District Energy Options Dialogue

A BC Clean Air Research Project

Final Report

Prepared for

City of Vancouver, BC Hydro, BC Clean Air Research

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Project Briefing Note

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Introduction

This briefing note summarizes the results of the district energy options dialogue, a joint project of the BC Clean Air Research Fund, the City of Vancouver and BC Hydro. The objectives of the project were:

- to better understand stakeholder concerns with respect to the potential consequences of local energy options;
- to build a common understanding about the advantages and disadvantages of different energy options among participating stakeholders experts and opinion leaders;
- to develop transferable tools and methods for effectively characterizing the performance of energy options;
- to develop and test multiattribute approaches to assessing stakeholder values and using them to inform decisions;
- to develop transferable methods for effectively engaging the range of stakeholders and experts in choices about local energy supply options.

This briefing note summarizes briefly what was done and what some of the key implications are for municipal planners and policy. A more detailed summary of the project and its outcomes will be documented in a manuscript to be submitted to a peer-reviewed journal in April 2012.

Background

District energy has been identified as a key tool to enable Vancouver to meet its sustainability goals, especially with respect to a low carbon future. District energy in this context refers the neighborhood-scale provision of thermal energy to meet space heat and domestic hot water requirements. There are a variety of options available to provide these energy services. For the purposes of this project, we considered only technologies that are likely to be technically and economically feasible at the neighborhood scale in Vancouver – primarily conventional building-scale technologies and a range of district scale options using biomass, natural gas and heat pump technologies. Feasibility studies in the Lower Mainland and elsewhere typically find that district energy options consistently emerge as favorable options on the basis of costs and greenhouse gas emission reduction, but receive a mixed response from stakeholders who are concerned about other considerations, such as health, visibility and aesthetic effects. In order to better understand public values and perceptions with respect to air quality and other concerns, the BC Clean Air Research Fund, the City of

Vancouver and BC Hydro sponsored this collaborative research project. The project was designed and facilitated by Compass Resource Management.

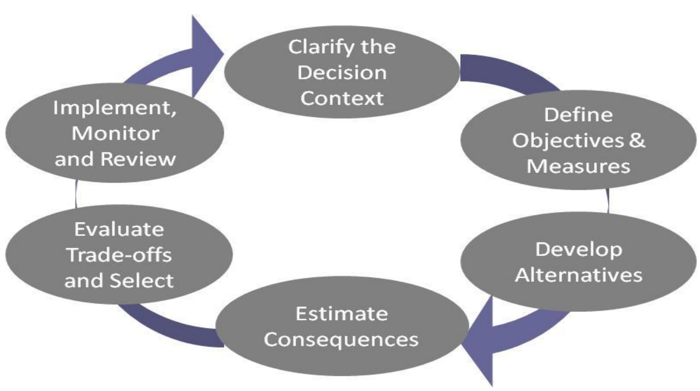
The Process

We used a Structured Decision Making (SDM) framework to guide both the technical analysis and the stakeholder deliberative process. SDM is an organized and inclusive approach to understanding complex problems and generating and evaluating creative alternatives. It's founded on the idea that good decisions are based on an in-depth understanding of both values (what's important) and consequences (what's likely to happen if an alternative is implemented). It's particularly useful for helping groups work productively together on decisions marked by technical uncertainty and controversial trade-offs. Based on multi-attribute evaluation methods, it ensures that both analyses and deliberations are structured around sound principles from decision theory and as a result, it supports consistency, transparency and defensibility in decision making.

The core steps in SDM include (Figure 1):

- clearly defining the problem and the decision to be made;
- setting clear objectives and measures of performance;
- developing a range of creative alternatives;
- estimating the consequences of the alternatives, including clarifying key uncertainties and their implications for the decision;
- understanding the values of the people and organizations affected by the decision – that is, the importance they assign to different kinds of outcomes – and making value-based trade-offs;
- monitoring and learning from implementation.

Figure 1 Steps in SDM



Over the course of six months, we worked with a group of opinion leaders and stakeholders through each of the first five steps of the SDM process for a realistic but hypothetical district energy planning problem. We held four stakeholder workshops (Table 1) and conducted a range of technical analysis and expert elicitations to inform each of these workshops. Participants were invited to review a variety of heat-source technologies, provide input on relevant objectives (the criteria that should be used to evaluate and compare technology options); gain an understanding of key consequences and uncertainties, and discuss key value-based trade-offs required to make district energy choices.

Table 1 Stakeholder Workshops

Workshop # 1	– Introduce project purpose, scope and methods – Identify stakeholder issues and objectives
Workshop #2	– Present energy options and preliminary consequences – Identify additional information needs
Workshop #3	– Present detailed information on consequences – Explore key uncertainties with subject matter experts
Workshop #4	– Review key trade-offs – Elicit and discuss values and preferences – Identify areas of agreement and difference

All processes to engage stakeholders in decision making need to find a balance between breadth and depth. Broad consultation processes engage many stakeholders but in a necessarily somewhat superficial way; deep processes engage fewer stakeholders in a more in-depth process. SDM is an in-depth process, usually used with a group of 10-25 people who work iteratively on a complex problem over a series of several meetings to develop a common understanding and well-informed preferences. Participants in an SDM process should represent all the major affected interests, involve a diversity of organizations and affiliations, encompass both expert and lay perspectives, and include individuals with different predispositions for and against district energy. Of particular value to the process are opinion leaders who are skeptical, open to learning and able to see multiple points of view. To help identify participants, we considered:

- Who is a vocal champion for local air quality or local energy sustainability?
  Who is a vocal opponent of district energy generally or of particular technologies?
- Who is recognized as knowledgeable with respect to local air emissions and GHG emission reduction?

- Who is recognized as a legitimate representative of an affected group of people (e.g., chair or appointee of a neighbourhood association, ENGOs, industry representatives, etc.)?
- Who can look at both local and regional concerns and will make a genuine effort to consider them both?
- Who could play an important role in implementation of local energy options?
- Who will be able to effectively communicate about what they've learned and has the ability to influence a wide range of opinions?

The methods used in the project were intended for use with a small group of opinion leaders in a realistic but hypothetical decision problem. The methods and insights from working with this group may be adapted for site-specific analyses, either in a similar small group environment or in broader public consultation exercises.

Decision Context

We developed a hypothetical decision based on an archetypal neighborhood. Our neighborhood is typical of the neighborhoods being considered for district energy options in the City of Vancouver. It's a residential downtown neighborhood, with an area of 500,000 m^2 consisting of 90% residential space and 10% commercial/retail. Under a business as usual scenario, all commercial heat loads and all domestic hot water loads are met with natural gas. Residential space heat needs are met with 50% gas and 50% electric baseboards. Overall energy demand is about 25% electricity and 75% natural gas. The district energy options under consideration include: natural gas cogeneration, biomass combustion and gasification and heat pumps. (See Table 2 for details.)

For the purposes of our analysis we considered two scenarios. The first scenario (and our primary focus) is a single neighborhood - that is, evaluating and comparing options for a single district energy system. However, to understand the long term regional implications of policy decisions about district energy decisions, it's important to consider potential cumulative effects. So we also looked at a hypothetical build-out scenario. We assumed that 20 neighborhood scale energy centers would be an aggressive upper bound for the lower Fraser Valley region.

The decision or question we invited stakeholders to address was: Given a neighborhood like the one we've defined, which energy option or options are preferred, and under what conditions? Since the City of Vancouver is considering multiple proposals for district energy systems, decisions about local energy options have implications not just for the local community but also for the province as a whole. We were explicitly asking stakeholders to consider these trade-offs.

Objectives and Measures

Objectives reflect the things that matter and that need to be considered when choosing among energy options. Performance measures define the specific metric or information that will be used to report the performance of the options with respect to each objective. In Workshop #1 stakeholders defined a wide range of concerns related to district energy planning and policy. We separated this long list into a relatively concise list of objectives that can be used to compare discrete energy options and another list of broader policy and planning considerations. The latter are considerations that are important in broader planning for district energy in the City of Vancouver, but are not useful for selecting among different energy (fuel and technology) options.

Below we summarize the set of objectives and performance measures that were used in selecting among energy options.

Cost to Ratepayers, measured as annual energy cost in $/year. This objective represents an interest in the affordability of heat/energy services. We assume that the costs associated with neighborhood scale energy systems are fully passed on to ratepayers. The measure reports the annual cost of energy for a 1000 $ft.^2$ apartment under each option.

Climate/GHG, measured as net emissions of CO2 [tonnes of CO2e/year]. This objective reflects an interest in reducing human impacts on climate. Greenhouse gas emissions are a proxy for the social, economic and ecological effects of climate change. Net greenhouse gas emissions are a combination of:

- On-site emissions from on-site combustion of fossil fuels [which includes, for biomass options, vehicle emissions associated with the transportation of wood waste] and

- Regional changes in emissions caused by displacing regional electricity generation from more greenhouse gas intensive sources.

Health, measured as Chronic Exposure Mortality risk [CEM]. This objective reflects an interest in minimizing the impact of emissions on respiratory and cardiovascular health. "Chronic exposure mortality" refers to the portion of total mortality that is attributable to long-term exposure to air pollution. It's a statistical term, derived from comparing mortality rates in cities with different levels of air pollution and can be used to compare relative risks from different sources. Two measures report:

- Local or near-source health effects attributable to emissions of fine particulate matter; and

- Regional or downstream health effects attributable to the formation of ozone.

These can be summed to report total health effects from each option (assuming they are equally weighted).

Regional Visibility, measured as the extent of visual impairment in deciviews, attributable to emissions of particulate matter at the site and the production of ozone regionally. This objective reflects an interest in minimizing impacts on the clarity of views in the eastern part of the airshed. A deciview is a commonly used measure of visual impairment. One deciview corresponds to a change in visibility that is just perceptible to a human observer.

Upstream Environment, measured as the Production Offset [MWe]**.** This objective captures the interest in maximizing the upstream benefits of the local generation of electricity. If energy is not produced on-site, it is produced remotely. This remote energy production has environmental implications. The upstream production offset reports the electricity generation capacity that would otherwise be installed at remote facilities and transmitted to the Lower Fraser Valley to meet neighborhood heating supplied by electricity. The measure is a proxy for the range of adverse effects associated with remote electricity generation at new facilities.

Local Livability, measured by a) an Index of Amenity or Fit, b) the volume of Traffic, and c) the size of the Visible Steam Plume. Recognizing that the introduction of local energy systems may have an impact on the aesthetics and livability of the local community, this objective captures an interest in maximizing the extent to which the facility “fits” with and supports the local community.

- The Amenity Index is a score of 1 to 5 that captures how well the facility fits in with the aesthetics of the neighborhood and supports the community character and quality of life. It incorporates the facility footprint, scale and layout [massing] and visibility; stack height; noise, odor and light pollution; and design quality. All of these are influenced primarily by the quality of the architectural design and the extent to which it responds to the priorities and preferences of neighborhoods residents.

- Traffic [number of vehicles per day]. This measure reports the estimated number of trucks required to transport fuel to the energy center every day is important because of health effects, inconvenience, aesthetics and safety in the local neighborhood.

- The Steam Plume Score is a score of 1 to 5 that reports the relative aesthetic effect of the steam plume associated with different local energy facilities. A plume may be visible during cool weather; in Vancouver, this is estimated to be roughly one third of days, mostly in the fall and winter. The frequency is unlikely to change with different technologies but the size likely will. This plume is composed of water vapor and the effects are related to aesthetics, not health.

Local Economy, measured by the number of direct and indirect jobs. This objective reflects an interest in the local economic benefits of local energy systems. The most concrete benefit comes from employment. In some communities a district energy system could also act as a catalyst for development activity - this is especially true in communities where a district energy system reduces cost or increases reliability of energy services. Two measures report:

- Person-years of direct and indirect employment associated with construction, and
- The number of full-time equivalent jobs for ongoing operation.

Energy Resilience, measured by the Resilience Index [score of 1 to 5]. Resilience encompasses the ability to absorb acute events as well as the ability to adapt to long-term changes. Natural Resilience is the ability to continue operations in the aftermath of natural disasters which affect the transmission and delivery of energy. Market resilience is the ability to absorb changes in energy markets. Resilience is reported using a five-point scale that encompasses: Reliability, Redundancy, Islanding, Fuel Flexibility, and Technology Flexibility. Resilience may be particularly important when the facility is intended to provide heat and electricity to an essential service, such as a hospital or school.

All of the objectives and measures are discussed in more detail in a set of District Energy Objectives Backgrounders.

Options

The district energy options under consideration are summarized in Table 2. All of these are considered technically and economically feasible in Vancouver neighborhoods based on a number of existing feasibility studies, although some (e.g., heat pumps) require some site-specific conditions and won't be applicable in all cases.

For the purposes of estimating consequences, we assume that:

- All systems are implemented with best available technology and are configured with particulate matter emissions control equipment [ESP];
- All district energy options include natural gas boiler capacity for peaking/backup purposes, and all options have associated gas consumption;
- All district energy options include capital costs for distribution piping in energy transfer stations at buildings and fan allowance for maintenance and operating costs

Table 2 District Energy Options

Technology	Primary Fuel Sources	Description
Conventional (BAU) (1)	Natural gas and electricity	In-suite electric baseboard heaters with natural gas boilers for domestic hot water and warming ventilation air. We use this as the Reference or Business-As-Usual case.
Biomass Combustion	Recovered wood waste	Clean wood waste is burned in an energy centre to produce hot water for heat. Fuel sources include forestry residue and urban wood waste. Fuel is transported by truck to the energy centre.
Biomass Gasification	Recovered wood waste	As above, but the wood waste is first converted to `syngas` resulting in a slightly different emissions profile.
Biomass CHP (2)	Recovered wood waste	Biomass cogeneration system (Organic Rankin Cycle) produces electricity and heat, with heat captured and directed to the district energy system.
Natural Gas CHP	Natural gas	Natural gas cogeneration system (gas fired reciprocating engines) for electricity with waste heat captured and directed to district energy system.
Heat Pumps (3)	Recovered **sewage** heat and electricity	Sewage flows are diverted from a sewer lift station or manhole to a heat pump where the heat is transferred to water and increased in temperature for delivery to end users.

(1) BAU = Business-As-Usual. This is what would happen in the absence of district energy.
(2) CHP = Combined Heat and Power

(3) All heat pump options require site-specific conditions to apply. We assume that sewer heat recovery is viable for our hypothetical neighborhood. In some cases, heat recovery from ground or ocean sources may be viable; in other cases, no heat pump applications may be viable.

Consequences

Between Workshops 1 and 2, we conducted a preliminary evaluation of options. Using readily available information, we characterized the consequences of the candidate energy options against the objectives that had been identified in Workshop 1. Based on input from stakeholders in Workshop 2, we refined the measures used to report consequences, prioritized the remaining information gaps and uncertainties, and allocated project resources based on identified priorities. We solicited input from recognized experts in the fields of air quality related health effects, air quality related visibility effects, energy production and greenhouse gas emissions and energy system resilience. In addition, because we found that people were particularly concerned about and had difficulty envisioning the aesthetic impact of an energy facility (e.g., what would it look and feel like to have an energy facility in your community?), we solicited the help of a team of experts in techniques for visualizing changes in community form and design. Stakeholders provided input on expert selection.

We estimated the performance of each energy option on each performance measure, using a combination of existing information and models, new models and analyses, and expert judgment. No new data or field studies were collected or implemented. Box 1 provides a brief summary of the approach used to estimate local and regional health effects.

We prepared a set of plain-language backgrounders for participants that described some background information on each objective, why it was important, what performance measure(s) we used to report on it and how we calculated it, and key messages about the performance of the energy options. The backgrounders were reviewed by 2-3 subject matter experts to confirm that they were accurate and represented a fair and balanced summary of information and key messages. We then held Workshop 3 at which subject matter experts were available to present key messages and answer stakeholder questions.

Box 3 How were local and regional health effects estimated?

To estimate local effects, we first estimated primary $PM_{2.5}$ emissions from each of the energy options using a combination of emissions test data and published emission factors, with uncertainty bands to account for variability in operating performance. With these estimated annual emissions, we used a simple screening dispersion model (US EPA SCREEN3) to estimate primary $PM_{2.5}$

concentrations in a circular "local area" surrounding the facility. Because we were modelling a generic facility location, we employed a flat modelling domain with ground-level receptors that excluded to 10km from the source. In order to utilize the hourly maximum concentrations produced by SCREEN3 to determine chronic health impacts, we utilized a Lower Fraser Valley specific averaging factor (based on air quality monitoring data) to convert hourly maxima to annual average exposure concentrations. We estimated the exposed population in the "local area" around the facility using population density data for City of Vancouver from the 2006 Census of Canada. Because the modeling location was generic, statistical analysis of block-level population data was performed to produce a generic population density scenario. The population around the facility was assigned to concentric rings, over which the PM2.5 concentration attributable to the source as assumed to be constant. Finally, we applied published concentration response functions that relate changes in $PM_{2.5}$ concentrations to chronic health effects, and employed expert judgment (Morgan et al, 2009) to define a best guess and upper and lower bounds on local health effects based on a review of key uncertainties. The results for a single facility were extrapolated linearly to a build-out scenario of 20 plants within the region.

To estimate the regional health effects attributable to new district energy plants, we first estimated peak ozone season (April – September) emissions of ozone precursors (NO_x and VOC) from a single district energy facility, with uncertainty bands based on emissions test data to account for variability in operating performance. Based on the recent work by Steyn et al (2011) characterizing ozone formation processes in the Lower Fraser Valley, we developed spatially explicit linear functions to relate emissions and incremental ozone concentrations in the VOC-limited and NO_x limited extents of the Lower Fraser Valley (roughly VOC-limited for Metro Vancouver, and NO_x limited for the Fraser Valley Regional District). Though all emissions from DE facilities included in the study would occur in the VOC-limited extent of the LFV, we made the conservative assumption that all NO_x emitted by the facility would be transported to the NO_x limited extent, where it would lead to ozone formation. We estimated the exposed population in each of the VOC-limited and NO_x limited extents of the LFV using population density data from the 2006 Census of Canada. Finally, we used published concentration response functions that relate changes in ozone concentration to chronic health effects across the Lower Fraser Valley, and reviewed the methodology with local air quality and health experts. The results for a single facility were extrapolated linearly to a build-out scenario of 20 plants. Details of the local and regional air pollutant concentration modelling are reported in Levelton Consultants, 2011.

To help participants understand and focus on trade-offs, we used a color-coded consequence table (Table 3). In Table 3, the BAU alternative has been highlighted, and is shown in blue (the choice of alternative is arbitrary and any other alternative could be similarly highlighted). Objectives that are 'worse than' the selected alternative are shown in red, and those that are better are shown in green. Items that are the same or very similar to the highlighted alternative are white. 'Better' and 'worse' are determined by the preferred directionality of each indicator, as shown in the 'Dir' column of the table, where 'L' indicates that 'lower is better' and 'H' indicates that 'higher is better'.

This approach allows easy comparisons of pairs of options, and highlights key trade-offs. Comparing BAU with Heat Pumps, for example, we can see that Heat Pumps are superior on every metric with the exception of Cost. This sets up a relatively simple trade-off question: are the benefits associated with heat pumps worth $240 per ratepayer per year relative to BAU? Working through the table in this way, stakeholders built a common understanding of the relative performance of the alternatives and identified key trade-offs. We used this technique to eliminate "dominated" alternatives (alternatives that are outperformed on all objectives by another alternative) and insensitive objectives (objectives that don't vary across the alternatives).

This paired comparison of consequences demonstrated that, for our hypothetical neighborhood, the costs and performance characteristics of the Biomass Combustion and Gasification technologies were very similar[1]; for simplicity, only the Gasification option is shown in Table 3. Below we summarize key differences in performance across the options and some of the key learnings.

Cost was calculated based on existing studies in the region. Based on the assumptions used for this neighborhood, Biomass Gasification (and Combustion) is roughly equal to the BAU in terms of cost. Heat Pump and Natural Gas CHP technologies are the most expensive.

Climate. Climate change is affected by greenhouse gas emissions from on-site and off-site sources. It is relatively straightforward to calculate greenhouse gas emissions from on-site combustion. On the basis of on-site emissions alone, all options except Natural Gas CHP outperform BAU. Since all options offset energy from the grid, they reduce overall GHG emissions from the region. In theory these could be summed to report the total change in GHG emissions. However, for transparency, and because the regional emissions are somewhat uncertain,

[1] They were identical except for regional health effects, for which the Combustion process produces slightly higher effects. In reality, site-specific conditions might cause small cost differences as well.

we left these as two separate line items. This allowed participants to weight them differently if they wished.

An important learning for participants occurred on the subject of the carbon neutrality of biomass. There were two key messages on this point: wood waste diverted from a waste stream (i.e., it was harvested for other reasons and would otherwise be sent to landfill) is carbon neutral. If the wood for a biomass system comes from a waste stream but is still harvested in BC, it would still be considered carbon neutral by the BC Government, however there was more debate about the validity of this assumption. A key uncertainty is the availability of carbon-neutral biomass supply. Preliminary analysis suggests the availability of a long term supply of clean wood waste, but further analysis is required. The calculation of greenhouse gas emissions from off-site electricity generation is more complex. The technical analysis acknowledged uncertainty in these calculations

The **Upstream Environmental** benefits of the options are driven by the amount of energy capacity they offset – in other words the electricity generation facilities that won't have to be built. The largest benefit is therefore associated with the CHP options, followed by Biomass Gasification (and Combustion) and Heat Pumps. Participants found the Upstream Environmental benefits most compelling when discussing the possibility of a broader district energy strategy encompassing multiple facilities that would have the potential to offset larger, more environmentally risky generation projects.

Health effects are divided into local and regional effects. They can be summed if they are weighted equally. By reporting them separately we are transparent about where they occur and stakeholders have the opportunity to weight them differently if they wish. In some cases stakeholders weighted regional health effects higher due to equity concerns.

Health effects are small but non-zero and generated significant discussion. Participants spent considerable time discussing the meaning of the indicator #CEMs/year, with the help of air quality and health experts who were present. Of particular note is that the health risks associated with the BAU scenario are non-zero – in other words, current heating systems cause statistical mortality risk. This risk drops under Heat Pumps, but rises under other options. To put the magnitude of the emissions and corresponding health effects into perspective, experts noted that the emissions and associated local health effects from a district energy plant (using any of the technologies under consideration) are less than the emissions and associated health effects from ten residential fireplaces operating in the neighborhood[2]. Stakeholders were not asked at this stage to indicate whether such an impact was acceptable. The goal was simply to develop a common understanding of the magnitude of the impact.

Stakeholders concerned about uncertainty in the methods for estimating air quality emissions, concentrations and associated health and visibility effects. After presenting modeled results at Workshop 3, at the request of stakeholders we engaged an independent expert to ensure that the specific characteristics of the Fraser Valley airshed were accounted for. Of particular concern was the known complexity of the processes driving tropospheric ozone production in the Fraser Valley. These more detailed analyses produced slightly refined estimates of health (and visibility) effects, but fundamentally confirmed the conclusion of earlier analyses: that the health effects of modern district energy plants, provided best available technology is used and effective monitoring and enforcement is in place, are small but non-zero for both the single plant and the build-out scenario.

Visibility analyses found that the effects of the range of options under consideration will not be detectable, even under a build-out scenario. Visibility effects are driven by particulate matter and ozone production. As for health effects, initial visibility modeling was subsequently confirmed by more detailed airshed-specific analysis of an independent expert. After review of the results, participants decided that Visibility was not significantly affected by the options under consideration and removed it from further consideration. It does not appear in Table 3.

Livability was an important concern of stakeholders. We wondered in the early part of the process whether livability would really be influenced by the choice of energy fuel and technology, but given the priority assigned to it by stakeholders, it was explored in some detail. Visualization experts created illustrations of our hypothetical neighborhood and then introduced energy facilities with different footprint areas, massings, and stack heights. They also varied the building façade and streetscape to show the extent to which a facility's architectural design could influence its compatibility with a neighborhood. Photographs of actual facilities illustrated a range of amenity scores – from a (1) for a "utilitarian" facility to a (5) for a facility that was a true "public asset". As a result of this work, stakeholders concluded that aesthetic effects (as reported by the Amenity Index) vary little with the choice of energy technology or fuel. Instead, they are largely a function of the quality and level of investment in architectural design and consultation with the community. Biomass options were scored slightly lower to reflect the fact that it may be more difficult to address community concerns with a biomass

[2] Ten fireplaces operating 10% of the time produce more particulate emissions – and much less heat – than any of the neighborhood-scale DE plants considered in this analysis.

plant. There is some additional traffic associated with the fuel delivery of biomass systems. Participants noted that it would be useful to have an indicator of the number of trucks or kilometers travelled on local roads as opposed to arterials or connectors.

Local Economy. All of the options produce more direct and indirect jobs than the BAU. The number of jobs is driven by the estimated capital cost and the jobs are primarily construction-related. There is slightly more employment associated with Biomass CHP due to complexity in operations and maintenance.

In the absence of local economic studies, the analysis for this objective involved transferring the results from limited studies done elsewhere in Canada to the Lower Mainland. The level of analysis was deemed sufficient in this case, although more might be warranted in some cases. We note that the contribution of local economic benefits of local energy to a local economy might be more influential in communities where the existing energy source is particularly expensive or unreliable. In such cases, it could stimulate new investment in a variety of sectors.

Resilience. All of the DE options outperform the BAU on resilience, with Biomass CHP performing the best, followed by Natural Gas CHP and Biomass Combustion/Gasification. Heat Pumps score slightly lower due to reliance on the electricity grid.

Table 3 Consequence Table with BAU Highlighted

Obj.	Sub Objective	Units	Dir	NG CHP (30)	Heat Pump (30)	BAU (30)	Biomass (G-30)	Biomass CHP (G-30)
Minimize Cost								
	Cost to Ratepayers	$/year	L	$ 1,230	$ 1,190	$ 950	$ 975	$ 1,010
Minimize Climate Change								
	Operational GHG Emissions	t CO2e/year	L	19,100	4,200	8,100	3,400	3,400
	Regional GHG Emissions	t CO2e/year	L	-20,300	-2,700	0	-8,100	-11,000
Maximize Upstream Environmental Benefits								
	Upstream Production Offset	MW	H	14	8	0	10	12
Minimize Adverse Health Effects								
	Chronic Local Health Effects	# CEMs/year	L	0.06	0.01	0.03	0.09	0.10
	Chronic Regional Health Effects	# CEMs/year	L	0.03	0.01	0.01	0.01	0.02
Maximize Local Livability								
	Amenity Index	Scale 1-5	H	3	3	3	2	2
	Traffic	# trucks/weekday	L	0.0	0.0	0.0	2.1	2.7
	Steam Plume	Scale 1-4	L	2	1	1	3	3
Maximize Local Economic Development								
	Employment P-Years	person-years	H	158	149	43	135	162
	Plant Operator FTEs	#FTEs	H	1.5	1.5	1.5	1.5	2.0
Maximize Energy System Resiliency								
	Resilience Index	1 to 5	H	4	3	1	4	5

Trade-offs

Through this process, stakeholders developed a solid and common understanding of consequences. However, even when people agree about the facts of the situation – in this case the estimated consequences and uncertainties associated with different energy options – they may quite reasonably disagree about what to do about it. Some people may find that even small impacts or risks are unacceptable (risks outweigh benefits), while others may find them acceptable (benefits outweigh risks). These are value based judgments, and it's reasonable to expect that people will differ in the judgments they make.

At Workshop 4 we shifted the focus to these value-based judgments. After presenting updated information in response to stakeholder questions raised at Workshop 3, we conducted a trade-off analysis designed to gain insight into stakeholder priorities and preferences – which district energy options are preferred, which are acceptable, and under what conditions. Stakeholders answered a series of weighting, ranking and trade-off questions, the results of which were summarized and used to facilitate discussion. In short, stakeholders were asked to:

1) Rank the alternatives directly;

2) Weight the objectives and sub-objectives, from which ranks and scores for the alternatives were derived;

3) Discuss the weights assigned and reasons, from which some participants gained new information or perspectives and adjusted their preferences;

4) Based on learnings from the discussion, indicate their level of support for each alternative.

Methods and results are described in Failing et al (in preparation). Here we summarize some key findings about preferences for the options under consideration, and the conditions under which different options would be acceptable.

Heat pumps are the most broadly acceptable option, outperforming other options on all objectives except cost:

- Heat pumps are a preferred option where site-specific conditions are favorable;
- Because the pumps are only viable as a small number of sites, a district energy strategy that relies solely on heat pumps will be limited;
- The cost premium associated with heat pumps in our case study is seen as significant and should be considered in energy planning;
- Site-specific district energy analyses should consider industrial waste heat utilization, as well as heat pumps from ground and ocean sources where available.

Natural Gas Cogeneration could be supported as a transition strategy. However, there is little support for building long-term natural gas infrastructure:

- Natural gas is viewed by some as incompatible with BC's current policy direction with respect to "clean and renewable" supplies of new energy;
- There are increasing concerns about the environmental implications associated with unconventional sources of natural gas such as shale gas and oil sands development;
- Natural gas is seen as inconsistent with the priority given by society to GHG reductions as reflected in local, provincial, national and international policy commitments;
- That said, participants acknowledged that natural gas cogeneration outperforms BAU.
- An important uncertainty is the effect of natural gas cogeneration on the average GHG-intensity of electricity produced in the WECC. Most

participants gave regional GHG emissions a low weight to reflect uncertainty.

Biomass may be supported under some conditions, namely:

- A sustainable source of clean wood waste can be guaranteed;
- Facilities make use of best available scrubbing technologies;
- Effective monitoring and compliance measures ensure that actual performance meets predicted performance;
- Local modeling of health effects is conducted;
- Stack height, local dispersion characteristics and topography are taken into account;
- Appropriate road access facilitates the transport of fuel via arterials and connectors rather than local roads;
- Consultation with the community and appropriate investment in architectural design ensures that there is strong compatibility and fit with the local community.

While the analysis presented in this project reports similar performance characteristics for Biomass Gasification and Biomass Combustion technologies. Gasification was preferred by some stakeholders to Combustion because of its stricter input fuel requirements, which would help to guarantee a clean wood waste source.

At the conclusion of the discussion, stakeholders were asked whether, if a proposal were to be made concerning each of these technologies in a neighborhood resembling our archetypal neighborhood in the City of Vancouver, they would:

E = Endorse – Probably support the proposal, depending on site-specific factors

A = Accept – Probably accept the proposal, depending on site-specific factors

O - Oppose – Probably oppose the proposal, regardless of site-specific factors

Results are summarized in Table 4.

Table 4 Summary of expressed level of support for various alternatives

	Biomass (C30)	Biomass CHP	Nat Gas CHP (30)	Heat Pump (30)	BAU (30)	Biomass (G30)	Biomass CHP
1	O	O	O	E	O	A	A
2	A	A	O	E	O	A	E
3	E	E	A	E	O	E	E
4	A	E	O	E	O	A	E
5	O	O	A	E	A	O	O
6	E	E	A	E	O	E	E
7	A	A	A	A	A	A	A
8	A	A	A	E	A	A	A
9	A	A	O	O	A	A	A
10	A	A	O	E	A	E	E
11	O	O	E	E	O	A	A
12	O	O	O	E	A	O	O

Table 4 Notes:

- Participants 1 and 11 noted that biomass combustion systems were not supported because combustion systems can accommodate dirty fuel sources. They viewed the selection of gasification technology as a means of ensuring that the wood source was clean.
- Participant 5 noted that biomass options could be acceptable at sites with more commercial/industrial orientation rather than residential and/or if the local community were in support.
- Those who do not support Natural Gas CHP suggested it might be supportable as a transition strategy. Those who accepted or endorsed it did so because it may be the only practical alternative to BAU, and it clearly outperforms BAU.
- Participant 9 opposed Heat Pumps and Nat Gas CHP on the basis of cost to ratepayers.

Broader Implications

Stakeholder acceptance of district energy (regardless of the specific technology/fuel selected) may depend on the following.

Improved monitoring and enforcement. The judgments provided above assume that district energy plants perform as predicted. A number of stakeholders expressed lack of confidence in monitoring and enforcement. While the COV does not have jurisdiction over monitoring, it may be useful to explore opportunities to effect improvements in monitoring and enforcement in partnership with Metro Vancouver and MOE.

Demonstration of a long term reliable supply of clean wood waste. All of our analysis relied on the assumption of a clean wood waste supply, and stakeholder judgments about the acceptability of biomass options are contingent on this assumption. Further analysis of the supply chain is required.

Commitment to community consultation and adequate investment in architectural quality. Stakeholders agreed that energy systems could not only be neutral but even a positive influence on local communities. However this will require consultation and investment in architectural excellence. Energy planners should consider: a) guidelines or principles related to the architectural design quality; b) guidelines and principles related to community consultation.

The development and use of visualization techniques that allow stakeholders to gain a good understanding of the look and feel of proposed energy facilities and how they will affect their community.

Demonstration that individual projects are considered within a broader District Energy strategy that:

- Considers the cumulative effects on air quality of portfolios (or sets) of district energy projects;
- Considers site-specific and regional spatial effects
- Identifies and targets neighborhoods with high opportunity for district energy in consideration of technical potential, community character, population exposure profiles, local dispersion characteristics and regional ozone production processes;
- Explores uncertainty in pricing and fuel supply.

Demonstration that a range of options have been considered at a given site and that the selection is based on consideration of multiple objectives, especially:

- Net greenhouse gas emissions;
- Net costs or savings to rate payers;
- Local health effects arising from particulate emissions;
- Regional health effects arising from the production of ozone;
- Compatibility with the character of the local community.

Demonstration that once a district energy option is selected (i.e., technology and fuel) that a range of alternative facility designs will be considered, with public input. Such alternatives should consider local livability objectives such as:

- Compatibility or fit with the local neighborhood
- Noise, odor and light pollution
- Traffic volume and patterns, especially on local roads

Consideration of emission offsets. Preliminary analysis shows that replacement of ten open fireplaces in a neighborhood could offset the incremental particulate emissions associated with any of the district energy options considered. While some stakeholders oppose offsets on the grounds that such low hanging fruit (fireplace replacements) should be implemented anyway, it remains true that an offset policy could offer the possibility of PM2.5-neutral district energy systems.

Process Considerations

This project used a Structured Decision Making process to help a small group of opinion leaders engage in a hypothetical decision about district energy. The goal was in part to help build a better understanding of district energy technologies, and in part to test methods for engaging with stakeholders and experts on real district energy planning and decision making applications. Feedback from participants indicated that it was a valuable process for:

- Building a common understanding of district energy and its consequences
- Learning about values and engaging in explicit considerations of difficult trade-offs
- Learning about important but not-easily-quantifiable consequences such as local livability.

Feedback from experts indicated that it produced:

- A fair and balanced summary of consequences and trade-offs, and
- A level of technical analysis with respect to air quality impacts that was unusual in stakeholder processes they had seen.

Although the decision context in this case was hypothetical, the positive feedback suggests that the structured, multiattribute approach provided a sound framework for options analysis, supported learning by participants about the nature and consequences of district energy, and provided a forum for meaningful and informed input. The approach can be replicated for real site-specific decisions, as well as for a broader spatially-explicit regional strategy. Some considerations when designing future stakeholder engagement processes:

- **Iteration and Learning.** In technically intensive decision problems such as district energy, informed decision making requires that participants have an opportunity to learn about the options and their consequences. It's useful if they meet multiple times – 3-4 meetings allows time for participants to absorb and process information about the alternatives and their consequences that is new and perhaps surprising. A large body of research demonstrates that people tend to remember information that confirms what they already believe; they discount or forget information that disconfirms it. Having multiple meetings helps to counter this common bias and offers an opportunity to respond to questions and lack of confidence in initial findings.

- **Responsiveness**. The process needs to be responsive to stakeholder concerns. Stakeholders initially identified a long list of objectives. Although it was not clear initially exactly whether and how they would be affected by energy choices (e.g., livability) they were examined in detail and stakeholders reached their own conclusions based on analysis and expert input. Stakeholders were invited to identify experts that they thought should be consulted, and we engaged multiple experts to provide input and participate in workshops. Stakeholders had access to these experts and could pose questions to them directly. This improved trust in the estimated consequences.

- **Separation of Facts and Values.** It's useful to separate the process of learning about facts (consequences of the options) from the process of making value-based choices or preferences. This separation gives people time to process and think about the consequence estimates of experts which is useful for informed choices. It also helps to clarify the reasons why people agree or disagree. For example, in this case, some participants initially had low confidence in the estimates of the air emissions and associated health effects of biomass technologies. When additional experts were called in and provided supporting judgements, a common understanding of the consequences was achieved. For some stakeholders, biomass technologies remained unacceptable, but this is now recognized as an informed value judgment. Those in favor of biomass cannot discount these judgments as uninformed, nor can those opposing biomass propagate exaggerated claims about its consequences. The debate about biomass will benefit from a common base of information and a hopefully disciplined and respectful dialogue about difficult value-based trade-offs.

- **Transferable Materials**. The plain-language backgrounders provided all participants with a fairly sophisticated but still understandable description of consequences. Circulation of these in advance of workshops prepared them for the workshops. Nonetheless, the availability of independent experts at Workshops 3 and 4 to answer questions was critical in building a common understanding and trust in the estimated consequences. These backgrounders could be adapted for a broader public audience and used as a template for developing site-specific materials.

Areas of further research that would be of value to support informed stakeholder deliberations and ultimately decisions about the net benefits of district energy options include: :

- **Develop an indicator of comparative health risk for use in project level analyses.** Participants in this process received a presentation on the statistical nature of the CEM indicator and its use and interpretation in public policy and decision making. In a broader public process, there may be value in translating this indicator into a comparative index (e.g., a bounded scale of 1-10) that presents the relative health risks from a range of common emission sources in an urban environment. More broadly, research is needed into how the choice of indicator influences the importance assigned to health effects. This is particularly important given the likelihood of strong affective responses to any indicator reporting health effects in terms of mortality, which may decrease sensitivity to magnitude.

- **Development and testing of methods for weighting uncertainty in multi-attribute trade-off analysis.** We offered participants the opportunity to assign different weights to less certain indicators than more certain ones (e.g., off-site and on-site GHG emissions respectively). This weighting should be informed by an explicit characterization of the degree of uncertainty as assessed by experts. Different methods of characterization are likely to influence the weights (Gregory et al, 2012); more applied research is needed to explore these influences.

- **Development of visualization techniques and constructed scales for amenity or aesthetic considerations.** While this scale doesn't vary very much across energy fuel and technology options, it varies substantially with architectural design quality and corresponding funding levels. Tools for helping people gain a good understanding of how a modern district energy system would look and feel in their community would support informed stakeholder input.