PAPER ARCHITECTURAL ENGINEERING LAB 10

4FFland

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ABBREVIATIONS

4F	-	Food, feed, fuel and fertilizer
AEB	-	Afval energie bedrijf: waste incineration / co-generation plant in Amsterdam
DES	-	Distributed energy sources
DG	-	Distributed generation
EPM	-	Energy potential mapping
ESM	-	Energy system mapping
FER	-	Fuel energy ratio
GHG	-	Green house gas displacement
HCS	-	Heat cold storage
ICL	-	ICL fertilizers (Israel Chemical Ltd.): company in the Westpoort area that mines and trades phosphate fertilizers. They also produce fertilizer from RWZI wastes.
LCA	-	Live cycle analyses
PV	-	Photovoltaic
RWZI	-	Riool water zuivering: sewage treatment plant in Amsterdam

ABSTRACT

This paper presents a research which seeks ways to transform the Brettenzone, an existing recreational area in Amsterdam, into an energyscape: a landscape which produces renewable energy. Renewable energy production will increasingly start to compete with other forms of land use such as recreation, nature and agriculture. Its careful integration therefore becomes detrimental. This paper discusses renewable energy systems and what determines their sustainability. It offers a set of analysis methods which can be used when designing for renewable energy production. These methods include energy potential and system mapping. This paper also presents an analysis of Amsterdam's energy system and it's potentials for renewable energy production using the before mentioned methods. This analyses describes the design casus and seeks to identify possibilities for an intervention. It gives a set of possibilities producing renewable energy in the Brettenzone which include: recycling nutrients from industrial waste streams to agriculturally produce food and biogas, producing electrical power using PV cells, harvesting heat for the district network using solar collectors and aquifers, as well as harvesting cold for a future district network (Teleport) using deep water source cooling (Sloterplas), absorption cooling devices, the Binnen-IJ and aquifers. The most promising proposal, an agricultural enterprise producing food and biogas, is analysed further. Such an enterprise would produce food, feed and fuel whilst maintaining a theoretically closed cycle of fertilising nutrients. This paper present research into the requirements of such a food, feed, fuel and fertiliser farm entitled, the 4F farm. The paper presents the aspects which determine the sustainability of the 4F farm with an emphasis on the bioenergy aspect. It explores possible sources of plant biomass by comparing their biogas yield rates as well as their climatic requirements in comparison to the conditions in Amsterdam. A similar analysis is made for manure as a source of biomass. The biogas production process is also discussed as well as the required systems and equipment. From this paper it can be concluded that the described food and biogas farm should seek to optimize the yield of food, feed, fuel and fertilizer in that respective order of importance. Also it offers the required data and recommendations for designing the 4F farm. The paper notes however that the 4F's energy yields per acre are not sufficient to fulfill the ambition of acting as an energyscape. For this goal to be reached the 4F farm should also integrate other energy harvesting techniques such as PV cells or solar collectors. The 4F farm can be sufficient however to sustain a small autarkic neighbourhood.

Keywords: *energy landscapes, energyscape, energy potential mapping, architectural design, bio-gas, industrial ecology, district networks, 4F farming, closed cycle farming*

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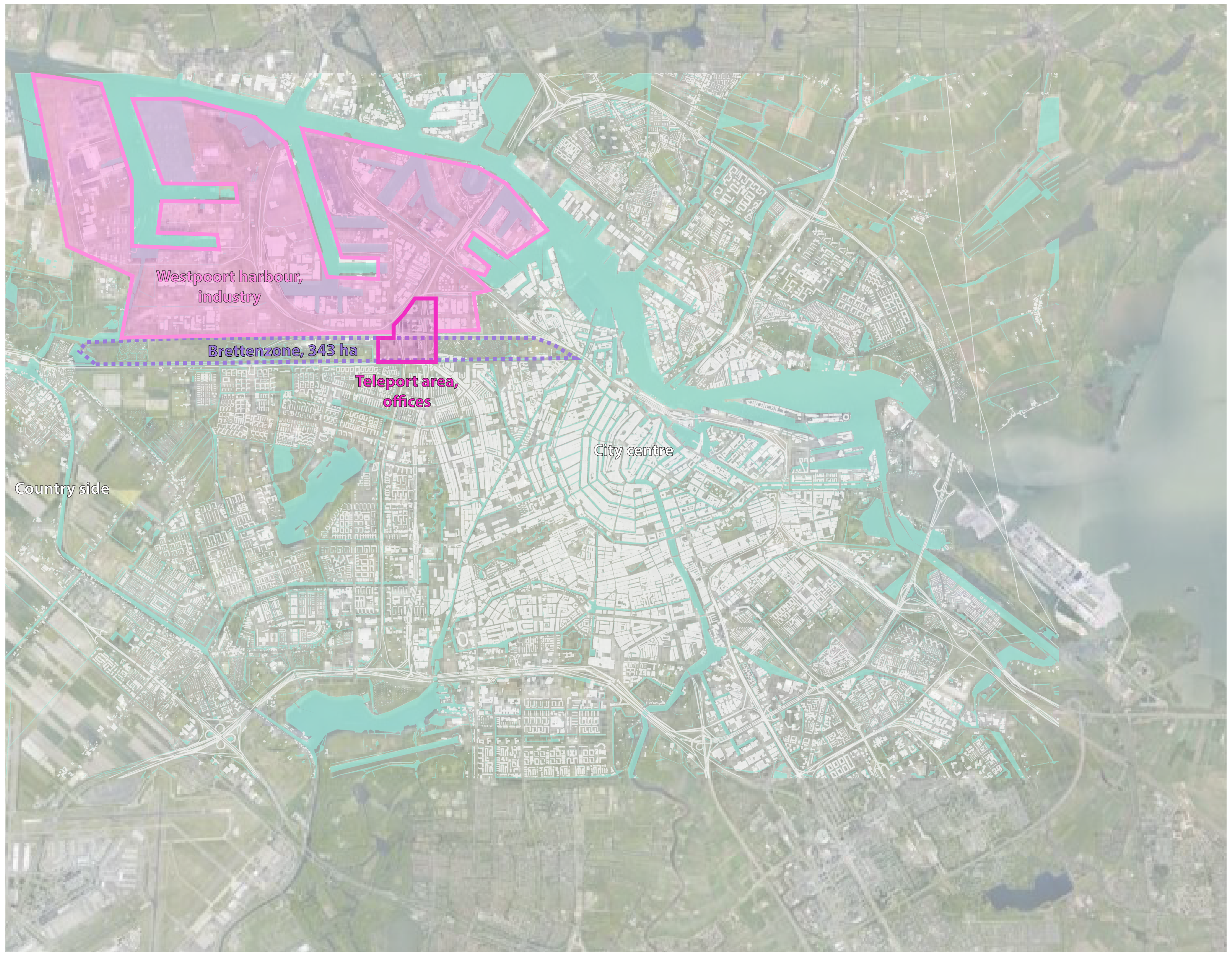

Fig. 0.0.1 The Brettenzone.
Illustration by author.
Underlay: Google earth, retrieved 10th of June 2013

INTRODUCTION

This paper presents the results of a research into an energy producing landscape in the Brettenzone, Amsterdam. This research is done as part of a graduation project for the degree master of architecture at the TU Delft. The goal of this research is to act as the foundation for a future design project. This design project is to be located somewhere in the Brettenzone, a 342 hectare large area in Amsterdam. The area stretches eastward from the city center to the city's limits. From its most Western point outward it contains: a city park, cultural and recreational facilities, allotment gardens, a high rise office area, sporting grounds and an area designated to wildlife from where it extends to Amsterdam's rural surroundings. North of the Brettenzone lies Westpoort, Amsterdam's harbour area, housing light and heavy industry (fig. 0.0.1).

In the near future we will become increasingly dependent on renewable energy sources. Because these sources have a lower energy density than fossil and fissile sources they will have a larger impact on our agricultural and urban environment. Integrating renewable energy production into these environments sustainably therefore becomes detrimental. Sustainable here means this production is integrated in such a manner that it does not compete with agriculture, biodiversity or recreation but rather complements these themes. The central question of this research and design project is therefore as follows:

How can the existing communal gardens in the Brettenzone (Amsterdam) be transformed into an energy producing landscape which complements the recreational and natural value of the area?

Part of this question should be addressed in a design. This paper seeks to address the part which can be addressed by other forms of research. In the first chapter the framework of this research will be laid out. Here the term sustainbility will be operationalised. Also this chapter will present the strategies and methods which will be used in rest of this paper. It will explain how energy systems and potentials can be mapped to offer a designer insight in local potentials for renewable energy production.

In the second chapter Amsterdam's energy system and its energetic potentials will be analysed using a series of maps. The goal is to identify potentials and opportunities which could be exploited in the design. This chapter concludes with synthesizing these potentials in a series of proposals entitled 'the program of possibilities'. The most attractive proposals are then presented in the form of a preliminary energyscape design. This design encompasses an agricultural facility where food and biogas are produced whilst maintaining a closed cycle of fertilising nutrients.

The third chapter explores the requirements for this food, feed, fuel and fertiliser producing enterprise, entitled, the F4 farm. The emphasis here lies on the topic of biogas production. The chapter explains the general issues concerning bioenergy. Furthermore it explains how the anaerobic process works which produces biogas. Also, this chapter compares different sources of agricultural biomass and what is needed for their cultivation or husbandry. The chapter concludes with the biogas production system and its required equipment. In this chapter it is explained that the proposed agricultural facility should balance the production of food, feed, fuel and fertilizer and in that respective order of importance. Chapter 3 is meant to offer the required data for obtaining such a balance in a future design. This paper will conclude with suggestions for further research and a set of recommendations for the design project.

Although the goal of this paper is to function as a reference for my specific design project, it might also be suited as a reference for others. Architects, students or planners working within the Amsterdam context and wish to incorporate the city's energy system or renewable energy production in their design can consult chapter 2. This chapter might also be of use to those interested in agricultural production or closing nutrient cycles on the city scale. Chapter 3 offers data which could be helpful for farmers who wish to gain more from their production process and its residues. To designers who want to incorporate plants or livestock into their design section 3.3 as well as appendix B and C might be of particular interest. If the tables are used as reference it is advised to consult the accompanying texts as they discuss how the data can or cannot be used.

1. FRAMEWORK: SUSTAINABLE STRATEGIES AND METHODS

In this chapter the framework for the research will be laid out. In the first section the term 'sustainability' will be operationalized. In the second section general aspects of renewable energy will be discussed as well as some issues concerning energy systems. The chapter will conclude by presenting multiple design tools which architects can use to incorporate 'sustainability' in their design process. Some of these tools where used in the analysis which is presented in chapter two.

1.1 Strategies for sustainable energy production and planning

Renewable energy systems cannot be considered outside the context of sustainable development. This section will describe the view of sustainability which will be used throughout this paper. It will explain how this definition of sustainability can be used to evaluate the sustainability of energy systems. It will also present a strategy for designing and planning such energy systems.

A generally accepted definition of sustainable development is the one given by the World Commission on Environment and Development, often referred to as the Brundtland commission. This commission defined sustainable development as: *"an approach to progress which meets the needs of the present without compromising the ability of future generations to meet their own needs."* (Brundtland 1987, 8) It is a common conception that there are three kinds of indicators of such a development, namely: environmental, economic and social indicators. (Tester 2005, 280, 281) These three often conflict with each other as can be seen in fig. 1.1.1. Development can only be considered 'sustainable' if these three development goals are balanced appropriately. How they should be weighed and measured however is less clear.

A clearer description of sustainability can be found by subdividing each of the three pillars into different categories which can be measured. For instance: energy use, biodiversity and water resource management can be considered as sub-indicators of environmental protection. (Tester 2005, 280) Similar subdivision can be made for the economic and societal aspects. Although these sub-indicators can be measured individually still the question remains of how to weigh biodiversity against energy use. More complex a task would be to weigh biodiversity against poverty reduction. What makes the subject of sustainability even more complex is that the systems these indicators refer to interact with each other. According to Christina du Plessis the key characteristic of sustainability science is that: *"it deals with problems that encompass multiple and interacting scales, levels, dynamics, actors and system thresholds in social-ecological systems; it emphasises learning, adaptation an thus reflection; and it acknowledges and makes use of multiple participants (e.g. scientists, stakeholders, practitioners) and epistemologies to co-produce knowledge."* (Du Plessis 2009, 34,35). According to Jefferson Tester one way to approach sustainability is to view to world as a set of interacting systems. In this context a system is considered as: *"a collection of processes which interact synergistically or adversely."* (Tester 2005, 191) Tester makes a distinction between closed systems and open systems. Closed systems are systems of which the boundaries are clearly defined. An open system however is: *"one for which easily circumscribed physical boundaries are elusive and for which interactions of the system components extend over large length and time scales"* (Tester 2005, 192) Jón Kristinsson's illustration of the environmental system is a good example of an open system. Kristinson considers the environmental system as four interacting components: the abiotic and dynamic physical shell of the earth (atmosphere etc.); the technical component (everything made by human beings); the biotic component (plants and animals, etc.); the abiotic earth (the soil etc.). (Kristinsson 2012, 20) The arrows show how the components interact. The components also interact with other social and economic systems. In Kristinson's scheme for instance ideas, information, education, services and products arise from the technical component.

Tester points out that it is impossible to describe such an open system completely. He states that we cannot hope to present all information required to understand this system well enough to give accurate recommendations on good stewardship for the environment. (Tester 2005, 192) A similar problem is noted by du Plessis for urban planning in general. She refers to the work of Horts Rittel and Melvin Webber who state that because urban planning deals with so many complexly interacting factors it can be considered a *'wicked problem'*. Du Plessis mentions the characteristics of such a problem which include: lacking a definitive problem formulation, lacking criteria to indicate when a solution has been reached, being essentially unique and being nested across levels, that is: every problem can be considered a symptom of a problem at a different level. (Du Plessis 2009, 33,34 who refers to Rittel and Webber 1973). The complex nature of sustainability in planning energy systems however is by no means a reason for apathy. For as Tester states:

> *"… we can draw upon this recognition of the terrible complexity of the energy-environmental system, abysmally qualitative though it may be, to inspire us to seek sustainable pathways that pay heed to protecting all system components rather than improving one vital component at the expense of degrading another of equal or greater importance."* (Tester 2005, 192)

Furthermore Tester also mentions some general principles of sustainable development. The principles most relevant to this paper are: (Tester 2005, 287,288)

1. ***Clarity.*** One should establish a clear vision of sustainable development and clear goals that provide a practical definition of that vision in terms that are meaningful for decision making.

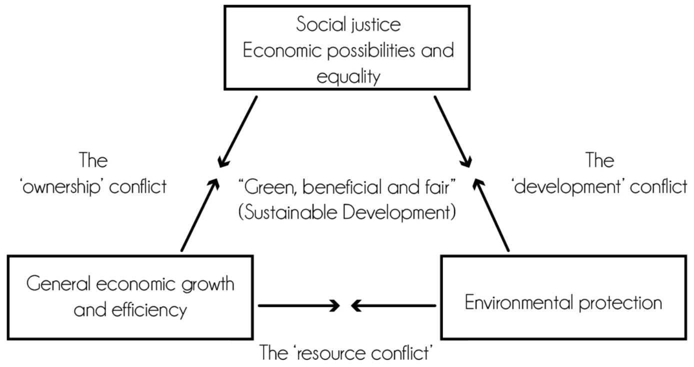

Fig. 1.1.1 Triangle of conflicting goals.
Image taken from: Timmeren (2006, 36) translated from Dutch by author.

Primary Energy Source	Energy Transfer Process	Renewable Energy Type
Solar Radiation/ Photon flux	absorption on semi-conductor surface → conversion to electrons via photoelectric effect → conversion to electricity;	photovoltaic (PV)
	absorption on surfaces → conversion to thermal energy;	solar thermal
	differential absorption on the earth's land surfaces and oceans → conversion to kinetic energy;	wind, waves
	selective absorption of light energy to drive photosynthesis → conversion of CO_2 and H_2O to glucose → further metabolically driven conversions to carbohydrates, fats, and proteins;	biomass energy, bio fuels
	solar heat absorption → water evaporation → heat loss to the atmosphere → water condensation → rain → PE in water storage	hydro (solar)
Gravitational forces and planetary motion	PE and KE contained in stored water;	hydro (solar)
	dissipative forces induce periodic KE changes in ocean	tidal
Gravitational forces and friction	Stored and generated thermal energy in the earth's crust transported to surface by conduction and fluid convection, enhanced by tectonic plate motion;	geothermal
Nuclear energy	radioactive decay of isotopes deposits energy in the earth's interior (e.g., K, U, Th)	geothermal

PE = potential energy
KE = kinetic energy

Table. 1.2.1 Renewable energy types and energy transfer processes.
Image taken from: Tester (2005, 409)
N.B.: potential energy and kinetic energy are abbreviated here as PE and KE respectively.

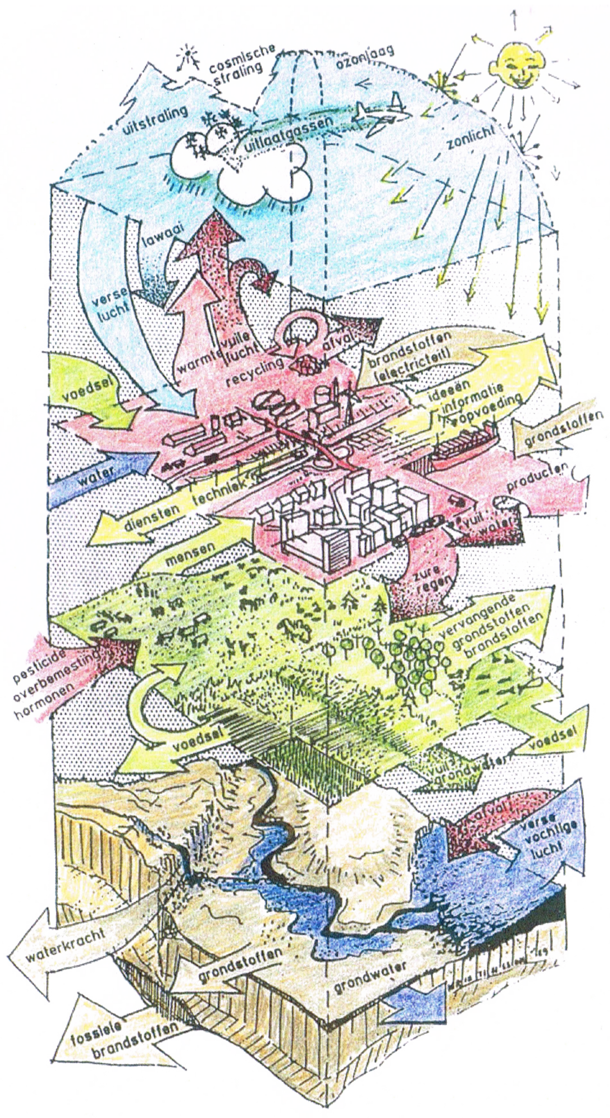

Fig. 1.1.2 The environmental system.
Image taken from: Kristinsson (2012, 20)

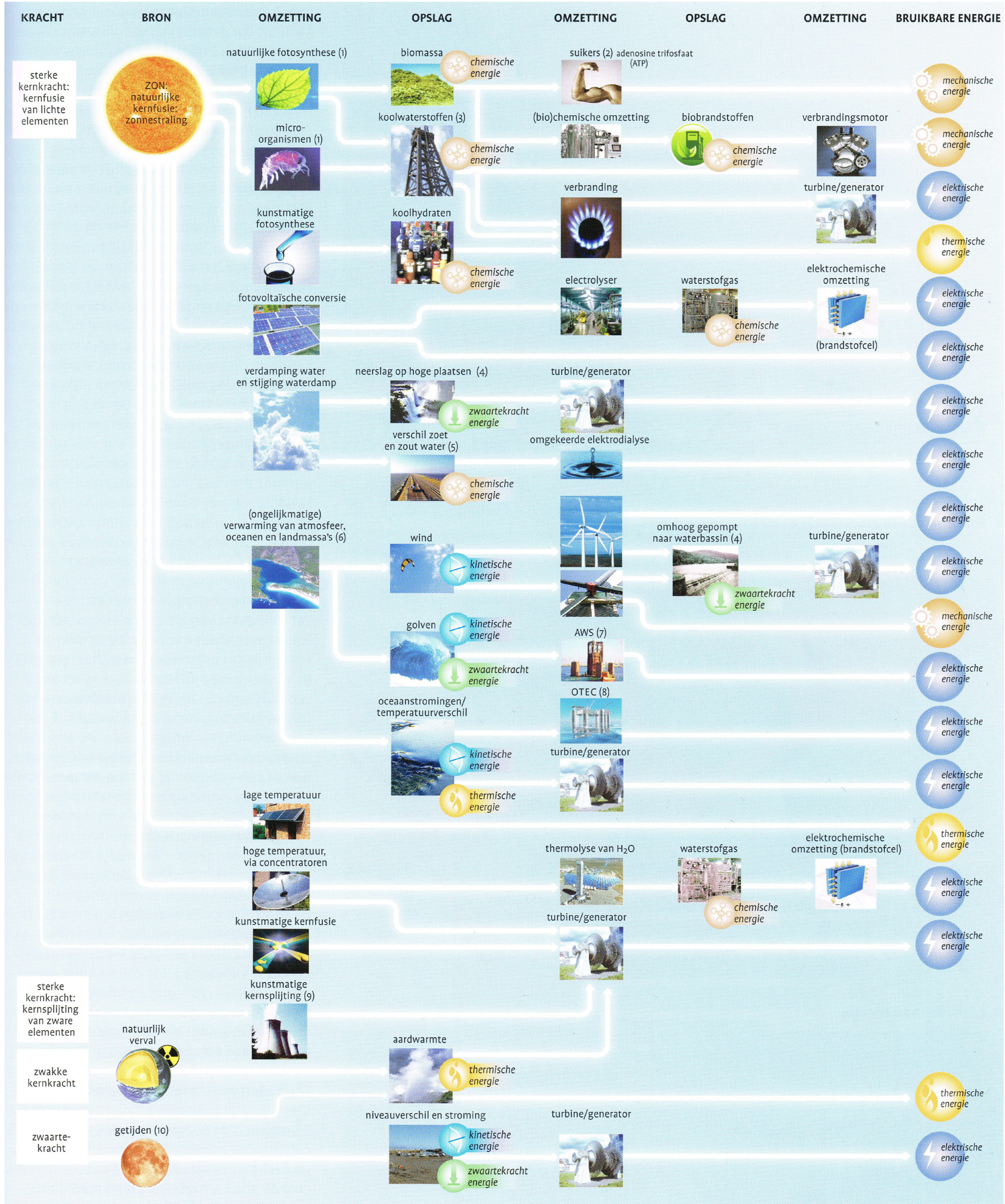

Fig. 1.2.2 Renewable energy types and energy transfer processes.
Image taken from: KNMI (2012, 9)

2. ***Holistic perspective.*** Assessment of progress towards sustainable development should:
   - Include a review of the whole system as well as its parts.
   - Consider the well-being of ecological, and economic sub-systems, their state as well as their direction and rate of change of that state, of their component parts, and the interaction between the parts.
   - Consider both positive and negative consequences of human activity, in a way which reflects the costs and benefits for human and ecological systems.

3. ***Essential elements.*** Assessment of progress towards sustainable development should:
   - Consider equity and disparity with the current population and between present and future generations. Dealing with consideration such as resource use, over-consumption and poverty, human rights, and access to services, as appropriate.
   - Consider the ecological conditions on which life depends.
   - Consider economic development and other, non-market activities that contribute to human/social well-being.

4. ***Adequate scope.*** Assessment of progress towards sustainable development should:
   - Adopt a time horizon long enough to capture both human and ecosystem time scales thus responding to needs of future generations as well as to those for current to short-term decision making.
   - Define the space of study large enough to include not only local but also long-distance impacts on people and ecosystems.
   - Build on historic and current conditions to anticipate future conditions- where we want to go, where we could go.

5. ***Practical focus.*** Assessment of progress towards sustainable development should be based on:
   - A limited number of key issues for analysis.

6. ***Openness.*** Assessment of progress towards sustainable development should:
   - Make the methods and data that are used accessible to all.
   - Make explicit all judgements, assumptions and uncertainties in data interpretations.

In this section the vision on sustainability was introduced which will be used throughout this paper. This vision will be elaborated upon in the remainder of this chapter. This paper attempts to approach sustainability in a holistic manner however: the key issue of this paper is renewable energy production and the associated reduction in carbon dioxide emissions. Other environmental concerns such as material scarcity, water scarcity and biodiversity will also be addressed but as a secondary concern and only in a qualitative manner. Social and economic aspects will also be treated in the same manner. Furthermore in this study the local conditions and consequences of possible interventions will be addressed most thoroughly. The goal of this paper is to provide insight which may lead to a design which has 'sustainable value' in the present, in 2050 and in 2100 without damaging the possibilities of even further generations. This paper seeks for innovative solutions in the present which could also function within a presumed future economy based fully on renewable energy. Where assumptions, calculations and judgments are not explicitly mentioned in the text they can be found in appendix A.

1.2 Renewable energy and energy systems

All types of renewable energy originate from one or a combination of three primary sources: solar radiation, gravitational forces and heat generating from radioactive decay. (Tester 2005, 408) Fossil and fissile energy sources also originate from these primary sources. However they take a much longer time to evolve. Table. 1.2.1 shows how energy is transferred from the primary energy sources into the form in which it is harvested using renewable energy technologies. This transfer process is further illustrated by the images in fig. 1.2.2. This paper will not discuss the exact workings of all renewable energy types. In chapter two the potential of all relevant renewable energy types will be considered and only those which show most potential will be discussed in detail in chapter 3.

According to Tester the expression 'renewable energy' contains a range of assumptions concerning time scales. It implies energy which is continuously available without any depletion or degradation. He illustrates this point with solar energy which, although it varies depending on season and weather conditions, is available for a certain time period on a daily basis.

Biomass, wind and other renewable energy sources show similar variations, although they vary over different time scales. (Tester 2005, 410) What defines these energy sources as renewable (as opposed to non-renewable fossil fuels) is that they replenish themselves over far shorter periods of time. However when we consider short enough time periods renewable resources have to be regarded as depletable as well. The time over which a renewable energy source is replenished is critical when estimating its viability for a specific use. How and when renewable energy can be harvested is essential for how and when it is used. Because of this the possibility to store renewable energy is crucial in determining an energy source's viability. (Tester 2005, 411) For instance: If we want to use thermal solar energy to heat our houses during the night, some sort of storage is necessary. The diurnal cycle, seasonal differences as well as the extent to which the energy can be stored are important factors in considering solar heat as an energy source.

Another important aspect of renewable energy sources is that the *'quality'* of renewable sources varies widely depending on geographical location. Quality here refers to the amount of effort which has to be made to harvest the energy. Variations in quality can be seen between countries but also between different plots. (Tester 2005, 411) The quality of biomass for instance depends on levels of solar irradiation, the availability of water, the amount of nutrients in the soil and the distance between where it is produced and where it is eventually used. Therefore the quality of biomass as an energy source differs from region to region.

Renewable energy sources also differ from fossil and fissile sources in that they have a much lower energy density. This means it requires more space and matter to harvest the energy. Therefore renewable-energy related land use competes more with other types of land use such as food production or recreation. (Stremke and Van den Dobbelsteen 2012b, 3)

Energy systems consist of three types of elements: storage, transmission and distribution. Storage allows us to decouple the moment of energy harvesting from that of its use. There are four reasons why storage is required. Firstly energy needs to be readily dispatchable and has to respond to fluctuations in demand (fig. 1.2.3). Furthermore the energy system has to be able to respond to interruptions in its supply such as those with intermittent sources as the wind. Thirdly being able to store energy allows it to be used more efficient. It allows us to recover wasted energy and allows energy sources, such as power plants, to run at optimum efficiency even at times when there is little need for their energy. Finally storage helps to meet distribution and transmission capacity requirements and limitations. For instance: it might not always be possible to distribute energy as fast as it is generated. At such times storage makes sure this energy does not go to waste. (Tester 2005, 656) Table 1.2.4 and fig. 1.2.5 give the approximate storage time, energy density and application for different storage technologies. In this context it should be mentioned that it is expected that hydrogen will become an important mode of storage and possibly a dominant energy carrier in the future. (Tester 2005, 414)

Energy can be transmitted in the form of electricity, hydrocarbon fuels, or using a cooling or heating medium depending on the kind of energy which is transported and its eventual use. The ways in which different kinds of energy are transported and distributed in the Netherlands and Amsterdam will be discussed in chapter two. In the Netherlands, as well most other developed countries, electrical transmission and distribution is done within a centralized system. In such a system electrical power is generated in large central power plants and transmitted to distribution systems using high-voltage lines from where it is distributed amongst its consumers (fig. 1.2.6 Top). (Tester 2005, 678) In the Netherlands, however, we also see some examples of decentralisation. In such examples energy is generated by a multitude of distributed sources which are closer to the point of consumption. According to Tester, distributed generation (DG) or distributed energy sources (DES) have some advantages over centralized systems such as that they allow more integration generating electrical energy and thermal energy. Also these systems are less vulnerable to black outs. In some cases DG may also require less transportation and distribution infrastructure. (Tester 2005, 681) They may however require more infrastructure for instance when a DG system is chosen to replace an existing centralized system. According to tester DG systems are also better suitable for renewable energy sources as these sources tend to be more dispersed and less dense. Also DG systems are better equipped to deal with the localized differences in energy quality. (Tester 2005, 683)

In his work *Autonomie en Heteronomie* Arjan van den Timmeren discusses the sustainable value of both centralized and decentralized energy and sanitation systems. He notes that the existing Dutch energy infrastructure is highly centralized and does not function well from a sustainability perspective. (Timmeren 2006, 92-98, 114) The existing system is rigid and therefore very determining for further development. Van Timmeren also points out that decentralized systems are better equipped to deal with fluctuations in demand and production. (Timmeren 2006, 202,214) Furthermore he states that where in the past due to the *'economy of scale'* large scale production tended to be more efficient and cost effective, this effect has diminished because new energy transformation techniques have had most influence on smaller scale production. (Timmeren 2006, 204,205) Besides the advantages in sustainability decentralized systems are also more suited for double land use, where for instance the space on top of buildings is used for producing energy. Such double use of ground helps to keep the costs of land low. (Timmeren 2006, 206) In his work Van Timmeren therefore advocates a system of interconnected decentralized or subsystems. (Timmeren 2006, 202) This means not a set of small autarkic systems but rather a whole of connected semi-autarkic parts. (Timmeren 2006, 252) Furthermore van Timmeren postulates the idea of also interconnecting different *'essential streams'* or systems, i.e. sanitation,

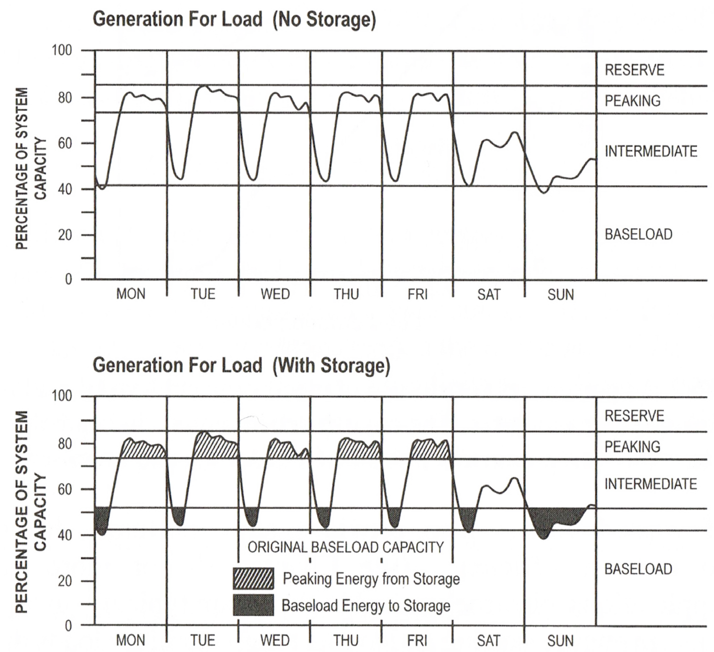

Fig. 1.2.3 Top: Typical weekly load curve of an electric utility. Bottom: shows how storage can help meet fluctuations in demand.
Image taken from: Tester (2005, 654)

Mode	Primary Energy Type	Characteristic Energy Density kJ/kg	Primary Application Sector
Pumped Hydropower	Potential	1 (100 m head)	Electric
Compressed Air Energy Storage	Potential	15,000 in kJ/m^3	Electric
Flywheels	Kinetic	30–360	Transport
Thermal	Enthalpy (sensible + latent)	Water (100– 40°C)—250 Rock (250–50°C)—180 Salt (latent)—300	Buildings
Fossil Fuels	Reaction Enthalpy	Gas—47,000 Oil—42,000 Coal—32,000	Transport, Electric, Industrial, Buildings
Biomass	Reaction Enthalpy	Drywood—15,000	Transport, Electric, Industrial, Building
Batteries	Electrochemical	Lead acid—60–180 Nickel metal hydride—370 Li-ion—400– 600 Li-polymer ~ 1,400	Transport, Buildings
Superconducting Magnetic Energy Storage (SMES)	Electromagnetic	100–10,000	Electric
Supercapacitors	Electrostatic	18–36	Transport

Table 1.2.4 Conversion energy storage modes.
Image taken from: Tester (2005, 654)

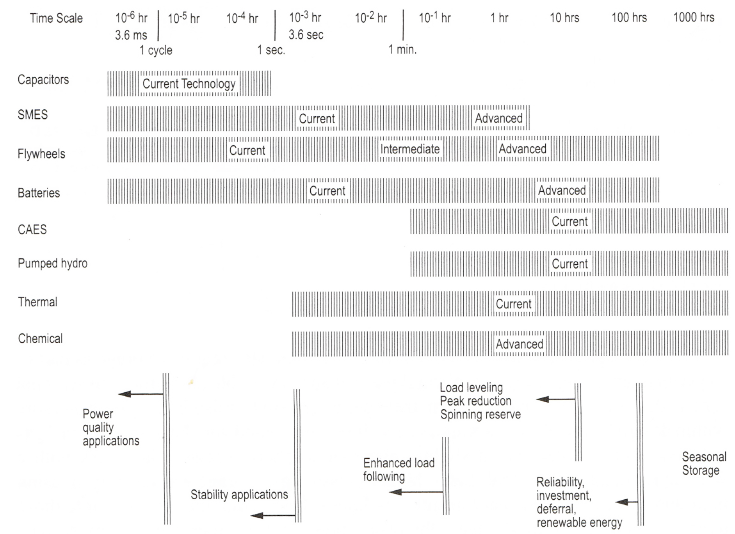

Fig. 1.2.5 Characteristic times for energy storage.
Image taken from: Tester (2005, 654)

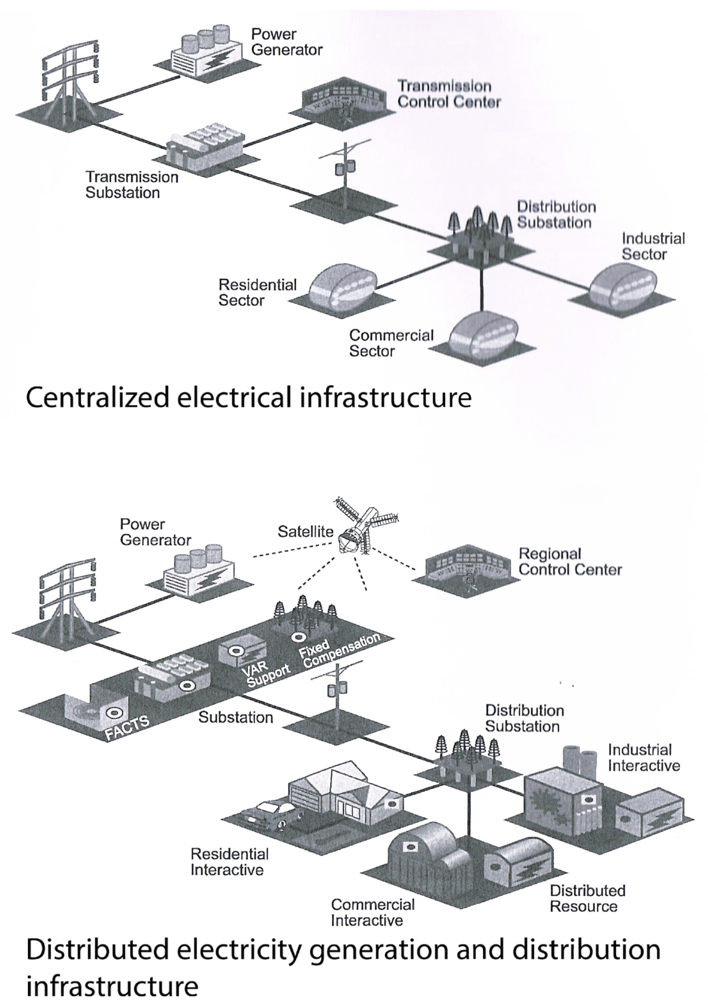

Fig. 1.2.6 Centralized (top) versus distributed (bottom) electrical systems.
Image taken from: Tester (2005, 680)

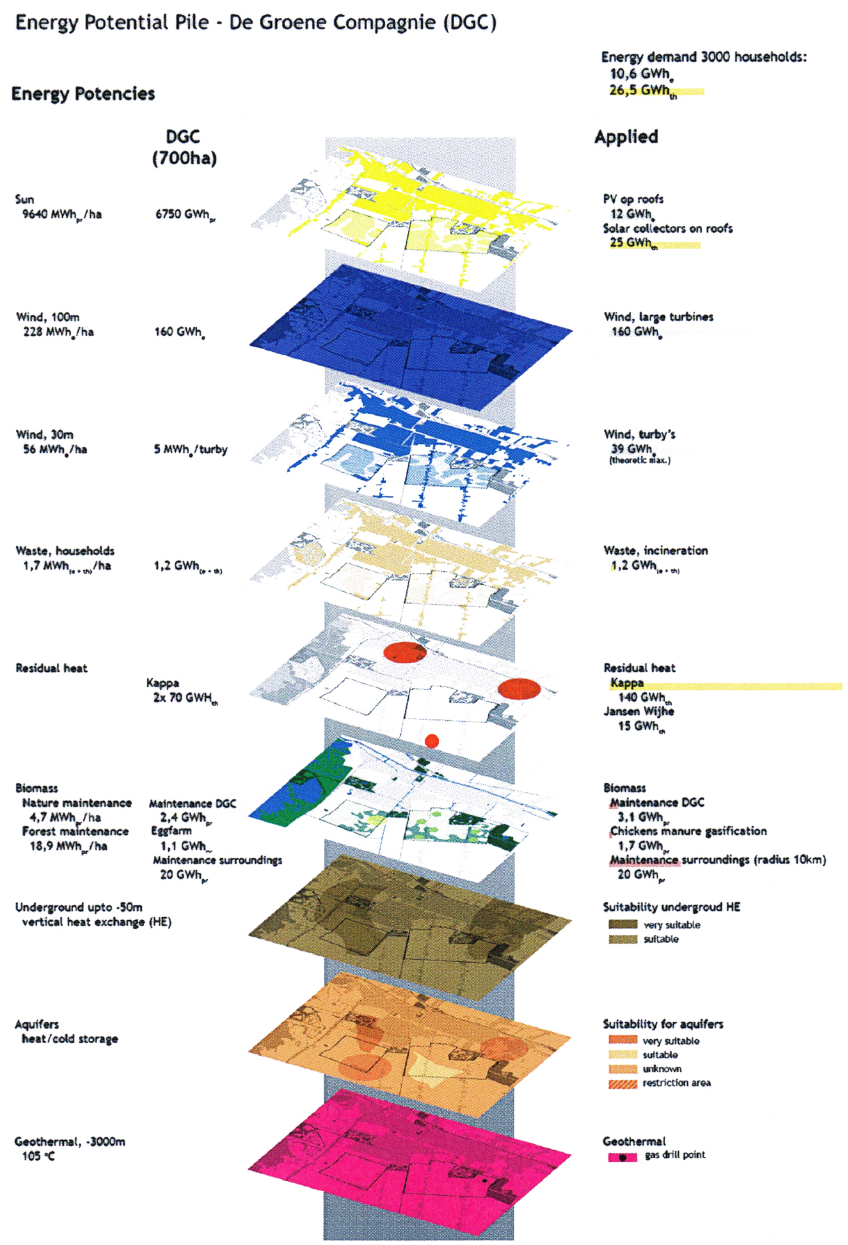

Fig. 1.3.1 Energy potential map for the expansion plan of Hoogezand-Sappemeer.
Image taken from: van den Dobbelsteen et al. (2011, 4)

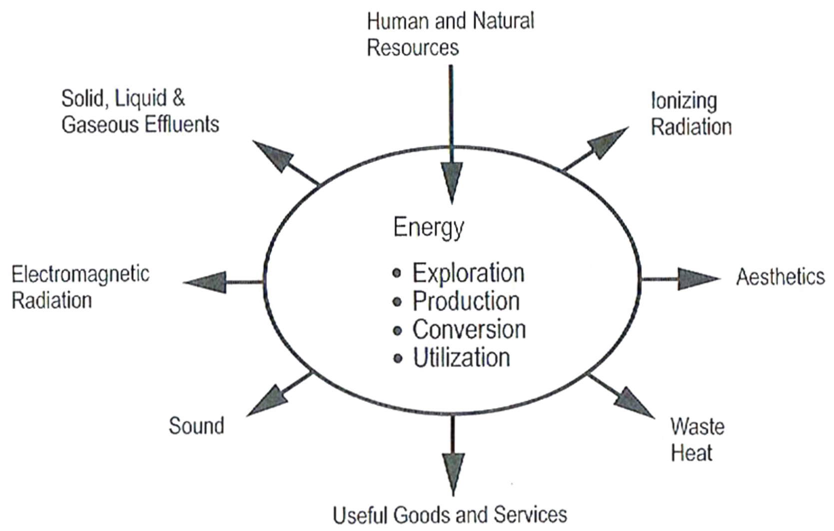

Fig. 1.3.2 Interactions of an energy system other systems.
Image taken from: (Tester 2005, 139)

energy and food production, so that they can benefit from each others waste streams. (Timmeren 2006, 292)

Because the existing energy system determines the future possibilities, Amsterdam's existing system will be analysed in chapter 2 of this paper. However all recommendations and conclusions in this paper are made from a paradigm which favours a system of interconnected autarkic parts where there is an integration of 'essential streams'.

1.3 Design methods

In this section energy analysis methods will presented which can be used when designing for renewable energy production. Firstly the energy potential mapping technique will be explained. This technique allows the designer to allocate and exploit local potentials. Furthermore the systems approach, which was introduced in the first section, will be discussed as a tool for responding to local opportunities, potentials and threats. This section will conclude by presenting the systems approach and the life cycle analysis method as means to evaluate the environmental consequences of proposed interventions or different alternatives.

As we saw from the previous section the quality of renewable energy sources is very dependent on local characteristics and can vary even on the scale of hectares. Local potentials for energy generation can vary depending on climate, landscape, and land use as well as natural, cultural and technical features. (Van den Dobbelsteen et al. 2007, 3) Locations with high potential for harvesting energy can be as widely dispersed as spots with the optimal wind speed or identifying opportunities for utilizing industrial of waste heat. The method of energy potential mapping (EPM) allows us find such potentials. This method encompasses the analysis of local climatic, topographic, geophysical and other local conditions and converting this information into maps. These maps show the local potentials for fuels, heat and cold and electricity. These maps can be subdivided into the levels or heights where the energy can be harvested. The potentials on each map are then quantified. Using these maps, local potentials can now be exploited in spatial planning. (Stremke and Van den Dobbelsteen 2012a, 74) The heat map can also have a slightly different purpose. If this map is done in a detailed manner, showing the energetic value of thermal sources and demand as well as the thermal infrastructure, it can be used to optimize the exergetic balance of an area. This could mean making heat cascades where high-quality heat is cascaded amongst high grade functions and cascaded further amongst lower grade functions when its quality is diminished. (Stremke and Van den Dobbelsteen 2012a, 74; van den Dobbelsteen et al. 2007, 5)

Analysing the energy system as a set of interlinked subsystems is another approach which the designer can use to define local potentials. This approach focuses more on existing infrastructures and the unutilized opportunities these offer. Here too the EPM division is useful distinguishing between an electrical, fuel, heat and cold system. Possibly food production and sanitation systems could be added. In an energy system mapping (ESM) information on infrastructure, energy and material flows and on important nodes in the system is collected, quantified, and subsequently converted into maps. In contrast to EPM here the links, or lack of links, between the different systems are important. In such an analysis waste streams can be identified which might be useful for one of the other systems. Also potentials for making additions using the existing infrastructure can be identified. The approach closely leans on the idea of industrial ecology. From the perspective of industrial ecology, industrial systems are viewed in concert with their surrounding systems. Industrial ecologists keep account of all inputs and outputs of materials and energy throughout a product's or process's life cycle and reject the idea that any material should be regarded as waste. (Tester 2005, 193,194) This approach can also be used to assess the environmental impact of a system. The approach is then used to analyse and quantify the interaction between the industrial system under scrutiny and the environmental system. Fig. 1.3.2 shows the interactions which would have to be taken into account when making such an analysis for an energy system.

If we would want to evaluate the environmental effects of a proposed intervention precisely, the tool to use would be a life cycle analysis (LCA). In this methodology an inventory is made of all the impacts associated with each stage of a process's or product's life cycle. The methodology requires a very extensive and precise analysis where all assumptions are made explicit. An LCA can be useful for choosing amongst alternatives and also helps to identify the most important sources or stages of negative impact. (Tester 2005, 273,274) However an LCA requires very precise data which is often only available in retrospect (Ashby, Shercliff, and Cebon 2007, 483; Ashby et al. 2005, 2; Domone and Illston 2010, 537-538) A designer often lacks the appropriate data, expertise and time to make a LCA. His choices however are the most determining. (Ashby et al. 2005)

There are many tools a designer can use which approximate an LCA. Let us consider the design of a building for instance. Here the environmental impact is determined by the subsequent phases: production, manufacture, use and disposal. For making a material selection which minimizes environmental impact during production, manufacture and disposal a designer can use the software CES developed by Granta. For a more precise evaluation of the impact of a particular design or design alternatives a designer can use the Eco-Audit tool within CES. With this tool the environmental impacts can be evaluated by filling in variables such as the amount of material, the chosen production process and transportation distances. To approximate the environmental impact during use a designer can make manual calculations of the energy use. However for this there is a multitude of software tools available as well.

The energy potential mapping and systems analysis which were mentioned earlier may also be too time consuming too incorporate into most design projects. However these methods can also be applied in a less extensive manner. Even without quantifying some of the potentials an EPM might still be useful. For instance, only evaluating the average wind speed at different locations already gives the designer an idea of which locations are suited for harvesting wind energy. Similarly a designer can learn much by mapping the different 'essential streams' in an area even without quantifying them precisely.

1.4 CONCLUSION

In this chapter 'sustainability' was operationalised. It was discussed that there are three kind of indicators of sustainability, namely: environmental, economic and social indicators. Sustainable development requires these three to be balanced. This is difficult however since these three cannot be measured or weighed as such. By considering different subcategories or the three pillars, which can be measured, much can be gained in objectivity. However weighing the different categories against each other remains problematic. Also we saw that this task becomes even more complex if we consider that there are interactions between the systems the different categories refer to, that is: the environment can be considered as a set of interlinked processes which have no clear boundaries. Such a system is too complex to describe accurately. However we saw this was no reason for apathy and we are forced to accept a qualitative recognition of this complexity and work with that. Hence it was stated that this paper will focus mainly on renewable energy production and the associated reduction in carbon dioxide emissions. Because this paper desires to have a holistic perspective it will also consider other environmental concerns as well as social and economic ones. Yet these are considered to be of secondary concern and they will only be treated in a qualitative manner.

This chapter also discussed the general issues concerning renewable energy and energy systems. The chapter noted how and when renewable energy is harvested is detrimental for how and when it can be used. Renewable energy is generally only available for a certain time period and in a specific form. Also the yield from renewable energy sources shows great variations which depend on many external factors. Storage therefore is an important aspect of renewable energy. Another important facet of renewable energy is that its quality varies greatly depending on geographic location. This means that some places are more suited for renewable energy generation than others, that is: some places require a greater amount of effort to harvest the energy. Also renewable energy sources have a smaller energy density than fossil an fissile sources which means it requires more space and matter to harvest the same amount of energy.

In this chapter also the differences between a centralised- and a decentralised energy system where discussed as well as their merits and flaws. It was stated that this paper acts from a paradigm favouring a decentralised system which exists of interconnected autarkic parts.

Finally this chapter discussed analysis methods designers can use to integrate sustainability in their design process. Energy potential mapping (EPM), energy system mappin (ESM) and life cycle analysis (LCA) where described as particularly useful methods. These methods require an extensive quantitative analysis for which the designer often lacks the time and expertise. However a qualitative variant of these methods can often already give much insight. Also, for making an approximation of an LCA much software is available. The EPM and ESM methods will be used in chapter 2 to make an analysis of Amsterdam's energy potentials.

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2. AMSTERDAM'S ENERGY SYSTEM AND POTENTIALS

Fig. 2.0.1 Physical model Amsterdam's energy system. It illustrates the connections between the sub-systems.
Model and photograph made by author.

In the following chapter the Amsterdam energy system and the city's potentials for harvesting renewable energy will be analysed. A series of maps will be presented which where made using the methodology described in chapter 1. The energy system will be analysed by presenting its different subsystems: the hydrocarbon, the electrical, the thermal (heat) and thermal (cold) energy system. The goal of this analyses is to expose opportunities for producing renewable energy in the Brettenzone. These opportunities will be summarized in a 'program of possibilities'. The 'program of possibilities' gives a set of proposals and interventions which arise from the context's potentials and possibilities. It gives a possible direction for solutions rather than just summarizing research results. Furthermore it tries to reveal the chances of failure and succes of the proposed intervention. The method of inquiry is inspired by the 'essay of clues' used by Arjan van Timmeren his work Autonomie en Heteronomie. (Timmeren 2006, 407) The most feasible elements from the program of possibilities where integrated in a preliminary design for an energyscape in the Brettenzone. This design will also be presented at the end of this chapter.

The maps presented in the following sections display the energy system as a set of closed systems. In reality the situation is more complex. As was mentioned in chapter 1, the energy system is in fact on open system which exists of multiple interacting subsystems. The model shown in fig. 2.0.1 was made to also gain insight in the connections between the different subsystems. Besides the interconnection of layers there is another reduction in the maps presented in this paper, namely, that all the systems presented here are also connected to other systems on a larger as well as a smaller scale. For instance: Amsterdam's electrical energy system is connected to that of Europe but also to that of its individual houses. To account for this, analyses where made on the neighbourhood or city scale, the national scale and the European scale. The interconnections between these scales is modeled into these maps schematically. It might be noted that the maps presenting different networks are not on the same scale, nor do they fit within the same frame. This is because these networks are very different in size. Amsterdam's district heat network for instance is only connected with that of Almere where Amsterdam's electrical network stretches is linked more closely to that of Purmerend and is in an integral part of the Dutch and the European network.

The energy potentials are also analysed on the local, national and European scale. This was done so the local potentials could be seen in context. A good potential for harvesting wind energy for instance is only 'good' relative to a place which is 'worse'. A fully quantified mapping would have been most desirable. Such a detailed analysis however is beyond the scope of this paper. Therefore exact numerical data is only given here where such data was easily available.

2.1 HYDROCARBON SYSTEM

In Amsterdam fossil fuels are still the dominant source for producing energy. Natural gas is used to heat most houses and offices and also powers the Nuon Hemweg 9 power plant. The Hemweg 8 power plant is powered using brown coals. Transportation is mainly fueled by gasoline. However biofuel is increasingly mixed into gasoline and the number of electrical vehicles is rising.

Yet a part of the city's energy and heat is generated in a more sustainable way. At Westpoort attempts have been made to close the carbon cycle as well as other material cycles (fig. 2.1.1). Waste for instance is burned to recover energy and heat at the incineration plant (AEB). The AEB is currently running experiments with catching the CO_2 from combustion. The CO_2 is sent to greenhouses as far as Westland where it is used for fertilisation. (Agema 2013) Sewage is processed at the purification plant (RWZI). Here sewage dredge is digested into biogas which is also burned at the AEB. Orgaworld, a corporation of companies using each others wastes, processes waste oils, fats and water into biogas and biodiesel. Water purifications at Orgaworld and at the RWZI also produce residues which are used as fertilizers. The RWZI residue is sent to ICL fertilizers which process it into artificial fertilizer. Orgaworld sells its residue itself as an organic fertilizer. (Haffmans 2013)

It can be concluded that there is a great potential in the existing system for biogas. The infrastructure for its production and consumption is there and biogas can be mixed into the existing gas network. Theoretically it could even be possible to convert the Hemweg 9 plant into a biogas plant. Biomass might also be an interesting option as it is already possible to use this in a co-firing process at the Hemweg 8 plant. Nuon is currently searching for a steady supplier for this. (Haffmans 2012, 16) Using CO_2 from the Nuon plants in greenhouses offers another potential to close cycles. Also there are large waste streams of wood and cacao shells which could be used as biomass. (Haffmans 2012)

From fig. 2.1.4 it can be seen that an agricultural area just west of Amsterdam has the potential to deliver large quantities of biomass. Furthermore there is also a small potential of harvesting biomass from Amsterdam's own green areas (fig. 1.5 and 1.6).

Fig. 2.1.7 shows the area's potential of producing crops especially for biomass. It can be seen that large quantities of energy could be produced if such crops where converted into biogas. It should be noted though that in some places this would involve clearing of existing green areas which might not be considered sustainable and could in some cases even lead to a net addition of CO_2 to the environment. It should be noted that changing the type of growth could also have adverse effects on the ecology of the area (fig. 2.1.8). Also the recreational value of many places in the area has to be taken into account (fig. 2.1.6).

From this analysis I can conclude that the existing system offers much potential for the utilization of biomass and biogass as sources of energy. The system also offers the possibility to be extended to utilize these sources further. In addition to the existing streams of biomaterial it might be interesting to also produce these resources in the Brettenzone as a short transportation distance is critical for biomass. (Prag 2013, 55) Such an intervention is only sustainable however, if the existing green has been taken into account.

EXISTING ENERGY SYSTEM

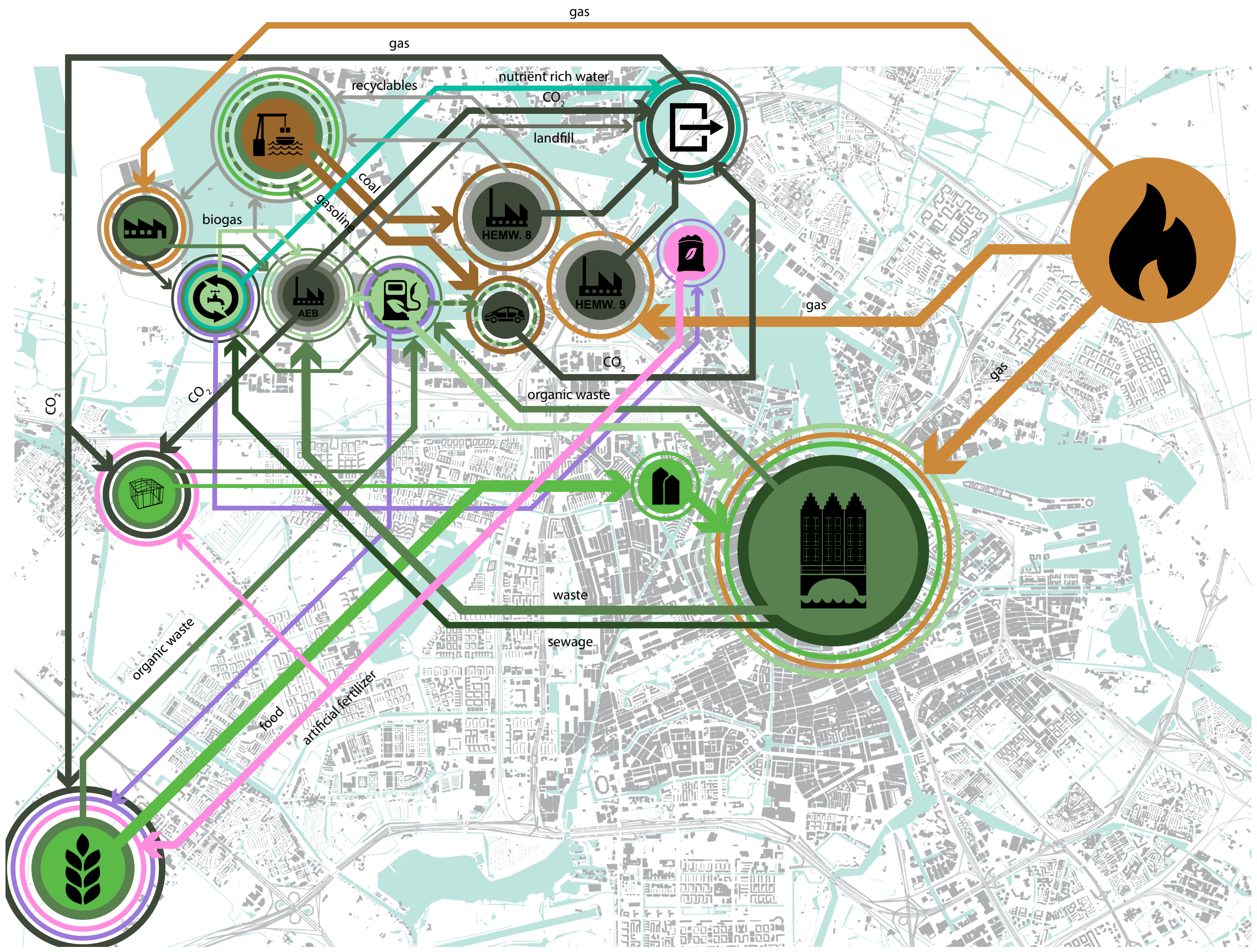


Fig. 2.1.1 The existing hydrocarbon system and associated material ecology.
Own illustration compiled with data from: NUON (2013a); Vattenfall (2010); NUON (2010); AEB (2006, 5), (2011, 3,4,9); Steffart (2012, 12,13); Orgaworld (2013); De Bosatlas van de energie (2012, 70, 119); Haffmans (2012, 2013); Agema (2013)

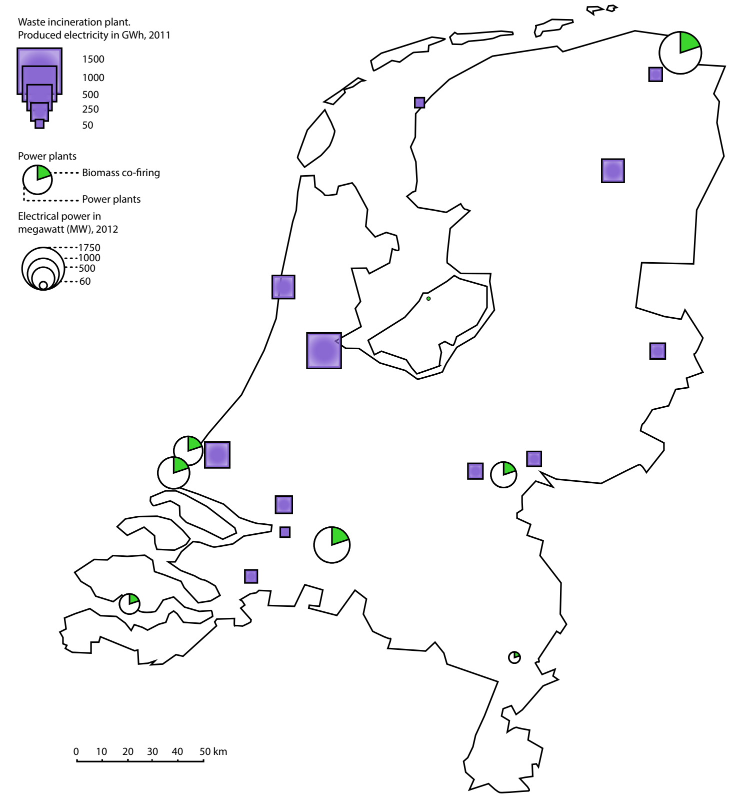


Fig. 2.1.2 Existing biomass co-firing plants, biomass plant and waste incineration plants.
Based on an illustration from: De Bosatlas van de energie (2012, 60). Additional data added from: NUON (2013d)

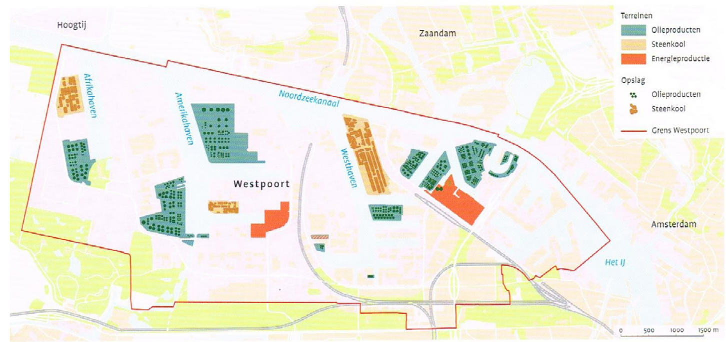


Fig. 2.1.3 Companies in the Westpoort which process or store carbon hydrogen products.
Image taken from: De Bosatlas van de energie (2012, 55).

POTENTIALS: BIO WASTES (DEPENDENT BIOMASS)

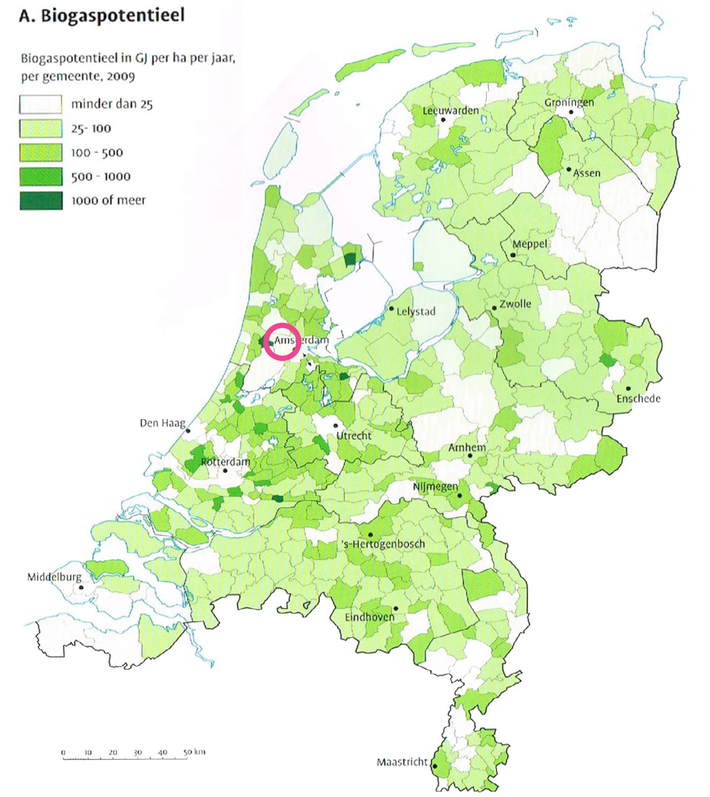
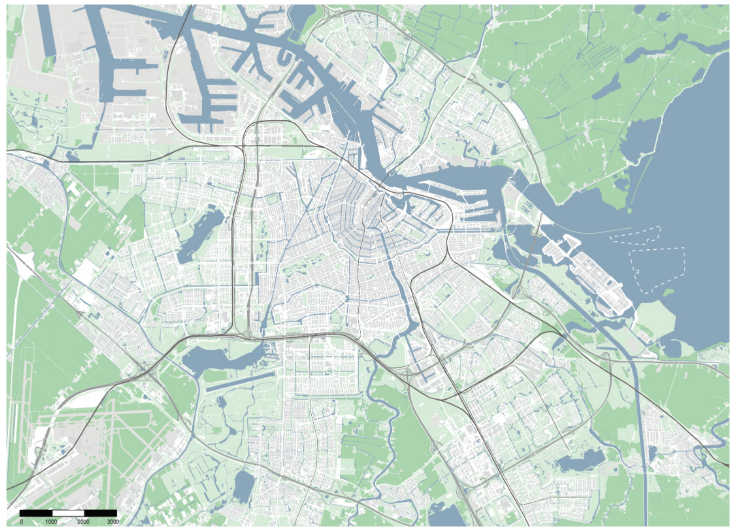


Fig. 2.1.4 Biogass potential of existing agriculture in the Netherlands. Image taken from: De Bosatlas van de energie (2012, 61)



Rural green. Urban green.

Fig. 2.1.5 Biomass potential from clippings from existing green areas in Amsterdam.
Image taken from: Kürschner et al. (2011, 23)

N.B.: Where this concerns utilizing biomass which would otherwise have been left to degrade naturally this has an additional benefit. This prevents emission of methane, which is a product of natural degradation, and instead causes the emission of CO2 during combustion or digestion. Methane is a twenty times stronger greenhouse gas than CO2.

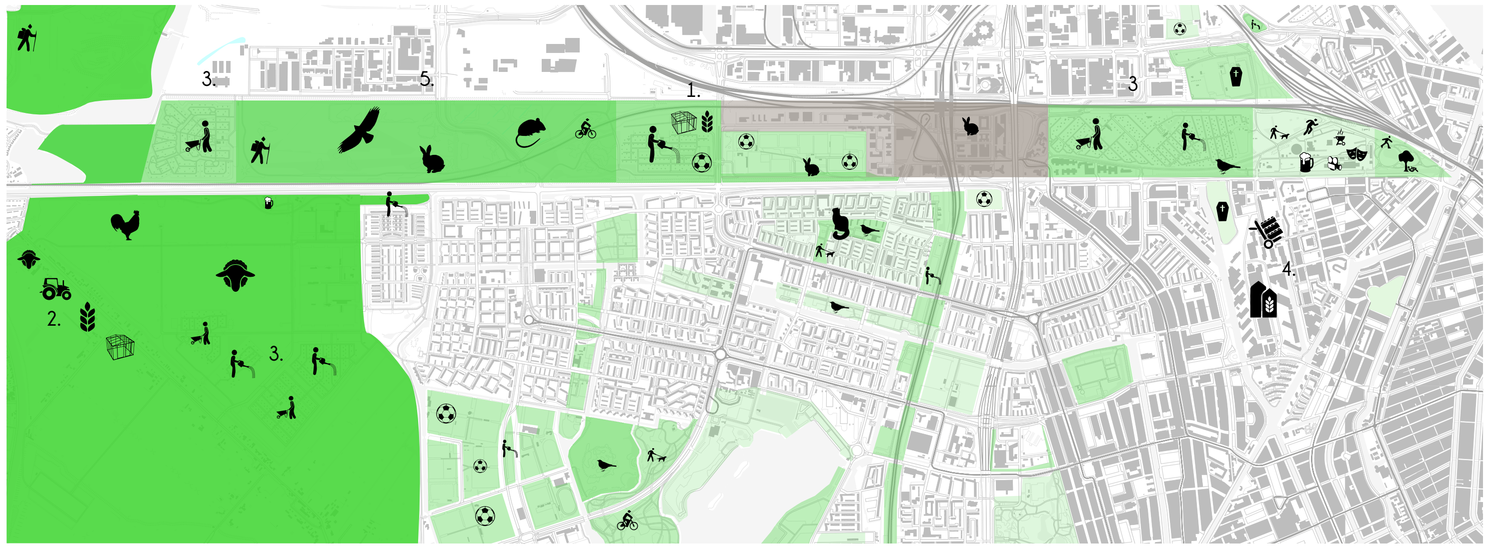


Fig. 2.1.6 Ecology, land use and character of green area.
Based on own observations and data from: DRO (2012)

- Agricultural land; polder landscape.
- Wetlands and meadows; diverse ecology.
- Allotment gardens / city park; Trees and canals.
- City park; opengrass field. Some ponds with reed.
- Allotment garden or school plots.
- Commercial green houses.
- Commercial life stock farming.
- Central food markets.
- City garbadge incineration heat plant.
- City sewage water purification.
- Rotie: corporation which manufactures bio-diesel from organic wastes.
- Graveyard
- Recreational area; catering and cultural industry, outdoor sports and lounging.
- Animal species sighted in personal observation.
- Lounging.
- Strolling.
- Sporting grounds.
- Cycling / jogging.

POTENTIALS: AGRICULTURE (FOOD AND BIOFUEL)

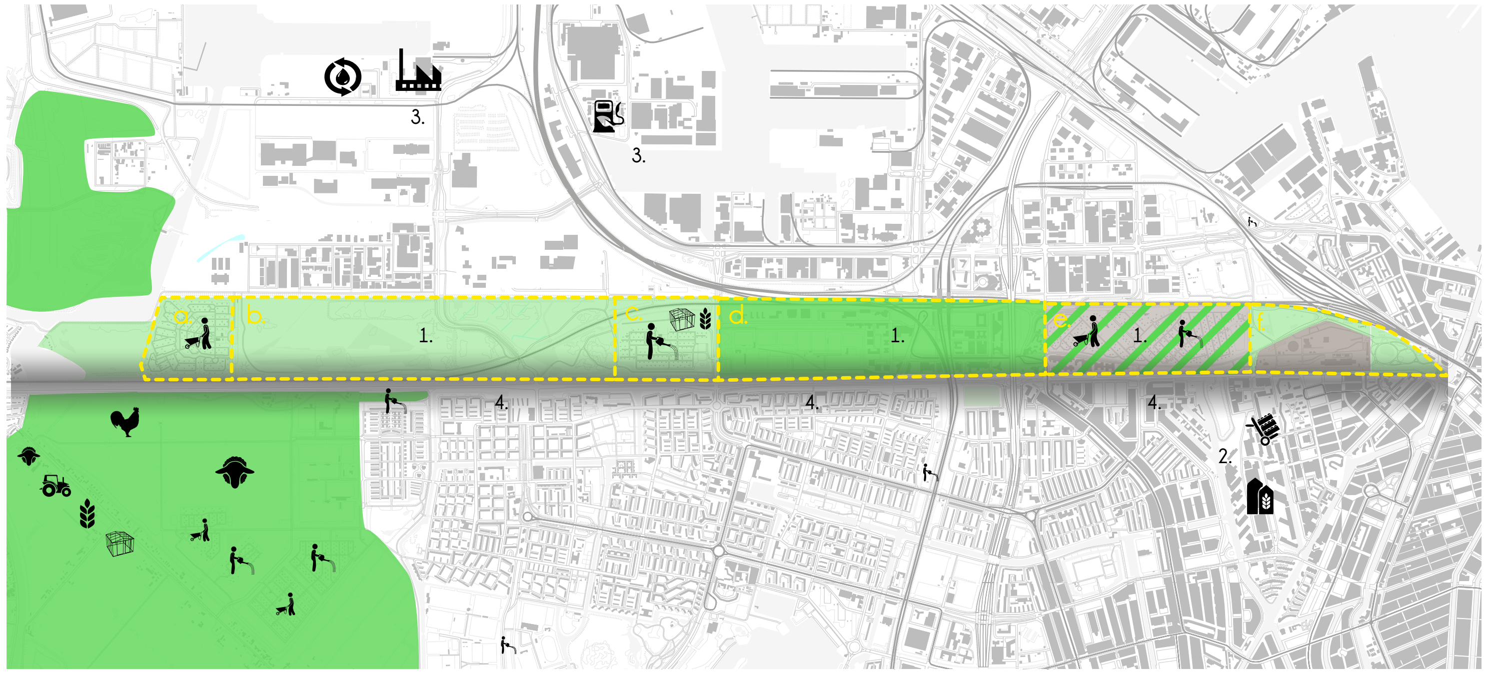


Fig. 2.1.7 Existing agricultural activities and the agricultural potential of the area.
Based on data from: DRO (2012) N.B.: In many areas biogas production from crops would require clearing existing plants.

- Agriculture, living and working allowed without further research.
- Allotment gardens, living and working allowed without further research. Agriculture requires further research in some areas.
- Contaminated area no living or agriculture allowed.
- No data available.
- Allotment garden or school plots.
- Commercial green houses.
- Commercial livestock farming.
- Central food markets.
- City garbadge incineration heat plant.
- City sewage water purification.
- Rotie: corporation which manufactures bio-diesel from organic wastes.

a. Area a: 27.5 ha
Potato potential: 1.3 · 10^6 kg
Biogas potential (grass): 751 mWh / y

b. Area b: 122.6 ha
Potato potential: 6.0 · 10^6 kg
Biogas potential (grass): 3,350 mWh / y

c. Area c: 28.4 ha
Potato potential: 1.4 · 10^6 kg
Biogas potential (grass): 776 mWh / y

d. Area d: 83.7 ha
Potato potential: 4.1 · 10^6 kg
Biogas potential (grass): 2,287 mWh / y

e. Area c: 49.7 ha
Potato potential: 2.4 · 10^6 kg
Biogas potential (grass): 1,358 mWh / y

f. Area d: 30.6 ha
Potato potential: 1.5 · 10^6 kg
Biogas potential (grass): 836 mWh / y

Total Brettenzone biogas potential:

Grass: 9,358 MWh/y (2,689 households)

Beets: 113,025 MWh/y (32,478 households)

Calculation based on:
CBS (2013); BAI (2008); Kompetenzzentrum Biomassenutzung Schleswig-Holstein (2013); NUON (2013c)

Fig. 2.1.8 Ecology: potentials and threats. Based on data from: DRO (2012)

- 10 or more kind of protected flora and fauna.
- 7, 8 or 9 kinds of protected flora and fauna.
- 4, 5 or 6 kinds of protected flora and fauna.
- 2 or 3 kinds of protected flora and fauna.
- 1 kind of protected flora or fauna.
- Fauna connection already executed.
- Planned fauna connection.
- Animal species sighted in personal observation.
- High speed traffic and trains causing a physical an noise barrier.

2.2 ELECTRICAL ENERGY SYSTEM

Most energy in the Netherlands is produced using fossil fuels. In Amsterdam the amount of energy produced by incinerating waste at the AEB is less then one tenth of that produced using coal and gas at the Nuon power plants. Furthermore only 48% of the waste incinerated at the AEB consists of biomass and only this fraction can be considered to be CO_2 neutral. (AEB 2008, 5) The amount of energy produced from wind turbines within the city limits is about one thousandth of that from the Nuon plants and the amount solar energy is about a millionth. At the national level renewable sources only account for 4.3% of the total energy consumption. (De Bosatlas van de energie 2012, 59)

Although fig. 2.2.1 gives insight in what production and consumption nodes there are within the city limits, it does not convey the distribution network accurately. This network is shown fig. 2.2.2 It is divided in a high-, middle and a low voltage network which are interconnected (fig. 2.2.3).

From this analyses of the existing system it can be concluded that within Amsterdam little electrical energy is produced from renewable sources. There is a large production of electricity from fossil fuels. The city is a good location for large power plants because of the proximity of the port as well as that of consumers of heat and steam. Wind or solar energy sources however do not necessarily have to be close to the place where they are consumed.

Fig. 2.2.4 shows Europe's irradiation by the sun. Irradiation is the sum of direct and indirect radiation. This can potentially be harvested by photovoltaic panels. The image shows that the south of Europe receives far more radiation then the northern countries. If energy production is considered a European problem it might be argued that it would be more cost effective to place PV panels in the south of Europe. Nonetheless energy from the sun can be harvested economically in the North as well. Fig. 2.2.5 (left) shows the amount of global irradiation for the Netherlands. The area near the coast receives about 10% more sun than the area further inland. This is because the coasts receive more direct sunlight. This can also be seen in fig. 2.2.5 (right) which shows the amount of hours of direct sunlight. Although PV cells also harvest diffuse sunlight they do have a better performance under direct light. It seems that the very south west point (Zee-land) of the Netherlands would be the most ideal place for solar panels. Within Amsterdam the differences are minimal. On average the city receives about 1000 kWh/m². Filling the entire Brettenzone with solar panels would yield roughly 411 GWh/y, one tenth of Amsterdam's total energy demand.

If we look at the energy density[1] in fig. 2.2.7 (left) which can be harvested from wind in Europe we see that off shore locations (with a depth less then fifty meters) near the Netherlands, Scandinavia, England and Ireland have the greatest energy density. On land we see that England and Ireland show the best conditions. Areas near the coast of the Netherlands, Scandinavia, Belgium and France also seem reasonable. If we look at the costs (right) however we see that the offshore locations become less attractive. The most cost-effective locations appear to be the aforementioned on-land locations. On a national level, coastal regions at the north of Noord Holland, the west of Friesland and at Zee-land experience the largest average wind speeds at both ten meters and hundred meters altitude (fig. 2.2.8). Amsterdam does not appear to be the most ideal place for harvesting wind energy. On the city scale we also see variations in wind speed at a hundred meters altitude. The worst locations appear to be the city center and the Westpoort area. Almost all wind turbines within the city however are located in Westpoort. This indicates that spatial and aesthetic considerations are often more important than energetic efficiency.

LOCAL SYSTEM

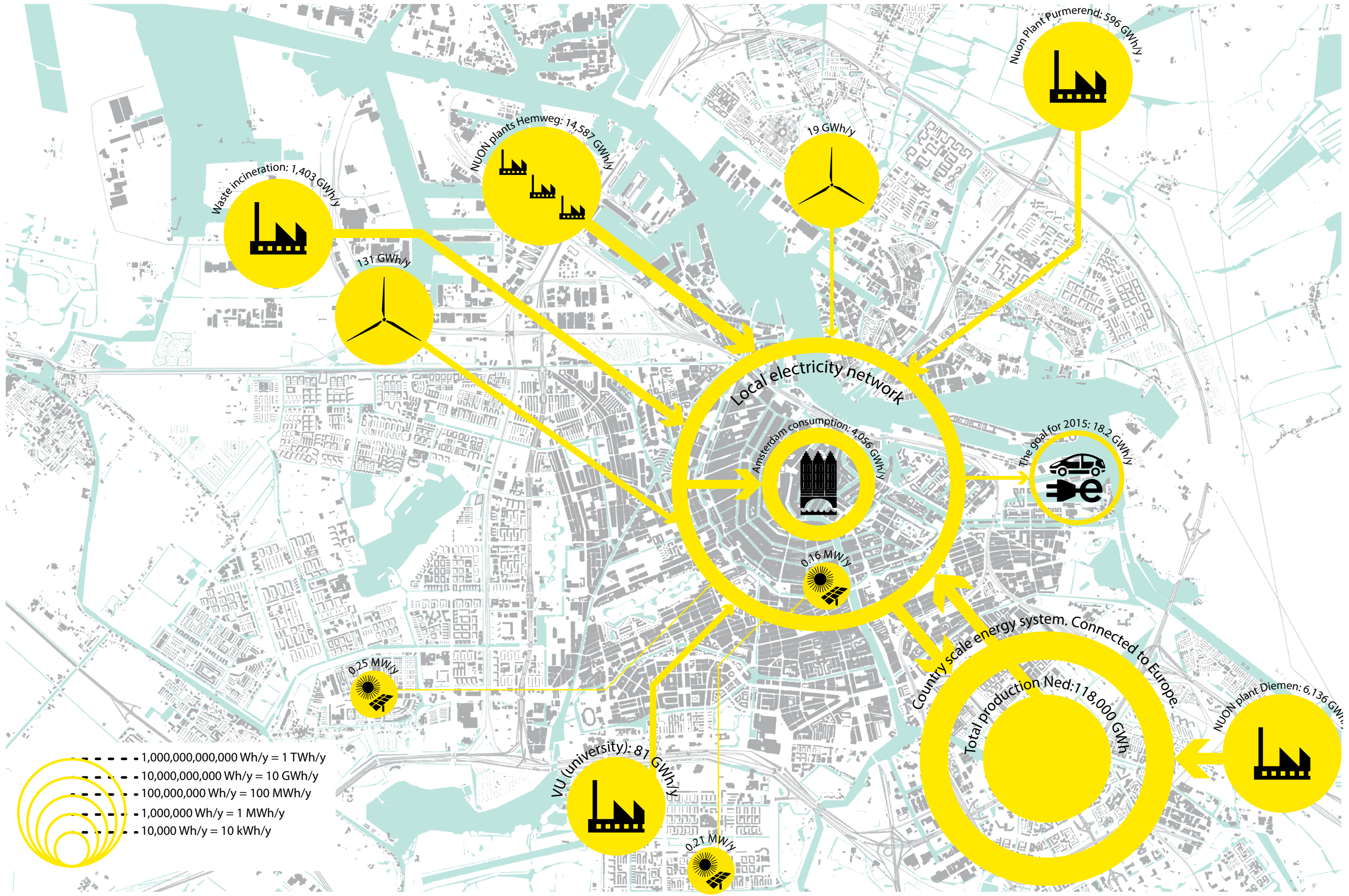
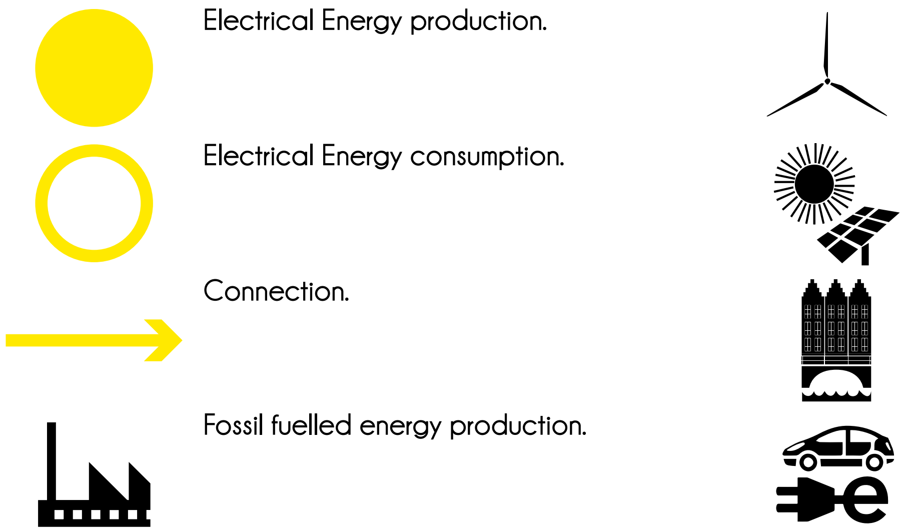


Fig. 2.2.1 The existing electrical system.
N.B.: The figure shows a simplification of the electrical network. In reality this network is divided in the manner shown in fig.2.3. The representation shown here should be seen as an inventarisation of where energy is produced and consumed and their corresponding quantities within the city.
Own illustration compiled with data from:
DMB (2011, 11); NUON (2013b); RenCom (2013); NUON (2011, 74; 2012, 42); De Bosatlas van de energie (2012, 77,119); Haven Bedrijf Amsterdam (2012, 4); Onze Energie (no date); Passier et al. (2009, 3); Lease plan (2013); CBS (2012)



1. Energy density: a measure for the effectiveness of a turbine on the chosen location. The area here refers to the circular area described by the moving arms of the turbine.

NATIONAL SYSTEM

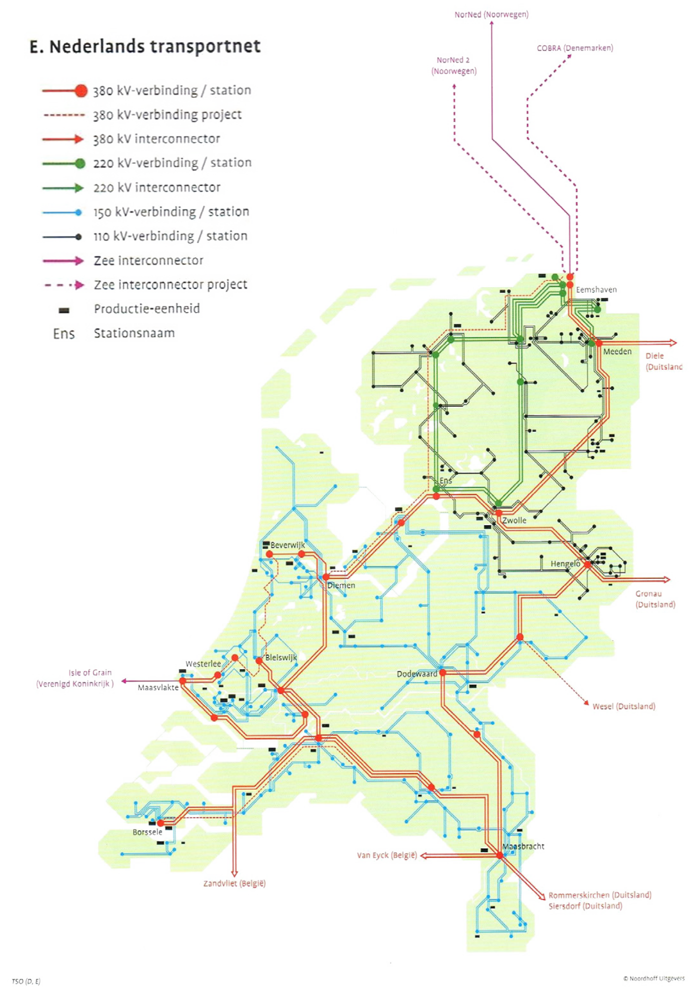


Fig. 2.2.2 National electricity network.
Divided in three voltage levels. The Dutch network is connected to that of Germany, Belgium, Denmark, Norway and England. The Netherlands forms a trade region with Germany, France, Belgium and Luxembourgh which collaborates with Scandinavia and the UK.
Image taken from: De Bosatlas van de energie (2012, 79)

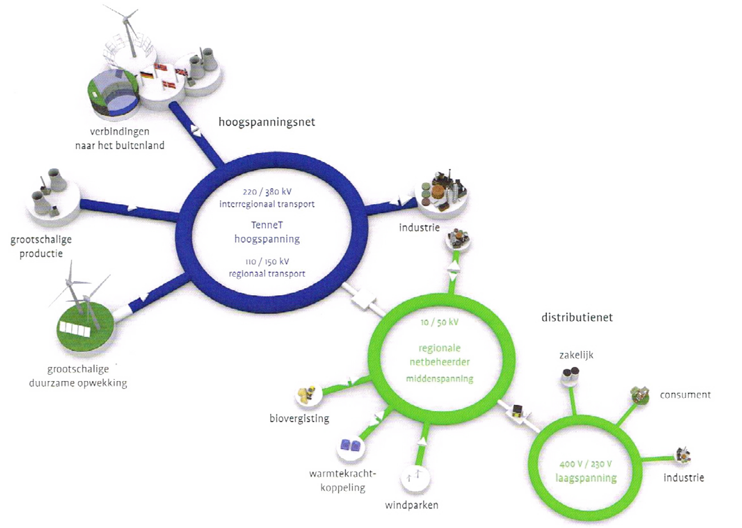


Fig. 2.2.3 Division of the national network.
Divided in a high-, middle- and low voltage network which are interconnected.
Image taken from: De Bosatlas van de energie (2012, 78)

SUN

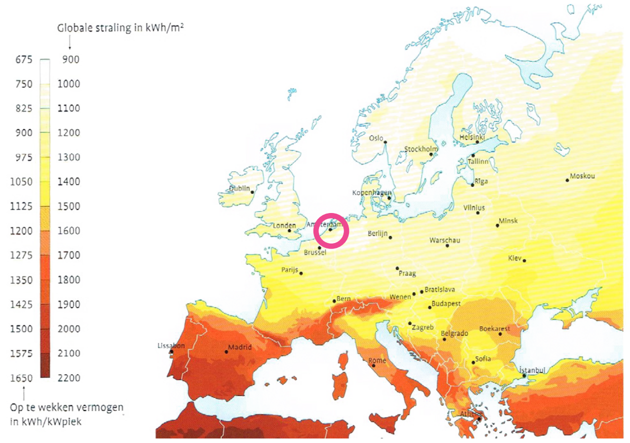


Fig. 2.2.4 Global irradiance (direct and diffuse light) on Europe.
A measure for the amount of energy which can be harvested with photovoltaic panels.
Image taken from: De Bosatlas van de energie (2012, 64)

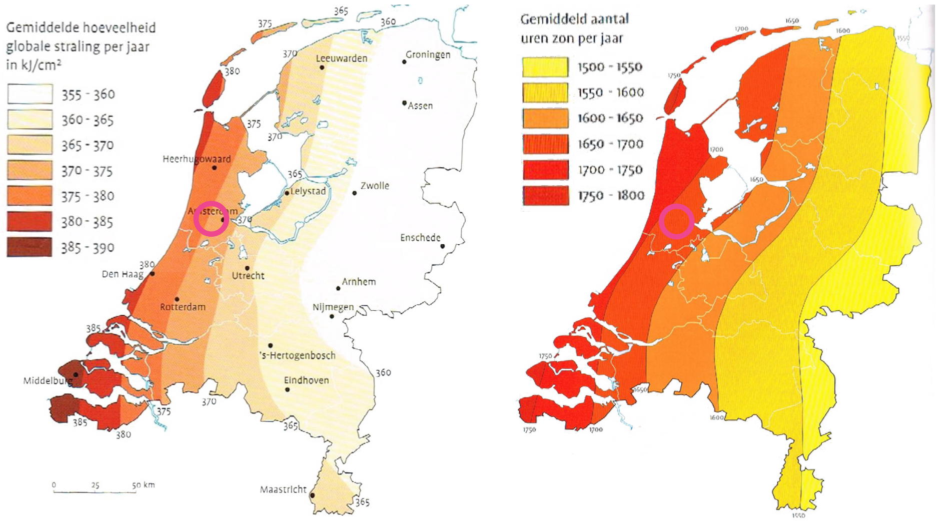


Fig. 2.2.5 Sun light on the Netherlands.
Left: Global irradiance (direct and diffuse light) Right: Sun hours (direct light)
Left: De Bosatlas van de energie (2012, 64) Right: De Bosatlas van het klimaat (2011, 48)

Fig. 2.2.6 Global irradiance (direct and diffuse light) on Amsterdam.
On average: 360,000 J/cm²y = 114 W/m²= 1000 kWh/m².
Photovoltaic cells would yield 60-150 kWhy^{-1}m^{-2}. (Kürschner et al. 2011, 20)
Total Brettenzone: 1200 $^{MWh}/_{ha*y}$ * 342.5 ha = 411 GWh/y (Van den Dobbelsteen 2013)

WIND

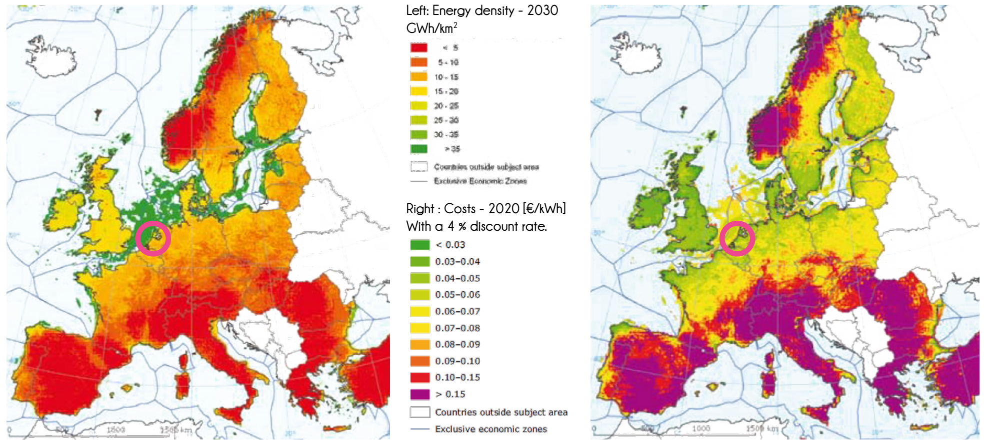


Fig. 2.2.7 Wind energy density in GWh/km² (left) and costs in €/kWh (right)
Energy density is a measure for the effectiveness of a wind turbine.
Images taken from: EEA (2009, 26,45)

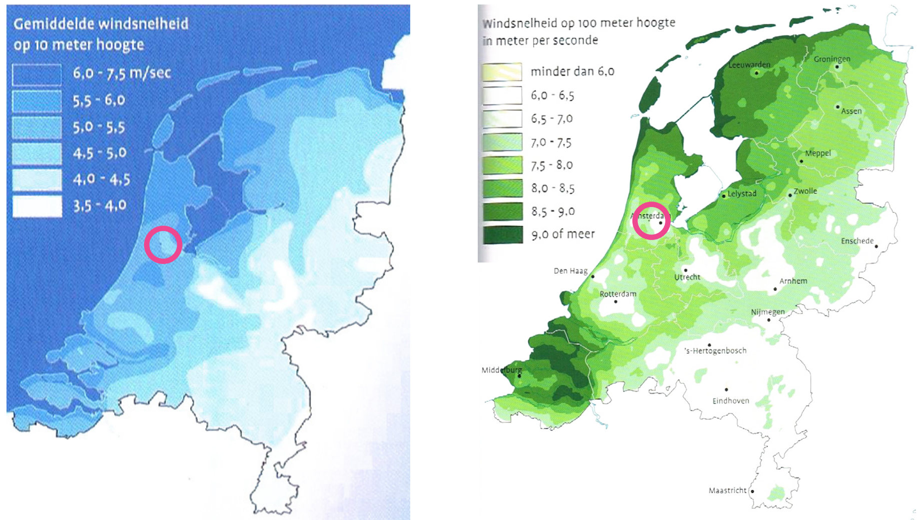


Fig. 2.2.8 Average wind speed at 10 m (left) and at 100 m (right) altitude.
Images taken from: De Bosatlas van de energie (2012, 67, 125)

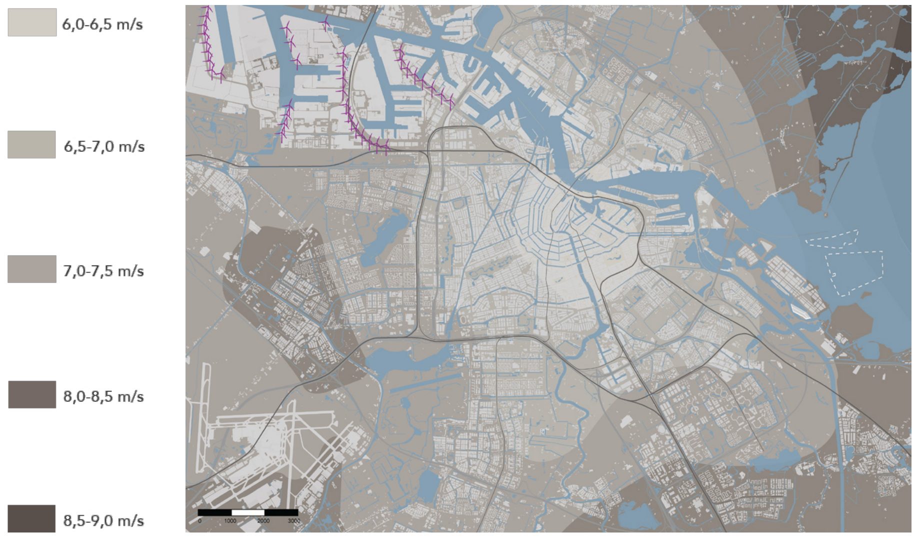


Fig. 2.2.9 Average wind speed over Amsterdam at 100 m altitude.
N.B.: Accurate data of the wind speed at 10 or 30 m does not exist.
Image taken from: Kürschner et al. (2011, 21)

WATER

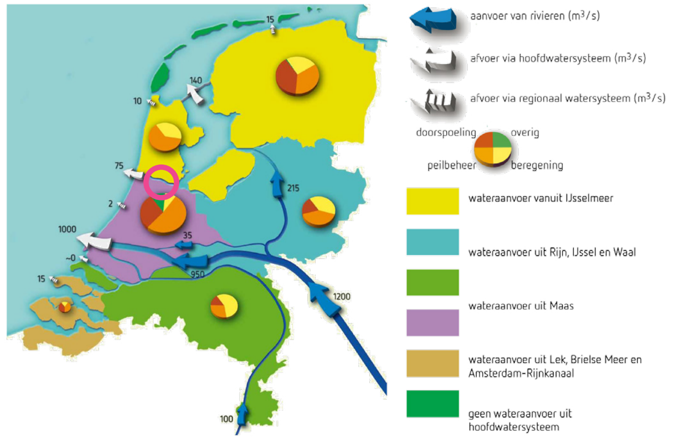


Fig. 2.2.10 Fresh water current at a supply through the Rhine of 1200 m^3.
Flow through Binnen-IJ: Av.: 95 m^3/s , Min: 0 m^3/s, Max: 250 m^3/s (Swinkels, Bijlsma, and Hommes 2010, 26; Rijkswaterstaat 1991, 7) Image taken from: Rijksoverheid (2009, 84)

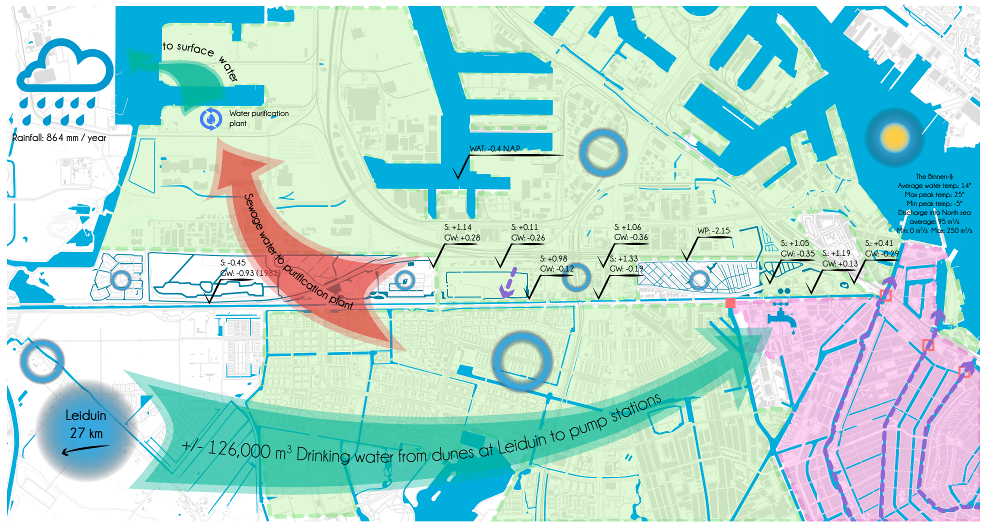


Fig. 2.2.11 Water cycle, surface water levels, ground water levels and rainfall.
Hollow circles: large fresh water consumption. Data from: (Waternet and Dienst Ruimtelijke Ordening 2010, 30, 31) (KNMI Klimaatdata en advies 2013, 1; Waternet 2013a, 2013b)

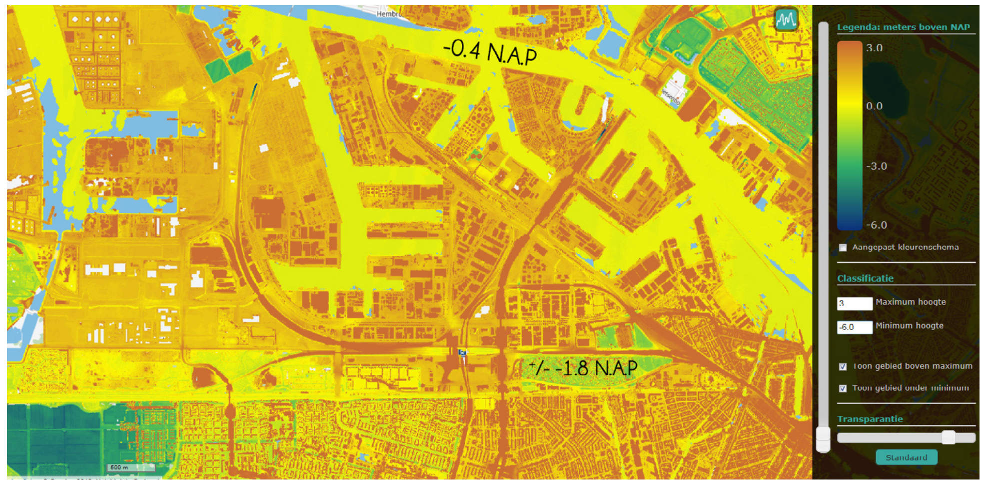


Fig. 2.2.12 Heights.
There is about 1.4 meters of difference between the Binnen-IJ surface water level and the lowest ground surface area in the Brettenzone (the 'Nut en genoegen' allotment gardens)
Image taken from: RWS and UvW (2013)

Although the Binnen-IJ has a reasonably high flow, other rivers in the southeast of the Netherlands have an even larger flow and are more suitable for harvesting energy (fig. 2.2.10). The Binnen-IJ is also less suitable because it acts as an important waterway. A greater potential can be found in the 1.4 meters of height difference between the Binnen-IJ and the lowest point in the Brettenzone (fig. 2.2.12). This height difference can be used to store energy in times of peak production making it dispatchable at moments when the demand is highest.

From this discussion I can conclude that solar energy has the largest potential for electrical energy generation within Amsterdam. For the other options the potential is greater elsewhere in the Netherlands.

2.3 THERMAL ENERGY SYSTEM: HEAT

Currently the majority of Amsterdam is heated using natural gas (fig. 2.3.1). However the city also houses an extensive district heating system. This system transfers waste heat from four co-generation plants within the city. The AEB and the co-generation plant Diemen owned by Nuon are the largest contributers to the system. Although the network covers a large area the number of buildings connected to the system is still limited. In the coming decades the network will be extended to form a closed circle and its service area will be enlarged.

Amsterdam also houses smaller local heating networks which are not shown in fig. 2.3.1. Their contribution to the city's demand however is much smaller than the city scale network. Some of these networks include heat / cold storage (HCS) systems such as those shown in fig. 2.3.3.

Only a fraction of the heat generated at AEB is produced by burning waste (fig. 2.3.2). The base load, the demand which is present throughout the year, is generated using 'renewable' sources such as biogas, solar heat and geothermic heat. The peak load is met using natural gas. (Westpoort Warmte 2011, 2) This means the heat produced at AEB only partly comes from renewable sources.

Heating networks are also used to exploit high temperature waste heat in the Westpoort area. The AEB delivers steam to heavy industry, after which it is distributed in a cascading manner to lighter industry which requires lower temperatures. (De Bosatlas van de energie 2012, 119) The AEB also delivers heat to nearby greenhouses. Much waste heat however currently goes unutilized. The Nuon plant at Hemweg 9 for instance is connected to the district heating system but does not yet supply it with heat because they are still looking for a large consumer of heat.

The Brettenzone has a good potential for harvesting heat from heat / cold storage systems. The area is suitable for systems utilizing heat / cold exchange in shallow layers (fig. 2.3.4) as well as deeper aquifers (fig. 2.3.5). The location is also reasonably suited for the extraction of geothermic heat. Other areas in Amsterdam are more suited however and it also remains questionable to what extent geothermic heat can be considered a renewable source.

For harvesting heat from the sun, especially direct sunlight is important (fig. 2.3.7 right). Amsterdam receives more direct light than areas in the South East of the Netherlands. Areas near the

EXISTING ENERGY SYSTEM

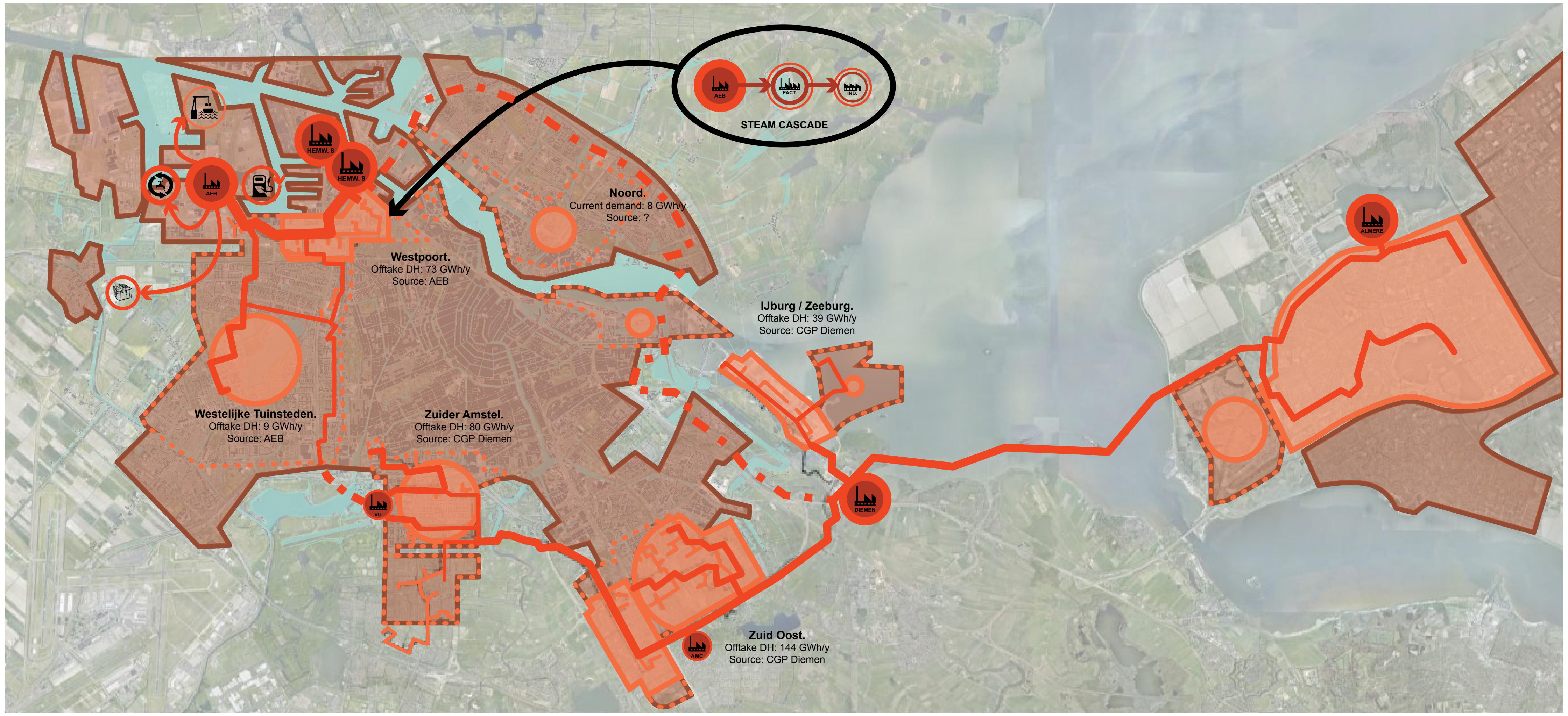
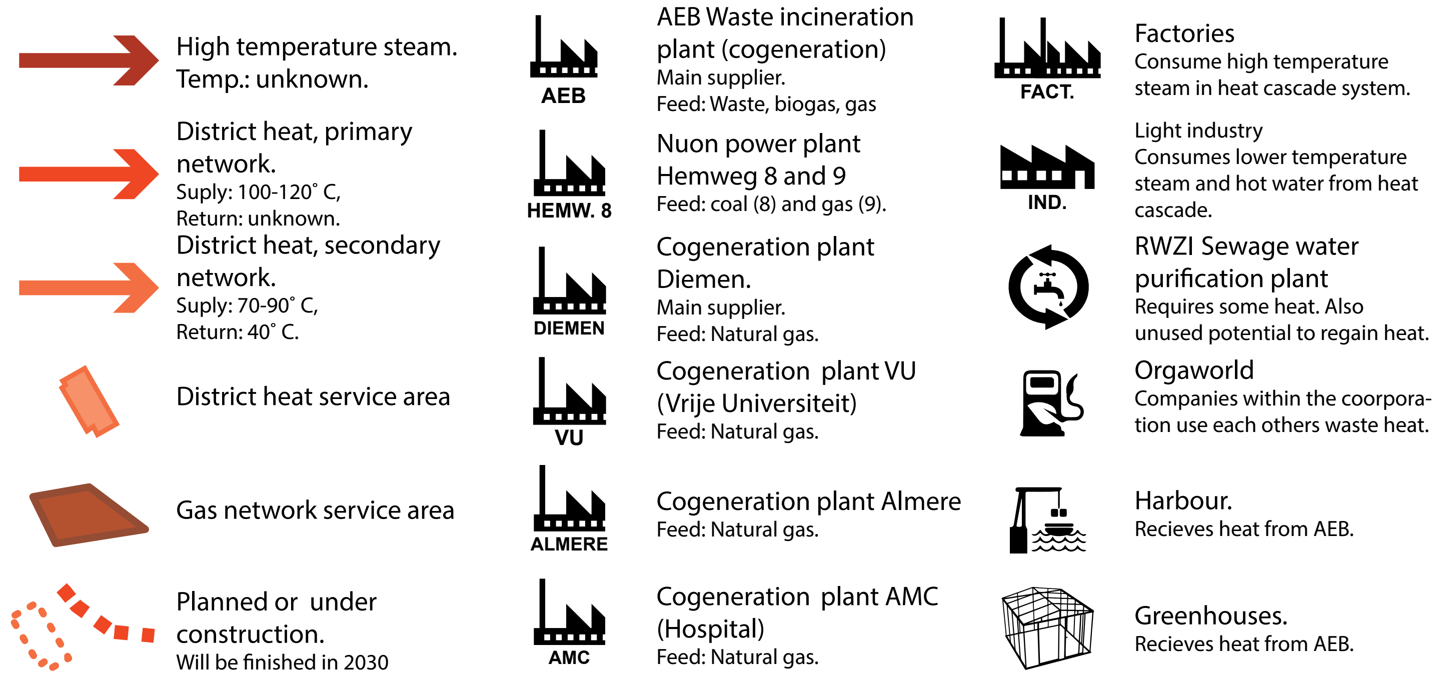


Fig. 2.3.1 The existing heat system.
N.B.: Some areas of the district heat network are currently being developed (Noord) or are not fully utilized yet (Westelijke Tuinsteden, Borneosporenburg, IJburg). Therefore accurate data of the exact service area is not available. These areas are indicated as circles. Furthermore detailed data on the secondary network is not available for all areas. Where this data was missing the secondary network is omitted.
Own illustration compiled with data from:
Groot et al. (2008, 6); De Bosatlas van de energie (2012, 119); Westpoort Warmte (2011, 1); AEB (2006, 3; 2011, 3); Steffart (2012, 12,13); Orgaworld (2013)



SYSTEM POTENTIAL:

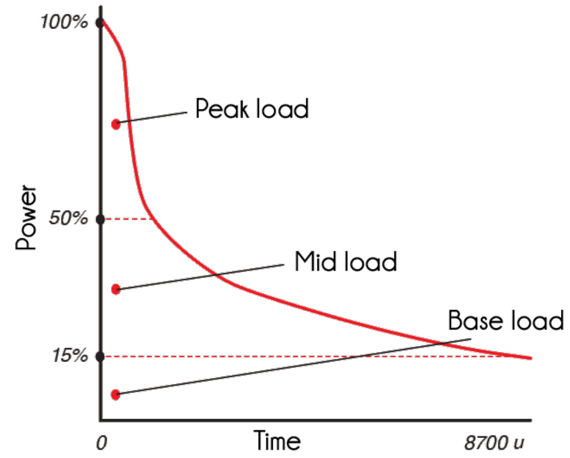


Fig. 2.3.2 Heat demand spread an average year.
The AEB meets the basic demand by using ´renewable´ sources such as biogas, solar energy and geothermic heat. The mid load is met by incinerating waste and the peak demand is met using natural gas.
Image taken from: Westpoort Warmte (2011, 2)

EARTH: STORAGE

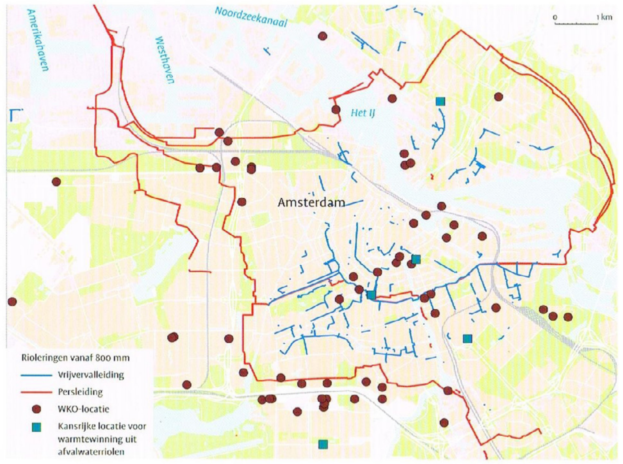


Fig. 2.3.3 Current heat / cold storage systems (brown dots).
Image taken from: De Bosatlas van de energie (2012, 70)

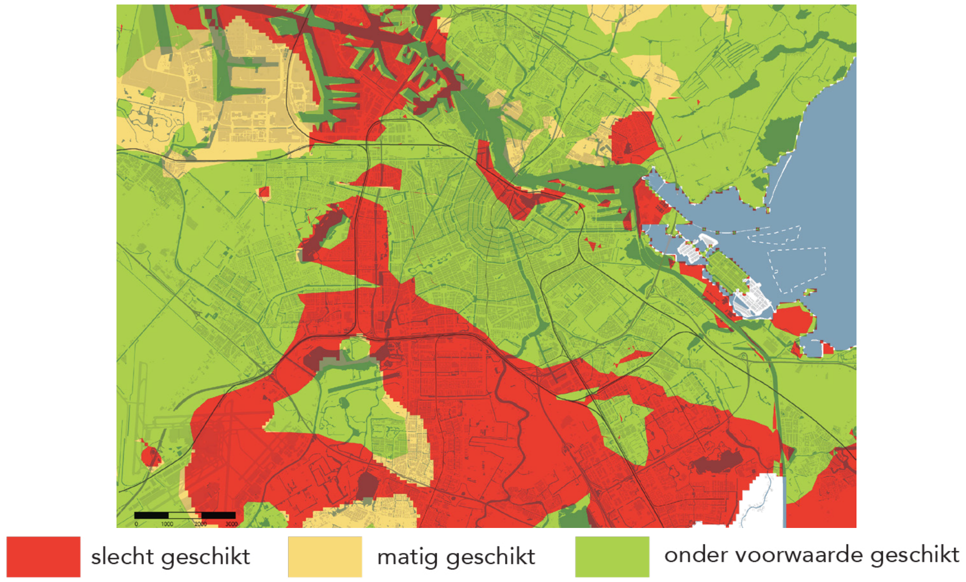


Fig. 2.3.4 Heat / cold exchange potential shallow (0-50 m deep) underground layers.
Image taken from: Kürschner et al. (2011, 25)

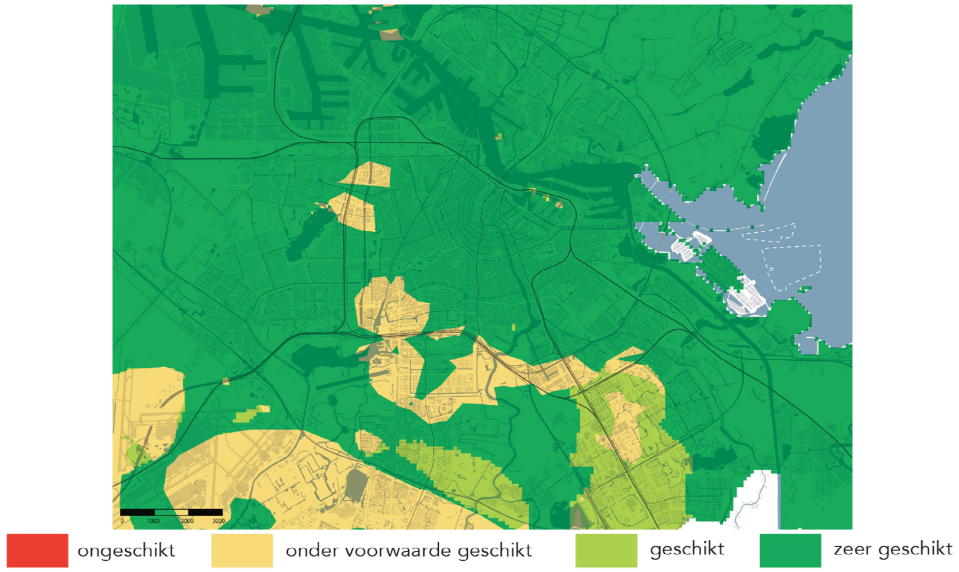


Fig. 2.3.5 Heat / cold storage potential in aquifers (50-250 m depth).
Image taken from: Kürschner et al. (2011, 26)

EARTH: EXTRACTION

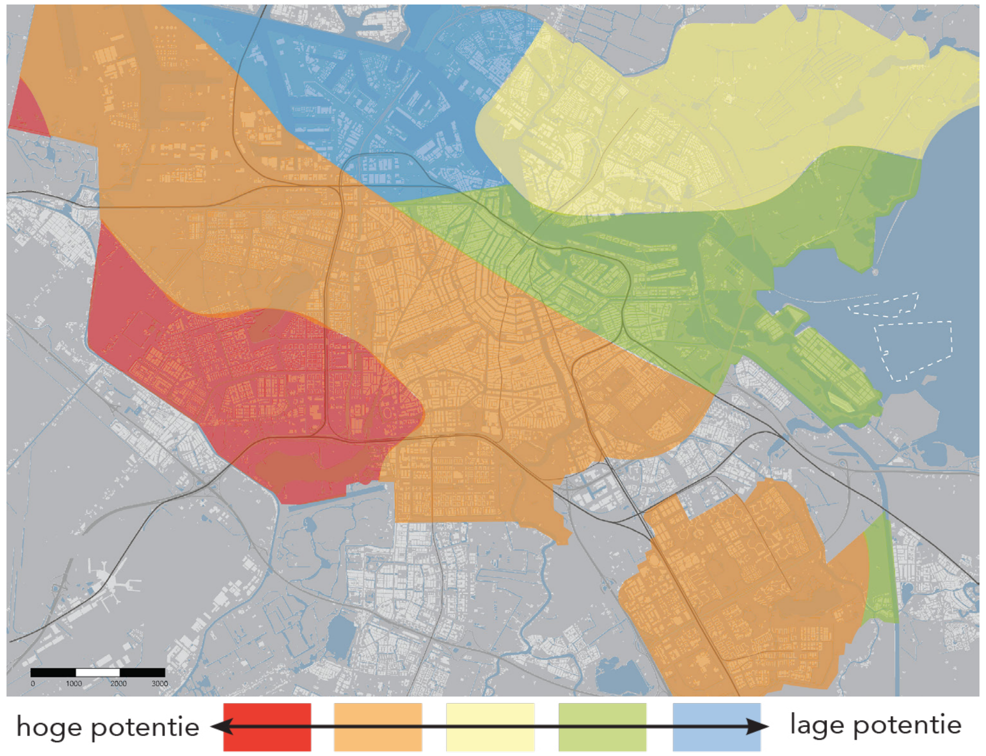


Fig. 2.3.6 Geothermic extraction potential (>2000 m depth).
Image taken from: Kürschner et al. (2011, 27)

WATER: EXTRACTION

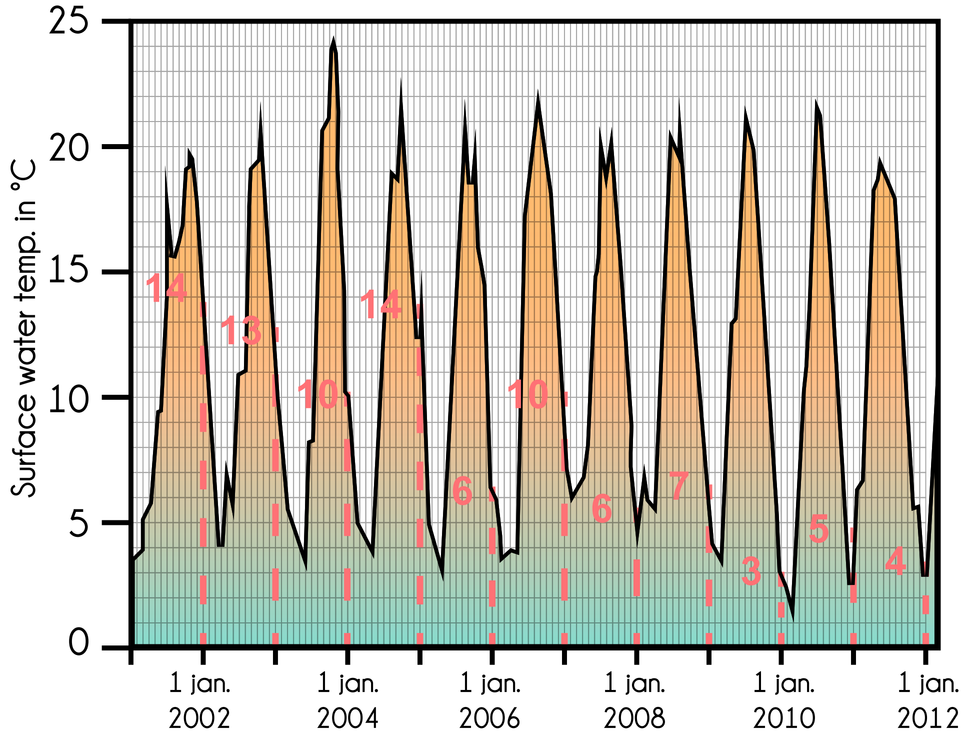


Fig. 2.3.8 Periodical fluctuations surface water temperature of het IJ.
Fluctuations are out of phase with the outside temperature. The red lines and numbers indicate the temperature in the middle of winter (1 Jan.).
Own illustration based on an image from: De Bosatlas van de energie (2012, 68)

SUN

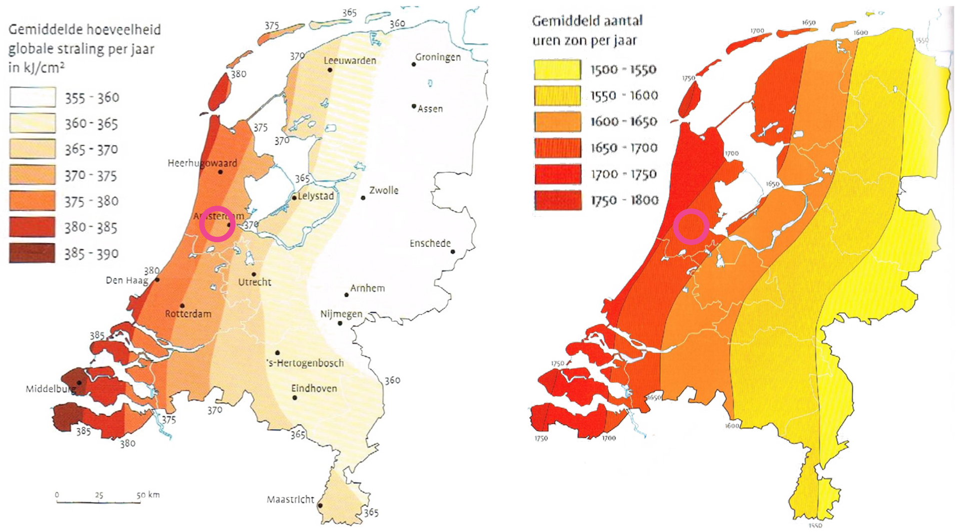


Fig. 2.3.7 Sun light on the Netherlands.
Left: Global irradiance (direct and diffuse light) Right: Sun hours (direct light)
Left: De Bosatlas van de energie (2012, 64) Right: (De Bosatlas van het klimaat 2011, 48)

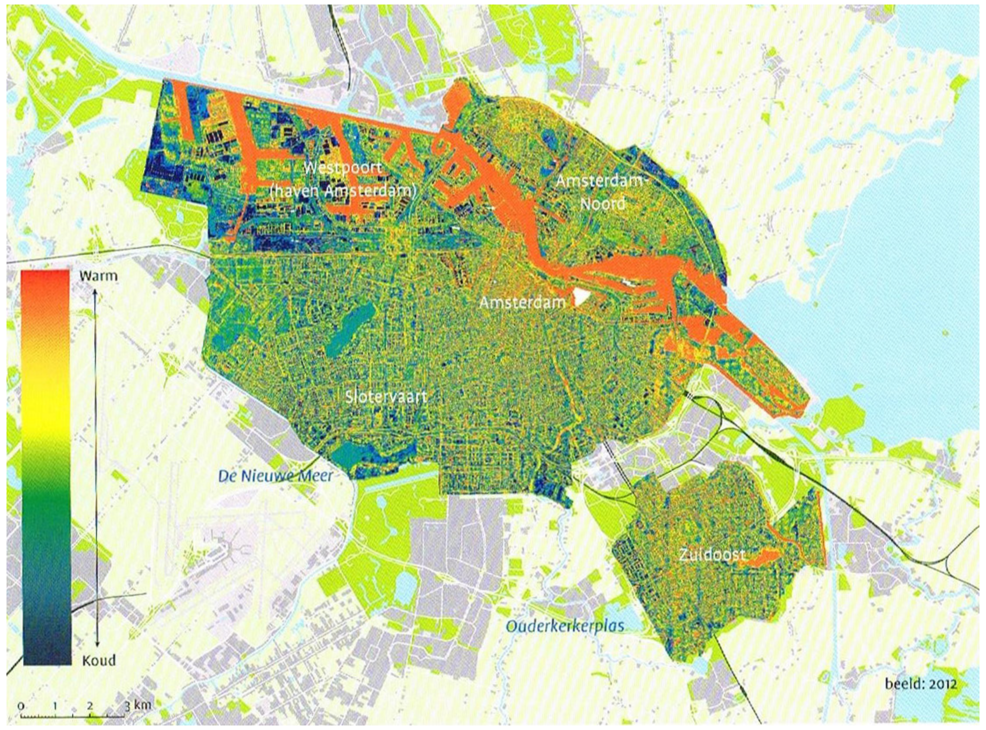


Fig. 2.3.9 Thermal image of Amsterdam.
The Binnen-IJ and het IJ collect and store heat from the sun (red). Deep lakes (blue green) remain cold throughout the year. Image taken from: De Bosatlas van de energie (2012, 68)

coast receive the most. Solar heat however has a good potential within the city especially because it needs to be produced close to where it is consumed.

It might also be possible to extract heat from the surface water of the Binnen-IJ. The periodic fluctuations in temperature of this water are out of phase with that of the outside air which means it can be used to heat or cool spaces (fig. 2.3.8). The water temperature, however, is very unpredictable making such a system less attractive. Although it may have potential in combination with another source which acts as a backup.

From this analysis it can be concluded that the system offers many possibilities such as utilizing biogas and solar sources. Furthermore these possibilities will be enlarged in the future. Also there is the opportunity of exploiting waste heat from the Nuon plants. These possibilities fit well to the local potentials: solar heat, HCS and biogas.

2.4 THERMAL ENERGY SYSTEM: COLD

Currently Amsterdam houses two local district cooling networks. One, at the Zuidas, uses water taken deep from the Nieuwe Meer (a deep lake) to cool offices. The other, to the South-East of Amsterdam, uses the same concept and takes water from de Ouderkerkerplas to cool offices and other functions in Amsterdam Zuid-Oost. The municipality has plans to expand this network by connecting the existing networks and extending them as far as the Teleport area. The large concentration of offices in the Teleport is still cooled using conventional and mostly nonrenewable sources. The city center houses a large variety of functions including offices. The offices here are also cooled using conventional, predominantly fossil energy sources (fig. 2.4.1).

As mentioned before Amsterdam already houses a number of HCS systems and the Brettenzone is also suited for such systems. (Fig. 2.4.3 and 2.4.4). Another local potential would be to supply cold using heat from solar collectors as a power source. Absorption cooling devices can run on such heat and only require a small amount of electricity to run their pumps.

As was mentioned in the previous section, surface water from the Binnen-IJ can also be used to cool. Again, however the large variation in the temperature of this water makes it an unreliable source. In combination with other techniques such as HCS it may be suitable for cooling the offices at the Teleport.

Amsterdam has more deep lakes than just the Nieuwe Meer and the Ouderkerkerplas (fig. 2.4.8). Close to the Brettenzone for instance lies the Sloterplas, an artificial lake which was dug to lay the sand foundations of the Westpoort and Teleport area. This lake is deep enough to use as a source of cold. Another possible source would be a deep part of the Binnen-IJ at the former NDSM wharf in Amsterdam Noord. This water lies further away. It would also require a connection across the Binnen-IJ.

In this section we have seen that in the future it is likely that the district cooling system will be extended and that the Brettenzone will be connected to this network. Using the Sloterplas and solar heat in combination with absorption cooling devices would then become attractive options to supply this network with cool water. Harvesting cold water from the Binnen-IJ and storing it using HCS systems could be another possibility.

EXISTING ENERGY SYSTEM

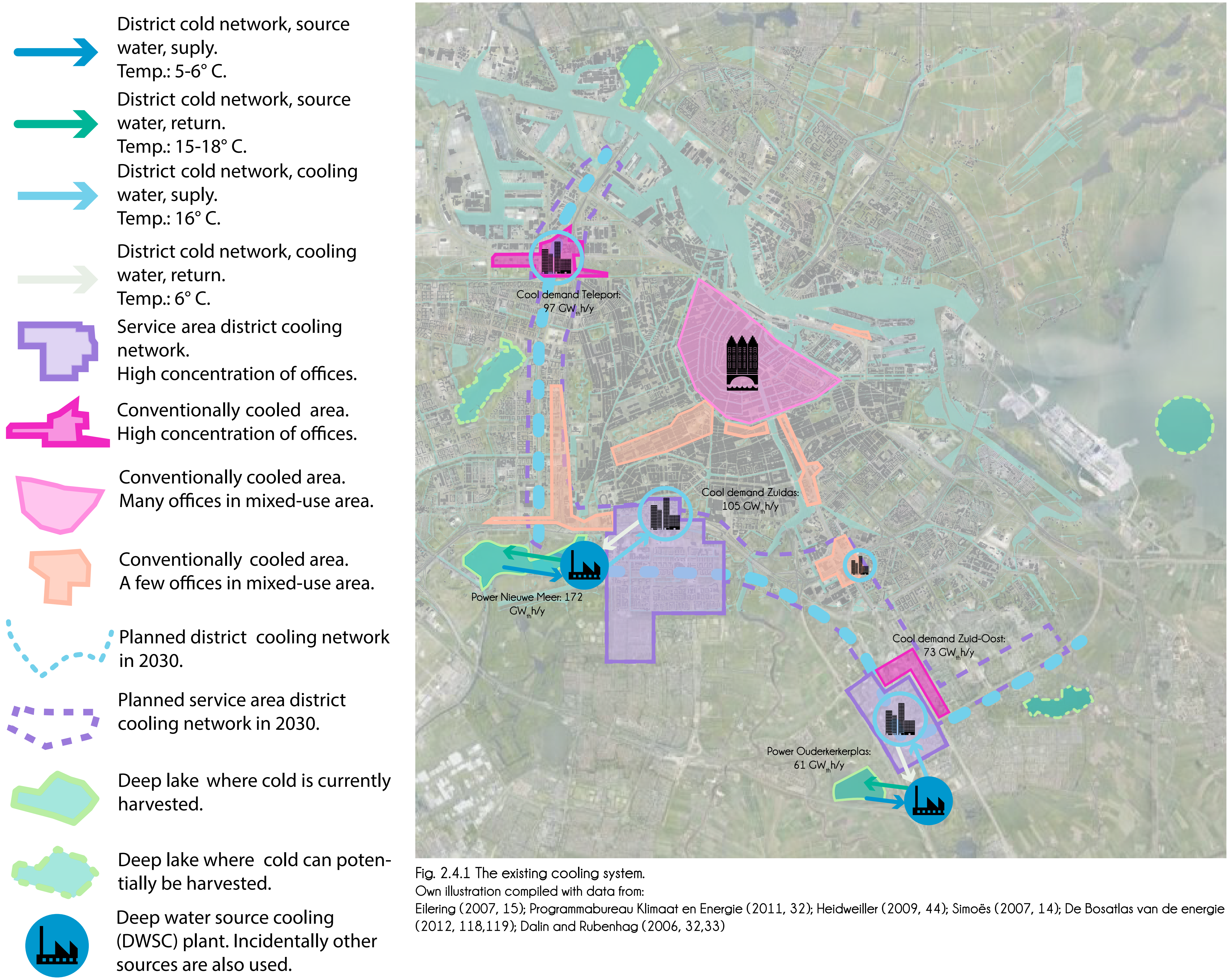


Fig. 2.4.1 The existing cooling system.
Own illustration compiled with data from:
Eilering (2007, 15); Programmabureau Klimaat en Energie (2011, 32); Heidweiller (2009, 44); Simoës (2007, 14); De Bosatlas van de energie (2012, 118,119); Dalin and Rubenhag (2006, 32,33)

EARTH: STORAGE

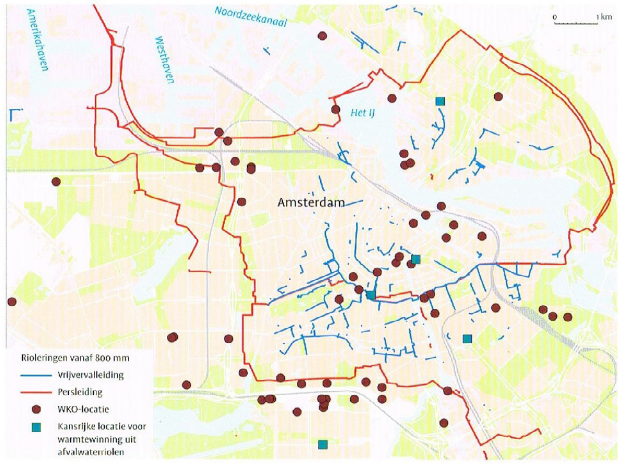


Fig. 2.4.2 Current heat / cold storage systems (brown dots).
Image taken from: De Bosatlas van de energie (2012, 70)

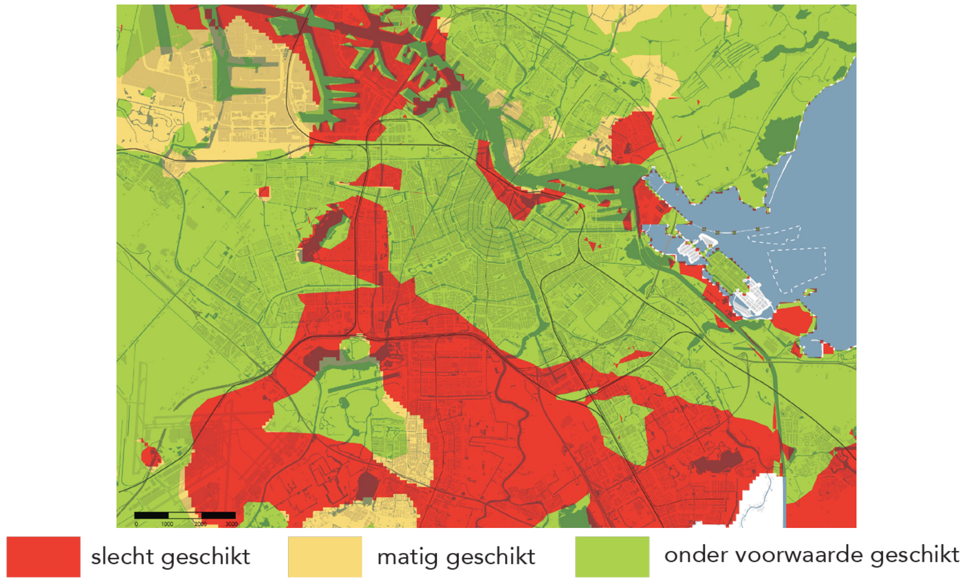


Fig. 2.4.3 Heat / cold exchange potential shallow (0-50 m deep) underground layers.
Image taken from: Kürschner et al. (2011, 25)

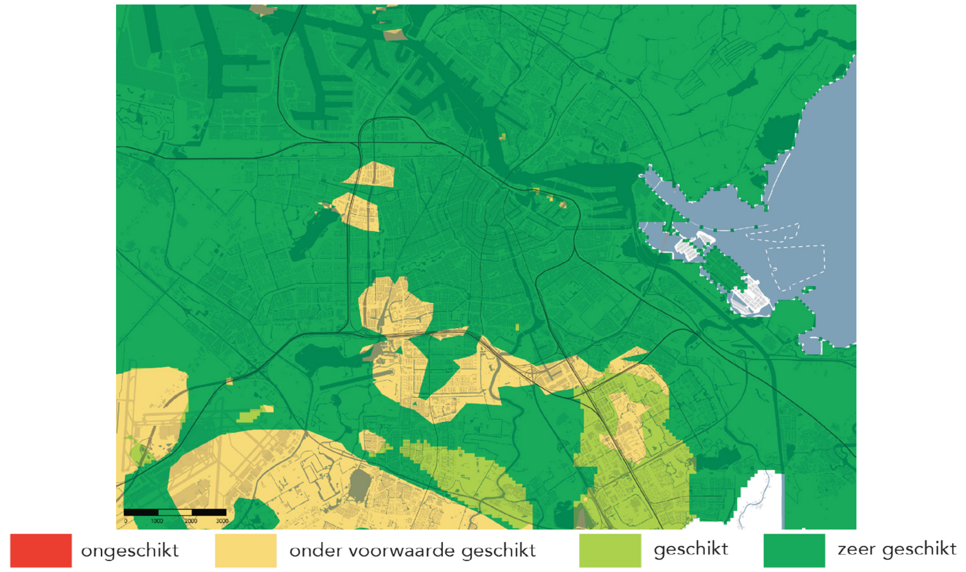


Fig. 2.4.4 Heat / cold storage potential in aquifers (50-250 m depth).
Image taken from: Kürschner et al. (2011, 26)

SUN: ABSORPTION COOLING

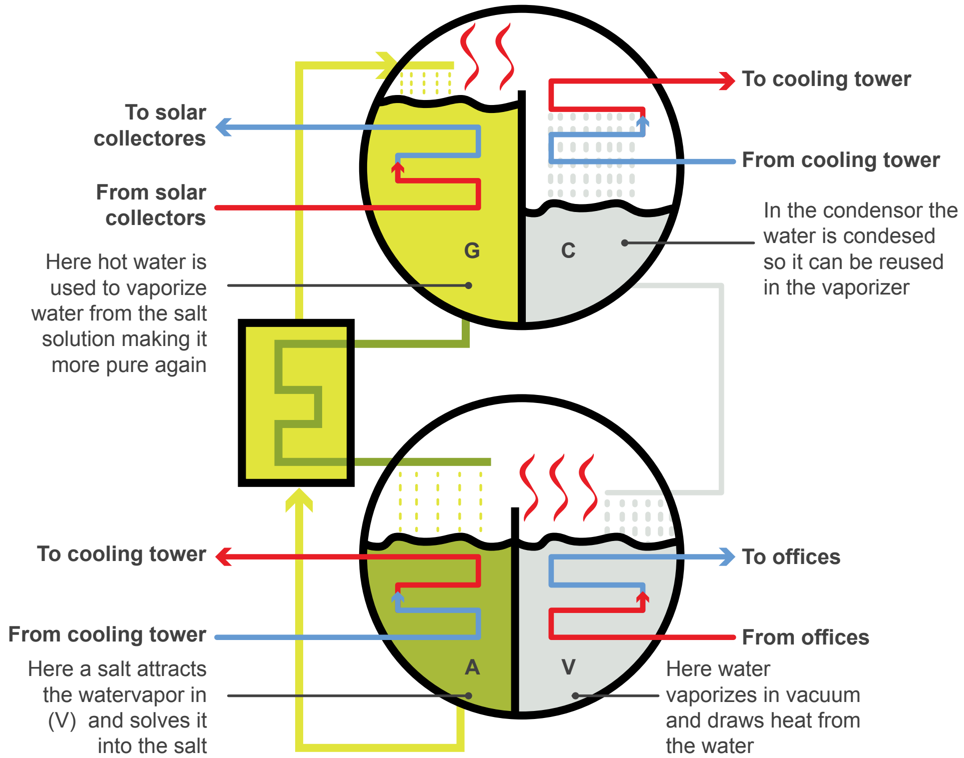


Fig. 2.4.5 An absorption cooling machine.
It cools water using heat as a power source.
Own illustration, based on an image taken from:
http://www.energieprojecten.nl/edu/ut_absorptiekoeling.html
Retrieved 27th of June 2012

Their potential for cooling in Amsterdam has also been noted by: (Programmabureau Klimaat en Energie 2011, 9, 13; Heidweiller 2009, 40,53; Simoës 2007, 21)

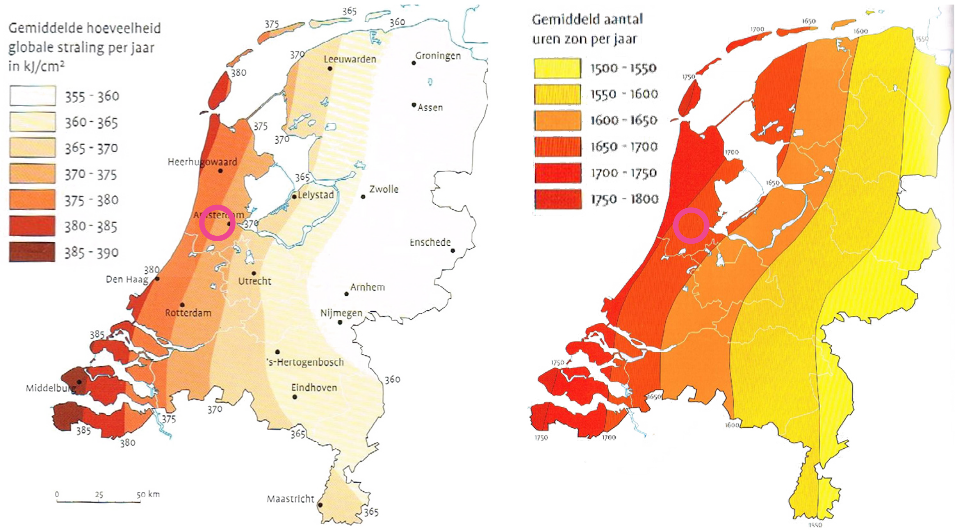


Fig. 2.4.6 Sun light on the Netherlands.
Left: Global irradiance (direct and diffuse light) Right: Sun hours (direct light, most important)
Left: De Bosatlas van de energie (2012, 64) Right: (De Bosatlas van het klimaat 2011, 48)

WATER: EXTRACTION

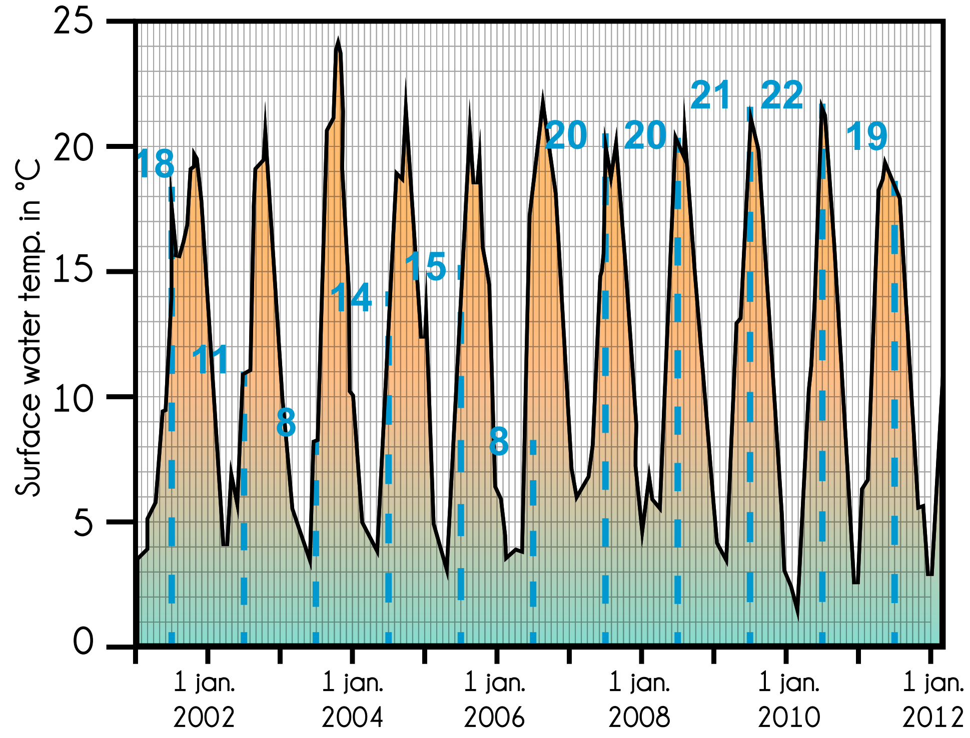


Fig. 2.4.7 Periodical fluctuations surface water temperature of het IJ.
Fluctuations are out of phase with the outside temperature. The blue lines and numbers indicate the temperature in the middle of summer (1 Jul).
Own illustration based on an image from: De Bosatlas van de energie (2012, 68)

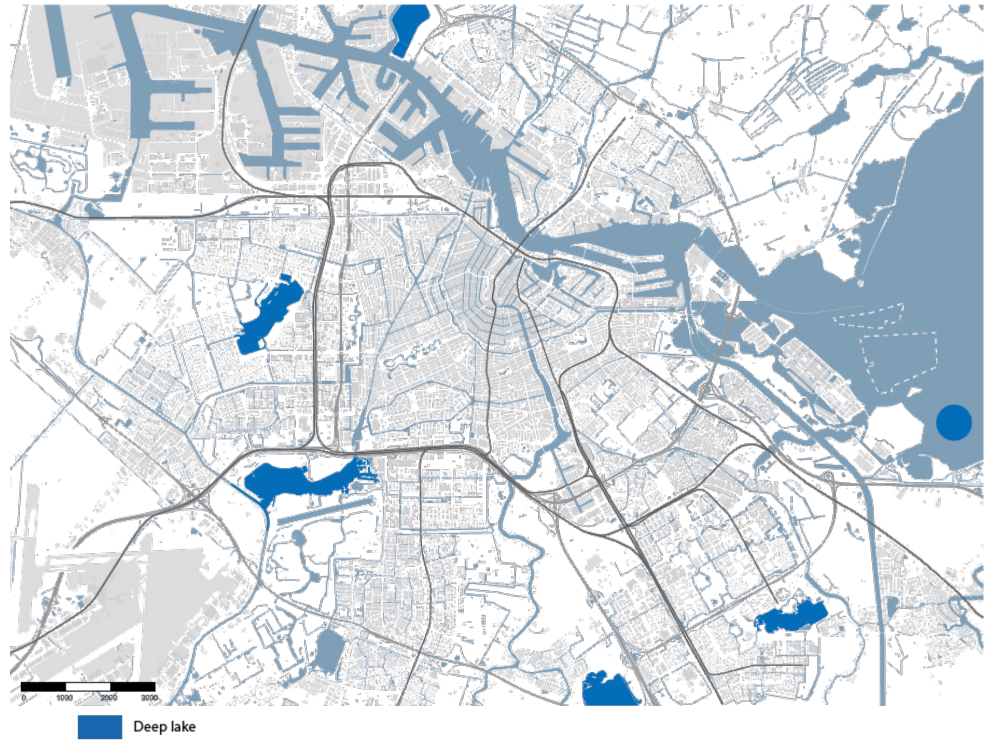


Fig. 2.4.8 Potential deep lake sources.
Lakes also show up on the thermal image displayed in fig. 2.3.9.
Image taken from: Kürschner et al. (2011, 24)

2.5 CONCLUSIONS AND PRELIMINARY ENERGYSCAPE DESIGN

In this section the possibilities and potentials mentioned in this chapter will be synthesized in a series of proposals. The most attractive proposals (green) will be presented in the form of a preliminary design for an energyscape in the Brettenzone.

PROGRAM OF POSSIBILITIES:

Hydrocarbon and associated material ecology:

1. Agricultural production using recycled nutrients from: disposed RWZI water, RWZI residues (currently only through ICL fertilizers), anaerobic digestion residue from biogas production by the collaboration of RWZI and AEB, fermentation residues from Orgaworld.
   Benefits and chances of success:
   + Phosphate is becoming increasingly scarce. This positively influences the economy of the describes endeavor.
   + Short transport distances mitigate CO_2 emissions. This is especially relevant for the organic residues from fermentation as this material is bulky.
   + The purified water at RWZI is currently disposed of. Adding another step to its life cycle offers more effective use of water resources.
   Downsides and chances of failure:
   - There are some Legislative problems with utilizing residues from sewage treatment plants in agriculture for human consumption. The legislation however is currently under scrutiny at the European Union.

2. Producing biomass for co-firing at Hemweg 8.
   Benefits and chances of success:
   + Large reduction in CO_2 emissions compared with the current situation.
   + Short transport distances mitigate CO_2 emissions. Biomass is bulky.
   + At the moment biomass is often imported from overseas. The extent to which the material can be can be considered a CO2 source is uncertain. Also the social and political consequences of this are questionable.
   Downsides and chances of failure:
   - Nutrients contained in the biomass are lost.
   - The proposal stimulates continuing the current (flawed) method of energy production and does not offer much perspective.

3. Producing biomass for producing biogas which can be utilized at AEB.
   Benefits and chances of success:
   + Fits well within the local system
   + Offers much future perspective. Can be utilized in the area in other ways (greengas, bioethanol, etc.). Also has perspective within a hydrogen economy.
   + Opportunities for a closed cycle.
   + Short transport distances mitigate CO_2 emissions. Biomass is bulky.
   Downsides and chances of failure:
   - Biogas is a low quality product. The yields per acre are low. Therefore the proposal is only feasible within a larger productive framework.

4. Using CO_2 from AEB for agricultural CO_2 fetilisation .
   Benefits and chances of success:
   + Infrastructure is there.
   + Offers future perspective. Potentially the AEB could deliver 400,000 tonnes of CO_2 per year for fertilisation which is substantial compared to their total emission of 1,000,000 tonnes. (Agema 2013)
   Downsides and chances of failure:
   - Currently only happens on an experimental scale.

Electrical energy:

1. Harvesting solar energy using PV cells.
   Benefits and chances of success:
   + Fits well in a future decentralised energy system.

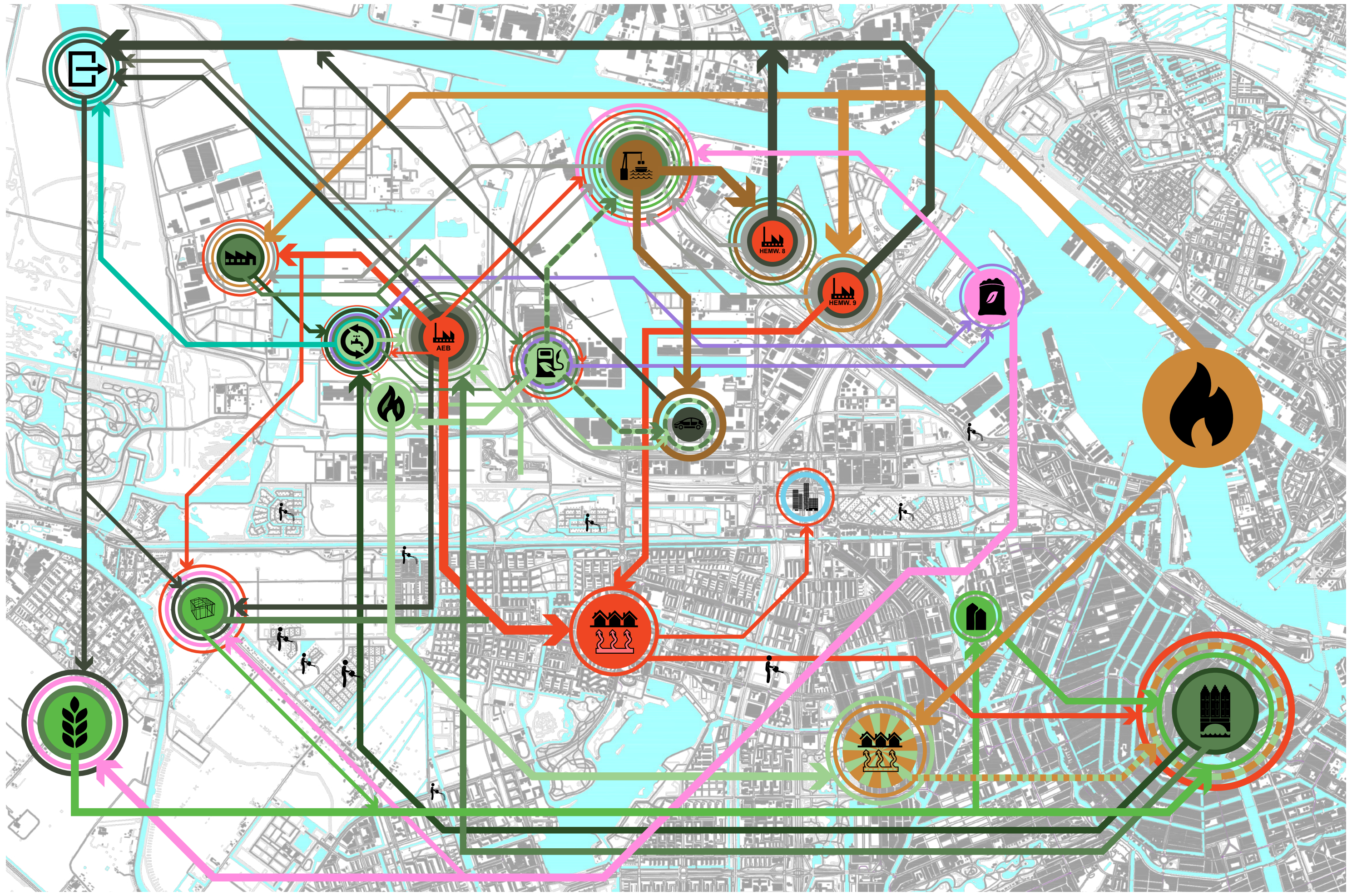
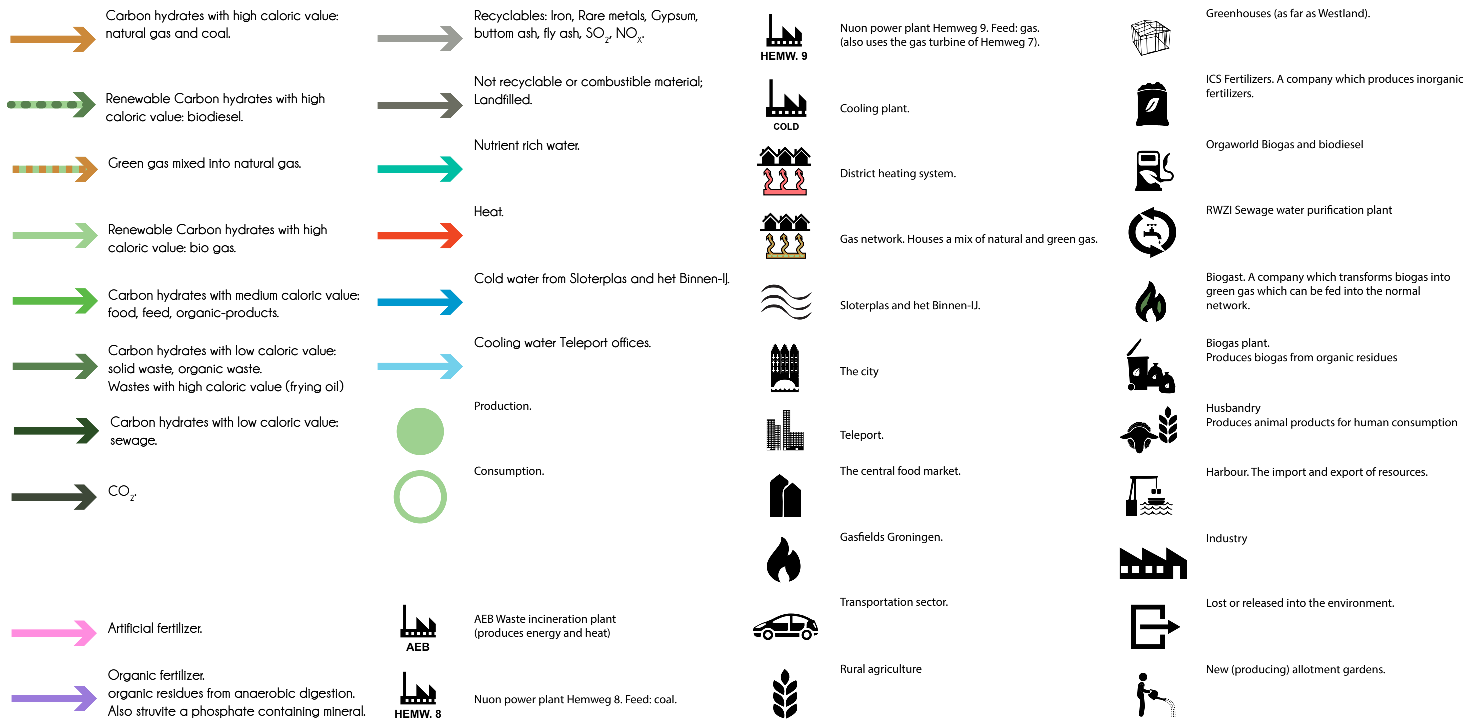


Fig. 2.5.1 Current situation.
For sources see previous sections.



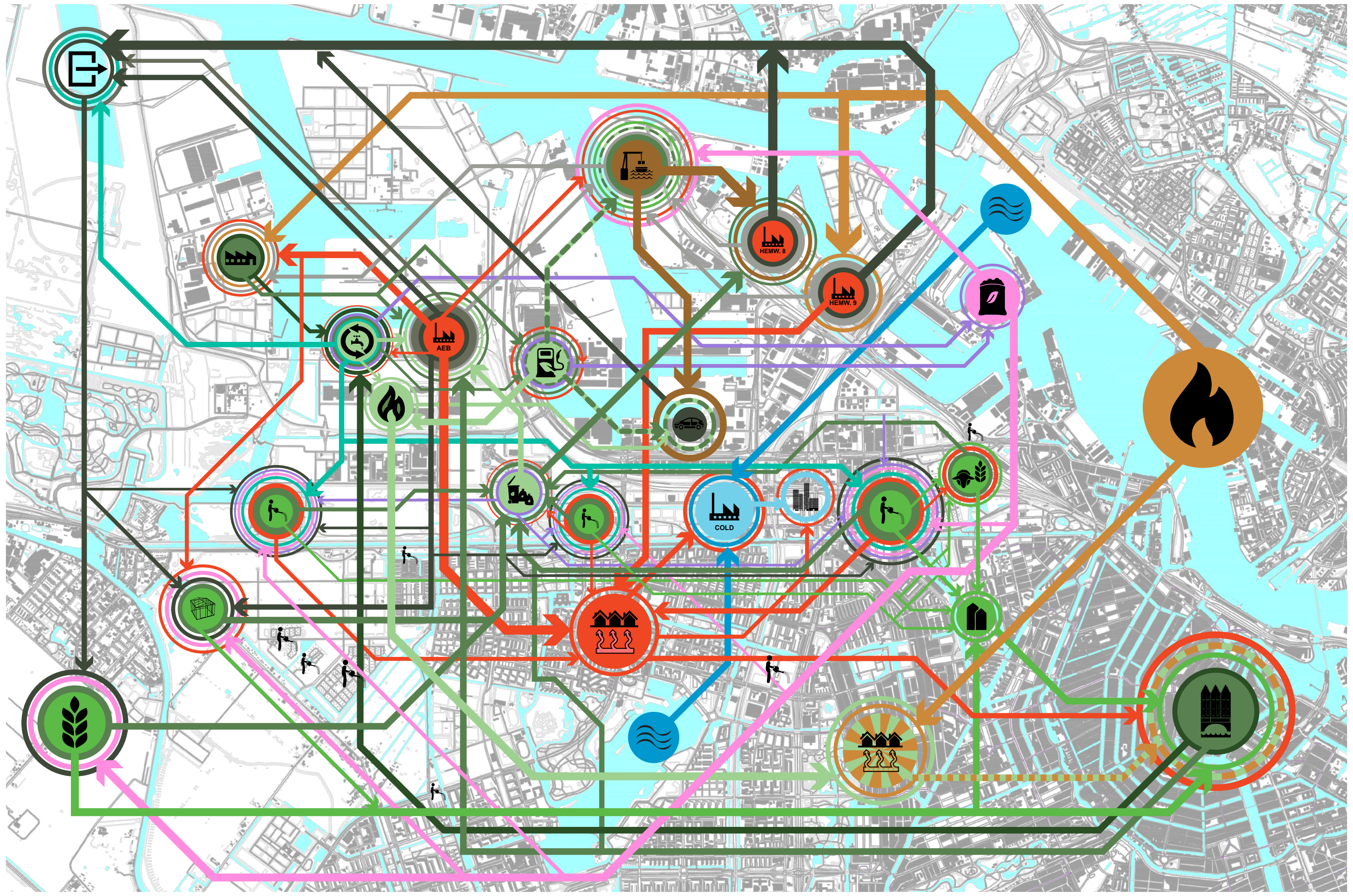


Fig. 2.5.2 Proposed energyscape design.

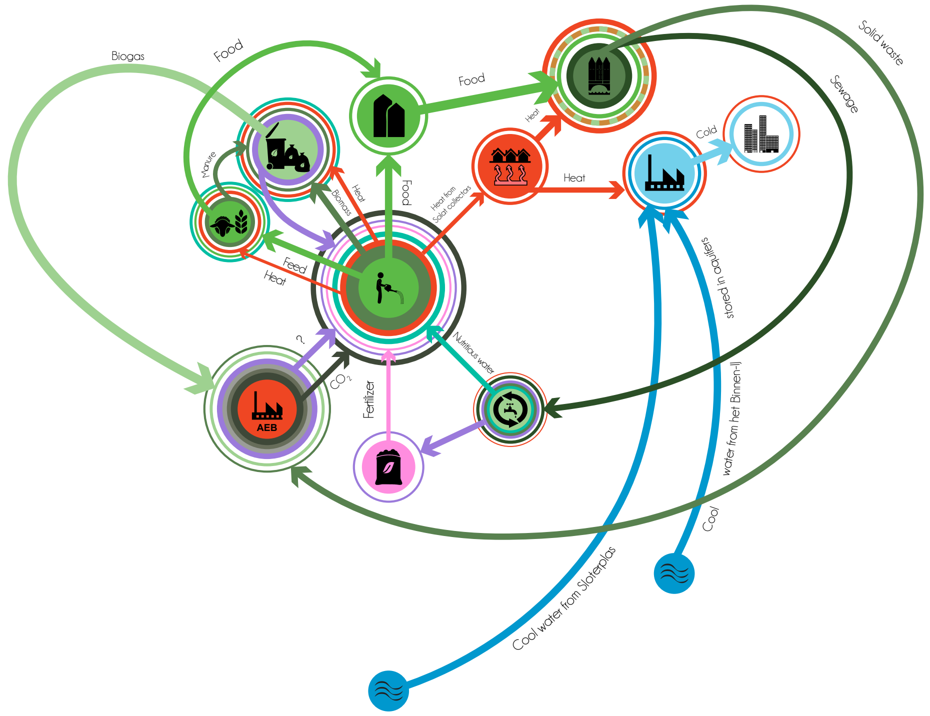


Fig. 2.5.3 Connections of the most important element: the production gardens.
Production gardens produce food, biomass and heat. Nutrients are recycled internally. The nutrients within the food are consumed in the city and are brought back to the production gardens via the RWZI and AEB. Also CO_2 from combustion at AEB is returned to the gardens.

+ Easily integrated with other functions. Offers a good potential to effectively use our space.

Downsides and chances of failure:

- Most other locations in the Netherlands are just as suitable.

Thermal energy, heat:

1. Feeding heat to the district heat system.

Benefits and chances of success:

+ Close to its consumption
+ The infrastructure is there.
+ Fits well in the probable future perspective.

2. Harvesting heat using solar collectors and storage in aquifers.

Benefits and chances of success:

+ Close to its consumption
+ Easily integrated with other functions. Offers a good potential to effectively use our space.

Downsides and chances of failure:

- Requires a large concentration of collectors. Not easily spread over a large area.
- Mainly harvests direct sunlight. This is not always available in the Netherlands.

Thermal energy, cold:

1. Feeding cold to a district cold system.

Benefits and chances of success:

+ Close to its consumption
+ Fits well in the probable future perspective.

Downsides and chances of failure:

- Expensive.

2. Harvesting cold from Sloterplas.

Benefits and chances of success:

+ Offers potential for a large reduction in CO_2 emissions.
+ Fits well in the probable future perspective.

Downsides and chances of failure:

- Expensive.
- Large transmission losses.

3. Harvesting cold from Binnen-IJ and storage in aquifers

Benefits and chances of success:

+ Offers potential for a large reduction in CO_2 emissions.
+ Fits well in the probable future perspective.

Downsides and chances of failure:

- Expensive.
- Large transmission losses.
- Large annual fluctuations; uncertain system.

4. Harvesting cold from absorption cooling devices (heat).

Benefits and chances of success:

+ Requires no new infrastructure and could be applied in a very short time.

Downsides and chances of failure:

- Requires a lot of electrical energy.

These possibilities (green) where translated into the preliminary energyscape design shown in fig. 2.5.2. The elements which are added are a cooling plant which cools offices in the Teleport area and a series of production gardens producing food, biomass, and possibly heat and electricity from solar sources. The cooling plant produces cold water using the sloterplas, water from the Binnen-IJ, aquifers and heat from the district heat network. Which precise option or combination is most feasible is a topic for further research. The production gardens produce food for the city as well as feed for husbandry. Also the gardens produce biomass which can be co-fermented with manure from the husbandry farm to produce biogas. In this process the contained nutrients can be recovered. The produced biogas can be upgraded at the AEB and used to produce thermal and electric energy. CO_2 from upgrading and combustion is then transported back to the gardens where it is used to fertilize plants increasing their growth. Nutrients contained in the food end up either as sewage or solid waste at the RWZI and AEB. Currently the RWZI nutrients could be regained via ICL-fertilizers. Those at the AEB could be regained via the residue of anaerobic digestion if the organic waste is separated. There are however a multitude of other senarios possible. There are currently experiments with growing maggots on organic waste at the AEB. (Agema 2013) These could offer a protein rich source of nutrients for the livestock at the production gardens and also offer a door through which nutrients could be let into the cycle. By also using processed water from the RWZI in the production gardens or in the biogas production process nutrients can be harvested which would otherwise have been wasted. The structures in the new energy scape could be clad in PV cells or equipped with heat harvesting devices to achieve an even larger energy yield.

Each of the before mentioned topics is a subject for further research. In this paper however only the production gardens will be treated further. The following chapter will research the feasibility of such a biofarm and try to provide appropriate tools for its design. The proposed farm would produce food, feed, fuel, and fertilizer and is therefore titled a 4F farm.

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3. BIOENERGY: FOOD, FEED, FUEL AND FERTILIZER

In chapter two of this paper we have seen that the production of biomass for conversion into biogas has a good potential as a source of renewable energy in the Brettenzone area. Also the 4F farm was presented: an agricultural enterprise which produces food, feed and fuel whilst maintaining a closed cycle of nutrients. In this chapter the requirements for such a 4F farm will be explored with an emphasis on utilizing biomass for biogas production. The goal of this chapter is to act as a reference which can be used whilst designing the 4F farm. The first section discusses some of the economic, environmental and societal aspects of bioenergy. In the second section the anaerobic process by which organic material is fermented into methane will be explained. The different sources of biomass will be discussed in the third section. The term biomass can refer to a great variety of organic materials including: agricultural wastes, sewage purification residues, manures, slaughterhouse wastes and energy crops to name but a few. This paper focuses on agricultural biomass, that is: from crops, plant wastes and manure. Crops which are especially cultivated for biomass are often referred to as *'dedicated'* biomass whereas biomass which results as a by-product is called *'dependent'* biomass. (Prag 2013, 52) This section will conclude by discussing the sources of biomass which are most suited for the proposed 4F farm. The fourth section concerns technologies for the anaerobic production of biogas from biomass. Biogas can also obtained from biomass via the process of gasification. This process however will not be treated in this paper as this technology is less suited for integration within an agricultural system. Also if gasification where to be used to produce methane the nutrients contained within the biomass would be lost. The fourth section also presents two systems which where designed for the 4F farm as well as the required equipment. The fifth and final section will conclude with a set of recommendations. It will explain how the design of the 4F farm could be optimised and gives suggestions for further research.

3.1 Economic, societal and environmental aspects of bioenergy

Biomass is already a substantial source of energy. In rich, developed countries it accounts for about three per cent of the total energy production. In poorer, developing economies it determines thirty eight per cent. (Deublein and Steinhauser 2008, 35) In the Netherlands about sixty per cent of all renewable electricity comes from biomass or one of its end-products. The most dominant sources of biomass are organic waste streams such as sewage and agricultural waste. It is expected that biomass will become an important source of energy in the future as can be seen from table 3.1.1 which shows a prediction of Europe's renewable energy sources until 2040. Different scenarios have been made by other authors. All these predictions include biomass as an important source of energy with an emphasis on thermal energy. (Deublein and Steinhauser 2008, 7,8)

Utilizing dependent or dedicated biomass has a good economic potential for the agricultural sector. It can be an additional source of income for farmers whose profession in Europe is under great stress. In this way biomass can also contribute to sustaining the traditional agricultural landscape. (Prag 2013, 55; Deublein and Steinhauser 2008, 83)

The biggest environmental potential of biomass is that theoretically it can be a CO2 neutral source of energy. During their life plants absorb CO2 and water to produce oxygen and carbohydrates, that is: biomass. In the production of fuel from biomass as well as its combustion the consumed energy is released in the form of heat when the carbohydrates react with oxygen to form CO2 again. There is no net gain or decrease in the amount of CO2 at the end of this cycle. (Gupta and Demirbas 2010, 42; Deublein and Steinhauser 2008, 13, 14, 89, 90) The combustion of some types of biomass can even help to further reduce to amount of greenhouse gasses. When organic material decomposes naturally it not only forms CO2 but also methane, a gas which has a greenhouse effect even greater than CO2. Combustion of organic material which would otherwise have been allowed to decompose, like that from forestry or agricultural manure for instance, can therefore contribute even more to diminishing global warming as combustion only produces CO2. (Prag 2013, 54, 77; Gupta and Demirbas 2010, 20,33,34; Deublein and Steinhauser 2008, 84,85)

Although the theoretical cycle of combusting biomass or fuels is carbon neutral, the same cannot be said of all its applications. Transporting and processing the biomass into a combustible form requires energy which often still originates from fossil fuels. (Gupta and Demirbas 2010) Some authors therefore state that very strictly speaking the term *'carbon lean'* might be more appropriate. (Prag 2013, 54) In some cases bio-fuel production can even cause a net addition of CO2 to the environment. Natural land cover such as forests acts as a buffer for CO2 because they store carbon. When these areas are replaced with energy crops which store much less CO2 this causes a *'carbon debt'*. (Giampietro and Mayumi 2009, 5 who refer to Fargione et al. 2008, 1235) These authors argue that the conversion of natural land cover into biofuel plantations has already had a negative effect on greenhouse gas emission in the US, Brazil and Southeast Asia. Furthermore conversion of land cover can also have negative effects on the biodiversity. (Giampietro and Mayumi 2009, 5; Danielsen et al. 2009; Gupta and Demirbas 2010, 186)

Production of dedicated crops can also have negative effects on world food prices. This happens when biofuel plantation starts to compete for the same land as agriculture but also for the same irrigation water and fertilizers. (Gupta and Demirbas 2010, 184-186) Also many biofuel crops, such as corn, are also sources of food. If the demand for corn as a source of biofuel rises the price for edible corn rises as well. This could also be seen during the 2007 world food crisis. During this crisis the

Renewable energy resource	2001	2010	2020	2030	2040
Biomass	1,080	1,313	1,791	2,483	3,271
Large hydro	22.7	266	309	341	358
Geothermal	43.2	86	186	333	493
Small hydro	9.5	19	49	106	189
Wind	4.7	44	266	542	688
Solar thermal	4.1	15	66	244	480
Photovoltaic	0.2	2	24	221	784
Solar thermal electricity	0.1	0.4	3	16	68
Marine (tidal/wave/ocean)	0.05	0.1	0.4	3	20
Total renewable energy sources	1,365.5	1,745.5	2,694.4	4,289	6,351
Total nonrenewable energy sources	8,672.5	8,803.5	8,730.6	8,063	6,959
Total energy sources	10,038	10,549	11,425	12,352	13,310
Renewable energy sources contribution (%)	13.6	16.6	23.6	34.7	47.7

Table 3.1.1 Global renewable energy scenarios until 2040.
Values in million ton oil equivalent (Mtoe). Table taken from: (Gupta and Demirbas 2010, 42 who refer to: EREC 2006)

	Natural gas (Netherlands, Groningen)	Biogas in general	Agricultural biogas
Constituants: Methane (CH_4) Carbon dioxide (CO_2) Other gases:	 *83.4 %* *1.3 %* *N_2: 10.6 %* *C_3H_8 0.7 %* *Traces of other gases*	 *55 - 70 %* *30 - 45 %* *Traces of other gases* *Small amounts of sulfides*	 *45 - 75 %* *25 - 55 %* Traces of other gases: *CO < 0.2 %,* *O2 : 0.01 - 5.00 %* *H2 : 0.5 %* *Small amounts of sulfides*
Energy content: Net calorific value:	 *9.27 kWh/Nm³*	*6.0 - 6.5 kWh/m³* *4.5 - 7.5 kWh/Nm³*	 *5.0 - 7.0 kWh/Nm³*
Data taken from: Deublein and Steinhauser (2008, 50-51) Percentages are by volume.			

Table. 3.2.1 Features and composition of biogas.

In general:

$$C_cH_hO_oN_nS_s + yH_2O \longrightarrow xCH_4 + nNH_3 + sH_2S + (c\text{-}x)CO_2$$

Where:

$$x = {}^{1}/_{8} \cdot (4c + h - 20 - 3n - 2s)$$
$$y = {}^{1}/_{8} \cdot (4c + h - 20 + 3n + 2s)$$

Example:

Carbohydrates: $C_6H_{12}O_6N_nS_s \longrightarrow 3CH_4 + 3CO_2$

Fats: $2C_{12}H_{24}O_6 + 6H_2O \longrightarrow 15CH_4 + 9CO_2$

Carbohydrates: $2C_{13}H_{25}O_7N_3S + 12H_2O \longrightarrow 13CH_4 + 6NH_3 + 2H_2S + 13CO_2$

Equations 3.2.2 Formation of methane from biomass. Features and composition of biogas.
Equations taken from: Deublein and Steinhauser (2008, 89) , printing error corrected and presentation altered by author.

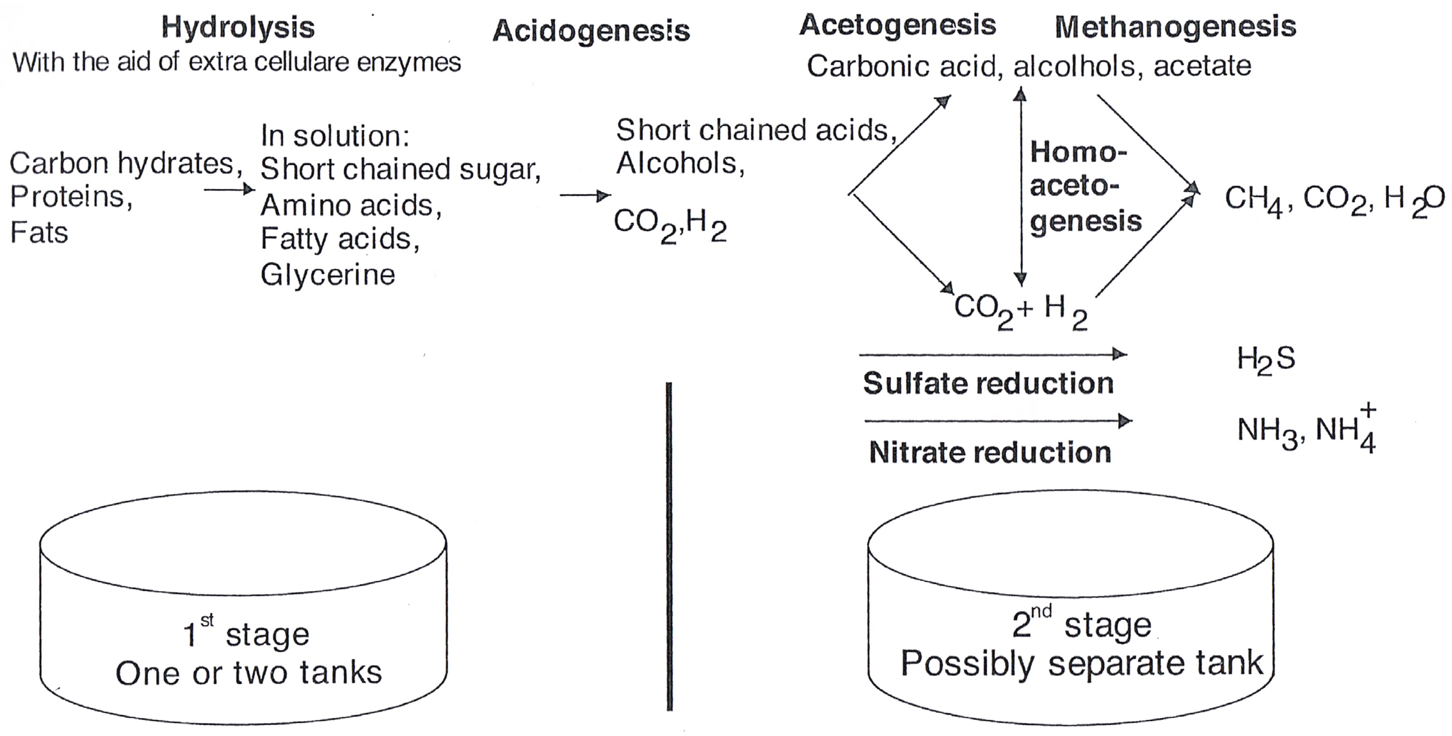


Fig. 3.2.3 Biochemical process of anaerobic digestion.
Image taken from: Deublein and Steinhauser (2008, 94)

Parameter	*Hydrolysis/acidogenesis*	*Methane formation*
Temperature	25–35 °C	Mesophilic: 32–42 °C Thermophilic: 50–58 °C
pH value	5.2–6.3	6.7–7.5
C:N ratio	10–45	20–30
DM content	<40% DM	<30% DM
Redox potential	+400 to –300 mV	<–250 mV
Required C:N:P:S ratio	500 : 15 : 5 : 3	600 : 15 : 5 : 3
Trace elements	No special requirements	Essential: Ni, Co, Mo, Se

Table 3.2.4 Parameters influencing methane formation.
Table taken from: Deublein and Steinhauser (2008, 89).

increasing demand for agro-biofuels combined with droughts and rising oil prices caused peaks in world food prices which led to famine in poorer undeveloped countries. (Giampietro and Mayumi 2009, 3)

Although biomass is not always a CO2 neutral source of energy, this does not mean we must dismiss it altogether. We do however have to evaluate the energy balance when we use it. A suitable tool for this is the LCA which was mentioned in chapter 1. Such an analysis quantifies all inputs and outputs starting from biomass growth to its final use as a biofuel. (Gupta and Demirbas 2010, 188) Fuel energy ratio (FER) and greenhouse gas displacement (GHG) are two measurements which are often used to evaluate biofuel-crops and other sources of biomass. FER is defined as the amount of biofuel energy produced divided by the amount of fossil energy required to manufacture the biofuel. A FER of larger than unity means there is a net energy gain. A FER of smaller than unity represents a net energy loss. GHG represents the net change in greenhouse gas emission when substituting a fossil fuel for specific biofuel. GHG is expressed in percentages where a negative value represents a decrease in greenhouse gas emissions.(Gupta and Demirbas 2010, 189) There are many instances where LCA's have shown that using biomass and even dedicated energy crops had a positive effect on greenhouse gas emissions. (Gupta and Demirbas 2010, 189,190)

From this analysis we can furthermore conclude that when producing dedicated biomass we should refrain from using food crops, choose a crop which requires little water, fertilizer and pesticide, and preferably use low-value marginal land. (Gupta and Demirbas 2010, 61) Also if producing dedicated biomass involves a drastic land-use conversion, the amount CO2 storage of the existing land and the existing ecosystem have to be taken into account. Finally it should be noted that CO2 balance of bioenergy can also be improved by only using renewable sources of energy when processing the biomass into a combustible form. (Gupta and Demirbas 2010, 175)

Although currently biomass is mainly used as a source of biogas, bioethanol and biomethanol it also has the potential to play a role in a future energy system based on hydrogen. Biofuels can be burned to power a hydrogen plant generating hydrogen from water. (Gupta and Demirbas 2010, 20,21) Another possibility would be to generate hydrogen from methane chemically in a more direct manner. (Blok et al. 1997, 161,162) Furthermore hydrogen can also be produced biologically by algae, bacteria and other microorganisms. (Wall, Harwood, and Demain 2008) Another promising perspective for bioenergy can be found in genetic manipulation of crops. In this manner both the solar energy harvesting efficiency and the total biomass yield can be increased. Many difficulties of biomass production might be overcome if the plant itself could be turned into small biofuel factory. This possibility is currently being researched. The idea is to biologically engineer a plant which directly converts CO2, sunlight and water into a biofuel. This fuel would then be harvested by tapping the plant non-destructively like with rubber plants. (Tester 2005, 444, 445)

3.2 Biogas formation by anaerobic digestion

Biogas is a fuel which consists mainly of methane and carbon dioxide. Its composition can be found in table 3.2.1. Here it can be seen that due to its lower methane content biogas has a lower heating value than natural gas. Biogas however can be refined into greengas whith properties similar to those of natural gas. One method in which biogas can be produced is by anaerobic digestion of biomass. In this process a multitude of symbiotic microorganisms, in the absence of oxygen, transform organic materials into biogas, nutrients, and cell matter leaving a residue of salts and organic material. (Wilkie 2008, 195)

The main organic components of plants are carbohydrate, fat and protein. Equation 3.2.2 shows how these components are converted to biogas by anaerobic digestion. Although the reaction is exothermic the amount of heat which is produced is small which means that bioreactors have to be heated and well insulated. (Deublein and Steinhauser 2008, 90) From the equation it can be seen that besides methane, carbon dioxide is produced. It should be noted that it is possible to extract this carbon dioxide if the biogas is refined. Within the fermentation process four phases can be distinguished: hydrolysis, acidogenesis, acetogenesis and methanation (fig. 3.2.3). In each phase different groups of microorganisms produce a different range of (intermediate) compounds. (Deublein and Steinhauser 2008, 13, 89, 93) In the hydrolysis phase undissolved substances like proteins, cellulose and fats are broken up into water-soluble monomers, that is, smaller polymer chains. In the second and third phases, the acidogenic and acetogenic phases, intermediate organic acids are formed as well other compounds including hydrogen. The bacteria of the acetogenic use the products of the acidogenic phase without influencing the acetogenic process. These two phases can therefore take place in different vessels if desired. The acetogenic and the last, methanogenic, phase however involve bacteria which live in symbiosis with each other and the two phases are therefore closely linked. Acetogenic digestion can only take place if the concentration of hydrogen is low and digestion in this phase therefore depends on methanogenic bacteria from the last phase to process excess hydrogen. In the final, mathanogenic phase, methane is produced from hydrogen, acids and other products of the acetogenic phase.

For the anaerobic microorganisms the constancy of their living conditions is important. If the temperature or substrate are changed the digestion process can come to a halt. When this happens it can last up to three weeks before the organisms have adapted to their new conditions and start producing methane again. (Deublein and Steinhauser 2008, 100) Table 3.2.4

shows the parameters which influence the microorganism's metabolism. It also shows the required range for each parameter. Most of these requirements can be met by adjusting the concentration of the substrate, applying additives, designing the equipment and process for the particular substrate and applying more or less heat. Two aspects however are determined largely by the feed material itself: the C/N ratio and the C/N/P/S ratio. The C/N ratio is important because in substrates with a low C/N ratio (too much nitrogen) increased formation of ammonia will occur which suppresses methane production. To high a C/N (lack of nitrogen) negatively influences the microorganisms formation of protein and hence the development of their structural material, meaning the microorganisms do not grow well. (Deublein and Steinhauser 2008, 116) In the consulted literature, different optimal ranges for the C/N ratio are mentioned but all fall within the range of 16:1-35:1. (Deublein and Steinhauser 2008, 116; Nijaguna 2006, 52; FAO 1992; Fujita, Scharer, and Moo-Young 1980, 177) The C/N/P/S ratio is a measure for the amount of nutrients available for the development of biomass within the anaerobic process. During the process however not much biomass is formed and this value is less important to this paper.

In general wood-like biomass has a high C/N (sawmill waste: 511) and therefore does not degrade well. This type of biomass also contains much lignin which takes longer to break up into smaller monomers during hydrolysis. Cellulose in general takes long to break up, therefore fresh plant material often has longer retention times than manure. Manure has a low C/N (swine manure: 7.4) and problems in degradation can arise from ammonia formation. Achieving a more optimal C/N ratio is one of the reasons why manure and agricultural crop waste are often co-fermented. Amongst sources of plant biomass leaf- and grass-like biomass show the best C/N ratio (fresh grass: 17.64) and often contain little lignin, making them ideal for fermentation. (Deublein and Steinhauser 2008, 77, 94, 116; Fujita, Scharer, and Moo-Young 1980, 177; FAO 1992) It should be noted that a high C/N ratio or a high lignin content do not necessarily make anaerobic digestion impossible. Rather they cause lower methane yields and require higher retention times. Furthermore the aspects mentioned here are merely indications. The anaerobic depends on many more factors and is much more complex then was suggested in this section. However for the scope of this paper, that is for selecting suitable crops and manures, the indicators explained here will suffice.

3.3 Biomass sources

In this section different agricultural sources of biomass will be compared on their suitability for the specific environment and climate in Amsterdam and on their potential for producing biogas. The goal is to identify plants and livestock which could be integrated into an agricultural food and energy production landscape in the Brettenzone. To facilitate the selection of crops, a table was made wherein aspects determining the climatic requirements of plants as well as aspects influencing their biogas potential are expressed. This table contains information on dependent sources of biomass (from food crop residues) as well as dedicated biomass from non-food sources (algae, waterhyacinths, etc.). In table 3.3.1 the first two pages of this table can be found. The complete table can be found in Appendix C. The table contains numbered columns. The first columns (1-10) of the table concern the growth requirements of a particular crop and some general aspects concerning the crops purpose. The last columns (11-17) concern the crops suitability to be used as a source of energy. In the following paragraphs aspects influencing biomass yield and the crops' potential for biogas production will be explained using the columns of the table. For aspects concerning climatic requirements the climatic conditions in Amsterdam will be presented too. In the table cells colored green indicate that a requirement is fulfilled without complications in the Amsterdam context. Blue indicates that the aspect can only be fulfilled using interventions such as a greenhouse. Red indicates that the requirement is impossible to fulfill or would require extreme amounts of energy and effort. Aspects concerning bioenergy potential where also colored. The meaning of these colors will also be explained in the following paragraphs. A stripe underneath a value in the table indicates that the data was used for calculations or that value is an assumption based on data from literature.

This section will continue by identifying crops with a good potential for producing food, feed and biogas using a simplified version of table 3.3.1. Using a similar method, the potential of different livestock for production of food and biogas will be evaluated. The section will conclude by discussing some particularly attractive combinations of plants and livestock.

Plants

Biomass is formed by plants during photosynthesis. In this process plants use solar power to convert carbon dioxide and water into sugar and oxygen. Plants can be grouped in three types: C3, C4 and CAM plants. For each of these three types biomass production happens in a different manner and each type therefore has particular properties and climatic requirements. In all types photosynthesis takes place through the Calvin Cycle. In this cycle an enzyme called RuBisCo (Rubilose 1.5-diphosphate carboxylation-oxygenase) acts as an catalyst in binding carbon dioxide and oxygen. One aspect in which C3 plants are distinct from C4 and CAM plants is that during hot summer weather C3 plants close their CO2 breathing pores to minimize evaporation of water. This stops the Calvin cycle and therefore biomass growth. In C4 plants CO2 is stored temporarily at a different place then where carbon fixation by the Calvin Cycle takes place. This means the plant does not

AGRICULTURAL RESIDUES

Residue	1. Residue yield (kg)	2. Primary yield (kg)	Type	4. Climate / geographic range	5. Lighting conditions	6. Temperature (°C)	7. Water / moisture
					Summer: 307,7 W/m^2 PAR or 1412 µmol/m^2s PAR [19] Av. day length: 15.2 hours (54,720 sec.), 77 mol/m^2 daily PAR **Spring and fall:** 217,5 W/m^2 PAR or 1000 µmol/m^2s PAR [19] Av. day length: 13.8 hours (49,680 sec.), 50 mol/m^2 daily PAR **Winter:** 52,9 W/m^2 PAR or 244 µmol/m^2s PAR [19], Av. day length: 8.8 hours (31,680 sec.), 8 mol/m^2 daily PAR **Average day (13 hours = 46,800 sec.) very slightly clouded:** 281,2 W/m^2 PAR or 1290 µmol/m^2s PAR, 60 mol/m^2 daily PAR **Average day (13 hours = 46,800 sec.) slightly clouded:** 199,5 W/m^2 PAR or 912 µmol/m^2s PAR [19], 43 mol/m^2 daily PAR **Average day (13 hours = 46,800 sec.) clouded:** 108,5 W/m^2 PAR or 495 µmol/m^2s PAR [19], 23 mol/m^2 daily PAR **Average (13 hours = 46,800 sec.) day densely clouded:** 41,0 W/m^2 PAR or 186 µmol/m^2s PAR [19], 9 mol/m^2 daily PAR	**Annual:** Av. temp.: 10.1 °C[66] Temp. max. > 30°C: 2 days [10] Temp. max. > 25°C: 20 days[10] Temp. max. > 20°C: 75 days[10] Temp. min. < 0 °C: 50 days [10] Temp. max. < 0 °C: 8 days [10] Temp. min. < -10 °C: 2 days[10] Extreme max.: 37,8°C[10; 7/8/2003] Extreme min.:-24.2°C[10; 8/1/1985] **Spring Av. temp.:** 9.08°C[10] **Summer Av. temp.:** 17.75°C[10] **Fall Av. temp.:** 10.75°C[10] **Winter Av. temp.:** 3.42°C[10]	**Average rainfall:** 884 mm/y [10] **Relative humidity:** Spring: 68%[66] Summer: 67%[66] Fall: 77%[66] Winter: 83%[66]
Cereal straw *(wheat, spelt, rye, ect..)*	*2,268 – 4,535 kg / ha·a* [1; average] *3,000 - 3,500 kg / ha·a* [3; average] *4,668 kg / ha·a* [1] [5; Netherlands 2011, total wheat: 7,781 kg/ha*y] *Assumption:* *3997 kg / ha·a*	Grain: *1,511 – 3,023 kg / ha·a* [1; average] *3,112 kg / ha·a* [1] [5; Netherlands 2011, total wheat: 7,781 kg/ha*y] *Assumption:* *2690 kg / ha·a*	*C3*[2]	Wheat: *Temperate zones, both warm and cold, humid to dry, irrigated and high-rainfall areas.* Spelt: - Rye: *Cool temperate zones (as far as arctic zones to northern Chile).*[8]	*For C3 Plants in general light saturation is reached when:* *88 W/m^2 PAR or 400 µmol/m^2s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m^2 daily PAR* Wheat: *For bread wheat 90% of saturation is reached at: 1,000 µmol/m^2s PAR*[4]*. Furthermore in Triticum aestivum wheat 54.0 - 69.12 mol/m^2 and 38.5 - 84.7 mol/m^2 daily PAR have shown good results.*[20] Rye [8]: *Flowering requires 14 hours daylight and 5-10°C. Vegetative growth stops when reproduction begins; shortened day length can extend vegetation length. Rye can harvest winter sun and shading is seldom a problem.* Conclusion: *During winter and on densely clouded days there is not enough radiation for saturation of photosynthesis. However light deprivation during winter can also extend vegetation length which makes wheat suitable as a winter crop.*	Wheat[4]: Germ.: *4-37°C* Germ. opt: *20-25°C* Growth min *4,5-5°C* Growth opt.: *15-25°C* Growth max.: *30-32°C* Withstands: *0°C* Rye[8] and winter wheats: Germ. min: *1-2°C* Germ. opt: *13-18°C* Growth min.: *4°C* Growth opt.: *5-10°C* Withstands:*-35°C (snow cover)*	Wheat: Rainfall: *250-1,750 mm/y, 450-650 mm/y*[4] *Tolerant to high ground water: 0.8-1m but not higher than 0.5m* Rye [8]: *Best with ample moisture and low rainfall.* *Drought tolerant. Moisture influences maturation date.*
Corn stover *(leaves and stalk)*	*5,442 kg / ha·a* [1; average] *6,000 - 10,000 kg / ha·a* [3; average] *5,693 kg / ha·a* [1] [5; Netherlands 2011, total maize: 12,336 kg/ha*y] *Assumption:* *5,500 kg / ha·a*	Corn: *6,349 kg / ha·a* [1; average] *6,642 kg / ha·a* [1] [5; Netherlands 2011, total maize: 12,336 kg/ha*y] *Assumption:* *6,500 kg / ha·a*	*C4*[2]	Maize: *Pan-tropical, Summer crop in temperate Europe.*	C4 Plants: *Minimum 500 µmol/m^2s or 109 W/m^2 PAR, provided daily for 16 hours.* *Higher values are desirable.* [12] *Up to 1000-2000 µmol/m^2s during 14-16 hours can increase growth. Which would mean 50.4-115.2 mol/m^2 daily PAR. Furthermore 20 hours during vegetative growth would be optimal.*[16 who refer to 12] *This would mean 72-144 mol/m^2 daily PAR.*	Germ. min.: 10°C[4] Germ. opt: *20-30°C*[4] Growth min.: *15°C* [4; if used for human consumption] Growth opt.: *21-23°C*[16] Growth alt.: *10-15°C*[4; if used for animal fodder] *Susceptible to frost* [4]	Min: *500 mm/y rainfall* [4] Opt.: *1,200-1,500 mm/y rainfall*[4] Opt.: *500-750 mm/y rainfall* [16] Opt.: *500-800 mm/y rainfall* [4] *(not drought tolerant, often irrigated)* [4]
Rice husk	*1,000 - 3,000 kg / ha·a* [3; average] *1681 kg / ha·a* [5; Spain 2011, total paddy: 7,641 kg/ha*y] (6; this yields about 22% husk) *Assumption: 1,500 kg / ha·a*	Rice grain: *5,502 kg / ha·a* [5; Spain 2011, total paddy: 7,641 kg/ha*y] (6; this yields about 72% rice)	C3	*Eastern and southern Asia, Middle East, Latin America, United states.* *Hot and humid climates.*[15]	*For C3 Plants in general light saturation is reached when:* *88 W/m^2 PAR or 400 µmol/m^2s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m^2 daily PAR* *Rice is a day-neutral plant.*[15] *Furthermore Rice (Oryza sativa) has show good results with 750-800 µmol/m^2s PAR during 12 hours.*[20] *This would mean: 32.4 - 34.6 mol/m^2.*	Reprod. min.: *17°C*[4] Growth min.: *10°C* [4; if used for human consumption] Growth opt.: *25°C*[14], *20-23°C*[13] Withstands: *40°C*[13] *Susceptible to frost* [4]	Min. lowland rice: *200 mm/month (1400 mm/y) rainfall* [15] Min. upland rice: *100 mm/month (1200 mm/y) rainfall* [15] *Can also be irrigated.* [15]

1. Gupta and Demirbas (2010, 59,60,69) *Some data was converted from tons US to kg.*
2. Deublein and Steinhauser (2008, 17-19, 58-62, 116)
3. Nijaguna (2006, 23, 26) *Some data was converted from tonnes UK to kg.*
4. FAO (1992) *Online repository available at: http://www.fao.org/docrep/003/w3647eW3647E03.htm Retrieved on: 5 may 2013, 15:40, and: http://www.fao.org/nr/water/cropinfo.html Retrieved on: 5 may 2013, 11:41*
5. FAO (2013) *Crop yield data for 2011. Online database available at: http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor. Retrieved on: 8 may 2013, 21:36*
6. DMI (2003, 8,70)
7. IENICA (2007) *Online database available at: http://www.ienica.net/cropsdatabase.htm Retrieved on: 8 may 2013, 23:29*
8. SAREP (2013) *Online database available at: http://www.sarep.ucdavis.edu/database/covercrops Retrieved on: 9 may 2013, 12:15*
9. ECN (2012) *Online database available at: http://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis Retrieved on: 9 may 2013, 14:34*
10. KNMI (2011) *Online database, available at: http://www.klimaatatlas.nl/klimaatatlas.php, Retrieved on 9 may 2013.*
11. Franceschini (1977, 30)vv
12. Sager and Mc Pharlane (1997, 4)
13. Lee (2001, 112)
14. Defoer et al. (2004, 39)
15. VASAT (2013) *Online educational source available at: http://vasat.icrisat.org Retrieved on: 10 may 2013, 14:20*
16. Eddy and Hahn (2010, 2,3)
17. Qing, Yang, and Wyman (2010, 5942)
18. Ndazi, Nyahumwa, and Tesha (2008, 1270)
19. Hemming et al. (2004, 17)
20. Wheeler and Sager (2006, 10,19)
21. Sözer and Yaldiz (2012, 2,3)
22. Ulusoy et al. (2009, 1002)
23. Dumitru and Gherman (2010, 586, 587)
24. Lehtomäki (2006, 12,13,20-22)
25. Hutnan et al. (2001, 242)
26. Van An (2004, 14)
27. Elbersen et al. (2004, 141)
28. Blade Energy Crops (2009, 3,4,5,11,12)
29. Mykleby (2012, 40)
30. Nichols et al. (2012, 1)
31. Ahn et al. (2010, 965,968)
32. Clifton-Brown, Stampfl, and Jones (2004, 509,512)
33. Pyter et al. (2007, 41)
34. Clifton-Brown et al. (2011, 383,375)

Tale 3.3.1 Plant cultivation and biogas potential. Selection from the complete table in Appendix C.

	CLIMATE				BIOGAS			
	5. Light	6. Temperature	7. Water		12. Side effects	13. Composition	15. Biogas potential	16. Co-fermentation potential
Residues							($10^3 m^3 ha^{-1} a^{-1}$)	($10^3 m^3 ha^{-1} a^{-1}$)
Wheat, rye, spelt *(straw, C3)*								
Sorghum *(straw, C3)*								
Barley *(straw, C3)*								
Sugar beet *(pulp + leaves, C3)*							1.2	No need for manure co-fermentation
Tomato *(debris, C3)*							1.4	4.5
Potato *(haulm, C3)*								
Corn *(stover, C4)*								1.7
Rice *(husk, C4)*								
Sugarcane *(bagasse, C4)*							Usually incinerated directly	3.0 - 3.7
Energy crops								
Switchgrass *(C4)*								
Miscanthus *(C4)*							3.5	6.1
Reed canary grass *(C3)*							2.3	1.7
Luzerne *(C3)*							1.4	No need for manure co-fermentation
Sunflower *(C3)*					Depends on which part is used		0.2 - 3.3	No need for manure co-fermentation
Water Hyacinth *(C3)*							1.0 - 1.9	3.0 - 5.6
Micro algae *(C3 like)*							1.9	No need for manure co-fermentation
Foliage plants *(C3)*								
Grass *(C3)*								2.1

Tale 3.3.2 Summary plant cultivation and biogas potential. Data taken from the complete table in Appendix C.

CROP / RESIDUE					BIOMASS		BIOGAS		
8. Soil / nutrition	**9. Life cycle**	**10. Primary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**11. Residue type**	**12. Notes on residue / secondary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**13. Biomass constituents.** Dry matter (DM percent) Organic dry matter in dry matter (oDM in DM percent) Ash content dry matter (percent) Carbon percentage (percent) C/N Lignin (percent) Protein (percent) C/N = *Measure for fermentation suitability (preferable: 16:1-25:1*[2] *or 20:1-30:1*[3]*, I assume 25:1*[4]*).* Green : *15 : 1 < C/N < 45 :1* Green/Red : *10 : 1 < C/N < 100 :1, and or ligning > 17%* Red : *10: 1> C/N, 100 :1 < C/N*	**14. Dry net calorific value (MJ/kg).** *Bituminous coal (for comparison): 27 - 30 MJ/kg*[1] *Hardwood pellets (for comparison): 20.31 MJ/kg*[9; #3248]	**15. Biogas potential** Yield (m^3/kg oDM) Yield / ha: (m^3/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a*	**16. Biogas Co-fermentation potential** Yield (m^3/kg oTS) Yield / ha: (m^3/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a* N.B.: *Yield is per organic weight of total solids. This includes manure which has to be mixed into the substrate. The fraction of the crops substrate which is effectively converted to methane differs for each crop. The previous column is therefore more suited for comparing different crops.*	**17. Production advice** U - Harmless S - Containing trash Complexity: I - No II - Litle III - High
Wheat: Nutrient demand[4]: *N: 150 kg/ha K: 25-50 kg/ha* *P: 35-45 kg/ha* *pH: 6-8*[4] Rye[8]: *Best on drained loam or clay loam. Also good on droughty, sandy infertile soils Responds to P addition but not to lime.* *Best: pH 5.0-7.0* *Tolerance: pH 4.5 - 8.0* [8].	Wheat: *Annual. Harvest in northern hemisphere is between April and September.* Spring wheat: *100-130 days* Wint. wheat: *180-250 days* Rye[8]: *Annual.* *Usually used as winter crop although spring sowing is possible.*	Wheat (common and durum): *Cereal, grain, animal forage and fodder, adhesives, alcohol* Spelt: *Idem. wheat. Large demand from organic supermarkets etc.* Rye[8]: *Grain, animal forage and fodder(low quality therefore mixed with other grains), hay, pasture, cover crop, green manure, alcohol.* *Good for soil erosion control and as rotation crop (with corn, combining with other grains lowers selling price).*	*Field residue*	*Low energy density .* *Compaction is expensive.* *Also used as forage, fodder and animal bedding*	DM = *86 %*[2]*, ca. 70 %*[2]*, Ass.:<u>78</u>%* oDM in DM= *89-94 %*[2]*, Ass: <u>92</u>%* Ash = *5.04 %*[9] Carb. = *46.02 %*[9] C/N = *90 : 1*[2]*, 130-150 : 1*[3]*, 87:1*[23] *,Ass.: <u>106 : 1</u>* Ligning: *20 %*[3] Protein = *negligible*[4] oDM yield: *<u>2,867</u> kg/ha·a* *Biogas production is reduced to 30% - 50% unless substrate with low C/N ratio is added.*	*17.21 MJ/kg*[9] *15.69 MJ/kg*[9] *(Dutch pellets)*	Straw: Yield: *0.23 - 0.25 m^3/kg*[24,23]*, Ass.: <u>0.24</u> m^3/kg* Yield / ha: *<u>688</u>* m^3*/ha·a* Ret. time: *40 days*[24]*, 120 days*[3]	Wheat straw: Yield: *0.2 - 0.5* m^3/kg[2], *Ass.: <u>0.35</u>* m^3/kg Yield / ha: *1000.4 m^3/ha·a*[24] Ret. time: *15 days*[21,24] 50% Wheat, 50% Cowm.: Yield: *0.1* m^3/kg[2] Yield / ha: *286.8* Ret. time: *15 days*[21,24] *Ass.: <u>643.6</u>* m^3*/ha·a*	*U, II*[2]
Requires a well-drained, fertile soil. Alluvial loams, deep latosols and clay loams are preferred[4] High nutrient demand[4]: *N: 200 kg/ha K: 60-100 kg/ha* *P: 50-80 kg/ha*	*Annual* *Cycle of 135 days* *In Europe it is used as a summer crop and planted in April.*[4]	*Cereal, vegetable, adhesives, soap, alcohol, biofuels.*	*Field residue*	*Direct burning possible.* *Pulp for paper industry and particle boards.*	DM = *<u>86</u> %*[2] oDM in DM= *72 %*[2]*, <u>89.7</u> %*[2] Ash = *4.75 %*[9] Carb. = *43.98 %*[9] C/N = *71 : 1*[9] *, 59 : 1*[78]*, Ass.: <u>65 : 1</u>* Lignin = *17.6 %* [19] Protein =*7.75%*[4]*,* oDM yield: *<u>4,243</u> kg/ha·a* *Stalks can production by 25%, properties similar to wheat straw.*[3]	*16.85 MJ/kg*[9] *17.6 MJ/kg*[1]	Yield: *0.162-0.211 m^3/kg*[78] *<u>0.19</u> m^3/kg* Yield / ha: *<u>806</u>* m^3*/ha·a* Ret. time: *75 days*[78] *,120 days*[3]	M. Straw, unknown mix: Yield: *0.4-1.0*[2]*, <u>0.7</u>* m^3/kg Yield/ha:*<u>2,970</u>* m^3*/ha·a*[24] Ret. time: *15 days*[21,24] 25% Stover, 75% Pigm.: Yield: *0.305 m^3/kg*[78; 50% of stover is gasified] *<u>1,294</u> m^3/ha·a* *Ret. time: 16 days*[24] *Ass.:<u>1,711</u>* m^3*/ha·a*	*U, II* [2]
Heavier soil with large water holding capacity. *Rice is either grown as low land crop standing in water or as an upland crop under rain fed conditions.*	*Annual* *Perennial in some parts of Asia.* *Can mature in 100-150 days*	*Cereal, Staple food, thickening agent, alcohol*	*Process residue*	*Uniform in nature, good flow characteristics. Suitable for gasification, however: High silica content can cause problems in boilers.*[1] *Also yields 6 % bran (459 kg / ha·a) which can be used in: bread, biscuits, cattle feed, organic fertilizer, medicine and wax making.*[1]	DM = *25-50 %*[2]*, Ass.: <u>38%</u>* oDM in DM = *70-95 %*[2]*, Ass.: <u>83%</u>* Ash = *19.50 %*[9] Carb. = *48.25 %*[9] C/N = *<u>78.58 : 1</u>*[9] Lignin: *33 %* [18]*,* Protein = *3.98%*[4] oDM yield: *<u>1,358</u> kg/ha·a* *Rice straw can reduce biogas production by 25% other properties are similar to wheat straw.*[3]	*12.06 MJ/kg*[9]	Yield: - Yield / ha: - Ret. time: *33 days*[3]	Husk: Yield: *0.55-0.62, <u>0.59</u>* m^3/kg[2] Ret. time: *33 days*[3] Paddy straw: Yield: *0.24-0.37, <u>0.31</u>* m^3/kg[24] Ret. time: - Total yield / ha: *421* m^3/*ha·a*[24]	*U, II* [2]

35. Heaton (2010,1,2)
36. Maughan et al. (2012, 6-8,14)
37. Thelen et al. 2009)
38. Braun, Weiland, and Wellinger (2008,5)
39. Klimiuk et al. (2010,1)
40. USDA and NCRS (2002a)
41. USDA and NCRS (2002b)
42. -
43. Samson, Duxbury, and Mulkins (2000,3)
44. Landström, Lomakka, and Andersson (1996,334)
45. Poiša et al. (2011,229)
46. Vervuren, Beurskens, and Blom (1999,960)
47. Dubrovskis, Adamovics, and Plume (2009,243)
48. Sukkel (2008)
49. Heiermann et al. (2009)
50. Braun, Weiland, and Wellinger (2008, 5)
51. Hasan and Chakrabarti (2009, 54-56)
52. Spencer and Bowes (1986, 528)
53. Reddy and D'Angelo (1990, 27)
54. Pienkos and Darzins (2009, 432,434,435)
55. Darzins, Pienkos, and Edye (2010, 18)
56. Converti et al. (2009, 1147)
57. Lv et al. (2010, 6797)
58. Kebede and Ahlgren (1996, 101)
59. Smith et al. (1990, 1433)
60. Johnson et al. (2000, 423)
61. Kao and Lin (2010, 650)
62. Tu and Ma (2003, 245)
63. Blombäck (2004, 2)
64. Ericsson, Blombäck, and Neumann (2012, 2)
65. Anderson et al. (-)
Online database, available at: http://earthobservatory.nasa.gov/Experiments/Biome/biograssland.php, Retrieved on 29 may 2013, 22:50.
66. KNMI (2011a, 23)
67. Becker (2007, 3)
77. Patil, Tran, and Giselrød (2008, 1191)
77. Fujita, Scharer, and Moo-Young (1980, 177,180,183)
78. Zheng et al. (2009, 5142, 5144)
79. Norman and Murphy (2005, 2)
80. Amon et al. (2007, 3207, 3210)
82. Raja and Lee (2012, 20)
83. Daniel-Gromke, Ertem, and Rensberg (2011, 48,49)
84. Reitsema (2012)

need to close its pores to prevent evaporation. In CAM plants the problem is circumvented by only taking up CO2 at night and processing it through the Calvin Cycle during the day. (Deublein and Steinhauser 2008, 13-18) Because of their different CO2 fixation process C4 and CAM plants are better suited for dry and warm conditions and can potentially generate biomass faster than C3 plants. This can also be seen from column 1,2 and 3 of the crop table. Generally C4 plants give higher yields than C3 plants. Furthermore C3 plants generally thrive in a temperate climate such as that in Europe while C4 plants are better equipped for tropical, sub-tropical and desert regions. (Deublein and Steinhauser 2008, 16-19) This explains why C3 plants generally score better in columns 4-7 of the crop table which express the climatic conditions. Because of their different manner of CO2 fixation, photosynthesis in C3 plants is limited more by the amount of CO2 in the air. This means that although all plant growth responds positively to increased CO2 levels, C3 plants respond more intensely. (Peet and Krizek 1997, 4)

Although the sun drives photosynthesis plants do not utilize light from the full spectrum of sunlight. Generally plants only use light with wavelengths in the range of 400-700 nm. This range is referred to as photosynthetically active radiation (PAR). (Sager and Mc Pharlane 1997, 2) PAR is often expressed in W/M_2 PAR or $\mu mol/m^2s$ PAR. In appendix B. a table containing conversion factors for different PAR units can be found. If the amount of PAR in $\mu mol/m^2s$ is multiplied by the amount of seconds of exposure time during the day the total amount of daily received PAR can be obtained. This is expressed in $\mu mol/m^2$ daily PAR. The amount of PAR which reaches a plant in the open field in the Netherlands was determined from weather data by Hemming et al. These authors determined the amount of PAR for each of the seasons, as well as for different cloud conditions. (Hemming et al. 2004, 17) Their data was used to evaluate whether light requirements or optimal saturation of different plant species was met under Dutch lighting conditions (column 5). It should be noted that this data only expresses the amount of PAR which reaches the top leaves of a plant. Because plants grow in different densities and configurations the amount of PAR reaching the lower leaves will be different for each plant species. Therefore the values given in the crop table are only useful for rough indications and should not be used indiscriminately. In the table green cells indicate that a plant receives enough light for optimal growth throughout its life cycle. A red and green color indicate that light conditions are only sufficient during a part of the plants growth cycle. For this reason maize for instance cannot fully mature in the Netherlands and is only suited as crop for animal feed or biofuel. All C3 plants receive enough PAR under Dutch conditions. C4 plants often can grow under Dutch light but do not reach their optimal yield.

Temperature is another aspect influencing crop growth. Most plants show optimal growth as well as germination (hatching from seed) in certain temperature ranges. Furthermore not all crops are frost resistant. In column 6 the temperature requirements of different plants are compared to the temperature conditions in the Netherlands throughout their life cycle. Here green means the availing temperatures are suited for a plant to grow out in the open. Blue means a plant would have to be cultivated in a greenhouse and red means cultivation would require a too extreme amount of heating to be feasible. Column 7 displays the amount of yearly rainfall in the Netherlands and tests whether this fits the plants need for water. A blue color here means that a plant would require irrigation or a pond. Column 8t displays soil characteristics and the amount of nutrients required by a crop. This data should be compared with the characteristics of the soil in the Brettenzone, however, that is beyond the scope of this paper.

Columns 12 to 17 concern a plant's or residue's potential as a source of bioenergy. Column 12 displays alternative uses of residues and tests whether biogas production would compete with other uses such as fiberboard production or animal feed. Competing with other aspects is considered a negative aspect. Furthermore the column also contains additional notes on the plants. Certain plants for instance have useful side effects such as cleansing of waste waters. Other plants have negative side effects such as threatening biodiversity. The plants total aspects in this column where evaluated qualitatively. Column 13 displays the biomass's constituents. The amount of dry matter and organic dry matter of the biomass where used to determine the yield of biogas as only organic dry matter is converted to methane. Here the C/N ratio and the lignin content where used to determine the ease of fermentation. The ranges determining cell color are shown in the table. Green indicates a biomass source requires little preprocessing and can be digested directly. Some of these might still require drying and cutting to size though. A red and green cell means that biomass would probably degrade slowly and should be mixed with other types of biomass to obtain shorter retention times. This color can also indicate a high lignin content which means that the biomass would have to be pretreated. (Deublein and Steinhauser 2008, 77) For a red cell these last properties are even worse indicating a long retention time and a need for extensive pretreatment. This however does not mean it is impossible to ferment the substance. Column 14 displays the dry net calorific value of the biomass. This value has no direct link to biogas yield but rather indicates potential for direct incineration. The few green colored cells indicate that a biomass source can potentially be incinerated directly and could also be considered in a co-firing process. This criterion was not used in evaluating the crops. Column 14 and 15 respectively concern the pure potential of the biomass source and the potential for co-fermentation with liquid manure. Here the yield of biogas per unit of dry organic biomass weighed is given as well as the yield per hectare and the required retention time. The color of the cell is determined here by the yield per hectare. The different ranges are shown in the table. A green, or good, potential can mean that the biomass source has a high methane formation rate or that the crop delivers a large amount of organic material or waste per hectare. The 17th and final column gives the biogas production advice as it was given in literature. (Deublein and Steinhauser 2008, 57-62) A few cells in this column are colored red/green. This means the biomass source might contain trash which has to be removed.

In table 3.3.2 a summary of the entire plant potential table can be found. Table 3.3.1 shows how each plant scored on the most important aspects. The three columns on the left indicate whether a plant can easily be cultivated in Amsterdam. The four columns on the right indicate the biogas potential of the plant or plant residue. The top half of the table contains information on food plants and their residues. Of the presented food plants only the C3 plants thrive in the Dutch climate. The plants most easily cultivated are: wheat, barley, sugar beet and the potato plant. Tomatoes can only be grown in greenhouses. Amongst these plants tomato and sugar beet residues show most biogas production potential. They are easily fermented and have large yields. These plants however are not sources of staple food and sugar beet is only used for sugar production and animal feed. Amongst the staple food residues wheat straw and maize stover have the largest biogas yield. However fermentation of straw does require pretreatment. Straw contains large quantities of lignocellulose which have to be thermally or chemically disintegrated. (Deublein and Steinhauser 2008, 77) Maize stover has a high yield when it is co-fermented with manure. It should be noted that the yields of co-fermentation are indicative of whether fermentation can be improved for a certain crops. The exact co-fermentation yields of different crops however should not be compared with each other as the amount of manure in the substrate differs for some crops. A downside to cultivating maize is that under Dutch lighting conditions maize cannot reach its full maturity. Therefore maize grown in the Netherlands is only suited for animal feed or bioenergy. No particular option stands out which incorporates a good food, feed and biogas potential. What we can conclude from this is that the optimal utilization of space and light cannot be found using one crop. Rather such an optimum could be reached from crop rotations. For instance growing maize for protein rich forage and biomass during summer and rye for human food, protein poor forage and animal bedding during winter. Liquid manure could then be produced by coupled animal husbandry.

In the lower half of the table the dedicated energy plants can be found. Again the lighting and temperature requirements of C3 are met under Dutch conditions with the exception of water hyacinths and algae. These plants would require a higher temperature which could be achieved by a heated pond or a greenhouse. Furthermore these are aquatic and an artificial pond or containment vessel needs to be built if there is no suitable water available. Canary grass might also require artificial irrigation as yearly rainfall is not sufficient for optimal growth. This plant is native to the Netherlands and grows in the wild on a variety of soil. However the plant prefers poorly drained soils subjected to flooding. The C4 grasses Miscanthus and Switchgrass do not reach their optimal growth in the Netherlands. Nonetheless these grasses can still be grown and give high biomass yields.

Miscanthus, water hyacinths and algae show most potential for biogas production. Especially their high yields make them attractive sources of biomass. Although water hyacinths have a low C/N they still show some problems in digestion. One of the problems is that the plant floats in the substrate if it is directly fed into the digester making complete digestion difficult. This and other problems can be prevented by cutting the plants up and mixing them with manure or urine. (Raja and Lee 2012, 15, 16) Miscanthus has a high C/N ratio and is therefore best co-fermented with manure. It might also require thermal or chemical pretreatment. Utilizing Water hyacinths and Miscanthus for biogas would not compete much with human or animal feed markets. Water hyacinths can only be fed to goats and fish and are not used as a feed material in the Netherlands. Miscanthus is only used as a low protein feed. Algae however have a high protein content and can potentially be used as high quality feed. Reed canarygrass, Sunflowers and meadow grass also show good yields. Using the complete sunflower however could compete with their use as chicken feed and using grass could compete with its function as a grazing field. Utilizing some of the before-mentioned crops could also have other benefits than just biogas. For instance Algae, Waterhyacinths and Reed canarygrass can be used for waste water purification. Miscanthus, Switchgrass and Reed canary grass store atmospheric CO_2 in the soil and can be used for carbon sequestration. Switchgrass can be used as a forage crop and be harvested for biomass within the same year. An attractive property of Luzerne is that it can be grown in the undergrowth of wheat. Luzerne is a good source of protein or biogas and this kind of crop rotation also improves soil conditions.

Like with the food crops there is no optimal choice of a specific biogas crop. Each plant has its own merits and a selection should therefore be based on utilizing the plant's specific properties and additional functions. One thing which could be exploited is that not all plants require much light and nutrition. Waterhyacinths, algae and reed canary grass for instance could also grow in places with less direct sunlight. Some meadow grass types and especially undergrowth foliage plants can even thrive in shade. These properties could be exploited by growing these plants on plots of land which otherwise would not be utilized or growing them in the shadow of food crops which do require much direct light. Plants for biogas production could also be incorporated in crop rotation system. Table 3.3.3 shows some possibilities for crop rotation systems in Germany. According to Deublein and Steinhause yields of 25,000 to 30,000 kg of total dry mass can be obtained if the crops shown in the table are planted subsequently within one year. (Deublein and Steinhauser 2008, 14) Table 3.3.4 shows a crop rotation in Austria where food, feed and biogas production where integrated. The biomass yields in this table are somewhat higher than in the plant potential table presented in this paper. This is because in this paper average yields where assumed rather than maximum yields.

1st Planting	*2nd Planting*	*3rd Planting*
Wheat	Maize (mass-producing species)	GPS
Winter rye	Sunflower	
Winter barley	Sorghum	
Triticale,	Sudan grass	
Winter oat	Hemp	
Winter rape	Mustard	
Beets	Phacelia	
Winter peas	Radish	
Incarnat clover	Sweet pea	
Winter sweet pea	Peas	

Table 3.3.3 Some possibilities for crop rotation in Germany.
N.B.: GPS: a mixture of winter wheat and peas.
Table taken from: Deublein and Steinhauser (2008, 15).

Example of biomass and methane yields from a sustainable crop rotation in Lower Austria that integrates food, feed and energy crop production

Year	Crop	Biomass yield (t VS ha^{-1})	Specific CH_4 yield (l_N kg^{-1} VS)	CH_4 yield per hectare (m_N^3 ha^{-1} a^{-1})	
				Crop only	Crop rotation
1	Maize (whole crop silage)	15.12	390	5897	1179
2	Winter wheat (straw)	5.44	189	1028	206
	Intercrop (clover grass)	2.71	335	906	181
3	Summer barley (straw)	3.81	189	720	144
4	Sugar beet (leaves)	7.20	210	1512	302
	Pressed beet pulp silage	14.36	430	6173	1235
5	Sunflower (whole crop silage)	11.02	300	3300	660
	Intercrop (lucerne)	3.61	335	1208	242
Methane yield of the whole crop rotation (m_N^3 ha^{-1} a^{-1})					4149

Table 3.3.4 Methane yield for five year crop rotation in Austria where food, feed and energy production where integrated.
Table taken from: Amon et al. (2007, 3210)

Biogas potentials: manure and husbandry						
Animal	Feeder cattle	Diary cow	Feeder pig	Sheep over 1 year (Assumed: goat)	Horse over 3 years	Poultry: Laying hen (up to 1600g)
GVE / AU	*1.0* [1]	*1.2* [1]	*0.12* [1]	*0.1* [1]	*1.1* [1]	*0.0030* [1]
Manure production one animal *(m^3/a)*	*18.0* [1]	*19.8*[1]	*1.62*[1]	*1.08* [1]	*8.3* [1]	*0.07* [1]
Manure density *(kg/m^3)*	*828* [2]	*828* [2]	*828* [2; assumption from cow manure]	*828* [2; assumption from cow manure]	*1,009* [10]	*961* [11]
Manure production one animal *($kg \cdot a^{-1}$), ($kg \cdot GVE^{-1} a^{-1}$),*	*14,904* *14,904*	*16,394* *12,420*	*1,341* *11,175*	*894* *8,940* *N.B. Manure production llama: 1,950 kg/a* *Goat: 253 kg/a*	*8,375* *7,614*	*67.2* *22,400*
Composition DM *(percent)* oDM *(percent)* C/N: *(ratio)*	*6 - 11%* [1] *8.5%* *68 - 85%* [1] *77%* 18 - 45[3,4,5 fresh: higher] 18 : 1[3]	*6 - 11%* [1] *8.5%* *68 - 85%* [1] *77%* 18 - 45[3,4,5 fresh: higher] 18:1[3]	*3 - 10%* [1] *6.5%* *77 - 85% 81%* 14:1[3], 18:1[5; average], *7.4:1*[8]	*18 - 25%* [1] *22%* *77 - 85% 81%* [1] 16:1[3], 20:1[5; average]	*28%* [1] *25%* [1] 25 - 30[3]	*10-29%* [1] *19.5%* *67-77%* [1] *72%* 6 - 15[3], 17[5; average]
Biogas yield *(m^3/kg oDM)*	*0.1 - 0.8* [1; liquid manure] *Assump.: 0.45*	*0.1 - 0.8* [1; liquid manure] *Assump.: 0.45*	*0.3 - 0.8* [1; liquid manure] *Assump.: 0.55*	*0.3 - 0.4* [1; fresh excreta] *Assump.: 0.35*	*0.4 - 0.6* [1; fresh excreta] *Assump.: 0.5*	*0.3 - 0.8* [1; fresh excreta] *Assump.: 0.55*
Biogas yield one animal *($m^3 \cdot a^{-1}$)*	*439*	*483*	*39*	*56*	*293*	*5.2*
Biogas yield per GVE *($m^3 \cdot GVE^{-1} \cdot a^{-1}$)*	*439* *204 - 548* [1] *Assump.: 408*	*403* *204 - 548* [1] *Assump.: 403*	*325* *219 - 456* [1] *Assump.: 331*	*560* * range not available, possibly misleading. *Assump.: 560**	*266* * range not available, possibly misleading. *Assump.: 266**	*1,729* *1,278 - 1,460* [1] *Assump.: 1460*
Feed one animal *($kg \cdot a^{-1}$)*	*8,730* [7] *10% protein* [6]	*10,476* [7; calculated from feeder catle] *15% protein* [6]	*1,048* [7; calculated from feeder catle] *15% protein* [6; assumed complies with conventional pig fodders]	*873* [7; calculated from feeder catle] *10% protein* [6; assumed]	*9,603* [7; calculated from feeder catle] *10% protein* [6; assumed]	*26.2* [7; calculated from feeder catle] *15% protein* [12]
Protein rich feeds:	*Sugar beet leaves (12%), tomato plant waste (13%), potato haulm (25-30%), switchgrass (10-15%), reed canary grass (16%), Luzerne (18-20%), Algae (51-58%) Foliage plants (20%), Grass (20.5%) Cereal grains (10-15%)*	*potato haulm (25-30%), reed canary grass (16%), Luzerne (18-20%), Algae (51-58%) Foliage plants (20%), Grass (20.5%) Cereal (10-30%)*	*potato haulm (25-30%), pototoes (15%). Algae (51-58%) Luzerne (silaged 18-20%), Grass (20.5%)*	*Sugar beet leaves (12%), tomato plant waste (13%), potato haulm (25-30%), reed canary grass (16%), Luzerne (18-20%), Algae (51-58%) Foliage plants (20%), Grass (20.5%) Water hycacinth (goats, 16%) Cereal grains (10-15%) Luzerne (18-20%),*	*Sugar beet leaves (12%), tomato plant waste (13%), potato haulm (25-30%), reed canary grass (16%), Luzerne (18-20%), Algae (51-58%) Foliage plants (20%), Grass (20.5%) Cereal grains (10-15%)*	*Luzerne (18-20%), Algae (51-58%) pototoes (15%).*
Protein lean feeds:	*Maize (whole plant or stover 7-8%),*	*Maize (whole plant or stover 7-8%), sugar beet leaves (12%), switchgrass (10-15%), tomato plant waste (13%) Cereal grains (10-15%)*	*Maize starch sugar beet leaves (12%), Cereal grains (10-15%)*	*Maize (whole plant or stover 7-8%),*	*Maize (whole plant or stover 7-8%),*	*Cereal grains (10-15%) Maize (7-8%),*
Protein poor feeds:	*Straw (0%), beet pulp (5%), sunflower (2%), miscanthus (3%)*	*Straw (0%), beet pulp (5%), sunflower (2%), miscanthus (3%)*	*beet pulp (5%)*	*Straw (0%), beet pulp (5%), sunflower (2%), miscanthus (3%)*	*Straw (0%), beet pulp (5%), sunflower (2%), miscanthus (3%)*	*beet pulp (5%), sunflower (2%),*
1. Deublein and Steinhauser (2008, 62,63) 2. Arora et al. (2004, 4) 3. Jenkins (2005, 34)	4. Atiyeh et al. (2000) 5. ECN (2012) 6. FAO (1992)	7. Butler et al. (1997, 6) 8. Fujita, Scharer, and Moo-Young (1980, 177) 9. Edwards (2002)	10. (Wheeler et al. 2005, 2) 11. Tao and Mancl (2008, 2) 12. Firman (1993)			

Tale 3.3.5 Biogas potentials and feeding requirements of husbandry animals.

Manure and animal husbandry

Generally liquid manure is more suited for anaerobic digestion than fresh crops. Manures have a low C/N value, flow well and are easy to handle. Also manure is available throughout the year where most plant material is harvested in batches and only during certain periods. Manure is the most utilized feed in biogas plants where it is often mixed with co-substrates to achieve higher yields. Besides increasing biogas production co-fermentation also shortens the retention time of plant fermentation and it allows for a more continous process. Commercial operation of a biogas plant is often only possible when it a co-fermentation process is used. Co-fermentation is only rewarding however if the feed materials are brought in from no further than fifteen to twenty kilometer. (Deublein and Steinhauser 2008, 57, 65; Prag 2013, 77)

Using liquid manure as a substrate however also has some drawbacks. All manures contain foreign matter which may impair the fermentation process. Pig and poultry manure can for instance contain minerals and sand which was present in their feed. Also sawdust scatter used as poultry bedding can contain the substrate. Other contaminants contained in most manure are soil, animal remains (skin, tail, etc.), cords, wires, plastics and stones. Presence of such contaminants in large quantities lead to a more complex operation of the plant and therefore higher expenses. Furthermore the anaerobic process may also be affected by organic acids, antibiotics, disinfectants and other additives to the animal's feed. (Deublein and Steinhauser 2008, 62, 64)

Table 3.3.5 shows potential yields and feed requirements for different kinds of livestock. Biogas yields are only meaning full if they express the amount of gas that is produced for a certain amount of effort, space or energy. With livestock the amount of effort can be expressed in the amount of feed the animal consumes as well as the quantity of space it inhabits. Space here is also related mainly to the amount of acres that an animal requires to be fed. Therefore the amount of produced biogas compared to the amount of feed the animal consumes can be a useful indicator of the animals relative energy production.

Animals, and humans, need nutrition to supply them with energy but also for producing the proteins which form their muscles, organs and other products such as milk. The goal of feed selection is therefore to find types with a high energy content which are most suited for building proteins. (Butler et al. 1997, 1) Amongst the energy-rich sources of feed the quality of a particular feed is mainly determined by its crude protein content and its digestibility. If protein and digestibility are high, more feed can be consumed by the animal. Crude fiber makes a feed harder to digest. Sheep are less susceptible to digestion problems than cattle and cattle in turn are better digesters than pigs. (Butler et al. 1997, 7, 8) A useful measure for comparing the feed impact of different types of life stock is the animal unit (AU). An animal unit expresses the amount of food required by livestock as compared to that consumed by a non-lactating cow. The dry cow is considered to have an AU of unity and other animals or physical conditions are expressed as a fraction of this. (Butler et al. 1997, 8) Different regions often have their own type of animal units. Their values however rarely differ much. The GVE is a livestock unit utilized in Germany which also uses the dry cow as a reference point.

Table 3.3.5 shows the potential biogas yields per GVE of different animals. It can be seen that sheep and poultry give the largest yields. The high biogas yield of sheep may be somewhat misleading as there is not much data available on fermentation of sheep manure. For the other animal types ranges of yields were found and the yield assumed in the table was obtained from an average of this range. For sheep however only a single reported value was available. The high biogas yield for poultry yield is indicative of poultry manure's good fermentation qualities. These qualities are best explained by the lack of raw fibers in chicken feed which makes their manure easier to break down. (Deublein and Steinhauser 2008, 64) Poultry also have relatively high manure production. However this does not mean poultry are the best choice for a farm which also wishes to have high biogas yields. Cow and pig manure for instance are easier to collect and to mix with co-substrate. Also a biogas plant for poultry manure has to be purpose-built and is only feasible if it is coupled to a relatively large poultry farm. (Prag 2013, 77) Cow and pig manure are actually the most common source of manure for biogas production. Pig manure is an especially attractive source of biomass because of its liquidity.

Again an ideal candidate for an energy producing farm in the Brettenzone cannot be specified. Rather the choice for a particular kind of livestock should be derived from a consideration of the entire chain including the crops which were used to feed the animal. Table 3.3.5 also shows a list of crops which can be fed to the different types of livestock. These feeds match the plants in the plant potential table. The feed types are ordered in three categories of protein content. The amount of protein which defines each category differs for each animal and was determined using assumptions on the animals specific diet. The highest protein content category contains the high quality feed types. These types would offer an appropriate diet for the animal. They can also be fed to the animal in combination with the medium or low quality feeds in order to increase agricultural productivity.

An optimum design for the conceived agricultural enterprise in the Brettenzone should arise from a 'smart' combination of food crops, feed crops and livestock. The goal should be to achieve the highest yields in food, feed, and energy in that respective order. Designing a balanced agricultural ecology requires the use of a mass balance which represents these different streams. In such a consideration also the substrate residue has to be taken into account. To use this residue for fertilization of farm land it should be free of contaminants. Using the substrates mentioned in this paper this should be possible. However even with 'clean' residues there is a limitation. The upper limit of nitrogen allowed on agricultural land by legislation has to be taken into account. In Germany nitrogen is limited to 210 kg/ha. (Deublein and Steinhauser 2008, 65) For modeling and optimizing the before-mentioned mass balance computational methods can be used. It can be questioned whether computational optimization would be useful though as the numbers which are given in this paper are not very precise. Therefore it can be argued that an exact optimization using these numbers would not be very meaningful.

3.4 Biogas production: technology and equipment

The anaerobic process can take place using either wet or dry fermentation. Wet fermentation refers to a process where the substrate's water content exceeds 85%. If the water content is lower the process is referred to as dry fermentation. For agricultural plants both processes have their own merits and disadvantages. Amongst the benefits of wet fermentation are: a wider spectrum of applicable substrates, a larger potential for digesting pasty substrates containing more water, a greater ease of mechanical mixing, easier transportation, more control over pH value, DM concentration and other process variables and a higher quality residue. A wet process seems most suited for the envisioned production gardens as these will produce a wide variety of plant material. Also higher quality of residue is attractive because one of the goals is to close material cycles. An important drawback of the wet process however is that it consumes more energy. The consumed energy amounts for 30-45% of that which is produced as opposed to less than 15% when using a dry process. Also odor control is more difficult in a wet process and dry fermentation offers a more robust technology with fewer rotating parts. (Deublein and Steinhauser 2008, 224, 225) In this paper a wet process is assumed, still, in the eventual design it may be attractive to utilize a dry process in places where odor is critical or where low maintenance and operation are required. Furthermore a co-fermentation process is considered to be most suitable for the production gardens as this offers the highest biogas yields as well as the greatest potential for closing cycles.

It is yet uncertain whether production under the envisioned concept will take place in large professional agricultural enterprises, in a more decentralized semi-professional system using unskilled workers, or in a combination of both. Therefore a production system was designed for both these extremes. For the more professional large-scale production method *Biogas from waste and renewable resources* by Dieter Deublein and Angelika Steinhauser was consulted. (Deublein and Steinhauser 2008) For the semi-professional system *Biogas plants* by Ludwig Sasse was used for guidance. (Sasse 1984) Both works contain guidelines and recommendations for designing biogas plants as well as descriptions of the required equipment. The two systems were designed for the substrates which where mentioned in the previous section.

The semi-professional system is illustrated by fig. 3.4.1. This system is entitled 'low-tech' because it requires little complex technology. It is only suited for small scale bioreactors. High yields can still be obtained using this plant design if many of the biogas plants are coupled within a decentralized system. The exact process would be different for each type of plant or residue but generally the process would include the following steps. For plant material with high water content such as water hyacinths or algae the process would start with drying the plants (A). This could be done by exposing it to the sun directly. It would be more effective though to utilize heat from solar collectors or the district heat network. For most plant material though, drying would not be necessary. (Deublein and Steinhauser 2008, 223, 224) Because particle size greatly influences the degree of digestion comminution (C), that is cutting or grinding, is recommended for most substrates. These substrates include straws and leaves as well as large lumps of excrement. (Lehtomäki 2006, 15; Deublein and Steinhauser 2008, 226) To reduce odor problems it is best if comminution and processing is done inside underneath a sprinkling installation. Some substrates might already have been comminuted in the field when they are collected.

Once the material has the appropriate particle size it can be fed into the preparation tank (D) where it is mixed with water. In this tank the substrate can be preheated. A 'low-tech' solution to this is by covering the tank with a glass lid and letting the sun heat the substrate. (Sasse 1984, 38) From the preparation tank the substrate is fed into the anaerobic reactor (F). This is done either by a pump or in some processes it is drawn into the reactor when gas is withdrawn from it. In the 'low-tech' design a single reaction tank is used. This tank may contain two segments, one for each phase. This enables an optimum degradation in each phase and prevents the substrate from exiting the reactor to soon. (Sasse 1984, 38, 40) The best results however are with long horizontal single channel tanks. To enable a good spread of the bacteria the substrate should be stirred or agitated. For simple plant with a volume of less than 50 m^3 this occurs through feeding and by the process itself. It can be aided by poking the substrate with a stick through the feeding hole. Larger plants however require mechanical agitation. This can be done using mechanical devices (paddles, propellers, screws) inside the tank, hydraulic pumps outside the tank or by injecting biogas into the tank. The screw agitator is most commonly used. (Deublein and Steinhauser 2008, 254; Sasse 1984, 38, 39, 42, 53) The reaction tank can be heated by elements integrated into its wall or inside the tank itself. Other options are circulating the substrate past an external heating element or using heated agitation devices. Again the district heat system or solar energy coupled with aquifers offer potential sources. Unheated reactors can also be applied. High temperatures are maintained by covering these with a greenhouse or fixing them underground. In all cases the reactor should be properly insulated. Production

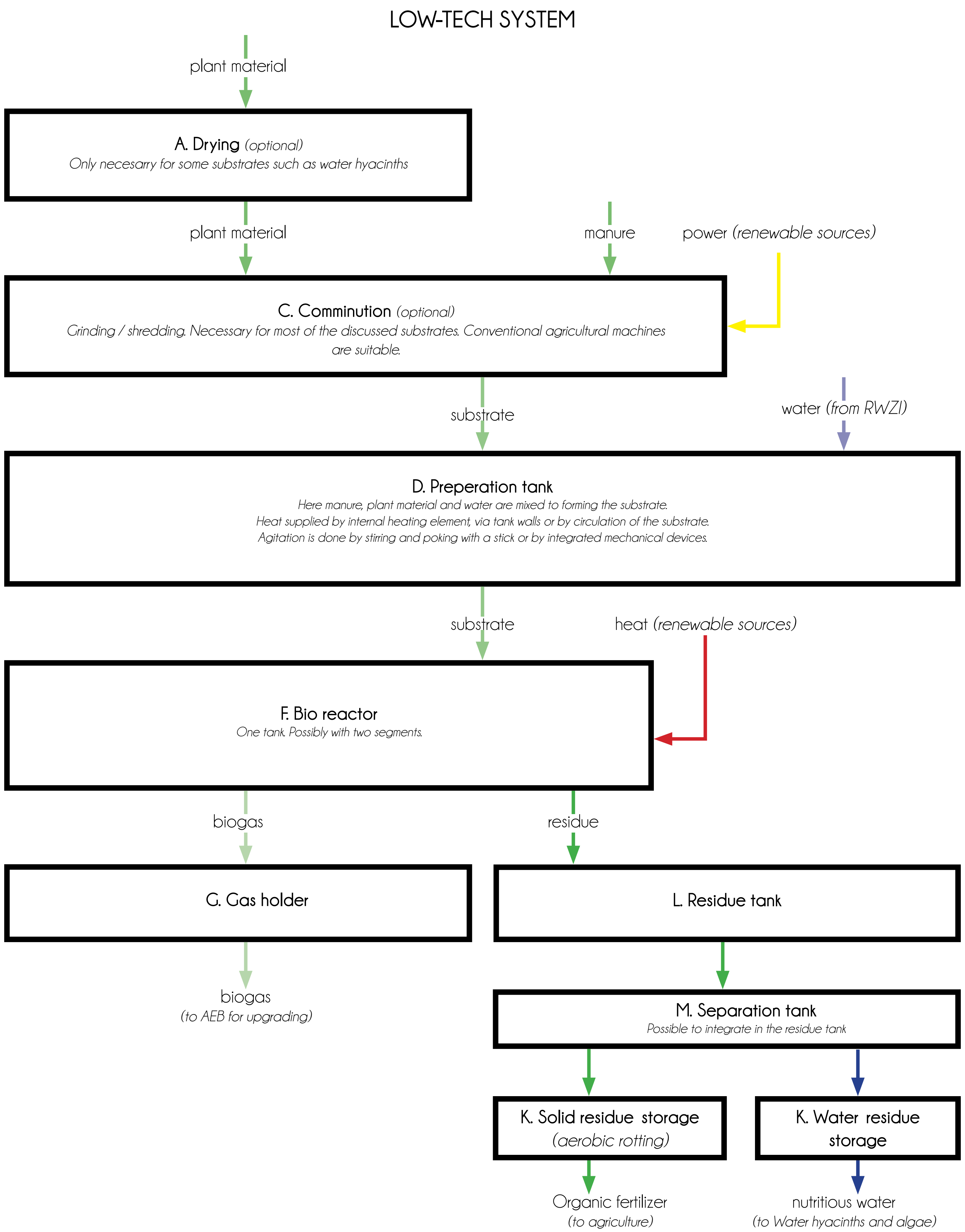


Fig. 3.4.1 Low-tech system.
System design based on: Deublein and Steinhauser (2008, 199-333)

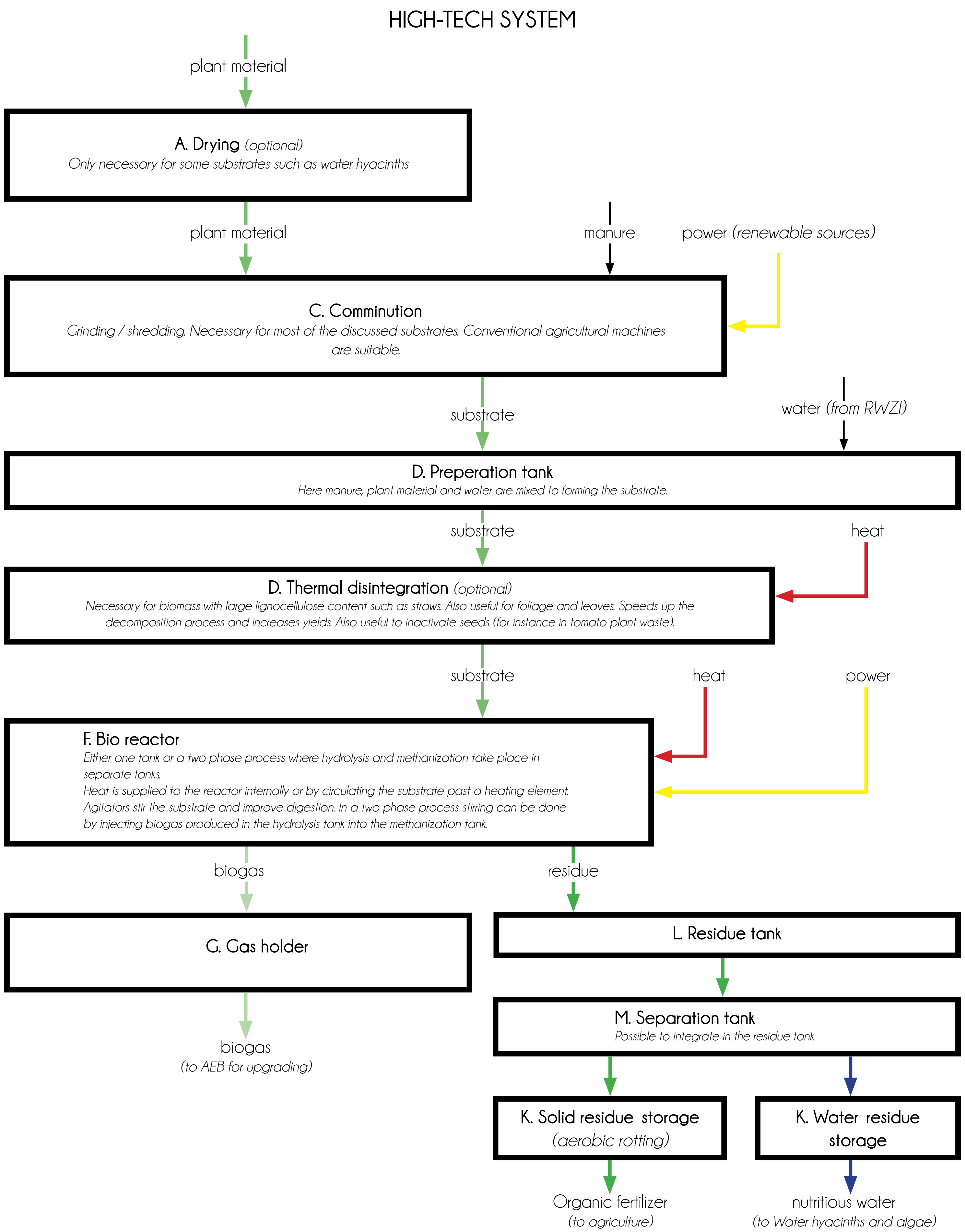


Fig. 3.4.2 High-tech system.
System design based on: Deublein and Steinhauser (2008, 199-333)

during winter in an unheated plant can drop as low as half that during summer. (Sasse 1984, 53)

In some plant designs the produced gas will be contained within the reactor itself. In other designs it is directly caught and transferred to a gasholder. For all designs the gas will eventually have to be contained in a larger gasholder before it is transfered to the AEB or other companies in the harbour (G). The process leaves a residue which consist of non-degraded organic material and nutrients. Because the residue can still produce methane, odors and volatile gases it should be left to ferment anaerobically in the residue tank (L) for at least twelve to twenty four hours. The exact time is determined by legislation. (Deublein and Steinhauser 2008, 311, 403) After this final retention the residue has lost its typical odor. The residue still contains a large quantity of water. This water can be drained or pressed out using mechanical equipment (M). The solid residue is than left to aerobically rot after which it can be used as an organic fertilizer. The water can then also be used as a fertilizer. An attractive option would be to use the water for cultivating algae or water hyacinths which are especially effective in utilizing the contained nutrients. If the water is to be disposed directly or used for other purposes it needs to be biologically treated first. (Deublein and Steinhauser 2008, 223, 224, 264-269, 403-405)

The 'high-tech' system utilizes more complex technology and is better suited for large bioreactors. Drying and comminution proceed in the same manner as with the low-tech system. One important difference however is that the high-tech system could also encompass the process step of thermal disintegration. In this step difficultly digestible substrates such as straw are heated causing lignocellulose to decompose. Such a treatment could also help to inactivate seeds in for instance tomato plant waste, which could also cause problems in digestion. (Deublein and Steinhauser 2008, 77, 229, 231) The bioreactor in the high-tech system also uses more refined equipment. The process can take place in on or two tanks. In the two phase process hydrolysis and methanization are separated in order to allow an optimization of both processes. In such a process some biogas is already produced in the first tank. It is possible to inject this gas into the methanization tank where it acts as a steering device. The two phase reactor design can be used to improve the yield of badly digestible substrates. (Deublein and Steinhauser 2008, 258-263) The single phase process is compatible with that in the low-tech system. However here heating and mechanical agitation are detrimental. From the reactor biogas is again transferred to a gasholder. In some reactors the liquid residue is separated from the liquid part as it exits the reactor. The residue is treated in the same manner as with the low-tech system. During all process steps a greater degree of automation could be applied in the high-tech system. This involves covered conveyor belts, feeding screws, etc.

The equipment which could be used in the two systems described in this section also varies from very high-tech to relatively simple systems. Figure 3.4.3 shows a few of the bioreactor possibilities. The top row illustrates the simplest technologies. In F.1 a fixed dome plant can be seen. Here is gas formed in the top of the reactor chamber. Gas pressure then pushes the substrate out into a compensating tank. Here the residue is removed after which new feed is added into the preparation tank. Then gas is withdrawn from the chamber causing the feed to be sucked into the digester. F.2 works in a similar manner but here the gas pressure is constant due to an expanding external gasholder. A floating drum plant can be seen in F.3. Here an expanding gasholder is integrated into the digester design. The top of gas chamber floats in the slurry itself or in a water jacket allowing it to expand. When gas is extracted from the chamber the tops sinks back to its original position. These plant types have short lifetimes and are only applicable in small sizes because the movement of the top becomes problematic in larger designs. F.4 shows a balloon plant. In such a plant gas is stored in an expanding balloon. When the balloon is not elastic therefore the balloon behaves like a fixed dome plant when the balloon is filled. (Sasse 1984, 13-16) The lower rows in fig. 3.4.3 show some of the more advanced bioreactors related to the before mentioned simple systems. The most commonly used fixed reactor types are of the steel and concrete types shown in F.4 and F.5. For the larger types it is often more economical to build them above the ground. The different types of gasholders which can be used also differ much in their complexity. These vary from plastic balloons to tanks and large steel structures (fig. 3.4.5).

3.5 Conclusions

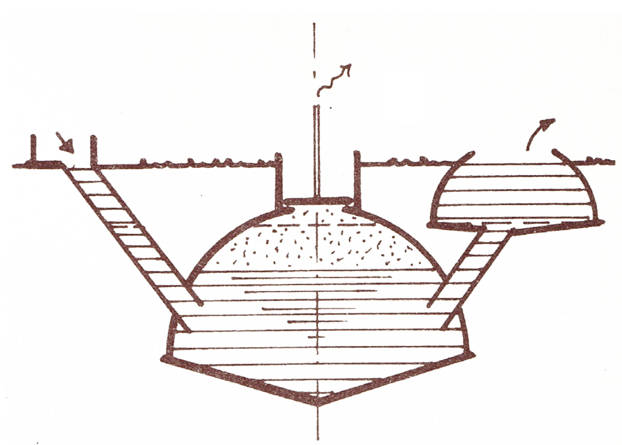
In the previous sections we have seen that biomass is already widely used as a source of renewable energy and that it is expected to become an even more important source of energy in the future. Although it theoretically offers a CO_2 neutral source of energy it might be more accurate to describe it as 'carbon lean' as fossil energy is consumed during its processing and transportation. Also bioenergy can also have an associated 'carbon debt' when for instance CO_2 buffering forests are replaced with fields of energy crops. Production of such dedicated energy crops can also negatively effect food prices. The price of maize for biofuel for instance is directly coupled with that of food maize. A less direct effect of dedicated energy crops is that they compete for the same land, fertilizers and irrigation water as food crops. These negative associations however do not mean we should dismiss biomass as a source of energy. Rather we have to consider the full life cycle of its production process when we use it. LCA offers a good method for this.
In this chapter we have also seen that biomass has good future perspectives, such as: its possible integration in a hydrogen energy system and genetic manipulation of crops.

This chapter has also described the anaerobic digestion process where a multitude of symbiotic microorganisms, in the absence of oxygen, transform organic materials into biogas, nutrients, and cell matter leaving a residue of salts and organic material. This four step process involves hydrolysis of complex organic material into smaller monomers and subsequent formation of organic acids and finally methanation. The process can take place within one tank or two using two tanks. In this last method one tank is used for the first two phases and the other is used for the last. The process depends on a multitude of variables. The most important variables for selecting a substrate are the C/N ratio and the lignin content. A C/N of between 16:1 and 35:1 and a low lignin content (0-15%) are most easily fermented. Other values for these parameters lead to longer retention times and lower methane yields. These aspects make straws harder to digest than leaf-like material. To offer better fermentation qualities, easier processing and higher yields plant material and manure are often co-fermented.

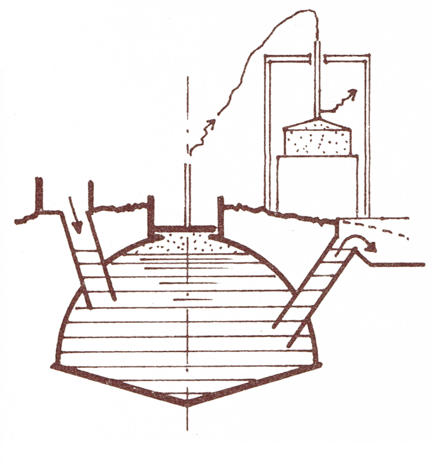
The third section discussed possible plant and manure biomass sources and offered data which can be used to optimize the yield of food, feed, fuel whilst recycling nutrients. The tables given in appendix C can also be used to design a crop scheme which makes optimal use of light and space.

Furthermore this chapter presented two system designs. The low-tech system is suited for small scale production and can be operated by unskilled workers. With this system high yields can still be accomplished by coupling many of these bioreactors within a decentralysed system. The high-tech system is meant for large scale digestion and is also suited for hard-to digest biomass sources. It however involves complex equipment and can only be applied within a professional operation scheme. This chapter also presented examples of the required equipment which varied from very low-tech to very high-tech.

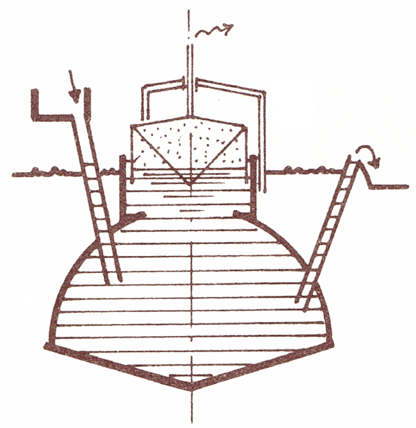
The data and recommendation which were offered in this chapter can be used as reference when designing the 4F farm. The goal in this design has to be to maximize the yields of food, feed and fuel in that respective order of importance. The balance between these three must be such that there is a closed cycle of fertilizer. To obtain this equilibrium a quantitative mass balance should be used during the design. If the design is coupled with light studies also the use of light and space can be optimised. For both techniques computational methods are recommended.



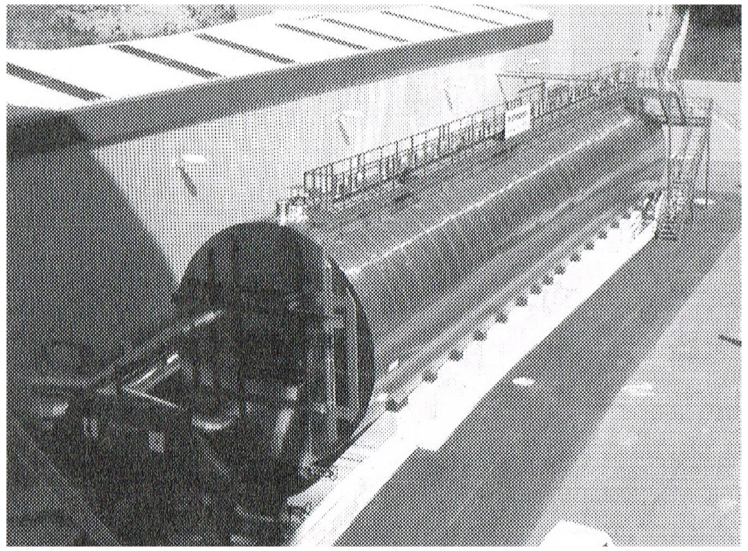
F.1 Simple fixed dome plant



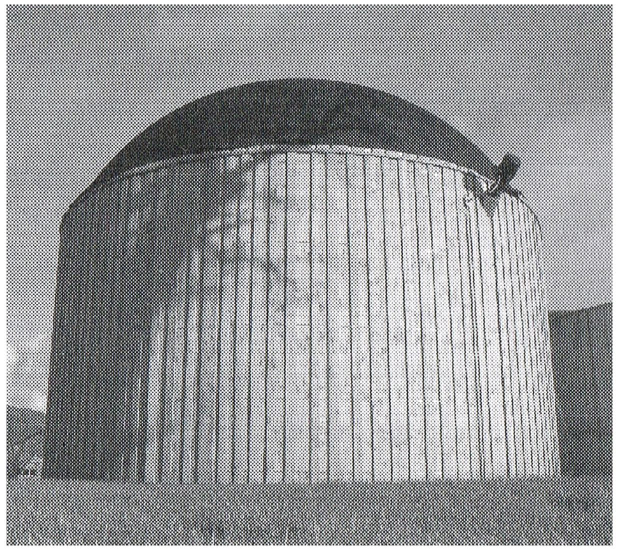
F.2 Simple fixed dome plant with separate gasholder



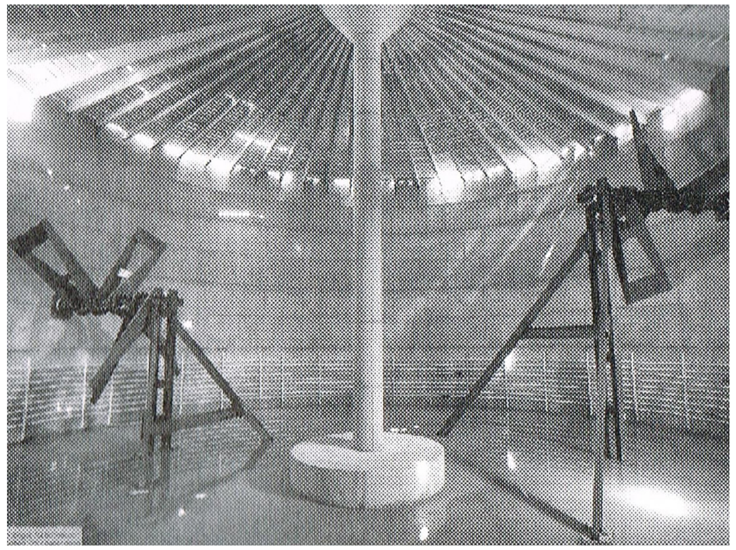
F.3 Simple floating-drum plant



F.4 Steel bioreactor vat in Austria

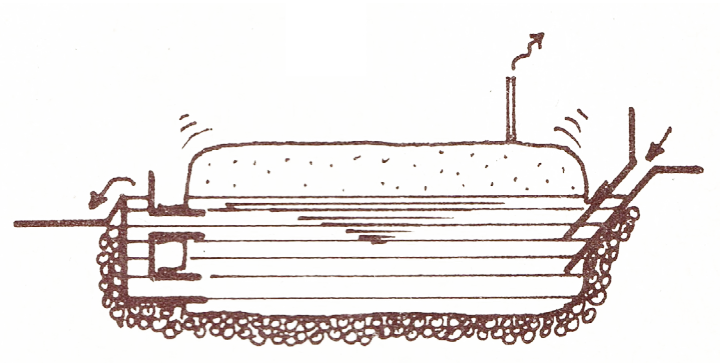


F. 5 Reinforced concrete bioreactor common throughout Europe

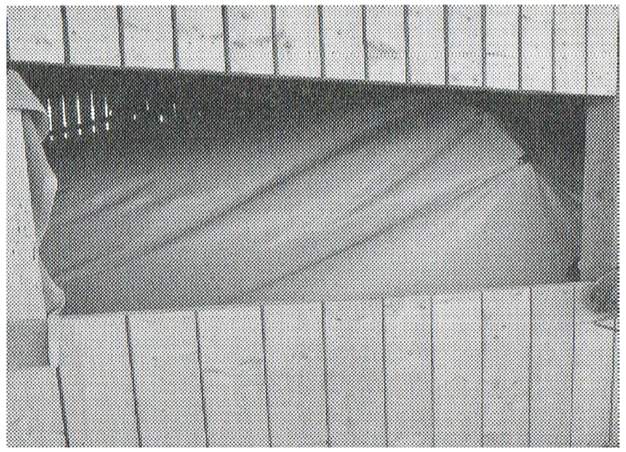


F.5 Heating and agitation devices inside a vertical bioreactor

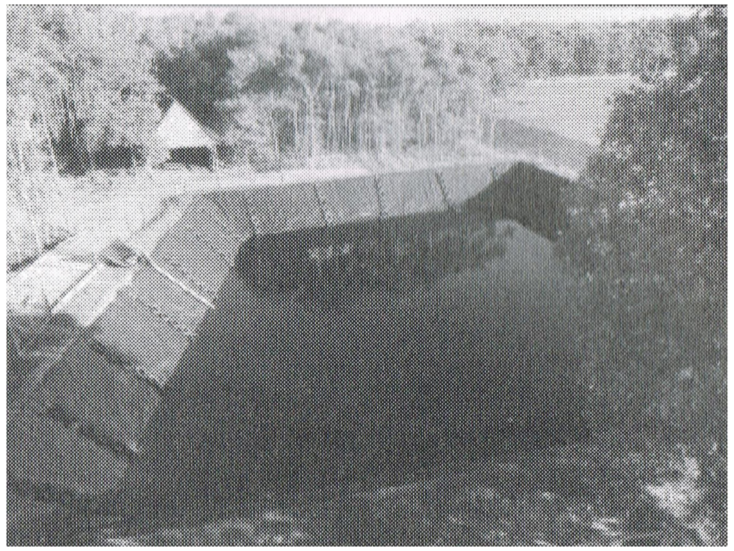
Fig. 3.4.3 Biogas reactor equipment.
Top row: simple small scale systems. Most common in third world countries. Images taken from: Sasse (1984, 14).
Lower rows: complex large scale systems. Include heating, steering and agitation devices. Common throughout Europe. Deublein and Steinhauser (2008, 201).



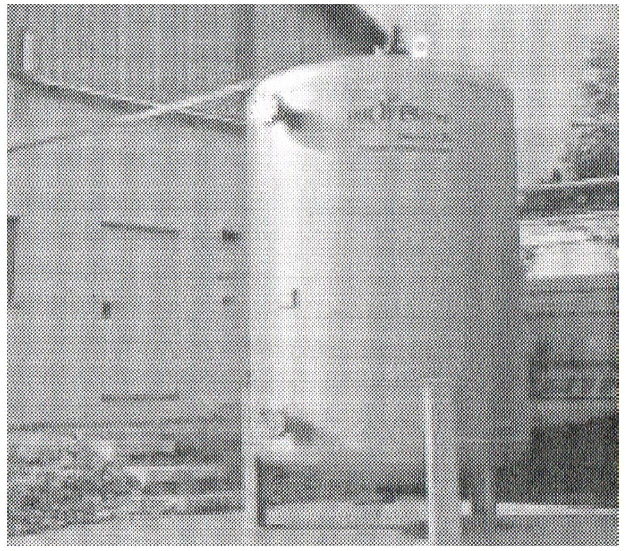
F.4 Simple balloon plant



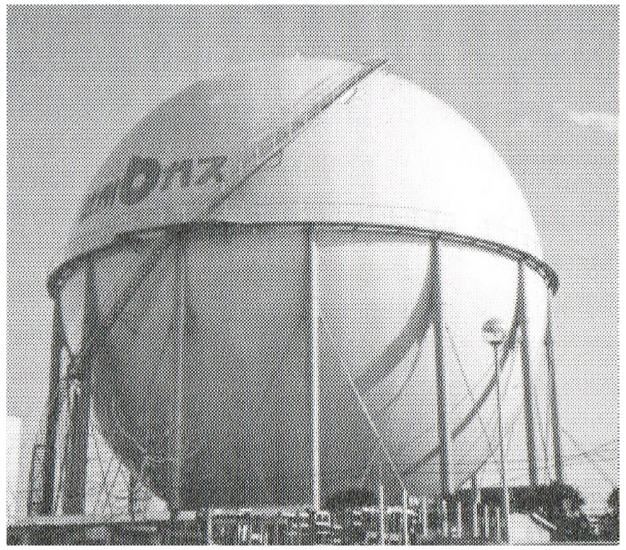
G.1 Simple gasholder: enclosed thermoplastic foil



F.6 Large scale ballon covered basin (balloon takes of)



G.2 Gasholder: steel containment tank



G.3 Large gasholder: spherical steel structure

Figure 3.4.4 Continued.

Fig. 3.4.5 Gasholders used in biogas production.
Images taken from: Deublein and Steinhauser (2008, 329).

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4. CONCLUSION AND DISCUSSION

In this paper we have seen that renewable energy production will only be 'sustainable' if not only technical matters are taken into account. Such production can only be considered sustainable if also social, economic and ecological aspects are considered. This paper has presented energy system and potential mapping (ESM and EPM) as methods for identifying energetic opportunities.

Amsterdam's specific potentials where mapped and it was concluded that production of food and biogas seemed particularly promising. Also harvesting energy from the sun and aquifers and supplying this to the district heat network is an attractive option. Utilizing PV cells for producing electrical power, as well as harvesting cold from Sloterplas, het Binnen-IJ and absorption cooling devices where also identified as having energetic opportunities in the Brettenzone.

These opportunities where synthesized in a preliminary design for an energyscape in the Brettenzone. This design places a large emphasis on agricultural production of food and biogas where a closed cycle of fertilizing nutrients is maintained. In chapter three it was concluded that if such an enterprise is to be sustainable it should focus on producing food, feed, fuel and fertilizer in that respective order of importance. Therefore the production facility has been titled a 4F farm. Chapter three also gave a set of data which can be used to balance and optimize these four F's. Furthermore such a design should seek to optimize the use of light and space. Such an optimisation can be achieved in design by sun studies in conjunction with a quantitative mass balance expressing the 4F yields. For both computative methods seem most suited (fig. 4.1).

The goal of this paper was to research the possibilities of a renewable energy producing landscape in the Brettenzone and its associated reduction in CO2 emissions. In the proposed intervention some reduction will be achieved due to shorter transport distances. The most substantial contribution however comes from the production of biogas. If we look at table 3.3.4 we see that biogas yields vary roughly between 1,000 $m^3ha^{-1}a^{-1}$ and 3,000 $m^3ha^{-1}a^{-1}$. In this paper yield estimates where taken rather conservatively where yield ranges where available. If we assume that yields will be maximized in the design by optimisation of light and space and also assume that yields will increase due to CO2 and nutrient fertilisation than the following estimate seems reasonable:

3,000 $m^3ha^{-1}a^{-1} \cdot 1.32 \cdot 0.63 \cdot 6.25$ $kWhm^{-3} \cdot 0.95 \cdot 343$ ha = 5,080,816 $kWha^{-1}$ or 5,1 $GWha^{-1}$ or 14,8 $MWhha^{-1}a^{-1}$

For a sense of scale this is:

$^1/_{800}$ of Amsterdam's total annual electrical energy consumption or the electrical energy demand of 1,694 Amsterdam households.

Where:

1.32		=	Average increase in yield with CO_2 fetilisation. N.B.: C3 plants react much stronger than C4. (Peet and Krizek 1997, 68)
0.63		=	Fraction of energy which is left if we subtract the energy that is needed for the wet fermentation process. (Deublein and Steinhauser 2008, 224, 255)
6.25	$kWhm^{-3}$	=	Average energy content biogas. (Deublein and Steinhauser 2008, 50)
0.95		=	Efficiency biogas combustion AEB. (AEB 2006, 17) N.B.: This efficiency is unusually high. This is because in the process both electrical and thermal energy are utilized. Furthermore even the heat contained in combustion gases is used to dry waste for AEB's incineration process. The efficiency is very process and context specific. Normally such efficiencies are in the 0.3-0.4 range.
343 ha		=	Plan area
3,000	$kWha^{-1}$	=	Average electrical energy consumption of an Amsterdam household. (KNMI 2012, 29)

Although the energy produced is not fully in the form of electrical energy the calculation above still offers an indication of the contribution of bioenergy in the design. This is somewhat disappointing, especially if we consider the amount of space which has to be asserted to achieve these yields and the ambitions of this research. The results are not surprising though as biogas is a low-value energy product. It should be noted that the biomass yields assumed in this paper are quite conservative. For instance algae and water hyacinths have been reported to achieve yields of up to a two fold of that assumed here. Furthermore the energy potentials of the other interventions (harvesting solar heat, cooling using Sloterplas, etc.) have not been quantified yet and are likely to be substantial. Also food produced in the production gardens should be considered in a full evaluation. Nonetheless, if an energyscape is the goal, than the 4F farm can only be considered an effective intervention if the integration of PV cells or solar collectors in the design greatly increases the overall energy yield per hectare. These should therefore be amongst the most important topics for further research. An alternative would be to reset the goal. For instance: a productive landscape, where energy harvesting is just an aspect, might be a more useful goal. If this goal is chosen a topic

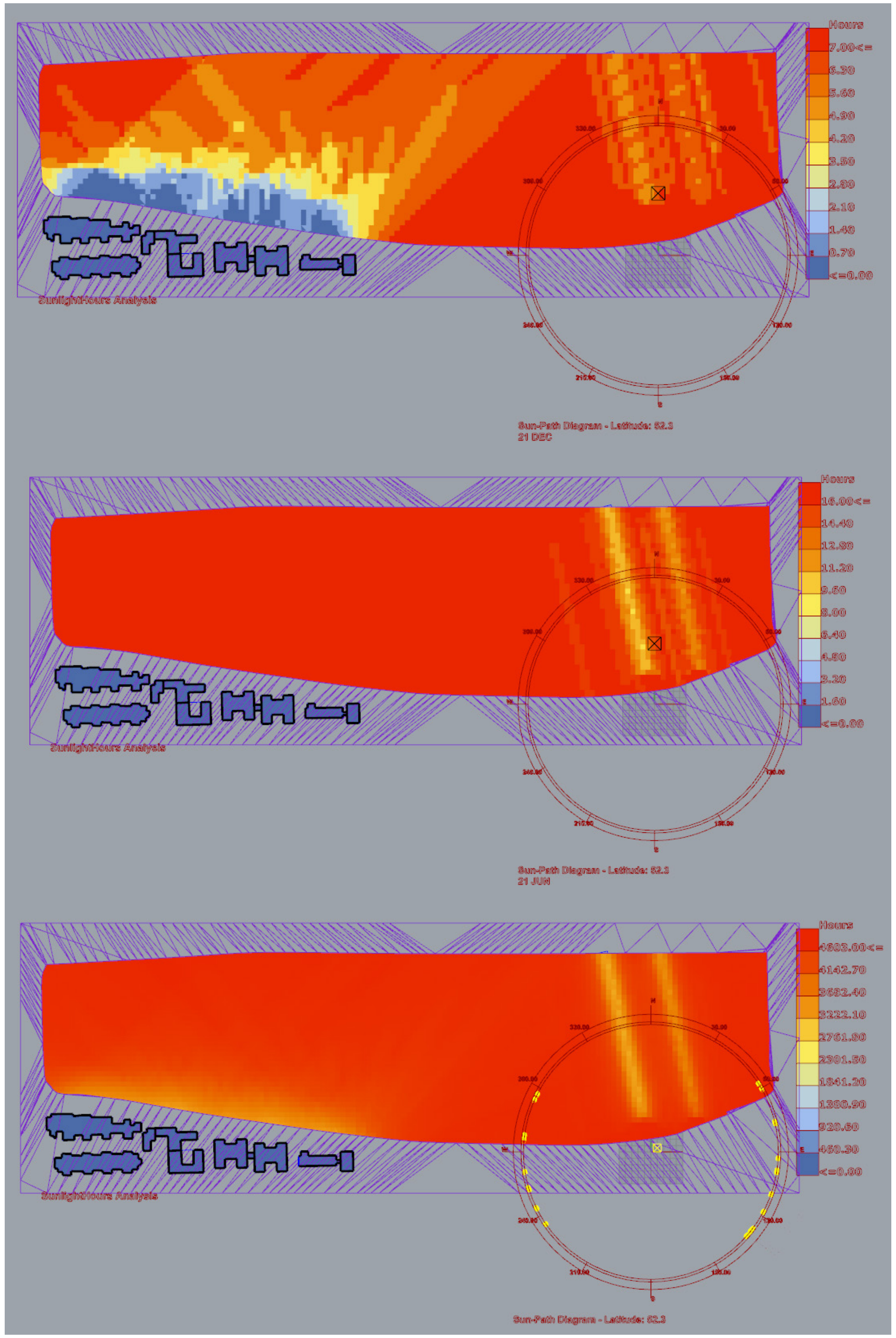

Fig. 4.01 Example of a preliminary sun analyses. Allotment garden in the Brettenzone.
Images show the amount of sunhours for clear weater. Top: 21 Dec; middle: 21 Jun.; bottom: complete year.
Images produced using Rhino®, Grasshopper® and Ladybug®.

for further research could be the integration of apiculture (bee keeping), fungi culture and aqua culture into the production scheme. These topics offer possibilities to increase overall yields, to close cycles and to increase the sustainable value of the design. Also the scale of the goal should be re-evaluated. From this calculation we can conclude that the 4F farm could also be part of a CO_2 neutral scheme for roughly 1,700 dwellings. This could also be an attractive goal which could be coupled to some of the surrounding neighbourhoods.

APENDIX A: MAPPING DATA

Maps:

(DRO 2012)

Agrarian production potential:

Hoeveelheid are gebruikt voor productie van consumptie aardappelen in Nederland in 2005: 6,582,821 are = 658,282,100 m2 (CBS 2013)
Hoeveelheid consumptie aardappelen geproduceerd in 2005: 3,213,019,000 kg (BAI 2008)
3,213,019,000 kg / 658,282,100 m2 = 4.9 kg / m2 = 48809 kg / ha

Biogas energy potential:

Total energy potential grass: 751 + 3350 + 776 + 2287 + 1358 + 836 = 9358 MWh/y (Kompetenzzentrum Biomassenutzung Schleswig-Holstein 2013)
Total energy potential sugar beets: 330 MWh / hec year * 342.5 hec/year = 113,025 MWh/y (32,478 households)
Average household in the Netherlands uses: 3480 kWh / y (NUON 2013c)
The area could provide bio gas energy for (9358 * 10^3) / 3480 = 2689 households.

All sources agrarian and biogas potential: (CBS 2013; BAI 2008; Kompetenzzentrum Biomassenutzung Schleswig-Holstein 2013; NUON 2013c)

Wind:

Year average wind direction and speed at Schiphol. Based on monthly averages from: (KNMI 2011b).

Average wind speed at 10 meters altitude: Teleport area: 4.5 – 5 m/s, Western Brettenzone: 5.0 – 5.5 m/s (De Bosatlas van de energie 2012, 125)
Average wind speed at 100 meters altitude: Teleport area: 6.5 – 7.0 m/s, Western Brettenzone: 7.0 – 7.5 m/s (De Bosatlas van de energie 2012, 67)

Potential Yield 5MW turbines: 275 MWh / hec year * 342.5 hec = 94187.5 MWh/year
Small urban turbines: 120 MWh / hec year * 342.5 hec = 41100 MWh/year

European wind maps: (EEA 2009, 26,45)

Sun:

On average 1500 sun hours per year in the Netherlands. (KNMI 2011a)
Picture sun hours: (De Bosatlas van het klimaat 2011, 48)
Average global radiation / year: 370 - 375 kJ/cm2 (Teleport) 375 - 380 kJ/cm2 (far western end) (De Bosatlas van de energie 2012, 65)

Potential yield solar collectors entire area:
3500 MWh/hec year * 342.5 hec = 1,198,750 mWh / year (Van den Dobbelsteen 2013)
Potential yield PV cells entire area:
1200 MWh/hec year * 342.5 hec = 411,000 mWh / year (Van den Dobbelsteen 2013)

Final:
Differences within Amsterdam are negligible. On average the city receives 360,000 J/cm2 = 114 W/m2.
This would mean a potential of 1000 kWh/m2y.
Photovoltaic cells can harvest about 60-150 kWh/m2y of this energy. (Kürschner et al. 2011, 20)
360 000 J/cm2 = 36 * 109 J/m2, 36 * 109 J/m2 / 31,536,000 sec /y = 114 W/m2 (power)
114 W/m2 * 8766 h/y = 999324 = 1000 kWh/m2y (Kürschner et al. 2011, 20)

Water:

Water level Binnen-IJ:
-0.42 m beneeth N.A.P (Partnerschap Vismigratie Noordzeekanaal 2012, 68) 0.4 acording to (Waternet and Dienst Ruimtelijke Ordening 2010, 29)
Water speed Binnen-IJ gemiddeld: 95 m3/s. This is the amount of water which is dispatched from the North Sea channel when the supply through the Rhine is 1200 m3/s. (Rijksoverheid 2009, 84; Swinkels, Bijlsma, and Hommes 2010, 26)
Min: 0 m3/s. Max: 250 m3/s (Rijkswaterstaat 1991, 7)

Average temp: 14° (leefomgeving 2012) Max: 25° Min: -5° (Burgos and van den Beld 2009, 1)
Average water temperature 14 degrees: (van Gaalen et al. 2012)
Alternative source temperature: Max: 24° (August) Min: -5° (March) (De Bosatlas van de energie 2012, 68)

Total flow sources: (Rijksoverheid 2009, 84; Swinkels, Bijlsma, and Hommes 2010, 26; Rijkswaterstaat 1991, 7)

Water cycle:
Water purification plant in Amsterdam West treats 70% of all the Amsterdam sewage water. This is equivalent to the amount of sewage water of 1.1 million people. Furthermore Amsterdam contains regions where rainwater and sewage water are drained separately (green) and also regions where rain water is drained through the sewage system. (Waternet and Dienst Ruimtelijke Ordening 2010, 30)
Drinking water for Amsterdam is produced at Leiduin (70%) and Weesperkarspel (30%). The dunes at Leiduin purify the water. At this facility on average 180,000 m3 of drinking water is produced (per day). 70% of this water used in Amsterdam (126,000). (Waternet and Dienst Ruimtelijke Ordening 2010, 31)

Rainfall: 864 mm / year (KNMI Klimaatdata en advies 2013, 1)
Ground water levels and street levels (Waternet 2013a)
Surface water levels (Waternet 2013b)
Water flow directions in canals (Waternet and Dienst Ruimtelijke Ordening 2010, 32)

Total water cycle and levels sources: (Waternet and Dienst Ruimtelijke Ordening 2010, 30, 31) (KNMI Klimaatdata en advies 2013, 1; Waternet 2013a, 2013b)
Ground surface levels: (RWS and UvW 2013)

Hydrocarbon system and associated material ecology:

NUON Hemweg 8. Feed: coal (1.6 * 10^9 kg/y) (NUON 2013a) Recycled waste streams: bottom ash, fly as, SO2, NOX. (Vattenfall. 2010)
NUON Hemweg 9. Feed: natural gas. (NUON 2010)
AEB (Afval Energie Bedrijf).

Waste: 1.4 * 109 kg/y. Estimate of 2008 (AEB 2006, 5; 2011, 3) 530*106kg/y is processed in the incineration plant. (AEB 2011, 4)
Sewage dredge: 100 * 106 kg/y. Estimate of 2008 (AEB 2006, 5; 2011, 3)
Capacity: 125 MW, Electrical energy production: 106 MWhe/y. (AEB 2011, 3)

Heat production: 250,000 GJ/y. (AEB 2006, 3)
250,000 *109/3,600,000 = 69 * 106 kWh/y = 69 GWh/y
More recent documents state their heat production is: 500,000 GJ/y. (AEB 2011, 3)
500,000 *109/3,600,000 = 139 * 106 kWh/y = 139 GWh/y

Only 48% of the waste consist of biomass. Only this fraction can be considered a CO2 neutral energy source. (AEB 2008, 5)

Recyclables:

Iron: 17,740,000 kg/y (AEB 2011, 3)
Precious metals: 2,595,000 kg/y (AEB 2011, 3)
Gypsum: 530*106 * (4.5/1000) = 2,385,000 kg/y (AEB 2011, 9)
Aggregate for construction and infrastructure (from bottom and fly ashes):
530*106 * (209/1000) = 110,770,000 kg/y (AEB 2011, 9)

Unrecyclable waste to be landfilled: 530*106 * (0.5/1000) = 265,000 kg/y (AEB 2011, 9)

The industrial ecology of AEB and Orgaworld: the Green mills concept. (Steffart 2012, 12,13; Orgaworld 2013)
The ecology between AEB and RWZI: the eco-port concept. (De Bosatlas van de energie 2012, 70, 119; AEB 2006, 17)

Phosphate cycle:
At the RWZI struvite, a phosphate carrying mineral, is recovered from sewage dredge. (De Bosatlas van de energie 2012, 118-119) This struvite is used by ICL fertilizers to produce artificial manure. This company also uses compost like residues from Orgaworld for their fertilizers. (Haffmans 2012, 6; Mirck 2011) On the extent to which this recycling takes place the sources are inconclusive. This recycling process is a relatively new innovation and most sources are not up to date.

All sources Carbon hydrogen system: (NUON 2013a; Vattenfall. 2010; NUON 2010; AEB 2006, 5; 2011, 3,4,9; Steffart 2012, 12,13; Orgaworld 2013; De Bosatlas van de energie 2012, 70, 119)

Existing biomass co-firing plants and waste incineration plants: (De Bosatlas van de energie 2012, 60).
Biomass plant Lelystad: (NUON 2013d)
Programmatic distribution: (DRO 2012)

Carbon hydrogen biomass potential:
Co-firing biomass at Hemweg 8: Nuon had plans to start co-firing biomass as early as 2012. However they are still looking for a supplier which can deliver at least 20,000,000 kg/y (Haffmans 2012, 16)

Reasons for producing biomass in the Brettenzone: The material required for firing in biomass plants is rather bulky. Therefore short transportation distances are preferable. (Prag 2013, 55)

Biomass potential existing green areas Amsterdam: (Kürschner et al. 2011, 23)

Electrical energy:
Consumption:
Average use of households from 2006 to 2009:
(1590 + 1577 + 1471 +1544) / 4 = 1545 GWh/y
Average use of companies from 2006 to 2009:
(2260 + 2365 + 2644 +2777) / 4 = 2511 GWh/y
Total 1545 + 2511 = 4056 GWh/y (DMB 2011, 11)

Solar production locations and quantaties. (NUON 2013b)
The source gives values in MW/y. This unit has to be a mistake. If I assume that MWh/y was meant, then:
Scale: 10 log (0.16*106)*2.5 = 13
Scale: 10 log (0.25*106)*2.5 = 13
This roughly complies with data from: (RenCom 2013).
Scale: 10 log (0.21*106)*2.5 = 13
If I assume that MW was meant, then:
0.16 MW * 8766 h/y = 1403 MW/y = 1 GWh/y, Scale: 10 log (1.4*109)*2.5 = 22.5
0.25 MW * 8766 h/y = 2192 MW/y = 2 GWh/y, Scale: 10 log (2.1*109)*2.5 = 23.3
0.21 MW * 8766 h/y = 1841 MW/y = 2 GWh/y, Scale: 10 log (1.8*109)*2.5 = 23.1
NUON plants at Hemweg:
Production: 2009: 4940 GWh, 2010: 2990 GWh, 2011:3421 GWh (NUON 2011, 74; 2012, 42) This comes down to an average of: 3783.67 GWh
1664 MW * 8766 h/y = 14586624 MWh/y = 14587 GWh/y (De Bosatlas van de energie 2012, 77) <- Most recent. So I will take this one.
Scale: 10 log (14587*109) * 2.5 = 32.5
Nuon plant Purmerend:
68 MW * 8766 h/y = 596,088 MWh/y = 596 GWh/y
Scale: 10 log (596*109)*2.5 = 30
Nuon plant Diemen:
700 MW * 8766 h/y = 6,136,299 MWh/y = 6136 GWh/y
Scale: 10 log (6136*109)*2.5 = 32.5
Afval Energie Bedrijf:
1 million MWh/y = 1000 GWh/y. (Amsterdam 2012, 4)
160 MW * 8766 h/y = 1402560 MWh / y = 1403 GWh/y (De Bosatlas van de energie 2012, 77)
Scale: 10 log (1403*109) * 2.5 = 30
Cogeneration plant VU:
9.2 MW * 8766 h/y = 80647 MWh / y = 81 GWh/y
Scale: 10 log (81*109) * 2.5 = 27
Windmill park westpoort harbour (37 turbines):
Capacity: 15 MW. (De Bosatlas van de energie 2012, 119)
15 *106 J/s * 31,536,000 sec /y = 4.73 * 1014 J/y
1 kWh = 3.6 MJ so: 4.73 * 1014 J/y = 131. 40 GWh/y
15 MW * 8766 h/y = 131490 MW/y = 131 GWh/y
Scale: (10 log 131*109) * 2.5 = 27
Windmills Amsterdam Noord:
One windmill with a capacity 2 MW and one with capacity of 0.16 MW. (Onze Energie).
2.16 *106 J/s * 31,536,000 sec /y = 6.81 * 1013 J/y = 18.92 GWh
2.16 MW * 8766 h/y = 18935 MWh/y = 19 GWh/y
Scale: (10 log 19*109) * 2.5 = 26
Country production 2010:
118,000*106 kWh/y = 118,000 GWh/y (De Bosatlas van de energie 2012, 77)
Scale: (10 log 118,000*109) * 2.5 = 35
Country consumption 2010:
20 PJ = 20 * 278 *106 = 5560 * 106 kWh = 5560 GWh/y
Consumption electrical vehicles:
Planned number of electrical vehicles in 2015: 10,000. (Passier et al. 2009, 3)
I will assume these cars have a consumption of 140 Wh/km. (Lease plan 2013)
On average a Dutch car drives 13,300 km (CBS 2012)
This would mean a total consumption of 13,000 * 140 * 10,000 = 1.82 * 1010 Wh/y = 18.2 GWh/y
Scale: (10 log 18.2*109) * 2.5 = 26

Scale measure:
10 points = 10(10/2.5)=10,000 Wh/y = 10 kWh/y
15 points = 10(15/2.5)=1,000,000 Wh/y = 1 MWh/y
20 points = 10(20/2.5)=100,000,000 Wh/y = 100 MWh/y
25 points = 10(25/2.5)=10,000,000,000 Wh/y = 10 GWh/y
30 points = 10(25/2.5)=1,000,000,000,000 Wh/y = 1 TWh/y

Total electrical energy system sources: (DMB 2011, 11; NUON 2013b; RenCom 2013; NUON 2011, 74; 2012, 42; De Bosatlas van de energie 2012, 77,119; Amsterdam 2012, 4; Onze Energie; Passier et al. 2009, 3; Lease plan 2013; CBS 2012)

Thermal energy, heat:
District heating system:
Demand: (Groot et al. 2008, 6)
Westpoort: 261 TJ/y, 261 TJ/y / 3.6 MJ/kWh = 72,500,000 kWh/y = 73 GWh/y.
Westelijke Tuinsteden: 34 TJ/y, 261 TJ/y / 3.6 MJ/kWh = 9,444,000 kWh/y = 9 GWh/y.
Amsterdam Noord: 27 TJ/y, 27 TJ/y / 3.6 MJ/kWh = 7500,000 kWh/y = 8 GWh/y.
Zuider Amstel: 289 TJ/y, 289 TJ/y / 3.6 MJ/kWh = 80,277,777 kWh/y = 80 GWh/y.
Zuid Oost: 521 TJ/y, 521 TJ/y / 3.6 MJ/kWh = 72500 kWh/y = 144 GWh/y.
IJburg / Zeeburg: 140 TJ/y, 261 TJ/y / 3.6 MJ/kWh = 38,888,888 kWh/y = 39 GWh/y.

Network structure: (Groot et al. 2008, 8,17; De Bosatlas van de energie 2012, 119; Westpoort Warmte 2011, 1)

Production nodes: (AEB 2006, 3; 2011, 3; Steffart 2012, 12,13; Orgaworld 2013) (De Bosatlas van de energie 2012, 70, 119; AEB 2006, 17)

Total sources heat system: (Groot et al. 2008, 6; De Bosatlas van de energie 2012, 119; Westpoort Warmte 2011, 1; AEB 2006, 3; 2011, 3; Steffart 2012, 12,13; Orgaworld 2013)

Production curve Westpoort Warmte: (Westpoort Warmte 2011, 2)

Cold:

Demand Zuid-Oost:
73 GWh/y based on the amount of offices. 20 GWh/y will be generated in a conventional manner. (Eilering 2007, 15)
Average capacity taken from monthly capacities:
6 MW.(Eilering 2007, 68) This would mean a cooling power of 6 MW * 8766 h/y = 53 GWh/y Or 61 GWh/y according to: (Programmabureau Klimaat en Energie 2011, 32)
Scale: 10 log (53 * 109) * 2 = 21
Temperature cooling water for offices, supply: 16° C, return: 6° C.(Eilering 2007, 26)
Demand Zuidas: 105 GWh/y (Heidweiller 2009, 44)
Desired cooling capacity: 119 MW. (Heidweiller 2009, 48)
Capacity Nieuwe Meer: 75 MW. (Heidweiller 2009, 52) or 172 GWh/y (Programmabureau Klimaat en Energie 2011, 32)
Demand Teleport: 97 GWh (Simoës 2007, 14)
Temperature Ouderkerplas side, supply: 5-6° C, return: 15-18° C.(Eilering 2007, 26)
Cooling water for offices, suply: 16° C, return: 6° C. (Eilering 2007, 21)

Total sources cooling system: (Eilering 2007, 15; Programmabureau Klimaat en Energie 2011, 32; Heidweiller 2009, 44; Simoës 2007, 14; De Bosatlas van de energie 2012, 118,119; Dalin and Rubenhag 2006, 32,33)

Absorption cooling device:
In the vaporizer (V) water is made to vaporize by placing it in vacuum and in open connection to a salt solution in the absorber (A). The salt solution sucks water vapor from it's surroundings and causes water to vaporize even at a low temperature. The same process makes kitchen salt become moist if the salt shaker is left open. This vaporizing draws heat from the office cooling water. In order for the system to work the salt solution has to remain concentrated and can't be too diluted with water. Therefore the salt solution is sent to the generator (G) where hot water from the solar collectors is used to boil water out from the salt solution. The water in the vaporizer also needs to be replenished. Therefore the water vapor from the generator is made to condense again using cooling water. It can then be reused in the vaporizer.
Own illustration, based on an image taken from:
http://www.energieprojecten.nl/edu/ut_absorptiekoeling.html Retrieved 27th of June 2012
Possibility of using them: (Programmabureau Klimaat en Energie 2011, 9, 13; Heidweiller 2009, 40,53; Simoës 2007, 21)

APPENDIX B. PAR LIGHT CONDITIONS AND UNIT CONVERSION TABLES

Heldere hemel					Bedekte hemel				
Air mass	1,0	1,5	2,0	5,6	Cloud optical depth	3	10	30	100
Zonnestand	90°	48,5°	30°	10°	Bewolkingsgraad	zeer licht bewolkt	licht bewolkt	bewolkt	dicht bewolkt
Seizoen in NL	-	zomer	voorjaar & najaar	winter					
Energie-inhoud in W m^{-2}									
PAR	491,9	307,7	217,5	52,9	**PAR**	281,2	199,5	108,5	41,0
B	169,0	104,2	72,9	17,8	**B**	95,5	69,4	38,8	15,0
R	150,2	95,4	68,4	17,1	**R**	87,1	60,4	32,1	11,9
UV	68,6	39,9	27,0	6,6	**UV**	35,8	27,7	16,6	6,8
R:FR	1,20	1,20	1,21	1,23	**R:FR**	1,29	1,66	1,97	3,30
Aantal fotonen in µmol m^{-2} s^{-1}									
PAR	2253	1412	1000	244	**PAR**	1290	912	495	186
B	640	395	276	67	**B**	362	263	147	57
R	817	519	372	93	**R**	474	329	175	65
UV	208	121	82	20	**UV**	109	84	50	20
R:FR	1,08	1,09	1,09	1,11	**R:FR**	1,17	1,50	1,78	2,98

Table. A.1 PAR lighting conditions in the Netherlands.
Taken from: Hemming et al. (2004, 17)

Radiation Source	Multiply by Indicated Value					
	Photons to Wm^{-2}	Wm^{-2} to Photons	Photons to lux[b]	Lux[b] to Photons	Wm^{-2} to lux[b]	lux[b] to Wm^{-2}
Sunlight	0.219	4.57	54	0.019	0.249	4.02
Cool white fluorescent	0.218	4.59	74	0.014	0.341	2.93
Plant growth fluorescent[c]	0.208	4.80	33	0.030	0.158	6.34
High-pressure sodium	0.201	4.98	82	0.012	0.408	2.45
High-pressure metal halide	0.218	4.59	71	0.014	0.328	3.05
Low-pressure sodium	0.203	4.92	106	0.009	0.521	1.92
Incandescent 100W tungsten halogen	0.200	5.00	50	0.020	0.251	3.99

[a] Values vary depending on luminaire, lamp, ballast, and hours of use
[b] Multiply lux times 93.02 to obtain foot candles
[c] GTE Gro-Lux

Table. A.2 PAR conversion factors.
Taken from: Sager and Mc Pharlane (1997, 3)

APPENDIX C. PLANT POTENTIAL TABLE

AGRICULTURAL RESIDUES

CROP / RESIDUE

Residue	**1. Residue yield (kg)**	**2. Primary yield (kg)**	**Type**	**4. Climate / geographic range**	**5. Lighting conditions**	**6. Temperature (˚C)**	**7. Water / moisture**
					Summer: 307,7 $^{W}/_{m2}$ PAR or 1412 µmol/m²s PAR [19] Av. day length: 15.2 hours (54,720 sec.), 77 mol/m² daily PAR **Spring and fall:** 217,5 $^{W}/_{m2}$ PAR or 1000 µmol/m²s PAR [19] Av. day length: 13.8 hours (49,680 sec.), 50 mol/m² daily PAR **Winter:** 52,9 $^{W}/_{m2}$ PAR or 244 µmol/m²s PAR [19], Av. day length: 8.8 hours (31,680 sec.), 8 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) very slightly clouded:** 281,2$^{W}/_{m2}$ PAR or 1290 µmol/m²s PAR, 60 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) slightly clouded:** 199,5 $^{W}/_{m2}$ PAR or 912 µmol/m²s PAR [19], 43 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) clouded:** 108,5 $^{W}/_{m2}$ PAR or 495 µmol/m²s PAR [19], 23 mol/m² daily PAR **Average (13 hours = 46,800 sec.) day densely clouded:** 41,0 $^{W}/_{m2}$ PAR or 186 µmol/m²s PAR [19], 9 mol/m² daily PAR	**Annual:** Av. temp.: 10.1 ˚C[66] Temp. max. > 30˚C : 2 days [10] Temp. max. > 25˚C: 20 days[10] Temp. max. > 20˚C: 75 days[10] Temp. min. < 0 ˚C: 50 days [10] Temp. max. < 0 ˚C: 8 days [10] Temp. min. < -10 ˚C: 2 days[10] Extreme max.: 37,8˚C[10; 7/8/2003] Extreme min.:-24.2˚C[10; 8/1/1985] **Spring Av. temp.:** 9.08˚C[10] **Summer Av. temp.:** 17.75˚C[10] **Fall Av. temp.:** 10.75˚C[10] **Winter Av. temp.:** 3.42˚C[10]	**Average rainfall:** 884 mm/y [10] **Relative humidity:** Spring: 68%[66] Summer: 67%[66] Fall: 77%[66] Winter: 83%[66]
Cereal straw *(wheat, spelt, rye, ect..)*	*2,268 – 4,535 kg / ha·a* [1; average] *3,000 - 3,500 kg / ha·a* [3; average] *4,668 kg / ha·a* [1] [5; Netherlands 2011, total wheat: 7,781 kg/ha*y] *Assumption:* *3997 kg / ha·a*	Grain: *1,511 – 3,023 kg / ha·a* [1; average] *3,112 kg / ha·a* [1] [5; Netherlands 2011, total wheat: 7,781 kg/ha*y] *Assumption:* *2690 kg / ha·a*	*C3*[2]	Wheat: *Temperate zones, both warm and cold, humid to dry, irrigated and high-rainfall areas.* Spelt: - Rye: *Cool temperate zones (as far as arctic zones to northern Chile).*[8]	*For C3 Plants in general light saturation is reached when:* *88 $^{W}/_{m2}$ PAR or 400 µmol/m²s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m² daily PAR* Wheat: *For bread wheat 90% of saturation is reached at: 1,000 µmol/m²s PAR*[4]*. Furthermore in Triticum aestivum wheat 54.0 - 69.12 mol/m² and 38.5 - 84.7 mol/m² daily PAR have shown good results.*[20] Rye [8]: *Flowering requires 14 hours daylight and 5-10˚C. Vegetative growth stops when reproduction begins; shortened day length can extend vegetation length. Rye can harvest winter sun and shading is seldom a problem.* Conclusion: *During winter and on densely clouded days there is not enough radiation for saturation of photosynthesis. However light deprivation during winter can also extend vegetation length which makes wheat suitable as a winter crop.*	Wheat[4]: Germ.: *4-37˚C* Germ. opt: *20-25˚C* Growth min *4,5-5˚C* Growth opt.: *15-25˚C* Growth max.: *30-32˚C* Withstands: *0˚C* Rye[8] and winter wheats: Germ. min: *1-2˚C* Germ. opt: *13-18˚C* Growth min.: *4˚C* Growth opt.: *5-10˚C* Withstands:*-35˚C (snow cover)*	Wheat: Rainfall: *250-1,750 mm/y, 450-650 mm/y*[4] *Tolerant to high ground water: 0.8-1m but not higher than 0.5m* Rye [8]: *Best with ample moisture and low rainfall.* *Drought tolerant. Moisture influences maturation date.*
Sorghum straw *(Sorghum Bicolor)*	*700 - 1,200 kg / ha·a* [4;8] *Assumption: 950 kg / ha·a*	Grain: *800 - 1300 kg / ha·a* [4] *Assumption: 1,050 kg / ha·a*	C3	*US, Africa.*[8]	*For C3 Plants in general light saturation is reached when:* *88 $^{W}/_{m2}$ PAR or 400 µmol/m²s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m² daily PAR* *Day-neutral.*[15] *Some types have performed well in partly shaded areas.*[8]	Growth min.: *15˚C* [4; if used for human consumption] Growth opt.: *25-30˚C*[16] Growth alt.: *10-15˚C*[4; if used for animal fodder] Growth max.: *35˚C* [4] *Susceptible to frost* [8]	*Most areas 450 - 650 mm/y rainfall*[4] *Dry areas: 425 - 450 mm/y rainfall*[4] *Suitable for dry areas with low or erratic rainfall.*[8]
Barley straw	*2,418 kg / ha·a* [5; Ned. 2011, total barley: 6,045 kg/ha*y]	Grain: *3,627 kg / ha·a* [5; Ned. 2011, total barley: 6,045 kg/ha*y]	C3	*Eastern Europe / West Asia, California, North Africa.* *Does not grow in hot humid climates.*[8]	*For C3 Plants in general light saturation is reached when:* *88 $^{W}/_{m2}$ PAR or 400 µmol/m²s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m² daily PAR*	Germ. min.: *-8˚C* [8] *Grows best in cool dry climates however Barley is less cold resistant than wheat and rye.*[8]	*Can tolerate droughts*[8] *Assumption, wheat:* *250-1,750 mm/y*[4]

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2. Deublein and Steinhauser (2008, 17-19, 58-62, 116)
3. Nijaguna (2006, 23, 26) *Some data was converted from tonnes UK to kg.*
4. FAO (1992) *Online repository available at: http://www.fao.org/docrep/003 w3647eW3647E03.htm Retrieved on: 5 may 2013, 15:40, and: http://www.fao.org/nr/water/cropinfo.html Retrieved on: 5 may 2013, 11:41*
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8. SAREP (2013) *Online database available at: http://www.sarep.ucdavis.edu/ database/covercrops Retrieved on: 9 may 2013, 12:15*
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16. Eddy and Hahn (2010, 2,3)
17. Qing, Yang, and Wyman (2010, 5942)
18. Ndazi, Nyahumwa, and Tesha (2008, 1270)
19. Hemming et al. (2004, 17)
20. Wheeler and Sager (2006, 10,19)
21. Sözer and Yaldiz (2012, 2,3)
22. Ulusoy et al. (2009, 1002)
23. Dumitru and Gherman (2010, 586, 587)
24. Lehtomäki (2006, 12,13,20-22)
25. Hutnan et al. (2001, 242)
26. Van An (2004, 14)
27. Elbersen et al. (2004, 141)
28. Blade Energy Crops (2009, 3,4,5,11,12)
29. Mykleby (2012, 40)
30. Nichols et al. (2012, 1)
31. Ahn et al. (2010, 965,968)
32. Clifton-Brown, Stampfl, and Jones (2004, 509,512)
33. Pyter et al. (2007, 41)
34. Clifton-Brown et al. (2011, 383,375)

CROP / RESIDUE					BIOMASS		BIOGAS		
8. Soil / nutrition	**9. Life cycle**	**10. Primary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**11. Residue type**	**12. Notes on residue / secondary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**13. Biomass constituents.** Dry matter (DM percent) Organic dry matter in dry matter (oDM in DM percent) Ash content dry matter (percent) Carbon percentage (percent) C/N Lignin (percent) Protein (percent) C/N = *Measure for fermentation suitability (preferable: 16:1-25:1[2] or 20:1-30:1[3], I assume 25:1[4]).* Green *: 15 : 1 < C/N < 45 :1* Green/Red *: 10 : 1 < C/N < 100 :1, and or ligning > 17%* Red *: 10: 1> C/N, 100 :1 < C/N*	**14. Dry net calorific value (MJ/kg).** *Bituminous coal (for comparison): 27 - 30 MJ/kg[1]* *Hardwood pellets (for comparison): 20.31 MJ/kg[9; #3248]*	**15. Biogas potential** Yield (m³/kg oDM) Yield / ha: (m³/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a*	**16. Biogas Co-fermentation potential** Yield (m³/kg oTS) Yield / ha: (m³/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a* N.B.: *Yield is per organic weight of total solids. This includes manure which has to be mixed into the substrate. The fraction of the crops substrate which is effectively converted to methane differs for each crop. The previous column is therefore more suited for comparing different crops.*	**17. Production advice** U - Harmless S - Containing trash Complexity: I - No II - Litle III - High
Wheat: Nutrient demand[4]: *N: 150 kg/ha K: 25-50 kg/ha* *P: 35-45 kg/ha* *pH: 6-8[4]* Rye[8]: *Best on drained loam or clay loam. Also good on droughty, sandy infertile soils Responds to P addition but not to lime.* *Best: pH 5.0-7.0* *Tolerance: pH 4.5 - 8.0 [8].*	Wheat: *Annual. Harvest in northern hemisphere is between April and September.* Spring wheat: *100-130 days* Wint. wheat: *180-250 days* Rye[8]: *Annual.* *Usually used as winter crop although spring sowing is possible.*	Wheat (common and durum): *Cereal, grain, animal forage and fodder, adhesives, alcohol* Spelt: *Idem. wheat. Large demand from organic supermarkets etc.* Rye[8]: *Grain, animal forage and fodder(low quality therefore mixed with other grains), hay, pasture, cover crop, green manure, alcohol.* *Good for soil erosion control and as rotation crop (with corn, combining with other grains lowers selling price).*	*Field residue*	*Low energy density .* *Compaction is expensive.* *Also used as forage, fodder and animal bedding*	DM = *86 %[2], ca. 70 %[2], Ass.:78%* oDM in DM= *89-94 %[2], Ass: 92%* Ash = *5.04 %[9]* Carb. = *46.02 %[9]* C/N = *90 : 1[2], 130-150 : 1[3], 87:1[23] ,Ass.: 106 : 1* Ligning: *20 %[3]* Protein = *negligible[4]* oDM yield: *2,867 kg/ha·a* *Biogas production is reduced to 30% - 50% unless substrate with low C/N ratio is added.*	*17.21 MJ/kg[9]* *15.69 MJ/kg[9]* *(Dutch pellets)*	Straw: Yield: *0.23 - 0.25 m³/kg[24,23], Ass.: 0.24 m³/kg* Yield / ha: *688* m³/*ha·a* Ret. time: *40 days[24], 120 days[3]*	Wheat straw: Yield: *0.2 - 0.5* m³/kg[2], *Ass.: 0.35* m³/kg Yield / ha: *1000.4 m³/ha·a[24]* Ret. time: *15 days[21,24]* 50% Wheat, 50% Cowm.: Yield: *0.1* m³/kg[2] Yield / ha: *286.8* Ret. time: *15 days[21,24]* *Ass.: 643.6* m³/*ha·a*	*U, II[2]*
Nutrient demand[4]: *N: 180 kg/ha K: 35-80 kg/ha* *P: 45 kg/ha* *Tolerates high pH, up to: 8.0 - 9.0 [8]* *Requires 1 to 1.5 m deep soils.* *Does best on well aerated and well drained soils.[4]*	*Annual warm season crop.[8]* *90 - 125 days.[8]*	*Cereal, grain, animal forage and fodder, biomass, enhancing soil life.[8]*	*Field residue*	*Animal fodder, forage and bedding.*	DM = *86 %[2], 93.03[9], 70 %[2], 83%* oDM in DM = *89 - 94 %[2] 91.5%* Ash = *5.04 %[9], 6.47%[9]* Carb. = *43.32 %[9], 50.92 [3]* C/N = *100.85 : 1[3], 90 : 1[2],95 : 1* Lignin: *- %* Protein = *negligible[4]* oDM yield: *721 kg/ha·a*	*15.4 MJ/kg.[1; sweet sorghum)*	Straw: Yield: *0.23-0.25* m³/kg[24,23], 0.24 m³/kg Yield / ha: *173* m³/*ha·a* Ret. time: *40 days[24], 120 days[3]*	Wheat straw: Yield: *0.2-0.5* m³/kg[2] 0.24 m³/kg Yield / ha: *172* m³/*ha·a[24]* Ret. time: *15 days[21,24]* 50% Wheat, 50% Cowm.: Yield: *0.1* m³/kg[2] Yield / ha: *72* m³/*ha·a* Ret. time: *15 days[21,24]*	*U, II [2]*
Can grow on light droughty soil as well as saline soils. Does well on drained fertile loams and light clay soils.[8] *pH > 6.0 [8]*	*Annual winter grass.[8]* *Flowers April - July.[8]*	*Cereal, grain, animal forage and fodder*	*Field residue*	*Animal forage, fodder and bedding*	DM = *88.47 %[2], ca. 70 %[2], 79%* oDM in DM = *89 - 94 %[2], 92%* Ash = *5.20 %[9]* Carb. = *40.87 %[9]* C/N = *77.11 : 1[9], 90 : 1[2], 84 : 1* Lignin: *- %* Protein = *negligible[4]* oDM yield: *1,757 kg/ha·a*	*17.43 MJ/kg.[9]*	*Yield: 0.159–0.226 m³/kg[24], 0.36 m³/kg[24]* *Assumption: 0.19 m³/kg* *Yield / ha: 334* m³/*ha·a[24]* *Ret. time: 40 days[24]*	20% Bar., 80% Cowm.: Yield: *0.160* m³/kg[24] Yield / ha: *281* m³/*ha·a* Ret. time: *25 days[24]*	*U, II[2]*

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36. Maughan et al. (2012, 6-8,14)
37. Thelen et al. 2009)
38. Braun, Weiland, and Wellinger (2008,5)
39. Klimiuk et al. (2010,1)
40. USDA and NCRS (2002a)
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45. Poiša et al. (2011,229)
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47. Dubrovskis, Adamovics, and Plume (2009,243)
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84. Reitsema (2012)

AGRICULTURAL RESIDUES

				CROP / RESIDUE			
Residue	**1. Residue yield (kg)**	**2. Primary yield (kg)**	**Type**	**4. Climate / geographic range**	**5. Lighting conditions**	**6. Temperature (˚C)**	**7. Water / moisture**
					Summer: 307,7 $^{W}/_{m2}$ PAR or 1412 μmol/m^2s PAR [19] Av. day length: 15.2 hours (54,720 sec.), 77 mol/m^2 daily PAR **Spring and fall:** 217,5 $^{W}/_{m2}$ PAR or 1000 μmol/m^2s PAR [19] Av. day length: 13.8 hours (49,680 sec.), 50 mol/m^2 daily PAR **Winter:** 52,9 $^{W}/_{m2}$ PAR or 244 μmol/m^2s PAR [19], Av. day length: 8.8 hours (31,680 sec.), 8 mol/m^2 daily PAR **Average day (13 hours = 46,800 sec.) very slightly clouded:** 281,2$^{W}/_{m2}$ PAR or 1290 μmol/m^2s PAR, 60 mol/m^2 daily PAR **Average day (13 hours = 46,800 sec.) slightly clouded:** 199,5 $^{W}/_{m2}$ PAR or 912 μmol/m^2s PAR [19], 43 mol/m^2 daily PAR **Average day (13 hours = 46,800 sec.) clouded:** 108,5 $^{W}/_{m2}$ PAR or 495 μmol/m^2s PAR [19], 23 mol/m^2 daily PAR **Average (13 hours = 46,800 sec.) day densely clouded:** 41,0 $^{W}/_{m2}$ PAR or 186 μmol/m^2s PAR [19], 9 mol/m^2 daily PAR	**Annual:** Av. temp.: 10.1 ˚C[66] Temp. max. > 30˚C : 2 days [10] Temp. max. > 25˚C: 20 days[10] Temp. max. > 20˚C: 75 days[10] Temp. min. < 0 ˚C: 50 days [10] Temp. max. < 0 ˚C: 8 days [10] Temp. min. < -10 ˚C: 2 days[10] Extreme max.: 37,8˚C[10; 7/8/2003] Extreme min.:-24.2˚C[10; 8/1/1985] **Spring Av. temp.:** 9.08˚C[10] **Summer Av. temp.:** 17.75˚C[10] **Fall Av. temp.:** 10.75˚C[10] **Winter Av. temp.:** 3.42˚C[10]	**Average rainfall:** 884 mm/y [10] **Relative humidity:** Spring: 68%[66] Summer: 67%[66] Fall: 77%[66] Winter: 83%[66]
Pulp from sugar beat	Pulp: *8,000 - 15,000 kg / ha·a* [3; average] *16,000 - 36,000 kg / ha·a* [7, 23] *Assumption: 37,500 kg / ha·a* Leaves: *18,000 kg / ha·a*	Sugar: *6,000 - 7000 kg / ha·a* [7; fresh beet 40,000 kg/ha*y) 6,000 - 9000 kg / ha·a [4; fresh beet 40,000 - 60,000 kg/ha*y] *Assumption: 14,500 kg / ha·a* Molasses: *1,200 - 2,700 kg / ha·a* [7; fresh beet 40,000 kg/ha*y] *Assumption: 1,950 kg / ha·a*	*C3*[2]	*Subtropics and temperate zone.*[4]	*For C3 Plants in general light saturation is reached when:* *88 $^{W}/_{m2}$ PAR or 400 μmol/m^2s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m^2 daily PAR*	Germ. min.: *5˚C* [4] Germ. opt.: *7-10˚C* [4] Growth opt. day: *20-25˚C* [4] Growth opt. night:*15-20˚C*[4] Growth max.: *30˚C* [4]	*550 - 750 mm/y rainfall*[4]
Tomato debris	*70,000 kg / ha·a*[83; intensive cultivation in greenhouses in Turkey]	*200,000 kg / ha·a* [83; intensive cultivation in greenhouses in Turkey] *480,000 kg / ha·a* [84; average yield of greenhouses in the Netherlands]	C3	*Outside: Temperate climates.* *In greenhouses: Colder temperate climates.*	Min.: *4.6 mol/m^2d daily PAR.*[19] Opt. growth: *30 mol/m^2d daily PAR.*[19] Good result where seen with: *26.6 - 38.6 mol/m^2d daily PAR.*[12] Also with: *500 - 750 μmol/m^2s PAR during 12 hours. Which is equal to: 21.6 - 32.4 mol/m^2d daily PAR.*[12] Assumption: *30 mol/m^2d daily PAR*	Growth. opt. day: *18-25˚C*[4] Growth. opt.night:*18-20˚C*[4]	*400-600 mm/y*[4] *Dry climates are preferred.*[4]
Potato haulm	*4,300 - 6,000 kg / ha·a* [26; dry mass] *Assumption: 5,150 kg / ha·a*	Potato: *3,000 - 4,000 kg / ha·a* [26] *Assumption: 3,500 kg / ha·a*	*C3*	*Grown globally. Mostly in the temperate climates.*[4]	Good result where seen with: *500 - 800 μmol/m^2s PAR during 12 hours.*[12] *Which is equal to: 21.6 - 32.6 mol/m^2d daily PAR.*	Growth opt. day: *18-20˚C* [4] Growth opt. night < *15˚C*[4] Growth min.: *10˚C* [4] Growth max.: *30˚C* [4]	*500-700 mm/y*[4]

1. Gupta and Demirbas (2010, 59,60,69) *Some data was converted from tons US to kg.*
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34. Clifton-Brown et al. (2011, 383,375)

CROP / RESIDUE					BIOMASS		BIOGAS		
8. Soil / nutrition	**9. Life cycle**	**10. Primary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**11. Residue type**	**12. Notes on residue / secondary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**13. Biomass constituents.** Dry matter (DM percent) Organic dry matter in dry matter (oDM in DM percent) Ash content dry matter (percent) Carbon percentage (percent) C/N Lignin (percent) Protein (percent) C/N = *Measure for fermentation suitability (preferable: 16:1-25:1*[2] *or 20:1-30:1*[3]*, I assume 25:1*[4]*).* Green : *15 : 1 < C/N < 45 :1* Green/Red : *10 : 1 < C/N < 100 :1, and or ligning > 17%* Red : *10: 1> C/N, 100 :1 < C/N*	**14. Dry net calorific value (MJ/kg).** *Bituminous coal (for comparison): 27 - 30 MJ/kg*[1] *Hardwood pellets (for comparison): 20.31 MJ/kg*[9; #3248]	**15. Biogas potential** Yield (m^3/kg oDM) Yield / ha: (m^3/ha·a) Retention time (d) Green > *1,000 kg/ha·a* Green/Red > *500 kg/ha·a* Red < *500 kg/ha·a*	**16. Biogas Co-fermentation potential** Yield (m^3/kg oTS) Yield / ha: (m^3/ha·a) Retention time (d) Green > *1,000 kg/ha·a* Green/Red > *500 kg/ha·a* Red < *500 kg/ha·a* N.B.: *Yield is per organic weight of total solids. This includes manure which has to be mixed into the substrate. The fraction of the crops substrate which is effectively converted to methane differs for each crop. The previous column is therefore more suited for comparing different crops.*	**17. Production advice** U - Harmless S - Containing trash Complexity: I - No II - Litle III - High
Nutrient demand[4]: *N: 150 kg/ha K: 100-160 kg/ha* *P: 50-70 kg/ha* *pH > 5.5* [8] *Does best on well drained soils. Drains water from 0.7-1.2 meters of soil depth.*[4]	*Biannual crop. For sugar production crops are harvested after first year.*[4] *In the Mediterranean sugar beet is planted in march and harvested after 160 days.*[4]	Total sugar beet: *bioethanol, animal f odder* Sugar (syrup)[23]: *Sugar, alcohol* Molasses [23]: *Chemical industry, bioethanol, biogas.*	*Process residue*	Pulp[23]: *Animal fodder, biogas* Leaves[23]: *Animal fodder, biogas*	Beet pulp: DM = *16.7 %*[9] oDM in DM = *80-95 %*[2]*, 88%* Ash = *4.07 %*[9] Carb. = *5.93%*[9] C/N = *28.24:1* [9] Lignin: - %, Protein: *5%*[9;#1052] oDM yield: *5,511 kg/ha·a* Beet leaves: DM = *12.8 %*[9]*, 15-18 %*[2]*, 15%* oDM in DM = *78-80 %*[2]*, 79%* Ash = - Carb. = *41 %*[23] C/N = *41* [23] Lignin: *1.6 %*[9], Protein: *12%*[9; #2622] oDM yield: *2,133 kg/ha·a*	Beet pulp: *12.45 MJ/kg.*[9] Beet leaves: -	Pressed beet pulp: Yield: *0.09* m^3/kg[25] Ret. time: *31 days*[25] Yield / ha: *238* m^3*/ha·a* Beet leaves: Yield: *0.216* m^3/kg[24] *0.45* m^3/kg[25], 0.4-0.8 m^3/kg[2] *Assumption: 0.6* m^3*/kg* Ret. time: - Yield / ha: *1,280* m^3*/ha·a* Yield / ha: *1,518* m^3*/ha·a*	Little need for co-fermentation of beet pulp as the C/N value is already near the optimum.	*U,S,II* [2]
Nutrient demand[4]: *N: 100-150 kg/ha K: 160-240 kg/ha* *P: 65-110 kg/ha* *pH: 5-7*[8] *Does best on well drained light loam soils.*[4]	*100-140 days.*[8]	*Vegetable, other food products*	*Field residue*	*Compost*	DM = *35 %*[83] oDM in DM = *80.0 %*[83] Ash = *20.20 %*[9; #2261 plant waste] Carb. = *3.99 %*[9; #2887 full tomato plant] C/N = *16.6 : 1* [9; #2887 full tomato plant] Lignin: *10.5 %*[9] Protein = *13.00%* [9;#2261 plant waste] oDM yield: *19,600 kg/ha·a*	Full tomato plant: *13.94 MJ/kg.*[9; #2887 full tomato plant] Plant waste: *-0.25 MJ/kg.*[9;#2261]	90% Tom., 10% Cowm.: Yield: *0.07* m^3/kg[24] *(or 0.1* m^3*/kg*d)* Yield / ha: *1,372* m^3*/ha·a* Ret. time: *15 days*[21]	30% Tom., 70% Cowm.: Yield: *0.28* m^3/kg[21] *(or 0.1* m^3*/kg*d)* Yield / ha: *4,508* m^3*/ha·a* Ret. time: *15 days*[21]	-
Nutrient demand[4]: *N: 80-120 kg/ha K: 125-160 kg/ha* *P: 50-80 kg/ha* *pH: 5-6*[4] *Requires well drained and well aerated soils.*[4]	*115-165 days.*[4]	*Vegetable, animal fodder, other food products.*	*Field residue*	*Compost, animal fodder*	DM = *25%*[2;] oDM in DM = *97 %*[2] Ash = - Carb. = *40 %*[23] C/N = *22:1* [23] Lignin: - Protein = *25-29.8%* [26] oDM yield: *1,249 kg/ha·a*	-	Yield: 0.395 m^3/kg[23] Yield / ha: *493* m^3*/ha·a* Ret. time: *26-79 days*[2]	20% Pot., 80% Pigm.: Yield: *0.30-0.33* m^3/kg[24] 0.32 m^3/kg Yield / ha: *340* m^3*/ha·a* Ret. time: *26 days*[24] Unknown mixture: Yield: *0.8-1.0* m^3*/kg*[2] *0.9* m^3*/kg* Yield / ha: *1,124* m^3*/ha·a*[2] Ret. time: *79days*[2] Assumption: *732* m^3*/ha·a*	*U, S, II*[2]

35. Heaton (2010,1,2)
36. Maughan et al. (2012, 6-8,14)
37. Thelen et al. 2009)
38. Braun, Weiland, and Wellinger (2008,5)
39. Klimiuk et al. (2010,1)
40. USDA and NCRS (2002a)
41. USDA and NCRS (2002b)
42. -
43. Samson, Duxbury, and Mulkins (2000,3)
44. Landström, Lomakka, and Andersson (1996,334)
45. Poiša et al. (2011,229)
46. Vervuren, Beurskens, and Blom (1999,960)
47. Dubrovskis, Adamovics, and Plume (2009,243)
48. Sukkel (2008)
49. Heiermann et al. (2009)
50. Braun, Weiland, and Wellinger (2008, 5)
51. Hasan and Chakrabarti (2009, 54-56)
52. Spencer and Bowes (1986, 528)
53. Reddy and D'Angelo (1990, 27)
54. Pienkos and Darzins (2009, 432,434,435)
55. Darzins, Pienkos, and Edye (2010, 18)
56. Converti et al. (2009, 1147)
57. Lv et al. (2010, 6797)
58. Kebede and Ahlgren (1996, 101)
59. Smith et al. (1990, 1433)
60. Johnson et al. (2000, 423)
61. Kao and Lin (2010, 650)
62. Tu and Ma (2003, 245)
63. Blombäck (2004, 2)
64. Ericsson, Blombäck, and Neumann (2012, 2)
65. Anderson et al. (-)
Online database, available at: http://earthobservatory.nasa.gov/Experiments/Biome/biograssland.php, Retrieved on 29 may 2013, 22:50.
66. KNMI (2011a, 23)
67. Becker (2007, 3)
77. Patil, Tran, and Giselrød (2008, 1191)
77. Fujita, Scharer, and Moo-Young (1980, 177,180,183)
78. Zheng et al. (2009, 5142, 5144)
79. Norman and Murphy (2005, 2)
80. Amon et al. (2007, 3207, 3210)
82. Raja and Lee (2012, 20)
83. Daniel-Gromke, Ertem, and Rensberg (2011, 48,49)
84. Reitsema (2012)

AGRICULTURAL RESIDUES

CROP / RESIDUE

Residue	1. Residue yield (kg)	2. Primary yield (kg)	Type	4. Climate / geographic range	5. Lighting conditions	6. Temperature (˚C)	7. Water / moisture
					Summer: 307,7 $^{W}/_{m2}$ PAR or 1412 µmol/m²s PAR [19] Av. day length: 15.2 hours (54,720 sec.), 77 mol/m² daily PAR **Spring and fall:** 217,5 $^{W}/_{m2}$ PAR or 1000 µmol/m²s PAR [19] Av. day length: 13.8 hours (49,680 sec.), 50 mol/m² daily PAR **Winter:** 52,9 $^{W}/_{m2}$ PAR or 244 µmol/m²s PAR [19], Av. day length: 8.8 hours (31,680 sec.), 8 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) very slightly clouded:** 281,2$^{W}/_{m2}$ PAR or 1290 µmol/m²s PAR, 60 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) slightly clouded:** 199,5 $^{W}/_{m2}$ PAR or 912 µmol/m²s PAR [19], 43 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) clouded:** 108,5 $^{W}/_{m2}$ PAR or 495 µmol/m²s PAR [19], 23 mol/m² daily PAR **Average (13 hours = 46,800 sec.) day densely clouded:** 41,0 $^{W}/_{m2}$ PAR or 186 µmol/m²s PAR [19], 9 mol/m² daily PAR	**Annual:** Av. temp.: 10.1 ˚C[66] Temp. max. > 30˚C: 2 days [10] Temp. max. > 25˚C: 20 days[10] Temp. max. > 20˚C: 75 days[10] Temp. min. < 0 ˚C: 50 days [10] Temp. max. < 0 ˚C: 8 days [10] Temp. min. < -10 ˚C: 2 days[10] Extreme max.: 37,8˚C[10; 7/8/2003] Extreme min.:-24.2˚C[10; 8/1/1985] **Spring Av. temp.:** 9.08˚C[10] **Summer Av. temp.:** 17.75˚C[10] **Fall Av. temp.:** 10.75˚C[10] **Winter Av. temp.:** 3.42˚C[10]	**Average rainfall:** 884 mm/y [10] **Relative humidity:** Spring: 68%[66] Summer: 67%[66] Fall: 77%[66] Winter: 83%[66]
Corn stover *(leaves and stalk)*	*5,442 kg / ha·a* [1; average] *6,000 - 10,000 kg / ha·a* [3; average] *5,693 kg / ha·a* [1] [5; Netherlands 2011, total maize: 12,336 kg/ha*y] *Assumption:* *<u>5,500</u> kg / ha·a*	Corn: *6,349 kg / ha·a* [1; average] *6,642 kg / ha·a* [1] [5; Netherlands 2011, total maize: 12,336 kg/ha*y] *Assumption:* *<u>6,500</u> kg / ha·a*	*C4*[2]	Maize: *Pan-tropical, Summer crop in temperate Europe.*	C4 Plants: *Minimum 500 µmol/m²s or 109 $^{W}/_{m2}$ PAR, provided daily for 16 hours.* *Higher values are desirable.* [12] *Up to 1000-2000 µmol/m²s during 14-16 hours can increase growth. Which would mean 50.4-115.2 mol/m² daily PAR. Furthermore 20 hours during vegetative growth would be optimal.*[16 who refer to 12] *This would mean 72-144 mol/m² daily PAR.*	Germ. min.: 10˚*C*[4] Germ. opt: *20-30˚C*[4] Growth min.: *15˚C* [4; if used for human consumption] Growth opt.: *21-23˚C*[16] Growth alt.: *10-15˚C*[4; if used for animal fodder] *Susceptible to frost* [4]	Min: *500 mm/y rainfall* [4] Opt.: *1,200-1,500 mm/y rainfall*[4] Opt.: *500-750 mm/y rainfall* [16] Opt.: *500-800 mm/y rainfall* [4] *(not drought tolerant, often irrigated)* [4]
Rice husk	*1,000 - 3,000 kg / ha·a* [3; average] *1681 kg / ha·a* [5; Spain 2011, total paddy: 7,641 kg/ha*y] [6; this yields about 22% husk] *Assumption: <u>1,500</u> kg / ha·a*	Rice grain: *<u>5,502</u> kg / ha·a* [5; Spain 2011, total paddy: 7,641 kg/ha*y] [6; this yields about 72% rice]	*C3*	*Eastern and southern Asia, Middle East, Latin America, United states.* *Hot and humid climates.*[15]	*For C3 Plants in general light saturation is reached when:* *88 $^{W}/_{m2}$ PAR or 400 µmol/m²s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m² daily PAR* *Rice is a day-neutral plant.*[15] *Furthermore Rice (Oryza sativa) has show good results with 750-800 µmol/m²s PAR during 12 hours.*[20] *This would mean: 32.4 - 34.6 mol/m².*	Reprod. min.: *17˚C*[4] Growth min.: *10˚C* [4; if used for human consumption] Growth opt.: *25˚C*[14], *20-23˚C*[13] Withstands: *40˚C*[13] *Susceptible to frost* [4]	Min. lowland rice: *200 mm/month (1400 mm/y) rainfall* [15] Min. upland rice: *100 mm/month (1200 mm/y) rainfall* [15] *Can also be irrigated.* [15]
Bagasse *(sugar cane pressing residue)*	*20,000 - 25,000 kg / ha·a* [3; average] *9,813 kg / ha·a* [1][5; United states 2011] *Assumption: <u>16,156</u> kg / ha·a*	Sugar: *20,769-25,961 kg / ha·a* [1][3; average] *10,190 / ha·a* [1][5; United states 2011] [4; average yield of cane: 70,000-150,000 kg/ha·a, Total biomass 255,000-480,000 kg/ha·a] *Assumption: <u>16,778</u> kg / ha·a*	*C4*[4]	*Tropical and subtropical climate.*[1] *Largest producing countries are China, Thailand, Brazil and India.* *Sugarcane requires a long warm growing season.*[4]	C4 Plants: *Minimum 500 µmol/m²s or 109 $^{W}/_{m2}$ PAR, provided daily for 16 hours. This would come down to 28.8 mol/m² daily PAR (57,600 seconds in 16 hours).* Requires high incidence of irradiation. Assumption: *50.4-115.2 mol/m² daily PAR is required for optimal growth.*	Germ. opt.: *32-38˚C* [4] Growth min.: *20˚C* [4] Growth opt.: *22-30˚C* [4] Ripening opt.: *10-20˚C* [4] *Requires warm long growing season and cool but not freezing ripening and harvest period.*[4]	Min: *600 mm/y rainfall* [9] Opt.: *1,500-2,500 mm/y rainfall* [9] *Water content ground: 15%* [9]

1. Gupta and Demirbas (2010, 59,60,69) *Some data was converted from tons US to kg.*
2. Deublein and Steinhauser (2008, 17-19, 58-62, 116)
3. Nijaguna (2006, 23, 26) *Some data was converted from tonnes UK to kg.*
4. FAO (1992) *Online repository available at: http://www.fao.org/docrep/003/w3647eW3647E03.htm Retrieved on: 5 may 2013, 15:40, and: http://www.fao.org/nr/water/cropinfo.html Retrieved on: 5 may 2013, 11:41*
5. FAO (2013) *Crop yield data for 2011. Online database available at: http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor. Retrieved on: 8 may 2013, 21:36*
6. DMI (2003, 8,70)
7. IENICA (2007) *Online database available at: http://www.ienica.net/cropsdatabase.htm Retrieved on: 8 may 2013, 23:29*
8. SAREP (2013) *Online database available at: http://www.sarep.ucdavis.edu/database/covercrops Retrieved on: 9 may 2013, 12:15*
9. ECN (2012) *Online database available at: http://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis Retrieved on: 9 may 2013, 14:34*
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11. Franceschini (1977, 30)vv
12. Sager and Mc Pharlane (1997, 4)
13. Lee (2001, 112)
14. Defoer et al. (2004, 39)
15. VASAT (2013) *Online educational source available at: http://vasat.icrisat.org Retrieved on: 10 may 2013, 14:20*
16. Eddy and Hahn (2010, 2,3)
17. Qing, Yang, and Wyman (2010, 5942)
18. Ndazi, Nyahumwa, and Tesha (2008, 1270)
19. Hemming et al. (2004, 17)
20. Wheeler and Sager (2006, 10,19)
21. Sözer and Yaldiz (2012, 2,3)
22. Ulusoy et al. (2009, 1002)
23. Dumitru and Gherman (2010, 586, 587)
24. Lehtomäki (2006, 12,13,20-22)
25. Hutnan et al. (2001, 242)
26. Van An (2004, 14)
27. Elbersen et al. (2004, 141)
28. Blade Energy Crops (2009, 3,4,5,11,12)
29. Mykleby (2012, 40)
30. Nichols et al. (2012, 1)
31. Ahn et al. (2010, 965,968)
32. Clifton-Brown, Stampfl, and Jones (2004, 509,512)
33. Pyter et al. (2007, 41)
34. Clifton-Brown et al. (2011, 383,375)

CROP / RESIDUE					BIOMASS		BIOGAS		
8. Soil / nutrition	**9. Life cycle**	**10. Primary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**11. Residue type**	**12. Notes on residue / secondary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**13. Biomass constituents.** Dry matter (DM percent) Organic dry matter in dry matter (oDM in DM percent) Ash content dry matter (percent) Carbon percentage (percent) C/N Lignin (percent) Protein (percent) *C/N = Measure for fermentation suitability (preferable: 16:1-25:1[2] or 20:1-30:1[3], I assume 25:1[4]).* Green : *15 : 1 < C/N < 45 :1* Green/Red : *10 : 1 < C/N < 100 :1, and or ligning > 17%* Red : *10: 1> C/N, 100 :1 < C/N*	**14. Dry net calorific value (MJ/kg).** *Bituminous coal (for comparison): 27 - 30 MJ/kg[1]* *Hardwood pellets (for comparison): 20.31 MJ/kg[9; #3248]*	**15. Biogas potential** Yield (m^3/kg oDM) Yield / ha: (m^3/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a*	**16. Biogas Co-fermentation potential** Yield (m^3/kg oTS) Yield / ha: (m^3/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a* N.B.: *Yield is per organic weight of total solids. This includes manure which has to be mixed into the substrate. The fraction of the crops substrate which is effectively converted to methane differs for each crop. The previous column is therefore more suited for comparing different crops.*	**17. Production advice** U - Harmless S - Containing trash Complexity: I - No II - Litle III - High
Requires a well-drained, fertile soil. Alluvial loams, deep latosols and clay loams are preferred[4] High nutrient demand[4]: *N: 200 kg/ha K: 60-100 kg/ha* *P: 50-80 kg/ha*	*Annual* *Cycle of 135 days* *In Europe it is used as a summer crop and planted in April.*[4]	*Cereal, vegetable, adhesives, soap, alcohol, biofuels.*	*Field residue*	*Direct burning possible.* *Pulp for paper industry and particle boards.*	DM = <u>86</u> *%*[2] oDM in DM= *72 %*[2], <u>89.7</u> *%*[2] Ash = *4.75 %*[9] Carb. = *43.98 %*[9] C/N = *71 : 1*[9] *, 59 : 1*[78], *Ass.:* <u>65 : 1</u> Lignin = *17.6 %* [19] Protein *=7.75%*[4], oDM yield: <u>4,243</u> *kg/ha·a* *Stalks can production by 25%, properties similair to wheat straw.*[3]	*16.85 MJ/kg*[9] *17.6 MJ/kg*[1]	Yield: *0.162-0.211 m^3/kg*[78] <u>0.19</u> *m^3/kg* Yield / ha: <u>806</u> m^3*/ha·a* Ret. time: *75 days*[78] *,120 days*[3]	M. Straw, unknown mix: Yield: *0.4-1.0*[2], <u>0.7</u> m^3/kg Yield/ha:<u>2,970</u> m^3*/ha·a*[24] Ret. time: *15 days*[21,24] 25% Stover, 75% Pigm.: Yield: *0.305 m^3/kg*[78; 50% of stover is gasified] <u>1,294</u> *m^3/ha·a* *Ret. time: 16 days*[24] *Ass.:*<u>1,711</u> m^3*/ha·a*	*U, II* [2]
Heavier soil with large water holding capacity. *Rice is either grown as low land crop standing in water or as an upland crop under rain fed conditions.*	*Annual* *Perennial in some parts of Asia.* *Can mature in 100-150 days*	*Cereal, Staple food, thickening agent, alcohol*	*Process residue*	*Uniform in nature, good flow characteristics. Suitable for gasification, however: High silica content can cause problems in boilers.*[1] *Also yields 6 % bran (459 kg / ha·a) which can be used in: bread, biscuits, cattle feed, organic fertilizer, medicine and wax making.*[1]	DM = *25-50 %*[2], *Ass.:* <u>38%</u> oDM in DM = *70-95 %*[2], *Ass.:* <u>83%</u> Ash = *19.50 %*[9] Carb. = *48.25 %*[9] C/N = <u>78.58 : 1</u>[9] Lignin: *33 %* [18], Protein = *3.98%*[4] oDM yield: <u>1,358</u> *kg/ha·a* *Rice straw can reduce biogas production by 25% other properties are similair to wheat straw.*[3]	*12.06 MJ/kg*[9]	Yield: - Yield / ha: - Ret. time: *33 days*[3]	Husk: Yield: *0.55-0.62,* <u>0.59</u> m^3/kg[2] Ret. time: *33 days*[3] Paddy straw: Yield: *0.24-0.37,* <u>0.31</u> m^3/kg[24] Ret. time: - Total yield / ha: *421* m^3*/ha·a*[24]	*U, II* [2]
Nutrient demand[4]: *N: 100-200 kg/ha K: 125-160 kg/ha* *P: 20-90 kg/ha* *pH: 5-8.5*[4] *Soil depth min. 1 m.* [4] *Optimal depth: 5 m.* [4]	*Annual.*[1] *9-24 months, usually 15-16 months.*[4] *Sugar cane crushing 6-7 months.*[1]	*Sugar, animal fodder, energy crop, alcohol, yeast.*[4] *Sugarcane has the best sun harvesting efficiency.*	*Process residue*	*Direct combustion used within sugar process to cook cane and evaporate syrup. Usually however there is an excess of bagasse.*[1] *Bagasse is also used in particle board and paper.*	DM = *93 %*[9;#2342] oDM in DM = *82.10 %*[9;#2342] Ash = *3.0 %*[4], *3.2-5.5 %*[1] Carb. = *45.39 %*[9] C/N = <u>150:1</u> [3] Lignin: *20 %* [4] Protein = *3%*[9; #2612] oDM yield: <u>12,336</u> *kg/ha·a*	*19.2 MJ/kg.*[1; 9; #2342] *18.1 MJ/kg.*[1]	Yield: - Yield / ha: - Ret. time: - *Bagasse is better suited for direct incineration.*[1,3]	Yield: *0.2 - 0.5 m^3/kg*[2] *Assumption: 0.25 m^3/kg* Yield /ha:*3,084*m^3*/ha·a*[24] Ret. time: *20 days* [3; estimate] 66% Bag., 33% Cowm.: Yield: *0.3* m^3/kg[3] Yield / ha: *3701* m^3*/ha·a* Ret. time: *20 days*[3; estimate]	*N.A.*

35. Heaton (2010,1,2)
36. Maughan et al. (2012, 6-8,14)
37. Thelen et al. 2009)
38. Braun, Weiland, and Wellinger (2008,5)
39. Klimiuk et al. (2010,1)
40. USDA and NCRS (2002a)
41. USDA and NCRS (2002b)
42. -
43. Samson, Duxbury, and Mulkins (2000,3)
44. Landström, Lomakka, and Andersson (1996,334)
45. Poiša et al. (2011,229)
46. Vervuren, Beurskens, and Blom (1999,960)
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48. Sukkel (2008)
49. Heiermann et al. (2009)
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51. Hasan and Chakrabarti (2009, 54-56)
52. Spencer and Bowes (1986, 528)
53. Reddy and D'Angelo (1990, 27)
54. Pienkos and Darzins (2009, 432,434,435)
55. Darzins, Pienkos, and Edye (2010, 18)
56. Converti et al. (2009, 1147)
57. Lv et al. (2010, 6797)
58. Kebede and Ahlgren (1996, 101)
59. Smith et al. (1990, 1433)
60. Johnson et al. (2000, 423)
61. Kao and Lin (2010, 650)
62. Tu and Ma (2003, 245)
63. Blombäck (2004, 2)
64. Ericsson, Blombäck, and Neumann (2012, 2)
65. Anderson et al. (-)
Online database, available at: http://earthobservatory.nasa.gov/Experiments/Biome/biograssland.php, Retrieved on 29 may 2013, 22:50.
66. KNMI (2011a, 23)
67. Becker (2007, 3)
77. Patil, Tran, and Giselrød (2008, 1191)
77. Fujita, Scharer, and Moo-Young (1980, 177,180,183)
78. Zheng et al. (2009, 5142, 5144)
79. Norman and Murphy (2005, 2)
80. Amon et al. (2007, 3207, 3210)
82. Raja and Lee (2012, 20)
83. Daniel-Gromke, Ertem, and Rensberg (2011, 48,49)
84. Reitsema (2012)

DEDICATED ENERGY CROPS AND PLANTS, NON FOOD

CROP / RESIDUE

Plants	1. Residue yield (kg)	2. Primary yield (kg)	Type	4. Climate / geographic range	5. Lighting conditions	6. Temperature (˚C)	7. Water / moisture
					Summer: 307,7 $^{W}/_{m2}$ PAR or 1412 μmol/m²s PAR [19] Av. day length: 15.2 hours (54,720 sec.), 77 mol/m² daily PAR **Spring and fall:** 217,5 $^{W}/_{m2}$ PAR or 1000 μmol/m²s PAR [19] Av. day length: 13.8 hours (49,680 sec.), 50 mol/m² daily PAR **Winter:** 52,9 $^{W}/_{m2}$ PAR or 244 μmol/m²s PAR [19], Av. day length: 8.8 hours (31,680 sec.), 8 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) very slightly clouded:** 281,2$^{W}/_{m2}$ PAR or 1290 μmol/m²s PAR, 60 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) slightly clouded:** 199,5 $^{W}/_{m2}$ PAR or 912 μmol/m²s PAR [19], 43 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) clouded:** 108,5 $^{W}/_{m2}$ PAR or 495 μmol/m²s PAR [19], 23 mol/m² daily PAR **Average (13 hours = 46,800 sec.) day densely clouded:** 41,0 $^{W}/_{m2}$ PAR or 186 μmol/m²s PAR [19], 9 mol/m² daily PAR	**Annual:** Av. temp.: 10.1 ˚C[66] Temp. max. > 30˚C: 2 days [10] Temp. max. > 25˚C: 20 days[10] Temp. max. > 20˚C: 75 days[10] Temp. min. < 0 ˚C: 50 days [10] Temp. max. < 0 ˚C: 8 days [10] Temp. min. < -10 ˚C: 2 days[10] Extreme max.: 37,8˚C[10; 7/8/2003] Extreme min.:-24.2˚C[10; 8/1/1985] **Spring Av. temp.:** 9.08˚C[10] **Summer Av. temp.:** 17.75˚C[10] **Fall Av. temp.:** 10.75˚C[10] **Winter Av. temp.:** 3.42˚C[10]	**Average rainfall:** 884 mm/y [10] **Relative humidity:** Spring: 68%[66] Summer: 67%[66] Fall: 77%[66] Winter: 83%[66]
Switchgrass *Panicum Virgatum*	-	5,200-11,100 *kg / ha·a* [1] In a northern climate: 2,000-6,000 *kg / ha·a* [28] Assumption: *4,000 kg / ha·a*	*C4*	*Native to US, Canada and Mexico.* *Can grow in both warm and cold temperate climates: US, Northwest Europe, Southern Europe, China, Southern part of Latin America.* *Upland types are suited to colder climates, lowland types to warmer climates.*[27,28] *Eastern Europe / West Asia, California, North Africa.* *Does not grow in hot humid climates.*[8]	C4 Plants: *Minimum 500 μmol/m²s or 109 $^{W}/_{m2}$ PAR, provided daily for 16 hours. This would come down to 28.8 mol/m² daily PAR (57,600 seconds in 16 hours).* Compatible with Reed: *Photosynthetic saturation in Reed is reached at 1500 μmol/m²s.*[29]	Germ. min.: *7.9*[34]*, 9-10˚C*[28] Germ. opt.: *24-29˚C*[28]	*Without irrigation:* *510-640 mm/y*[4] *rainfall.*
Miscanthus *Misccanthus Gigan-teus*	-	*1,400 - 18,200 kg / ha·a* [1] *2,000 - 25,000 kg / ha·a* [2; from the third year] *10,000 - 40,000 kg / ha·a* [32] *10,000 - 15,000 kg / ha·a* [35] Germany: *26,400 kg / ha·a* [32] Assumption: <u>*26,400*</u> *kg / ha·a* *Yields are lowest in the first year and are highest from the third year on.*	*C4*[2]	*Native to Asia.* [32][33] *Grown in US, Europe (as disperse as Italy and Denmark), Asia, Africa.*[35]	C4 Plants: *Minimum 500 μmol/m²s or 109 $^{W}/_{m2}$ PAR, provided daily for 16 hours. This would come down to 28.8 mol/m² daily PAR (57,600 seconds in 16 hours).* Compatible with Reed: *Photosynthetic saturation in Reed is reached at 1500 μmol/m²s.*[29]	Germ. min.: *9.6-11.6˚C*[34] Germ. opt.: *16.1˚C*[34] Growth. min.: *10˚C*[32]*, 6.1˚C*[35] Withstands:*-23˚C*[33]	*500-1220 mm/y*[36]
Reed canary grass *Phalaris arundinacea*	-	*9,400 - 10,100 kg / ha·a* [1] *9,000 kg / ha·a* [41] *7,000 - 12,000 kg / ha·a* [43] Assumption: <u>*9,417*</u> *kg / ha·a*	*C3*	*US, Canada, Europe, Scandinavia, Netherlands.*[40] [41] *Doe well in wet, cool regions.*[43]	*For C3 Plants in general light saturation is reached when:* *88 $^{W}/_{m2}$ PAR or 400 μmol/m²s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m² daily PAR* Good result where seen with: *125 μmol/m²s PAR during 16 hours.*[46] *Which is equal to: 7.2 mol/m²d daily PAR.* *Canary reed can grow in partially shaded areas.*	Germ. min.: *7˚C*[34] Growth min.: *5˚C* [44] Withstands:*-34˚C*[40]	Unirrigated: *4572 mm/y*[4] *rainfall* *Reed canary grass is suited for irriga-tion and can stand is inundated soils.*

1. Gupta and Demirbas (2010, 59,60,69) *Some data was converted from tons US to kg.*
2. Deublein and Steinhauser (2008, 17-19, 58-62, 116)
3. Nijaguna (2006, 23, 26) *Some data was converted from tonnes UK to kg.*
4. FAO (1992) *Online repository available at: http://www.fao.org/docrep/003 w3647eW3647E03.htm Retrieved on: 5 may 2013, 15:40, and: http://www.fao.org/nr/water/cropinfo.html Retrieved on: 5 may 2013, 11:41*
5. FAO (2013) *Crop yield data for 2011. Online database available at: http://faostat.fao.org/site/567/DesktopDefault. aspx?PageID=567#ancor. Retrieved on: 8 may 2013, 21:36*
6. DMI (2003, 8,70)
7. IENICA (2007) *Online database available at: http://www.ienica.net/cropsdatabase. htm Retrieved on: 8 may 2013, 23:29*
8. SAREP (2013) *Online database available at: http://www.sarep.ucdavis.edu/ database/covercrops Retrieved on: 9 may 2013, 12:15*
9. ECN (2012) *Online database available at: http://www.ecn.nl/phyllis2/Browse/Stan-dard/ECN-Phyllis Retrieved on: 9 may 2013, 14:34*
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11. Franceschini (1977, 30)vv
12. Sager and Mc Pharlane (1997, 4)
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14. Defoer et al. (2004, 39)
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18. Ndazi, Nyahumwa, and Tesha (2008, 1270)
19. Hemming et al. (2004, 17)
20. Wheeler and Sager (2006, 10,19)
21. Sözer and Yaldiz (2012, 2,3)
22. Ulusoy et al. (2009, 1002)
23. Dumitru and Gherman (2010, 586, 587)
24. Lehtomäki (2006, 12,13,20-22)
25. Hutnan et al. (2001, 242)
26. Van An (2004, 14)
27. Elbersen et al. (2004, 141)
28. Blade Energy Crops (2009, 3,4,5,11,12)
29. Mykleby (2012, 40)
30. Nichols et al. (2012, 1)
31. Ahn et al. (2010, 965,968)
32. Clifton-Brown, Stampfl, and Jones (2004, 509,512)
33. Pyter et al. (2007, 41)
34. Clifton-Brown et al. (2011, 383,375)

CROP / RESIDUE					BIOMASS		BIOGAS		
8. Soil / nutrition	**9. Life cycle**	**10. Primary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**11. Residue type**	**12. Notes on residue / secondary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**13. Biomass constituents.** Dry matter (DM percent) Organic dry matter in dry matter (oDM in DM percent) Ash content dry matter (percent) Carbon percentage (percent) C/N Lignin (percent) Protein (percent) C/N = *Measure for fermentation suitability (preferable: 16:1-25:1*[2] *or 20:1-30:1*[3]*, I assume 25:1*[4]*).* Green : *15 : 1 < C/N < 45 :1* Green/Red : *10 : 1 < C/N < 100 :1, and or ligning > 17%* Red : *10: 1> C/N, 100 :1 < C/N*	**14. Dry net calorific value (MJ/kg).** *Bituminous coal (for comparison): 27 - 30 MJ/kg*[1] *Hardwood pellets (for comparison): 20.31 MJ/kg*[9; #3248]	**15. Biogas potential** Yield (m^3/kg oDM) Yield / ha: (m^3/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a*	**16. Biogas Co-fermentation potential** Yield (m^3/kg oTS) Yield / ha: (m^3/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a* N.B.: *Yield is per organic weight of total solids. This includes manure which has to be mixed into the substrate. The fraction of the crops substrate which is effectively converted to methane differs for each crop. The previous column is therefore more suited for comparing different crops.*	**17. Production advice** U - Harmless S - Containing trash Complexity: I - No II - Litle III - High
Nutrient demand: *N: 0-212*[1] *kg/ha or 12.4 kg/ha for each tonne produced.*[28] *P & K: Depends on soil and how the biomass is used. With biogas substrate can be recycled.* [28] *pH optimum: 6.0-8.0* [28] *Tolerates pH: 5.0* [28]	*Perennial warm season grass. Reseeding plant.* *Usually grown for 5 years*[1] *but can survive up to 15 years.* *Usually planted in spring. In hotter climates (late) summer, and fall planting can also be possible. May emerge in 3-14 days.*	*Forage or grazing field for cows (toxic to horses, sheep and goats), Soil conversion, bioenergy, bioplastics, game cover (can have positive effects on wildlife)* *CO2 sequestration*	*Field residue*	*Lowland Switchgrass can be used as a dual-purpose grazing and bioenergy crop. Grazing is then done in spring and biomass harvesting is done at the end of the season.*[30] *CO2 sequestration*	DM =80 %[28], *91.84 %*[9; #701], 86% oDM in DM = *79.19 %*[9; #701] Ash = *4.5-5.8 %*[9; #701] Carb. = 46.86 %[9; #701] C/N = *80.79 : 1*[9; #701] Lignin: *15 %* [28] Protein: *10-15 %* [28] oDM yield: *2,724 kg/ha·a*	*18.3 MJ/kg.*[1] *17.36 MJ/kg.*[9]	*Yield:* *0.179–0.218 m^3/kg*[38; Miscanthus] *0.20 m^3/kg* *Yield/ha:* *545* m^3*/ha·a* *Ret. time: 30-40 days*[estimate compared with other grass crops]	19% Switch., 81% Pigm.: Yield: *0.337* m^3/kg[31] Yield / ha: *918 m^3/ha·a*[24] Ret. time: *62 days*[24]	-
Nutrient demand: *N: 60* [1] *kg/ha or up to 200*[36] *kg/ha* *P: -* *K: -* *pH: -* *Does best on the same soils as corn: well drained soil, clay loams.*[36]	*Perennial grass. Reseeding plant. Replanting after 15 years.* *Yields increase each year and are maximal after the third year.*[36]	*Bioenergy, Low quality forage, Grazing field.* *CO2 sequestration* *Plant is sterile so does not threaten plant biodiversity.*[37] *game cover (can have positive effects on wildlife)*	*Field residue*	*Plant is sterile so does not threaten plant biodiversity.*[37] *game cover (can have positive effects on wildlife),* *CO2 sequestration*	DM = 93.1 *%*[9] oDM in DM = *74.50 %*[9] Ash = *4.5-5.8 %*[9; #701] Carb. = 43.7*%*[9; #701] C/N = *84.06 : 1*[9; #701] Lignin: *15 %* [28; switchgrass] Protein: *3.4 %* [79] oDM yield: *18,291 kg/ha·a*	*17.1 - 19.4MJ/kg.*[1] *18.1 MJ/kg.*[9]	*Yield:* *0.179–0.218 m^3/kg*[38] *0.19 m^3/kg*[39; M. Sacchiriflorus] *Ass.: 0.19 m^3/kg* *Yield/ha:* *3,475 m^3/ha·a* *Ret. time: 30-40 days*[estimate compared with other grass crops]	Yield: *0.337* m^3/kg[estimated from switchgrass] Yield / ha: *6,164 m^3/ha·a* Ret. time: *62 days* [estimated from switchgrass]	-
Nutrient demand: *N: 140*[1] *kg/ha K: 100*[1] *kg/ha* *P: - kg/ha* *pH: -* *Does well on a wide variety of soils but is mainly used on poorly drained soils and those subjected to inundation.* *Can withstand inundation for up to 60-70 days.*[40]	*Perennial grass. Reseeding plant.* *Flowers in June-July. Suited for spring grazing and fall harvest. Spring harvest also possible.* *For biofuel reed canary grass is better harvested in spring.*[44]	*Forage, Grazing, Erosion control,*[40] *Filter fields (water purification), biofuels,*[41] *Has aggressive growth. Dominates wetlands and shades out other plants.*	*Field residue*	*Erosion control,*[40] *Filter fields (water purification)* *Has aggressive growth. Dominates wetlands and shades out other plants.* *CO2 sequestration*	DM = *90.5 %*[9, #1909] oDM in DM = *74.00 %*[9, #2124] Ash = *6.3 %*[42]*, 5.16 %*[9] Carb. = *46.00%*[9, #2124] C/N = *52 : 1*[9, #2124] Lignin: *22.5 %*[45]*, 4.00 %* [9, #2257]*, 13.3 %* Protein: *16.00%* [9, #2257] oDM yield: *6,307 kg/ha·a*	*17.16 - 18.13MJ/kg*[45] *17.6 MJ/kg* [9, #2124]	Yield: 0.36 m^3/kg[24] Yield / ha: *2,270 m^3/ha·a* Ret. time: *20-30 days*[assumption compared with other grass crops]	75% Ree., 25% Cowm.: Yield: *0.263* m^3/kg[47] Yield / ha: *1,658 m^3/ha·a* Ret. time: *26 days*[24]	-

35. Heaton (2010,1,2)
36. Maughan et al. (2012, 6-8,14)
37. Thelen et al. 2009)
38. Braun, Weiland, and Wellinger (2008,5)
39. Klimiuk et al. (2010,1)
40. USDA and NCRS (2002a)
41. USDA and NCRS (2002b)
42. -
43. Samson, Duxbury, and Mulkins (2000,3)
44. Landström, Lomakka, and Andersson (1996,334)
45. Poiša et al. (2011,229)
46. Vervuren, Beurskens, and Blom (1999,960)
47. Dubrovskis, Adamovics, and Plume (2009,243)
48. Sukkel (2008)
49. Heiermann et al. (2009)
50. Braun, Weiland, and Wellinger (2008, 5)
51. Hasan and Chakrabarti (2009, 54-56)
52. Spencer and Bowes (1986, 528)
53. Reddy and D'Angelo (1990, 27)
54. Pienkos and Darzins (2009, 432,434,435)
55. Darzins, Pienkos, and Edye (2010, 18)
56. Converti et al. (2009, 1147)
57. Lv et al. (2010, 6797)
58. Kebede and Ahlgren (1996, 101)
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77. Patil, Tran, and Giselrød (2008, 1191)
77. Fujita, Scharer, and Moo-Young (1980, 177,180,183)
78. Zheng et al. (2009, 5142, 5144)
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83. Daniel-Gromke, Ertem, and Rensberg (2011, 48,49)
84. Reitsema (2012)

DEDICATED ENERGY CROPS AND PLANTS, NON FOOD							
			CROP / RESIDUE				
Plants	**1. Residue yield (kg)**	**2. Primary yield (kg)**	**Type**	**4. Climate / geographic range**	**5. Lighting conditions** **Summer:** 307,7 $^{W}/_{m2}$ PAR or 1412 µmol/m²s PAR [19] Av. day length: 15.2 hours (54,720 sec.), 77 mol/m² daily PAR **Spring and fall:** 217,5 $^{W}/_{m2}$ PAR or 1000 µmol/m²s PAR [19] Av. day length: 13.8 hours (49,680 sec.), 50 mol/m² daily PAR **Winter:** 52,9 $^{W}/_{m2}$ PAR or 244 µmol/m²s PAR [19], Av. day length: 8.8 hours (31,680 sec.), 8 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) very slightly clouded:** 281,2$^{W}/_{m2}$ PAR or 1290 µmol/m²s PAR, 60 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) slightly clouded:** 199,5 $^{W}/_{m2}$ PAR or 912 µmol/m²s PAR [19], 43 mol/m² daily PAR **Average day (13 hours = 46,800 sec.) clouded:** 108,5 $^{W}/_{m2}$ PAR or 495 µmol/m²s PAR [19], 23 mol/m² daily PAR **Average (13 hours = 46,800 sec.) day densely clouded:** 41,0 $^{W}/_{m2}$ PAR or 186 µmol/m²s PAR [19], 9 mol/m² daily PAR	**6. Temperature (˚C)** **Annual:** Av. temp.: 10.1 ˚C[66] Temp. max. > 30˚C: 2 days [10] Temp. max. > 25˚C: 20 days[10] Temp. max. > 20˚C: 75 days[10] Temp. min. < 0 ˚C: 50 days [10] Temp. max. < 0 ˚C: 8 days [10] Temp. min. < -10 ˚C: 2 days[10] Extreme max.: 37,8˚C[10; 7/8/2003] Extreme min.:-24.2˚C[10; 8/1/1985] **Spring Av. temp.:** 9.08˚C[10] **Summer Av. temp.:** 17.75˚C[10] **Fall Av. temp.:** 10.75˚C[10] **Winter Av. temp.:** 3.42˚C[10]	**7. Water / moisture** **Average rainfall:** 884 mm/y [10] **Relative humidity:** Spring: 68%[66] Summer: 67%[66] Fall: 77%[66] Winter: 83%[66]
Alfalfa / Luzerne *Medicago sativa*	-	7,000-12,000 *kg / ha·a* [1] Assumption: <u>9,500</u> *kg / ha·a*	*C3*	*Originated in the Mediterranean. Grown globally.*	*For C3 Plants in general light saturation is reached when:* *88 $^{W}/_{m2}$ PAR or 400 µmol/m²s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m² daily PAR*	Growth min.: *5˚C* [4] Growth opt.: *25˚C* [4] Growth max.: 30˚*C* [4] Withstands > *-4˚C* [4] *Hibernates during winter.*[4]	*During growing period:* *800-1600 mm/y*[4] *rainfall.*
Sunflower *Helianthus annuus*	Stalks: <u>2,500</u> *kg / ha·a*[3; this seems to low]	Poultry feed or seeds for human consumption: *800 - 1,500 kg / ha·a* [4] Oil crop: *2,500- 3,500 kg / ha·a* [4] Total plant as energy crop: *11,200 kg / ha·a* [80; Yield in kg VS] Assumption, seeds: <u>1,150</u> *kg / ha·a*	*C3*	*Originated in Central and North America.* *Grown in temperate climates, subtropics.*[4]	*For C3 Plants in general light saturation is reached when:* *88 $^{W}/_{m2}$ PAR or 400 µmol/m²s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m² daily PAR* *Short day plant*[4]	Growth. opt.: *18-25˚C*[4] Withstands > 0˚*C*[4] *Frost sensitive.*[4]	*600-1000 mm/y*[4]
Water hyacinth *Eichhornia crassipes*	-	Fertile ponds: *15,000 - 20,000 kg / ha·a* [51] Artificially fertilized ponds: *75,600 - 191,000 kg / ha·a* [51] Fertilized with sewage effluant: *219,000 kg / ha·a,*[51; up to 657,000 has been reported. However it remains questionable if such yields can be obtained on a large scale] In general: *Up to 250,000 kg / ha·a* [52] Assumption sewage effluant: <u>200,000</u> *kg / ha·a* Assumption artificially fertilized ponds: <u>133,300</u> *kg / ha·a*	*C3*[52]	*Native to tropical and subtropical South America. Grows in North America, Asia, Australia, Africa and New Zealand. In tropical and subtropical regions.*[52]	*For C3 Plants in general light saturation is reached when:* *88 $^{W}/_{m2}$ PAR or 400 µmol/m²s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m² daily PAR* Good result where seen with: *650 µmol/m²s PAR during 12 hours.*[52; 25 C photoperiod and 20 C scotoperiod] *Which is equal to: 28.08 mol/m²d daily PAR.*	Growth min.: *13˚C* [51] Growth good: *14-29˚C* [51] Growth opt.: *30˚C* [51] Growth max.: *40˚C* [51] *Frost sensitive*[40]	Min. relative air humidity: *15-40%*[52] *Requires a pond*

1. Gupta and Demirbas (2010, 59,60,69) *Some data was converted from tons US to kg.*
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23. Dumitru and Gherman (2010, 586, 587)
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26. Van An (2004, 14)
27. Elbersen et al. (2004, 141)
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30. Nichols et al. (2012, 1)
31. Ahn et al. (2010, 965,968)
32. Clifton-Brown, Stampfl, and Jones (2004, 509,512)
33. Pyter et al. (2007, 41)
34. Clifton-Brown et al. (2011, 383,375)

CROP / RESIDUE					BIOMASS		BIOGAS		
8. Soil / nutrition	**9. Life cycle**	**10. Primary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**11. Residue type**	**12. Notes on residue / secondary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**13. Biomass constituents.** Dry matter (DM percent) Organic dry matter in dry matter (oDM in DM percent) Ash content dry matter (percent) Carbon percentage (percent) C/N Lignin (percent) Protein (percent) *C/N = Measure for fermentation suitability (preferable: 16:1-25:1[2] or 20:1-30:1[3], I assume 25:1[4]).* Green *: 15 : 1 < C/N < 45 :1* Green/Red *: 10 : 1 < C/N < 100 :1, and or ligning > 17%* Red *: 10: 1> C/N, 100 :1 < C/N*	**14. Dry net calorific value (MJ/kg).** *Bituminous coal (for comparison): 27 - 30 MJ/kg[1]* *Hardwood pellets (for comparison): 20.31 MJ/kg[9; #3248]*	**15. Biogas potential** Yield (m^3/kg oDM) Yield / ha: (m^3/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a*	**16. Biogas Co-fermentation potential** Yield (m^3/kg oTS) Yield / ha: (m^3/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a* N.B.: *Yield is per organic weight of total solids. This includes manure which has to be mixed into the substrate. The fraction of the crops substrate which is effectively converted to methane differs for each crop. The previous column is therefore more suited for comparing different crops.*	**17. Production advice** U - Harmless S - Containing trash Complexity: I - No II - Litle III - High
Nutrient demand: *N: 0 kg/ha[1,4; fixes atmospheric nitrogen]* *P: 55-65 kg/ha[4]* *K: 75-100 kg/ha[4]* *pH: -* *Grows on a wide variety of soils. Prefers well drained soils.[4]* *Somewhat sensitive to soil salinity.*	*Perennial grass. Reseeding plant.* *Sown in March-April or in September.* *Grown for 3-4 years or 6-9 years in cold continental climates.* *2-12 cuts per growing season.*	*Forage (fresh from the field or as hay),* *Fodder* *Improving soil fertility,* *Compost.*	*Field residue*	*Can be grown in the undergrowth of wheat. After grain harvest the Alfalfa then fully develops.* *In this way Alfalfa can bin 25-50 kg N / tonne of above ground matter.*	*DM = 92.10 %[9; #1902]* oDM in DM = *43 %[49]* Ash = *7.83 %[9; #1902]* Carb. = 43.01 %[9; #1902] C/N = *15 : 1[9; #1902]* Lignin: *- %* Protein: *18-20 %[4; of oDM = 8-8.6% DM]* oDM yield: *3,762 kg/ha·a*	*17.69 MJ/kg.[9, #1902]*	*Yield:* *0.365* m^3/kg[24] *Yield/ha:* *1,373* m^3/ha·a *Ret. time: 28 days[49]*	Co-fermentation with manure would make the C/N value worse.	-
Nutrient demand [3][4]: *N: 50-1000 kg/ha K: 60-125 kg/ha* *P: 20-45 kg/ha* *pH: 6.0 - 7.5* *Grows on a wide range of soils.*	*Annual plant.* *70 day cycle in short season climates. Up to 130-200 day cycle in long season climates.[4]*	*Poultry feed,* *Human consumption (seed or oil),* *Biodiesel.*	*Field residue*	*If sunflowers are pressed for oil than the husk that remain can be used as a source of energy. This husk has a calorific value of 20 MJ/kg.[50]*	DM =*35 %[2; total plant]* oDM in DM = *88 %[2; total plant]* Ash = *4.18%[9]* Carb. = *60.33%[9; #419, waste]* C/N = *30.2 : 1[9; #419, waste]* Lignin: *17.50 %[9]* Protein: *2.10%[9; #1081, stalks]* oDM yield total plant: *1,124 kg/ha·a* oDM yield stalks: *770 kg/ha·a*	-	*Yield:* *0.154–0.4* m^3/kg[2; total plant] *Assumption: 0.28 m^3/kg* *Yield/ha stalks estimate:* *216 m^3/ha·a* *Yield/ha energy crop:* *3,300 m^3/ha·a* *Ret. time: -*	Little need for co-fermentation of beet pulp as the C/N value is already near the optimum.	*U, S, II[2]*
Nutrient demand: *Min. N: 0.05-1[51] kg/ha K: -* *Min. P: 0.02-0.1[51] kg/ha* *pH: -* *Requires fresh water. Water hyacinths are very sensitive to water fertility.[51] Furthermore increased CO2 can greatly increase dry weight production.[52]* *Plant floats freely. Roots are submerged but leaves are exposed.*	*Perennial plant.* *Can be harvested annually or multiple times per year. Annual harvesting shows greatest uptake of nutrients while harvesting 21 times per year showed greatest biomass yield.[53]*	*Forage for goats (toxic for other animals),* *Braiding,* *Paper,* *Biogas,* *Cleaning industrial wastewater.*	*Field residue*	*Cleaning industrial wastewater.*	Fresh plant: DM =8.1 *%[9;#2356] (51; mean from varies sources)* Dried plant: DM =89.6 *%[51]* oDM in DM = *62 %[9, #1148]* Ash = *30.3 %[51], 22.12 %[9, #1148]* Carb. = 36.37%*[9, #1148], 44.24 %[3]* C/N = 19.95:1%*[9, #1148], 20.51 %[3], 20* Lignin: *7.00-26.36 %[51] 16.7%* Protein: *15.8% [51]* oDM yield sew. effl.: *8,999 kg/ha·a* oDM yield fert. pond: *5,998 kg/ha·a*	*13.77 MJ/kg[9, #1148]*	Yield: *0.14, 0.16, 0.18 m^3/kg[24]* *0.02 m^3/kg[3]* *0.348 m^3/kg[24]* *Assumption: 0.17 m^3/kg* Yield / ha: *With sewage effluent:* *1,529 m^3/ha·a* *Art. fertilized:* *1,019 m^3/ha·a* *Optimistic:* *1,912 m^3/ha·a* *Maximum reported:* *5,025 m^3/ha·a* Ret. time: *46 days[3]*	Yield 90%[mass %] W.hyacinth 10%[mass %] Cow manure: *0.505[81; at 40°C] m^3/kg[81]* Yield / ha: Sewg. effl: *4,544 m^3/ha·a* *Fert. pond: 3,029 m^3/ha·a* *Optimistic: 5,680 m^3/ha·a* *Maximum reported:* *14,927 m^3/ha·a*	-

35. Heaton (2010,1,2)
36. Maughan et al. (2012, 6-8,14)
37. Thelen et al. 2009)
38. Braun, Weiland, and Wellinger (2008,5)
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47. Dubrovskis, Adamovics, and Plume (2009,243)
48. Sukkel (2008)
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50. Braun, Weiland, and Wellinger (2008, 5)
51. Hasan and Chakrabarti (2009, 54-56)
52. Spencer and Bowes (1986, 528)
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54. Pienkos and Darzins (2009, 432,434,435)
55. Darzins, Pienkos, and Edye (2010, 18)
56. Converti et al. (2009, 1147)
57. Lv et al. (2010, 6797)
58. Kebede and Ahlgren (1996, 101)
59. Smith et al. (1990, 1433)
60. Johnson et al. (2000, 423)
61. Kao and Lin (2010, 650)
62. Tu and Ma (2003, 245)
63. Blombäck (2004, 2)
64. Ericsson, Blombäck, and Neumann (2012, 2)
65. Anderson et al. (-)
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66. KNMI (2011a, 23)
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77. Patil, Tran, and Giselrød (2008, 1191)
77. Fujita, Scharer, and Moo-Young (1980, 177,180,183)
78. Zheng et al. (2009, 5142, 5144)
79. Norman and Murphy (2005, 2)
80. Amon et al. (2007, 3207, 3210)
82. Raja and Lee (2012, 20)
83. Daniel-Gromke, Ertem, and Rensberg (2011, 48,49)
84. Reitsema (2012)

DEDICATED ENERGY CROPS AND PLANTS, NON FOOD

CROP / RESIDUE

Plants	1. Residue yield (kg)	2. Primary yield (kg)	Type	4. Climate / geographic range	5. Lighting conditions	6. Temperature (˚C)	7. Water / moisture
					Summer: 307,7 $^{W}/_{m2}$ PAR or 1412 µmol/m^2s PAR [19] Av. day length: 15.2 hours (54,720 sec.), 77 mol/m^2 daily PAR **Spring and fall:** 217,5 $^{W}/_{m2}$ PAR or 1000 µmol/m^2s PAR [19] Av. day length: 13.8 hours (49,680 sec.), 50 mol/m^2 daily PAR **Winter:** 52,9 $^{W}/_{m2}$ PAR or 244 µmol/m^2s PAR [19], Av. day length: 8.8 hours (31,680 sec.), 8 mol/m^2 daily PAR **Average day (13 hours = 46,800 sec.) very slightly clouded:** 281,2$^{W}/_{m2}$ PAR or 1290 µmol/m^2s PAR, 60 mol/m^2 daily PAR **Average day (13 hours = 46,800 sec.) slightly clouded:** 199,5 $^{W}/_{m2}$ PAR or 912 µmol/m^2s PAR [19], 43 mol/m^2 daily PAR **Average day (13 hours = 46,800 sec.) clouded:** 108,5 $^{W}/_{m2}$ PAR or 495 µmol/m^2s PAR [19], 23 mol/m^2 daily PAR **Average (13 hours = 46,800 sec.) day densely clouded:** 41,0 $^{W}/_{m2}$ PAR or 186 µmol/m^2s PAR [19], 9 mol/m^2 daily PAR	**Annual:** Av. temp.: 10.1 ˚C[66] Temp. max. > 30˚C : 2 days [10] Temp. max. > 25˚C: 20 days[10] Temp. max. > 20˚C: 75 days[10] Temp. min. < 0 ˚C: 50 days [10] Temp. max. < 0 ˚C: 8 days [10] Temp. min. < -10 ˚C: 2 days[10] Extreme max.: 37,8˚C[10; 7/8/2003] Extreme min.:-24.2˚C[10; 8/1/1985] **Spring Av. temp.:** 9.08˚C[10] **Summer Av. temp.:** 17.75˚C[10] **Fall Av. temp.:** 10.75˚C[10] **Winter Av. temp.:** 3.42˚C[10]	**Average rainfall:** 884 mm/y [10] **Relative humidity:** Spring: 68%[66] Summer: 67%[66] Fall: 77%[66] Winter: 83%[66]
Micro algae *Chlorella Vulgaris* *Dunaliella Salina* *Nannochloropsis Oculata* *Spirulina Platensis*	-	Low production: 36,500 *kg / ha·a* [54] Medium production: 91,250 *kg / ha·a* [54] High production: 182,500 *kg / ha·a* [54] Open ponds algae production: 73,000 - *109,500 kg / ha·a* [55] Raceway ponds algae production: 70,262 - *90,338 kg / ha·a* [55] Assumption: *80,482 kg / ha·a*	*C3* [55]	*Grow globally in both salt and fresh water.*	*Algea utilize light in the blue (400-500 nm) and near-ultra violet (380-400 nm).*[12] C. Vulgaris and N. Oculata, good results: *70.0 µmol/m^2s.*[56; 24 hour photoperiod] *equal to 6 mol/m^2 daily PAR* D. Salina, good results: *0.5 µmol/m^2s.*[59; 24 hour photoperiod] *equal to 0.0432 mol/m^2 daily PAR* C. Vulgaris optimum: *60.0 µmol/m^2s.*[57; 24 hour photoperiod] *equal to 5.2 mol/m^2 daily PAR* S. Platensin optimum: *300.0 µmol/m^2s.*[58; 24 hour photoperiod] *equal to 25 mol/m^2 daily PAR*	C. Vulgaris, good results: *25˚C*[56,57] C. Vulgaris, cleansing opt.: *45˚C*[56,57] D. Salina, good results: *30˚C*[59] N. Oculata, optimum: *25˚C*[56] S. Platensis, good results: *30˚C*[58]	Open pond: *1,000-2,000 L/kg* [54] Closed system: *100-200 L/kg* [54]
Foliage plants *Undergrowth plants.* *Example: ferns*	-	Fern biomass in Borneo, one year after a forest fire: 1,800 kg / ha·a [42]	*C3*	*Foliage plants are distributed globally. Large concentrations can be found in coniferous forests, temperate deciduous forests, rain forests and shrub lands.*	*For C3 Plants in general light saturation is reached when:* *88 $^{W}/_{m2}$ PAR or 400 µmol/m^2s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m^2 daily PAR* Light requirement are very divers: Fern, Trichomanes Speciosum: *Photosynthetic saturation at 5-10 µmol/m^2s.*[60] Amphibious fern, Masilea Quadrifolio: *Photosynthetic saturation at 800 µmol/m^2s.*[61]	Wide variety of temperatures. Chinese brake fern: Growth. good.: *23-28˚C*[62]	-
Grasss *(Meadow / grassland)* *Assumption:* *Agrostis Capillaris*	-	7,700 *kg / ha·a*[2]	C3[2]	*Grows globally in temperate climates. Grasslands are as widely dispersed as North America, South America, South Africa, steppes of central Eurasia and deserts in Australia.*[65]	*For C3 Plants in general light saturation is reached when:* *88 $^{W}/_{m2}$ PAR or 400 µmol/m^2s PAR is provided daily for 16 hours.*[12] *This would mean 23 mol/m^2 daily PAR* *Good results seen with:* *300 µmol/m^2s*[64; 16 hour photoperiod] *or 17.82 mol/m^2 daily PAR* *400 µmol/m^2s*[63; 18 hour photoperiod] *or 25.91 mol/m^2 daily PAR* *Agrostis Cappilaris tolerates shade and can be found around forest edges. Furthermore other grass type are available which tolerate shade even better.*[4]	Good results seen with: Day temp.: *20˚C*[63] Night temp.: *15˚C* [63] Extremely resistant to summer heat and winter cold.[4]	*500-900 mm/y*[65] *rainfall* *Relative humidity: 70%*[63]

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2. Deublein and Steinhauser (2008, 17-19, 58-62, 116)
3. Nijaguna (2006, 23, 26) *Some data was converted from tonnes UK to kg.*
4. FAO (1992) *Online repository available at: http://www.fao.org/docrep/003 w3647eW3647E03.htm Retrieved on: 5 may 2013, 15:40, and: http://www.fao.org/nr/water/cropinfo.html Retrieved on: 5 may 2013, 11:41*
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11. Franceschini (1977, 30)vv
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13. Lee (2001, 112)
14. Defoer et al. (2004, 39)
15. VASAT (2013) *Online educational source available at: http://vasat.icrisat.org Retrieved on: 10 may 2013, 14:20*
16. Eddy and Hahn (2010, 2,3)
17. Qing, Yang, and Wyman (2010, 5942)
18. Ndazi, Nyahumwa, and Tesha (2008, 1270)
19. Hemming et al. (2004, 17)
20. Wheeler and Sager (2006, 10,19)
21. Sözer and Yaldiz (2012, 2,3)
22. Ulusoy et al. (2009, 1002)
23. Dumitru and Gherman (2010, 586, 587)
24. Lehtomäki (2006, 12,13,20-22)
25. Hutnan et al. (2001, 242)
26. Van An (2004, 14)
27. Elbersen et al. (2004, 141)
28. Blade Energy Crops (2009, 3,4,5,11,12)
29. Mykleby (2012, 40)
30. Nichols et al. (2012, 1)
31. Ahn et al. (2010, 965,968)
32. Clifton-Brown, Stampfl, and Jones (2004, 509,512)
33. Pyter et al. (2007, 41)
34. Clifton-Brown et al. (2011, 383,375)

CROP / RESIDUE					BIOMASS		BIOGAS		
8. Soil / nutrition	**9. Life cycle**	**10. Primary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**11. Residue type**	**12. Notes on residue / secondary uses** N.B. Feed definitions as used in this table: *Forage: plants material (leaves and stem) eaten by grazing livestock. Originates from either pastures, crop residue or immature crops. Is grazed from the field or brought to the animal as hay or silage.* *Fodder: feed from plants or other sources brought to the animal in processed form. Mixed pellets, oils or pulp.*	**13. Biomass constituents.** Dry matter (DM percent) Organic dry matter in dry matter (oDM in DM percent) Ash content dry matter (percent) Carbon percentage (percent) C/N Lignin (percent) Protein (percent) C/N = *Measure for fermentation suitability (preferable: 16:1-25:1[2] or 20:1-30:1[3], I assume 25:1[4]).* Green : *15 : 1 < C/N < 45 :1* Green/Red : *10 : 1 < C/N < 100 :1, and or ligning > 17%* Red : *10: 1> C/N, 100 :1 < C/N*	**14. Dry net calorific value (MJ/kg).** *Bituminous coal (for comparison): 27 - 30 MJ/kg[1]* *Hardwood pellets (for comparison): 20.31 MJ/kg[9; #3248]*	**15. Biogas potential** Yield (m^3/kg oDM) Yield / ha: (m^3/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a*	**16. Biogas Co-fermentation potential** Yield (m^3/kg oTS) Yield / ha: (m^3/ha·a) Retention time (d) Green *> 1,000 kg/ha·a* Green/Red *> 500 kg/ha·a* Red *< 500 kg/ha·a* N.B.: *Yield is per organic weight of total solids. This includes manure which has to be mixed into the substrate. The fraction of the crops substrate which is effectively converted to methane differs for each crop. The previous column is therefore more suited for comparing different crops.*	**17. Production advice** U - Harmless S - Containing trash Complexity: I - No II - Litle III - High
S. Platensis good results seen with[58]: *N: 412 mg/L, P: 89 mg/L, C: 2400 mg/L, S: 184 mg/L, Na: 6545 mg/L, K: 672 mg/L, Ca: 11mg/L, Mg: 20 mg/L, Cl: 626 mg/L, Fe: 6 mg/L.* C. Vulgaris optimal with[57]: *KNO_3: $1.0 \cdot 10^{-3}$ mol/L, 1% CO_2.*	*Grows continually. Harvest depends on type and cultivation process. Multiple harvests per year or continuous harvesting are also possible.*	*Animal feed (fodder),* *Human consumption,* *Bio energy,* *Bio plastics,* S. Platensis: *Dietary supplement* D. Salina: *Cosmetics, medicine*	*Field residue*	-	Fresh micro algae: DM = *10-20%[77], Assumption: 15%* Dried micro algae: DM = 94.78 *%[9; #1921]* oDM in DM = 81.80 *%[9; #1921]* Ash = *2.52 %[9; #1921]* Carb. = 52.73 *%[9; #1921]* C/N = 6.6:1 *%[9; #1921]* Lignin = - Protein = *51-58 % [67]* oDM yield: *9,875 kg/ha·a*	*21.90 MJ/kg.[9; #1921]*	*Yield:* *0.15-0.24* m^3/kg[50] *Assumption: 0.195 m^3/kg* *Yield/ha:* *1,926* m^3*/ha·a* *Ret. time: -*	Co-fermentation with manure would make the C/N value worse.	-
Require little nutrition.	*Perennial.*	*Ornamental plants,* *Natural reserves,* *Erosion control,* *Waste water treatment.*	*Field residue*	-	Fresh leaves: DM = *12-42%[2], Assumption: 27%* Withered leaves: DM =67.05 *%[9;#3065]* oDM in DM = *40.60 %[9;#3065],82%[2]* Ash = *43.77 %[9;#3065]* Carb. = 30.17*%[9;#3065]* C/N = *29.3:1[9;#3065]* Lignin = *9.9 % [9;#2630 fresh]* Protein = *20.10% [9;#2630 fresh]* oDM yield: *399 kg/ha·a*	*11.93 MJ/kg.[9;#3065]*	*Yield:* *0.42–0.43* m^3/kg[50] *Assumption: 0.425* m^3/kg *Yield/ha:* *170 m^3/ha·a* *Ret. time: 8-20 days[2]*	Yield: *0.6* m^3/kg[2] Yield / ha: *239 m^3/ha·a* Ret. time: *8-20 days[2]*	*U, S, II[2]*
Nutrient demand: *N: difficult to determine precisely, however. N increases growth and plant health.[64]* *K: -* *P: -* *pH: -* *Does well on normally drained or dry soils.*	*Perennial grass.* *Multiple clippings / grazings year.*	*Forage,* *Grazing,* *Ornamental* *Compost.*	*Field residue*	*Biogas production might compete with grass as a forage.*	Fresh cuttings from lawns: DM =*37 %[2]* oDM in DM = *93 %[2]* Grass pellet mixture: DM =88.6 *%[9, #2732]* oDM in DM = 71.0 *%[9, #2732]* Ash = 12.1 *%[9, #2732]* Carb. = 44.10 *%[9, #2732]* C/N = *17.64 : 1[9, #2732]* Lignin = *9.00 %[9; #1044]* Protein = *20.5%[4]* oDM yield: *2,650 kg/ha·a*	*17.35MJ/kg[9; #2732]*	Yield: *0.34 m^3/kg[24; oDM]* *0.17-0.28 m^3/kg[50; oDM]* *Assumption: 0.30 m^3/kg oDM* Yield / ha: *795 m^3/ha·a* Ret. time: *10 days[2]*	Yield: *0.7-0.9* m^3/kg[2; oDM, fresh cuttings] 0.8 Yield / ha: *2,120* m^3*/ha·a* Ret. time: *10 days[2]*	*U, S, II[2]* *Fresh grass cuttings can have earth content. This does not occur with ensilaged grass.*

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36. Maughan et al. (2012, 6-8,14)
37. Thelen et al. 2009)
38. Braun, Weiland, and Wellinger (2008,5)
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55. Darzins, Pienkos, and Edye (2010, 18,48)
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80. Amon et al. (2007, 3207, 3210)
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83. Daniel-Gromke, Ertem, and Rensberg (2011, 48,49)
84. Reitsema (2012)

PAPER ARCHITECTURAL ENGINEERING LAB 10

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