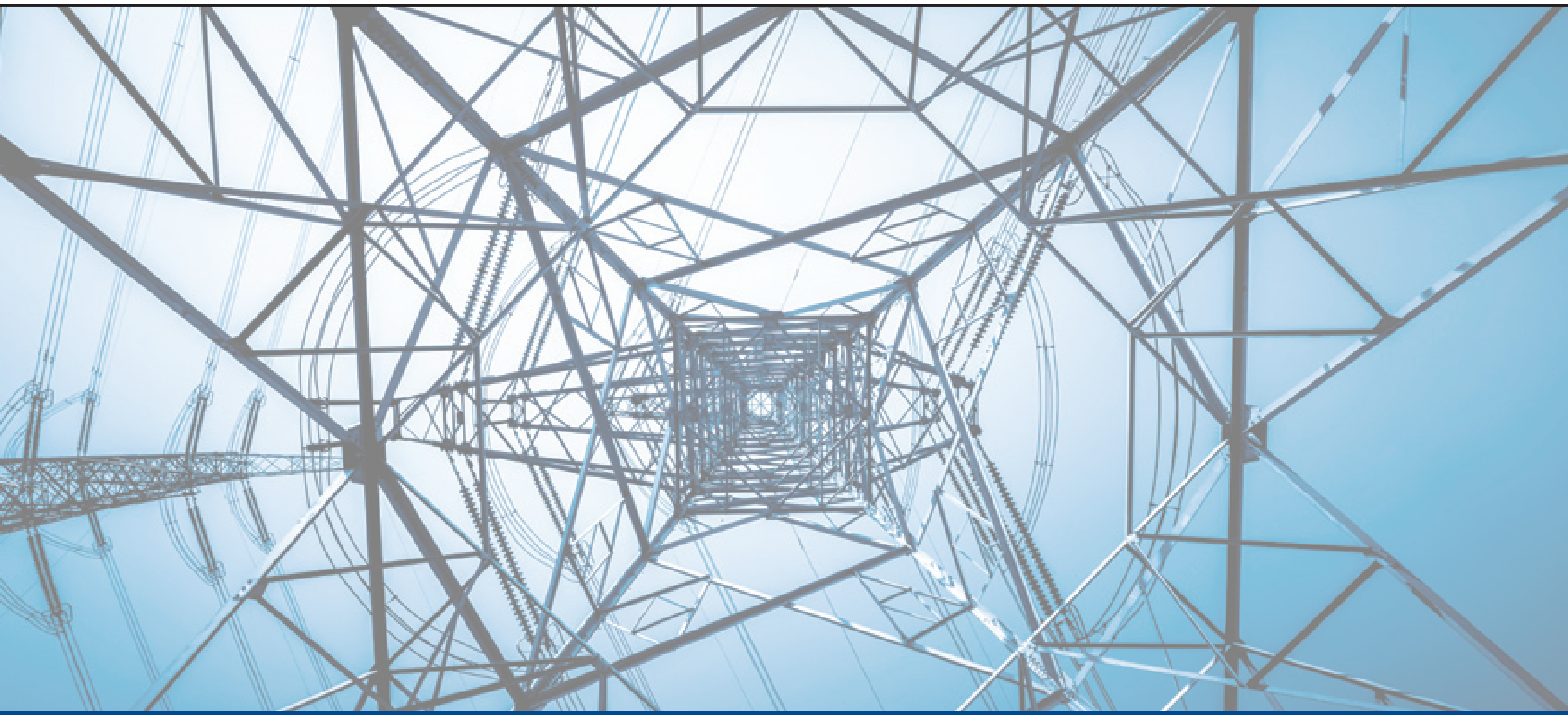
About the MIT Energy Initiative

MITEI works to help transform global energy systems. It is a research, education, and outreach program that, in its depth and breadth, is without peer at U.S. academic institutions. An Institute-wide initiative, MITEI pairs MIT's world-class research teams with key players across the innovation spectrum to help improve today's energy systems and shape tomorrow's global energy marketplace. It is also a resource for policy makers and the public, providing unbiased analysis and serving as an honest broker for industry and government.

MITEI has more than 68 industry and public partners and has funded more than 128 novel or early-stage energy research projects submitted by faculty from across MIT.

MITEI's educational offerings combine single-discipline depth with multidiscipline breadth, transforming the MIT campus into an energy learning laboratory. The Energy Studies Minor established in 2009 is the fifth largest minor at MIT.

The Utility of the Future brings together a diverse consortium of leading international companies to address emerging issues in the electric power sector, and provides a neutral framework within which to evaluate the economic, regulatory, and technological impacts of the ongoing evolution of the power sector worldwide. The study team from MIT and IIT-Comillas combines a breadth of skills in quantitative economic and engineering modeling, with a sophisticated understanding of the complex interactions in the electric power industry. The team includes faculty with decades of experience in advising governments, corporations, and institutions on regulation and market design. The consortium partners — industrial and other market participants — bring valuable real-world expertise and experience to the study.



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