PROJECT DELIVERY AND CONTRACT STRATEGY FOR DISTRICT ENERGY PROJECTS – A LIFECYCLE APPROACH

by

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Abstract

New district energy projects provide Canadians with an opportunity to decentralize their energy supply, create efficiency in the production and distribution of energy and enable the use of renewable fuels. With the support of Provincial and Federal initiatives, public institutions and municipalities across Canada are beginning to consider these systems as viable solutions to their energy needs. However, relatively few of these projects have been built in Canada and a clear methodology for delivery of these projects has yet to emerge. The selection of an appropriate project delivery strategy is essential to ensuring the owner's key objectives can be met over the entire lifecycle of the district energy facility.

Through a comprehensive literature review, case study interviews and questionnaires, this research has identified and validated the key project delivery and contract strategy (PDCS) selection factors (objectives) for owners of new Canadian district energy projects. These selection factors have been aligned with a comprehensive list of PDCS alternatives, using relative effectiveness values. The scoring of these effectiveness values has been validated through a series of workshops with senior industry representatives across a range of key disciplines. The final data were used to produce a simple PDCS decision support tool for project managers who are considering building a district energy facility in Canada.

Preface

A paper based on this research was co-authored by Dr. Kasun Hewage and is titled *Project Delivery* and *Contract Strategy for District Energy Projects – A Lifecycle Approach.* This paper has been submitted to the ASCE Journal of Construction and Engineering Management and is currently under review for publication.

A University of British Columbia Okanagan Behavior Research Ethics Board certificate was received for this research. The UBC-BREB number is H10-01000.

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List of Abbreviations

AHP	Analytical Hierarchical Process
BIM	Building Information Modeling
CM	Construction Manager
CMR	Construction Manager at Risk
DBB	Design-Bid-Build
DBB-EP	Design-Bid-Build with Early Procurement
DBB-PM	Design-Bid-Build with Project Manager
DB	Design-Build
DBOM	Design-Build-Operate-Maintain
DBOMF	Design-Build-Operate-Maintain-Finance
DE	District Energy
DWH	Domestic Hot Water
EPC	Engineering Procurement and Construction
ETS	Energy Transfer Station
GHG	Green House Gas
IPD	Integrated Project Delivery
JV	Joint Venture
MAUT	Multi-Attribute Utility Theory
MDB	Multiple Design-Build
MPC	Multiple Prime Contractors
M-DBB	Multiple Design-Bid-Build
MW	Megawatt
P3	Public Private Partnership
PDCS	Project Delivery and Contract Strategies
REV	Relative Effectiveness Value
RFP	Request for Proposals
SF	Selection Factor
SMARTS	Simple Multi-Attribute Rating Technique with Swing Weights

Glossary

<u>General Terminology:</u>

Project Delivery (PD) is the procurement approach, financing strategy and management system developed for accomplishing the project's objectives and tasks in order to deliver a project that is successful throughout its lifecycle from concept to implementation, operation, and maintenance (Pishdad & Beliveau 2010).

Contracting Strategy (CS) describes the roles and responsibilities of the contracting parties. It determines the risk allocation strategies, methods of payment, basis for reimbursement, and incentive strategies for encouraging enhanced contribution to the project (Pishdad & Beliveau 2010).

The Compensation Approach is the method by which the owner has agreed to compensate each party to the contract. Typical compensation approaches included: negotiated price, competitive price, guaranteed maximum price, unit price, cost-plus, etc. (Bowers et al., 2003)

The Selection Factors represent those project lifecycle objectives that will influence the owner's selection of the PDCS option.

The Relative Effectiveness Values are the numerical values that describe the effectiveness of each PDCS to meet the objectives described by each selection factor.

District Energy Systems produce steam, hot water or chilled water at a central plant. The steam or water is then piped underground to individual buildings for space heating, domestic hot water heating and air conditioning (IDEA web site 2011). The district energy plant can use both fossil and renewable based fuels.

Building Lifecycle requires that the building be viewed in the context of its entire life. The building lifecycle includes all seven phases of a project: pre-planning, design, procurement, construction, commissioning, operation and maintenance and deconstruction*.

**Note: for the purpose of this study the demolition of the facility was not included in the development of the PDCS selection factors or development of the Relative Effectiveness Values.*

Specific Project Delivery and Contract Strategy (PDCS) Alternatives:

Design-Bid-Build (DBB): The owner contracts separately for the design and construction of the facility. A single prime contractor is responsible for all construction subcontracts. A single prime (or coordinating) consultant is responsible for the sub-consultants.

Design-Bid-Build with Early Procurement (DBB-EP): Similar to DBB, except that the owner separately procures some large pieces of equipment and/or materials early in the project. These are typically handed over to the prime contractor, to be incorporated in the work.

Multiple Design-Bid-Build (M-DBB): Similar to DBB except that the owner contracts separately with two or more prime contractors and/or one or more prime consultants. M-DBB is often used where scope and schedule allow for a phased project delivery.

Construction Manager (CM): The owner contracts with a construction manager who is engaged early in the design phase and acts as the owner's agent. Design services are contracted separately and are the responsibility of a prime (coordinating) consultant. Trade contracts are held directly by the owner and may be awarded sequentially as the design and construction progresses.

Construction Manager at Risk (CMR): Similar to CM except that the CM and the owner agree to a guaranteed maximum (fixed) price for the construction work, based on the detailed design documents.

Design-Build (DB): The owner prepares a performance specification for the project. The owner then contracts with a single entity for the detailed design and construction of the facility.

Design-Build-Operate-Maintain (DBOM): Similar to DB, except that the operation and maintenance of the facility is included in the contract, for a fixed period of time.

Design-Build-Operate-Maintain-Finance (DBOMF): Similar to DBOM, except that the owner contracts with a single private entity and financing of the project is included, for a fixed period of time.

Public-Private-Partnership (P3): Similar to DBOMF, except that a public-sector owner contracts with a single private entity and financing of the project is included, for a fixed period of time. In Canada these projects are typically limited to $50 million or greater.

****Note:*** *A detailed description complete with graphic representation of phasing and relationships for each PDCS alternative is contained in Appendix D.*

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Chapter 1: Introduction

District energy systems rely on a central plant to produce heating and cooling capabilities and domestic hot water, all of which are distributed through a network of piping to groups of buildings. These new energy systems are emerging as a viable way to supplement the traditional energy infrastructure in urban communities across Canada. Unlike conventional large utility providers within the traditional infrastructure, the owners and stakeholders of district energy systems are diverse, ranging from municipalities to institutions and private developers, all of whom see the benefit of a system that can provide locally distributed energy and can embrace alternative energy sources.

The planning and construction of a district energy system presents many of the same issues and difficulties as with a large energy infrastructure project, but these projects are unique in many ways. One way to ensure that such a project is successful and that the project lifecycle objectives are met is through the selection of a suitable project delivery strategy. A delivery strategy will drive project cost, schedule and quality, and ultimately operating and maintenance costs. The role of the project owners and disparate group of stakeholders is a key issue in the choice of delivery strategy. Each owner will seek a project delivery strategy that is most closely aligned with their specific key lifecycle objectives and beyond that with their long-term goals. No single delivery strategy will be best suited to all. To make informed project delivery decisions, owners will need to consider all of the alternatives and seek to understand the potential benefits and risks associated with each project delivery option.

The purpose of this research is to better understand which objectives are most important to owners of district energy projects in Canada, align those objectives with project delivery alternatives, and provide a tool to assist owners with the selection of an appropriate project delivery strategy for their district energy project.

1.1 Background

Nicholas Stern's extensive report to the British government on the subject of climate change asserts that, "there is now clear scientific evidence that emissions from economic activity, particularly the burning of fossil fuels for energy, are causing changes to the earth's climate" (Stern, 2007). It is clear that if no action is taken these changes will result in increased, irreversible damage to our environment, with significant economic and social cost. Our ability to find alternative sources of energy production, and to use the energy we have more efficiently, could be one of the defining problems of this century. Stern's report further states that, "effective action on the scale required to tackle climate change requires a widespread shift to new or improved technology in key sectors such as power generation…"(Stern, 2007).

The cost of energy does not currently take into account the cost of restoring the environment at the fuel extraction site, or the impact of the pollution generated from burning the fuel. This has contributed to a distortion of energy pricing, which in turn has promoted the continued use of established fossil fuel technology. "Integrating the value of the environment into energy planning will ensure that the most sustainable energy choice will be the most economical. This will significantly change fuel choices, technology preference and the overall planning structure for communities and infrastructure” (Mitra et al., 2010).

As part of a clean energy initiative, governments in Canada have provided significant support to the development and promotion of planned energy systems at the community level. These projects are known as district energy systems and they involve the production of thermal energy at a central plant and its distribution to buildings within a district. This government support has resulted in substantial advances in district energy systems technology and has increased the potential for viable projects of this kind in urban centers throughout Canada. New district energy systems projects in Canada are still relatively few and are typically one-of-a-kind construction projects where the risks have been mitigated by the contribution of government grants and other incentives. According to a recent Canadian District Energy Association report, eleven new district energy systems have been reported to have been built in Canada since 2000 and 42% of the total 54 plants in Canada were commissioned after 1990 (CDEA 2009).

It is understood that as public and private sector owners become increasingly responsible for building, maintaining and operating district energy systems without the help of government incentives, the financial risks they pose will increase. Properly addressing these risks through well-managed project delivery is, therefore, essential. If new district energy projects are to be constructed on a large scale throughout North America, a clear method for the selection of an appropriate PDCS for these projects is needed. This research aims to provide a tool to support public sector managers in selecting a PDCS for their district energy projects.

1.2 Current Situation and Problem Statement

It has been shown that the project delivery decision greatly impacts the efficiency of execution for that project (Gordon, 1994; Oyetunji & Anderson, 2006). This applies to all phases of the project lifecycle. Research also reveals that project owners will most often select a PDCS method because they are familiar with it and not because it is appropriate for the project (Pishdad & Beliveau, 2010). For new district energy projects in Canada, where the risks are largely undefined, falling back on familiar PDCS strategies can have a significant negative impact for the owner. The selection of PDCS therefore constitutes a "critical success factor" for a project (Oyetunji & Anderson, 2006). Past studies of PDCS selection have looked at a broad spectrum of capital building projects. This research aims to understand the PDCS options for new district energy projects and to develop a tool to ensure key selection factors and PDCS objectives for those projects are aligned.

Significant research has already been undertaken (see Chapter 2 section 2.2) in trying to understand the critical components of PDCS for general capital building projects and in developing tools to assist owners in selecting the appropriate delivery methods. However, these studies have not fully reflected emerging trends in the delivery of infrastructure projects. One key area that has been neglected is the consideration of lifecycle costs in the planning of these projects (Pishdad & Beliveau, 2010). A district energy facility will be expected to consistently deliver energy over its lifetime. It may have significant operating and maintenance costs, sensitive community engagement needs and/or unique environmental implications. The lifecycle cost considerations for these projects cannot be ignored and should be at the forefront when selecting a PDCS.

1.3 Research Question

The purpose of this research is to understand the relationship between a standard set of PDCS alternatives (i.e. the options for procurement, financing and management in the context of the roles and responsibilities of each contracted party) and the key PDCS selection factors (i.e. the objectives that will influence the owner's selection of the PDCS alternative) identified by its owners over the lifecycle of a district energy project in Canada. Understanding this relationship will help future owners of Canadian district energy projects address the question: "Which PDCS alternative (or alternatives) should be used to best ensure that the project's key lifecycle objectives will be met?"

This overarching question breaks down into a number of component parts as follows:

1. What are the characteristics of a district energy project in Canada that distinguish it from other infrastructure projects?
2. Which PDCS alternatives are appropriate for these projects?
3. Which key objectives form the principal PDCS selection factors for the owners of these projects?
4. Which of the principal PDCS selection factors are the most important to owners of these projects?

How effective is each PDCS alternative in achieving the objectives defined by the principal PDCS selection factors?

1.4 Research Objectives

The objective of this research is to develop a PDCS selection decision support framework that can be used by public sector owners who are considering building a district energy system in Canada. To achieve this objective, the following research steps were followed:

1. Identify the basic technology, location, financing structure and other general information about district energy projects that have been recently developed in Canada.
2. Identify a standard list of PDCS alternatives that are currently being used on large capital building projects in Canada
3. Identify the PDCS alternatives that owners in Canada used for their district energy projects, the functional and contractual relationships of each PDCS that was used and the compensation approach.
4. Identify a standard list of PDCS selection factors that describe the key lifecycle objectives for owners of district energy projects.
5. Identify the importance of each PDCS selection factor to owners of district energy projects and create a list of valid selection factors.
6. Identify how effective each PDCS is in ensuring that the objectives of the validated selection factors will be achieved over the life of the project.
7. Evaluate current PDCS decision analysis methodology and tools.
8. Develop a simple decision-making support tool to assist owners when choosing a PDCS for their district energy project.
9. Validate the PDCS decision support tool.

1.5 Research Deliverables

This research has four key deliverables, which are aimed at providing value to select industry stakeholders and supporting future academic research in this field. The research deliverables are as follows:

1. A validated list of PDCS alternatives and PDCS selection factors for new district energy projects in Canada.
2. Relative importance of each of the validated PDCS selection factors.
3. Relative effectiveness of each PDCS alternative in achieving the objectives identified by each selection factor.
4. A computer-based tool that can support the PDCS decision-making process for public sector owners who are considering building district energy systems.

Chapter 2: Review of Relevant Literature

There is a substantial body of literature describing district energy system technology and its application in Canada. There is also significant research on the various construction project delivery alternatives and the importance of the project delivery decision in the lifecycle of a conventional construction project. The research also explores methods supporting PDCS decision-making, often using multi-criteria decision analysis techniques. As a result, several software tools have been developed supporting the PDCS decision-making process for capital construction projects.

This literature review draws on this body of research, using current academic and industry publications, to characterize and define contemporary district energy projects. The review examines research identifying and validating PDCS alternatives and selection factors for capital building projects, and undertakes a thorough review of the development of PDCS decision-making tools. The gaps in current research relating to PDCS decision-making are identified and provide direction for this research project. The two primary gaps in prior research on this subject that this thesis addresses are summarized as follows:

- Selection of PDCS alternatives specifically for district energy projects.
- Selection of PDCS alternatives in the context of the entire project lifecycle.

2.1 District Energy Systems

Since the 19th century, the decentralized energy systems that were once prevalent throughout the United States and Canada (primarily coal and wood stoves) have become progressively centralized. Because of the great distances that the energy must travel, a centralized system results in greater losses from the transmission and distribution of energy. A recent report on energy efficiency in the US electrical grid states that while transmission losses depend greatly on the physical characteristics of the system, loss values of between 6% and 8% are considered normal (ABB, 2007). The report goes on to calculate that in 2005, the financial impact to the US economy due to transmission and distribution losses was close to USD $19.5 billion (ABB, 2007). District energy systems allow for the energy generation technology to be closer to the end-user compared to conventional centralized energy infrastructures and therefore, result in significantly less transmission loss. These systems could contribute greatly to a more efficient energy delivery system, reversing the trend set by central energy utilities over the last century.

According to the US Department of Energy's Federal Energy Management Program, district energy systems are small, modular, decentralized, grid-connected or off-grid energy systems, located in or near the place where the energy is used (US DOE, 2011). District energy connects multiple energy users, through an underground piping network, and provides a medium that allows for the transfer of energy (IDEA, 2011). The energy can be transported by steam, hot water, or chilled water. A district energy system may be designed with a central energy plant, or with multiple plants connected by pipes that provide space heating, hot water, steam and chilled water to a group of buildings (Gilmour and Warren, 2008).

Energy in a district system can be generated or recovered using either one or a combination of system solutions. These systems can include conventional boilers, combined heat and power (CHP) systems, biomass boilers, heat pumps and other technologies. The types of energy generation technologies in a district energy system are typically designed to optimize the use of available local fuel and rejected heat from nearby industrial and commercial activities (Gilmour & Warren, 2008). In this way they are often seen as an enabler of alternative low-carbon and/or renewable energy sources that may not otherwise have been available under a conventional energy system. Figure 1 shows the flow of energy in a district energy system and the potential for use of current and future alternative energy sources.

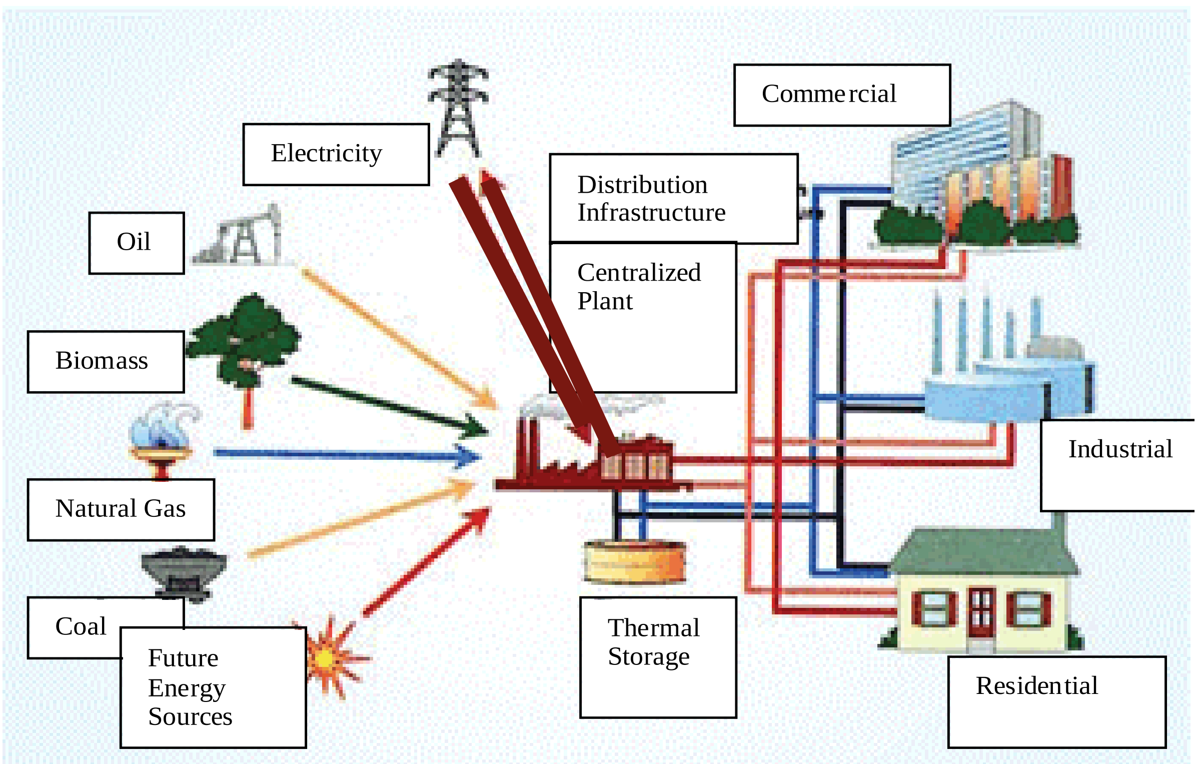


Figure 1: District Energy System

From: http://www.districtenergy.com/services/districtenergy.html (modified)

Currently, district energy in North America exists either in the central business districts of large cities, or in clusters of public buildings, such as university campuses, where there is common ownership of real estate and energy facilities (IDEA Report, 2005). More recently private developers who have assembled larger parcels of land in urban centers are being encouraged by municipalities, through incentives and regulations, to promote energy conservation and low-carbon energy by servicing their buildings with district energy systems.

Because district energy systems are responsible for a portion of the generation and distribution of energy to a community, they share many of the lifecycle attributes and objectives of conventional large utility projects. However, district energy projects are relatively small in scope and cost when compared to conventional utility mega-projects. As well, they are also often owned, operated and/or maintained by a municipality or institution in conjunction with their conventional building stock. With these broad and potentially competing objectives, district energy project can present unique PDCS challenges.

2.2 Project Delivery Alternatives for Capital Building Projects

For most infrastructure projects it is the owner who organizes the funds and pays (directly or indirectly) for the execution of the work over the life of the project. In this way, the owner assumes a lead role in the life of that project. It is understood that in the early stages of a building project the owner has the responsibility of performing several critical business related functions, including financing, cash flow and pro-forma development. Figure 2 (original concept by Paulson, 1976) shows the importance of the decisions made early in the project, when influence over the project is high and the cumulative cost is low.

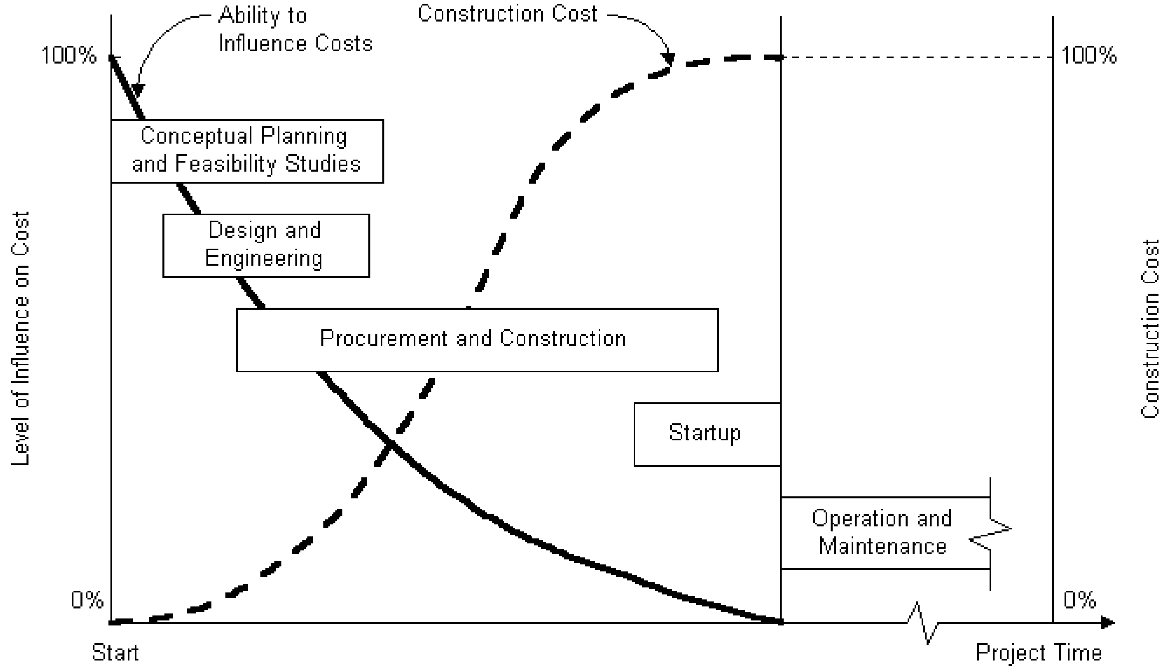


Figure 2: Level of Influence on Cost over Time

From: Hendrickson (2008)

Successful execution of these early decisions directly impacts the owner's perception of the project's success. The selection of a project delivery system and contracting strategy is one of the primary functions that the owner performs during early project development. The project delivery decision is clearly the owner's decision problem (Oyetunji, 2001) and the extent to which the owner's objectives are achieved depends greatly on the extent to which the owner's objectives can be aligned with those of the other stakeholders (Bowers et al., 2003).

An appropriate PDCS is an important tool in the promotion of the necessary harmony between the objectives of the owner and those of the other key stakeholders. According to Pishdad and Beliveau (2010), the PDCS serves as the procurement approach, the financing strategy and the management system for accomplishing the project's objectives, which together will deliver a project that is successful throughout its lifecycle. The PDCS describes the roles and responsibilities of the contracting parties; it determines the risk allocation strategies, methods of payment, basis for reimbursement, and incentive strategies for encouraging enhanced contribution to the project; and it creates improved efficiencies in the contracting process that can lead to overall cost savings. It has been estimated that the selection of a more efficient contracting method could reduce project cost by as much as 5% (Gordon, 1994).

Gordon (1994) is one of the earliest contributors to modern research in decision making for construction contracting methods. He suggested that modern projects do not always meet the criteria of the traditional design-bid-build (DBB) procurement strategy. Accordingly, while owners may use the traditional method out of familiarity, they should also be looking to “alternative” contracting methods to best meet their objectives. According to Gordon, these alternative methods include construction management (CM), multiple prime, design-build (DB), turnkey and build-operate-transfer.

A more recent comprehensive study, undertaken for the Construction Industry Institute (CII) by Bowers et al. (2003), also looked to expand and validate the traditional list of viable PDCS options. The authors identify the four main characteristics of PDCS alternatives:

1. The sequence of project phases.
2. The functional responsibility of each party.
3. The contractual relationship of the parties.
4. The compensation approach for each contractual relationship.

Using these characteristics as a framework, and through an extensive industrial survey, the CII study by Bowers et al. (2003), validates twelve PDCS alternatives, shown in in the following list.

1. Traditional design-bid-build (DBB)
2. DBB with early procurement
3. DBB with project manager
4. DBB with construction manager
5. DBB with early procurement construction manager
6. Construction manager at risk
7. Design-build or engineer, procure, construct (EPC)
8. Multiple design-build
9. Parallel primes
10. DBB with staged development
11. Turnkey
12. Fast track

In their report for the CII, Bowers et al. (2003) identify several key assumptions that influence the list of PDCS factors validated by their work. The PDCS options in their study exclude the pre-construction planning phase of the project lifecycle. In addition, the study does not fully consider commissioning and start up or operate-maintain types of contracts. Lastly, the PDCS options considered in the CII report are all based on 100% owner financing of the project. These omissions in the existing research represent a gap that is critical to our understanding of the delivery of district energy projects. This present research aims to address this gap.

J.B. Miller, of MIT's Infrastructure Systems Development Research Group, also concludes that project planning for public infrastructure is an owner-driven process that must correlate with the owner's overall economic needs and social policies (Miller et al., 2000). However, Miller argued that to properly align the project objectives an owner has to consider business planning, design, construction, operation and maintenance, early on in the project lifecycle. He suggests that "emerging" or innovative project delivery methods offer owners a choice in their search for value. To this end, he argues for the simultaneous use of multiple project delivery methods, and he introduces two additional methods to those previously mentioned: design-build-operate, and design-build-finance-operate (Miller et al., 2000). These terms have been extended in this research as design-build-operate-maintain (DBOM) and design-build-operate-maintain-finance (DBOMF) respectively (see glossary).

According to Miller, DBOM is a project delivery method that integrates operation with the tasks of design and construction (Miller et al., 2000).   DMOMF is a project delivery method similar to DBOM, except that the responsibility for financing the project is assumed completely by the contractor, typically at the contractor's risk. Usually, financing relies on future user fees. Control of the infrastructure asset is returned to the owner at the end of the contract period. For public projects in Canada, the DBOMF is often called a P3 (public-private-partnership).

In recent years there has been increased interest in promoting methods other than traditional DBB as a way of leveraging schedule and budget savings. Notable examples of research on expanding the use of alternative PDCS methods include work by Trauner (2007) and Anderson and Damnjanovic (2008). These authors focus on US highway infrastructure as an opportunity to explore alternate delivery methods to expedite schedules and promote cost savings. Others, including Dahl (2005), and Russell et al. (2006), have also focused their research on new project delivery methods, including design-build-operate-maintain and P3 respectively, as ways of promoting innovation and sustainable building practices.

2.3 Toward Integrated Project Delivery and Partnership

More recently, the construction industry has come to see partnering, through alliance agreements or integrated project delivery (IPD), as a viable method of project delivery. This new delivery approach is seen as a way of improving project outcomes by aligning goals, creating incentives and encouraging a collaborative approach to construction projects. It has been argued that the increased use of building information modeling (BIM) technology suggests an integrated project team. BIM proponents have encouraged owners and consultants to consider the IPD approach. However, according to current research (Kent & Beceric-Gerber, 2010) the number of projects using IPD remains relatively small. There are several reasons for this slow adoption of IPD, including concern regarding increased risk to owners and the need for new legal frameworks to mitigate risk. Although some owners and consultants have worked on IPD or IPD-like projects, there are few examples of successful project delivery using this method (Kent & Beceric-Gerber, 2010). Increasingly, public sector entities are seeing the advantage of collaborative and partnership-type delivery models, especially where the advantages identified are in line with the project objectives.

2.4 Project Delivery and Community Energy Infrastructure

Power generation and alternative energy projects are complicated, highly regulated and often fast-tracked projects that come with substantial financial risks (Gonzales, 2009). New district energy projects are no exception. The need for innovative technical and managerial solutions to overcome these challenges is significant. Russell and Tawiah (2006) found that the willingness to share both the risks and rewards of adopting innovative solutions for project procurement strategies could be a powerful driver for innovation. This willingness is linked to the risk attitudes of project stakeholders and their understanding of the risk–innovation relationship. Risks differ dramatically from project to project and risk allocation is a key part of any successful procurement and management strategy (Miller et al., 2000). Selecting the appropriate PDCS is an important way to facilitate sharing/trust, to allocate risk among the stakeholders and to ensure project objectives are aligned.

"One of the clear teachings of the history of construction management in the United States is that no single form of project delivery and finance is preferable across numerous projects and sectors over time" (Miller et al., 2000). A comprehensive lifecycle analysis of a district energy project is the key factor to making an informed procurement decision (Damecour, 2008). It would follow that the owner's selection of an appropriate PDCS is essential to ensuring the success of a district energy project over its entire lifecycle.

2.5 PDCS Selection Factors

Identifying the project characteristics and objectives should be the first step in the owner's PDCS decision-making process. Gordon is one of the earliest researchers to define the *project drivers* that he suggests should influence the project delivery decision. He identifies time constraints, flexibility for change, pre-construction service needs, design process interaction and financial constraints as key project drivers (Gordon, 1994). Gordon also distinguishes a separate list of *owner's drivers,* which he defines as construction sophistication, current capabilities, risk aversion and restrictions on methods (i.e. permits). Gordon suggests that, in order to maximize the benefits offered to them, owners will need to adequately define drivers, while understanding the characteristics of each delivery method and the conditions of the construction market (Gordon, 1994).

According to research by Bowers et al. for the CII (2003), the PDCS selection factors are a key indicator of the owner's project objectives. In addition to validating the twelve PDCS alternatives described in section 2.2, their 2003 CII report also identified and validated thirty potential PDCS selection factors that apply to a wide range of capital facility projects. Oyetunji (2001) further refined Bowers' list to twenty selection factors. The 20 selection factors developed by Oyetunji in his 2001 thesis are shown in the following list:

1. Completion within original budget is critical to project success
2. Minimal cost is critical to project success
3. Owner's cash flow for the project is constrained
4. Owner critically requires early (and reliable) cost figures to facilitate financial planning and business decisions
5. Owner assumes minimal financial risk on the project
6. Completion within schedule is highly critical to project success
7. Early completion is critical to project success
8. Early procurement of long lead equipment and/or materials is critical to project success
9. An above normal level of changes are anticipated in the execution of the project
10. A below normal level of changes is anticipated in the execution of the project
11. Confidentiality of business/engineering details of the project is critical to project success
12. Local conditions at the project site are favorable to project execution
13. Owner desires a high degree of control/influence over the project execution
14. Owner desires a minimal degree of control/influence over the project execution
15. Owner desires a substantial use of its own resources in the execution of the project
16. Owner desires a minimal use of its own resources in the execution of the project
17. Project features are well defined at the award of the design and/or construction contract

18. Project features are not well defined at the award of the design and/or construction contract
19. Owner prefers minimal number of parties to be accountable for project performance
20. Project design/engineering or construction is complex, innovative or non-standard

For this research, Oyetunji's list of 20 selection factors was reviewed in the context of district energy projects and then further refined. Owners and operators of actual district energy projects in Canada were asked to verify and score the selection factors identified in this new list. The re-developed list of 22 selection factors, specifically applicable to district energy projects, is provided in Chapter 3, section 3.3.

2.6 PDCS Effectiveness

A key step in the development of a PDCS decision support framework is to form an understanding of the relationship between the owner's PDCS selection factors and the available PDCS alternatives. There are two ways that this has been studied. One is by collecting performance-based empirical data to validate a cause and effect relationship between PDCS alternatives and project outcomes. The other is through the aggregated opinions of experts with a wide range of experience in project delivery.

2.6.1 Performance-Based Empirical Studies

PDCS effectiveness can be determined through a performance-based empirical investigation of the project delivery systems, using data collected from completed projects to draw conclusions about PDCS effectiveness. One of the most often cited papers to use this approach is Konchar and Sanvido's *Comparison of U.S. Project Delivery Systems* (1998). The authors compared the cost, schedule and quality performance of US building projects that had used design-bid-build, construction management and design-build delivery methods.

Konchar and Sanvido sent surveys to 7,600 potential participants across the US construction sector. Of these, 378 surveys were returned (a response rate of 5.1%) and of these only 301 were usable for the analysis. An additional 50 previously non-responsive surveys were gathered and added to the combined data set. A total of 351 projects were included in the final study. Konchar and Sanvido made specific comparisons between project delivery systems, performance metrics and facility classes. They then used statistical models developed to measure average project performance against these criteria. Finally, they drew conclusions about the relative effectiveness of each of the three delivery alternatives with respect to cost, schedule and quality.

While collecting larger and more varied samples from completed projects has proven to be a valid methodology to measure project performance against the PDCS alternatives, there were several reasons why it was not used for this research.

1. Konchar and Sanvido focused on a wide range of capital projects that allowed for a broad scope of data collection possibilities. This research is limited to district energy projects and very few of these projects have been built. Therefore, empirical data on project performance is very limited (see section 8.2 for further discussion on the

limited sample size available for this study).

2. Much of the data required to validate the project's performance through empirical performance-based testing are protected as a result of business confidentiality. Access to data and the ability to validate the accuracy of data would be difficult for district energy projects in Canada.
3. Konchar and Sanvido's research was limited to using three PDCS selection factors to measure the effectiveness of three PDCS alternatives. This research looks at 22 selection factors and 10 PDCS alternatives, making data collection that relies on performance based metrics, a massive undertaking.
4. The performance measures of the Konchar and Savindo study only looked at the design and construction phases of the project. This limited the ability of their study to assess the lifecycle objectives of the project owners. As discussed previously, it was felt that the lifecycle objectives such as certainty around operations and maintenance, and emissions and fuel costs are at least as important to owners as the certainty of capital cost and schedule performance.
5. Of the three measurements of performance selected by Konchar and Sanvido only cost and schedule could be measured objectively. Measurement of quality required subjective ranking by the research participants and was based on perception. Many of the lifecycle objectives identified in the 22 selection factors used for this study also cannot be measured objectively and therefore are better suited to the methodology described in Chapter 3.

One of the key limitations identified by Konchar and Sanvido in using performance-based evidence as a measure of PDCS effectiveness is that the cause and effect relationship is hard to validate. Other variables can impact project delivery performance in meaningful ways that are not as easy to measure. For example, the total cost impact of owner instigated scope changes, unforeseen sub-surface site conditions, or the impact of poor weather are not easy to quantify, yet it is understood that they can have a significant impact on cost and schedule.

While a carefully selected PDCS method will not guarantee certain objectives will be met, it can help mitigate risks by predicting and controlling future outcomes (such as those mentioned above) through contract strategies. As discussed previously, contract strategy is a tool for distributing risk amongst the project stakeholders. For this reason, there is clear value in measuring PDCS effectiveness based on the aggregated experience and consensus opinions of experts who have deep knowledge of project delivery.

2.6.2 The Delphi Method

The Delphi approach has gained popularity for research problems where the phenomenon being studied is complex or where performance-based empirical data is not available. With the Delphi method, the experiences, knowledge, and presumptions of experts are collected through an interactive process, normally by interview or survey. Delphi is able to reveal and utilize the tacit knowledge of experts and allows others to view and evaluate it (Lilja et al. 2011). In contrast, the performance-based data collection methodology discussed in Chapter 3 relies on explicit knowledge, drawing conclusions from events that have occurred, where documentation is reliable and available.

When planning an infrastructure project, future situations are unique and most probably not repeatable events. Therefore, any future predictions are based on probability. The Delphi method relies on the assumption that experts are able to place their greater experience behind their predictions, which then carry more weight than those of people with no direct experience (Lilja et al., 2011). In this way they are in the best position to assess potential project risks and assign the appropriate contract strategy alternatives to mitigate those risks.

It is understood that in studies where the aim is to collect qualitative data and information from a limited group of experts, or a group of people that can be regarded as experts because of their knowledge and/or experience, some variation of the Delphi method is an appropriate research methodology for the researcher to consider (Lilja et al., 2011).

2.6.3 PDCS Relative Effectiveness Values

For the decision analysis approach used by Oyetunji (2001) the selection factors were represented as measurement attributes (see column three of Table 2-3). The measurement attribute allowed for a quantitative measure of the performance of the PDCS alternatives with respect to the selection factor. Oyetunji called this measurement the relative effectiveness value (REV). The REV provides a numerical value that describes the ability of each PDCS alternative to attain the measurement attribute of each selection factor. With the REV, a quantitative decision analysis methodology can be implemented to compare alternative delivery systems and identify an optimal delivery alternative for a given project (Oyetunji and Anderson, 2006).

Oyetunji (2001) suggested that the REV for PDCS selection should be based on the opinion of senior project managers, experienced with multiple delivery methods for a variety of project types. Alhazmi and McCaffer (2000) and Cheung et al. (2000) argued in support of the same methodology for their analytical hierarchical process (AHP) based project procurement selection models. This prior research concluded that it was significantly more valuable to have a variety of expert opinions that could be aggregated to produce a single effectiveness value for each of the PDCS alternatives.

Oyetunji (2001) and others used decision conferencing workshops for aggregating the individual scores of the REVs. Observations during the course of these aggregation workshops supported the notion that collaborative consensus on PDCS REV scores capitalized on the positive aspects of decision-making in small groups, and generated shared understanding of the PDCS decision problem. According to Oyetunji and Anderson (2003), "the two main approaches for combining individual judgments to produce *super* judgments are mathematical aggregation and behavioral aggregation". Mathematical aggregation involves techniques such as calculating a simple average of the judgments of individual group members. With behavioral aggregation the members of the group reach a judgment, communicating with each other in open discussion. A comparison of these approaches by Oyuntuji (2001) showed that behavioral aggregation was suitable for the purpose of establishing REVs for PDCS selection. This methodology is consistent with the Delphi-based approach described in section 2.6.2. The methodology used to establish the PDCS effectiveness values for this research is further described in Chapter 3, section 3.4.

2.7 PDCS Decision Support Tools

When describing the process of selecting a project delivery strategy for a building project, Gordon (1994) uses the analogy of choosing a golf club "you know which are not appropriate, but several will work, one of which may be the best". The question of how to select the "best" project delivery option has been studied extensively.

Much of this research focuses on the development of PDCS decision support tools to assist owners in selecting the most appropriate delivery method for their project. These tools use a variety of approaches to the problem but all set out to answer the same fundamental question. Pichdad and Beliveau (2010) compiled the relevant literature and provided a comprehensive analysis of the research on PDCS selection tools to date.

PDCS tools generally consist of three parts: independent selection factors, dependent PDCS alternatives, and a decision support framework (Pishdad & Beliveau, 2010). The decision support methodology is developed based on existing knowledge of the PDCS and how they relate to the selection factors. The role of the PDCS selection tool is to align the owner's objectives, through chosen selection factors, with the appropriate PDCS option. Creating a project selection tool involves developing a process to align project goals and objectives with the PDCS alternative that would most likely achieve these objectives (Trauner 2007).

As discussed in Chapter 2, section 2.5, Oyntunji (2001) used the REVs to quantify a relationship between selection factors and PDCS options. This was then applied to a multi-criteria decision analysis tool, using a simple attribute rating technique with swing weights

(SMARTS). Oyetunji's (2001) SMARTS based model for selection analysis requires the definition of several variables for each particular project. These variables include:

- The relevant delivery system alternatives
- The relevant selection factors
- The appropriate weighting of selection factors for the subject project
- Quantitative measures of the performance of the alternatives with respect to the selection factors

Similar research on decision-making tools for PDCS selection has been carried out using AHP models (Chua et al., 1999; Alhazmi et al., 2000; Al Khalil, 2002; Mahdi et al., 2005; Mafakheri et al., 2007). For all of these studies the appropriate alternatives of PDCS elements are selected through a decision support framework. The framework is developed based on the existing knowledge regarding the characteristics of PDCS elements and their compatibility with the selection factors (Pishdad & Beliveau 2010).

The majority of research to date that is directed towards PDCS decision support tools focuses on one-size-fits-all PDCS decision-making software that can be applied to a wide range of capital building projects. Notable exceptions include Touren et al. (2009), Trauner Consulting (2007) and Anderson et al. (2008) whose reports for US public transportation authorities focus specifically on decisions around the delivery of transportation infrastructure. In addition, most of these PDCS decision support tools consider only the design and construction phases of the project. Pishdad and Beliveau (2010) confirm that important emerging trends, such as lifecycle cost, have not to date been fully addressed in the research on this subject.

It can be concluded that district energy projects have unique qualities that differentiate them from typical capital building projects. For this reason, this research will only focus on selection factors specific to new district energy projects and their relationship to PDCS options. It will also view these selection factors as they relate to the total lifecycle of these projects, and not simply the design and construction phases. In this way it is hoped to fill a gap in the current research and build on a foundation of research to further develop PDCS methods specifically for the delivery of district energy projects and similar alternative energy infrastructure.

2.8 Case Study Research

As discussed in section 2.6.1, there is a significant body of research aimed at developing improved PDCS decision-making strategies using relatively large data samples and performance-based variables. Konchar and Sanvido (1998), and a later study by Bowers et al. for the CII (2003), show that large sample sizes are required to provide convincing quantitative analysis of project delivery success. However, it can be very difficult to collect data in quantities substantial enough to justify quantitative research in the field of construction. This is especially true with new district energy projects in Canada, where only a handful of these projects have been built. Where the research methodology involves subjective tests, the quality of large data samples can also be impacted by the diverse perceptions of success or failure of different project owners (Korkmaz, 2007) and by the wide range in professional experience of the research participants.

It became apparent early in the development of the research methodology for this study that, while an improved understanding of the delivery of new district energy projects in Canada was a unique and relevant research question, the limited sample size of suitable research participants would present a significant challenge to data collection. As the methodology was developed and the scope of research participants was established, it became obvious that large data samples would not be available. As well, it was apparent that the “real life” context of the problem meant that it was greatly influenced by the relative experience and opinions of the research participants. A review of research using case studies revealed that this methodology would be an appropriate way to address these limitations.

Yin (1994) states that “in general, case studies are the preferred strategy…when the investigator has little control over the events, and when the focus is on a contemporary phenomenon within some real life context”. Research has also found that this intimate interaction with actual evidence can produce theory that is closer to reality (Eisenhardt, 1989) and that the case study allows an academic investigation to better retain the characteristics of a real life event (Yin, 1994). Case study research has gained popularity recently, not only in the humanities, but also in business and engineering disciplines. It is now seen as one of the best bridges from complex qualitative evidence to mainstream deductive research (Eisenhardt & Graebnar, 2007). While case study research is often used to test new theory, cases can also help sharpen existing theory by pointing to gaps in the research and beginning to fill them (Siggelkow, 2007).

According to Eisenhardt and Graebnar (2007), a case study approach is appropriate when "the research question is *tightly* scoped within the context of an existing theory, and the justification rests heavily on the ability of qualitative data to offer insight into complex social processes that quantitative data cannot easily reveal". In understanding the selection of PDCS delivery alternatives for district energy projects, expert opinion from experienced senior managers stood out as the best source of data. The importance of PDCS selection factors for a project and how those factors match with PDCS options is a subjective measure that can only be obtained by consulting expert opinion.

Case study research can be conducted using one unique case. In that instance it will typically "exploit opportunities to explore a significant phenomenon under rare or extreme circumstances" (Eisenhardt & Graebnar, 2007). However, it is understood that multiple-case studies typically provide a stronger base for theory development (Yin, 1994). While multiple cases are likely to result in better theory, sampling is more complicated. With multiple cases, the selection is based more on the contribution to theory development within the set of cases than it is on the unique factors of the single case (Yin, 1994). While the cases may be chosen randomly, if this suits the research problem, random selection is not necessary (Eisehardt, 1989). In fact "it is often desirable to choose a particular organization precisely because it is very special in the sense of allowing one to gain certain insights that other organizations would not be able to provide" (Siggelkow, 2007).

The cases chosen for this research were selected for their ability to provide a unique and insightful view into the selection of PDCS alternatives for district energy projects in Canada.

The methodology for selection of case study projects is found in Chapter 3, section 3.1. A detailed description of each case study project can be found in Chapter 4, section 4.1.

Chapter 3: Research Methodology

The methodology utilized for this research relies on a multi-phased approach to data collection. Multiple tools were utilized including: questionnaires, interviews, workshops and a comprehensive literature review. The flowchart shown in Figure 3 provides a high-level summary of the methodology used for this research. Data was compiled, analyzed and presented using a variety of methods, outlined in Chapters 4, 5 and 6.

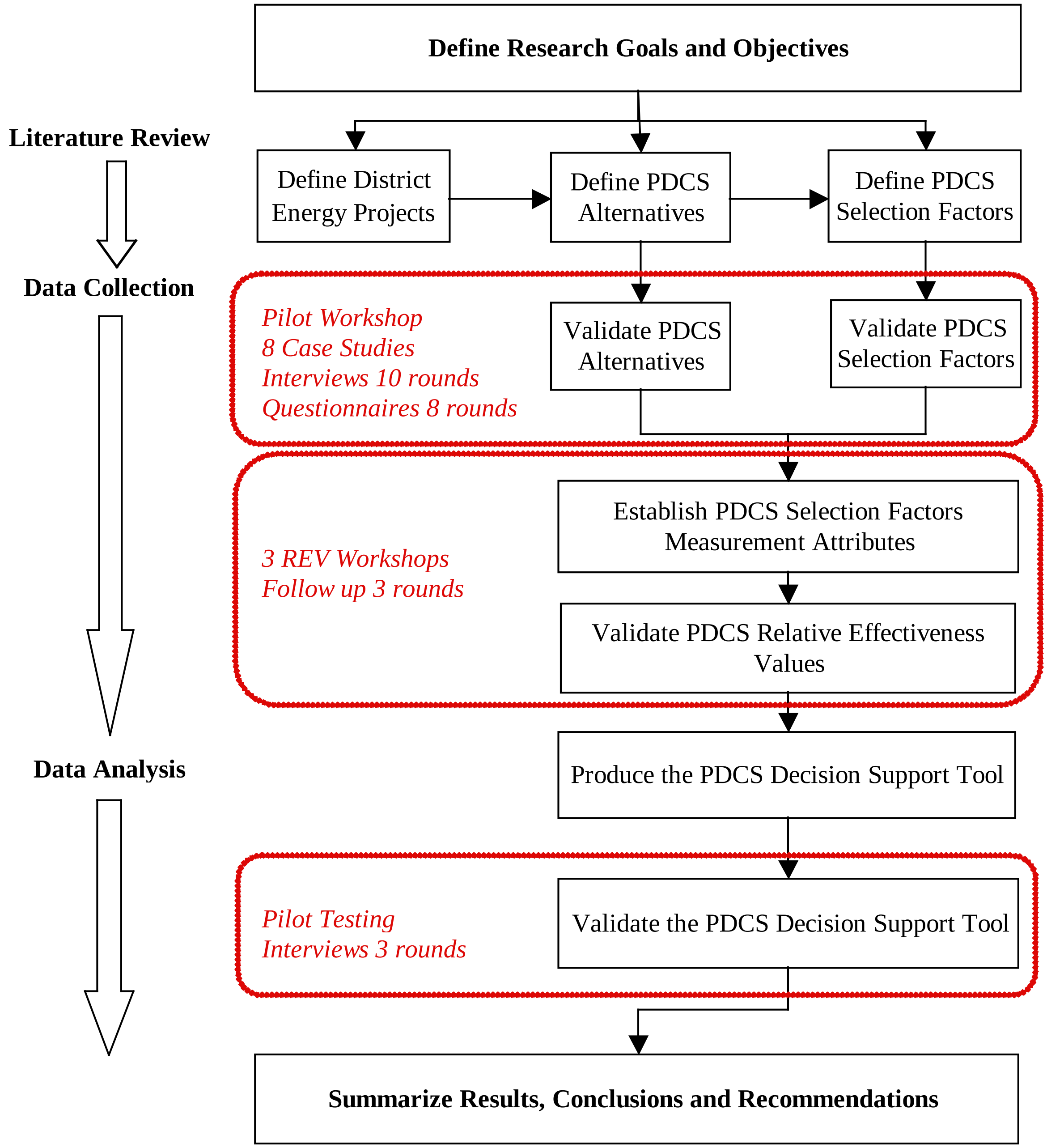


Figure 3: Research Methodology Flowchart

3.1 Selection of the Case Study Projects

The case study projects that were selected were restricted to district energy projects that have been built in Canada in the last 15 years, or are still under construction there. It was essential to have access to a senior manager who was familiar with the project's delivery process and who was willing and available to participate in the study. Case study projects were selected using the following methods:

1. Part of the literature review was focused on industry associations representing district energy providers and owners in North America. These sources were used to define and describe district energy projects for the purpose of selecting the case study projects. Specifically, the Canadian District Energy Association's National Survey Report on District Energy (2009) and the NRC's Canmet Energy Community Energy Case Studies (2009) provided a good baseline from which to select the district energy projects for this research.
2. A pilot test group was established consisting of two senior public sector project managers who have had experience with the delivery of a district energy project. They were asked to review the proposed interview-questionnaire and describe the distinguishing attributes of their own projects. This information was incorporated into the final questionnaire.
3. Senior managers representing the owners of the eight case study projects were contacted and first asked to provide general background for their project. The initial interview questions asked for the defining characteristics of each district energy system, such as fuel cost, energy output, etc. (see Appendix A).

4. The case study projects used for this research are described in detail in Chapter 4, section 4.1.

3.2 Selection of the PDCS Alternatives

The PDCS alternatives describe the project delivery and contracting strategies available to owners when they are in the pre-planning stage of their district energy project. The initial list was identified in the literature review and was further enhanced to include alternatives deemed suitable for the delivery of new district energy projects. The method for establishing the final list of PDCS alternatives for this research was as follows:

1. The pilot test group was asked to review the global set of PDCS options that were listed in the draft questionnaire. This set was based on the list established by Bowers et al. (2003), with additional PDCS alternatives deemed by the researcher to be appropriate for district energy projects. The final list of PDCS alternates is shown in Table 3-1.
2. The original list of PDCS options was confirmed based on the results of the first workshop with the pilot test group and was included in the research questionnaire (see Appendix A).
3. An appendix to the list of PDCS alternatives was developed to help describe the phasing and relationships for each PDCS through a graphical representation of each (see Appendix B).

4. Respondents to the questionnaire were asked to provide new PDCS options, if appropriate, and to add a graphical representation similar to the one described in item 3 above.
5. The data collected to validate PDCS alternatives is presented in Chapter 5.

Table 3-1: PDCS Alternatives for Research Questionnaire

1. Design-Bid-Build (DBB)
2. Design-Bid-Build with Early Procurement (DBB-EP)
3. Design-Bid-Build with Project Manager (DBB-PM)
4. Construction Manager (CM)
5. Construction Manager at Risk (CMR)
6. Design-Build (DB)
7. Multiple Design-Build (MDB)
8. Multiple Prime Contractors (MPC)
9. Design-Build-Operate-Maintain (DBOM)
10. Public Private Partnership (P3)

3.3 Scoring the PDCS Selection Factors

The initial list of PDCS selection factors was established from previous research, through the literature review (see Chapter 2, section 2.5). Additional selection factors were added and the final list was validated through the pilot test group workshop, interviews and questionnaire.

Table 3-2 describes the original 22 selection factors that were included in the questionnaire and scored by the research participants during the case study interviews. Participants were told that several of the selection factors on the list had been validated by previous research. They were also advised that the list had been enhanced to include the lifecycle objectives of district energy projects based on the researcher's own understanding of these projects.

Participants were advised that there would be an opportunity to add their own selection factors to the list, if they felt any important ones were missing.

The final list of selection factors is shown in Table 3-2. The method for validating PDCS selection factors was as follows:

1. The pilot test group was asked to review the global set of selection factors. The initial list was based on the selection factors established by Oyetunji (2001) (see Table 2-3). The list was updated to include additional selection factors for district energy projects and to take into account lifecycle objectives that Oyentuji (2001) had not considered. This group was asked to contribute any new selection factors they felt would be appropriate.
2. The list of selection factors was confirmed, based on the discussion with the focus group, and included with the interview questionnaire.
3. Respondents to the questionnaire survey were asked to score the selection factors from 1-100 (see Appendix A). They were also asked to provide new selection factors, if appropriate.
4. The data collected to validate selection factor importance scores is shown in Chapter 5, sections 5.1 and 5.2. The list of validated PDCS selection factors can be found in section 5.3.

Table 3-2: PDCS Selection Factors for Questionnaire

1	Minimal capital cost was critical to project success
2	Construction completion within original capital budget was critical to project success
3	Minimal operating and maintenance cost was critical to the project success
4	Owner wished to defer capital cost over the life of the project
5	Owner required early and reliable capital cost figures to facilitate financial planning and business objectives
6	Owner required early and reliable operating and maintenance cost figures to facilitate financial planning and business objectives
7	Owner required early and reliable energy output and system efficiency figures to facilitate financial planning and business objectives
8	Owner required certainty of fuel cost to facilitate financial planning and business objectives
9	Owner wished to assume minimal financial risk on the project
10	Completion within original schedule was critical to project success
11	Early procurement of long lead items was critical to project success
12	An above average number of changes was anticipated on this project
13	Confidentiality of business and/or engineering details was critical to project success
14	The owner desired a high degree of control and influence over the project design and construction
15	Owner desired a high degree of control and influence over the design of operation and maintenance of the facility
16	Owner desired substantial use of their own resources in the commissioning, operation and maintenance of the facility
17	Owner desired minimal use of their own resources in the commissioning, operation and maintenance of the facility
18	Owner desired substantial influence and control over the pre-planning phase of the facility
19	Owner desired minimal influence and control over the pre-planning phase of the facility
20	Project scope of work was not well defined at the start of the construction contract
21	Owner wished to limit number of parties directly accountable for the project's performance
22	Owner required certainty of emissions and other environmental concerns to accomplish their pre-planning objectives

3.4 Scoring the PDCS Relative Effectiveness Values (REV)

The need to develop REV's to build a decision support tool is identified in Chapter 2, section 2.6. As discussed in section 2.6.2, research has shown that it is most productive to have small groups of experts provide data on the effectiveness of the PDCS in the form of REV scores.

In their discussion of the Delphi approach, Lilja et al. (2011) recommend that a panel should be as varied as possible, to ensure "rich discourse" and a "real achievement of consensus". Their paper argues that with homogenous groups there is the risk of "axiomatic consensus", described as a phenomenon where people with the same background, education and experience seldom find new approaches or solutions to a problem (Lilja et al. 2011). With this in mind, three separate workshop groups were assembled. While the members of each group had a wide range of experiences and professional backgrounds, the construction project delivery experience within each group was fairly similar.

Decisions on the selection of PDCS alternatives for building projects generally come from three perspectives. Ultimately, project managers and procurement specialists representing the owner will make the decision on which PDCS alternative will be used. However, they are often influenced by the opinion of their prime consulting team and/or their construction team. Therefore REV scoring was solicited, not only from the owner's perspective, but also from that of the consultants and contractors.

The data collection for the REV scoring was conducted over three workshop sessions with senior construction professionals experienced in a wide range of project delivery alternatives.

The following four steps outline the method used to collect data for the REV scoring:

- Develop the REV worksheet
- Arrange and conduct workshops
- Distribute transcripts from each workshop and debrief participants
- Follow-up, if required

These results of these four steps are discussed in greater detail in Chapter 6. A summary of the step-by-step method for validation of the REVs is as follows:

1. Three separate workshops were scheduled with senior managers (representing owners, consultants and contractors) experienced in delivering institutional, commercial and industrial (ICI) construction projects in Canada.
2. Attendees of the workshops were asked to score each selection factor measurement attribute against each PDCS. This was carried out as collaborative exercises in order to validate the measurement attributes and establish a baseline score for the REVs. Each group provided a single score in each category.
3. Where there was a significant discrepancy in the scoring between one group and the other two, that group was asked to re-visit the question. In those cases the scoring from all three groups was made available in accordance with the Delphi approach.
4. Consensus scores from each of the three workshops were then aggregated to produce a summary table of single scores for each PDCS option against each selection factor.

5. Absolute consensus amongst the three separate workshops was not required (and not possible). A single REV score was developed by aggregating the three scores.
6. The data collected to validate the REV of each PDCS alternative is presented in Chapter 6.

3.5 Developing the PDCS Decision Support Tool

According to Oyentuji and Anderson (2003, 2006), the decision process for solving selection problems under certainty is a multi-step one, based on the decision analysis technique that is adopted. For multi-attribute utility theory (MAUT) and the closely related simple multi-attribute rating technique with swing weights (SMARTS) used by Oyentuji (2001), the methodology can be broken down into nine steps. These steps are as follows:

1. Identify the relevant alternatives.
2. Define evaluation objectives and environment.
3. Break down objectives and environment into selection factors and define the measurement attribute of each selection factor.
4. Define the value function for the measurement attribute of each selection factor.
5. Determine the preference weightings for each selection factor.
6. Determine how well each PDCS alternative would perform with respect to the measurement attribute of each selection factor.
7. Determine the relative value of the PDCS performance by applying the value function to the performance level of each alternative with respect to each selection factor.

8. Apply the aggregation rule to obtain an overall score for each alternative over the set of selection factors utilizing the relative values and preference weightings obtained in Steps 5 and 7 above.
9. Select the optimal alternative on basis of overall score or rating.

The methodology utilized by Oyentuji and Anderson (2003, 2006) and described in items 1 to 9 above was used as a framework for the development of the decision tool for this research. While the SMARTS methodology was not used in its true form, the basic principles were adopted to build this decision support tool.

Chapter 4: Case Study Projects

4.1 Introduction to Case Study Projects

Seven unique case studies were conducted for this research. These were all district energy projects that have been built (or are currently under construction) within the past 15 years, in Canada. General information was gathered about these projects including technical data about the system operation. Additionally, specific information about the PDCS decision process and the relevant selection factors was collected. Data were gathered primarily through phone interviews with owner representatives. Participants were asked questions from a pre-prepared questionnaire. Two participants chose to complete the questionnaire on their own, with follow up from the researcher to clarify their responses. A summary of the technical data gathered for these projects can be found in Table 4-15. The data on case study projects was retrieved from interview transcripts, unless otherwise noted.

In order to verify the interview data and to enhance general understanding about the case study projects, relevant web sites were consulted for each project. These sources are not referenced in order to protect the confidentiality of the projects and that of the research participants.

4.1.1 Case Study Project 1

Case study project 1 is located in British Columbia. The first phase of the project is currently under construction. It will be completed in 6-8 phases over 3.5 years. The system is owned and operated by a large institution. The individual who was interviewed is a senior director with the infrastructure development department at the institution and has 40 years experience in the construction industry.

The district energy system is designed to produce 60+MW of heating. It will also provide domestic hot water to buildings. The system is designed for a 40-year expected life span. The primary source of fuel for the main heating plant is natural gas with natural gas also used for backup and energy peaking loads. The main system will be supplemented with a biomass plant that is currently under construction. The biomass plant will co-generate heat and power and the system will eventually incorporate thermal and electrical storage capacity. The owner is considering waste heat, as well as other alternative energy sources, for future production of heating and power to supply the district energy system and the electrical grid.

The project will be funded by the energy savings and deferred maintenance of the existing heating systems. A key driver for the project was to avoid the significant maintenance and repair costs anticipated for the existing steam infrastructure. Another important driver was the desire to reduce the financial and social cost of greenhouse gas (GHG) from the institution. The project (all phases) is estimated to cost $85 million. It is expected that the project be completed in three and a half years. The phasing of the project is intended to allow the owner to ensure the system is performing to expectations before committing to a large capital expense.

Table 4-1 shows who was functionally responsible for each of the seven phases of the project's lifecycle. Table 4-2 shows the compensation approach for each party that was contracted with the owner to deliver this project.

Table 4-1: Case Study Project 1 - Function Responsibility

Phase:	DE Plant	DE Pipe Materials	DE Pipe Civil Work	Buildings
Pre-Planning	O/D	O/D	O/D	O/D
Design	D	D	D	D
Procurement	O	O	O	O
Construction	C	C	C	C
Commissioning	O/D/C	O/D/C	O/D/C	O/D/C
Operating & Maintenance	O	O	O	O
Decommissioning	O	O	O	O

O = Owner D = Design Consultant C = Contractor

Table 4-2: Case Study Project 1 - Compensation Approach

Compensation / Contract	Competitive Price	Negotiated Price	Guaranteed Maximum Price	Unit Price	Cost Plus	In-House	Other (Please Specify)
Pre-Planning		X				X	
DE System Designers	X						
Building Designers	X						
DE System Contractor	X						
General Contractor	X						
Commissioning	X						
Operating (excluding fuel)						X	
Maintenance						X	
Fuel	X			X			

4.1.2 Case Study Project 2

Case study project 2 is located in British Columbia. It is owned and operated by a large institution and became operational in March 2011. The individual who was interviewed is a senior director of the physical plant and one of the key individuals responsible for the delivery of capital projects for the institution. He has 35 years experience operating and managing the construction of industrial facilities.

This district energy system is designed to produce 10MW of heating, 5MW of which are generated from renewable sources. The system is designed for a 50-year expected life span, assuming a major re-build at 25 years. Its primary source of fuel is biomass, with natural gas used for backup and peaking loads. The system does not have built-in energy storage capacity and does not currently have the ability to co-generate electrical power.

The project capital cost was $20.7 million, $8.5 million of which came from the provincial government's Public Sector Energy Conservation Agreement and Innovative Clean Energy Fund. The balance of the project capital came from the federal government's Knowledge Infrastructure Funds. It was expected that the project would be complete in 18 months and it was delivered on schedule.

The Table 4-3 shows the party that was functionally responsible for each of the seven phases of the project's lifecycle. Table 4-4 shows the compensation approach for each party that was contracted with the owner to deliver this project.

Table 4-3: Case Study Project 2 - Function Responsibility

Phase:	Upgrade Boiler Plant	New Biomass Plant	DE Pipe & Civil Work	System Buildings
Pre-Planning	O/D/CM	O/DB	O/D/CM	O/D/CM/DB
Design	D	DB	D	D
Procurement	O/CM	DB	O/CM	O/CM
Construction	CM	DB	CM	CM
Commissioning	O/CM	O/DB	O/CM	O/CM
Operating & Maintenance	O	O	O	O
Decommissioning	O	O	O	O

O = Owner D = Design Consultant DB = Design-Build Contractor CM = Const. Manager

Table 4-4: Case Study Project 2 - Compensation Approach

Compensation / Contract	Competitive Price	Negotiated Price	Guaranteed Maximum Price	Unit Price	Cost Plus	In-House
Pre-Planning		X				X
Biomass System Designers		X				
Building Designers		X				
Biomass System Contractor		X				
Construction Manager (at risk)	X					
Commissioning		X				
Operating (excluding fuel)						X
Maintenance						X
Fuel				X		

4.1.3 Case Study Project 3

Case study project 3 is located in British Columbia. It is owned and operated by a large urban municipality and commenced operation in January 2009. The individual who was interviewed is the owner's senior manager for the municipality district energy utility and has five years of experience in this role.

This district energy system is designed to produce 19.5MW of heating. It also provides domestic hot water to buildings. The system is designed for a 30-year expected life span. Its primary source of fuel is waste heat recovery with natural gas used for backup and peaking loads. The system does not have built in backup storage and does not have the capacity to co-generate electrical power at this time. Solar panels on the buildings will feed thermal energy back into the system, if solar generation is available.

The project capital cost was $31.0 million. Funding for this project is based on a cost recovery utility model. A Federation of Canadian Municipalities (Green Municipal Fund) loan provided $5.0 million of the capital cost. A further $9.5 million came from a Provincial grant. The remaining portion of the capital funding was raised through debenture-funding. The operation and maintenance cost is $3.3 million, with $2.2 million of that amount going to debt financing.

Table 4-5 shows the party that was functionally responsible for each of the seven phases of the project's lifecycle. Table 4-6 shows the compensation approach for each party that was contracted with the owner to deliver this project.

Table 4-5: Case Study Project 3 - Function Responsibility

Phase:	DE Plant	DE Pipe Materials	DE Pipe Civil Work	Buildings
Pre-Planning	O/D	O/D	O/D	O/D
Design	D	D	D	D
Procurement	O/D	O/D	O/C	O/C
Construction	C	C	C	C
Commissioning	O	N/A	O	O
Operating & Maintenance	O/C	O	O	O
Decommissioning	O	O	O	O

O = Owner D = Design Consultant C= Contractor

Table 4-6: Case Study Project 3 - Compensation Approach

Contract \ Compensation	Competitive Price	Negotiated Price	Guaranteed Maximum Price	Unit Price	Cost Plus	In-House
Pre-Planning		X				
DE System Designers		X				
Building Designers		X				
DE System Contractor	X					
General Contractor	X					
Commissioning						X
Operating (excluding fuel)						X
Maintenance	X					
Fuel	See below					
Other: Natural gas		X				
Electricity			X			

4.1.4 Case Study Project 4

Case study project 4 is located in Alberta. It became operational in 2006 and is municipally owned and operated. The individual who was interviewed is a senior project manager with the utilities department at the municipality and has 30 years of experience managing infrastructure projects.

This district energy system is designed to produce 10MW of heating, and to provide domestic hot water for buildings. The system is designed for a 25-year expected life span. Its primary source of fuel is natural gas, with natural gas also used for backup and peaking loads. The system does not have built-in backup storage capacity at this time.

Funding for this project came from a low interest loan from the provincial ME First program, from a municipal grant program and from internal borrowing. The project cost was approximately $8 million. The project was completed in 24 months.

Table 4-7 shows the party that was functionally responsible for each of the seven phases of the project's lifecycle. Table 4-8 shows the compensation approach for each party that was contracted with the owner to deliver this project.

Table 4-7: Case Study Project 4 - Function Responsibility

Phase:	DE Plant	DE Pipe Materials	DE Pipe & Civil Work	Buildings
Pre-Planning	O/D	O/D	O	O/D
Design	D	D	D	D
Procurement	O/C	O	O	C
Construction	C	C	C	C
Commissioning	O/C	O/C	O/C	O/C
Operating & Maintenance	O	O	O	O
Decommissioning	O	O	O	O

O = Owner D = Design Consultant C= Design-Build Contractor

Table 4-8: Case Study Project 4 - Compensation Approach

Contract \ Compensation	Competitive Price	Negotiated Price	Guaranteed Maximum Price	Unit Price	Cost Plus	In-House
Pre-Planning	X					
Biomass System Designers	X					
Building Designers	X					
Biomass System Contractor	X					
General Contractor	X					
Commissioning		X				
Operating (excluding fuel)						X
Maintenance						X
Fuel						X

4.1.5 Case Study Project 5

Case study project 5 is located in Ontario. It is the oldest district energy system in Canada, originally built in 1880. The system underwent a major upgrade in 1993, and it is this which is the focus of this case study. The system was built using private financing and it is privately owned and operated. The individual who was interviewed is the senior advisor on sustainable energy management and has 20 years of experience building and managing energy infrastructure projects.

This district energy system is designed to produce 100MW of heating and cooling and co-generate 20MW of electrical power. Its primary source of fuel is natural gas with fuel oil used for backup. It does not have built in backup storage. The system was described as a district energy “mega-system”, meaning it is a high temperature system that recovers waste energy from the principal processes to generate additional energy. With the higher capital and operating costs of a larger system, superior energy output is achieved.

Table 4-9 shows the party that was functionally responsible for each of the seven phases of the project's lifecycle. Table 4-10 shows the compensation approach for each party that was contracted with the owner to deliver this project.

Table 4-9: Case Study Project 5 - Function Responsibility

Phase:	DE Plant	DE Pipe Materials	DE Pipe & Civil Work	Buildings
Pre-Planning	O	O	O	O
Design	O	O	O	O
Procurement	O	O	O	O
Construction	O	O	O	O
Commissioning	O	O	O	O
Operating & Maintenance	O	O	O	O
Decommissioning	O	O	O	O

O = Owner D = Design Consultant C= Design-Build Contractor

Table 4-10: Case Study Project 5 - Compensation Approach

Compensation / Contract	Competitive Price	Negotiated Price	Guaranteed Maximum Price	Unit Price	Cost Plus	In-House
Pre-Planning						X
Biomass System Designers						X
Building Designers						X
Biomass System Contractor						X
Construction Manager						X
Commissioning						X
Operating (excluding fuel)						X
Maintenance						X
Fuel						X

4.1.6 Case Study Project 6

Case study project 6 is located in Ontario. It is the second phase of a three-phase district energy project that is currently under construction. The system is owned and operated by the subsidiary of a large municipality. The individual who was interviewed is a director of engineering and construction with the municipality's utility provider and has 20 years of experience managing infrastructure projects.

This district energy system is designed to produce 15MW of heating, 14MW of cooling and 5MW of process steam for a nearby hospital. It also supplies domestic hot water to the buildings and has the capacity to co-generate electrical power. The system is designed for a 25- to 50-year expected life span. The system's primary sources of fuel are natural gas for heating, electricity for cooling and fuel oil for backup. The system does not have built in energy storage capacity at this time.

Some of the project funding was provided though Infrastructure Ontario, however, a typical utility cost recovery model was used to finance the majority of the project. The project was started in November 2010 and is scheduled to be complete by the second quarter of 2012.

Table 4-11 shows the party that was functionally responsible for each of the seven phases of the project's lifecycle. Table 4-12 shows the compensation approach for each party that was contracted with the owner to deliver this project.

Table 4-11: Case Study Project 6 - Function Responsibility

Phase:	DE Plant	DE Pipe Materials	DE Pipe Civil Work	Buildings
Pre-Planning	O/D	O/D	O/D	O/D
Design	D	D	D	D
Procurement	O/CM	O	CM	CM
Construction	O/CM	CM	CM	CM
Commissioning	O/CM/D	CM	CM	D/CM
Operating & Maintenance	O	O	O	O
Decommissioning	O	O	O	O

O = Owner D = Design Consultant CM= Construction Manager

Table 4-12: Case Study Project 6 - Compensation Approach

Compensation / Contract	Competitive Price	Negotiated Price	Guaranteed Maximum Price	Unit Price	Cost Plus	In-House
Pre-Planning					X	X
DE System Designers					X	
Building Designers		X				
Construction Manager (at risk)					X	
Commissioning					X	X
Operating (excluding fuel)						X
Maintenance						X
Fuel					Market	

4.1.7 Case Study Project 7

Case study project 7 is located in British Columbia. It is currently under construction and will be owned and operated by a private developer. The individual who was interviewed is the Director of Land Development for the development company.

This district energy system is designed to produce 24MW of heating, 10MW of which will be from renewable energy sources. The system will also provide domestic hot water to buildings. The primary source of fuel will be waste heat with natural gas for backup and peaking loads. There will be a temporary plant powered by natural gas to service the development while the main heat recovery plant is being constructed. The system is not planned to have built in backup storage capacity.

At the time of the interview, an application had been sent to the Provincial Clean Energy Fund and BC Hydro grant program for partial funding of the project. The system will operate on a typical district energy cost recovery utility model.

Table 4-13 shows the party that was functionally responsible for each of the seven phases of the project's lifecycle. Table 4-14 shows the compensation approach for each party that was contracted with the owner to deliver this project.

Table 4-13: Case Study Project 7 - Function Responsibility

Phase:	Temp. Boiler Plant	Perm. Boiler Plant	Waste Heat Plant	DE Pipe Materials	DE Pipe Civil Work	System Buildings
Pre-Planning	O/D	O/D	O/D	O/D	O/D	O/D
Design	C	D	D	D	D	D
Procurement	O	O	O	O	O	O
Construction	C	C	C	C	C	C
Commissioning	C	C	C	C	C	C
Operating & Maintenance	TBD	TBD	TBD	TBD	TBD	TBD
Decommissioning	O	O	O	O	O	O

O = Owner D = Design Consultant C = Contractor

Table 4-14: Case Study Project 7 - Compensation Approach

Compensation / Contract	Competitive Price	Negotiated Price	Guaranteed Maximum Price	Unit Price	Cost Plus	In-House
Pre-Planning		X				X
DE System Designers		X				
Building Designers		X				
DE System Contractor	X					
General Contractor	X					
Commissioning	X					
Operating (excluding fuel)	TBD					
Maintenance	TBD					
Fuel (gas)				X		

4.1.8 Case Study Project 8

The information for case study project 8 came unsolicited from one of the consulting engineers who had been contacted to provide general information about district energy projects in Canada. This senior thermal engineer currently works in British Columbia but had worked in Abu Dhabi, United Arab Emirates, in the past and had designed and installed a large district energy system there.

Because this is not a Canadian project and the information did not come directly from the owner’s representative, the data collected from the questionnaire survey was not included in the further data analysis for this research.   However, the information is provided for interest and to compare against the Canadian case study projects. The selection factor importance scores were provided as well and, again, are included in Chapter 5 for information and comparison only.

This district energy system is designed to produce 87.9MW of cooling only. The plant can co-generate some electrical power and has the capacity for storage of thermal energy. The primary source of fuel is natural gas. The electrical utility is used for back-up and peaking loads. The project was completed in 21 months. The total cost of the project was not provided.

4.2 Summary of the Case Study Projects and Anecdotal Comments

Table 4-15 shows a summary of the technical information gathered for each of the seven valid Canadian case study projects and the eighth international project.

Table 4-15: Summary of Case Study Projects Technical Data

Case Study	**Life Span**	**Primary Output**	**Secondary Output**	**Co-gen Power**	**Energy Storage**	**Total Design Load**	**Primary Fuel**	**Back-up Fuel**
	(yrs)	(type)	(type)	(y/n)	(y/n)	(MW)	(type)	(type)
1	40	heat	dhw*	yes	yes	60	nat. gas	biomass & nat. gas
2	50	heat	none	no	no	10	biomass	nat. gas
3	30	heat	dhw*	no	yes	19.5	waste heat	nat. gas & elect.
4	25	heat	dhw*	no	no	10	nat. gas	nat. gas
5	n/a	heat/cool	none	yes	no	100	nat. gas	fuel oil
6	25-50	heat/cool/ steam	dhw*	yes	no	14/15/5	nat. gas/elect.	fuel oil
7	n/a	heat	dhw*	no	no	10	waste heat	nat. gas
8	40	cooling	none	yes	yes	88	nat. gas	elect.

*dhw = domestic hot water

Apart from the information gathered through the pre-prepared questionnaire, the case study interview conversations drew out some additional comments.

According to one participant, the "look" of the plant building became important during pre-planning and design. This drove up architectural costs substantially from their original estimates. As well, because it was built in an urban center, additional costs were incurred for seismic upgrades to the existing infrastructure and to meet seismic requirements for the new district energy plant.

Conversation with one interview participant revealed that for a biomass or similar alternative energy plant for their system, they would encourage maintenance agreements and a fuel purchase agreement as part of the contracting strategy with their supplier. This would help mitigate one of the largest risks in business planning, which is the "energy uptake" reliability. If the development is not built out fast enough there is a risk that supply will outweigh demand. Phased construction of the system is another way to mitigate this risk. By using phased construction an owner can build out the district energy system as demand increases.

In addition to the case study project interviews, the Canadian office of an engineering firm specializing in district energy projects throughout North America and Europe was contacted for general feedback. This firm described district energy systems as having two parts, production (plant) and distribution (piping and energy transfer stations (ETS)). The production component was further broken down into a conventional plant and an alternative energy plant. According to the interviewee, these two energy production components can be part of a single district energy system, but have different risk profiles and therefore require different project delivery methodologies.

This same engineering firm also suggested that there are two types of public sector district energy projects currently being considered in Canada. These are municipal district energy systems, which are "built to grow", and institutional systems, which are "built to fit". It was suggested that these two types of systems should be considered separately when selecting a PDCS method, as the life cycle objectives will vary for each.

4.3 Summary of the Case Study Project PDCS Methods

Each of the case study participants was asked to identify the PDCS alternative they utilized to deliver their project. The PDCS methods varied widely from project to project.

Case study project 1 is being built-out over several years, in phases. Multiple contractors will be used, one for each main component of the work, and for each phase. Each phase will be tendered separately under a multiple design-bid-build (M-DBB) delivery method. As sources of alternative energy are scoped they will be added to the system to supplement the base district energy plant, again under separate contracts. The method of delivery for these alternative energy projects to supplement the main natural gas fired boiler plant is undetermined at this time.

Case study project 2 used a construction-manager-at-risk (CMR) delivery method for the plant building shell, base boiler plant upgrades and distribution infrastructure. The biomass heating plant was separate and a DB contract was used for that portion of the work. It was very important to the owner that the biomass plant was designed and commissioned to their satisfaction, as they would be responsible for running it. The DB contract had tight performance specifications and the owner was very involved in monitoring the design process.

Case study project 3 used a DBB delivery method for the distribution piping and the ETSs. A design-bid-build with early procurement DBB-EP approach was used for the main plant in order to expedite the schedule. Separate contractors were used for each separate scope of work. The main heat pumps for the waste heat recovery system were a very specialized design and were delivered using a DBOM delivery method.

The research participant for case study project 4 did not provide the delivery method used for their project. Follow up correspondence could not solicit a response on this item.

Case study project 5 was built in 1993 and is the earliest of the case study projects. Because there were not many district energy systems being built in Canada at that time, the owner felt that a DBOM using in-house design and construction expertise was the only viable delivery option. According to the research participant, it became apparent that with the increased risk in the chosen delivery method, came increased control. It was felt that decisions could be made quickly because the owner had more control over the delivery process, which helped the project to be delivered under budget and ahead of schedule.

Case study project 6 is being built using a CMR delivery method. The CMR approach had been used by this owner on previous infrastructure projects. This delivery method was chosen to leverage the success experienced in past projects and to ensure the owner would be working with a familiar firm for the construction of the district energy system. Select pieces of major equipment were purchased directly by the owner. Procurement and delivery of this major equipment is outside the CM's scope of work and will be coordinated directly by the owner.

Case study project 7 is being built using a DBB-MPC delivery method for each phase of the distribution infrastructure, as the overall development is built-out. Because the system will come on line progressively, the owner has elected to build a temporary gas fired boiler plant, using a DBOM delivery method, to service the first phases. The future permanent waste heat recovery plant will likely be built using a DBB delivery method.

Case study project 8 was delivered under a joint venture (JV) – engineering procurement and construction (EPC) agreement. Functional responsibility for all stages of the project was shared between the two JV partners. One partner took responsibility for the majority of the pre-planning and the operation and maintenance. The other partner was responsible for design, construction and commissioning of the entire system.

Table 4-16 shows a summary of the PDCS alternatives that were used for each of the case study projects.

Table 4-16: PDCS Alternatives Used on Case Study Projects

Case Study	DE Plant	Buildings	DE Pipe Materials	DE Pipe Civil Work	Energy Transfer Stations	Heat Pumps
# 1	M-DBB and DBB-EP (Phased)					
# 2	DB (Turnkey)	CMR				
# 3	DBB-EP		DBB		DBB	DBM
# 4						
# 5	DBOM with Financing (Owner/Operator)					
# 6	CMR					
# 7	DBB (DBOM)	DBB	DBB - MPC (Phased)			
# 8	JV - EPC					

Chapter 5: PDCS Selection Factors

5.1 Overview of Data Collection

As described in section 3.3, participants were asked to score the importance of each selection factor for their project. This is a subjective measure and a baseline was needed to enable the scoring. Each participant was told that their most important selection factor (or factors) would receive a score of 100 and that the relative importance of all other factors should be judged against that score. The questionnaire was completed in an interview format, so the participants could be asked periodically to revisit their high scores to ensure that the relative importance of the scoring was maintained.

A transcript of the discussion was sent to the participants within a day of the interview. They were asked to check it for accuracy and to provide any comments, if necessary. Two participants asked to fill out the questionnaire on their own and submit it without the interview process. In one case, the completed questionnaire was taken at face value without the opportunity to revisit the data. In the other case, there was an opportunity to review the answers with the participant and some small changes were made to the final transcript.

The use of a 1-100 scale allowed the participants to visualize the scoring as a percentage. This assisted them in establishing the relative importance of each selection factor against their own top score. It also provided the most flexibility for future analysis of the data as these scores could be easily converted to 1-10 or 0-1 score, if needed. Participants were told that they could have several selection factors that rated 100 but that they had to be of equal importance.

The selection factor scores for the seven valid case study projects are shown in Table 5-1. The scores provided for case study project #8 are included for information and comparison only and have not been incorporated into the average or median scores.

Table 5-1: Summary of Selection Factor Scores from Case Studies

	Selection Factor Importance Score (0-100)									
Selection Factor	Case Study #1	Case Study #2	Case Study #3	Case Study #4	Case Study #5	Case Study #6	Case Study #7	Average Score	Median Score	Case Study #8
1	30	20	90	40	50	65	100	56	50	70
2	100	100	60	95	100	75	100	90	100	90
3	70	100	90	90	60	85	100	85	90	n/a
4	80	0	90	90	0	10	100	53	80	60
5	70	100	90	95	90	80	100	89	90	80
6	70	80	90	90	90	80	80	83	80	n/a
7	70	80	90	95	100	80	80	85	80	80
8	60	80	90	95	100	10	90	75	90	90
9	20	100	80	80	10	30	70	56	70	50
10	60	100	90	80	80	95	100	86	90	80
11	50	100	90	80	100	95	100	88	95	90
12	0	90	90	90	10	10	80	53	80	50
13	0	90	20	90	100	65	10	54	65	80
14	40	90	90	95	100	80	50	78	90	60
15	70	90	90	95	100	80	80	86	90	80
16	20	90	90	90	90	100	n/a	80	90	70
17	0	0	0	10	0	0	n/a	2	0	n/a
18	70	90	90	80	100	90	90	87	90	75
19	0	0	0	10	0	0	n/a	2	0	25
20	0	0	n/a	10	n/a	0	n/a	3	0	90
21	0	20	90	50	0	35	30	32	30	80
22	50	100	90	95	100	30	100	81	95	50

5.2 Analysis of PDCS Selection Factor Scores

Based on the scoring from the case study projects, shown in Table 5-1, the list of valid selection factors to be used for the PDCS decision support tool, was revised. Changes to the final list of selection factors were made as follows:

1. Selection factor #13 refers to confidentiality of "business objectives and/or engineering details". The case studies showed that, with district energy projects, the owner does not have the proprietary technology and is not terribly concerned about protecting it. The owner's business objectives are however very important and in many cases had to be closely guarded. Selection factor #13 was changed to include only the confidentiality of business objectives.

2. Selection factor #15 refers to the owner's level of influence over the design of the operation and maintenance of the facility. It became apparent during the interviews that this question was redundant, as it was already covered in selection factor #14, which refers to the owner's desired level of control over design and construction. A comprehensive design of the facility will inherently incorporate the operation and maintenance requirements. Selection factor #15 was deleted from the final list for the REV workshops and was not used in the decision support tool developed for this research.

3. Selection factor #17 refers to the owner's desire to have minimal use of their own resources in the commissioning, operating and maintenance of the district energy facility. Participants felt that selection factor #17 was a redundant question, particularly since selection factor #16, the owner's desire to have maximum use of

their own resources, is the opposite to it. It therefore scored very low, or was left unanswered. However, it is important for the PDCS selection tool that the owners are given a choice of high or low involvement of their own forces in the operation and maintenance of the facility. These two objectives will drive different PDCS alternatives. Again, the fact that this selection factor scored low could also be a result of the low number of case study projects. Selection factor #17 was left in the list for the REV workshops, even though it scored low.

4. Selection factor #19 refers to the owner's desire to have minimal influence and control over the pre-planning phase of the facility. This selection factor scored very low. It was evident from the case study interviews that this was not an objective that an owner would consider. If they did not have the capacity to conduct the pre-planning with their own forces they would hire a consultant to act as an agent on their behalf. Selection factor #19 was deleted from the final list for the REV workshops and was not used in the decision support tool.

5. Selection factor #20 refers to the project scope of work being poorly defined at the start of the construction contract. This selection factor also scored very low. Two problems with this selection factor were revealed during the interviews. First, it did not read as an objective. While the other factors used words like "required", "desired" and "wished", selection factor #20 described a potential condition of the project. In this way it cannot be considered as an objective. Second, it is highly unlikely that an owner would have this as an objective. It is more likely that a desire to fast track the schedule would cause an owner to defer key decisions for business reasons and to make changes as the project progressed. In this way selection factor

#12, which refers to the owner anticipating a high level of changes on the project, is a more appropriate measure of this objective. Selection factor #20 was deleted from the final list for the REV workshops and was not used in the decision support tool.

6. Selection factor #21 refers to the owners desire to limit the number of parties directly accountable for project performance. The average and median score for selection factor #21, was 32 (with a median score of 30). This is a relatively low score and could signal that this was not an important selection factor to owners of these projects. However, because of the low number of case study projects, the average and median scores were less significant indicators than they would be with a larger data sample. Selection factor #21 was scored highly by case study #3 and it was felt that this one high score was enough to include it in the selection criteria for PDCS alternatives.

The selection factor scores for case study project #8 provide some interesting insights to the PDCS method used for that project and the overall PDCS decision for district energy projects in Canada. Many of the selection factors from the survey for case study #8 are well aligned with the average scores for the other case study projects. The largest deviation from the average scores is apparent in selection factors #20 and #21. Selection factor #20 refers to the scope of work not being well defined at the start of construction and selection factor #21 refers to the owner’s desire to limit the number of parties directly accountable for the project’s performance. Both of these factors scored high for case study #8 and very low for the Canadian case study projects.

As described in section 4.3, the owners for case study project #8 chose to use a joint venture delivery method for that project. A joint venture is an agreement in which parties agree to develop a new entity for a given time, by contributing equity. Under this agreement, the joint venture partners share revenues, expenses and assets. A joint venture agreement for an infrastructure project would allow the partners to have total control over changes to the scope of work and would limit the number of parties accountable for the project's performance to the joint venture partners. In this way, the objectives described by selection factors #20 and #21 would be addressed by this delivery method.

The closest example of a joint venture in public infrastructure construction in Canada is the P3. Under this type of agreement, the industry partner will typically create a joint venture company to engage with the public-sector owner for the design, construction, operation and maintenance of the infrastructure asset for a given period of time (see Appendix C for definition of P3). The public-sector owner will not engage in the joint venture partnership, but will benefit from the comprehensive design-build knowledge and financial depth of the joint venture partnership, including an important contribution towards the capital cost and operational expenses of the project. None of the case study projects used a P3 delivery method and in the review of literature no Canadian district energy projects could be found that had used a P3 delivery method. Further discussion of the limitations of P3 delivery methods for district energy projects in Canada can be found in Chapter 6, section 6.1.1.

5.3 Summary of Validated PDCS Selection Factors

The final list of validated selection factors and their corresponding measurement attributes is shown in table 5-2. The measurement attribute for each of these validated selection factors was used to establish the PDCS REV scores described in Chapter 6. The wording for the selection factors was changed to the present tense, to accommodate future projects as opposed to projects that had already occurred (as required for the questionnaire).

Table 5-2: Final Selection Factors and Measurement Attributes

	Selection Factor	**Measurement Attribute**
1	Minimal capital cost is critical to project success	The delivery system is effective in ensuring the lowest reasonable capital cost for design and construction
2	Construction completion within original capital budget is critical to project success	The delivery system is effective in controlling capital cost growth during design and construction
3	Minimal operating and maintenance cost is critical to the project success	The delivery system is effective in ensuring lowest reasonable operating and maintenance cost over the life of the project
4	Owner wishes to defer capital cost over the life of the project	The delivery system is effective in deferring capital cost over the life of the project
5	Owner requires early and reliable capital cost figures to facilitate financial planning and business objectives	The delivery system is effective in ensuring certainty around capital cost estimates during the pre-planning phase
6	Owner requires early and reliable operating and maintenance cost figures to facilitate financial planning and business objectives	The delivery system is effective in ensuring certainty around operating and maintenance cost estimates during the pre-planning phase
7	Owner requires early and reliable energy output and system efficiency figures to facilitate financial planning and business objectives	The delivery system is effective in ensuring certainty around system efficiency and energy production estimates during the pre-planning phase
8	Owner requires certainty of fuel cost to facilitate financial and business planning objectives	The delivery system is effective in ensuring certainty around fuel cost estimates during pre-planning phase
9	Owner wishes to assume minimal financial risk on the project	The delivery system is effective in transferring a high level of financial risk to third parties over the life of the project
10	Completion within original schedule is critical to project success	The delivery system is effective in controlling against time extensions in the design and construction phases

	Selection Factor	Measurement Attribute
11	Early procurement of long lead items is critical to project success	The delivery system is effective in promoting early procurement of long lead materials, equipment and services for the construction phase
12	An above average number of changes is anticipated on this project	The delivery system is effective in incorporating changes during the construction phase with minimal cost and schedule impact
13	Confidentiality of business details is critical to project success	The delivery system is effective in protecting confidentiality of the owner's business objectives over the life of the project
14	The owner desires a high degree of control and influence over the project design and construction	The delivery system is effective in ensuring the owner could control the design and construction phases of the project
15	Owner desires substantial use of their own resources in the commissioning, operating and maintaining the facility	The delivery system is effective in ensuring the owner would use their own resources for commissioning, operation and maintenance of the facility
16	Owner desires minimal use of their own resources in the commissioning operating and maintenance of the facility	The delivery system is effective in ensuring the owner has minimal use their own resources for commissioning, operation and maintenance of the facility
17	Owner desires substantial influence and control over the pre-planning phase of the facility	The delivery system is effective in maximizing the owner's role in the pre-planning phase of the project
18	Owner wishes to limit number of parties directly accountable for the projects performance	The delivery system is effective in minimizing the number of contracts directly with the owner over the life of the project
19	Owner requires certainty of emissions and other environmental concerns to accomplish the pre-planning objectives	The delivery system is effective in providing certainly for the owner with regards to emissions and environmental issues over the life of the project.

Chapter 6: PDCS Relative Effectiveness Values

6.1 Overview of Data Collection

In keeping with the methodology described in Chapter 3 and Table 3-3, the data collection for the REV scoring was conducted over three workshop sessions with senior construction professionals, from varied backgrounds and experienced in a wide range of project delivery alternatives. The results of this data collection exercise are outlined in section 6.1.1 through 6.1.6.

6.1.1 Development of the REV Worksheet

The first step in establishing REV scores was to develop the REV worksheet used for scoring. In order to accomplish this, the list of PDCS alternatives that would be considered in the PDCS selection tool had to be finalized. The original list of PDCS alternatives that was included with the case study questionnaire is listed in section 3.2, Table 3-1. Through discussion during the case study interviews and subsequent discussion with experts in the field, it was apparent that some changes to this list were necessary for the REV workshops.

DBB-PM is not used commonly enough in Canada to be considered for the selection tool. Most public sector owners who are considering a major infrastructure construction project, such as a district energy system, will have project managers in-house. Where they don't have the expertise, they would be likely to consider a PDCS alternative that placed the functional and contractual responsibility for project management on a third-party. It is unlikely that a delivery strategy would be selected simply to meet this criterion. DBB-PM was removed from the final list.

MPC was changed to Multiple Design-Bid-Build (M-DBB). There were two reasons for this. First, the term multiple prime contractors assumes that the same designer was used for all scopes of work. In contrast, M-DBB can have one design team or can allow for different designers for different phases. Second, in discussion with industry experts, it was thought that the term "prime contractor" referred more to the role and responsibilities of the general contractor and was intended to distinguish them from the sub-contractors. Participants felt that this term does not accurately describe the actual contractual relationship with the owner. It was suggested that the term M-DBB more clearly represents the specific delivery method being used. M-DBB was added and moved to number three on the PDCS list so it was closer to the other DBB alternatives when being considered in the REV scoring.

It also surfaced that MDB is not a viable option for district energy projects. This delivery system may work on a mega-project, where the scale of the construction makes it reasonable to partition the project into multiple design build components. However, in discussion with industry experts, it was apparent that this approach is not reasonable for even the largest district energy system. MDB was removed from the final list.

In their publications, PPP Canada have advised that infrastructure projects considered for public-private partnerships will be limited to those that are $50 million or greater (PPP Canada, 2009). The P3 delivery method was included as part of the REV scoring workshops, as it is a viable option for the larger district energy projects. However, the PDCS selection tool will be developed such that P3 will not be an available PDCS alternative for projects under $50 million in total project value.

The revised list of PDCS alternatives that was used for the REV worksheet is shown in Table 6-1. The final worksheet used for the REV workshops is shown in sections 6.1.3, .4 and .5, Tables 6-2, 6-3 and 6-4. Appendix C includes a definition of each PDCS alternatives and a graphical representation of the phasing and contractual relationships.

Table 6-1: Final PDCS Alternatives for REV Worksheet

1.	Design-Bid-Build (DBB)
2.	Design-Bid-Build with Early Procurement (DBB-EP)
3.	Multiple Design-Bid-Build (M-DBB)
4.	Construction Management (CM)
5.	Construction Manager at Risk (CMR)
6.	Design-Build (DB)
7.	Design-Build-Operate-Maintain (DBOM)
8.	Public Private Partnership (P3)

6.1.2 PDCS Effectiveness Value Workshops

In selecting participants for the REV workshops it was important to find individuals who were not involved in the case study interviews at which the selection factors were determined. The case study projects exhausted the group of project managers with district energy experience who were available for this research. As the objective of the REV workshops was to align selection factors with PDCS alternatives, finding individuals with extensive experience in the delivery of major public industrial, commercial and institutional (ICI) building projects was very important. The selection factors validated from the case studies are broad objectives and could apply to a variety of infrastructure projects, not just to district energy projects. While it was necessary that the workshop participants understood the broad objectives of the study, they did not need to have direct experience with district energy projects to accurately score the PDCS effectiveness.

As discussed in section 2.2, the selection of the PDCS is the owner's decision. In planning the methodology for validating the REVs, it was obvious that the input of project managers representing the owner was essential to establishing accurate REV scores. However, in many instances the principal design team and/or construction manager may also have significant influence over the owner's PDCS decision. Often an owner with limited project management expertise, or limited experience with a specific type of project, will rely on third party construction professionals to contribute to the PDCS decision. For this reason, workshops #2 and #3 were held with project managers representing contractors and design professionals respectively.

The REV workshops were each held in the office of the participant organization. Participants were briefly introduced to the research project and the overall goal of the research was discussed. The process used to validate the 19 selection factors on the REV worksheet was explained to the workshop participants. The eight PDCS alternatives in the REV worksheet were also reviewed to ensure the terminology was clearly understood by all parties. In all three workshops, the eight delivery methods were familiar to all of the participants prior to the meeting. The workshops ranged from one and a half to two hours.

6.1.3 PDCS Effectiveness Workshop #1

REV workshop #1 was attended by a group of three senior project managers from the construction department of a large public institution in Vancouver, BC. These individuals are responsible for the delivery of large institutional, industrial and commercial building projects. Results from REV workshop #1 are shown in Table 6-2.

Table 6-2: Relative Effectiveness Value Scores – Workshop #1

	Selection Factor Measurement Attribute	DBB	DBB-EP	M-DBB	CM	CMR	DB	DB-OM	P3
1	The delivery system is effective in ensuring the lowest reasonable capital cost for design and construction	90	100	90	60	65	60	50	40
2	The delivery system is effective in controlling capital cost growth during design and construction	70	80	100	50	50	70	70	50
3	The delivery system is effective in ensuring lowest reasonable operating and maintenance cost over the life of the project	80	100	100	80	90	50	80	80
4	The delivery system is effective in deferring capital cost over the life of the project	0	0	0	0	0	0	0	100
5	The delivery system is effective in ensuring certainty around capital cost estimates during the pre-planning phase	0	0	0	100	100	0	0	0
6	The delivery system is effective in ensuring certainty around operating and maintenance cost estimates during the pre-planning phase	50	50	50	30	30	70	100	100

	Selection Factor Measurement Attribute	DBB	DBB-EP	M-DBB	CM	CMR	DB	DB-OM	P3
7	The delivery system is effective in ensuring certainty around system efficiency and energy production estimates during the pre-planning phase	0	0	0	0	0	80	100	100
8	The delivery system is effective in ensuring certainty around fuel cost estimates during the pre-planning phase	0	0	0	0	0	80	100	100
9	The delivery system is effective in transferring a high level of financial risk to third parties over the life of the project	0	0	0	0	0	0	80	100
10	The delivery system is effective in controlling against time extensions in the design and construction phases	0	70	70	100	100	20	20	20
11	The delivery system is effective in promoting early procurement of long lead materials, equipment and services for the construction phase	0	100	80	100	100	0	0	0
12	The delivery system is effective in incorporating changes during the construction phase with minimal cost and schedule impact	20	20	30	50	50	0	0	0
13	The delivery system is effective in protecting confidentiality of the owner's business objectives over the life of the project	90	90	100	50	50	10	0	0
14	The delivery system is effective in ensuring the owner can control the design and construction phases of the project	80	80	100	85	85	10	0	0

	Selection Factor Measurement Attribute	DBB	DBB-EP	M-DBB	CM	CMR	DB	DB-OM	P3
15	The delivery system is effective in ensuring the owner can use their own resources for commissioning, operation and maintenance of the facility	100	100	100	100	100	100	0	0
16	The delivery system is effective in ensuring the owner has minimal use of their own resources for commissioning, operation and maintenance of the facility	0	0	0	0	0	0	100	100
17	The delivery system is effective in maximizing the owner's role in the pre-planning phase of the project	100	100	100	100	100	80	80	10
18	The delivery system is effective in minimizing the number of contracts directly with the owner over the life of the project	60	50	40	0	60	50	80	100
19	The delivery system is effective in providing certainly for the owner with regards to emissions and environmental issues over the life of the project	0	0	0	0	0	80	100	100

6.1.4 PDCS Effectiveness Workshop #2

REV workshop #2 was attended by a group of three senior project managers from a mid-sized general contracting and construction management firm with offices in Victoria and Vancouver, BC. These individuals are responsible for the construction of large ICI building projects for clients across Western Canada. Results from the REV workshop #2 are shown in Table 6-3.

Table 6-3: Relative Effectiveness Value Scores - Workshop #2

	Selection Factor Measurement Attribute	DBB	DBB -EP	M-DBB	CM	CMR	DB	DB-OM	P3
1	The delivery system is effective in ensuring the lowest reasonable capital cost for design and construction	80	80	100	60	50	50	50	30
2	The delivery system is effective in controlling capital cost growth during design and construction	60	60	60	65	70	100	100	100
3	The delivery system is effective in ensuring lowest reasonable operating and maintenance cost over the life of the project	70	70	70	80	80	50	100	100
4	The delivery system is effective in deferring capital cost over the life of the project	0	0	0	0	0	0	0	100
5	The delivery system is effective in ensuring certainty around capital cost estimates during the pre-planning phase	80	80	80	100	100	60	60	30
6	The delivery system is effective in ensuring certainty around operating and maintenance cost estimates during the pre-planning phase	40	40	40	50	60	30	100	100
7	The delivery system is effective in ensuring certainty around system efficiency and energy production estimates during the pre-planning phase	40	40	40	50	60	30	100	100
8	The delivery system is effective in ensuring certainty around fuel cost estimates during the pre-planning phase	40	40	40	50	60	30	100	100

	Selection Factor Measurement Attribute	DBB	DBB -EP	M-DBB	CM	CMR	DB	DB-OM	P3
9	The delivery system is effective in transferring a high level of financial risk to third parties over the life of the project	50	50	50	10	20	60	80	100
10	The delivery system is effective in controlling against time extensions in the design and construction phases	20	80	80	100	80	60	40	30
11	The delivery system is effective in promoting early procurement of long lead materials, equipment and services for the construction phase	20	100	80	100	80	60	40	30
12	The delivery system is effective in incorporating changes during the construction phase with minimal cost and schedule impact	50	60	100	80	55	30	20	10
13	The delivery system is effective in protecting confidentiality of the owner's business objectives over the life of the project	100	100	100	80	85	30	20	10
14	The delivery system is effective in ensuring the owner can control the design and construction phases of the project	80	80	90	100	80	30	30	30
15	The delivery system is effective in ensuring the owner can use their own resources for commissioning, operation and maintenance of the facility	100	100	100	100	100	100	0	0
16	The delivery system is effective in ensuring the owner has minimal use of their own resources for commissioning, operation and maintenance of the facility	0	0	0	0	0	0	100	100

	Selection Factor Measurement Attribute	DBB	DBB -EP	M-DBB	CM	CMR	DB	DB-OM	P3
17	The delivery system is effective in maximizing the owner's role in the pre-planning phase of the project	100	100	100	100	100	20	20	10
18	The delivery system is effective in minimizing the number of contracts directly with the owner over the life of the project	70	60	60	0	70	80	90	100
19	The delivery system is effective in providing certainly for the owner with regards to emissions and environmental issues over the life of the project	0	0	0	10	10	90	100	100

6.1.5 PDCS Effectiveness Workshop #3

REV workshop #3 was attended by a group of two senior partners, an associate architect, and two senior project architects from a mid-size architectural firm in Vancouver, BC. These individuals are responsible for the design of large ICI building projects throughout Western Canada. Results from REV workshop #3 are shown in Table 6-4.

Table 6-4: Relative Effectiveness Value Scores - Workshop #3

	Selection Factor Measurement Attribute	DBB	DBB-EP	M-DBB	CM	CMR	DB	DB-OM	P3
1	The delivery system is effective in ensuring the lowest reasonable capital cost for design and construction	80	70	70	50	50	100	50	30
2	The delivery system is effective in controlling capital cost growth during design and construction	70	70	80	90	100	50	50	40
3	The delivery system is effective in ensuring lowest reasonable operating and maintenance cost over the life of the project	100	100	100	100	90	70	60	50

	Selection Factor Measurement Attribute	DBB	DBB-EP	M-DBB	CM	CMR	DB	DB-OM	P3
4	The delivery system is effective in deferring capital cost over the life of the project	0	0	0	0	0	0	20	100
5	The delivery system is effective in ensuring certainty around capital cost estimates during the pre-planning phase	70	80	80	100	100	50	40	30
6	The delivery system is effective in ensuring certainty around operating and maintenance cost estimates during the pre-planning phase	70	70	70	75	75	20	100	100
7	The delivery system is effective in ensuring certainty around system efficiency and energy production estimates during the pre-planning phase	70	70	70	75	75	20	100	100
8	The delivery system is effective in ensuring certainty around fuel cost estimates during the pre-planning phase	60	60	60	65	60	20	100	100
9	The delivery system is effective in transferring a high level of financial risk to third parties over the life of the project	0	0	0	10	0	0	90	100
10	The delivery system is effective in controlling against time extensions in the design and construction phases	50	60	60	20	30	100	100	100
11	The delivery system is effective in promoting early procurement of long lead materials, equipment and services for the construction	0	100	100	100	100	0	0	0

	Selection Factor Measurement Attribute	DBB	DBB-EP	M-DBB	CM	CMR	DB	DB-OM	P3
12	The delivery system is effective in incorporating changes during the construction phase with minimal cost and schedule impact	50	50	50	100	100	0	0	0
13	The delivery system is effective in protecting confidentiality of the owner’s business objectives over the life of the project	100	100	100	80	80	40	30	0
14	The delivery system is effective in ensuring the owner can control the design and construction phases of the project	100	100	100	90	90	0	0	0
15	The delivery system is effective in ensuring the owner can use their own resources for commissioning, operation and maintenance of the facility	100	100	100	100	100	100	0	0
16	The delivery system is effective in ensuring the owner has minimal use of their own resources for commissioning, operation and maintenance of the facility	0	0	0	0	0	0	100	100
17	The delivery system is effective in maximizing the owner's role in the pre-planning phase of the project	80	80	80	80	80	30	20	10
18	The delivery system is effective in minimizing the number of contracts directly with the owner over the life of the project	50	60	60	0	50	80	90	100
19	The delivery system is effective in providing certainly for the owner with regards to emissions and environmental issues over the life of the project	20	20	20	30	30	70	100	100

6.1.6 Analysis of Relative Effectiveness Value Workshops

An overview of Tables 6-2 to 6-4 reveals a fairly good alignment between the REV scores gathered from the three separate workshops. The following are the four exceptions:

1. There was a relatively large discrepancy in the scores received from workshop #1 for selection factors 5, 7 and 8. These three selection factors relate to certainty around capital, operating/maintenance and fuel costs respectively.

   This was the first workshop and that stage the researcher had limited experience in leading the groups and facilitating the discussion around these issues. The need to help accurately set a baseline and range for scoring was not well understood at this early session. For this reason, there was a perception from the participants that the scores were to be either very high or very low. There was little consideration for the mid-range. For example, where DBB may not allow for the most certainty around the capital cost until the bids are received, a well-managed design process with a qualified cost consultant on-board will bring some level of cost certainty during pre-planning.

   With this in mind, (and consistent with the Delphi approach discussed in section 2.6.2) a key representative from workshop #1 was re-interviewed. There was further discussion about the range of scoring available. The assumption of a base level of competency from the consulting professionals, for all delivery options, was also discussed. Consistent with the Delphi approach, scoring from the other two workshops was shared with this individual during this second interview. The original scores were revised and the new scores were more consistent with those from the other workshops. The revised scores are included in the final REV scoring summary sheet in Table 6-5.

2. Selection factor 17 also relates to the owner's role in pre-planning and was subject to the same misunderstanding for the members of workshop #1.

   There was an assumption in workshop #1 that a well-written DB performance specification would provide control over pre-planning. It was revealed in the subsequent workshops that when control over the design phase was handed over to the DB contractor the influence of the owner was limited compared to the DBB and CM options. Through further discussion with the representative from workshop #1, the scores for selection factor 17 were also revised. The revised scores are shown in the final REV scoring summary sheet in Table 6-5.

3. Another large discrepancy was found in the scoring for selection factor 10, which reads: "The delivery system is effective in controlling against time extensions in the design and construction phases".

   This statement was intended to be from an owner's perspective, something which was initially unclear to the participants of workshop #3. While the other two groups felt that a CM delivery method allowed the owner to be much more contractually agile and therefore able to expedite the schedule where necessary, the participants of workshop #3 did not see it this way and scored it low.

In further discussions with a key representative from workshop #3 it was agreed that with the integrated design options, control over time and schedule lies with the DB, DBOM or P3 contractor, not with the owner. Consequently, the owner has no influence over the schedule, other than to enforce the contractual completion date. It was agreed that CM and CMR would allow the most flexibility and therefore the most control for the owner.

As a result of this discussion, the scores from workshop #3 for selection factor 10 were revised to be closer with the scores from the other two workshops. The revised scores are shown in the final REV scoring summary sheet in table 6-5.

4. The final large discrepancy was noted for selection factor 12, which relates to the PDCS alternative's ability to incorporate changes during the construction phase. While most PDCS alternatives scored fairly closely, two scores stood out. Workshop #2 scored M-DBB substantially higher than the others and workshop #3 scored CMR very high compared to the others.

   During the subsequent review it became apparent that in these two instances the workshop participants had not correctly assessed the PDCS effectiveness and the scores reflected this. Discussion with the representative from workshop #1 confirmed this interpretation. Rather than revisit this with the other two groups, these scores were removed from the aggregate scoring sheet. This change is shown in the final REV scoring summary sheet in Table 6-5.

6.2 Summary of Relative Effectiveness Value Scores

Table 6-5, on the following two pages, shows the summary of the final REV scores used to develop the decision support tool that accompanies this research project.

Table 6-5: Summary of Final REV Scores

		PDCS Effectiveness Score (0-100)																							
	Selection Factor Measurement Attribute	DBB			DBB-EP			M-DBB			CM			CMR			DB			DBOM			P3		
		#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
1	The delivery system is effective in ensuring the lowest reasonable capital cost for design and construction	90	80	80	100	80	70	90	100	70	60	60	50	65	50	50	60	50	100	50	50	50	40	30	30
2	The delivery system is effective in controlling capital cost growth during design and construction	70	60	70	80	60	70	100	60	80	50	65	90	50	70	100	70	100	50	70	100	50	50	100	40
3	The delivery system is effective in ensuring lowest reasonable operating and maintenance cost over the life of the project	80	70	100	100	70	100	100	70	100	80	80	100	90	80	90	50	50	70	80	100	60	80	100	50
4	The delivery system is effective in deferring capital cost over the life of the project	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	100	100	100
5	The delivery system is effective in ensuring certainty around capital cost estimates during the pre-planning phase	70	80	70	70	80	80	70	80	80	100	100	100	100	100	100	20	60	50	20	60	40	0	30	30
6	The delivery system is effective in ensuring certainty around operating and maintenance cost estimates during the pre-planning phase	50	40	70	50	40	70	50	40	70	30	50	75	30	60	75	70	30	20	100	100	100	100	100	100
7	The delivery system is effective in ensuring certainty around system efficiency and energy production estimates during the pre-planning phase	70	40	70	70	40	70	70	40	70	60	50	75	70	60	75	30	30	20	100	100	100	100	100	100
8	The delivery system is effective in ensuring certainty around fuel cost estimates during pre-planning phase	60	40	60	60	40	60	60	40	60	60	50	65	60	60	60	30	30	20	100	100	100	100	100	100
9	The delivery system is effective in transferring a high level of financial risk to third parties over the life of the project	0	50	0	0	50	0	0	50	0	0	10	10	0	20	0	0	60	0	80	80	90	100	100	100
10	The delivery system is effective in controlling against time extensions in the design and construction phases	0	20	50	70	80	60	70	80	60	100	100	100	100	80	90	20	40	100	20	40	30	20	30	25

	Selection Factor Measurement Attribute	PDCS Effectiveness Score (0-100)																							
		DBB			DBB-EP			M-DBB			CM			CMR			DB			DBOM			P3		
		#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
11	The delivery system is effective in promoting early procurement of long lead materials, equipment and services for the construction phase	0	20	0	100	100	100	80	80	100	100	100	100	100	80	100	0	60	0	0	40	0	0	30	0
12	The delivery system is effective in incorporating changes during the construction phase with minimal cost and schedule impact	20	50	50	20	60	50	30	n/a	50	50	80	100	50	55	n/a	0	30	0	0	20	0	0	10	0
13	The delivery system is effective in protecting confidentiality of the owner's business objectives over the life of the project	90	100	100	90	100	100	100	100	100	50	80	80	50	85	80	10	30	40	0	20	30	0	10	0
14	The delivery system is effective in ensuring the owner can control the design and construction phases of the project	80	80	100	80	80	100	100	90	100	85	100	90	85	80	90	10	30	0	0	30	0	0	30	0
15	The delivery system is effective in ensuring the owner can use their own resources for commissioning, operation and maintenance of the facility	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	0	0	0	0	0
16	The delivery system is effective in ensuring the owner has minimal use of their own resources for commissioning, operation and maintenance of the facility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100	100	100	100	100
17	The delivery system is effective in maximizing the owner's role in the pre-planning phase of the project	100	100	80	100	100	80	100	100	80	100	100	80	100	100	80	30	20	30	30	20	20	10	10	10
18	The delivery system is effective in minimizing the number of contracts directly with the owner over the life of the project	60	70	50	50	60	60	40	60	60	0	0	0	60	70	50	50	80	80	80	90	90	100	100	100
19	The delivery system is effective in providing certainly for the owner with regards to emissions and environmental issues over the life of the project	0	0	20	0	0	20	0	0	20	0	10	30	0	10	30	80	90	70	100	100	100	100	100	100

Chapter 7: PDCS Selection Support Tool Development

7.1 Overview of the PDCS Decision Support Tool

According to Gordon (1994), there is no formula that allows an owner to simply enter project variables to produce a contracting method. In many cases, there is not one single best method but several that are appropriate. This is as true today as it was two decades ago when his paper was written. Gordon reminds us that the selection process often takes a "process of elimination" approach, paring away obviously inappropriate methods until reasonable alternatives remain. That being said, generally, a structured process provides the decision maker with greater insights into the decision problem (Oyentuji & Anderson, 2006), and in this way helps an owner reach a better project delivery decision.

The PDCS decision support tool developed from this research will not provide a single conclusive answer to the PDCS question for a district energy project. However, it will require the decision maker to take a step-by-step approach to the problem. It will encourage them to think about the key lifecycle objectives for their district energy project and will help them determine which project delivery options may best align with their objectives. This process will enhance the strength of their eventual PDCS delivery decision.

Section 7.1.1 through 7.1.4 outline the four steps involved in using the proposed PDCS decision support tool developed from this research. The PDCS decision support tool is included by reference and represented by a flowchart shown in in Appendix D. The program itself is available upon request of the author.

7.1.1 *Step 1 – General Project Information*

Step 1 of the decision support tool involves the user providing some general information about the project.

The information gathered in step one allows for:

1. General project information, used to populate reports generated by the program
2. General technical information, used to populate step two (see section 7.1.2)
3. General cost information, used to frame the PDCS decision alternatives and to determine whether P3 is a valid PDCS alternative.

In addition, this general information about cost, schedule and lifespan of the facility will create some context around the overall project objectives for the decision maker. A screen image for step 1 is shown in Figure 4.

Step 1. GENERAL PROJECT INFORMATION:

Please enter the following information about your district energy project:

Project Information	
Name of Institution:	TEST
Name of district energy project:	BC future 2020
Location of district energy project:	Vancouver
District Energy System Technology	
Primary output (heating, cooling, dhw, other):	heating
- Design load (MW):	10MW
Secondary output (heating, cooling, dhw, other):	dhw
- Design load (MW)	2MW
Conventional fuel plant (yes/no):	yes
Alternative fuel plant (yes/no):	no
Co-generation of power (yes/no):	yes
Built in energy storage (yes/no):	yes
Other technology? (yes/no):	no
Budget and Schedule	
Estimated capital cost (millions)*:	$53.0
Estimated O&M cost (millions/per yr):	$2.0
Estimated project duration (months):	24
Expected life span of the facility (yrs)	30

Next

* Note: Projects under $50 million will not be considered for a P3 delivery method.

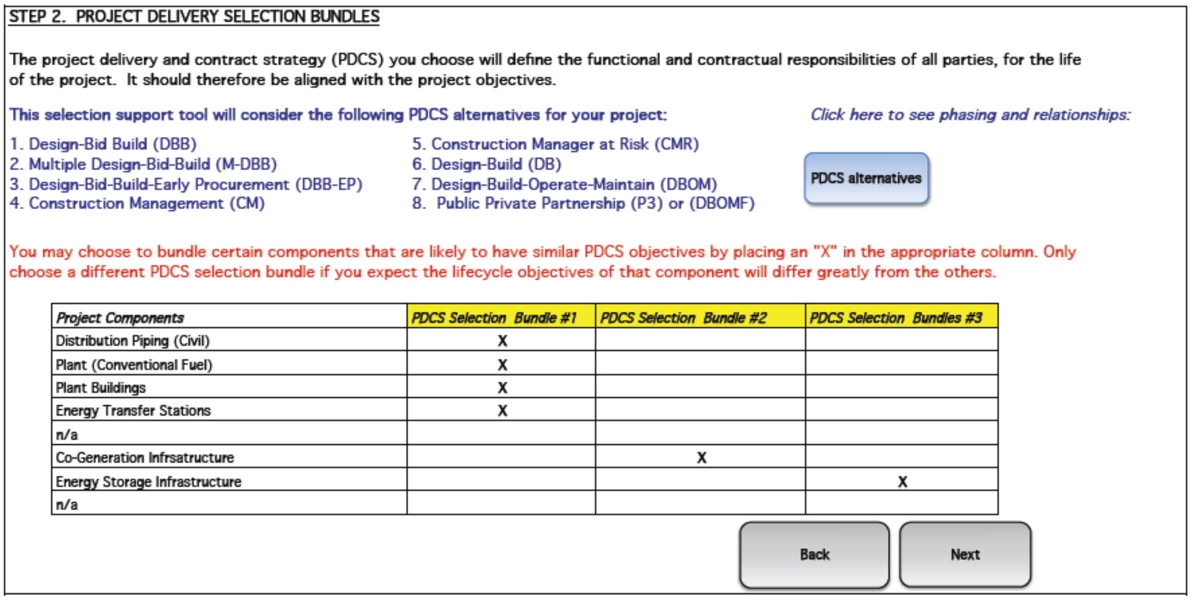
Figure 4: District Energy PDCS Decision Support Tool – Screen Image from Step 1

7.1.2 Step 2 – PDCS Selection Bundle

Step 2 of the decision support tool requires the user to "bundle" the components of their district energy project, such that different PDCS can be applied to these different bundles. The need for this step was a result of information gathered from the case study interviews. As Table 4-16 shows, three of the seven case study projects chose to use different PDCS methods for different components of their project. The ability to bundle the project components allows the user to choose and rank different selection factors for each bundle. This will drive different PDCS selection metrics from the decision support tool. Section 7.1.3 will describe how selection factors are ranked.

Several of the project components are drawn from the general project information entered in Step 1. The program limits the user to three PDCS selection bundles in the interests of simplicity. This is an arbitrary limit and could be modified through further development of the tool.

A secondary objective of step 2 is to provide the user with a general definition of each PDCS alternative. This also describes how the phasing, functional relationships and contractual relationships are arranged for each PDCS alternative. All of this gives the decision-maker some context for the outcome of the PDCS decision tool prior to identifying the PDCS selection bundles and ranking project objectives. Scrolling over each PDCS alterative on the screen enables a definition to show up. Pressing a button on the screen allows access to diagrams that describe the phasing and the relationships for each PDCS alternative (see Appendix C). Figure 5 shows a screen image from step 2.



STEP 2. PROJECT DELIVERY SELECTION BUNDLES

The project delivery and contract strategy (PDCS) you choose will define the functional and contractual responsibilities of all parties, for the life of the project. It should therefore be aligned with the project objectives.

This selection support tool will consider the following PDCS alternatives for your project:

Click here to see phasing and relationships:

1. Design-Bid Build (DBB)
2. Multiple Design-Bid-Build (M-DBB)
3. Design-Bid-Build-Early Procurement (DBB-EP)
4. Construction Management (CM)
5. Construction Manager at Risk (CMR)
6. Design-Build (DB)
7. Design-Build-Operate-Maintain (DBOM)
8. Public Private Partnership (P3) or (DBOMF)

PDCS alternatives

You may choose to bundle certain components that are likely to have similar PDCS objectives by placing an "X" in the appropriate column. Only choose a different PDCS selection bundle if you expect the lifecycle objectives of that component will differ greatly from the others.

Project Components	*PDCS Selection Bundle #1*	*PDCS Selection Bundle #2*	*PDCS Selection Bundles #3*
Distribution Piping (Civil)	X		
Plant (Conventional Fuel)	X		
Plant Buildings	X		
Energy Transfer Stations	X		
n/a			
Co-Generation Infrsatructure		X	
Energy Storage Infrastructure			X
n/a			

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Figure 5: District Energy PDCS Decision Support Tool – Screen Image from Step 2

7.1.3 Step 3 – Rank the PDCS Selection Factors

Step 3 is where the PDCS selection factors are chosen and ranked. The program asks that the top ten selection factors be placed in order of importance for each PDCS selection bundle. The components contained in each bundle are listed on the screen.

The three effectiveness values from each separate workshop (see Table 6-5) were aggregated using a simple average to create one value. The ranked selection factors can then be multiplied against the aggregated effectiveness value of each PDCS alternative. This calculation provides the overall score for each PDCS alternative. The effectiveness values are hidden and only operate in the background calculation.

The option to move to the next bundle is provided by pressing the “bundle” icon on the screen. Each bundle can have a unique set of objectives and, therefore, different selection factors driving the PDCS decision. The program allows for different selection factors to be chosen for each bundle and a different rank for each selection factor. The rank allows for a weighted score for each selection factor. The program is designed such that the #1 ranked selection factor is valued at 100% and the value of each subsequent rank is reduced by 10% (i.e. Rank #9 is multiplied by 90% and then multiplied against the aggregated REV for each PDCS). Figure 6 shows a screen image from step 3.

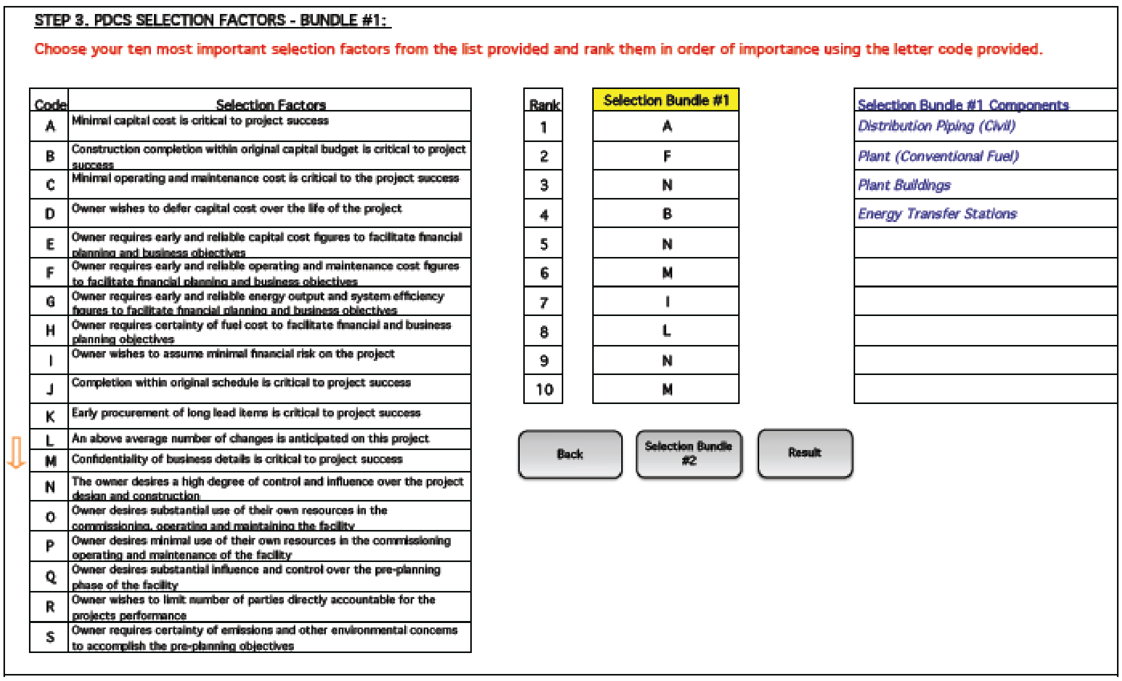

Figure 6: District Energy PDCS Decision Support Tool – Screen Image from Step 3

7.1.4 Summary of PDCS Selection Alternatives

The final step provides the user with a summary showing all of the PDCS alternatives and how each ranks based on the weighted selection factors they had entered into step 3. Each bundle is shown separately, with the understanding that a different PDCS decision could be made for each. A screen image from the summary step is shown in Figure 7.

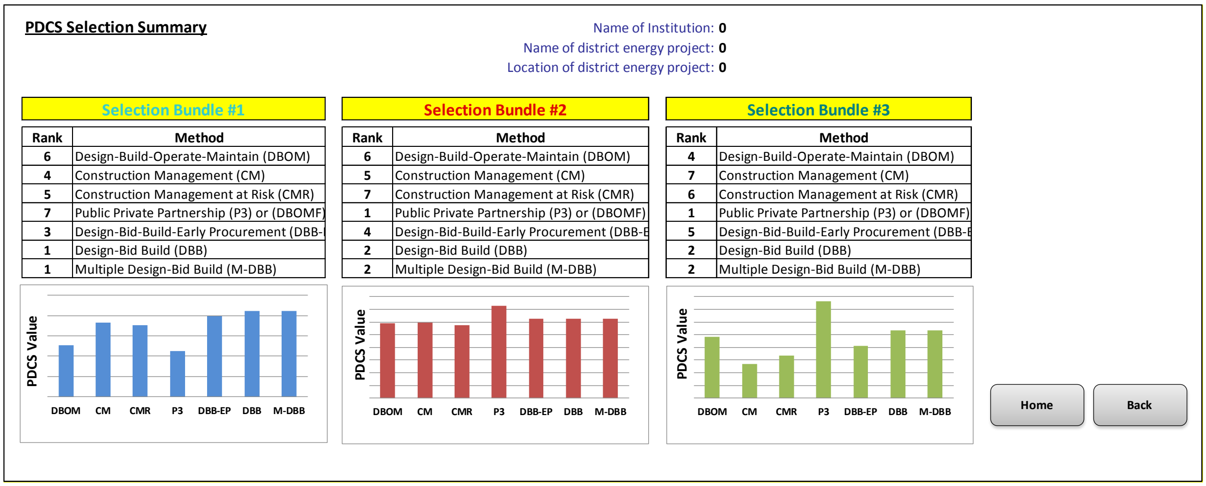

Figure 7: District Energy PDCS Decision Support Tool – Screen Image from Step 4

7.2 Validation of the PDCS Decision Support Tool

In keeping with the methodology described in Table 3-3, the pilot PDCS decision support tool required validation. A research participant was chosen who had not previously been involved in the study. This person is a senior construction project manager currently representing a large institution in Vancouver, BC. He has more than 30 years experience as a project architect and project manager on large ICI projects.

The steps to validate the pilot version of the decision support tool were as follows:

1. An initial meeting was held to introduce the overall research project, the methodology behind the decision support tool and the steps required to use the program.
2. The research participant was given two weeks to review the program on his own.
3. A second brief meeting was held after one week, at the request of the participant, to answer general questions about the overall mechanics of using the program.

4. A final meeting was held after two weeks to debrief.
5. Recommended changes were made
6. Two additional participants were asked to comment on the revised tool.

The three main deficiencies identified by the pilot test (steps 1-4) indicated a need for:

1. Better description and instructions for choosing a PDSC selection bundle.
2. Better instructions on how to rank the PDCS selection factors.
3. Better visualization capability through an improved display of the results on the summary page.

Specific discussion around these three points is as follows:

Based on the feedback, the instructions for Step 2 were revised to add more description to the term "PDCS selection bundle". The user is now told to bundle the components that they feel are likely to have the same selection factors. They are also reminded that a second (or third) selection bundle should be selected only if the lifecycle objectives of that component are expected to be significantly different from the other components. Future development of the tool could include additional programming that helps the user better organize and visualize the component into bundles.

The pilot test also identified that if one or more cells used to rank the selection factor in Step 3 are left empty, the summary sheet would not provide a PDCS recommendation for that bundle. This function is intentional and ensures consistency in scores from bundle to bundle. As well, it seemed unclear to the pilot test participant that the same selection factor could be selected as many times as he wanted. The ability to enter the same selection factor in multiple cells within each bundle (and consequently improve the importance ranking of that factor) could also be made clearer in future development of the program.

Finally, it was recommended that improved development of the presentation capability of the program is necessary. Better visualization of the results displayed in Step 4 would help the decision maker understand the relative differences between each alternative much better than with the simple bar chart currently provided. A chart that is specifically designed to display multivariate data (such as a radar chart) would greatly improve the user's ability to compare the strengths and weaknesses of each alternative. This added visualization capacity would be a major improvement to the tool and should be considered in the future development of the program.

After the recommended changes had been made, two additional senior project management professionals tested the final version of the tool. These individuals had participated in on of the REV workshops but had no other involvement in the development of the PDCS decision support tool. Direct comments from these two individuals were as follows:

…"The tool was extremely effective (even retroactively) in re-stating project objectives and highlighting the key factors for project success, from an owner's perspective. My results were well aligned with the delivery methods previously chosen for these projects, and from

this perspective, I feel the tool works very well. I was impressed with how responsive the tool is to shifting objectives allowing you to fine tune your project delivery method based on an adjustment of project values. I can see the benefit of this tool as giving the owner the assurance early on in a project that they have chosen the delivery method that would best fit the project goals"

…"It was very simple to use and allows for a lot of granularity in inputs. For the <district> hot water project it gave me the response I expected, DBB and MDBB, both for the DPS/ETS portion and the Peaking Plant phase. When I changed the parameters from capital cost certainty to a differed funding priority it again delivered the response I expected, P3. <It is a> very effective tool for owners contemplating various project delivery methods and forms of contract".

The final version of the pilot PDCS decision support developed for this research is referenced in Appendix D.

Chapter 8: Conclusions and Recommendations

This study was able to identify and fill a gap in the current research by introducing the idea of long-term lifecycle objectives as drivers of project delivery decisions, and beginning to validate that link. By limiting the study to district energy projects, the study was able to leverage the unique lifecycle objectives of those projects, specifically to demonstrate the relationship between PDCS selection factors and PDCS effectiveness. The hope is that this methodology could help shape PDCS decisions for projects with similar profiles, throughout the industry and thus promote the future success of these projects.

Specific examples where the unique lifecycle objectives of district energy projects were identified as important selection factors in an owner's PDCS decision-making included:

- Certainty of operating and maintenance costs over all phases of the project lifecycle and responsibility for resources to be assigned to operation and maintenance.
- Certainty of long-term fuel cost throughout the operation and maintenance phase, especially where alternative energy sources are being considered.
- Flexibility to change scope and certainty of development needs where system must be built to accommodate unconfirmed energy demand scenarios.
- Certainty of emissions and other environmental concerns, especially where alternative energy sources are being considered.

In these cases where these objectives were deemed to be important to an owner, the PDCS decision support tool developed by this research often directed them towards delivery models that they may have not otherwise considered. These PDCS alternatives often included integrated delivery solutions and partnering opportunities such as DBOM and P3.

By utilizing input from senior industry representatives, this research was able to enhance understanding of the relationship between PDCS alternatives and the key PDCS selection factors, over the lifecycle of a district energy project in Canada. It follows that through a better understanding of this relationship, future owners of Canadian district energy projects will have more insight into the question: Which PDCS alternative (or alternatives) should be used to best ensure that the project's key lifecycle objectives will be met? This question was the inspiration that drove the research deliverables and the springboard for exploring the research objectives. It is unlikely that the simple PDCS decision support tool developed with this research could provide an owner with a definitive answer as to which PDCS alternative they should use. However, by providing a structured format in which an owner can "think through" the PDCS decision, it can be argued that a better decision will be made.

8.1 Research Contributions

This research contributed to the already large body of knowledge in the field of PDCS decision making in general, and took steps toward building theory around the specific challenges present in the delivery of district energy infrastructure projects. More specifically, the results of this study will help public sector owners to:

1. Begin to validate an expanded set of PDCS selection factors and related effectiveness values that are appropriate to the entire lifecycle of a project (not just the design and construction phases).
2. Gain a better understanding of which lifecycle objectives may be important and determine how these objectives may inform the PDCS decision specifically for district energy infrastructure projects.
3. Develop a simple decision making framework for the delivery of community scale energy infrastructure projects that may help owners make informed decisions about their PDCS alternatives and justify those decisions to stakeholders.

8.2 Research Limitations

One limitation to this research was the small sample size available for the case study projects. The methodology for data collection required that the research participants had significant experience both as project managers and in the delivery of district energy projects. This is a small market with a limited number of players, when compared with conventional ICI construction projects. While eight case studies was a notable achievement considering the number of new district energy project built in Canada, it was difficult to get a large enough sample size from the questionnaires and surveys to provide meaningful data for the required analysis. Increased input from additional case study projects could have enhanced the list of validated selection factors.

Secondly, the limited number of REV workshops and relatively small attendance at these workshops meant that the PDCS effectiveness values are not nearly as well developed as they could have been.   This limitation was less due to the availability of participants, was and more due to the limited resources available to complete this research project. There are, no doubt, many experienced construction professionals who could contribute their knowledge of PDCS effectiveness though similar workshops. This could have greatly enhanced the conclusions made by this research and would have strengthened the data in support of the PDCS decision support tool.

Lastly, the decision support tool itself was produced with limited resources. In addition to the relatively small data sets to draw on as discussed above, the limited time and resources available resulted in a simple tool with little reporting and visualization capability. These qualities are essential to decision support and would have greatly enhanced the functionality of this program. The limited visualization capability of the program was identified as the main deficiency during the validation of the support tool (see section 7.2).

8.3 Future Research

Research in engineering project management and in related disciplines has been deficient in the discussion of lifecycle cost as it relates to PDCS decision-making. This was acknowledged by Pishdad and Believau (2010) and confirmed by the other literature reviewed for this study. By looking at district energy projects in isolation, this research was able to acknowledge the gap in previous studies relating to lifecycle cost, and begin to address it. However, the limited data collected for this study (discussed in section 8.2) means that further development is necessary to support the conclusions. Additional research to increase data collection of validation of the owner's lifecycle objectives and associated PDCS effectiveness values would contribute greatly to this subject.

In the course of this research it became apparent that many of the selection factors that drive the PDCS decision are, in fact, risk mitigation strategies for the owner. For example, if a project driver is certainty around fuel cost then a PDCS strategy such as DBOM or P3 will mitigate that risk. This is a potentially important direction for future research. Another important area of future research is theory development around our understanding of how the PDCS phasing and contractual relationships over the life of a project affect the owner's ability to promote innovation and accept risk. Understanding this could enable more public sector owners to take on community scale alternative energy infrastructure projects that may otherwise be outside their acceptable risk profile. Research that goes further to identify the major risk components and builds risk mitigation strategies through effective (and creative) PDCS methodology could help promote further development of community scale alternative energy infrastructure.

8.4 Concluding Remarks

Much of the traditional energy infrastructure that we currently rely on in Canada is built on a model of centralized energy production and distribution that accepts inefficient production and transmission losses as a matter of course. A significant portion of the energy infrastructure built over the last century relies on non-renewable and carbon intensive fuel sources. As this traditional infrastructure ages and is replaced, the opportunity exists to re-think the overall methodology for the way we plan and deliver new energy infrastructure projects. District energy provides one example of how this new infrastructure can be built to accommodate our immediate energy needs in a more sustainable way.

For district energy, the larger questions of business competitiveness in the greater energy markets and public policy around governance and social license are beginning to be answered. These projects are becoming a reality across Canada. If they don't meet the objectives from which they were conceived they will be considered a failure, both by their owners and by the public, who depend on the reliability of such energy projects. If failure becomes common, then the likelihood that they can become part of the energy infrastructure of our future is diminished. One way to mitigate the risk of failure is through sound project delivery decision-making. The hope is that this research can contribute towards that goal and enable these projects to be a long-term success.

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Appendices

Appendix A - Research Questionnaire

District Energy - Project Delivery and Contract Strategy Questionnaire

RESEARCH QUESTIONNAIRE

PROJECT DELIVERY AND CONTRACT STRATEGIES (PDCS)
FOR DISTRICT ENERGY PROJECTS.

PART 1. BACKGROUND:

The objective of this research is to identify the most appropriate PDCS option (or options) for the delivery of District Energy projects for public institutions in Canada and provide a PDCS decision support tool for public sector managers who are considering these projects.

Glossary of Key Terms:

The PDCS Option defines the procurement approach, financing strategy and a project management system developed for accomplishing the project's life cycle objectives. The contract strategy describes the roles and responsibilities of the contracting parties. It determines the risk allocation strategies, methods of payment, basis for reimbursement, and incentive strategies. PDCS have four main characteristics:

(i) The sequence of the project phases.

(ii) The functional responsibility of each party

(iii) The contractual relationship of the parties.

(iv) The compensation approach for each contractual relationship.

The Compensation Approach is the method by which the owner has agreed to compensate each party to the contract. Typical compensation approaches included; negotiated price, competitive price, guaranteed maximum price, unit price, cost-plus, etc.

The Selection Factors are the factors that influence the selection of the PDCS option.

The Relative Effectiveness Values are the numerical value to describe the importance of each selection factor relative to the PDCS.

Building Lifecycle refers to the view of a building over the course of its entire life, taking into account the pre-planning, design, construction, commissioning, operation, maintenance and deconstruction phases.

The following is a list of traditional PDCS Options*:

1. Design-Bid-Build (DBB)
2. Design-Bid-Build with Early Procurement (DBB-EP)
3. Design-Bid-Build with Project Manager (DBB-PM)
4. Construction Manager (CM)
5. Construction Manager at Risk (CMR)
6. Design-Build (DB)
7. Multiple Design-Build (MDB)
8. Multiple Prime Contractors (MPC)
9. Design-Build-Operate-Maintain (DBOM)
10. Public Private Partnership (P3)

**A legend describing the phasing, contractual and functional relationships for each PDCS option are contained in APPENDIX A of this questionnaire.*

PART 2. GENERAL PROJECT INFORMATION

A. Demographic Information (kept confidential)

Name of institution/company:______________________________________

Name of respondent:____

Current position with the institution/company:__________________________

Management experience (years):____________________________________

Email address:____

B. Project Information:

1. Name of district energy project:_________________________________
2. Location of district energy project:______________________________
3. Describe the district energy system technology
   - (i) Expected life span of the facility________________________
   - (ii) Primary output (heating, cooling, hot water):______________
   - (iii) Secondary output (heating, cooling, hot water):____________
   - (iv) Co-generation of power (yes/no):______________________
   - (v) Built in energy storage (yes/no):______________________
   - (vi) Design load (MW):________________________________
   - (vii) Primary source of fuel:_____________________________
   - (viii) Backup source of fuel:_____________________________
   - (ix) Other technology:_________________________________
4. Briefly describe general operation of the system:

   ____

   ____

   ____

5. Describe the source(s) of funding for the project:

   ____

   ____

   ____

6. Budget and Schedule

Estimated capital cost:________________ Actual capital cost:_______________

Estimated O&M cost (per yr):__________ Actual O&M cost (per yr):_________

Estimated project duration:____________ Actual project duration:____________

PART 3. PDCS DECISION MAKING

A. PDCS Options

From the ten PDCS options described in Part 1, please identify the one used for your project:

____

If none of the options match your project delivery method, please complete the following additional questions. If you found a match please go to question (iii).

(i) Phasing: Using a bar chart (see sample bar chart in appendix A), please describe the sequence of the design, procurement and construction for your project:

(ii) Contractual Relationships: Using a bubble diagram (see sample bubble diagram in appendix A), please describe the contractual relationship to the owner of each member of the project team.

(iii) Functional Responsibility: In the following table, please name which party was (or is) responsible for each of the seven main phases of the project life cycle.

Phase:	DE Plant	DE Pipe Materials	DE Pipe Civil Work	Buildings
Pre-Planning				
Design				
Procurement				
Construction				
Commissioning				
Operating & Maintenance				
Decommissioning				

(iv) Compensation Approach: Each PDCS will have a unique compensation approach. Please indicate the compensation approach for each party who was contracted with the owner on your project.

Compensation / Contract	Competitive Price	Negotiated Price	Guaranteed Maximum Price	Unit Price	Cost Plus	In-House	Other (Please Specify)
Pre-Planning							
DE System Designers							
Building Designers							
DE System Contractor							
General Contractor							
Construction Manager (at risk)							
Construction Manager (agent)							
Commissioning							
Operating (excluding fuel)							
Maintenance							
Fuel							
Other:							

B. Selection Factors and Effectiveness Values

Please score the importance of each selection factor to the success of your project. Also please score the effectiveness of your chosen PDCS in facilitating that attribute. If the selection factor did not apply please indicate by using "N/A".

	Selection Factor	Selection Factor Importance Score (0-100)
1	Minimal capital cost was critical to project success	
2	Construction completion within original capital budget was critical to project success	
3	Minimal operating and maintenance cost was critical to the project success	
4	Owner wished to defer capital cost over the life of the project	
5	Owner required early and reliable capital cost figures to facilitate financial planning and business objectives	
6	Owner required early and reliable operating and maintenance cost figures to facilitate financial planning and business objectives	
7	Owner required early and reliable energy output and system efficiency figures to facilitate financial planning and business objectives	
8	Owner required certainty of fuel cost to facilitate financial and business planning objectives	
9	Owner wished to assume minimal financial risk on the project	
10	Completion within original schedule was critical to project success	
11	Early procurement of long lead items was critical to project success	
12	An above average number of changes was anticipated on this project	
13	Confidentiality of business and/or engineering details was critical to project success	
14	The owner desired a high degree of control and influence over the project design and construction	
15	Owner desires a high degree of control and influence over the design for operation and maintenance of the facility	
16	Owner desired substantial use of their own resources in the commissioning, operating and maintaining the facility	
17	Owner desired minimal use of their own resources in the commissioning operating and maintenance of the facility	

	Selection Factor	Selection Factor Importance Score (0-100)
18	Owner desired substantial influence and control over the pre-planning phase of the facility	
19	Owner desired minimal influence and control over the pre-planning phase of the facility	
20	Project scope of work was not well defined at the start of the construction contract	
21	Owner wished to limit number of parties directly accountable for the projects performance	
22	Owner required certainty of emissions and other environmental concerns to accomplish their pre-planning objectives	
23	Other:	
24	Other:	
25	Other:	

Appendix B - Appendix A to Research Questionnaire

Appendix A

List of PDCS Options:

1. Design-Bid-Build (DBB)
2. DBB with Early Procurement (DBB-EP)
3. DBB with Project Manager (DBB-PM)
4. Construction Management (CM)
5. CM at Risk (CMR)
6. Design-Build (DB)
7. Multiple Design-Build (MDB)
8. Multiple Prime Contractors (MPC)
9. DB-Operate-Maintain (DBOM)
10. Public Private Partnership (P3)

Notes:

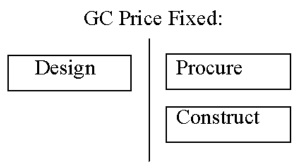
1. Where not otherwise noted the Owner assumes responsibility for operation and maintenance and decommissioning of the facility.
2. Where not otherwise noted the Owner assumes responsibility for pre-planning and financing the facility

Legend:

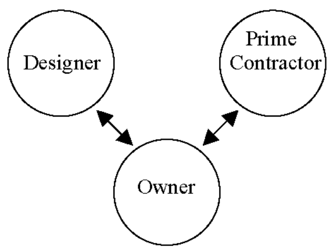
= Contractual/Functional Relationship

= Functional Relationship Only

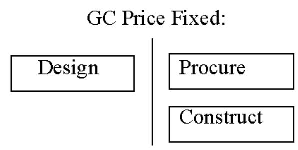
PDCS 1 (DBB) Phasing:



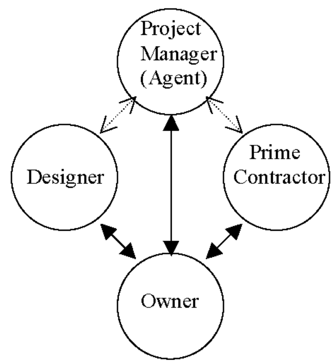
PDCS 2 (DBB) Relationships:



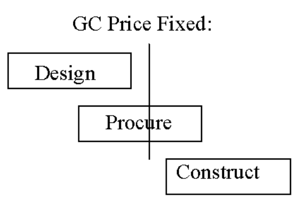
PDCS 3 (DBB-PM) Phasing:



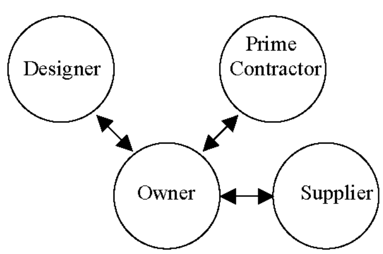
PDCS 3 (DBB-PM) Relationships:



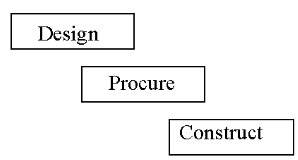
PDCS 2 (DBB-EP) Phasing:



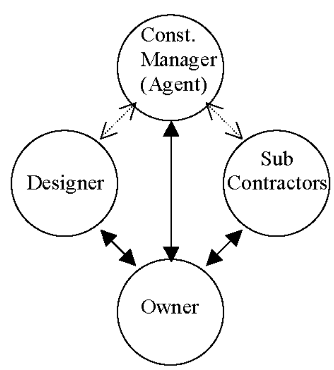
PDCS 2 (DBB-EP) Relationships:



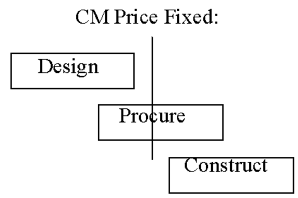
PDCS 4 (CM) Phasing:



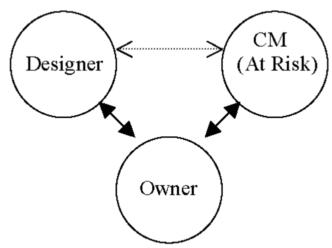
PDCS 4 (CM) Relationships:



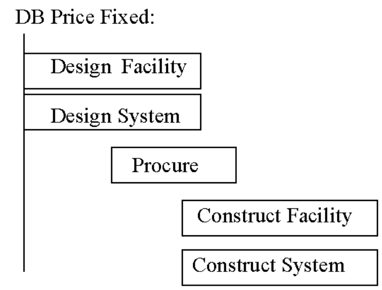
PDCS 5 (CMR) Phasing:



PDCS 5 (CMR) Relationships:



PDCS 7 (MDB) Phasing:



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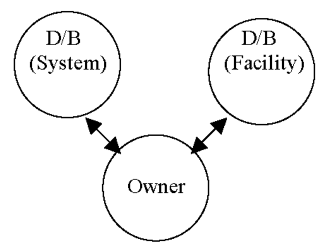

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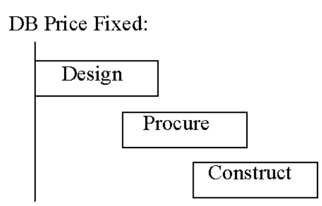

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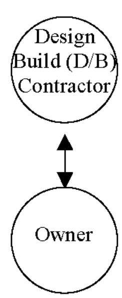

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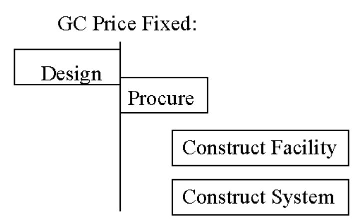

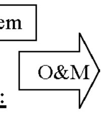

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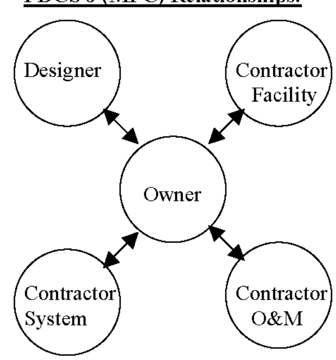
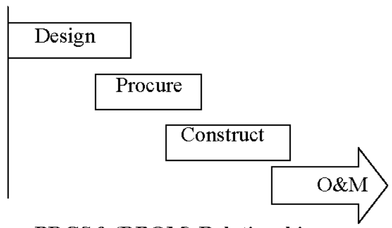
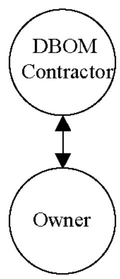


PDCS 9 (DBOM) Phasing:

DBOM Price Fixed:

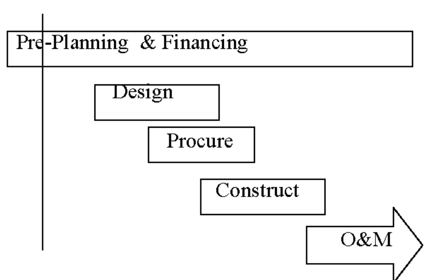


PDCS 9 (DBOM) Relationships:

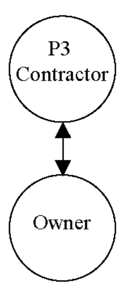


PDCS 10 (P3) Phasing:

P3 Price Fixed:



PDCS 10. Relationships:



Appendix C - Definition of PDCS Alternatives for District Energy Projects

District Energy - Project Delivery and Contract Strategy Alternatives

PDCS Alternatives:

1. Design-Bid-Build (DBB): The owner contracts separately for the design and construction of the facility. A single prime contractor is responsible for all construction subcontracts. A single prime (or coordinating) consultant is responsible for the sub-consultants.

2. Design-Bid-Build with Early Procurement (DBB-EP): Similar to DBB, except that the owner separately procures some large pieces of equipment and/or materials early in the project. These are typically handed over to the prime contractor, to be incorporated in the work.

3. Multiple Design-Bid-Build (M-DBB): Similar to DBB except that the owner contracts separately with two or more prime contractors and/or one or more prime consultants. M-DBB is often used where scope and schedule allow for a phased delivery.

4. Construction Management (CM): The owner contracts with a construction manager who is engaged early in the design phase and acts as the owner's agent. Design services are contracted separately and are the responsibility of a prime (coordinating) consultant. Trade contracts are held directly by the owner and may be awarded sequentially as the design and construction progresses.

5. Construction Manager at Risk (CMR): Similar to CM except that the CM and the owner agree to a guaranteed maximum (fixed) price for the construction work, based on the detailed design documents.

6. Design-Build (DB): The owner prepares a performance specification for the project. The owner then contracts with a single entity for the detailed design and construction of the facility.

7. Design-Build-Operate-Maintain (DBOM): Similar to DB, except that the operation and maintenance of the facility is included in the contract, for a fixed period of time.

8. *Design-Build-Operate-Maintain-Finance (DBOMF):* Similar to DBOM, except that the owner contracts with a single private entity and financing of the project is included, for a fixed period of time.

9. Public Private Partnership (P3): Similar to DBOM, except that the public-sector owner contracts with a single private entity and financing of the project is included, for a fixed period of time.

Notes:

1. Unless otherwise noted the owner assumes responsibility for operation and maintenance and decommissioning of the facility.

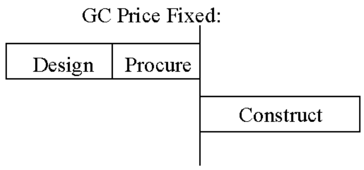
2. Unless otherwise noted the owner assumes responsibility for pre-planning and financing of the facility.

Legend:

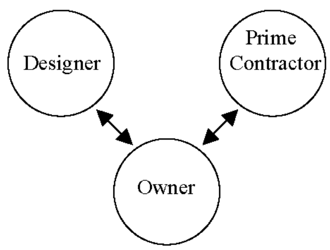
= Contractual/Functional Relationship

= Functional Relationship Only

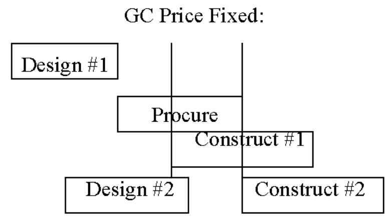
PDCS 1. (DBB) Phasing:



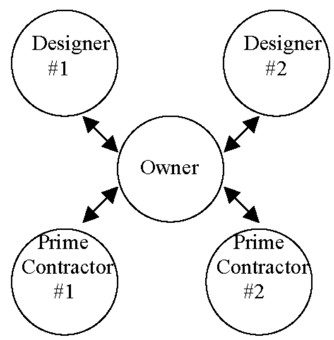
PDCS 2. (DBB) Relationships:



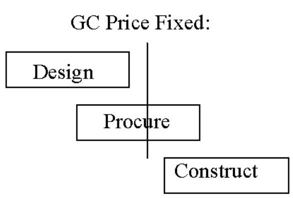
PDCS 3. (M-DBB) Phasing:



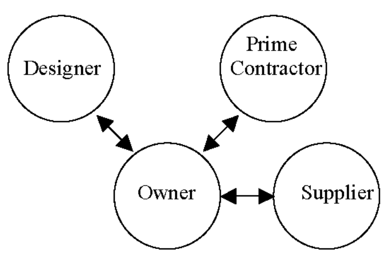
PDCS 3. (M-DBB) Relationships:



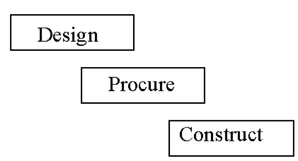
PDCS 2. (DBB-EP) Phasing:



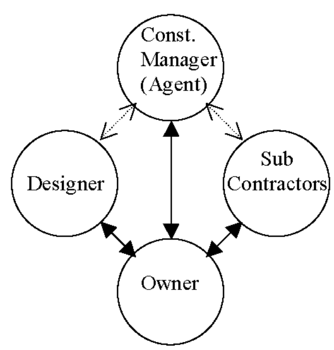
PDCS 2. (DBB-EP) Relationships:



PDCS 4. (CM) Phasing:

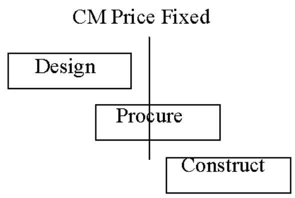


PDCS 4. (CM) Relationships:

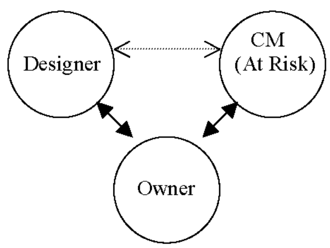


District Energy - Project Delivery and Contract Strategy Alternatives

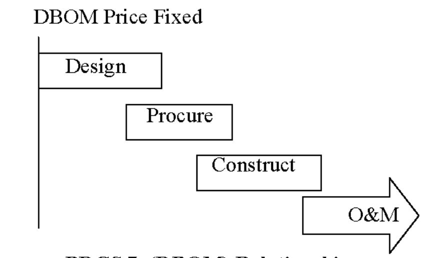
PDCS 5. (CMR) Phasing:



PDCS 5. (CMR) Relationships:



PDCS 7. (DBOM) Phasing:



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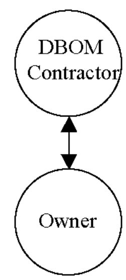
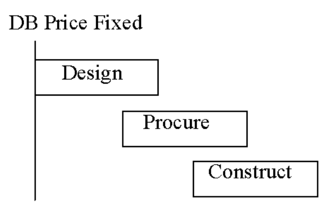


PDCS 6. (DB) Phasing:



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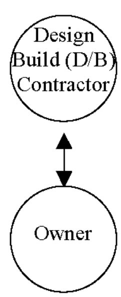
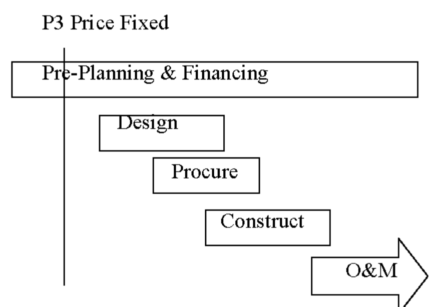


PDCS 8. DBOMF & P3 Phasing:



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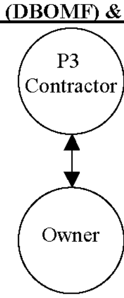

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Appendix D - Pilot PDCS Decision Support Tool for District Energy Projects

The flow chart shown in Figure 8 represents the high level operation of the PDCS decision support tool developed for this research. An MS-Office Exel file containing the district energy PDCS decision support tool developed for this research is available by request of the author.

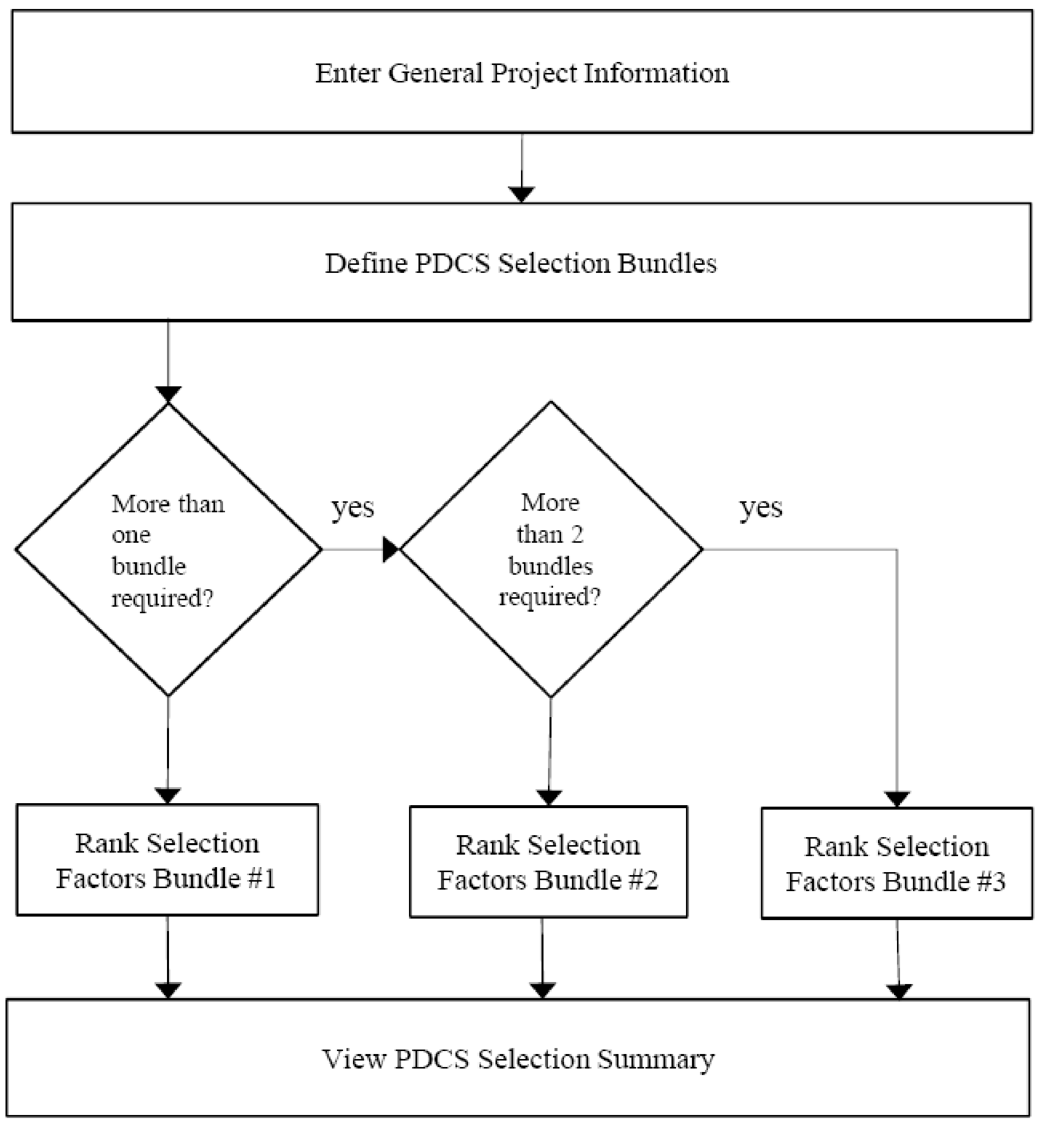

Figure 8: PDCS Decision Support Tool Flowchart