To
The City of St Paul & The Technical Advisory Group

Document type
Report

Date
December 4, 2014

Intended for the review and discussion of the Technical Advisory Group, Subcommittee on Technical Issues

FORD SITE ENERGY STUDY
ENERGY TECHNOLOGIES AND SYSTEM REPORT

FORD SITE ENERGY STUDY
ENERGY TECHNOLOGIES AND SYSTEM REPORT

Revision	**01**
Date	**2014-11-19**
Made by	**Jakob Bjerregaard**
Checked by	**Klaus Fafner**
Approved by	**Pernille M. Overbye**
Description	**Intended for the review and discussion of the Technical Advisory Group, Subcommittee on Technical Issues**

Ref	1100012867-33-07-1
Document ID	400824-9

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark
T +45 5161 1000
F +45 5161 1001
www.ramboll.com

CONTENTS

1. INTRODUCTION

Ramboll have been appointed to carry out a study of the opportunities for a future energy system for the redevelopment of the site of the former Ford assembly plant.

This document outlines the work done in relation to exploring opportunities for energy supply technologies and systems. It serves as an introduction for discussing which system setup to take forward for more detailed concept design.

The work has been carried out in a 4-step process:
1. Creation of gross list with all interesting technologies
2. Initial screening of technologies filtering clearly incompatible or non-viable technologies
3. Evaluation of technologies based on priorities
4. Production system scenarios creation and evaluation.

2. INITIAL GROS LIST AND SCREENING

An initial gross list was identified, consisting of the most relevant and promising technologies for the Ford site within production and storage of energy covering total 35 technologies. Some technologies are generic basic technologies that can be applied (almost) anywhere such as boilers and regular heat pumps, whereas other technologies are very specific in their requirements for input or conditions, such as industrial waste heat recovery or deep geothermal.

2.1 Decentralized vs centralized solutions

The gross list of technologies includes both decentralized solutions and centralized energy production:
- Decentralized production is when heating and cooling is produced locally at the individual customers - subsidiary for a building block with a group of customers.
- Centralized production is when heating and cooling are produced at a large central plant - inclusive a peak load or backup plant that can be situated at another location in order to enhance the supply security.

For all centralized heating and cooling solutions water-based distribution networks are required. The networks use pre-insulated piping systems in steel, or in cross-linked polyethylene (PEX), or reinforced combinations (AluPEX). The centralized solutions are named district heating and district cooling with piped systems for distributing hot or chilled water generated in centralized locations.

For district heating the pipes are heavily insulated with PUR (polyurethane) to minimize the heat losses. For district cooling PEX pipes with limited or no insulation can be used.

It is common to use a twin pipe system in which the supply and return pipes are integrated in the same casing pipes. This reduces the installation costs and minimizes heat losses as well.

District heating is recognized as a key measure for ensuring long-term energy security, due to its technological flexibility and the capability of networks to be switched to renewable and local resources of e.g. surplus energy. Thus district heating recognized as a cost efficiency way of cutting carbon emissions.

Decentralised heating and cooling can be so-called central heating and cooling, i.e. building or block heating and cooling where hot water or chilled water (or air) is distributed via piped systems to the apartments/rooms from a central boiler room, which attached to or integrated in the building or block.

Fully decentralised heating and cooling is when heat for space heating and DHW and cooling is produced as closed as possible to the end users, i.e. at each apartment or room. The energy source is normally either electricity or gas, and there is no or very limited requirements for a piped distribution system based on water or air.

Decentralized solutions where energy is generated or stored by a variety of small, often grid-connected devices close to the customers they serve, are called Distributed Energy Systems.

Decentralized solution benefits are related by being close to the consumer, the independence of central systems, low or no distribution losses, etc. Disadvantages are often related to noise, dirt and allocation of space, especially in private residential areas.

2.2 Limitations in the choice of technology

All of the technologies described in the following can in principle be attractive solutions - given the right circumstances/context. Therefore, an evaluation should not only focus on the technology, but also under what conditions (price structures, consumer demands, laws, regulations, space available, impact on the local environment (smoke, noise, waste), synergy with other infrastructure, etc.) they can be exploited.

An initial screening ruled out four technologies for various reasons:

- Wind turbines in the vicinity: It's unlikely to receive permits and public acceptance for setting up wind turbines in close proximity of the site
- Waste incineration plant: The size of plant required to achieve a viable business case is not compatible with the site dimensions and the stress on the traffic system for supplying the waste is deemed unacceptable.
- Deep-geothermal: The potential and risks associated with such a project cannot be rightly evaluated through this general study.
- Small-scale nuclear power plant: Small scale nuclear power plants are yet to become economically viable and also pose a safety threat for the community.

Some technologies are still included, although the right circumstances may not be in place. This is true for e.g. cooling storage in the old sand tunnels, but they cannot be ruled out already, and will be considered for the project, while the specific requirements and conditions is looked into.

3. SCORING OF TECHNOLOGIES

To evaluate the potential of the different technologies in a future energy system for the Ford Site, all technologies have been rated on a scale from 1 to 5, 1 being useless/counterproductive and 5 being outstanding/perfect, in five categories stemming from the priorities and goals for the site, as discussed and agreed with the technical advisory group (TAG).
No weighting or priority has been given to any of the categories, which essentially means that a technology can receive a high score without being e.g. economically viable or a low carbon technology.

The five categories are:

- Net Zero: Net Zero concerns the CO_2 emissions and primary energy use of the technology. The highest score have been given to 100% renewable technologies. Other GHG emissions have also been taken into account.

- Resilience: Resilience is understood as the security for energy supply that the technology delivers, in particular in case of power grid failures. On site power production has been given high rankings, but fuel diversification and -independence has also been considered.
- Legacy/Innovation: Developing technologies with high potential have high score, whereas traditional concepts with no innovation are evaluated poorly.
- Energy efficiency: Energy efficiency is evaluated on the conversion efficiencies and energy losses for the technologies. Renewable energy has not been given preference as is often the case due to a 0 primary energy factor by definition.
- Cost effectiveness: The technologies are evaluated primarily on the expected levelized cost of energy (LCOE) over the technical lifetime. The levels of economic risk related to the technology have been considered. There is uncertainty towards the relative value of power vs heat, which may lead to changes in evaluation later on.

The evaluations are based on comparison with the expected business as usual scenario being, heating supplied from individual gas boilers, electricity supplied from the power distribution company, Xcel plus possibly an air-air heat pump for cooling.

For ease of comparison the technologies have been divided into the following sub-groups, which will be presented and evaluated below one by one:

- Combustion technologies
- Heat pump technologies
- Solar energy technologies
- Alternative technologies

3.1 Combustion technologies

Table 1: Technology evaluations - Combustion

	Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
Frying/vegetarian oil boiler	19	5	4	3	4	3
Biomass CHP	18	5	5	3	3	2
Natural gas CHP	18	3	4	2	5	4
Industrial waste boiler	18	5	3	3	4	3
Biomass boiler	16	5	4	2	2	3
Natural gas boiler	16	2	4	1	4	5

The combustion technologies are in general evaluated highly on resilience, as they provide security of supply to the system, CHPs' obviously more than boilers due to the local power production. The exception is the industrial-waste-boiler, because sourcing of the fuel could be unstable. The net zero category depends very much on the renewability of the fuel input. CHP's are rated higher than boilers using the same fuel as emissions per energy output are lower.

Innovation level is generally low for the combustion technologies, "new" fuel types and the advanced technologies in CHP's add to the innovation.

Energy efficiency is generally good, although some smaller plants do often not perform as good as larger plants, and boilers are less efficient than CHP's, which provides simultaneous generation of heat and power in a single process.

The boilers are relatively cheap and so the cost efficiency depends solely on the access to cheap fuels, natural gas is regarded very cheap, whereas the others are more uncertain and needs investigation. CHP's are more capital intensive, and therefore the potential power price for electricity delivered to the grid is essential.

3.2 Heat pump technologies

Table 2: Technology evaluations – Heat pump technologies

	Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
Absorption cooling	17	5	2	5	3	2
Compressor cooling	14	2	3	2	2	5
Cooling Tower with River water	14	4	3	2	2	3
Electric heat pumps	23	5	3	5	5	5
Electrical heater/boiler	13	3	2	2	2	4
Free cooling, river	21	5	3	3	5	5
Gas driven heat pump	15	3	4	2	4	2
Ice/Snow cooling/storage	20	5	3	5	5	2
Industrial surplus heat	18	4	2	3	5	4
Sewage water Heat pump	19	4	4	5	4	2
Shallow Geothermal	18	4	4	4	4	2

Heat pumps employ the same technology as air conditioners for cooling, but when heat is called for DHW and space heating in cool months - their simultaneous reverse operation can also be exploited, by moving heat from a low-temperature level to the desired warmer comfort temperature level. . Heat pumps usually draw heat from the ambient (input heat) and convert the heat to a higher temperature (output heat) through a closed process; either compressor heat pumps (using electricity) or absorption heat pumps (using heat; e.g. steam, hot water or flue gas).

A general advantage of heat pumps is that the heat pump is able to utilize energy at a low temperature level. Additionally the heat pump is flexible concerning use of renewable energy, waste and surplus heat. The combined utilization of a heat source at a low temperature level and the use of for example gas as driving power enables more effective resource utilization compared with conventional heat production technologies.

Compared with traditional heating technologies, heat pumps are more complex and have high investments costs. However, this is counterbalanced by considerable savings in operating costs.

3.3 Solar energy technologies

Table 3: Technology evaluations – Solar energy

	Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
Photovoltaic, centralised	19	5	3	4	5	2
Photovoltaic, decentralised	18	5	3	4	5	1
Solar heating, centralised	20	5	3	4	5	3
Solar heating, decentralised	19	5	3	4	5	2

The solar energy technologies are all driven by solar energy and as such considered fully net zero. They do not affect resilience of the energy system much in itself, as they only produce energy in summer during daytime. However, solar thermal can together with thermal storage deliver a stable heat production for long periods during the year.

The systems are considered innovative and energy efficient, the de-central solutions maybe a bit less than the central technologies due to scale.
The decentralised PV are the least cost inefficient due to high initial costs and inflexible operation, whereas solar heating and in particular decentralised solar thermal panels are more capable of aligning consumption and production when storage is used.

3.4 Alternative technologies

Table 4: Technology evaluations – alternative technologies

	Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
Anaerobic digestion	15	5	2	4	2	2
Gasification	16	5	2	5	3	1
Nat gas Fuel-cell CHP	17	3	4	5	4	1
Off-site PV or Wind electricity	20	5	2	3	5	5

A number of technologies that do not conform to the more conventional groupings above have also been evaluated.
The anaerobic digestion (AD) and the gasification are novel technologies running on waste and biomass respectively. They are both considered renewable energy producers although it depends on the input. The resilience is questionable, AD is hardly flexible and unused gas has to be stored or flared, or exported to the natural gas network after being upgraded to natural gas quality level. Gasification is very innovative, but also not very reliable and will need time for testing. The energy efficiency is hard to asses, as it depends on the alternative, but the process in itself is not very efficient. Cost effectiveness is not good.

Fuel cells are also an emerging technology. The net zero performance is somewhat medium, when considering a gas driven version. It has good resilience and energy efficiency, but short technical lifetime and high capital investment makes the business case hard to prove positive.

Off-site renewable energy production is efficient on energy and cost, but adds no resilience to the site. It also does not add much to the legacy of the project.

4. SYSTEM DESIGNS

Following the scoring of the individual technologies a number interesting system designs have been put together. The idea is to highlight the opportunities and synergies of the technologies. Due to the large number of interesting technologies it has not been possible to include all technologies in a system design.

4.1 Assumptions

Due to the great uncertainty towards the future development of the Ford Site, the consultants have used a rough estimate of in total 10MW site energy demand for the system designs.
The expectation is that around half of the energy demand will come from domestic hot water and space heating; electricity will take up around 30% and cooling demand around 15%.

For individual supply designs the following specific energy demand is assumed in modern dwellings:

Heating (approx.):
- DHW: 3 Kbtu/sf/yr (11 kWh/sqrm/yr)
- Space heating: 2,5 Kbtu/sf/yr (9 kWh/sqrm/yr)

Electricity (approx.):
- Appliances: 3 Kbtu/sf/yr (11 kWh/sqrm/yr)
- Comfort cooling: 1,5 Kbtu/sf/yr (5 kWh/sqrm/yr)

Power grid and market
For the scenarios created it has been assumed that excess power from CHP production can be sold to the power grid for a meaningful price through a power purchase agreement with the power distribution company.

River water
It is assumed that a permit for utilising the river water for cooling purposes can be obtained.

4.2 SC0: BAU

The business as usual (BAU) scenario with individual gas boilers for space heating, electricity from the power grid and electric air-air heat pumps for cooling has been assessed as the baseline scenario. The electricity from the grid is considered to have a share of 25% renewable energy, 25% nuclear energy and 50% fossil fuel based energy (coal and natural gas).

System components:
- Individual gas boilers for space heating and DHW.
- Electric air-air heat pumps for comfort cooling.

Evaluation:
The system delivers a relatively clean energy based on natural gas and electricity from the power grid. In terms of resilience the technologies are reliable, although it does not provide any heating and electricity supply to the site in case of respectively gas cut off and power grid failure.
The system can hardly be seen as innovative, but it is fairly energy efficient and cost effective.

Table 5: SC0 – Business as usual evaluation

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
13	3	3	1	3	3

4.3 SC1: ALL GAS

A basic district energy scenario based on natural gas would consist of a central natural gas CHP with a peak-load and backup gas boiler, and comfort cooling coming from a centralized compressor plant in combination with free river-cooling.

System components:

- Gas engine/ Gas turbine, single cycle 5-10 MW
- Gas boiler, 5-10 MW
- Central compressor heat pump for comfort cooling
- District heating network and cold water network.

A large hot water tank could be added to the setup, but it would require variation in electricity prices to be economically viable.

Evaluation:
The system delivers a fossil fuelled energy based on the natural gas CHP. In terms of resilience the technologies are proven and reliable, although it does not provide any energy supply to the site in case of gas cut off and down time in the power grid.

The system can hardly be seen as innovative, but it is fairly energy efficient and cost effective.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
18	2	4	2	5	5

Specific assumptions and critical factors: None

4.4 SC2: Centralized Biomass CHP scenario

A scenario with centralized CO_2 neutral generation of heat and electricity has been set up. A central CHP plant provides heat for space heating and domestic hot water and produces at the same time electricity to the power grid (back pressure mode). A central cooling plant (electric heat pump supplemented with cold river water) provides comfort cooling during the summer and heat for DHW at the same time and can thereby (partly) replace the central CHP plant in the summer period. Central short-term heat tank could be beneficial for the optimization of heating/cooling production.

As the investment in a biomass CHP plant is high it requires high utilization level (many hours of operation), therefore intermittent renewables are not expected to be compatible.

System components:

- Biomass CHP for heat and power production
- Biomass boiler (or gas boiler) as backup
- Biomass storage
- Central electric heat pump supplemented with river water for comfort cooling
- District heating network and cold water network.

Evaluation:
The system provides CO_2 neutral heat and power production. But transportation, handling and combustion of biomass could cause impact on the local air environment. In terms of resilience the technologies are proven and reliable, if biomass supply is reliable. The system can hardly be seen as innovative, but it is energy efficient and cost effective.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
18	4	4	3	4	3

Specific assumptions and critical factors: Access to sustainable biomass. Biomass transportation and handling should be carried out without critical impact on the surrounding town environment.

4.5 SC3: Centralized Biomass Boiler scenario

A scenario with centralized CO_2 neutral generation of heat-only been set up. A biomass boiler plant provides heat for space heating and domestic hot water. A central solar heat plant with central seasonal heat storage (Sunstore) will decrease the use of biomass. A central cooling plant (electric heat pump supplemented with cold river water) provides comfort cooling during the summer and heat for DHW at the same time, and replaces together with solar heat the biomass boiler, especially in the summer period. The central seasonal heat storage will be used for system optimization and as peak load/backup.

System components:

- Biomass boiler for heat production
- Solar heat plant with seasonal heat storage (Sunstore)
- Biomass storage
- Central electric heat pump supplemented with river water for comfort cooling
- District heating network and cold water network.

Evaluation:
The system provides CO_2 neutral heat production. But transportation, handling and combustion of biomass could cause impact on the local air environment. In terms of resilience the technologies are proven and reliable, if biomass supply is reliable. The system can hardly be seen as innovative – except for the seasonal heat storage, but it is energy efficient and cost effective.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
19	5	5	4	3	2

4.6 SC4 & SC5: Biomass Gasification & Anaerobic Biomass Digestion scenarios

Biomass gasification and anaerobic biomass digestion are considered as high risk solutions: Biomass gasification cannot be regarded as fully market mature and anaerobic digestion to produce biogas for CHP can be considered to be problematic in a town environment (smell risks, biomass/digested biomass management) in addition to being expensive.

Therefore no further evaluation is presented in the report for these alternatives. In case of special favourable conditions arise, they might be revived.

4.7 SC6: Centralized Sun-Heat Pump scenario

A scenario with centralized generation of energy has been set up. A central electric heat pump provides heat for space heating and domestic hot water. The heat pump is a reverse cycle type that also provides comfort cooling during the summer, and storage surplus heat from the cooling process in a seasonal storage. A central solar collector plant is together with a central seasonal heat storage connected to deliver a share of the annual heat demand. Underground cooling when using the heat pump during the heating season is an option.

If demand for local CO_2 Net Zero is ranged highly: A central photovoltaics (PV) plant - or a share of a large wind farm - produces electricity equal to the total electricity demand throughout the year inclusive electricity for the heat pump.

System components:

- Central electric reversible heat pump for heating/cooling
- Seasonal heat storage
- Central solar heating plant
- District heating network and cold water network
- Central PV plant/Share of a large wind farm.

Evaluation:
The system delivers a relatively clean energy based on decentralized heat and power production. However, dependency on the power grid is required anyway. In terms of resilience the technologies are proven and reliable. The system - except for the central seasonal heat storage- can hardly be seen as innovative, but it is fairly energy efficient and cost effective.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
19	5	3	3	4	[illegible]

Specific assumptions and critical factors:
We assume that the electricity grid will balance the supply and demand timing mismatch by the PV in such a way that the customers only pay a minor fee.

4.8 SC7: Individual Sun-Heat Pump scenario

A scenario with decentralized generation of energy has been set up. An individual air-water heat pump provides heat for space heating and domestic hot water. The heat pump is a reverse cycle type that also provides comfort cooling during the summer. Roof mounted solar collectors are together with individual hot water tanks connected to deliver a major share of the annual DHW demand.

If demand for local CO_2 Net Zero is ranged highly: Roof/wall integrated photovoltaics (PV) installation produces electricity equal to the electricity demand throughout the year inclusive electricity for the individual heat pumps.

System components per individual dwelling unit:

- Electric heat pump (air-water) for heating/cooling
- 2,5 m2 thermal solar collector for DHW
- 2 m3 hot water tank
- PV (1/3 of room sf), equivalent to electricity use, 160 W/m2, 1000 h/y.

Evaluation
The system delivers a relatively clean energy based on decentralized heat and power production. However, dependency on the power grid is required anyway. In terms of resilience the technologies are proven and reliable. The system can hardly be seen as innovative, but it is fairly energy efficient and cost effective.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
17	5	3	3	[illegible]	2

Specific assumptions and critical factors:
We assume that the electricity grid will balance the supply and demand timing mismatch by the PV in such a way that the customers only pay a minor fee.

4.9 SC8: Individual ALL ELECTRIC scenario

A scenario with decentralized generation of energy has been set up. Electric heaters provide heat for space heating and domestic hot water. Use of electric baseboards can minimize the allocation of space. Electricity is also used for comfort cooling during the summer by an electric air conditioner. In general, air conditioning can refer to any form of decentralized grid-connected devices that modifies the condition of indoor air (heating, cooling, humidification, cleaning, ventilation).

If demand for local CO2 Net Zero is ranged highly: Roof/wall integrated photovoltaics (PV) installation produces electricity equal to the electricity demand throughout the year inclusive electricity for heating, HTW and cooling.

System components per individual dwelling unit:

- De-central electric devices for heating/cooling and HTW.
- PV (1/3 of room sf), equivalent to electricity use, 160 W/m2, 1000 h/y.

Evaluation
The scenario delivers a relatively clean energy based on decentralized heat and power production. However, dependency on the power grid is required anyway. In terms of resilience the technologies are proven and reliable. The system can hardly be seen as innovative, but it is fairly cost effective and also energy efficient due to nearly no distribution losses.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effecti
17	5	3	1	[illegible]	4

Specific assumptions and critical factors:
We assume that the electricity grid will balance the supply and demand timing mismatch by the PV in such a way that the customers only pay a minor fee.

4.10 Substitutes and complements

Some technologies that received a good evaluation have not been used in any of the proposed system designs. That does not necessarily mean that they could not meaningfully be deployed.

Some are direct substitutes of chosen technologies e.g. one type of boiler for another, and can easily be switched. Others could complement the systems, if e.g. solar thermal panels were replaced with PV's. It would affect the rest of the setup, but could eventually be viable, if the power purchase agreement is attractive enough.

5. CONSIDERATIONS

For the further work the consultant askes the TAG to consider the following:

- Is any technology missing that should be in the list?
- Are the ratings fair?
- Do you agree with the assumptions laid out in the paper?
- How should the agreed 5 goals (Net-Zero, Resilience, Innovation, Energy Efficiency and Cost Effectiveness) be weighted and prioritised if any?
- Which setup should be taken forward for further detailed design?