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Validation of District Energy Systems for American Communities

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Validation of District Energy Systems for American Communities

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Task 2 – Evaluation of Existing Tools Provisioning for District Energy Systems

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EXECUTIVE SUMMARY

OVERVIEW

This project was established to meet the U.S. Department of Energy's Advanced Manufacturing Office requirements for advancing the case for district energy (DE) systems. It aims to identify distinct opportunities for accelerating adoption, integration, and deployment of DE systems and local energy economies (LEE). In particular, this project responds to a 2019 report to Congress,[1] with a scope of work comprising three project tasks, developed to identify the key next steps in advancing the case for across the U.S.:

1. **Literature review:** Identify the use and opportunities for expansion of DE systems and LEE.
2. **Tool evaluation:** Evaluate the use of existing tools, software, and resources in the development of DE systems through a literature search and engagement with relevant stakeholders.
3. **Advancement opportunities:** Further characterize the necessary features for establishing successful DE systems based on previous tasks, and identify additional analysis needs.

This report constitutes the research output and main deliverable for Task 2 (Tool evaluation). The project team evaluated the use of tools, software, and resources (referred to collectively as *tools* throughout this report) in the DE project development process. The **objectives of Task 2** were threefold: (1) determine to what extent existing tools meet the DE sector's needs, (2) identify gaps in provision of the appropriate tools, and (3) identify priority areas for future research that could further support the development and expansion of DE in the U.S.

METHOD AND PROCESS

To meet the three project objectives for Task 2 just described, the team completed the following activities:

- **Characterize the Project Development Process:** Leveraging published literature on the DE development process, we described the DE project development process and created a framework for characterizing and describing it. Table 1 summarizes this framework, from early DE concept development through project delivery and operations (including future extension and expansion of DE projects in the operational phase), associates each of these stages with key task areas and analytical needs and identifies which stakeholder groups are represented in each stage.

Stakeholder Engagement Legend		
	(white)	Not involved
	(light hatching)	Occasionally involved
	(medium hatching)	Often involved, as consultant or interested party
	(dense hatching)	Often involved, as lead or client
	(dark grey)	Always involved, as lead or client

	Major Tasks and Sub-Tasks	Stakeholders

[1] The U.S. Department of Energy's report to Congress titled, "Energy Efficiency and Energy Security Benefits of District Energy."

		Planning and Policy	Qualitative Screening	Mapping and Visualization	Energy Demand Assessments	Quantitative Screening	Energy Modeling	Hydraulic Analysis	Cost Assessment	Environmental Impact Analysis	Infrastructure Planning	Detailed Design	Economic Analysis	Business Pan Development	A&E Firm	Owner Operator	DE Developer	Municipality	Building Developer
Development Stages	Concept Development	X	X																
	Data Collection	X		X															
	Defining the Project	X	X	X	X														
	Options Appraisal	X		X	X	X	X		X		X		X						
	Feasibility Study				X	X	X	X	X	X	X	X	X						
	Financial Analysis				X				X		X	X	X	X					
	Business Planning								X				X	X					

Table 1 : Stages of Project Development, Major Tasks and Stakeholder Involvement

- **Illustrate utilization of tools during project development:** Based on knowledge of current DE sector practices and feedback from industry stakeholders, we identified and described types and examples of tools utilized within the project development process.

- **Understand DE sector needs:** We conducted 20 expert elicitations across 5 DE sector stakeholder groups (e.g., A&E firms, system owners/operators, DE system developers, local government planners, and building developers and owners). Discussions were structured around several key questions that reflect the project development framework. They included: commercially available tools currently utilized, tools developed internally based on need, challenges experienced during project development related to tools and resources, and new tools that may help address key challenges and barriers.

Through these activities, our objective was to understand the prevailing challenges in developing DE systems and identify where tools could be used to help overcome these challenges. DE development includes activities from early concept development through project construction and delivery. This includes challenges that are currently addressed in a non-systematic way, which consequently may be less rigorous, rather inefficient, or both.

To represent the DE sector feedback broadly, we developed and distributed a questionnaire that prioritized research topics identified from our expert discussions. The questionnaire was circulated to a large cohort of DE sector stakeholders through the International District Energy Association. We shared a web-based the questionnaire to 9,125 individuals and received 197 responses in total.

RESEARCH FINDINGS

Priorities for Research to Support DE

Four priority research areas were identified in this study - two that represent needs more broadly, and two that are specific to the DE sector.

For development of cost-effective and sustainable infrastructure generally:

1. Development of public datasets for GIS analysis. **This was the top ranked response for almost all stakeholder groups.**
2. Develop an integrated LCA framework and resource for projects.

DE sector-specific:

1. Create a high-level screening tool that supports pre-technical appraisal evaluation and early data analysis of potential projects
2. Create a DE optimization tool to account for thermal, electrical and economic objectives during technical appraisals.

Table 2 summarizes the top four ranked topics (ranked by questionnaire response count), the barriers addressed, and the research opportunity.

Table 2: Priorities for Future Research

Topic	**Barrier or Opportunity**	**Proposed Research Focus**
Graphical Information Systems (GIS) Datasets for DE Systems Potential Assessment	GIS datasets were identified as having significant value in evaluation of opportunities in terms of connecting sources of energy demand to locations of demand.	Suggested priorities include data on thermal energy demand at the building level, potential sources of local waste heat (such as wastewater treatment facilities identified in Task 1), and approved air permits (related to fuel combustion). This activity would be relevant to both implementation of new and expansion / modernization of existing DE systems.
High-level screening tool for technical appraisal and early data analysis	Decision-making tools that are simple to use and workable with limited data and/or information, are invaluable — the earlier that a field of options can be narrowed, the better.	A number of stakeholder groups referred to the need for screening tools as a valuable asset in DE system appraisal. Needs would vary according to intended user group(s), in terms of key objectives, inputs, outputs, and data analysis processes.
DE optimization tool to account for thermal, electrical and economic objectives during technical appraisals	System optimization is typically conducted at the detailed feasibility study stage via techno-economic analysis and then tweaked thereafter in the design or value engineering process thereafter. This process does not take into account financial or business priorities and may fail to capture the impact of decisions made after design completion.	Functionality that supports a user's ability to toggle between priorities and objectives in terms of technical and financial performance metrics, to achieve specific goal(s) is not currently available, to the best knowledge of project team stakeholders. This would be a valuable addition to the tool box in supporting iterative analysis and co-optimization.
LCA framework for technical appraisal and data analysis	LCA data and supporting assessment frameworks exist, but feedback suggests that users require signposting and guidance on how to best utilize these disparate services in a coordinated manner.	Consolidation of resources from current service providers (such as Athena Sustainable Materials Institute [ASMI], and GREET [Argonne National Lab]) into a single resource for streamlined decision-making.

Additional Research Opportunities
Structured questions in our expert elicitations were designed to identify and validate research topics based on user needs and tool gaps. Based on responses, the themes across questions, and direct response to the final question, "what are the perceived gaps in the tools market," we identified the following needs:

- A self-auditing tool for relating energy model inputs and outputs
- A multi-year utility price forecast, including uncertainty analysis
- Mathematical models to support the case for conversion of older legacy systems
- A tool to explore and evaluate interactions between heating, cooling, and electric loads
- A visualization tool linking sources and sinks
- A systematic process and method to assess the feasibility of district energy for developments / buildings under review as a part of their sustainability review process
- A process or method for modularizing DE systems

Characterization of the Project Development Process
The literature search focused on describing the process of DE system development and identifying tools used during each stage of that process, including early concept planning, construction, and detailed technical and financial appraisal of potential projects.

One major difference between early financial planning activities and tools such as techno-economic assessments conducted later in the project development process is the availability of reliable data (technical and non-technical). This has a direct impact on the degree to which tools may be of value. Tools that can appropriately represent uncertainty of outcomes, and appropriately reflect risks would be of significant value.

We found that tools were limited for early planning and development, at least in part, because a standard structure or accepted practice was not well documented or understood. We also suggest that tools available for early visualization and conceptualization were underutilized due to the same absence of an accepted structure or practice.

There are always multiple stakeholders involved in DE projects, all with responsibilities that reflect local norms and practices, resources and conditions (socio-economic, political and environmental). Therefore, we conclude that as there are myriad considerations and challenges associated with getting a project implemented, tools should be developed primarily with the subject matter experts – A&E firms and DE Developers – in mind. Other stakeholders should be conversant in the relevant issues, so they may ask appropriate questions, and make good decisions based on the information presented to them.

Utilization of tools during project development
From discussions with experts and stakeholders, we found that the system design process requires tools for assessing technical performance, economic viability, and uncertainty/risk management and mitigation. These scenario planning tools, which include GIS mapping and analysis, often align with priorities that are guided by policy, planning guidelines, and regulations.

Of the stakeholder groups we spoke with directly, A&E firms and Owner Operators are the primary tool users due to their immersion in design development, operation, and optimization of DE projects. This aligned with expectations because the A&E firms are contracted experts for hire and are commonly employed by all other stakeholder groups, and the Owner Operators include operators, users, and energy consumers of DE systems.

Although all stakeholder groups use tools that are commercially available (for purchase or licensing) or open source (freely available), some develop their own tools. Developed tools are commonly used to supplement off-the-shelf tools and may indicate a need for new and more comprehensive tools. Alternatively, off-the-shelf tools could be expanded and customized to meet user needs.

Ultimately, we found that DE tools are selected based on the individual stakeholder's priorities and are not consistent during DE development. A&E firms stated that training, knowledge, and experience were all factors to take into account when considering adoption of tools. Flexibility to perform a range of analysis types and transparency were also critical, characteristics that were also identified as vital by the DE Developers.

For Owners and Operators, the biggest influence on use of tools was internal capability and capacity – people to do the work. Even if there was an available resource, tools needed to have a compelling value add to be considered. From a financial assessment standpoint, a move towards evaluating Campus systems in a 'DE as a Utility' framework were considered critical to appropriate comparisons with alternatives.

Understanding DE sector tool needs

From the expert elicitations, we identified several tool and knowledge gaps throughout the project development process. For early-stage efforts, a relative absence of reliable data was the most frequently referenced challenge. Pathways to solutions included filling in basic or foundational data gaps where possible, or providing tools capable of generating results with very few data inputs. For design processes, common themes included a need for robust techno-economic analysis, uncertainty around technical performance, system design requirements and associated risk of unnecessary capital costs, optimization to divergent metrics and priorities, and sustainability and provenance of materials. Financing — and specifically, the capital cost barrier of such large, long-lead time investments — was also identified as a key issue.

Providing the tools and mechanisms to resolve these gaps, and process innovations that reduce costs of doing work and tools that reduce uncertainty and risk, would help advance the DE market. Process innovation appears to be rather localized – more should be done to push the processes that have had success for some leading organizations. A good example is creation of information hubs for individual projects, whereby all parties to a project have access to latest documentation. This would ensure consistency of key data inputs, and support timely updates and necessary revisions to analysis for as the project moves along. It would strongly mitigate the risk of costly rework, and provides an excellent opportunity for efficient document version control, archiving, and project team cohesion. This activity could be led by any major stakeholder – in this case it was the Municipal group that suggested this. Referring to the best practices presented in Appendix D gives many examples of best practices that could be more widely applied.

DE Sector Practices: Capabilities and Standards Development

The expert elicitations also highlighted that DE development practices vary significantly across the DE sector because the size and resources of each organization varies the effort allocated to DE development. For resource-constrained organizations, which were mainly Municipalities and Owner Operators, this tends to lead to less optimal outcomes in terms of laying the groundwork for projects, optimizing operations, and appropriately planning for expansion. The main recommendations for avoiding development pitfalls and standardizing DE development practices were as follows:

1. Leverage the knowledge and experience of the many leaders in the field for all stakeholder group types, both the U.S. and overseas, to benefit U.S. practitioners.
2. Disseminate underutilized business models - such as Energy-as-a-Service (EaaS) - and practices from other countries and market sectors widely, to help further open potential opportunities.
3. Assess and evaluate characteristics beyond business-as-usual, and incorporate the value of new revenue streams and risk reduction strategies. This topic extends beyond the DE sector but is a significant opportunity area for this group of technologies. Resilience and the value of carbon are still somewhat novel concepts in system performance appraisals and overall valuation. In terms of adapting to climate change and limiting its impact, both are critical considerations for now and in the future.
4. Develop and utilize economic evaluation frameworks specific to DE project challenges and opportunities, rather than the conventional business models from other sectors. Develop accompanying guidance materials that reflect these models and that address the challenges of (a) extended project buildout schedules and (b) infrastructure useful life significantly longer than conventional financial evaluation time horizons.

   For (a), innovation on financing structures and schedules would help ameliorate this particular burden. It was suggested to us that adoption of a utility-style appraisal framework might be appropriate.

   For (b) Equipment lifetime for DE primary pipe infrastructure is typically many decades, and these lifetimes should continue to improve with a move to lower supply temperatures (for heating and hot water) and new composite materials. This extended life should be reflected in the required rate of return on the network portion of the investment (which is also frequently the largest portion of the capital cost).

5. Effectively communicate the benefits of DE to all relevant stakeholders to spur its future growth, and in particular to planners and policy makers.

Based on our expert elicitations, we also identified activities and practices that support development of DE systems. Although not originally a priority for this research, each represents a method, process or activity that stakeholders utilize to support the case for DE. It was often clear that practices mentioned were more broadly applicable, and may represent priorities for some of the other stakeholder groups. All of the topics identified constitute opportunities for industry working groups to lead improvement in the DE sector. A full list of best practices identified in the expert elicitations is provided in Appendix D.

1. INTRODUCTION

Lawrence Berkeley National Laboratory (LBNL), in collaboration with the International District Energy Association (IDEA) has completed a DOE-sponsored research effort to understand the potential for district energy (DE) and local energy economies (LEEs). This has been achieved by assessing the opportunities for DE and LEEs in terms of single and multi-users, and examining the frameworks and methods for assessing local fuel resources and opportunities for DE and specific DE-compatible technologies.

This research task specifically examines the role of tools the development of new, or refurbishment and optimization of existing, DE systems. This report outlines the outcomes from these efforts and provides recommendations for future research areas.

1.1. MOTIVATION

Urban areas currently account for approximately 80% of the population of the U.S. Reducing energy use and carbon intensity associated with provision of energy services for towns and cities is a priority for reducing overall primary fuel use and the associated environmental impacts. The economic potential for DE in the heating markets alone, is estimated at 3,226PJ (3 Billion MMBtus), which translates to ~43% of demand for non-electric, useful heat.[2] Estimates made for DE potential on the cooling side are more difficult to come by, but market projections suggest a 50% increase in served floor area over the next 25 years or so.[3], to over 3 billion square feet.

District energy provides a path to low-to-zero carbon energy for urban areas. The scale and interconnectivity of these systems, and the energy production and thermal storage technologies that enable optimal operation, also offer opportunities to improve community and grid-scale resilience. DE systems provide flexibility to the emerging demand response and ancillary services markets, and are a potentially suitable foil for large-scale electrification.

The main goal of this study is to understand the degree to which tools aid the objectives and goals of practitioners and other stakeholders in the development and deployment of DE systems. Architecture and Engineering (A&E) firms, Owners & Operators, Building Developers, DE System Developers, and Municipalities are the 5 major stakeholder groups whose involvement in DE is of interest to this undertaking. The purpose of this study is to understand to what extent the infrastructure of the existing commercially available tools benefit and fulfill the requirements of the respective user groups. In this sense, the goal is to identify if there are opportunities for replacing internally developed processes in the workflows of different stakeholders with existing tools. Note that the intention of developing tools would be to concentrate on topics and issues that are unserved or under (i.e., partially) served, and to complement those that are already publicly available rather than to compete with an existing offering.

In order to meet the overall research brief, the study described here includes:

- A brief description of the value of District Energy
- A description of tasks in the project development cycle
- Representative tools that are currently brought to bear on DE projects by task / topic
- How and to what extent tools are utilized by our target stakeholder groups

[2] Gils, et al (2013)
[3] EIA (2018)

- Identification of best practices or opportunities for learning across industry stakeholder groups to leverage methods, practices or processes that are already in place
- Identification of any gaps or shortcomings in tools
- A prioritized list of recommendations for future areas of research

1.2. DISTRICT ENERGY OVERVIEW

1.2.1. What is District Energy?

District energy involves the distribution of heating, hot water and cooling to buildings by way of water or steam pipe networks, with thermal energy typically supplied from a central plant. Thermal energy may be recovered from regional thermal energy resources, such as geothermal heat, or generated directly using fossil or renewable fuels such as waste biomass or landfill gas.

Distribution pipes are buried underground and are installed alongside other infrastructure in the built environment. The main or primary pipe network is often hydraulically separated from the energy consumer via use of heat exchangers - this serves both a technical and commercial purpose. On the technical side, hydraulic separation is a measure to prevent over pressurization (and subsequent failure) of consumer distribution systems, and on the commercial side, is a useful demarcation point between distribution and consumption, and so supports simple utility-style metering and billing arrangements. Commercial or technical imperatives may also dictate the need for hydraulic separation of the network from energy generation at the central plant, although this is less common.

1.2.2. Why is DE important?

The aggregation of diverse, fluctuating thermal energy loads from multiple consumers into a single combined load at the central plant allows DE systems to operate more efficiently than distributed on-site building systems. An aggregated load avoids the need to size equipment based on the sum of peak demands for connected buildings or facilities, relying on inherent system diversity to reduce total installed thermal capacity. The economies of scale also support cost effective investment in large scale central plant, many options of which support the use of low or zero-carbon fuels and energy sources.

DE systems are inherently fuel-agnostic, and so can switch over to untapped regional low-carbon energy resources such as bioenergy, or an existing source of industrial waste heat, by retrofitting the central plant. DE systems worldwide have transitioned to alternative fuels over the years to accommodate changing regulations, cost drivers, and priorities of stakeholders.

Due to this fuel flexibility, DE offers a path to a lower carbon future, and in the case of existing systems, the potential to significantly reduce the carbon footprint of existing building stock, which is a far more significant challenge than controlling the carbon footprint of new construction. DE may also be designed and controlled so as to inherently support a couple of emerging priorities for energy utilities and local building customers - demand response and system resilience - both at the district level and by extension at the electricity grid level. Exploration of the technical and financial opportunities has been underway for the former for over a decade so, and the latter has become a focus area since the advent of extreme weather events affecting large metropolitan areas notably Superstorm Sandy that had significant consequences for cities on the eastern seaboard in the fall of 2012.

Energy storage is a key pillar of many demand response solutions. Incorporation of thermal storage as part of district cooling systems provides an opportunity to meet utility requests for controlled electrical load shedding via replacement of chiller operation with chilled water supply from thermal storage for the required time frame. Assuming the drive towards electrification continues, the opportunity to include hot water thermal storage as a load shedding and management tool is also there. The scale of these systems means that demand response could be accomplished at the Megawatt scale.

In a resilience context, on-site generation, such as CHP, may be used as local grid balancing assets, and can meet a portion of the electrical needs for local building customers - critical loads could be supplied for as long as necessary in principle.

1.2.3. DE Project Development

As large-scale, complex, capital projects, DE systems typically have a prolonged development timeframe that goes through multiple stages. The US Community Energy Guide[4] describes a conceptual 10 step development process from first ideas to delivery and handover for DE projects. The 'flightpath' that the report's authors refer to, shown in Figure 1, illustrates the project development path in terms of reduction in risk and increase in costs as a project progresses towards completion.

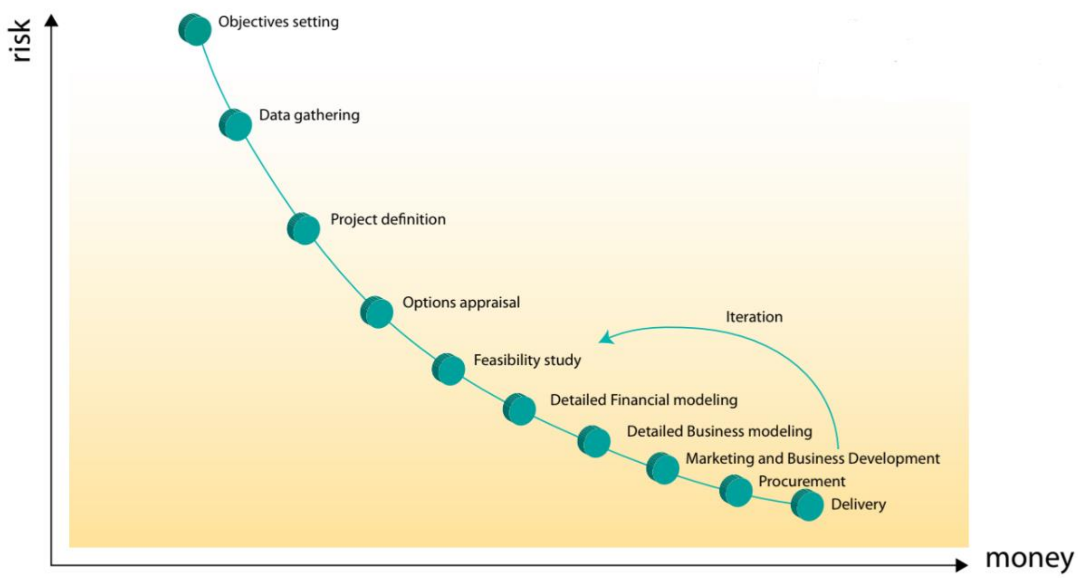


Figure 1: Project Development Flightpath (Source: US Community Energy Guide)

This concept is helpful in describing the phases of development as, it is possible to divide the process as follows:

1. Early Stage: This entails the preliminary effort needed in to assess the initial feasibility in order to determine whether further involvement in the project would deem to be feasible for the participating organization. The following steps of the flightpath would fit within this description:
    a. Objectives Setting
    b. Data Gathering
    c. Project Definition
    d. Options Appraisal
2. Detailed Analysis: Upon obtaining a select few options with higher confidence levels and lower risk, a detailed technical and financial feasibility analysis is carried out to determine the winner.

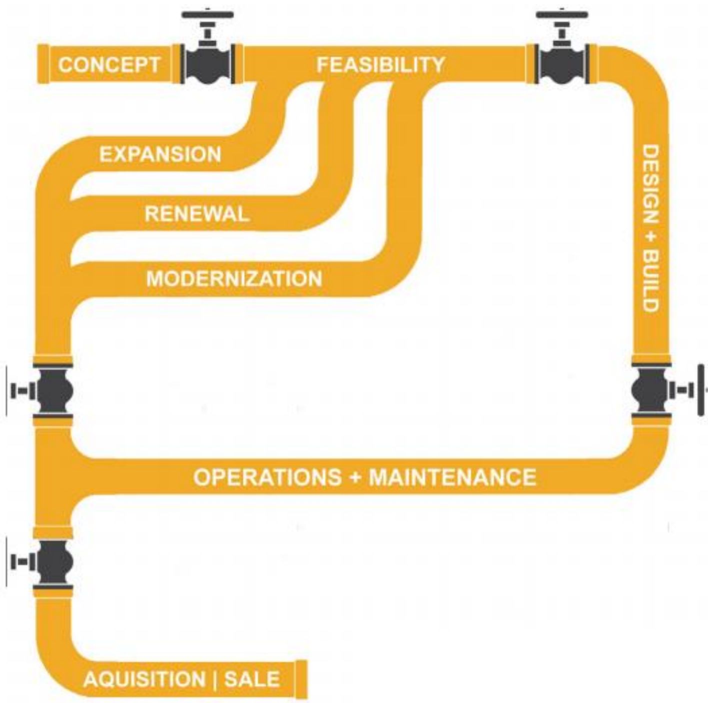
[4] IDEA (2012), Community Energy: Planning, Development and Delivery

These analyses are elaborate and granular with a lot of attention to detail. The following stages can be deemed to fall under this description:

   a. Feasibility Study
   b. Detailed Financial Modeling
   c. Detailed Business Modeling

3. Completion and Delivery: Encompasses the path from the selection of the one option that will be implemented to the successful implementation of the chosen option. Consists of the following steps:
   a. Marketing and Business Development
   b. Procurement
   c. Delivery

A recent IEA report[5] outlines a perspective that explicitly recognizes upgrade and expansion of existing systems as part of the concept life-cycle - also describing project stages in terms of categories leading towards completion and handover. This representation captures the fact that stages of a DE system lifecycle are not linear. Different stakeholders are involved in the activities relevant to the different stages in the pipeline.



Source: IDEA.

Figure 2: Stages of Project Development and Implementation (source: IDEA)

This representation can be broken down as follows:

1. Concept: The early data gathering and objective setting phase. The envisioned systems are drafted as a concept in the form of climate action plans by Municipalities, or campus utility master plans by Developers or energy maps by Developers/Municipalities/A&E firms.

[5] IEA (2014), Governance Models and Strategic Decision-Making Processes, for Deploying Thermal Grids

2. Feasibility: A detailed technical and financial analysis of the various shortlisted options is carried out in this stage of the project. Stakeholders conducting these activities are typically A&E Firms and Developers, for a range of client stakeholder types.
3. Design + Build: The stage involves the actual design, engineering and construction of the DE system. A&E Firms, Developers are usually involved in this phase of the project development pipeline.
4. Operations and Maintenance: Relates to the operation of the DE plant, performing regular maintenance and optimizing the performance to improve efficiency of operation. Stakeholders like Owners & Operators, A&E Firms are involved in this phase.
5. Expansion: Efforts to expand the capacity of a DE system, by geographic area or population, are carried out to satisfy additional load requirements that come from such growth. Owners & Operators, A&E firms, and Developers are involved in this stage of development.
6. Renewal: Assets that are aging are reviewed for necessary replacements in this stage of analysis. Owners & Operators are most involved in this stage of development while the services of A&E firms, and Developers may be employed
7. Modernization: More options become available for efficient performance and lower carbon footprint of DE systems as technology advances. As an example, using renewable resources is a big step towards carbon neutrality. Owners & Operators are most involved in this stage of development while the services of A&E firms, and Developers may be employed. (Municipality incentives?)
8. Sale and Acquisition: This relates to changes in the ownership of existing DE systems. It is becoming increasingly common for campuses to establish long-term concession agreements with DE system operators and financing partners.

1.3. ROLE OF TOOLS IN DE PROJECT DEVELOPMENT

The path to implementation and into operation and maintenance of DE systems involves a myriad interconnected considerations and decision points. Whether they are being retrofitted into an existing urban environment or installed in a relatively obstruction free site, the interconnectedness of the various project facets is always there (although implementation in a brownfield / greenfield setting is significantly less costly). In order to manage this development process, experts in the field lean heavily on tools to process data, conduct and support analysis, and make key decisions.

The paragraph below (italics added), taken from the IEA report on strategic decision-making for implementation of thermal grids, highlights the main aspects of a project that contribute to successful implementation:

> ***<u>Factors for Success</u>***
> *For a project to successfully navigate through the different lifecycle stages, maintain momentum and enable all participants to work toward project objectives, attention must be paid to key factors for good decision-making. Five key factors have been identified as critical components of strategies for success:*
>
> 1. *Risk: identifying, allocating and managing risk*
> 2. *Information: gathering and disseminating information needed for decision-making*
> 3. *Money: managing funds to align with the system lifecycle stage needs*
> 4. *People: including appropriate people and experts as needed in decision-making*
> 5. ***Tools: using available tools to improve decision-making***

The way that projects are organized, and the organizations, human beings and relationships involved, are significant success factors. Nevertheless, with detailed technical and non-technical analysis, any approach that offers the prospect of completing tasks in a more efficient and timely manner, reducing project costs, and mitigating project risk should be considered for inclusion in workflows. Where it makes sense to incorporate such approaches into a formal product structure, process, or service description, this should be encouraged, whether it be simulation tools, software based heuristic calcs, or reference documentation.

1.4. RESEARCH METHODOLOGY

The research method comprises two elements: a literature search, and engagement with industry experts and other stakeholder group representatives relevant to project development and success. This second element is itself separated into two sub-tasks. The major element consists of structured discussions with industry experts, that represent various stakeholder group types involved in the development of DE projects. A second, smaller task comprises market intelligence gathering via a questionnaire distributed to industry stakeholder groups. The second task is intended to verify information and reinforce (or otherwise) recommendations received during the structured discussions. These two activities shall help us better characterize priority topic areas for future research.

1.4.1. Literature Search

We conducted a literature search to help us characterize project development and the role of tools, models and other resources utilized along the way. From these documents and through our knowledge and understanding of the DE industry, we were able to understand the project development process, and the activities within it that rely on tools and software. Following this, we have described a conceptual path that projects go through from inception through to completion. These brief descriptions follow a 'what, how, why, who' framework (the 'when' is reflected in the sequence of stages and activities). For each task area in the process, we have identified representative or example tools that are involved in completion of task activities, referring to open source or free options where possible. Where we refer to commercially available products, this reflects feedback received via expert elicitations, and is not an endorsement of any particular software package or organization.

The literature search is intended to help provide examples of the currently available tools support, when utilized by stakeholders and practitioners in their roles in DE project development. We do not attempt to identify and represent the universe of tools utilized. We have reviewed the literature for tools that we characterize as representative of a type or group of tools that allow the user to conduct X, Y and Z analysis and deliver outcomes A, B and C to contribute to fulfilling the necessary analytical requirements and move the project forward.

We hypothesized that the technical appraisal and financial analysis phases (Options Appraisal, Feasibility Study, Financial Modeling and Business Modeling) of project development are very well served with commercial and research-grade products that cover requirements well. This is, at least in part, due to the fact that this part of the development process is relatively formal and structured and so requirements are closely adhered to by all practitioners and stakeholder groups - these requirements are reflected in the methods, tools and resources utilized. As highlighted in Figure 1 and Figure 2 above, this appraisal process is necessarily iterative, but this is typically within a well understood sequence of steps with a defined end point or handover to the implementation and handover phases of the project. We are also aware of the need for industry practitioners and stakeholders to develop their own tools and resources internally, to fulfill specific needs for projects that they identify as they occur. It is highly unlikely that these types of efforts will cease. This is often due to the inherent flexibility that the intended users require for a wide range of scenarios, and in the case of A&E firms and DE System Developers, is viewed as part of the competitive advantage for that particular organization.

As noted previously, for financial and business modeling, there are myriad options for the various stakeholders in terms of tools and resources and expertise. Many of them will have their own financial and business teams that are experienced at developing the necessary models that synthesize business operations - this is true of large capital projects generally. The topic of appropriate financial modeling frameworks as part of the overall project development cycle is worth elaborating on further, however.

In terms of the final phases - procurement and project delivery - these largely rely on project management-related tools and resources and some iteration on design - by the time a project reaches this point, the analysis has been completed, decisions have been made and the project team's focus is on getting the project built and operating on time and on budget to ensure that the loan payments can be made and that project value can be maintained at the level anticipated in the approved plans. We have not devoted attention to these activities.

From our literature search, there were several documents in particular that helped us describe the detail within the project development path and the practices and processes involved. These were as follows:

- US Community Energy Guide
- IEA Annex XI Final Report on Governance Models and Strategic Decision-Making Processes for Deploying Thermal Grids (Rao eta l, 2017)
- EPA Smart Growth Report on District Energy Planning
- A review of modeling approaches and tools for the simulation of district-scale energy systems (Allegrini et el, 2015)
- District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy (UNEP)
- IEA District Heating Transformation Roadmap

A full list of references is included in the bibliography.

1.4.2. Industry Engagement

The second part of our research comprised eliciting feedback from DE industry practitioners and stakeholders that are involved in the development of projects. This activity comprised engaging industry experts directly via structured discussions that reflected a) the range of sectors and skills represented in the cohort that we spoke with and b) covered the key topic areas with regards to project conceptualization, development and implementation.

Given the limits on numbers of structured discussions that could be completed and the fact that this would not be close to a representative sample, this was followed with a questionnaire distributed to a wider cohort. The objective was to verify feedback from the structured discussions, and attempt to prioritize activities based on responses.

Structured Expert Discussions

These representatives were identified from the membership of the International District Energy Association (IDEA), the international trade association for the district energy industry, as well as from our own list of industry contacts and experts that we have worked with previously on other projects.

The objective of these discussions was to understand the prevailing challenges within the industry, and where tools are currently brought to bear in resolving them. It is also to identify where there are gaps present that are either filled by other means or that are addressed in an ad hoc way - which in terms of achieving the goal or objectives, might be rather less rigorous, rather inefficient, or both.

In order to achieve this, we developed a list of questions around which our discussions with experts would be structured. Although the general approach to these discussions was to proceed through the questions in numerical order, a significant portion of discussions involved deviating from the script as conversations reflected the specific expertise and experience of our contacts. Detailed notes were taken for all of these discussions and the vast majority of them were recorded (following permission from each of the participants). This allowed the research team to represent each discussion in terms of response to specific questions and within the relevant focus topics.

In particular, our structured questions reflected the 5 topics identified as key success factors in the development of DE systems in the IEA report:

- Gathering and disseminating information needed for decision-making
- Managing funds to align with the system lifecycle stage needs
- Including appropriate people and experts in decision making
- Identifying, allocating and managing risk
- Using available tools to improve decision-making

The list of questions can be found in Appendix A.

Stakeholder Groups
Stakeholder groups of interest were identified by virtue of the role and responsibilities in developing DE projects - we prioritized talking to stakeholder types who were considered essential in project development. The preliminary list was identified from experts considered by the IDEA as potentially helpful to the project, bearing in mind their expertise, relationship with IDEA and the DE industry, and their likely availability.

The experts identified by IDEA represented five distinct stakeholder groups:

- Architectural and Engineering (A&E) firms - this group broadly fulfils the role of consultant or technical advisor, and will conduct work / analysis on hour-long behalf of any of the other stakeholders named here. They may be engaged at any point in the project development process
- Project Developers - in the DE context this group typically leads hour-long the energy infrastructure portion of capital projects, a team that will include a client, and a combination of the other stakeholder groups named here. They may be engaged in any or all of the Design, Build, Own, Operate, Manage, Transfer (DBOOM or DBOOT).
- Owners and Operators - representatives from this group that we spoke with represented public and private higher education institution sector, and as such, are both energy generator / supplier, and energy customer. Two representatives were from private sector companies that operate large district heating systems that supply heating and hot water to commercial clients in large U.S. cities.

- Municipalities - this group consists of local government representatives that do work in the sustainability, planning, and energy nexus. This group is responsible for setting policy, conducting inspections and providing planning approvals and monitoring compliance.
- Building Developers and Owners - this group comprises companies whose core business it is to own and operate commercial real estate. As such they are a target customer group for DE systems.

The project team intended to gather information from the Utilities stakeholder group, but were unable to engage with appropriate individuals to do so. The Utilities group, comprising publicly-owned or investor-owned entities, consist of regulated generators, suppliers, and distributors of gas and / or electricity to end use customers - residential, commercial and industrial. Their perspective with respect to working with operators of these systems, and supporting their development (or otherwise) would have provided a valuable additional perspective, especially in terms of how DE systems may be valued and assessed in terms of grid stability and resilience.

Industry Stakeholder Questionnaire

During our expert elicitations, we received many recommendations on topics for future research. These discussions reflected perspectives of a small number of individuals and organizations, and also a limited number of stakeholder group types. To help us prioritize suggested topics, we circulated a questionnaire to a large cohort of the DE sector, via an IDEA members list. The questionnaire response period was approximately three weeks. Positive responses to topics in the questionnaire helped us score and rank each research topic.

The questionnaire was necessarily high level and provided opportunities to a) provide free responses to specific questions and b) identify and elaborate on topics beyond those suggested in the expert elicitations. A breakdown of responses by stakeholder type is included in Appendix C. A sample of the questionnaire is also included in Appendix B of this report.

Limits of the Research

This study outlines outcomes and findings from research focused on the U.S. DE market. Our literature search was similarly tailored to the U.S. context - while we referred to studies and papers from outside the U.S., we limited our references here to U.S. focused studies, papers and publications.

In terms of the discussions with industry experts, time constraints meant that we could only speak directly with 20 people - as a result we cannot claim to have captured a representative picture of the state of the industry vis-a-vis tools, models and resources. We have attempted to address this shortcoming via use of a follow-up questionnaire, that sought feedback on suggestions from our expert discussions, as well as including stakeholder groups that we were not able to speak with directly.

2. DISTRICT ENERGY PROJECT DEVELOPMENT

2.1. PROJECT STAGES, RELATED TASKS AND EXAMPLE TOOLS

In the following section, we frame the project development process, referring to the U.S. Community Energy Guide and IEA Report examples. The Community Energy Guide in particular is instructive in separating project stages into recognizable, discreet sets of activities. These each reflect progress on the previous stage in terms of available data and information, a corresponding increase in the level of detail within analysis, and a reduction in uncertainty that the project will be implemented.

Listed below are the project development stages included in analysis here, along with a brief description of outputs from each stage:

- Concept Development: A description of the project opportunity and constraints at a high level, objectives setting – in particular, referring to policy, planning and zoning rules and regulations - and a list of energy options with criteria against which they will be assessed
- Data Collection: A review of key objectives, determining key data inputs, identification of the methods and processes of analysis and collection of key early-stage data
- Project Definition: Further refinement of data inputs and bounding of the project, final engagement with broad stakeholder groups, and development of energy technology options shortlist
- Options Appraisal: Verification of data collected to date, review of relevant plans, drawings, and associated site visits, review of buildings, including floor area and energy / load calculations, condition assessments for proposed existing building connections, and identification of preferred energy options
- Feasibility Study: In detail evaluation of preferred option(s) identified in the previous stage including detailed energy demand and consumption scenarios, associated plant sizing, hydraulic analysis, infrastructure planning, environmental impact assessments, all of which contribute to a techno-economic analysis
- Financial Modeling: A detailed financial plan, reflecting any final amendments to design, including impacts of value engineering, and clearly stated assumptions around the impact of varying debt and equity on financial performance, value of the energy-related assets, and detailed value-adjusted risk assessment
- Business Planning: Identification of project partners and description of roles, allocation of risk, scenario analysis according to contractual arrangements and business structure, and detailed summary of project performance in terms of return on investment

Table 3 is intended to help the reader understand the project development process at a high level - it summarizes how we describe the project development stages of interest to this research, identifies the main task areas associated with each stage and highlights the extent to which each of our target stakeholder groups are involved in each stage (darker shading denotes degree of involvement in each case). A more detailed description of each task follows, also identifying examples of tools that are utilized for the purposes described.

Stakeholder Engagement Legend

- Not involved
- Occasionally involved
- Often involved, as consultant or interested party
- Often involved, as lead or client
- Always involved, as lead or client

	Major Tasks and Sub-Tasks													Stakeholders				
Development Stages	Planning and Policy	Qualitative Screening	Mapping and Visualization	Energy Demand Assessments	Quantitative Screening	Energy Modeling	Hydraulic Analysis	Cost Assessment	Environmental Impact Analysis	Infrastructure Planning	Detailed Design	Economic Analysis	Business Pan Development	A&E Firm	Owner Operator	DE Developer	Municipality	Building Developer
Concept Development	X	X																
Data Collection	X		X															
Defining the Project	X	X	X	X														
Options Appraisal	X		X	X	X	X		X		X		X						
Feasibility Study				X	X	X	X	X	X	X	X	X						
Financial Analysis				X				X		X	X	X	X					
Business Planning								X				X	X					

Table 3: Stages of Project Development, Major Tasks and Stakeholder Involvement

It should be noted that tasks described in detail below may be completed within more than one stage of the project development process, and not necessarily in the order outlined - our framework is useful for the purposes of description but is one of several possibilities in terms of how tasks relate to topics.

There are also activities in the project development process that were of little interest to this study. Marketing, procurement, construction and project delivery were considered outside the scope of the research, because they are well understood, and critically, not specific to the DE sector. Consequently, there is no discussion of these project phases in this report.

2.2. Project Development Stages

2.2.1. Concept Development

At the outset of a new project that comprises investment in energy infrastructure, there is typically a catalyst that stimulates activity by relevant stakeholder groups. The range of possibilities is broad - it may be new land acquisition, signaling of new policy, a change in incentives (and therefore possible value), or master planning approval for a new site or new technological solution. Whatever it may be, a new scenario requires a) collection of available resources that frame the opportunity or challenge and b) convening of stakeholders to review these and other reference materials, that shall influence the range of energy infrastructure options under consideration.

Foundational documents to be reviewed shall include, but not be limited to:

- Local Climate Action Plan or Sustainability Plan
- Area Masterplans
- Municipal Planning and Zoning
- Local and State Codes and Regulations

From the review process and taking into account other less formalized objectives, identification of key project objectives, and desirable outcomes and outputs from project development process should be described and recorded. The resulting document should be revisited regularly throughout project development to confirm adherence to the original intent, until completion and handover.

Engagement with the community-at-large may be initiated at this point, the main purpose being to build understanding and consensus via a transparent early review process, where all perspectives are shared, and from those, a long list of community requirements for the project will emerge.

A preliminary list of technology options refers directly back to the project requirements, and may include options suggested by the local community and stakeholders. At this early stage, any scoring and ranking of energy options shall be qualitative in nature and therefore reflect characteristics of technologies rather than detailed performance (i.e., so more of a focus on fuel type, air quality impacts, technology footprint, local jobs associated with construction). They may also reflect value judgements of particular stakeholders. At this early stage, this process is unlikely to lead to exclusion of options.

Which stakeholder groups are typically involved?

Note: The Owner-Operator group typically manage their own projects from start to finish, and so are present throughout the development process, although in some cases they are responsible for analysis themselves *(as lead)* and in others, have analysis completed on their behalf *(as client).*

- Municipality
- Local Community
- Owner Operator *(as lead)*

Relevant Representative Tools:

Tool Type	Representative Tool(s)	Brief Description
Municipal Planning Portals	City of San Jose https://gisdata-csj.opendata.arcgis.com/	City planning portals are intended to provide a free, public access to location-specific data relevant to development planning, policy, and zoning. The quality of these online resources is likely to vary quite significantly, but these resources are designed to support visualization and analysis of locally available data

		of different types and formats, and in this representative case, is supported by GIS software.
Multi-Criteria Analysis (MCA) or Multi-Criteria Decision Analysis (MCDA)	These are process management tools – the 'engines' for this process range from simple, bespoke criteria scoring, ranking and weighting (MCA), to complex mathematical formula-based solutions (MCDA). MCA – many working examples online, but often bespoke, created by the user MCDA – example: Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)	MCA/MCDA aims to identify preferred options or outcomes from a list of options, taking into account a range of potentially disparate and often conflicting objectives and perspectives. The highest ranked outcomes may be interpreted as the preferred selections although this is not always true.
Project Visualization	Google Earth www.google.com/earth	The useability and flexibility of online maps, gives them a unique software classification. Supporting various data layers including street maps, building height and functionality such as distance measurement means that they are ideal for early conceptual development tasks.

2.2.2. Data Collection

There is no obvious handover point from project conceptualization to data collection - these two areas of activity may overlap significantly, happen simultaneously or there may be iteration between them. Critical examination of the original concepts will be further enabled as data for various aspects of the project become known. Key steps shall include:

- Review of key project objectives
- Determining key data inputs
- Determining methods and processes of analysis required to generate key outputs at an appropriate level of accuracy
- Collection of key early-stage data

Key data inputs reflect foundational principles and descriptions developed in the conceptualization stage, and comprise information and data that reflect emerging site-specific circumstances - for example, for a mixed-use commercial development, this would include number of proposed facilities, their sizes (storeys and floor area) and locations, identification of physical barriers and constraints. Data on building types and size supports estimates of energy demand and consumption at the building and system level – these estimates would form the basis of early analysis.

The means of representing data is determined by specifics and priorities of the project. Geographical Information Systems (GIS) are a visualization tool that may be deployed under a range of circumstances, from reviewing potential infrastructure routes, phasing pipe network installation according to development schedules, and planning energy generation and distribution strategies out to full system buildout. The GIS medium supports a range of different methods of data representation, annotation and levels of detail.

For example, mapping may be useful if planning and zoning data can be visualized in concert with locations of energy demand and existing and potential sources of supply. This approach may highlight near term (proposed project) and longer term (future development yet to be considered) opportunities for a given local area. Data collected shall ideally enable (high-level) analysis of technology options.

Which stakeholder groups are typically involved?

- Municipality
- Community
- Owner Operator *(as lead)*

Relevant Representative Tools, Methods and Resources:

Tool Type	Representative Tool	Brief Description
Graphical Information Systems (GIS)	QGIS https://qgis.org/en/site/	GIS software supports data visualization and interrogation of multiple data layers to provide clearer perspectives on complex, multifaceted challenges. They are utilized both as processors for evidence-based policy making and finding solutions to intersecting and interacting problems. The GIS format might be used to map the following: • Thermal energy density • Proximity of energy sources and sinks • Potential routes and load connections for buried pipe infrastructures
Building Load / Parcel Suitability Scoring	An example can be seen here (p. 20): https://19january2017snapshot.epa.gov/smartgrowth/district-scale-energy-planning.html	Process tools may assist in high-level analysis, in this case when determining the degree of appropriateness for inclusion of particular building types as connections on a district

		thermal network. The example scores each building type based on the degree to which each may provide system baseload (i.e., reliable, predictable portion of thermal energy sales).
Project Development Tools – Planning	Plan4DE http://plan4de.ssg.coop/ THERMOS https://www.thermos-project.eu/home/	Ideally, significant preparation and planning would be possible in the lead up to project concept development. Scenario analysis tools support early decision making on economic viability, utilizing high level, or necessarily approximate inputs, explicitly recognizing uncertainties. These may be spreadsheet or GIS platform-based.

2.2.3. Defining the Project

Technology option review and defining the project represents the final 'narrowing down' process prior to a more structured, formal process through options appraisal and feasibility study analysis. Depending on the project, it may also be a late opportunity for the community at large to provide input (best practice is that well managed projects provide timetabled engagement opportunities throughout the development process, but this may be limited to communications hereafter).
Decision making may still be based on high-level or 'best estimate' data, but looks to leverage this to go forward into the options appraisal. As noted, this process may be open to the public or at least invites representatives of all the relevant stakeholders - including the community - to observe and participate. Transparency is an important factor at this stage - it is key in demonstrating good faith and objectivity in the process.

The review process may comprise one or more assessment methods, depending on the priorities of the project - for example there may be variations on preferred technology type due to a local fuel or energy source, or considerations that relate to a range of technology options (which is more likely at this early stage). From experience in the DE sector, the project team are aware that technology screening and multi-criteria analysis are approaches that are utilized, in order to whittle down the number of options under consideration to a technology short list.

Which stakeholder groups are typically involved?

- Municipality
- Community
- DE Systems Developer
- Owner Operators *(as lead)*

Relevant Representative Tools and Resources:

Tool Type	Representative Tool / Method	Brief Description
Technical Screening Tools	RETScreen https://www.nrcan.gc.ca/maps-tools-publications/tools/data-analysis-software-modelling/retscreen/7465	Software tools for feasibility evaluation assess and optimize the technical and financial viability of potential clean energy projects, and may be utilized to do high level or more detailed analysis or what-if scenarios.

2.2.4. Technical Options Appraisal

A high-level techno-economic assessment is undertaken to determine appropriate options from a technology short-list. This assessment is more detailed than work completed previously, may include analysis steps and tools from the earlier development stages, and involves some or all of the following:

- Inputs from technology review / project definition
- Drawing's review
- Site visit(s) and review meetings
- Building loads review
    - Energy data for existing buildings
    - Floor area-based estimates for new construction
- Existing building conditions assessments
- More detailed local resources assessment (i.e., verifying data collected in earlier phase, determining nuances)

Significant effort will be put into better understanding possible energy demand scenarios - thermal energy requirements from information provided on loads proposed for connection to the system, form the basis of the assessment. Estimates on central plant or equipment sizing will often be made on the basis of rules of thumb, relying on spreadsheet calculations. Simple energy models may also be used.

Metrics for comparing options include equipment capital cost, energy sales revenues, labor costs, and the sum outputs of these, such as simple payback period and Net Present Value (NPV). All estimate will still be high level at this stage.

Site drawing reviews are conducted to identify showstoppers associated with any of the technology options under consideration, and may include review of potential infrastructure routes and suitable central plant locations.

The screening process in an options review or options appraisal is a necessary step to help the project stakeholders, and particularly potential investors, understand whether it is worthwhile conducting more detailed investigations, and investing time and money on further project development. Where DE systems are proposed for supply to existing buildings, a review of building system condition and operating temperature is critical to gauge the overall scope of the DE project – compatibility of customer building systems is critical for success, and may add significant capital cost to a project. Permitting and land availability issues may be considered in some detail for the first time, particularly if they are perceived as key constraints. For the reasons above, among others, this stage is often when projects fail.

The project developer takes the lead in carrying out the options appraisal process with support from the in-house engineering and planning team as well as consultants for work that needs outsourcing.

Which stakeholder groups are typically involved?

- Municipality
- A&E firm
- Developer
- Owner Operator *(as lead)*

Relevant Representative Tools and Resources:

Tool Type	Representative Tool	Brief Description
Template Load Profiles for Use in DE models	OpenEI https://openei.org/datasets/files/961/pub/	Published, verified energy load profiles for multiple building types in many climate zones, utilizing TMY data for specific climates. Data is provided by energy service and end use category type.
Economic Assessment Guidelines and Principles	AACE http://web.aacei.org/docs/default-source/toc/toc_18r-97.pdf?sfvrsn=8	A cost estimation classification system that classifies cost estimates according acceptable uncertainty (+/- percentage) to manage expectations of project stakeholders.

2.2.5. Feasibility Study

2.2.5.1. Energy and Load Characterization

Energy demand scenarios serves as a basis for comparing a narrower set of options. As a minimum requirement, systems assessed here must be able to meet demand and consumption patterns of customer connections, thus meeting needs of occupants, specific energy services and / or critical assets. Thus, it is vital to characterize loads (thermal and electric) as accurately as possible in order to proceed with more detailed techno-economic appraisal.

Energy data typically consists of time series (hourly, daily, monthly or annual) values for energy use at the individual facility (i.e., building) end-use level, wherein information about peak load and base load are included. Determining load patterns and diversity on the system is required in order to accurately estimate central plant capacities, and that of supporting equipment and network infrastructure. Inevitably, data inputs for this process vary in quality. For example, load profiles for unusually hot or cold years are potentially as problematic as energy estimates based on floor area, or building energy model data file outputs. However, as feasibility studies typically take several months, there are several opportunities to include more accurate or representative data.

Which stakeholder groups are typically involved?

- A&E firm and / or DE Developer
- Owner Operator *(as client)*
- Building Developer

Relevant Representative Tools and Resources:

Tool Type	Representative Tool	Brief Description
Individual Building Energy Models	EnergyPlus http://energyplus.net/ OpenStudio http://openstudio.net/	Building energy simulation modeling software that can provide inputs to modeling of DE systems in the form of static 8760 thermal and electric load profiles.
Utility Prices	Energy Information Administration https://www.eia.gov/	Wholesale and retail prices for fuels and grid electricity supply indicate realistic tariffs for provision of energy services under DE scenarios. These comprise key inputs to early reviews of cost-effectiveness of the various options under consideration.

2.2.5.2. DE System Energy Modeling

Once energy scenarios are represented, flows of energy within a system comprising production units, distribution infrastructure, supporting equipment and energy consumers are simulated to help determine theoretical behavior of the DE system under a range of environmental conditions.

Energy simulation models vary in the level of detail required on input data (some support default settings that users can elect to modify or not) but for feasibility studies, these models must be sufficiently robust to meet appropriate expectations of stakeholders. In order to achieve this, it is critical to account for and make explicit major uncertainties that remain. These will need to be reflected in the risk assessment, and accounted for in uncertainty analysis.

For a project to reach this stage, inappropriate technology options have been weeded out, and comparisons will typically be between two technology options, or more likely, a range of options for a single technology type (for a CHP-based application, this might be a range of production unit thermal capacities). Any assessment shall typically include a base case that reflects a minimal capital cost option.

Modeling distribution of thermal energy via pipe networks is necessary to determine appropriate geometries (length, diameter, types and locations of bands) and stresses within pipes - this is typically conducted via specialist software. Modelers thoroughly interrogate their simulation models to identify potentially feasible geometries - a preferred solution shall balance capital costs (equipment, pipes, and installation) with operating costs (principally pumping cost), while staying with appropriate safety tolerances of pipes.

The modeling process shall take several months and undergo several iterations, with multiple reviews, presentations to clients, information and data updates as corrections are made or new information becomes available. At conclusion, the system selected to move forward must have demonstrated a theoretical capability to meet needs and performance requirements under a range of scenarios. From a financial viability and business planning standpoint, this is an essential precursor to moving to development of a rigorous financial appraisal.

Which stakeholder groups are typically involved?

- A&E firm and / or DE Developer
- Owner Operator *(as client)*

Relevant Representative Tools and Resources:

Tool Type	Representative Tool	Brief Description
Modeling - sizing and operational optimization of energy production units System cost-level techno-economic analysis	UrbanOpt https://www.nrel.gov/buildings/urbanopt.html EnergyPRO https://www.emd.dk/energypro/	Software modeling packages for techno-economic analysis of energy production units - including cogeneration, heat pump technologies and renewable energy – and energy balance requirements – such as heat rejection. These utilize thermal or electric load inputs as scenarios against which to dispatch selected technologies according to user defined priorities and price signals.
Modeling – network hydraulic analysis	UrbanOpt https://www.nrel.gov/buildings/urbanopt.html AFT FATHOM https://www.aft.com/products/fathom/details	Modeling of steam and water flow properties in pipe networks, with focus on pipe stress, performance of network components (such as valves) and optimal design, including pumping energy, and supporting of what-if analysis for load connection.

2.2.5.3. **Infrastructure Planning**

Infrastructure planning comprises a couple of key items: identification of appropriate location(s) for central plant and pipe network route planning. Central plant is a necessary first step as this will in turn determine the pipe network dimension and geometry. Factors like whether the system is designed to be a central heating and / or cooling will help determine the location and dimensions of the plant, as will the technology selection and sizing that is an output of the economic modelling. The distribution network will be planned according to location of central plant, energy loads to be met and the route between source and demand.

During the planning process, it is important to consider various factors that could affect the infrastructure development such as man-made or topographical constraints, existing buried infrastructure, or permitting issues related to the land availability.

The process shall comprise a detailed site review and multiple site inspections and walkthroughs, and then multiple iterations of drawings (concept design) for review by the project team. The final set of concept design drawings shall be included in the Basis of Design that is a major output of the Feasibility Study.

Which stakeholder groups are typically involved?

- Municipality
- A&E firm and / or DE Developer
- Owner-Operator *(as lead)*
- Building Developer

Relevant Representative Tools and Resources:

Tool Type	Representative Tool	Brief Description
Infrastructure route planning	QGIS https://qgis.org/en/site/	GIS software supports optimization of network routes according to user input queries that determine search / sort constraints, cost reduction, efficiently managing workflows, and returning results that resolve complex distance (and therefore cost) calculations.
Site and infrastructure design drawings	FreeCAD https://www.freecadweb.org/	Software to support drafting of concept and detailed design drawings, up to and including standards required for inclusion with RFPs for major capital works.

2.2.5.4. Economic Modeling

Economic modeling is a process wherein all various costs and revenues associated with a scenario are included in what is often referred to as techno-economic analysis - in this case the comparison of several district energy options with a do-minimum base case - to determine the preferred option. Discounted cash flow analysis is employed to estimate the present value of all the costs and revenues that would accrue over the investment lifetime of the project. Financial viability is determined by how revenue fare against costs: operational costs and the costs to repay the capital investment should be lower than the revenues derived from system operations.

Input values for capital cost and unit operational cost items are put in the model. Capital costs are gathered from databases, equipment manufacturers, and contractors / installers. Operating cost inputs are applied as variable multipliers to energy modeling results (for example, to translate quantum of fuel consumption into a cost) and to other estimates (labor required to cover operations and maintenance of energy options under assessment, and should consider all possible future categories of costs and revenues. The model shall be reviewed and updated where necessary, with a record kept on which items are subject to significant uncertainty, and still require review or refinement.

Which stakeholder groups are typically involved?

- Municipality
- A&E firm and / or DE Developer
- Owner-Operator *(as lead or client)*
- Building Developer

Relevant Representative Tools and Resources:

Tool Type	Representative Tool	Brief Description
Flexible, customized, and user defined financial / business plan	Microsoft Excel https://www.microsoft.com/en-us/microsoft-365/excel	Spreadsheet software packages are the workhorse when it comes to calculations and analysis. It is also utilized as a platform for more complex dynamic analysis, and for developing cashflow models and financial plans.
Equipment and Labor Costs	RS Means https://www.rsmeans.com/	Up to date, referenceable prices and costs for labor and equipment are an essential input to developing sensible economic cases for analysis and review by project partners.

2.2.5.5. Sensitivity Analysis

A sensitivity analysis is often carried out as a part of the detailed economic modeling. The analysis of a district energy system is subject to a range of uncertainties. These variables may be technical parameters - such as annual operating hours - or financial parameters such as operating cost inputs - such as fuel prices or labor costs. The degree of sensitivity of the result (i.e., NPV) to variation of a particular input parameter is the main subject of interest - where there is high sensitivity, this will be included in the project risk register, which will also be developed as part of a feasibility study. This also serves as a signal to the various project stakeholders to characterize and quantify said input as carefully as possible in order that the 'true' range of values for that parameter can be understood, and consequently the range of possible outcomes that arise from the variation of that parameter. In particular, parties to the project may also understand if the potential impacts of variables sensitive to fluctuation violate any assumptions / constraints or even result in the loss of reliability or viability of the system. A Monte-Carlo-based sensitivity analysis is commonly utilized for risk analysis. It should be noted that often the change in optimality of a given solution when subject to modified input parameters cannot be identified merely with the help of a sensitivity analysis - a parametric analysis is needed. [https://www.diva-portal.org/smash/get/diva2:974027/FULLTEXT02]

Which stakeholder groups are typically involved?

- Municipality
- A&E firm and / or DE Developer
- Owner-Operator *(as client)*
- Building Developer

Relevant Representative Tools and Resources:

Tool Type	Representative Tool	Brief Description
Risk analysis	OpenRisk https://www.openriskmanagement.com/	This consists of multiple strategies and associated models / software to support risk management. Applicable for cost estimation, financial analysis, enterprise level risk management, business planning and portfolio optimization.

2.2.5.6. Environmental Modeling

All large-scale capital projects have an impact on the local environment, and many also impact environmental conditions globally. The construction phase is not relevant to the scope of this study, although there are clearly environmental impact assessments required. The operations phase is of interest here as there are multiple reasons to assess environmental performance, and metrics that apply to performance of specific technologies.

For example, fuel combustion in a district energy system central plant will result in gas emissions, the characteristics of which shall depend on the input fuel type and grade. A couple of assessments are necessary in this context - 1) what are the exhaust gases comprised of in terms of harmful pollutants? and 2) when these are exhausted to atmosphere, how do they impact surrounding communities? Flue gas dispersion modeling is essential in determining to what extent waste gases require pre-treatment prior to exhausting, and also what conditions must be satisfied in order to meet the minimum safety requirements in terms of environmental impacts (i.e., minimum exhaust gas temperature to ensure buoyancy, minimum height of stack to ensure dispersion at low concentrations when they reach ground level).

For ground-source thermal energy, impact on the long-term sustainability of the resource is of interest. An assessment of the capacity of the source to recover during the cooling season (or be recharged via putting heat of coolth back into the ground via reverse flow) is an essential element in assessing the feasibility of the project as a whole, but in this case, it is also inextricably tied to the environmental impact.

Which stakeholder groups are typically involved?

- Municipality
- A&E firm and / or DE Developer
- Owner-Operator *(as client)*
- Building Developer

Relevant Representative Tools and Resources:

Tool Type	Representative Tool	Brief Description
Flue gas dispersion modeling	AERMOD https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod	The U.S. standard modeling system (and associated inherent protocol), developed by AMT and the EPA, for energy plant that comprises fuel combustion.
Ground / water source heat stability analysis	Gaia Geothermal https://www.gaiageo.com/desktopindex.html	Integrated software modeling packages for design of stable geo-energy systems.
Life-Cycle Analysis (LCA)	Athena Impact Estimator https://calculatelca.com/software/impact-estimator/	Software tools designed to evaluate whole buildings and assemblies based on an internationally recognized life cycle assessment methodology, taking into account materials, transportation, construction and end of life removal and disposal.

2.2.6. Financial / Business Planning

2.2.6.1. Financial Modeling

Development of a financial model builds on work done during the feasibility study, where capital and operating costs are determined to an appropriate level to confirm financial viability. The financial plan adds more detail to the viability picture and may also lead to changes in the technical solution as a result of the outcome and will also influence the business plan and business structure.

There are several important items in the financial plan that are not considered during the feasibility study stage, such as the impact of debt and equity, plus costs that may only be properly assessed at the point where connection and supply to specific customers and customer types are being assessed. Billing. bad debt coverage, insurance and property taxes are some of the additional considerations that must be included in the costs side of the ledger. It may be considered good practice to invest in a system replacement fund once the project debt has been repaid [Comm Energy, p.31].

The product from the process should be a transparent financial plan in the form of a detailed cashflow analysis, that covers all possible revenues and costs for the proposed system, reflects the discount rate of the expected business structure as well as the cost of capital for the business (which shall itself also be influenced by business model). Emerging value centers for district energy systems include resilience and avoided environmental costs (which is already reflected by a carbon price in some markets). The DE industry is engaged in these topics and is working through industry groups to determine how to appropriately value these beneficial aspects associated with the energy production technologies.

One major addition to the financial plan is the valuation of risks that reside with the project. During development of the risk register at the feasibility study stage, risks will be mitigated or managed (allocated to parties best able to manage them). The risks that remain need to be valued appropriately within the financial plan in order that they may be addressed should they occur, and not threaten the safety or viability of project operations.

Which stakeholder groups are typically involved?

- DE Developer
- Owner-Operator *(as lead)*
- Building Developer

Relevant Representative Tools and Resources:

Tool Type	Representative Tool	Brief Description
Financial modeling	Graphite Financial https://graphitefinancial.com/open-source-financial-model/	Advanced financial modeling supports all of the basic financial frameworks and metrics (discounted cashflow and NPV, IRR etc.) and supports appraisal factoring in financial instruments and multiple additional variables, including via the Monte Carlo simulation method.

2.2.6.2. Business Modeling

The business modeling process comprises identification of the partners to the project, the consequent financial performance of the project for it to be successful (the private sector requires a higher rate of return than the public sector) and the allocation of risks amongst the project partners. The rate of return and risk questions, as well as the issue of control, will help determine the appropriate business structure and partnership constituents.

It is advisable at this stage to review the original project objectives at this stage, as this will remind the various parties of original priorities and necessary steps in order that those be preserved. The priorities shall also influence the final project constituent partners. This stage is important mainly because decisions taken may impact the financial viability of the project, and by extension, lead to an iteration of the feasibility study analysis.

Which stakeholder groups are typically involved?

- DE Developer
- Owner-Operator *(as lead)*
- Building Developer

Relevant Representative Tools and Resources:

Tool Type	Representative Tool	Brief Description
Business modeling	Open ModelSphere http://www.modelsphere.com/org/index.html	Business modeling platforms provide the capacity and flexibility for business planning in the DE and wider community-

		scale energy project realm. The framework provides transparency, long term forecasting capability and supports complex scenario analysis.

3. EXPERT STAKEHOLDER ELICITATIONS

This section summarizes outputs from our expert elicitations with DE sector stakeholder groups. First, we identify the stakeholder types that we engaged with, and briefly describe the roles they fulfill during the project development process. The purpose of these discussions was to identify challenges within the DE sector, understand how tools are currently brought to bear to resolve them, determine the gaps in tools provision that remain, and briefly describe the research necessary to fill those gaps.

Under key topic headings below, we summarize the outcomes of discussions that were facilitated via a set of structured questions. The summaries identify common threads within stakeholder groups for each topic, suggestions and recommendations on industry best practices, perceived gaps in the market, and describe the main themes of each discussion topic.

We spoke with 20 people in total, representing A&E firms (n=5), Owners and Operators (n=7), DE System Developers (n=3), Municipalities (n=3) and Building Developers (n=2)

3.1. STAKEHOLDER GROUPS SUMMARY

3.1.1. A&E Firm

The A&E Firm stakeholder group (AE) consisted of consultants that provide technical and / or non-technical (business / financial) expertise to their clients. Their work covered early-stage stakeholder engagement and client handholding, solutions conceptualization, feasibility study analysis, detailed system design and retrofit design of district thermal systems and financial / business planning for those projects that clear the earlier stage hurdles. A&E firms were not typically project leaders or advocates, but conducted direct analysis on behalf of their clients to a specific brief. This process often involved engagement with other project partners, at least one of which will be the local municipality. The policy and planning guidelines that local and state governments set and the accompanying reference documentation - such as land use zoning, development masterplans, and climate action plans - comprised key inputs to the work that the A&E stakeholder group undertake.

3.1.2. Owner Operators

The Owner Operator stakeholder group (OO) was made up of public and private universities that operate district thermal (and in some cases electrical) energy systems in order to meet energy requirements for campus buildings, which they typically also own. A couple of representatives of private sector entities that are energy service providers but not consumers of this same energy were also included in this group. The strategic plan for operating and expanding their DE systems was based on a masterplan, an infrastructure implementation roadmap or a climate action plan, and these frameworks provided the backdrop to many of their activities. This stakeholder group's focus was on their core mission - for campuses, was to meet the needs of students and faculty by providing safe, comfortable work locations in which to study and teach, and for Operator-Only, to meet the energy needs of public and private sector clients. Decision-making was on both a short and long-term basis - this presented conflicts and challenges. This group are involved in all stages of project development on their respective sites, although they often employed outside entities (such as A&E) to do assessments and analysis on their behalf. In addition to energy issues, water management was often also a key focus area.

3.1.3. DE System Developer

The DE System Developer (DV) stakeholder group consists of private sector organizations that design, build, operate and own (DBOO) and occasionally transfer (DBOOT) district thermal energy systems. The range of activities that they conduct during project development varies - they assess opportunities for developing new systems and improving operational performance and the business case for systems that they already own and operate. They conduct early-stage development activities on behalf of clients as well as following an option-narrowing assessment and feasibility study analysis. Development of detailed financial models and business planning was a key focus area for them - this is the point at which partners and clients commit to a specific energy solution – and in some cases this work may precede detailed energy modeling.

3.1.4. Municipal

The Municipal stakeholder group (MN) comprises local governments and public agencies whose primary task is to deliver a sustainable built environment for taxpayers (residents and businesses), in this case via appropriate retrofits and new construction, and ensure compliance with policy, in order to achieve their local energy and environmental goals. We wanted to understand the degree to which they incentivize and encourage District Energy development through their frameworks and standard workflows. In particular, policy-based tools such as zoning, permitting, energy benchmarking, disclosure ordinances and incentives constitute the routes to including DE as one of the solutions under consideration for new development or significant retrofits to existing buildings. This group also influences decisions via documents produced as outputs from the urban planning process, such local climate action plans and adopting resilience strategies; local communities are engaged through workshops to build consensus for the municipality's role in the path forward for the community in question, via their role as convener and facilitator in the early stages of project development.

3.1.5. Building Developer

The Building Developer stakeholder group (BD) is responsible for construction, ownership, and operation of buildings on a large scale, each with multiple building types and sizes in many countries across the globe. Discussions with them focused on methods and metrics utilized when making decisions around energy solutions for their facilities in the U.S. Implementation of facility energy systems is often a small portion of overall capital expenditure for a new development, and is a line item in portfolio operating budgets that cover all elements of facility labor, operations, and maintenance. The facilities that they operated are located in downtown city areas as well as large scale campuses - this helped us understand how two use different cases might be different from a planning, procurement, implementation and operations standpoint.

3.2. KEY TOPICS AND RESPONSES

3.2.1. Engagement with Publicly Available Tools

This topic centers around the degree to which our stakeholder groups utilized publicly available tools within their project development or operations workflows. We were interested in understanding factors that influence their use, and the purposes that these products serve.

A&E firms utilized many tools and software to support their workflows. Use cases reflected specific needs of clients and customers, but also a generalizable set of (largely) technical challenges that they typically faced. Tools were largely used to complete tasks in the options appraisal and feasibility study stages of the project development process, such as utility infrastructure planning, hydraulic/pipe flow and stress analysis, simulation of electrical power distribution systems, and energy modeling activities (at building and district / central plant level). Owner Operators deployed tools in the context of new project development (data collection and onwards, for projects that include connection of existing buildings as new customers) and operations (continuous improvement and optimization of existing systems). There were a range of institutional capacities and capabilities within this group, and these factors were significant in influencing the extent of tools adoption. One difference between well-resourced institutions and others was the degree to which they felt capable of leveraging DE system data. There were different approaches to DE systems appraisal expressed within this group, that reflected the roles of the representatives we spoke with – a facilities director was focused on optimization and technical improvements via use of technical tools and software, whereas a Director of Utilities was more focused on the big picture, engaging with what-if analysis at a financial management (accounting software) level. The DE System Developer group described work activities throughout the project development cycle, but referred to a narrow set of tools utilized within workflows, with each DE Developer apparently leveraging available tools that reflected their specific business development model priorities, and where they perceived the highest risks to be present or their expertise to be the most limited. The Municipal group stated that their use of tools was very limited – technical experts such as A&E firms were typically called on to conduct technical work. Their roles in early stages of project development meant that their tools consisted of inducements (financial incentives or regulatory / planning concessions) or leverage (zoning laws, minimum environmental performance thresholds). These opportunities would be evaluated through completion of technical work by others. They observed that use of GIS mapping and visualization were seen as a valuable step parts of the development process. Building Developers noted that while they conducted independent due diligence using financial appraisal tools, for the majority of the project development process, they were clients of others (such as A&E firms).

Themes

The factors influencing use of publicly available tools are particular to the type and size of entity concerned, and resources they have at their disposal to devote to tools (either purchase, training and cost-effective utilization, or both). Well-resourced entities were able to describe workflows in which tools could be integrated and their potential maximized. Tools identified were utilized largely in the technical appraisal of DE systems, although early-stage mapping and visualization were also identified as important. Perceptions of when tools were important reflected when in the project development processes stakeholders were engaged with the project team and / or involved in decision-making.

Descriptions of tools adoption by experts were notable in that the majority of them map to identifiable tasks within the formal, structured technical appraisal stages. Mapping and visualization, important early-stage scenario-setting tools in principle, was the exception in this regard. However, it is clear from discussions that these insightful approaches are not utilized consistently in the early stages of project development – this is understandable from a schedule management point of view, but may be a shortcoming from a strategic perspective, as these approaches can be instrumental in highlighting hitherto unseen opportunities (in terms of existing energy resources, or facilities that might be viable future customers).

3.2.2. Main Challenges and Barriers in Utilizing DE-related Tools

This topic centers around shortcoming of publicly available products tools on offer, and barriers that deter users from adoption.

A&E firms stated that training, knowledge, and experience were all factors to take into account when considering investment / adoption of tools from a management standpoint. From a technical standpoint, the lack of flexibility or the necessary graphical outputs to effectively present results to partners and clients. The black box nature of tools was also named as a consideration – where independent verification of relationship of inputs to outputs was necessary, potential adopters could have second thoughts. The biggest influence on the Owners and Operators was existing capacity and capability of staff – leveraging DE system data via tools and software was highly desirable, but they needed to be able to accomplish it quickly and easily, or alternatively prioritize other efforts. It was also noted that a lack of integration between tools and data acquisition / metering systems was a perceived drawback. DE System Developers said that publicly available tools did not offer the facility to customize inputs, processes or outputs that would meet their needs, and also, similar to the A&E firms, identified an absence of compelling graphical formats for presenting results. The Municipal and Building Developer groups were typically deterred from direct use of technical tools due to their use being outside their core mission, and that they could employ others to conduct the necessary analysis.

Themes

All groups identified technical and process related challenges associated with use of publicly available tools - experience, knowledge and training were key barriers. Specifically, a lack of flexibility to cover a range of technical scenarios and difficulty integrating with data acquisition and Building Automation Systems were cited as technical barriers. On the management and process side, the high hurdle associated with software training and cost-effectiveness of licensing / adoption were identified as the key disincentives to their use. This hurdle increased as software packages became less modular / more integrated. Generally, experience and knowledge were also noted as barriers. Again, the type and size of entity are a factor – the opportunity cost of investing time and resources in purchase and training for a tool are significantly greater for a small organization. Development of internal training support (videos, documentation) was identified as being necessary to leverage the benefits of specific tools – this is likely a viable option for larger organizations only, where resource specialization supports the cost-effectiveness of utilizing specific tools.

3.2.3. Internal Efforts in Development of Analytical Processes, Methods and Models

This topic focuses on stakeholder development of their own tools, software-based models and resources, and the factors the influence these activities. In part, we are interested in understanding whether there is scope for the tools described to be made more widely available.

The need to develop bespoke or task-specific tools is inevitable in a technical discipline with such a variation of needs and scenarios. A&E firms noted that development of early-stage screening calculators was a priority, as were a range of tools for tasks such as pump sizing and part-load performance evaluation. In response to a lack of flexibility in publicly available tools, one company had designed a tool that supported live 'what-if' reviews, which is a powerful combination of analysis and communication tool; invaluable when dealing with tight project timelines and with busy partners and clients. Owner Operators typically focused on developing tools for planning, monitoring, and optimizing their DE systems, for techno-economic purposes (facilities management focus) or financial and forecasting methods (strategic focus). Above all, the need to continually collect and evaluate data, identify variance with design operations or fault issues, and promptly resolve them was a priority. Interestingly, the degree to which internally developed tools were leveraged, was directly correlated to the (largely) commercial tools, that they also used – their own tools would piggyback on these. The Owner Operator with the most sophisticated system of internally developed tools had (as described) the most sophisticated campus monitoring system. However, tools had been developed by all member of this group, including web-based data download tools and finance orientated models for evaluation of DE expansion opportunities. DE System Developers continued to adapt and develop their own tools over time – this reflected a need for transparency, flexibility and customized outputs, including graphical communication outputs. It was noted by this group that Microsoft Excel was almost always the basis for these tools due to its useability, facility for programming, and ease of auditing. In particular, adapting appraisal frameworks to include resilience, and evaluating Campus systems in a 'DE as a Utility' framework was highlighted. Municipal stakeholders highlighted efforts towards identifying project delivery frameworks and partnership arrangements, principally business planning. One notable addition to cost and risk reduction was development of an online 'e-permitting' tool – a process by which opening up the street could be coordinated with multiple utilities, so that the cost of excavation and installation might be shared. This approach also offers a path to detailed recording and mapping of new infrastructure (and that discovered during excavations for new projects).

Themes

A&E firms, Owner Operators and Developers invest significant time in developing their own task or project-specific tools. This is to be expected and is unlikely to decline due to the unique circumstances of projects – are all developed in response to analytical needs and may be either better and / or cheaper than the alternative publicly available option. As noted, transparency was also highlighted a significant consideration. Well-resourced entities have invested significant time and effort in developing tools that were either fully integrated with other tools they themselves have developed (which has many potential benefits, including training and skills development) or that integrate with their existing commercial packages. One recommendation received was that the degree to which tools can be modified for specific purposes be a priority criterion when evaluating options. Task-specific tools are where the potential opportunities lie – screening tools in particular are of significant value due to the high uncertainty around data inputs at the early stage. The importance of visual communication and live what-if demonstration to colleagues and clients was a common theme across all three stakeholders, especially in terms of appropriately capturing financial implications of variations in technical approach. Finally, historical project data archives were identified as an invaluable resource for future work whether for design (equipment cost, confirmed equipment efficiencies) or operations (trend data for optimization, M&V, FDD). For Municipalities and Building Developers, their focus on process and role as lead clients respectively precluded their need to invest significant time in this area.

3.2.4. Client Management

This topic focuses on engagement processes, including with the local community-at-large. Transparency and inclusivity are critical to good relationships, as is recognition of the significant inherent uncertainty in the early stages when many of the fine details are missing and information available is necessary high level.

All stakeholders noted that dialogue around expectations with partners and clients was a critical step in satisfactory relationships and outcomes, and that presenting results in terms of appropriate value ranges was the only responsible approach – in particular we were pointed toward the AACE International principles for costs and value estimates.[6] In a similar vein, the notion of 'accuracy' was also debatable in some settings – utilizing 8760 energy data for a particularly cold or warm year would not be a good basis for a financial or business plan, and therefore focusing on ranges or multiple scenarios that would help avoid the peril of spurious accuracy was advocated for, again by all groups. In approaching problems this way, there was an explicit recognition of the inherent uncertainty of analysis. There was greater transparency and trust as a result. The A&E firm group noted their use of design charettes as a

[6] https://web.aacei.org/docs/default-source/toc/toc_18r-97.pdf?sfvrsn=4

valuable way for many parties to share information, and importantly, utilize visual tools when framing a project. Assignments of criteria and weighting might also take place, as a precursor to multi-criteria analysis. The Owner Operator group noted that they prioritized data collection as soon as possible, and in one case, the DE system operator informed prospective customers of performance required of their facility in order to become a customer. The Municipal group noted that absent of the need to conduct their own early-stage analysis, they nevertheless were responsible for setting some of the context around system performance (largely environment-related) and developed necessary evaluation criteria to reflect these policies and regulations. They did also note that the use of visualization tools, including GIS-based mapping that captured the locations of energy sources and sinks was a valuable community engagement tool.

Themes

All stakeholder groups agreed that managing expectations and transparency around where key uncertainties lay was a critical facet of early-stage data analysis, and identifying where most meaningful progress could be made on projects. Visual tools were highly regarded, for both expert and lay project stakeholder groups.

3.2.5. Interpretation and Translation of Data / Information from Other Stakeholders

This topic focuses on communication between stakeholders and also between the technical and non-technical disciplines involved in project development. In particular, we asked about practices for presenting information to other stakeholders in the project team.

A&E firms said that communication of ideas, results and comparisons of valuation methods (i.e., simple payback versus lifetime cost assessment) was influenced by the audience, but that for relatively large infrastructure projects, there was value in steering clients and projects partners towards more long-term investment evaluation frameworks. For Owner Operators the issue of data translation and communication meant catering specifically to financial management within their own organizations, presenting information as data or graphical representations of data. A priority for DE System Developers was maintaining strategic communication between project partners and stakeholders, and so communication aids were critical tools, particularly those that aid crosstalk between technical and financial professionals. The Municipal group were typically focused on communicating with stakeholders and the community-at-large. One of this group had sought advice from an international organization, experienced in widespread implementation of district energy systems, in order to disseminate information at the appropriate level of detail, throughout the project development process.

Themes

Communication between stakeholders and professional disciplines was highlighted as incredibly important. Quantifying and communicating technical performance impacts (such as adjustments to system design or equipment item specification) that result from financial decisions is a critical tool in developing a common understanding of a projects opportunities and challenges, and smoothing the process of moving a project forward. In particular, live demonstrations of ‘what-if’ analysis, with supporting graphical outputs could be key in identifying the technical and financial sweet spot, with decision makers in the room. Feedback suggests that these kinds of tools are not currently available in the marketplace, and it is a case of organizations building their own (if they have the resources to do so).

3.2.6. Progressing from Ideas through Concepts through Designs to Execution

The section below focuses on the early stages of a project, when ideas and concepts are being developed, early-stage data collection is under way and there is high uncertainty about the way forward. Topics covered were the relatively ad-hoc nature of early-stage analysis methods, and how this dovetails with more formal structured tasks such as options appraisal or feasibility study analysis.

A&E firms identified their need for a high-level screening framework, and that they would look to deploy this at the earliest possible opportunity. This often reflected a need to provide recommendations to clients based on very little information. It was noted that this type of work was often low or zero-fee, as a first exploratory step for a potential project. At this level, outcomes would ideally be 'green light / red light' in terms of determining whether to invest further time in project development or not. It was suggested that plenty of projects fail to proceed due to the absence of this type of tool. This is at least in part because clients often expect this kind of early work to be zero-cost – a precursor to contracted work. The next step might be criteria development and weighting (analogous to, but possibly not to the level of detail required in MCDA TOPSIS) in preparation for scoring and ranking of options, that might feed into master planning efforts. The options ranking process would typically involve a larger group of stakeholders (i.e., not just the project team) and might include criteria proposed by the community-at-large, as well as reflecting local, state and federal policy, and financial objectives of project partners. Fine tuning of design would be tackled later, such as part-load performance, and in response to detailed cashflow modeling, where equipment capacity might be amended. It was also suggested that the complex Life Cycle Analysis landscape (need for use of multiple tools, many inputs) was a hindrance early on, and that a simpler LCA tool that used some rules of thumb, and required far fewer inputs would be of significant value. We suggest that as materials vetting and product sourcing become more prevalent in the construction industry, the value of such a tool to industry would only increase. Owner Operators typically approached questions around new system connections from a systems analysis perspective. This might include estimates of energy impacts of new connections, arrived at using building type and floor area as primary inputs, 'what-if' analysis that included evaluating peak and part load impacts of new connections and changes to, per unit costs of energy supplied, as outputs from system models, or be high level technical and cashflow analysis. Each of these methods would determine what project elements should be the focus of next steps (those with the highest uncertainty and greatest impact on outcome). It was noted that in the absence of system level analysis, Microsoft Excel was typically the workhorse for this type of analysis. Referring to databases of local buildings (typically system connections) helped understanding of the likely energy and demand need of these potential connections, but also an assessment of building energy systems currently in place. The latter point is very significant for estimating costs of connection – if a significant building retrofit is required to make it 'DE system ready', this needs to be understood early. As projects progressed and more detail became apparent, recognizing the inherent inaccuracy and uncertainty of costs and project value in the early stages is critical – referring to the AACE Cost Estimation Classification System is a best practice method for such an exercise. DE System Developers described a range of early-stage activities; agreeing key inputs and assumptions to be included in analysis, high-level cashflow and financial modeling, fine-tuning of end-user load profiles. Their path towards a project also reflects the fact that they may own or operate the system, and so focus early on determining and refining cost inputs, including options such as conducting investment grade audits. This reflects their perception of risk, because they often must invest significantly in prospects. Municipalities are focused on community engagement early on, and as projects progress, may become facilitators in developing relationships between projects partners, including establishment of appropriate project delivery vehicles. Building Developers typically indicated key metrics by which they, as clients, preferred to have potential projects evaluated from the outset.

Aside of the financial indicators (simple payback or net present value were typical), sustainability was a consideration (including a cost of carbon in evaluations done on their behalf was noted) as was net space loss / gain for options under consideration.

Themes

The informal, unstructured nature of early-stage project development dictates that analysis activities are specific to the project and the organization. The main theme is that all parties to projects are looking to identify opportunities that are unviable as early as possible. A&E firms expressed a desire for a high-level screening tool specifically for this purpose. A challenge that all stakeholders faced early on was the inherent uncertainty around many of the key input assumptions, and therefore, significant questions about project viability. Their approaches represent strategies that each has adopted to minimize this uncertainty as far as possible, given the often-limited information available. Each organization had a roadmap for resolving these early-stage issues, which reflected their role and exposure to risk arising from failure of the project, and also reflected their workflows later in the project development process. One emerging area of risk is around Life Cycle Analysis due diligence – A&E firms suggested that development of a high level LCA tool would be a valuable addition to their appraisal toolkit.

3.2.7. Recognizing and Allocating Risk (at Various Project Stages)

This topic focuses on the processes adopted by each of the stakeholders and groups when it comes to risk mitigation and management, and describes approaches that are present throughout the project development process.

The principal method for assessment of uncertain outcomes for projects by A&E firms was to conduct sensitivity analysis, with a focus on the key input variables with the greatest uncertainty and having the greatest potential impact of viability. These key inputs to these efforts were identified variously as local utility costs, fuel and commodities prices, and equipment and labor costs. In this context, an absence of referenceable utility price forecasts was noted as an ongoing challenge for several practitioners. When conducting DE system modeling, uncertainty and risk were often framed in terms of spare capacity (pipes and hydraulic connections), redundancy (plant capacity) and resilience (operating flexibility and islanding capability). Final outcomes (the conclusion of analysis) would typically be recorded in a risk register, a living document that can be updated as characteristics of and circumstances change. Monte Carlo analysis was considered to be an option at the financial or business planning stage, although some practitioners regarded it as specialized work, to be contracted out. Owner Operators adopted various strategies against major risks and uncertainties. To cover volatility in the utility price market, an option that didn't require modeling was to lock in prices in preference to short-term trading. It was also noted that a tool to model commodity costs and capture complexity of the rates and tariff structure would be useful, although it was recognized that this was likely only useful to short time horizons. Valuing resilience in monetary terms and determining unit parameters and metrics could assist in appropriately assigning value for project design elements that reflect the need to design for grid stability and service interruptions. For the purposes of presenting financial results internally, it was almost essential that models that used were developed internally due to the need for confidence in the appraisal method and process, and for transparency / ease of auditing. DE System Developers focused on fine tuning energy load profile inputs and financial models, in an effort to minimize uncertainty, and conducted ongoing scenario analysis and sensitivity analysis to assist with risk management. For Municipalities, the most significant risk was the opportunity cost of committing significant resources to a project that was ultimately unsuccessful. Their key areas of influence were around de-risking of capital investment and reducing uncertainty for investors by facilitating alignment of project timelines. Masterplans and Capital

Planning documents were their main risk mitigation tools. Building Developers prevailed on their project teams to manage their two key ongoing risk areas – energy supply reliability, and management of operating costs – via the design process, but also recognizing ownership models and business structures that they would steer away from.

Themes

Identifying uncertainty and managing risk is a well understood process for businesses and practitioners – one significant challenge is using appropriate values and ranges for inputs that may vary significantly. In this regard, an absence of long-term forecasting for fuel and utility unit costs and commodity process can create significant uncertainties and project risks. However, it is not clear to what degree any such long-term forecasts would be useful – even short-term forecasts are inherently incorrect, and the further out the time horizon, the greater the potential for variance as a result of market fluctuations or unforeseen events. There is also a question around the utility and central power generation markets – what will they look like in 10+ years' time?

3.2.8. Opportunities for Widely Applicable Processes, Methods and Models

The final topic identifies where the perceived gaps in the market are. Items perceived as gaps by some, are considered best practices by others, suggesting that there is an opportunity to capitalize on existing knowledge and a desire for more collaboration, where appropriate.

A&E firms suggested that an inventory of already-buried assets (including coordination with other utility / infrastructure providers) would always be valuable from a cost management and risk reduction standpoint. GIS datasets and visualization tools, for energy use and energy flows within a district would be a valuable resource, and a self-auditing tool for relating energy model inputs and outputs would be a valuable resource for young engineers. As noted in the previous section multi-year utility price forecast, including uncertainty analysis, continues to be a key concern. Iterative system optimization on the basis of thermal, electrical, and financial objectives is still not a reality. Effective coupling of and iterations on technical and non-technical evaluations, would support more informed decision making and help bridge the gap between technical and non-technical disciplines on these inherently complex projects. A standard, referenceable Life Cycle Analysis tool would be of significant value. As noted above, there is great need for an early-stage screening tool - doing quick, cheap analysis for a variety of clients, to answer early, high level questions. It was also noted that there due to the age and type of DE systems in the U.S., there was a lot of debate around conversion to lower temperature (hot water) systems – mathematical models would provide essential theoretical support to the case for these conversions. Owner Operators noted that a macro level tool to explore and evaluate interactions between heating, cooling and electric loads to produce load profiles depending on the fuel use mix for the respective end uses and identify peak load profiles would be a useful addition to their work flow. To facilitate early decision-making, a screening tool would be an obvious priority, for the purposes of estimating primary energy savings and for estimating requirements for projects in terms of plant and equipment. DE System Developers suggested a visualization tool linking sources and sinks, and that allowed the user to populate a zone of interest, with information on potential customers, existing energy assets, potential fuel sources, and indications of energy intensities (also reflecting local climate) for local candidate building connections. A GIS-based waste heat inventory by location, and characterizing availability in terms of key metrics is consistent with a Local Energy Economies philosophy, and would provide significant opportunities for 'outside the box' thinking for specific projects. This approach could also be applied to other resources, such as local waste biomass or energy crops, or mapping of local geology that supports potential significant geo-energy fields. As with other stakeholders, development of a screening tool was a suggested priority, for the purpose of identifying key questions for further analysis, and presenting high level results in terms of scale, installed technology, environmental performance, and in the context of the facilities proposed for connection. Municipalities suggested that a structured process or method for modularizing DE systems could contribute to overcoming the significant first cost barrier. Building Developers agreed that a high-level screening tool would be of value.

Themes

The items identified above are all included in a list of future research opportunities below, or as items that require greater dissemination to DE sector stakeholders. The suggestions run the gamut of tools for early-stage strategic decision-making, stop/go signals, techno-economic tools, and referenceable data sources.

4. RESEARCH FINDINGS

The main research outcomes, in terms of gaps in tool provision to the DE sector, are presented below. The first section outlines best practices identified during the expert elicitations, and these may apply to one of more of the stakeholder groups. Some of these were identified as gaps by individual stakeholders, which is a reminder that both capacity and capability varies within these groups. These suggestions all emanated from the expert elicitations. The second section outlines the gaps in tool provision — the main objective of this effort — and the list of future research priorities.

1. Recommended Best Practices

The expert elicitations highlighted the already-known fact that practices vary considerably in the DE sector, both across and within stakeholder groups. As described in the Themes sub-sections of 3.2.1, 3.2.2 and 3.2.3, this reflects a number of factors, including the size of a particular organization and the resources it allocates to DE-directed efforts. For resource constrained organizations, which within our cohort were mainly Municipalities and Owner Operators, this may lead to less optimal outcomes in terms of laying the groundwork for projects, optimizing operations, and appropriately planning for expansion, respectively.

Five main best practice recommendations that reflect these concerns around resource constraints, were identified:

1. Leverage the knowledge and experience of the many leaders in the field for all stakeholder group types, both the U.S. and overseas, to benefit U.S. practitioners. Learning from experts is a significantly underutilized opportunity and latent resource. Greater industry working group activity appears to be the single biggest change that would benefit the DE sector. In particular, it would offer the opportunity to leverage the other practices listed in points 2–5 below.
2. Disseminate underutilized business models and practices widely to help further open potential opportunities. There are multiple underutilized financial paths — already developed and practiced in other markets — to assist with development of DE systems, and particularly to offset the significant upfront capital cost barrier associated with these large-scale systems.
3. Assess and evaluate characteristics beyond business-as-usual – such as resilience and value of carbon, and incorporate the value of these new revenue streams and risk reduction strategies. This is essential in order to appropriately evaluate DE systems. Metrics that reflect these more novel characteristics should be developed and disseminated.
4. Develop and utilize economic evaluation frameworks specific to DE project challenges and opportunities, rather than the conventional business models from other sectors. Develop accompanying guidance materials that reflect these models and that address the challenges of (a) extended project buildout schedules and (b) infrastructure useful life significantly longer than conventional financial evaluation time horizons. It was suggested that 'DE-as-a-Utility' appraisal framework may be most appropriate.
5. Effectively communicate the benefits of DE to policymakers and potential investors, to spur its future growth.

The following specific areas were suggested as future research topics, but we know of examples where each of these is currently being practiced:

- Project information hubs, for coordination, standard setting, and information sharing: Metropolitan Area Planning Council, Boston MA

- Resilience modeling and evaluation: various locations, including Berkeley Lab and Sandia National Laboratories
- Value engineering impact assessments: various, including Gordian (construction management)
- Buried services coordination: Metropolitan Area Planning Council, Boston MA

As specific existing practices, they require dissemination into the DE sector. With appropriate resourcing, each could become standard practice in instances where they add value. Each is included in our recommended practices summary in Appendix D.

A full list of best practices identified in the expert elicitations also can be found in Appendix D.

2. Priority Areas for Future Research

- GIS data and visualization tools, to represent energy use and energy flows within a district
- A self-auditing tool for relating energy model inputs and outputs
- A multi-year utility price forecast, including uncertainty analysis
- System optimization on the basis of thermal, electrical, and financial objectives (integrated TEA)
- A standard, referenceable life cycle analysis tool
- An early-stage screening tool
- Mathematical models to support the case for conversion of older legacy systems
- A tool to explore and evaluate interactions between heating, cooling, and electric loads
- A visualization tool linking sources and sinks
- A GIS-based waste heat inventory by location
- A systematic process and method to assess feasibility of district energy for developments and buildings under review as a part of their sustainability review process
- A process or method for modularizing DE systems

<u>Questionnaire on Research Topics</u>

We included the proposed research topics above in our questionnaire to a large cohort of DE sector professionals, in order to prioritize and rank suggested topics. The questionnaire was not designed to conduct statistical analysis — respondents were allowed to respond to as many or as few topics as they wanted. Each response to a suggested topic generated an individual score input of 1 for that topic. Each topic was weighted equally, so n responses for topic 1 and n+1 responses for topic 2 would mean a higher score by the value of 1, and a higher rank, for topic 2. Our priority was to understand the degree to which suggestions were perceived more widely as research topics worth pursuing.

The questionnaire was distributed to approximately 9,125 individuals who are members or industry contacts of the IDEA, and we received responses from 197 individuals. Respondents were from a wider group of stakeholder types than those represented in our expert elicitations. Summary results from the questionnaire are outlined below.

Questionnaire Responses

The bar chart in Figure 3 represents responses to research topic suggestions from our expert elicitations. Overall, it is clear that all of the suggested topics met with agreement from the questionnaire respondents, and therefore in principle, all represent potentially worthwhile future research areas. It is also worth noting that the majority of responses came from just two stakeholder types — A&E firms and Owner Operators. A full breakdown of respondents by stakeholder type and job title can be found in Appendix C.

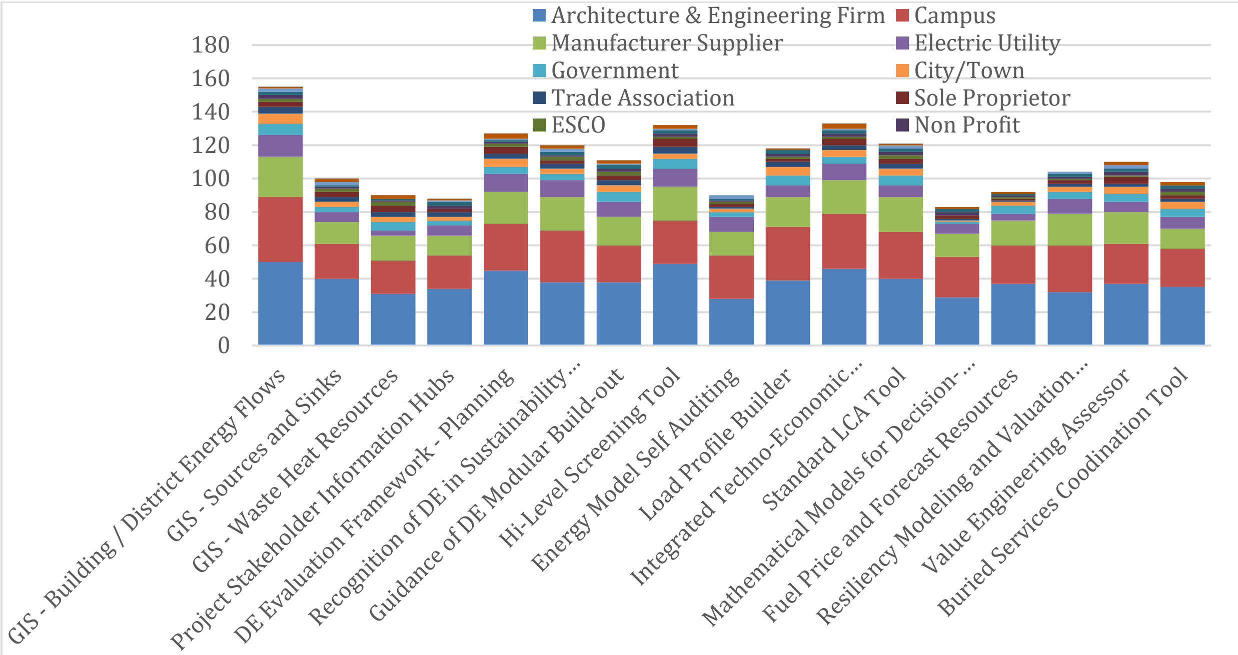


Figure 3: Questionnaire Responses to Research Topics Suggested via Expert Elicitations

Research Priorities: Short List

The research priorities (top 5 ranked), according to total questionnaire responses, are as follows:

- GIS datasets – Building / District Energy Flows (n = 155)
- High-Level Screening Tool (n = 132)
- Integrated Techno-Economic Analysis (n = 133)
- DE Evaluation Framework – Planning and Policy (n = 127)
- Standard LCA Tool (n= 121)

The results according to ranking by stakeholder group are presented in Table 4 below. Note that where there are identical rankings for more than one topic for a particular group, the number of responses to those topics were identical.

Table 4: Ranking of Priority Research Topic by Stakeholder Group[7]

Stakeholder Group	GIS Datasets and Visualization of Thermal Energy at the Building / District Level	System Optimization to Thermal, Electrical AND Financial Objectives	High-Level Screening Tool	DE Evaluation Framework – Planning and Policy	Standard, Referenceable LCA Tool
Architectural / Engineering Firms	1	3	2	4	5
Owner Operator (Campus)	1	2	8	5	5
Manufacturer	1	3	3	6	2
Electric Utility	1	4	2	2	9
Government	1	10	2	10	2
City / Town	1	4	9	2	4
Trade Association	1	3	1	3	3
Sole Proprietor	6	2	1	2	6
ESCO	1	9	9	1	1
Non-Profit	1	1	1	11	1
Operator	1	1	1	13	1
Unspecified	1	7	7	7	1
National Laboratory	10	1	3	1	10
Overall Ranking	**1**	**2**	**3**	**4**	**5**

One conclusion is that generating appropriate GIS-oriented datasets should be a research priority — it is the number 1 ranked choice for all but two of the responding groups. Open responses to the questionnaire — entered in comment fields — further support this conclusion. Generating datasets that could be utilized by the various software options (such as QGIS and ArcGIS) is the main open comment recommendation.

The other top scoring topics are broadly aligned with feedback from the two best represented stakeholder groups: A&E firms and Owner Operators. Two conclusions can be drawn here: (1) there is consistency around the tools needed within each of these two stakeholder groups, and (2) these needs

[7] A full breakdown of questionnaire responses can be found in Appendix B.

are somewhat aligned between those two groups. It is not possible to state with any certainty that the ranked order would be the same if other stakeholder groups were better represented.

Included in the open responses were comments related to two more of the top five ranked research topics. The concept of a high-level screening tool prompted various suggestions of what such a tool might consist of, from applicability at the early pre-master planning stage (where it would be a good potential fit for A&E firms, Developers, and Municipalities) through to plant sizing and optimization (which applies more to modeling). For the early-stage case, one sample example that was shared is from the GeoFease organization, which will conduct zero- / low-cost analysis for potential applications of ground source heat pump applications. Reviewing what other entities offer within the current market will provide a better idea of where the opportunities and gaps are; this kind of market assessment and scoping exercise would be an important prerequisite to efforts in this area. Life-cycle assessment tools also were explicitly called out separately in brief comments, and this is a direction that market leaders are heading. It should be noted that there already resources available in this area, but the questionnaire responses suggest these may not be sufficient for the DE sector.

Table 5: Priority Research Opportunities and Descriptions:

Topic	Barrier or Opportunity	Opportunity and Research Focus
Graphical Information Systems (GIS) Datasets for DE Systems Potential Assessment	GIS datasets were identified as having significant value in evaluation of opportunities in terms of connecting sources of energy demand to locations of demand.	Suggestions include data on thermal energy demand at the building level, potential sources of local waste heat (such as from wastewater treatment facilities), and approved air permits (related to fuel combustion). This activity would be relevant to both the implementation of new DE systems and expansion / modernization of existing ones. To focus GIS data collection efforts, confirming locations / geographies where DE is cost-effective via TEA would be a valuable precursor.
High-level screening tool	Decision-making tools that are simple to use and workable with limited data and/or information, are invaluable. The earlier that a field of options can be narrowed, the better.	A number of stakeholder groups referred to the need for screening tools as a valuable asset in DE system appraisal. Needs would vary according to intended user group(s), in terms of key objectives, inputs, outputs, and data analysis processes.
DE optimization to account for thermal, electrical and economic objectives	System optimization is typically conducted at the detailed feasibility study stage via techno-economic analysis and then tweaked thereafter in design or value engineering processes. This process does not take into account financial or business priorities. Financial decisions taken after design has been completed (such as via the Value Engineering process) may fail to capture the impact of these decisions via a further iteration of technical appraisal.	Functionality that supports user ability to toggle between priorities/objectives in terms of technical and financial performance metrics to achieve specific goal(s) is not currently available to the best knowledge of the project team's stakeholders. This would be a valuable addition to the tool box in supporting iterative analysis and co-optimization.
LCA framework	LCA data and supporting assessment frameworks exist, but feedback suggests that users require signposting and guidance on how to best utilize these disparate services in a coordinated manner.	Consolidation of resources from current service providers (such as Athena Sustainable Materials Institute [ASMI], for construction and GREET [Argonne National Lab]) for fuels and feedstocks, into a single online location would be helpful for supporting streamlined LCA-based decision-making during project development.

5. Appendix A - Expert Elicitation Questions

Summary of Expert Elicitation Participants

Stakeholder Group Type	Number
Architectural and Engineering Firm	5
Owners and Operator	7
DE System Developer	3
Municipality	3
Building Developer / Owner	2

Process

We requested each of the expert stakeholders contacted to meet with us to set aside an hour of their time to answer our structured questions and to cover other topics as they arose on an ad-hoc basis. In each case, the experts that accepted our invitation agreed to this request. Meetings were conducted via Zoom videoconference and typically involved two people from the LBNL team and one from IDEA.

Structured Questions

What types of tools does your organization utilize when it comes to developing DE projects?

What are the main barriers that you encounter in their use?

What tools have you developed in-house, and what were the main reasons for this?

How do you approach data accuracy according to project progress and manage expectations of other project stakeholders?

What are your main tools and strategies when it comes to communicating with other project stakeholders, including interpretation and translation of information and data?

How do you take early stage (high uncertainty) engineering and financial information and utilize it to create preliminary scenarios and outcomes?

What approaches do you utilize in mitigating risks at each project development stage?

Where should effort be focused when it comes to developing new tools and resources?

6. Appendix B – Questionnaire Structure and Response Options

Our project team at Lawrence Berkeley National Laboratory and IDEA have been speaking with industry experts to gather perspectives on the availability of appropriate tools and resources for development of district energy projects. The aim of this questionnaire is to better understand and contextualize the feedback that we've had from the relatively small sample of industry experts that we've engaged with directly. Responses are completely anonymous – as a consequence the results will not be shared with the respondents.

The industry experts and practitioners we have spoken with suggested that the following capabilities/practices would be a valuable addition to DE project development and decision making in the early-stage analysis/appraisal phase. Please tick options that apply to you in each category.

1. GIS CAPABILITIES

- o GIS dataset and visualization of energy balance and thermal energy inputs / outputs at the individual buildings <u>and</u> aggregated district level
- o GIS dataset and visualization for energy sources and sinks
- o GIS dataset and visualization for industrial / commercial waste heat resources
- o Other (please provide brief details): ___________________________
- o NA

2. DE AND SUSTAINABILTY PROVISION, FRAMEWORKS, MODULAR BUILDOUT AND DOCUMENT HOSTING

- o Online hub hosting foundational documents and key reference inputs, supporting consistent analysis by all stakeholder groups
- o Evaluation framework for district energy within planning process
- o Provisions for district energy in sustainability review processes
- o Guidelines and recommendations for modular build-out of DE systems
- o Other (please provide brief details): ______________________
- o NA

3. TOOLS FOR ENERGY MODELING AND HIGH-LEVEL SCREENING

- o A high-level screening tool for DE options
- o A self-auditing tool for energy modeling
- o A fuel-flexible load profile builder (i.e., heat load profiles that toggle between electrical and thermal sources)
- o Other (please provide brief details): ______________________
- o NA

4. TOOLS FOR DECISION MAKING AND OPTIMIZATION

- o A tool for optimizing to thermal, electrical <u>and</u> financial objectives
- o A standard, referenceable life cycle analysis tool
- o A mathematical model-based decision-making tool (to resolve, for example, steam to hot water conversion)
- o A referenceable resource for fuel prices and price forecasts
- o Other (please provide brief description): _____________________________
- o NA

5. **TOOLS AND CAPABILITIES FOR REDUCING COSTS, AND MITIGATING RISK IN DE PROJECTS.**

- o Resiliency modeling tool or plug-in
- o Appraisal tool for assessing value engineering impacts
- o Coordination tool for reducing costs of buried services installation
- o Other (please provide brief details): _________________
- o NA

6. **A main objective of this project is to understand which stakeholder groups and tasks are well resourced in terms of analysis and which are not. From the list below, please indicate which broad areas could be better provided include a brief description of the desired tool or capability.**

Criteria for evaluation (please provide brief details): _________________
Processes (please provide brief details): _________________
Methods (please provide brief details): _________________
Metrics (please provide brief details): _________________
Business and Financing (please provide brief details): _________________

7. **STAKEHOLDER GROUP TYPE**

Please indicate your stakeholder type within the DE industry

- o A&E firm
- o DE System Owner and Operator
- o DE Developer
- o Municipality
- o Utility
- o Building Owner / Operator
- o Other

8. **Please add any other specific comments pertaining to this topic that you may have:**

Comment Box (Any Submission Welcome) _________________

7. Appendix C – Breakdown of Questionnaire Responses

The pie charts in Figure 4 and Figure 5 below indicate the breakdown of respondents by stakeholder group type and by role in their organization. Figure 3 illustrates that our expert cohort overlaps significantly with our questionnaire cohort - 2 groups – Architectural and Engineering Firms (n=68, 35%), and Campus - Owners and Operators (n=47, 24%), Municipalities (n=6, 3%), represent over 60% of the responses. The Manufacturers group is the largest responding group that weren't included in our expert elicitation cohort, representing 17% (n=34). All other stakeholder groups each comprise less than 10% of the responses – Electric Utility (n=16, 8%), Non-Profits and Government (n=10, 5%), Trade Associations (n=4, 2%), National Laboratories (n=3, 2%), and ESCO's (n=2, 1%). The Sole Proprietor and Private Operator groups, which are unspecified stakeholder types, together contribute 3% (n=7).

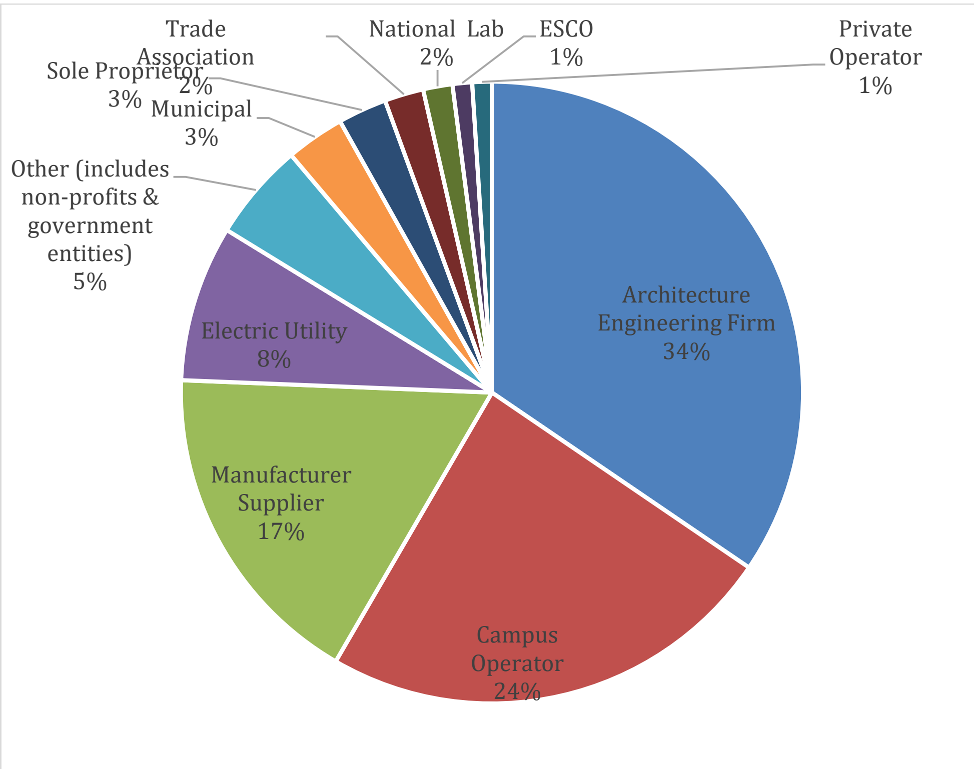


Figure 4: Questionnaire Responses by Stakeholder Type (n=197)

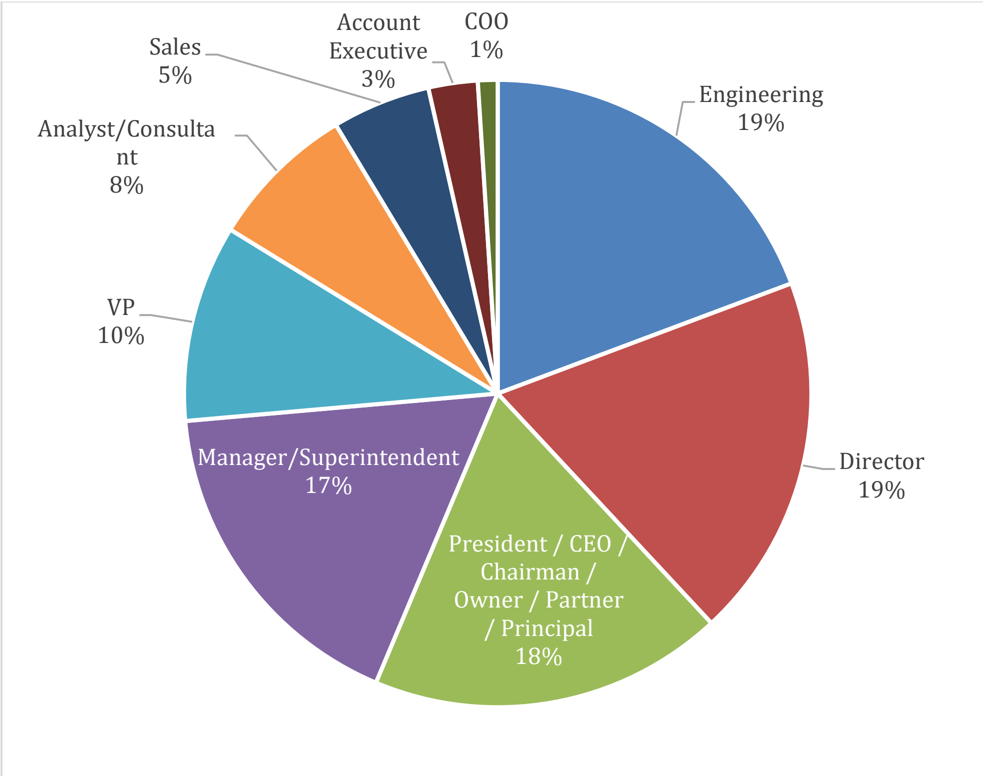


Figure 5: Questionnaire Responses by Job Title (n=197)

Table 6: Questionnaire Responses for Each Proposed Research Topic, By Number of Responses

	GIS dataset and visualization of energy balance and thermal energy inputs/outputs at the individual buildings and aggregated district level	GIS dataset and visualization for energy sources and sinks	GIS dataset and visualization for industrial/commercial waste heat resources	Online hub hosting foundational documents and key reference inputs, supporting consistent analysis by all stakeholder groups	Evaluation framework for district energy within planning process	Provisions for district energy in sustainability review processes	Guidelines and recommendations for modular build-out of DE systems
	GIS - Building / Distri	GIS - Sources and Sin	GIS - Waste Heat Re	Project Stakeholder I	DE Evaluation Frame	Recognition of DE in	Guidance of DE Mo
Architecture & Engineering Firm	50	40	31	34	45	38	38
Campus	39	21	20	20	28	31	22
Manufacturer Supplier	24	13	15	12	19	20	17
Electric Utility	13	6	3	6	11	10	9
Government	7	3	5	3	4	4	6
City/Town	6	3	3	2	5	3	4
Trade Association	4	3	3	3	3	3	3
Sole Proprietor	3	3	4	2	4	2	3
ESCO	2	2	2	0	2	2	2
Non Profit	2	1	1	2	1	1	2
Operator	2	1	1	2	1	2	2
Unspecified	2	2	0	1	1	2	1
National Lab	1	2	2	1	3	2	2
Total Responses	**155**	**100**	**90**	**88**	**127**	**120**	**111**

	A self auditing tool for energy modeling	A fuel-flexible load profile builder (i.e. heat load profiles that toggle between electrical and thermal sources)	A tool for optimizing to thermal, electrical and financial objectives	A standard, referenceable life cycle analysis tool	A mathematical model-based decision making tool (to resolve, for example, steam to hot water conversion)	A referenceable resource for fuel prices and price forecasts	Resiliency modeling tool or plug-in
	Energy Model Self Au	Load Profile Builder	Integrated Techno-E	Standard LCA Tool	Mathematical Mode	Fuel Price and Foreca	Resiliency Modeling a
Architecture & Engineering Firm	28	39	46	40	29	37	32
Campus	26	32	33	28	24	23	28
Manufacturer Supplier	14	18	20	21	14	15	19
Electric Utility	9	7	10	7	6	4	9
Government	3	6	4	6	1	5	4
City/Town	2	5	4	4	1	2	3
Trade Association	1	3	3	3	1	1	2
Sole Proprietor	2	2	4	3	2	1	2
ESCO	1	1	1	2	0	1	1
Non Profit	1	2	2	2	2	1	1
Operator	1	2	2	2	2	1	2
Unspecified	2	0	1	2	0	0	1
National Lab	0	1	3	1	1	1	0
Total Responses	**90**	**118**	**133**	**121**	**83**	**92**	**104**

Table 7: Questionnaire Responses for Each Proposed Research Topic, By Number of Responses Rank

	GIS dataset and visualization of energy balance and thermal energy inputs/outputs at the individual buildings and aggregated district level	GIS dataset and visualization for energy sources and sinks	GIS dataset and visualization for industrial/commercial waste heat resources	Online hub hosting foundational documents and key reference inputs, supporting consistent analysis by all stakeholder groups	Evaluation framework for district energy within planning process	Provisions for district energy in sustainability review processes	Guidelines and recommendations for modular build-out of DE systems
Architecture & Engineering Firm	1	5	15	13	4	8	8
Campus	1	15	16	16	5	4	14
Manufacturer Supplier	1	15	11	16	6	3	10
Electric Utility	1	12	17	12	2	4	6
Government	1	14	6	14	10	10	2
City/Town	1	9	9	14	2	9	4
Trade Association	1	3	3	3	3	3	3
Sole Proprietor	6	6	2	10	2	10	6
ESCO	1	1	1	16	1	1	1
Non Profit	1	11	11	1	11	11	1
Operator	1	13	13	1	13	1	1
Unspecified	1	1	13	7	7	1	7
National Lab	10	3	3	10	1	3	3
Rank	**1**	**11**	**14**	**16**	**4**	**6**	**8**

	A self auditing tool for energy modeling	A fuel-flexible load profile builder (i.e. heat load profiles that toggle between electrical and thermal sources)	A tool for optimizing to thermal, electrical and financial objectives	A standard, referenceable life cycle analysis tool	A mathematical model-based decision making tool (to resolve, for example, steam to hot water conversion)	A referenceable resource for fuel prices and price forecasts	Resiliency modeling tool or plug-in
Architecture & Engineering Firm	17	7	3	5	16	10	14
Campus	8	3	2	5	10	12	5
Manufacturer Supplier	13	9	3	2	13	11	6
Electric Utility	6	9	4	9	12	16	6
Government	14	2	10	2	17	6	10
City/Town	14	2	4	4	17	14	9
Trade Association	15	3	3	3	15	15	12
Sole Proprietor	10	10	2	6	10	17	10
ESCO	9	9	9	1	16	9	9
Non Profit	11	1	1	1	1	11	11
Operator	13	1	1	1	1	13	1
Unspecified	1	13	7	1	13	13	7
National Lab	16	10	1	10	10	10	16
Rank	**14**	**7**	**2**	**5**	**17**	**13**	**10**

8. Appendix D – Industry Best Practices: Tools, Resources and Metrics

Based on our expert elicitations, activities identified in Table 8 below represent practices that support development of DE systems. Each of these items represents a tool or activity that stakeholders utilize to support the case for DE. Each item was identified during the expert elicitations, and it was often clear that these practices might apply to or be priorities for other stakeholder groups – the table highlights a) who identified the practice and b) which of the other stakeholder groups might benefit from such a practice. All of the topics listed constitute opportunities for industry working groups to lead improvement in the DE sector.

Key for Table 6:

<u>Stakeholder Groups</u>

AE: A&E Firms
OO: Owner Operators
DV: DE System Developers
MN: Municipalities
BD: Building Developer

Table 8: Best Practices in the DE sector by stakeholder group

Themes	Best Practices Description	Identified by:	Also important to: AE	OO	DV	MN	BD
Planning and Policy Making in the DE Realm	• Craft FAR (Floor Area Ratio) to incentivize connections to DE	MN					X
	• Empower local government decision makers to steer early-stage project development by investing in dedicated planning tools and resources	MN					
Inherent challenges associated with DE buildout and uncertainty	• Collaborate with DE experts (including learning from foreign experience) to propel development	MN		X	X		X
	• Incorporate thermal energy mapping as a key input to high-level assessments, and policy and decision making	MN			X		
	• Develop metrics that recognize value of load diversity at the multi-building / district level	OO	X		X		
Capacity building in the DE industry	• Develop the necessary resources for building capacity and capabilities of the DE sector, including technical support, and key reference material for developing engineers.	AE		X	X		
Data collection and visualization	• Establish / curate data from implemented projects and operating DE systems, including ○ Building EUI by end use ○ Capital cost	AE / DV		X		X	

Themes	Best Practices Description	Identified by:	Also important to:				
			AE	OO	DV	MN	BD
	○ Historical and current energy prices						
	• Prioritize compilation of GIS data files as key infrastructure - for purposes of future construction and disaster response	AE / OO			X	X	
Easy to use tools that produce robust results for high-level analysis	• Adopt multi-stakeholder charettes as a key early design task	AE		X	X	X	
	• Adopt suitable metrics to determine go/no-go decisions in early stages of analysis	AE			X		
Simplifying early project assessment	• Categorize and characterize project benefits by technology / scale / location / pollutant	DV	X	X		X	
Challenges to commercial tool usage	• Customize commercial tools to suit specific needs where possible	AE / DV			X		
Incorporate multiple perspectives in design of DE systems	• Require input from plant operators in controls and sequencing design	OO			X		
	• Require commercial tool vendors in the design and construction process where appropriate	OO			X		
	• Require analysis by consultants be conducted utilizing tools and software familiar to client users	OO			X		
Linking technical and financial analysis	• Execute reviews of and revisions to financial / business and contractual objectives regularly	AE / OO			X		
	• Appropriately value property and assets (i.e., units of energy savings may be low, labor high, research material highest).	AE		X	X		
	• Determine the negative worth of value engineering and positive costs of avoiding it	AE		X	X		
	• Identify and confirm appropriate technical performance metrics for simple translation into financial analysis	AE		X	X		
Appropriate financial methods and metrics	• Perform lifetime cost analysis rather than a cost benefit analysis / simple payback calculation. Include lifecycle cost assessments.	MN / BD	X	X	X		
	• Equate DE Systems as utility-type investments, incorporating all possible cashflows in valuation	DV	X	X			

Themes	Best Practices Description	Identified by:	Also important to:				
			AE	OO	DV	MN	BD
Tools and methods to facilitate communication between stakeholders	• Establish goals at onset of project, for continuous reference throughout	AE		X	X	X	
	• Centralize relevant data and information in an online repository, including key reference documentation and agreed inputs to for analysis	MN	X		X		
	• Prioritize graphical data representations to ○ ensure effective communication ○ sense check client data	AE		X	X	X	
	• Demonstrate input-output sensitivity and impacts to project stakeholders in a live setting	DV	X	X		X	
Appropriate preparation for unforeseen events	• Plan for resilience from the outset of a project	DV	X	X		X	
	• Appropriately value district energy in a resilience context	MN					
	• Adopt industrial standards and operating practices to increase system resilience	OO					
Maximizing opportunities for cost/risk reduction	• Appropriately value lettable space gains under a DE case	OO / BD					
	• Prioritize coordination of major public works	MN	X	X	X		
	• Select robust, flexible technology options that perform over a range of scenarios	AE		X	X	X	
	• Limit use of commodities and market data only for near-term utility price forecasting	OO			X		
	• Respect the 1:10:100 rule - spend money and time on the design aspect of a project to avoid later costs	AE		X	X		
Optimization of DE plant operation	• Identify and mitigate barriers (technical and legacy contractual) for purposes of improving system operating efficiency	DV		X			
	• Conduct data repopulation and continuous review of a real-time hydraulic models	OO			X		
Operational Data visualization and analysis	• Develop and implement a system-wide GUI (energy portal) which indicates current and historical EUIs of thermal energy customers	OO					

Appendix E – Other Research Topics of Interest

Below is a summary of additional research topics of interest identified in the expert elicitations. These topics were not as highly scored and ranked in our questionnaire responses.

Table 9: Other Topics of Interest

Topic	Barrier or Opportunity	Proposed Research Focus
Technical Appraisal and Data Analysis		
Load Profiling Tool	Determining the impact of thermal energy in terms of overall peak condition and in terms of necessary energy supply and production resources continues to increase in importance. The tool needs to provide capability for aggregating thermal and electric loads and juxtaposing heating and cooling loads to provide analysis for supply options.	More research is needed to support quick, simple assessments of load conditions according to primary fuel type and energy production unit type. This will need to take into account 1) local conditions 2) available thermal energy options and 3) environmental implications of each option at site and source level and 4) in the move towards electrification, will be an important method to weigh energy source.
Supporting Pathways to Low and Zero-Carbon DE		
Addressing end of life district systems	Aging DE systems represent a unique opportunity to expand and repurpose them to enable LEE. Transitioning steam DE systems to hot water reduces energy losses in the distribution system, lowers maintenance costs, and can allow for coupling with low-grade thermal resources.	Further research and analysis needed to support decision-making around the modernization or replacement of aging DE (DH) infrastructure. In particular, data on the vintage, fuel type, and technologies used in DE systems are needed to target these unique opportunities for DE system upgrades and potential expansion. In particular, mathematical models would be a valuable addition to decision-making tools for switching to more efficient DH system operating temperatures.
Financing		
Address the challenges of financing high capital cost projects	DE systems are inherently expensive complex infrastructure, that don't begin to repay the capital until completed (typically 2+ years), and are often compared against low-cost alternatives that do well on simple payback, which is the first cut metric of choice.	Financing options exist that allocate cost and risk to appropriate project partners, but more research is needed to identify additional zero-first-cost financing options that could disrupt the DE market. A comparison of Payback vs LCA and highlighting drawbacks of not allowing for long-lived DE system assets will be useful for financiers.

Topic	Barrier or Opportunity	Proposed Research Focus
		Building developers like payback because they don't think in terms of 40 years life of building.
Cross-Cutting / Strategic		
Modularity, Flexibility, Future-Proofing and Resilience	Evaluation, demonstration and communication of valuable characteristics inherent to DE systems, to key stakeholders, such as Municipal Planners, Building Developers, Utilities	Research and analysis are required to characterize and quantify value of flexibility and responsiveness associated with a) on-site electrical generation (with gas engine CHP, black-start and island mode operation are not uncommon) and 2) district-scale thermal load controls and diversity, including use of large-scale (multi-Megawatt) thermal storage, in terms of demand response and grid services. In the context of resilience, DE systems have the capability to meet the needs of critical local facilities supplied directly, and provide support to electrical infrastructure at the local distribution network level. Tools that explore multiple satellite DE plants as an option to a single central plant are useful under Greenfield, current system expansion or end of life modernization scenarios.
DE System Simulation		
Modeling of electrification	Perceptions of electrification as a pathway to a zero-carbon energy future vary significantly. Some believe that it carries significant uncertainty and risk, due to the need to further load already constrained infrastructure.	As DE systems begin to move towards use of electrical energy production technologies to meet thermal energy services, more research is needed to determine implications of their deployment on electrical system flexibility, carbon intensity, security of supply, and resilience.

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