Cognitive
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Energy Management in Large Enterprises: A Field Study

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Executive summary

This report summarizes preliminary results from a field study of energy managers in large enterprises conducted in the winter of 2008-2009. Funding was provided by the Ontario Centre of Excellence for Energy through its Interact Program, designed to support new, short-term, applied problem-solving interactions between industry and research partners. The study is a collaboration between the University of Toronto, the Association of Major Power Consumers in Ontario and AITIA Analytics Inc.

Energy Managers at large industrial enterprises and other experts were interviewed to understand the complex and multidisciplinary challenges of industrial energy management. The study identified two fundamental processes in energy management:

- Developing information through deliberation and modeling – an active, collaborative process of seeking data and formulating analyses to develop answers to business questions
- Communicating this information across frames of reference – converting between the perspectives, vocabulary, and reasoning frames of people at all levels of an enterprise

Energy managers integrate operational and energy-related information and translate it into business-relevant information that can be applied by operators and managers. Energy managers at large industrial enterprises must cope with:

- Uncertainty – operational and energy systems are complex and never completely understood,
- Change – markets and industries are dynamic; information must be maintained or lose value,
- Collaboration – energy managers must establish the credibility of tools and recommendations.

To be effective, information technology tools must aid the energy manager in managing this complexity. Model assumptions, algorithms and recommendations must reliably be compared against qualitative expertise, inexpensively updated to reflect changes, and easily assessed by colleagues. Otherwise maintenance or engagement burdens will limit the scope, pace, and persistence of energy managers' work.

Supporting energy managers in translating effectively, quickly, and between broader audiences is an under-explored opportunity for energy management information technology. For many industries it may present an alternative to extensive investments in metering and modeling.

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Glossary

Abbreviation	Title
AMPCO	Association of Major Power Consumers in Ontario
CIPEC	Canadian Industry Program for Energy Conservation
EMO	Energy Management Opportunity
IT	Information Technology
NRCan	Natural Resources Canada
USDOE	United States Department of Energy

1 Study Overview

This report summarizes findings from interviews of nine energy managers, six energy management consultants and three program developers. Questions addressed energy management expertise, business processes, deliverables and the role of information technology. This section explains the study's motivation, scope and methodology, and provides an overview of some observations. More detailed observations are collected in the Appendix, Section 4.

1.1 Motivation

This study was sponsored by the Ontario Centres of Excellence (OCE), the Association of Major Power Consumers in Ontario (AMPCO) and AITIA Analytics Inc:

- OCE's mandate is to enable research with potential benefit to Ontario's competitiveness, for example by supporting more widespread and effective energy market participation.
- AMPCO's mission is to advocate for reduced costs and improved service for industrial electricity customers in Ontario.
- AITIA's goal is to inform, engage, and empower energy consumers to manage risks, reduce costs, and create opportunities for more effective energy management.
- The University of Toronto Cognitive Engineering Laboratory's mission is to study complex work environments and how information technology can support their safe and profitable operation.

This work aims to support the overlap between these interests: collaborative development of information technologies to support effective participation in energy markets by large industrial enterprises in Ontario.

1.2 Scope

The scope of this study addresses:

1) Energy managers' background, aptitudes and experience,
2) Cognitive work involved in energy management business activities,
3) Information technologies used to support this work.

The intent is to study interactions between energy managers and information technology, and the factors that influence their effectiveness. This study was conducted from a systems engineering perspective and may under-estimate the role of organizational and policy decisions considered by management studies.

Finally, rather than investigating each participant's particular circumstances, this study attempted to identify experiences common to many sectors or capture systematic differences.

1.3 Methodology

Interview requests were sent to AMPCO members, consultants, electricity agency professionals, and to British Columbia energy managers recommended by the provincial utility. The intent was to keep interviews representative of the range of energy management, but participants certainly reflect some self-selection bias.

Participant	Energy...	Sector
A	Manager	Manufacturing
B	Manager	Institution
C	Manager	Institution
D	Manager	Manufacturing
E	Manager	Manufacturing
F	Manager	Manufacturing
G	Manager	Manufacturing
H	Manager	Municipality
I	Manager	Manufacturing
J	Program	Distributor
K	Program	Agency
L	Program	Agency
M	Consultant	Various
N	Consultant	Various
O	Consultant	Markets
P	Consultant	Various
Q	Consultant	Systems
R	Consultant	Various

Table 1 – List of participants, with information removed for confidentiality. Referenced by letter, e.g. (A)

An Industrial Engineering PhD student conducted the interviews over the course of two months, most in person and the remaining third by telephone. Interviews were semi-structured, and questions were altered and developed as the study progressed. Later participants also completed a questionnaire.

1.4 Observations

The opportunistic nature of the interviews resulted in varied discussion topics and observations that we structured in terms of a rough descriptive model of energy management activities, presented in Figure 1.

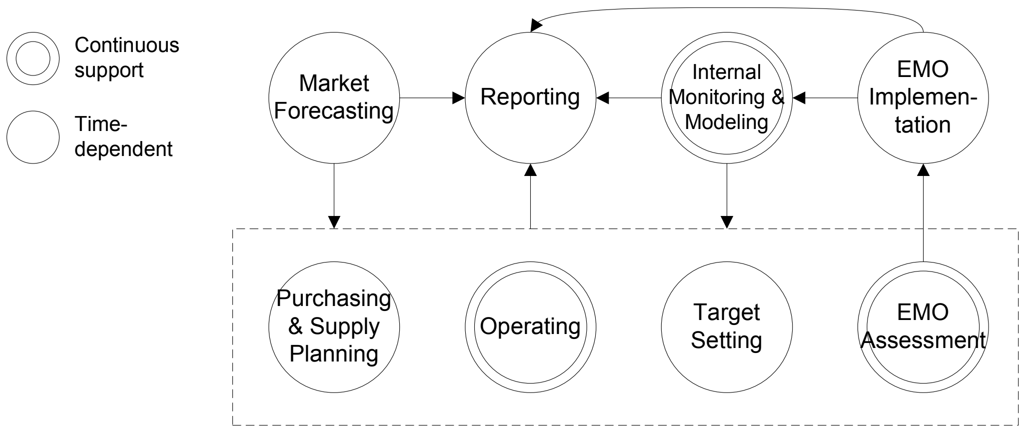


Figure 1 – Common types of energy management activites, with information flows

Circles in Figure 1 represent common recurring decision-making activities; arrows represent information flows that support activities. Market Forecasting, for example, develops information that is used to support the activities in Table 2.

Activity	Uses information about forecast:
Purchasing & supply planning	Energy spot prices
Operating	Timing of provincial electricity system peak
Target setting	Yearly mean prices
Energy management opportunity (EMO) Assessment	Energy prices over life-cycle

Table 2 – Example information flows for market forecasting activities

This rough classification is expanded further and used to organize specific observations in section 4.

2 Common Themes

Energy management varies substantially across enterprises. The common tasks described above are subject to high local variation. National-level agencies provide a broad perspective of core energy management themes, such as linking energy to opaque costs, with limited time and resources (Carbon Trust 2007) or ability to “decipher [energy] information in order to make good energy and business decisions” (Hooke, Landry & Hart 2003 p.2). The role of linking and explaining costs also recurred in participants’ interviews, where an energy manager’s role was described as a “communications bridge … a technical person who can bridge multiple worlds in a generalist sort of way from a position of credibility” (Participant K). The next sections present four recurring themes drawn from the interviews, and implications for future energy management information technology.

2.1 Uncertainty and understanding

The profile of energy use at an industrial enterprise encodes patterns from every production process and disturbance. Interpretation of this data is highly uncertain without deep understanding. Energy managers seek to develop an understanding that is 1) accurate enough to make intelligent business suggestions, and 2) shared widely enough to produce organizational action. To develop this, they consult three resources: their colleagues, themselves and their models.

Energy managers' colleagues develop understanding situated in their experience with operational and market processes. To pool this situated understanding, some enterprises maintain energy management committees as a communications venue (B,E,I). Others rely on energy managers seeking out colleagues to elicit and distribute knowledge (A,D). Outside of an enterprise, energy managers consult utility contacts, news of current events and other qualitative sources (listed in Section 4.3.1). Integrating knowledge is difficult: people in different divisions tend to think and speak in different languages suited to the primary business of their work areas. For example, accountants may reason about billing or reconciliation and speak in financial language. In contrast, production managers reason about scheduling or inventory and speak in engineering terms.

Energy managers use agreeable, extroverted communication in both technical and business language to mediate this investigative and explanatory process. Business skills are also used to structure interactions so they become routine, such as through business procedures, reporting, and shared language such as key performance indicators (Hooke, Landry & Hart 2003, B,E).

Shared understanding of energy opportunities develops over time, between people, and will always be incomplete. To capture this developing understanding in an objective, examinable form, energy managers formulate models and externalize them with tools. The most popular energy management modeling tools are spreadsheets, discussed in Section 4.3.3. When spreadsheet functionality becomes a limitation, some energy managers develop more sophisticated, customized tools through collaboration with software providers (A,D), while others apply their own programming abilities (D,E). Participants with computer programming skills used them often; one commented "I know what needs to be done so I program it quicker than I can explain it to an IT person"(E). One reason for the popularity of spreadsheets and self-programmed tools is discussed in the next section.

2.2 Change and modeling

Models access data, apply algorithms, and format results according to the understanding instilled in them by their creators. For equipment with a well-characterized stable condition, models can be developed into powerful, widely applicable tools, such as for electrical motors (A,E,J), lighting systems (B), or generation equipment (G, NRCan, 2009). Such tools are popular and well-regarded for components and as part of purpose-built models to evaluate specific energy management opportunities.

However, energy management decisions ultimately take place at a systems level where most industries are incompletely defined and unstable. Change is inherent in operations from sources including:

- Production: product type, scheduling (A,B,D)
- Equipment: addition, removal or efficiency upgrades (A,D)
- Maintenance: interruptions, temporary power connections (D,F)
- Meters/Sensors: addition, data faults, installation flaws, temporary connections (D,F)
- Business: Reorganization / accounting structure and systems (D)

These changes must be detected, interpreted and addressed by energy managers. Detection of changes can be automated in well-defined systems (G), but is more often a manual, collaborative process (D,F,Q). Changes must then be interpreted in production and modeling frames of reference, either as data anomalies to be corrected, as context to be used in later explanation or as new requirements for a reformulated model.

The variability inherent in most energy management means that systems-level models are continuous maintenance projects of assessment and revision, not well-defined deliverables. This may explain why energy managers with programming abilities tend to build and maintain their own tools (D, E) and the frustration with commercial IT solutions that require that changes be performed by vendor technicians (D).

2.3 Complexity and centralization

In individual, centralized problem-solving, more complex models are usually associated with increased predictive accuracy and simplified human interpretation. However, this general principle may mislead when models are developed and interpreted by different people.

As energy models grow more complex, they generally become more difficult to understand and interpret, especially when the system they model is highly variable. This will tend to encourage centralization since more complexity may make it harder for colleagues to understand the model's accuracy, evaluate its usefulness for their own applications, or contribute to maintaining it (Q). Instead, their decision-making process will depend more heavily on the credibility of the energy manager. Energy managers following a "show, don't tell" (F) approach will scale back their challenges, which in turn reduces program effectiveness (R).

Use of more complex modeling may encourage dependence on a centralized 'energy guru', whose time may be a bottleneck and whose loss will be critical to program sustainability (K). Gains in interpretation by model developers can be offset by losses to shared organizational understanding.

2.4 Collaboration and culture

Models are always imperfect, and their application relies on human interpretation to complete the designer's intent. Improving human interpretation of models is an alternative approach to developing more accurate shared understanding.

Energy managers can improve their own interpretation by designing models to suit their own frame of reference. However, since energy managers only have access to some of the shared understanding of an enterprise, engaging others through collaborative model interpretation is recommended (Carbon Trust 2007, Hooke, Landry & Hart 2003) and widely practiced (A,B). To collaboratively interpret a model requires translating. Colleagues first have to understand the model and its results, then coordinate the model's frame of reference with their own vocabulary, experiences and theories. For example, a production manager inspecting a weekly electricity consumption chart would first have to understand the sources of data, statistical methods, and electrical theories used, then coordinate this understanding with knowledge of production scheduling and un-reported activities.

Two approaches to improving the organizational interpretation of models are training and translation. The first approach is to educate colleagues to better understand the energy management frame of reference, sometimes arranged as formal programs (E). However, courses are expensive to distribute widely, so education is frequently carried out informally through everyday communication (A,F,L). The second approach is for the energy manager to translate models to better suit the audience. This is routinely done in reporting, using graphic charts, key performance indicators and familiar comparisons to provide context. The effort required to perform this translation means most reporting is done on monthly or greater time scales with focus on an upper management audience (A,B,D,E). More rapid reporting is possible with commercial tools such as report-generation software (L) or management dashboards (D), but speed alone does not guarantee effectiveness or adoption (J).

Information technology that supports energy managers' translation activities can encourage collaboration by:

- Being modifiable to match as many frames of reference as possible, using different units or even time scales (Hooke, Landry & Hart 2003). For example, workers experience time in terms of cyclical shift schedules, so coordinating energy reports in that time frame may improve understanding.
- Assisting colleagues in understanding and evaluating results, assumptions and uncertainties, by allowing exploration of the model's data and algorithms in an easily interpretable form.
- Being flexible enough to answer colleagues' unanticipated questions or be applied to alternate purposes. For example, statistical energy models can be applied as an indicator of equipment maintenance conditions (A)

Making it easier for colleagues to draw value from energy models and contribute to their interpretation and development might be the most effective technological intervention to sustaining a corporate culture of energy management.

3 Conclusions

Two visions of energy management information technology predominate in publications from North American (Hooke, Landry & Hart 2003) and UK (Carbon Trust 2007) industry agencies. While both agree on processes needed to introduce energy management to an enterprise, they present different suggestions for the end goal of IT development. The North American vision suggests that wide sub-metering infrastructure, sophisticated modeling tools, and real-time reporting will deliver the most value. In contrast, the UK vision considers coarse data sets and simple, explainable tools as more cost-effective. Interviewee opinions on these two visions differed – some participants at stable continuous process facilities (G) had successfully and wholeheartedly adopted the North American vision, while most participants were more aligned with the UK philosophy based on their experience with unanticipated costs of over-ambitious metering (A,E,F,L).

A key technical difference between these visions is meter data quantity, the product of equipment aggregation and feedback timescale. From a control-theoretic perspective, the value of finer aggregation and timescales is clear; the former reduces degrees of freedom in identifying power-consuming locations, while the latter increases the cut-off frequency of power consumption patterns the data can depict. Human limitations are clearly relevant; interpreting highly aggregated data requires complex understanding of the metered processes and is prone to error. Likewise, interpreting within coarse timescales is difficult in part because of human memory limitations; workers may not be able to recall activities correlated with energy use in past days.

This perspective de-emphasizes data maintenance costs and the role that human strengths can play in energy management. Energy managers' colleagues are not only an audience that must be persuaded, they are also a source of sophisticated situated understanding (Section 2.1). However, capturing shared understanding in data models requires ongoing maintenance whose cost rises with complexity (Section 2.2), and whose benefits may be partially counteracted by colleague disengagement (Section 2.3). Communication and translation tools are an alternate approach to address these side effects, ease interpretation bottlenecks, and engage colleagues (Section 2.4).

Benefits will be found in more energy management data, but data and models will be most effective if they support human roles in maintaining, validating, interpreting and assessing. An energy management model with finer data may be more useful, but a model that few understand is dangerous and a model that falls out-of-date is worthless.

This study has identified some of the complexities inherent in energy management, some of the work practices developed to cope with these complexities, and some broad opportunities for development of energy management information technology.

4 Addendum: Observations

This section collects observations that do not fit clearly into the themes discussed in Section 2. Topics include energy managers' personal characteristics, training opportunities, and common activities.

4.1 Who are Energy Managers?

Three main qualities were reported by participants as essential in an energy manager:

1. Technical & analytical abilities
    - Deep familiarity with practical production operational constraints
    - Fluent in electric power systems, thermodynamics, and energy calculations
2. Extroversion & agreeability
    - Comfortable motivating, explaining, persuading, leading, throughout organization.
3. Business-literate
    - Able to concisely and authoritatively communicate with management and justify capital projects

These qualities present concerns for recruiting and resourcing energy management expertise. Recruiting is challenging, as someone competent in all three aspects will always be in demand elsewhere in an organization (F). Compromising between the three qualities is likewise difficult, with some participants de-emphasizing technical expertise since it can be resourced from consultants (J), but conversely others viewing consultants' efforts as often "just another report" (E,K) that still demands sustained internal effort to implement. Some emphasize the importance of being comfortable conversing with both hourly workers & CEOs (P,Q), while many participants have developed committees to distribute responsibility for communicating (E,I, Carbon Trust 2007). Participants from consulting and program domains viewed business literacy as potentially the most important skill in an EM (J,K,L), yet participants who had formal business education de-emphasized its importance in their work (E). This study confirmed the lack of consensus on the relative importance of energy management abilities.

4.2 How do Energy Managers develop?

Some participants mentioned educational courses such as the Association of Energy Engineers' Certified Energy Manager course and Natural Resources Canada's "Dollars to $ense" workshops. Short reports and resources from national agencies (Carbon Trust 2007, Hooke, Landry & Hart 2003) were referenced by many (K,L) as educational sources, but popular energy management textbooks were not mentioned at all (Capeheart, Turner, Kennedy 2008, Turner 2001).

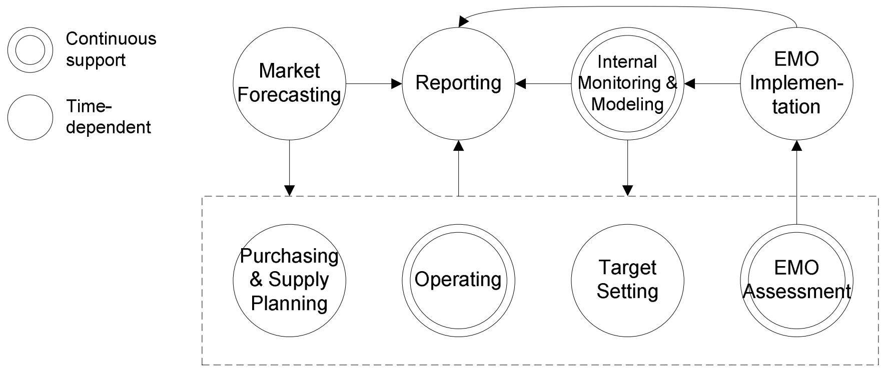
"Learning on the job" was the most common, and in one case the sole recommendation (B). Energy managers sometimes begin as a utility or process unit manager initiating changes "in their own backyard" (L). Small initial scope, followed by gradual expansion of energy management programs and technologies over multiple years was a widely reported practice (E,F,J,K,L). This is consistent with accepted theories of organizational change (Beer, Eisenstat & Spector 1990).

4.3 What roles do Energy Managers perform?

Energy management work is distributed differently in participants' organizations. These accounts are interpreted as falling into eight energy management activity categories, summarized in Figure 1, Section 1.4.

The frequency, delegation and sophistication of these activities varies greatly between organizations. For example, some reported that energy managers are often primarily purchasers and supply contract negotiators (K), while in three enterprises, (A,D,E), purchasing and forecasting were done separately. Similarly, process production optimization was considered by (E) as the core of energy management, while (D) considered it a separate activity. Within this variation, participants consistently reinforced the role of energy managers in securing commitment and demonstrating leadership. Overall, participants' account of EM-related business processes and deliverables were consistent with educational resources (Carbon Trust 2007, Hooke, Landry & Hart 2003).

Common interdependencies and typical information flows between the activities of Figure 1 are collected in Table 3. In the following sections, key observations and points of disagreement between participants are explored in the context of these activities.



Market Forecasting							
Long / short term energy cost, risks?	Reporting						
-	What / where are we consuming?	Internal Monitoring and Modeling					
Trends in spot prices?	How did you save us money?	Correctly billed? Typical MWh/peak?	Purchasing and Supply Planning				
Expected spot prices? Peak timing?	Production? Quality? Costs?	Overspend areas? Analysis meaning?	-	Operating			
How much will we need to improve?	What are tough / achievable targets?	What is historical benchmark?	-	-	Target Setting		
Projected prices over life cycle?	Payback, ROI, NPV? Disruption, Risks?	Areas with greatest potential?	-	How much will this complicate our work?	How great are our potential savings?	Energy Mgt. Opportunity Assessment	
-	Success stories?	Achieved savings? Model revisions?	-	-	-	What are the work orders?	Energy Mgt. Opportunity Implementation

Table 3 –Typical information flows between energy management activities of Figure 1

4.3.1 Market Forecasting

This activity was considered as the development of information on external energy prices and uncertainties. It can be exclusively market-facing as long as actions caused by the forecast do not have a significant effect on the market.

No participants conducted forecasts of electricity prices on hourly or daily levels, though one at least had tried and rejected 3rd party forecasts (B). IESO day-ahead forecasts are used, but perceived as too uncertain to trust for operational decisions by some participants (F) as they often have 95% confidence intervals that range from $0 to $100/MWh.

At monthly timescales, the most straightforward decision-making process discussed was monitoring and extrapolating historic natural gas price trends (B) to inform purchasing & supply decisions. Actual forecasting heuristics are certainly more complex and diverse so we did not try to elicit them.

Data sources used in monthly forecasting include quantitative data from physical and financial markets (D,L), but also extensive qualitative data. These include informal anecdotes from gas suppliers (D), as well as news and marketplace developments such as drought warnings, regulatory changes, UN or IEA policies and so on. This drives demand for dedicated news sources, as offered by CIPEC and the USDOE newsletters (L).

Forecasting actual delivered costs is even more complicated - as one participant put it, “you need a pretty good understanding of both the market and our internal processes to put this data together” (D). No participants reported forecasting variable non-energy components of bills such as uplift charges, and some considered the majority percentage of their bill as essentially “fixed” (B).

4.3.2 Reporting

Reporting was universally performed by participants at least on monthly, quarterly & yearly timescales. The degree to which management perceives energy as strategic seems to be correlated with report sophistication and frequency.

Visual presentation of data is common, typically through non-interactive paper reports. Reporting for sophisticated questions requires manual effort and several participants reported “making all the graphs” themselves (A,D,G). Reports generally evolve towards answering frequently-asked questions, but this process is labor intensive even in relatively stable enterprises (G).

Automation of reporting can potentially free up energy managers’ time. One participant fielding simple, repetitive questions successfully empowered colleagues to answer their own questions by publishing raw meter data on an intranet page (B). Some energy managers are uncertain how well ‘energy dashboards’ will support this process for more sophisticated questions (D, I)

4.3.3 Internal Monitoring and Modeling

Monitoring is internally-facing, and includes observation (not only metered data but of plant processes), interpretation (either by mental or computerized processes) and resolution of uncertainty and ambiguity. Knowledge generated through this process seems to directly inform all EM activities (with the possible exception of market forecasting and energy management opportunity implementation).

Participants' descriptions were consistent with descriptions in monitoring, targeting, & reporting literature (Carbon Trust 2008, Hooke, Landry & Hart 2003), but with some change of emphasis. Official accounts acknowledge that energy managers must "ensure that variations in input data are not caused by faulty measuring equipment or sensors" (Carbon Trust 2008 p.5), and that "abnormal consumption patterns must be filtered out" (Carbon Trust 2008 p.6) before the data is used, but do not further explore how this validation process is carried out. In enterprises with daily production schedules and regular infrastructure changes, participants suggested that data validation is necessary and frequently performed (A,D,E,F). Diagnosing causes and determining how anomalous data sections should be "filled in" requires not only electric and technical knowledge, but up-to-date qualitative knowledge of plant operations. It is an active process of constructing a meaningful data record (D,K,L,M) that supports long-term interpretation, and often is used to inform expansion of metering infrastructure (K,L).

This interpretation can be mental, or off-loaded onto a formal model. Participants reported both individual and socially distributed mental processes (B,E,F) as well as correlative (A,D, Carbon Trust 2008) and first-principles formal models (G, Hooke, Landry & Hart 2003). Energy managers support mental processes such as pattern-recognition and cause-and-effect reasoning by visually arranging data in the context of constraints. A common example is plotting data charts on shared time axes to make it easier to perceive simultaneous events (D).

4.3.4 Purchasing and Supply Planning

Information from market forecasting and internal modeling can support sophisticated energy purchasing strategies. We did not elicit many details of these methods, as many participants were not responsible for purchasing (A,E,D,G), and purchasing methods are often considered confidential.

Purchasing can substitute for accurate forecasts or flexible operation capability, such as by negotiating fixed-price contracts. One participant compensated for uncertainty in day-ahead electricity prices by negotiating natural gas contracts to allow internal generation decisions to be made in real time (B). No participants reported making purchasing decisions more rapidly than daily time scales. One consultant suggested that most organizations' electricity purchasing bids are updated so infrequently that control room operators sometimes re-enter identical data just to verify that their connection is still active (O).

4.3.5 Operating

The scope and frequency of communication between plant operation and energy management varies with the operating flexibility of the plant. Generally, participants reported having few options to influence the scheduling or operation of power-consuming equipment.

Some facilities with batch processing have sufficient flexibility to adopt simple operating protocols or schedules that shift energy-intensive operations to generally inexpensive hours (F). Other participants reported that their facilities' adoption of just-in-time/lean manufacturing techniques had eliminated opportunities for electricity peak management (D). Production planners, schedulers, and optimizers routinely request information at some facilities (A,D,E,G), but their actions generally cover timescales of weeks (D) or months (A) because of personnel and production lead-time constraints. Uncertainty in electricity market forecasts and charge determinants for transmission and distribution based on single highest monthly peaks seem to discourage efforts to interfere with operations, since one mistake can undo a month's efforts and lose hard-won credibility.

The only hourly-timescale operating changes reported by most participants was operation of onsite generation based on marginal cost calculations (B,D,F). Even this intervention presented difficulties in situations where onsite cogeneration would introduce downstream process disturbances (G).

4.3.6 Target Setting

Target setting was not discussed in enough detail to differ from official accounts (Carbon Trust 2008, Hooke, Landry, & Hart 2003). There was some preference for targeting against peers or competitors' benchmarks (B,D), which may be related to the need to convince colleagues of the strategic value of energy management.

4.3.7 Energy Management Opportunity Assessment

Assessing the feasibility and profitability of energy management opportunities is commonly performed through at least three strategies. The first is a quick engineering judgment that draws from the analyst's personal experience. This is often followed by the second strategy, a formal cost-benefit analysis with models to calculate savings, determine means of improving profitability and to justify decisions. For complex energy management opportunities, the second process may require significant modeling effort and present significant opportunity costs (F). A third strategy was observed in cases where technical and social systems could tolerate disruptions; participants collaborated with operations to pilot the intervention, then assessed whether results could be generalized (B,P,Q).

4.3.8 Energy Management Opportunity Implementation

The process of implementing an energy management opportunity is highly variable and project-specific. One commonality is their tendency to complicate monitoring and modeling. Each (successful) energy management opportunity project alters the plant's characteristics, which can require updates of first principles models. This is beneficial for reporting and quantifying savings of energy management opportunities, but can be ironic if the increases to modeling maintenance costs partially offset the benefits of implementing the energy management opportunity.

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