From degradation to productive rehabilitation; a cross-sectoral exploration of a renewable production landscape and bioremediation for the rehabilitation of the contaminated industrial site of Shell-Pernis

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Abstract:

The issues of environment challenges, increasing per capita demand and decreasing finite stocks are triggering the demand for greener alternatives in the resource production and consumption. A vital component of bioeconomy, is the concept of the biorefinery, which has the potential to replace conventional petroleum refineries in order to produce energy and material products with 2nd generation biomass feedstock. In the search for renewable production landscapes, the current situation of pollution and contamination cannot be neglected. The soils of Shell-Pernis are highly contaminated with Mineral oils, heavy metals (e.g. Zn, Cu, Cd, Hg, etc), and PAHs. Thereupon, a set of 25 different plant species are contrived, which form building blocks for ecological interventions to transform a deteriorated, fossil-based industrial sites to an accessible bio-industrial park. These interventions follow the rule of multiple functions, as all plants provide various ecosystem services such as the production of biofuels, bioremediation, attracting wildlife, fixating nitrogen, preventing erosion and other additional benefits. Hence, the interventions make it safer and healthier, and provide the public for a pleasant stay. In conclusion, in this paper it is shown how Shell-Pernis has the potential to become the flagship site of the green industry where bio-economic and rehabilitating activities are shown to the outer world to educate and stimulate a sustainable growth.

I Introduction

1.1 Port of Rotterdam and Shell-Pernis and its role in the Energy transition

The Port of Rotterdam lies at the Rhine-Meuse Delta and accommodates the largest harbour of Europe, contributing to a rich history of industry and logistics. The port is an area with major economic interests at regional, national and global level and, consists of many chemical and petrochemical companies forming a fuel hub for supraregional economic activities. The region is connections by rail, waterways and roads and an extensive network of underground pipelines with destinations of importance such as Germany, Belgium and other places in Europe. This network serves for the provision and the transportation of liquid bulk including crude oil and oil products (Van Ledden & Van de Visch, 2017).

In 1862 the first crude oil barrels arrived and by 1891 several oil enterprises had settled along the Maas. In 1901 the Koninklijke Olie, which would later on become the Royal Dutch Shell, became one of the residents. Rotterdam outgrew Amsterdam and became the main Dutch petroleum center, triggered by the demand for lightning oil. When the demand for fuel rapidly grew due to the car industry, Rotterdam went through another extensive growth. Pernis became the main petroleum site, containing the first and second petroleum port, where the Koninklijke Olie built their first gasoline refinery in 1902 and a trial distillation factory for petroleum. In 1918, along with rise of the oil age geared towards cars, an asphalt facility opened. During this time in 1906 the port expanded to the west and Waalhaven (Hein, 2018).

The chemical industrial site of Shell Chemie in Pernis developed along the development of the settled refineries, which after 1945 grew out to be one of the largest refineries in the world and the biggest one in Europe. The processing capacity increased from 1 million ton crude oil just after the second World War to over 25 million ton in 1969, the investment however was not small; Shell invested around 1.5 billion dollar in the industrial site. The Royal Dutch Shell group expanded their facility in Pernis to a "balancing refinery", a refinery that can process more than just crude oil. The building complex was able to take over shifts from other refineries all over Europe (Lintsen, 2003).

1.2 Shell-Pernis and the potential for a sustainable future

Today, Shell is one of the largest oil companies worldwide and one of the biggest CO_2 emitters, as the enterprise was reported 11th on the list of most polluting in 2015 (Griffin, 2017) and number 7 on 2017^{s} list with an overall contribution of 31.95 billion tonnes of CO_2-equivalent since 1965 (Heede, 2017). The polluting and exhausting activities of the Royal Dutch Shell leave their traces both worldwide as well as in the region of Rotterdam, resulting in heavily contaminated soils and subsoils, large areas suffering from heat stress and a substantial amount of GHG emissions in the air. For these reasons this research focuses on the area of Shell-Pernis (Vondelingenplaat), an important node in both the historical and current times of fossil resource provision and transition. In order to meet the demands of a sustainable future on a local and global level, this report gives a holistic proposal for sustainable rehabilitation of the location of Shell-Pernis during the resource transition.

1.3 Research Question & Sub-Questions

Shell-Pernis has been polluted and degraded due to over 100 years of industrial activities, resulting in the fact that it is listed as the most contaminated site of the region (DCMR, 2019). Asides from that, the region of Rotterdam is coping with the highest concentrations of GHG emission in the Netherlands and the harbour area is coping with extreme heat stress (CBS; RIVM; Emissieregistratie). In conclusion, the conventional energy landscapes and its artefacts (e.g. oil-refineries, gas-fired and coal-fired plants, etc.) are degrading the soils and causing negative impact on a regional and local level. In the search for a renewable energy landscape, the current situation of pollution and contamination cannot be neglected. **The aim of this research is to seek for a spatial solution within the transition from the fossil-based industry at Shell-Pernis to a renewable energy landscape whilst at the same time rehabilitating the degraded environment.** A cross-sectoral approach for renewable energy production landscapes and ecosystem services in the form of biorefineries and bioremediation is investigated. The main research question that is ought to be answered is as follows: *How can ecological interventions support the transformation from the fossil-based industrial site of Shell-Pernis into a productive bio-industrial park accessible for public functions?* In order to answer this comprehensive question, multiple sub-questions are formulated: (1) Which bio-economic activities related to fossil resource replacement are able to settle in the industrial site of Shell-Pernis? (2) What ecological interventions should be made to rehabilitate the polluted soils at Shell-Pernis? (3) How can the combined bio-economic activities and the ecological interventions introduced at the site of Shell-Pernis provide for public space and functions?

Shell-Pernis has the potential to become a showcase of a new type of industrial park, where the industry and nature are not considered as two separate elements but rather a symbiosis where the technical supports the biological and even more so, where the natural enhances the industrial.

II Method

First of all, literature will be researched regarding former studies and projects in the field of bio-economy related to fossil fuel replacements. Secondly, ecological interventions are researched by literature study on bioremediation techniques and their accompanying plants and organisms. Additionally, in order to determine which bio-remediation methods can be successfully applied to the site, the contaminants which are currently present on-site are researched through reports and literature. Finally, through the examination of the results of the former chapters and an exploration of different case studies that use bioremediation during the redevelopment of former industrial sites, a spatial vision and a design proposal for the heavily polluted industrial site of Shell-Pernis is sketched. A solution is sought between bioremediation and bio-economics which will make it viable and contributing to the company of Shell to lead the way into a sustainable future during the ongoing energy transition. In figure 1, the research and design flow of this paper is depicted.

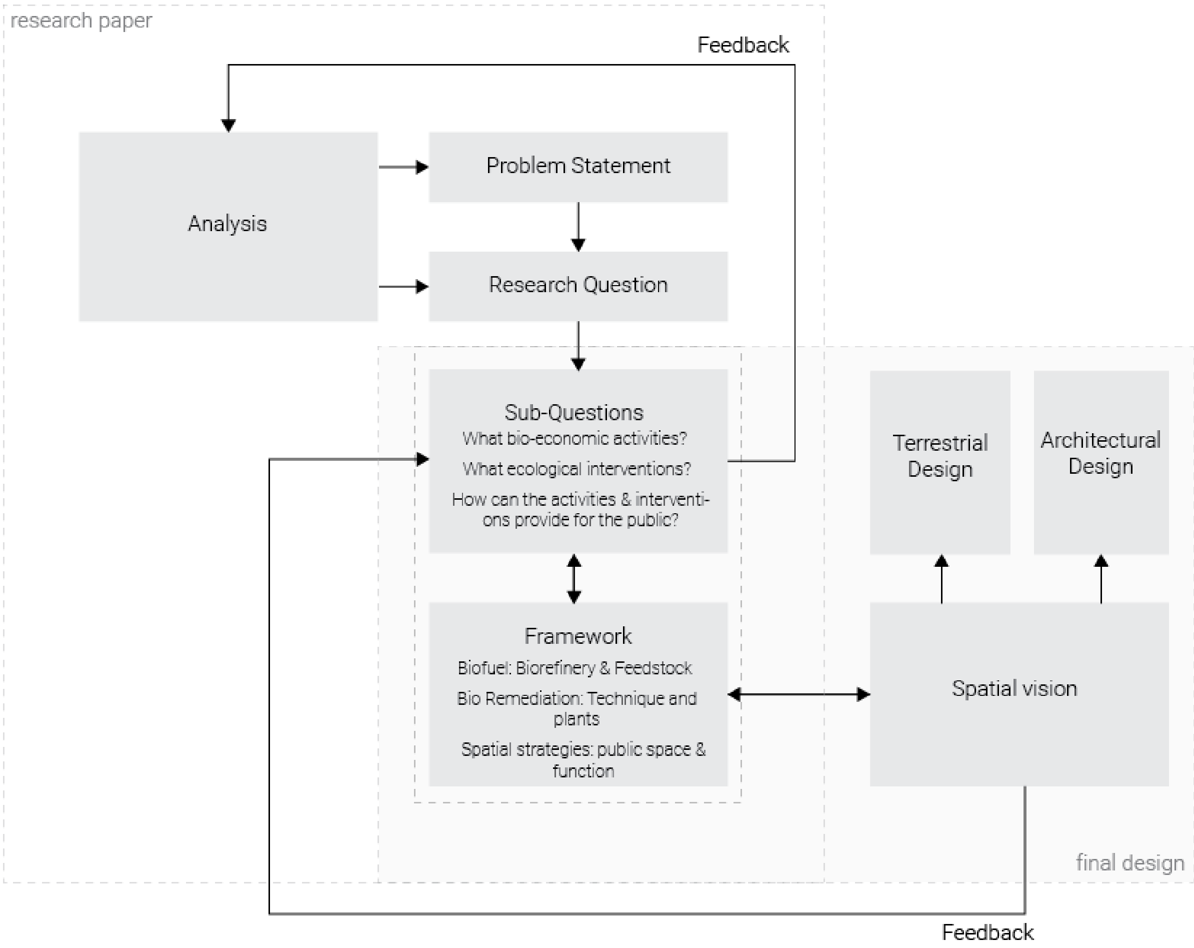


Figure 1: Research and design flow for the cross-sectoral exploration of bioremediation techniques and a renewable energy landscape for Shell-Pernis *(source: own image)*

2.1 Bioeconomy: from fossil to biobased production processes

In a matter of time, the demand for fossil resources will exceed the capacity of the stock, as crude-oil reserves are decreasing whilst the per capita demand for goods and energy increases. Currently, there are more than 2500 different oil-based products on our markets and the greater part of the energy requirements is met by fossil fuels. Furthermore, the purchase power of the population is still increasing whilst the environmental challenges related to climate change and GHG emissions arise. The issues of environment challenges, increasing per capita demand and decreasing finite stocks are triggering the demand for greener alternatives in the resource production and consumption, which causes a likely concomitant increase in biomass demand for production processes (Cheng et al., 2013; Zamora et al., 2012). Bioeconomy is a phenomenon that describes the sustainable conversion and production of biomass for food, energy, health and industrial products. The term *Bioeconomy* relates multiple disciplines that were thus far considered as separate, such as ecosystem services & industrial applications, business & sustainability and consumer products & biomass (Kathi, 2016; Cherubini, 2010). It is stated by the International Energy Agency (2009) that a vital component of the future bioeconomy is the biorefinery, considering it as a biomass production plant for a wide range of marketable products (Hassan et al., 2019). Biorefineries are playing an increasingly important role for global economic activities, with the potential to replace conventional petroleum refineries and become the fundamental method for fuel generation (Cheng et al., 2013). On these grounds, in this chapter the concept of the biorefinery is discussed, the accompanying sustainable processes are elucidated and the suitable crops for biorefinery are illustrated.

2.1.1 Concept of the Biorefinery

In 1997, the term 'biorefinery' was defined as follows: "*green biorefineries represent complex (to fully integrated) systems of sustainable, environment- and resource-friendly technologies for the comprehensive (holistic) utilization and the exploitation of biological raw materials in the form of green and residue biomass from a targeted sustainable regional land utilization*" (Kamm et al., 1998). The biorefinery concept includes a range of technological systems that are able to separate biomass resources (e.g. grasses, corn, wood, wastes) into their building blocks, which can then be processed into a wide spectrum of energy and a variety of marketable products (EA Bioenergy Task 42, 2008). As explained above, biorefinery products can be placed in two groups: material and energy products. Energy products are biological products which are used for energy provision, electricity, transportation or heat and material products are used for their chemical or physical properties, and at last there are certain products that could be used for either (e.g. bioethanol and biohydrogen) (Cherubini, 2010). In order to obtain these material and energy products there are in general four main routes for the conversion of biomass crops: direct combustion, thermal conversion (pyrolysis, gasification), biological conversion (anaerobic digestion, fermentation) and chemical conversion (transesterification).

Currently, the main feedstock for biorefineries is based on starch, which instead could be used for fodder and food. These sorts of feedstocks are also called first generation biomass. Second generation biomass processes use lignocellulosic biomass to municipal solid wastes as a raw material, which does not compete with either fodder or food (Steinbach, 2017). Last, third generation biomass, also called algae biomass, is often linked to the utilization of CO_2 as a feedstock (Lee et al. 2013). In regards to the project of Shell-Pernis second generation biomass is considered as feedstock. This type of biomass is significantly cheaper than first generation biomass, however, the production processes are dependent of newer technologies that are more complex and less developed. The conversion process of the second-generation feedstock usually passes through three different pathways; the bio-, the thermo-, and the chemical pathway (see Fig. 2)

(1) The **thermo-pathway** describes the extraction and treatment of biomass under high temperatures without or with a low concentration of oxidizing agent (e.g. CO_2, H_2O, water, air or O_2). The process with the lowest temperature (300 to 550 degree Celsius) will lead to the main product of biochar or solid biofuel. The mid-range process is pyrolysis; the biomass is heated without oxygen to high temperatures (550 to 750 degree Celsius) and the main output is oil. When heated to greater temperatures (750 to 1200 degree Celsius) with limited amounts of oxygen, gasification occurs and the major product becomes syngas with biochar (activated carbon) and bio-oils as side products.

(2) The **bio-pathway** relies on microorganisms (e.g. yeast) for the conversion process from biomass to biofuels. The first step of the bio pathway, usually, is biomass fractionation of the lignocellulosic biomass. Cellulose/hemicellulose and the lignin biomass are separated by either pulping processes, steam explosion or organosolv processes. Thereafter, either enzymatic or chemical hydrolysis for the saccharification of cellulose is required. Once the cellulose is isolated, hydrolysis is mandatory by the macromolecules in order to be fermented by yeast.

(3) The **chemical pathway** consists of esterification and is the process for oil-based refineries. Esterification is which is the process of converting free fatty acids into alkyl esters, which can then become biodiesel or other products as bioplastics, latex etc.

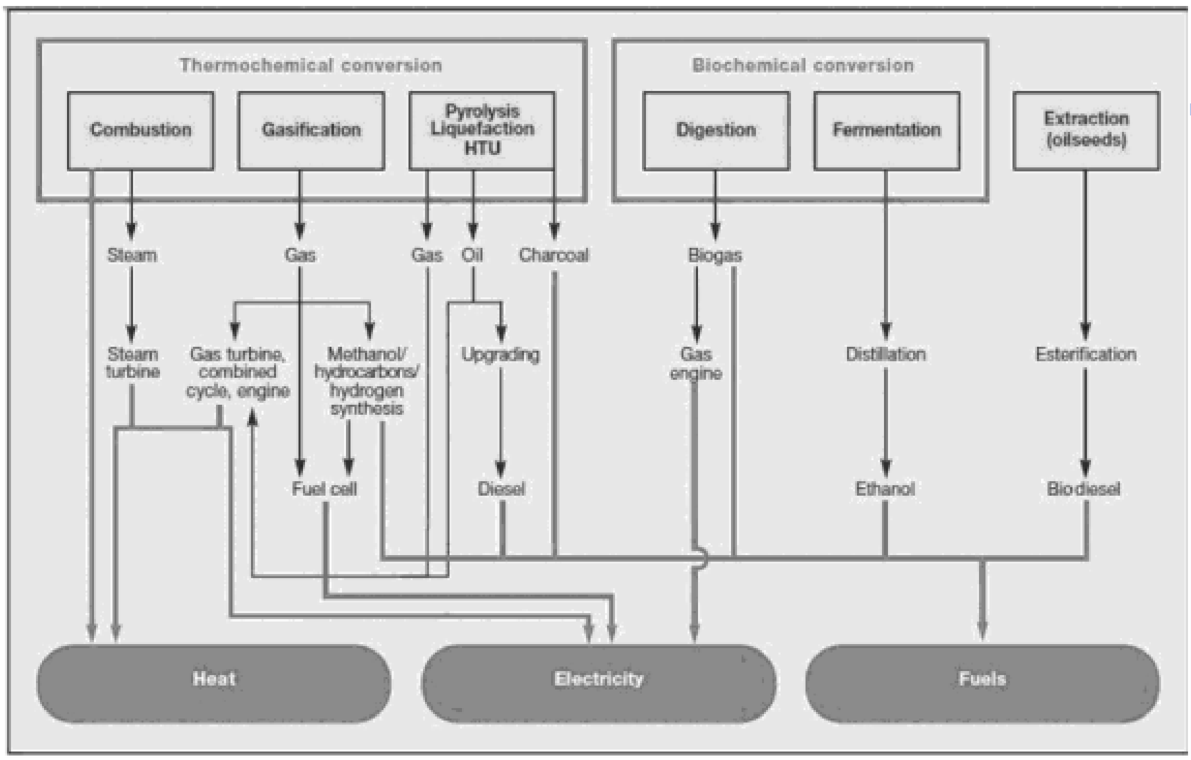


Figure 2: Thermal-, bio-, and chemical conversion methods of a biorefinery resulting in different energy and material products *(WEA, 2000)*

2.1.2 Case study: Inbicon Biorefinery

An example of a second generation biorefinery is the Inbicon Biorefinery in the industrial park of Kalundborg, which uses lignocellulosic biomass as its process feedstock for its operations. Originally the refinery was developed in order to process wheat straw, however the conversion processes have adapted so they are able to process a variety of lignocellulosic inputs as corn, stover, barley and rice straw, and bagasse from sugar production and garden and household waste. The refinery's final product is ethanol, used for automotive fuels. One of the side products is clean lignin powder, which is used by one of the largest power stations in Denmark to replace coal as the fuel (chemical-technology.com). Other by-products are C5 molasses which are used to feed livestock and small amounts of waste water which are utilised for scrubbing flue gasses in the power plant. Besides, the biorefinery uses the waste energy and other by-products from the neighbouring power plant (Holm-Nielsen, 2014). The waste heat streams of the Inbicon refinery are used for its own pre-treatment processes and conversion steps. The processes that the second-generation biomass follows through are explained below and in Appendix I the production process are visualised, based on the research of Holm-Nielsen (2014):

1. **Transport and storage:** Baling systems are used for the transportation of lignocellulosic biomass on-site which are stored under optimal conditions. Supply logistics are closely monitored to ensure an optimal constant inflow of biomass as possible. The capacity is limited to approx. 7 days of storage.
2. **Mechanical Treatment plant;** size reduction of baled raw material (either homogeneous and heterogeneous) by cutting and milling. Afterwards, the particles are more uniform in size and, thus more suitable for degradation in the next process.
3. **Thermal treatment;** The lignocellulose structure is separated in lignin and a mixture of hemicellulose and cellulose fraction. This is done through a hydro-thermal treatment process where the biomass is mixed with water and brought to high temperature and pressure.
4. **Enzymatic hydrolysis**
   The mixture of liquefying enzymes and cellulase are added to the mass of fibres and mixed for 24 hours in horizontal reactors. The conversion leads to liquified lower sugar products (C6), containing fermentable sugars and a solid mainly consisting of lignin. The liquid part is then pumped to a conventional first generation fermentation system and converted to ethanol.
5. **Fermentation and distillation**
   The fermentation process takes two to three days. Yeast is added to the sugars and it is continuously stirred. The main product is ethanol which is then passed through molecular sieves to remove water and purify the outflow. The final mixture is distilled to retrieve an anhydrous ethanol product.
6. **Final solid/liquid separation**
   Solid/liquid separation takes place to obtain dried C5 sugars which are sold as molasses and lignin fractions are combusted in a co-generation plant. In this case, the energy production exceeds the needs for the operation of the biorefinery and is therefore connected to the power grid.

2.1.3 2nd generation feedstock for Biorefineries

Due to the debate on first generation biomass and its sustainability and economic revenues (e.g. competition for land for food and fibre production, high costs and varying assessments of GHG emissions), the interest increased in second generation biomass, and primarily lignocellulosic feedstock materials (Sims et al., 2009). Lignocellulosic biomass can either be a by-product of agricultural processes (cereal straw, sugar cane bagasse, forest residues), wastes (organic municipal solid waste) or dedicated feedstocks (short-rotation crops, purpose grown vegetative grasses and other energy crops). Thorough research has been conducted in regards to biomass and viable energy crops for second generation biofuels of which a few are listed below. Energy crop types can be separated in two different categories based on their characteristics and structure: oil crops and dedicated lignocellulosic biomass crops (see image 2.1.2). In general, edible crops are left out, since they have a higher value and relevance in the food sector.

2.1.3.1 Oil crops

Oil crops can be converted through several processes into biodiesels, lubricants, soaps, medical uses, biopesticides and many other oil-based products (Halford, 2011). Currently, the market is dominated by four main oil crops, which accounted in 2009 for 82% of the worlds vegetative oil production: soy (31%), palm oil (20%), rapeseed (18%), and sunflower (11%). Considering the recent debate on food vs fuel, other oil crops are being considered more often. In this research the following plants are researched according to their favourable oil properties for the production of sustainable chemical products: Lesquerella *(Lesquerella fendleri),* Lunaria *(Lunaria annua)*, Jatropha *(Jahtropha curcas),* Castor *(Ricinus communis L.),* Safflower *(Carthamus tinctorius),* Sunflower *(Helianthus annuus)* (Halford, 2011; Aresta et al, 2012), and Hemp *(Cannabis Sativa)*. All of these crops are considered as non-food crops since they do not compete with agricultural lands as they are able to grow on less fertile lands and they need substantially lower inputs (e.g. water, nitrogen, pesticides) than food crops (Aresta et al., 2012, pp. 53). Some of the plants also have bioremediating properties, for example the Common Sunflower (*Helianthus Annuus*) or the Safflower (*Carthamus tinctorius*) which are considered to be hyperaccumulating (this phenomenon is elaborated in the chapter 2.2.1.), which gives them the ability to grow on polluted soils. The valorisation of oil crops is usually focused on one main product (biofuel), however the plants usually produce many other potentially useful products (i.e. chemicals and polymers, Biohydrogen, organic acids and extracts, etc). In conclusion, there is a wide range of potential applications, products and associated markets for the by-products of oil crops which can be obtained through the processes of a biorefinery. An example is given below in Figure 3, for the Jatropha plant. Furthermore, the properties, functions and characteristics of all selected plants are shown in Appendix II.

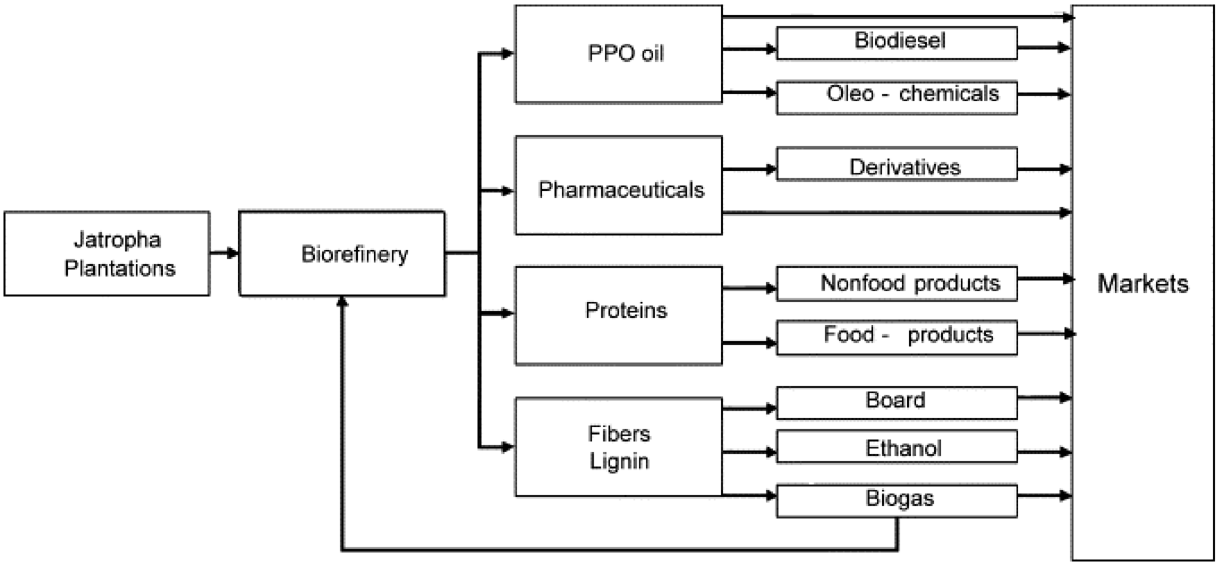


Figure 3: Production pathway of the Jatropha energy crop *(source: Aresta et al., 2012)*

Lignocellulosic Crops

Lignocellulose crops include short-rotation trees, plants and perennial crops, which have low input requirements in general (e.g. water, fertilizers) over a production period of 10-25 years, combined with high yield potentials. Lignocellulose is the fundamental component of biomass and can be used for the synthesis of chemicals as well as transportation fuels and, is in average composed of cellulose (38%-50%), hemicellulose (23%-32%), and lignin (15%-25%) (Aresta et al., 2012). These crops often do not solely offer an important energy resource but also contribute to soil protection, biodiversity, landscape improvement etc. Over the past years multiple funds from the EU are provided for research and development towards perennial crops in a range of European environments (Aresta et al., 2012). The lignocellulosic energy crops that are described and explored in this paper are: Hybrid Poplars *(Populus hybrids)*, Willow species *(Salix spp.)*, Switchgrass (*Panicum virgatum)*, Miscanthus *(Miscanthus x Giganteus)*, Black Locust *(Robina communis)*, Reed Canary Grass *(Phalaris arundinacea)*, Sorghum *(Sorghum spp.)*, Vetiver Grass *(Vetiveria zizanioides)*, Narrowleaf Cattail *(Typha angustfolia)*, and the Creeping Thistle *(Circium arvense)*. These crops are selected due to their high energy yield as well as their potential to grow on marginal lands, and additionally, do most of the species have bioremediating properties (as further explained in chapter 2.2).

2.1.4 Guidelines for biorefinery design

At last, to finish off this chapter, a few guidelines and suggestions are proposed for the design of a biorefinery and the careful selection of biomass. A biorefinery plant should aim to run in a completely sustainable way. It is opted by Cherubini (2010) that only residues and leftovers of the treatment and conversion processes that take place within the biorefinery should be sent to combustion. The heat and electricity produced from the residues should at first be used for the energy requirement of the internal processes, the excess energy can be sent to the grid. In doing so a biorefinery should produce at least one high value chemical/material product alongside the production of low-grade and high-volume products (as fodder and fertilizers). Finally, a biorefinery should produce one energy product besides heat and electricity, such as biofuel: either liquid, solid or gaseous. In general, biorefineries should never be used for the production of one selected product, in order to prevent becoming a threat to biodiversity. Monocultures can lead to the depletion of essential nutrients, different diseases, degradation of soils and desertification of arable land (Kołtuniewicz et al., 2016).

2.2 Rehabilitation of the degraded site of Shell-Pernis

In the past decades environmental contamination has occurred more often and more intense due to anthropogenic activities. It has been estimated that globally approximately 25% of the soils are highly degraded and 44% are moderately degraded (Tripathi, 2015). In order to decontaminate these deteriorated waters and soils, many chemical, physical and natural technologies have been developed. Bioremediation comprises the use of plants, microbes or their products to clean degraded and polluted land and is an eco-friendly solution as well as cost-effective compared to conventional sanitation methods (which in general involve lengthy chemical treatments and the removal of massive amounts of soil to landfill) (Ware et al., 2018). The bioremediating techniques can be applied to heavily contaminated sites, which are intoxicated with non-biodegradable metals and other pollutants (Singh, 2007). On top of that, besides the rehabilitating qualities, bioremediation techniques also provide other ecosystem services which reduce pressure on land resources and enhance the natural environment (e.g. reduce erosion and leeching, fixate nitrogen, enhance biodiversity, capture CO_2). In conclusion, bioremediation has the possibility to prepare a contaminated site for use, whilst preventing further spreading of pollutants in water, soils and air (Lemoine, 2016 p.361). A renown form of bioremediation that encompasses the use of green plants for remediation of soils and waters is phytoremediation. In this chapter the impact of industrial activities (including petroleum refineries, chemical factories and incinerators) on the natural environment (in Shell-Pernis) is researched and different phytoremediation techniques for the rehabilitation of the site are introduced.

2.2.1 Phytoremediation techniques

Multiple different types of Phytoremediation are recognized, such as: Phytoextraction, Rhizofiltration, Phytostablization, Phytovolatilization, Phytodegradation. These techniques include the uptake, stabilization or degradation of contaminants in water and soils by plants and their roots. In order to choose the suitable bioremediation type for the polluted site, knowledge is required concerning the different phytotechnology's related to the contaminants on the specific site.

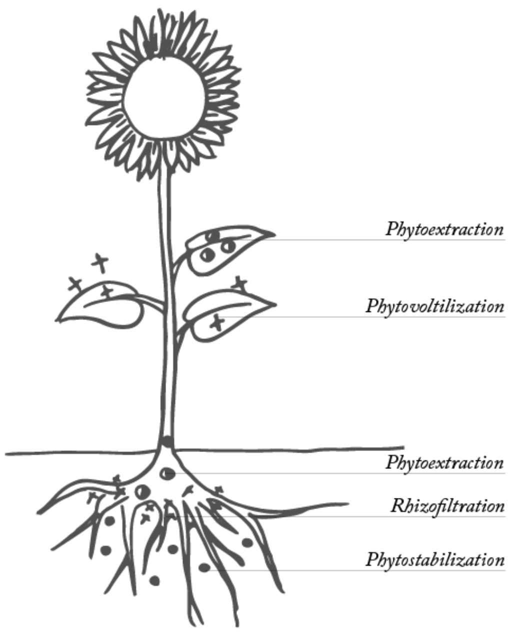


Figure 4: The five different techniques of Phytoremediation (Source: own image)

Below the different techniques of phytoremediation are further elaborated and examples of associated plants are given. The basic outline of the information is based on Advances in Biodegradation and Bioremediation of Industrial Waste from Chandra (2015).

1. Phytoextraction

Phytoextraction, also called phytoaccumulation, is a low-impact technology that uses accumulating plants to remove heavy metals and organic pollutants from soils. These types of plants absorb the contaminants and translocate them to the above-ground harvestable parts. The harvested mass is then ready for disposal or recycling. It has been shown possible to recover heavy metals from the ashes after incineration by phytomining, however, this process is only viable for precious metals. In addition, during the process erosion and leaching will be reduced by the coverup of the soils by the phytoextraction. According to Chandra (2015) there are two factors of great importance when considering phytoextractors: biomass production and bioconcentration. Biomass production is critical in order to make the process commercially viable, since it explains the number of crops required per site. The latter defines the ratio between the pollutant in the soil and shoot and can therefore be used as an indicator of the accumulating capacity of the plant (McGrath & Zhao, 2003). The largest number of hyperaccumulating species belong to the Brassicaceae in temperate climates. Species that have been found successful phytoextractors are: *Thlaspi caerulescens*, *Alyssum lesbiacum*, *Alyssum murale* and *Arabidopsis thaliana* for the accumulation of Zn, Cd, Ni, Cu, Pb and Cr (Baker at al., 1991).

1. Rhizofiltration

Rhizofiltration is the act of terrestrial and aquatic plants to absorb, concentrate and precipitate low concentrations of pollutants from aqueous sources. This technique is often used for the decontamination of surface waters or wastewater streams (e.g. agricultural runoff, acid mine drainage or industrial discharge). Rhizofiltrating plants absorbs metals by their roots, much like phytoextraction, however the heavy metals are not consistently translocated to the shoots. The Common sunflower *(Helianthus annuus)* and Indian mustard *(Brassica juncea)* are examples of plants competent at removing metals from ground waters and the Water Hyacinth *(Eichhornia crassipes)* from surface water.

2. *Phytostabilization*

Phytostabilisation is a technique of plants to prevent migration of the pollutants into groundwater, air, soil or water. It is often used for the rehabilitation of soils, sediment and sludges. The advantages of Phyto stabilisation is that there is no need for further disposal or recycling of the polluted biomass and it is useful when rapid immobilisation of heavy pollutants is needed, however the pollutant will remain present in the soils and demands monitoring afterwards.

3. *Phytovolatilization*

Phytovolatilization is the most controversial technique of all since the process contains the uptake and transpiration of water-soluble organic pollutants and compounds from the soils into the air. In some cases, absorbed heavy metals are released into the atmosphere in a gaseous state. Due to these reasons, this type of phytoremediation is avoided in this research.

4. Phytodegradation

Phytodegradation is one of the most used techniques since it includes the breakdown of organic pollutants in the soils by plants and accompanying microorganisms.

These phytoremediation techniques provide compared to conventional methodologies many additional valuable advantages. It is a low-cost technology, that after application solely has costs for harvesting and field managements (e.g. weed control), and the biomass can be incinerated for heat and energy production. Furthermore, the site disruption is minimal, this form of remediation is aesthetically pleasing and has a great public acceptance. However, phytoremediation is still a relatively new field and the ability to accumulate pollutants varies between species and cultivars within species (Garbisu, 2001), hence the species for a specific site should be carefully selected. The depth of the roots also defines the treatment zone (which is often not deeper than 1 meter) and the climatic conditions may limit the plant growth. Finally, there are chances of the contaminants entering the food chain by animals and insects eating the plants (Singh et al., 2017) .

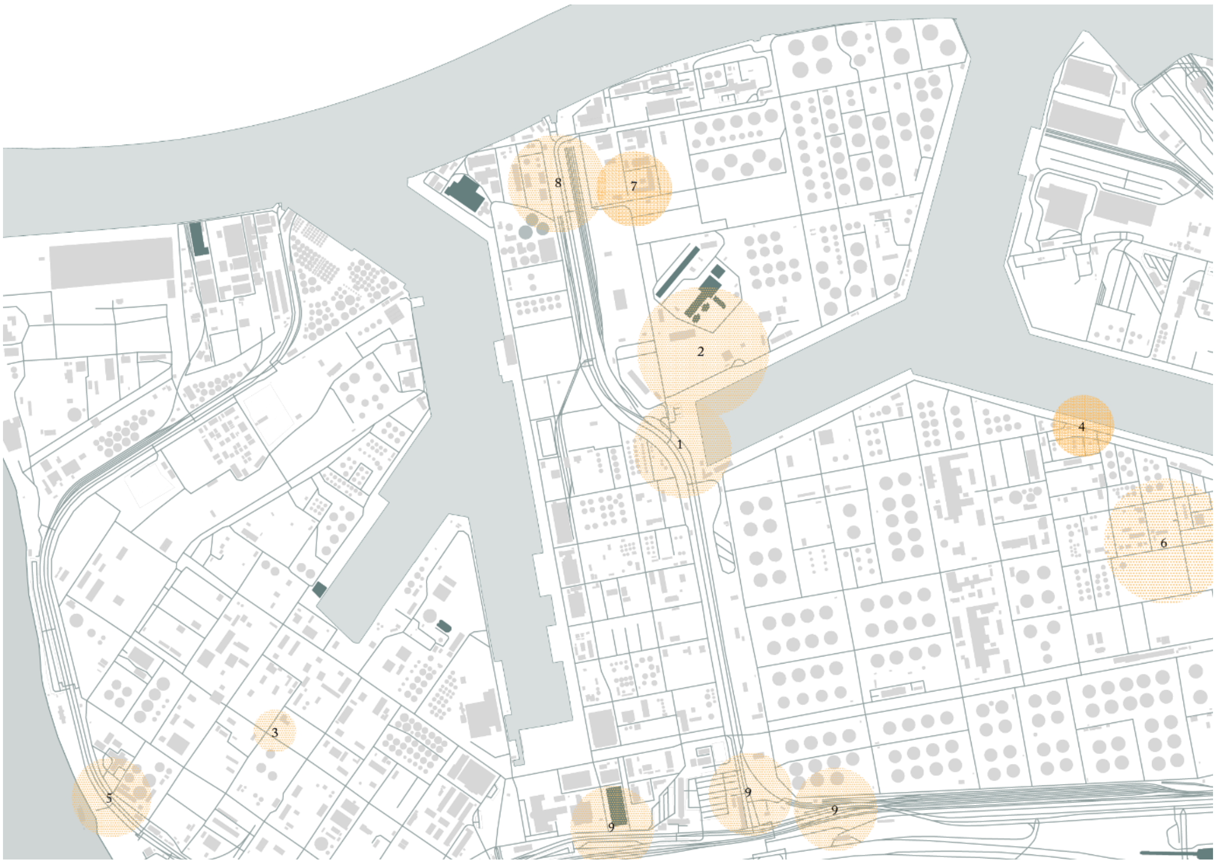
2.2.2 Contaminations in the soils of Shell-Pernis

Through analysis of historical activities and industrial purposes of the area in the past century, a hypothesis can be drawn about the expected contaminants currently present in the soils. A few of the historical (industrial) activities that took place in the area are as follows: (1926) embankment of the river with dredge spoils; (1948) laboratory, fuel tanks (underground), oil terminal, tank reconditioning process and tank cleaning; (1952) heavy fuel oil, benzene and crude oil storage (underground); (1955) Petrol fuel service station and (1956) Chemical waste storage. Nowadays, the area is occupied with different kinds of industries as crude oil refineries, a gas-fired energy plant, an asphalt production and recycle plant, and so on. Considering the historical presence of these enterprises it is expected to detect traces of mineral oils, Poly Aromatic Hydrocarbons (PAHs) and several heavy metals in the soils. For example, PAHs, which are often found in our soils as a result of incinerators, gasoline and diesel engines and industries, emission from furnaces and incinerators and asphalt processing and use. Another precedent is that prior to 1978 most fuels contained Lead (Pb), thus considering the historical activities it is likely to find certain amounts of Pb in the soils.

A lot of research has been conducted on the state of the soils in Shell-Pernis by different environmental research institutes (e.g. Tauw, Arcadis, Gemeente Rotterdam, DCMR). Every report rates the amount of pollution with a national determined grading system, which is as follows:

No pollution: Concentration is smaller or equal to the background value (indicated as -). Soil index< 0.0
Slightly polluted: Concentration is larger than the background value and smaller or equal to the intermediate values (indicated as +). Soil index >0.0 and <0.5
Moderate polluted: Concentration is larger than the intermediate values and smaller than the intervention values (indicated as ++). Soil index >0.5 and <0.1
Heavily polluted: Concentration is larger than the intervention values (indicated as +++). Soil index >1.0

According to the reports of the different pollutions (heavy metals, oils, and aromas) the amounts of contaminants are mapped and organised in Fig. 6 and Table 3 below. From this information a conclusion can be drawn on what interventions should take place, where these interventions should take place and to what extent. From Table 3 the conclusion can be drawn that Mineral oil C10-C40 and Zinc are the dominating contaminants in the soils of Shell-Pernis exceeding the intervention values at nearly every tested location. Heavy metals that exceed nearly all intermediate values are Lead, Cobalt, Copper and Cadmium. Other heavy metals that exceed the background values are Nickel, Mercury and Benzene.



Pollutants	abbrev.	1	2	3	4	5	6	7	8	9
Cadmium	Cd	++	+		++	+		++	++	
Barium	Ba	-	++		++	-		+	-	+
Copper	Cu	++	+++		++	+		+	++	+
Cobalt	Co	++	+		++			+++	+	++
Mercury	Hg	+	+		++	+		+	+	+
Lead	Pb	++	+++		++	+		+++	++	+
Zinc	Zn	+++	+++		++	+++		+++	+++	+
Nickel	Ni	+	++		++	-		++	+	+++
PAH's		+	+		++	+		+++	+	+++
Arseen	As		++					+++		+++
Aromaten	Tolu & Xylenen	+	+++	+++				+++		+++
Mineral oil C10-C40		+++	+++	+++	+++	++	+++	+++	+++	+
Benzene			+							+
1,1- en 1,2-dichloorpropaan	DCP						+++			++
dichloorpropenen	DP						+++			
1,2,3-trichloorpropaan	TCP						+++			+
Vluchtige Aromatische Stoffen	VAK						+++			

Figure 6 & Table 3 : Research Locations and the contaminants of the soils in Shell-Pernis (source: Own image & own table based on information retrieved from TAUW, 2019; Geofoxx, 2019; Arcadis, 2019; Arcadis, 2017; Arcadis, 2019;Gemeente Rotterdam, 2019; TAUW, 2019; Van der Helm, 2018;Grondslag 2019)

2.2.3 Phytoremediation crops for Shell-Pernis

Considering the pollutions found in the subsoil, topsoil and groundwater a number of suitable remediating plants are selected. The plants are selected on their bioremediation technique, suitable climatic conditions and the type of pollutant. The preference of the distribution area is that the plant is native in Europe (e.g. Salix sp.) or has already been in introduced or tested in the conditions similar to those of the Netherlands (e.g. Sorghum sp.).

The main element found in the soils is Zn, for this matter plants that have proven to extract or hyperaccumulate Zn from soils are chosen to be suitable for the site e.g. Kidney Fetch *(Anthyllis vulneraria).*, Halleri Cress *(Arabidopsis helleri),* Penny Cress *(Thlaspi caerulescens).* For the remediation of polluted groundwaters by rhizofiltration, a couple species are selected: e.g. Brown Seed Mustard *(Brassica juncea),* Common Sunflower *(Helianthus annuus)*, and multiple grass types which are often used for the filtration of wastewater (e.g. Narrowleaf Cattail *(Typha Angustfolia)* and Reed Canary Grass *(Phalaris virgatum).* These grasses should be placed in wetlands, resulting in the prevention of further degradation of the soils by erosion and pollutions leeching to the surface waters.

For the uptake or degradation of Mineral oils and PAHs in the soils, two tree species prove applicable; the Willow trees *(Salix ssp.)* and Poplar species *(Populus hybrids).* Willow trees (as *Salix planifolia* and *Salix nigra)* have shown results of being able to clean soilsand ground water from mineral oils, PAHs and other heavy metals by rhizofiltration and phytodegradation. Similarly, multiple grass types have shown positive results for the uptake mineral oils and PAHs from soils and groundwater; for example Vetiver Grass. According to Raman et al. (2017) this grass type particularly suitable for the remediation of wetland applications, wastewater treatment, and oil spill. The roots of the grass (similar to those of Miscanthus, Sorghum and Switchgrass) give the plant the ability to withstand extreme soil and weather conditions and they have a high metal adsorption capacity. Below the overview of phytoremediation plants is depicted in Table 3 and the full information about the species is available in appendix VI.

2.3 Spatial strategies for the development of public space and functions in industrial area's

The aim is to shift from a deteriorating fossil-based production landscape to a rehabilitating renewable production landscape. In order transform the degraded soils to healthy lands, the concept of bioremediation is implemented. At the same time, the transition from fossil fuels to renewable is represented by the development of a biorefinery and its feedstock. Links between the energy production landscape (feedstock for the biorefinery) and the rehabilitating landscape (bioremediating plants) are explored, which then can result in vision for the site: a futuristic industrial area where industry, mankind and nature co-exist in symbiosis. The ambition is to introduce space for public activities on top of the industrial productive layer. In this chapter terrestrial and architectural design solutions are provided in order to meet those criteria.

2.3.1 Terrestrial design: The principle of multiple functions

Over the past decades a shift has taken place in the paradigm in ecology related to urbanism and architectural interventions. Now, there is an increasing recognition of more resilient approaches to managing human activities and designing landscapes in cooperation with ecosystem services. In the design practices to develop areas of land for social occupation, it is shown that the assessment of natural resources as geological sites, water, habitat and soils can play a major role (Reed et al., 2014). In order to plan and design for multiple functions, in a way synergetic urban landscape planning Tillie (2018) states that 'Each urban intervention should improve the sustainability performance and with that improve the quality of life of the city' or in this case the site. These same principles ought to be considered when "designing" or "redesigning" sites occupied by industrial activities. Bill Mollison wrote a saying: "In nature you can never do just one thing", explaining that every component of a design should function in multiple ways. This allows for more yield of any given invested amount of energy and material. Focusing on the multiple functions will contribute to a landscape or garden design that meets multiple needs. Mollison states that it is the best for *forest garden systems plants* to have multiple functions; when designing an energy or bioremediating forestry system the aim is to retrieve the same results. Besides the function of bioremediation or energy crops additional functions could be: nitrogen fixating, wildlife attracting, attracting bees and insects, erosion prevention etc. (Mollison, Edible forest Gardens book from Jacke).

This rule is also considered when choosing the plants for the site of Shell-Pernis. As the aim is to facilitate nature, industry and mankind, plants with additional function or/and benefits for either all or two out of three are preferred (see the dispersion of plants in Figure 7) In the previous chapters (2.1 & 2.2) the suitable crops for energy & material production and bioremediation are explored, which gives us a total set of 25 plants (see Appendix VI) as building blocks for the terrestrial design of Shell-Pernis. The plants can form a productive, natural layer on the current industrial site which can serve for a healthier and aesthetically desired environment for tourists and visitors. Out of the 25 plants, 18 are suitable energy crops for a biorefinery (lignocellulose & oil crops), 20 crops have bioremediating properties, and 19 are flowering herbaceous plants or trees.

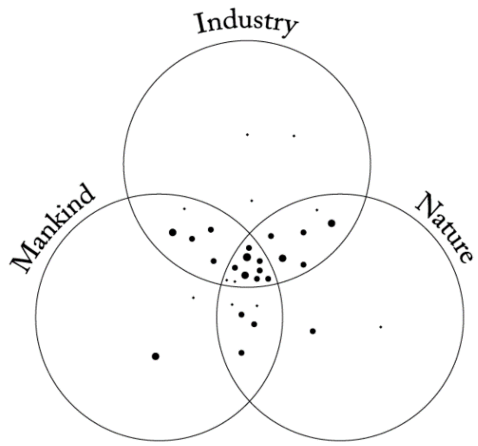


Figure 7: Dispersion of plants according to their functions (Source: own image)

2.2.4 Space for the public in Shell-Pernis

In contemplation of making a public space successful, four generally shared qualities are presented by Projects for Public Space (PPS): accessibility, activities, comfortability and sociability. Considering the first criterium, the PPS explains that accessible spaces are places that are easy to get to (visible from a distance, walkable, parking area, public transport) and to get through (roads & paths to where the people need to go, accessible for people with special needs). The second criterium is about the reason why people visit an area in the first place and whether they would return, this is also what makes the place unique and lively. The latter two, comfortability and sociability, explains whether a place is clean and safe and whether people are comfortable interacting (www.pps.org, 2020). Today, an industrial place such as Shell-Pernis, fails on all these criteria.

In order to introduce public activities to the area of Shell-Pernis the first two criteria are of great importance: what activities are available and how is the place accessible? The current industrial activities that take place in the site make use of finite resources and will, at some point be replaced by bio-based technologies. Thus, the technical artefacts that are part of the conventional landscape have the potential to become of historical value, such as other post-industrial commercialized buildings e.g. Gashouder at the Westerpark, Emscher park in Duisberg, Battersea in London. As mentioned before, the phytoremediation technique has the benefit of having high aesthetic value compared to conventional methods. Similar benefits account for biomass production compared to the mining of fossil resources (i.e. Sunflower fields). Both the vegetational interventions and the implementation of renewable energy technologies give the potential for Shell-Pernis to become a showcase and learning centre for business to business as well as tourists, visitors and students on renewable, nature inclusive solutions for contemporary environmental issues (e.g. soil degradation) and resource transition.

III Conclusion

Shell-Pernis has been polluted and degraded due to more than a century of industrial activities, resulting in a deteriorated and contaminated site. Thus, a spatial solution is sought for Shell-Pernis during the transition from a fossil-based industrial park to a renewable production landscape, whilst at the same time rehabilitating the degraded environment. The solution is found in bio-economic activities and terrestrial design with bioremediating and energy-producing crops. In the realm of bio-economic activities biorefineries will play a major role, due to the ability to produce a wide range of sustainable energy and material products. The feedstock that is delivered to biorefineries can be first generation, second generation or third generation biomass. Second generation biomass can either be a by-product of agricultural processes or dedicated feedstocks which can grow on marginal lands (in contradiction to first generation biomass). The aim of a biorefinery is to produce more than one marketable product through different processes (thermal, bio and chemical). For example, the Inbicon biorefinery in Demark produces as main product Ethanol for automotive fuels and as by-products lignin powder, C5 Molasses, water and energy. The above shows the overall potential of the second generation biorefinery as a replacement for conventional petroleum refineries during the resource transition from fossil to bio-based production processes in Shell-Pernis.

In order to decide what ecological interventions should be made to clean the soils and groundwater an inventory is made of the polluting historical industrial activities and the state of the contaminated soils (based on reports of environmental research institutes e.g. TAUW, Arcadis etc.). The results show that the site of Shell-Pernis is mainly contaminated with Zn and Mineral oils (C10-C40) followed by Copper, Cadmium, Cobalt and Lead, due to industrial activities such as oil and chemical terminals and storages, petroleum fuel stations, and incinerators. In order to clean the area, a sustainable sanitation process phytoremediation can be implemented. Five different forms of phytoremediation techniques are described (Phytoextraction, Rhizofiltration, Phytostablization, Phytovolatilization and Phytodegradation) and the accompanying plants that suit the climatic conditions of Shell-Pernis are used as building blocks for the terrestrial design. An overview of the plants that are considered valuable for the site are added to Appendix VI, this appendix allows architects, landscape architects or bio engineers to find suitable plants for bioremediation and bioeconomic activities to implement in their design.

At last, to transform Shell-Pernis into a public space, according to the PPS (Project for Public Spaces) the area needs to satisfy a set of criteria: accessibility, activities, comfortability and sociability. Currently Shell-Pernis fails on nearly all of those aspects. The first two are of great importance for the site, as there are currently no activities or accessible and safe routes for the public. The terrestrial design has the potential to demonstrate the power of the plants in their remediating properties and other ecosystem service(e.g. nitrogen fixation, erosion control, etc). The ecological interventions can support the transformation from a deteriorated, fossil-based industrial site to an accessible bio-industrial park by cleaning the soils and groundwater, attracting wildlife, fixating nitrogen, preventing erosion and other additional benefits. Hence, the interventions make it safer and healthier, and provide the public for a pleasant stay. The technical artefacts which are part of the present energy landscape, have potential to become historical assets, whilst the new bioeconomic activities can provide the public with educational purposes for students, visitors, tourists and business to business. In conclusion, the combination of alternative sustainable industry and the rehabilitating ecological interventions that provide for the production processes, creates the ability for a degraded site such as Shell-Pernis to showcase of a new type of industrial park, where the industry and nature are not considered as two separate elements but rather a symbiosis in which the technical supports the biological and even more so, where the natural enhances the industrial.

Discussion

The site of Shell-Pernis is chosen because of its large role in the history of energy provision and the fact that the site is highly degraded, also the capacity of oil that is now being processed in the petroleum refineries is not comparable with the biomass that could be grown at this very specific site. The aim of the project is to give an insight to natural solutions and their additional ecosystem services to environmental problems, and to show how heavy industrial sites can be dealt with during the resource transition from fossil fuels to bio-based fuels. On top of that, the location of Shell-Pernis would not be able to be open for the public (as aimed for in chapter 2.3) due to the safety and risk factors. However, the IEA has a long-term vision on creating integrated Bio-industrial Complexes in or near urban locations. Rehabilitating the site of Shell-Pernis to make the direct environment safe and healthier is a start to laying the cornerstones of completely integrated Bio-Industrial parks. Further research on safety and risk management of biorefineries is required though. In this research solely basic knowledge about the biorefinery concept is shared, a recommended source for those who would like to read more about biorefineries and the production processes is the following book: Biorefinery: From Biomass to Chemicals and Fuels by Aresta et al. (2012). Furthermore, investment in infrastructure for agricultural, transportation and conversion purposes is an important factor in the further development of bioenergy. The conversion of lignocellulosic biomass requires the availability of commercialized conversion processes for this type of feedstock as well as the market and supply infrastructure for the 2nd generation biofuel capacity. Besides, further research needs be done to the potential of the energy crops in the EU-region, including the amount of area that is needed to replace the amount of fossils resources (which are now transported imported from all over the world), the growth rate of the energy crops on marginal lands and in temperate climates, and the environmental costs of the full range of production processes (including transportation, storage, etc).

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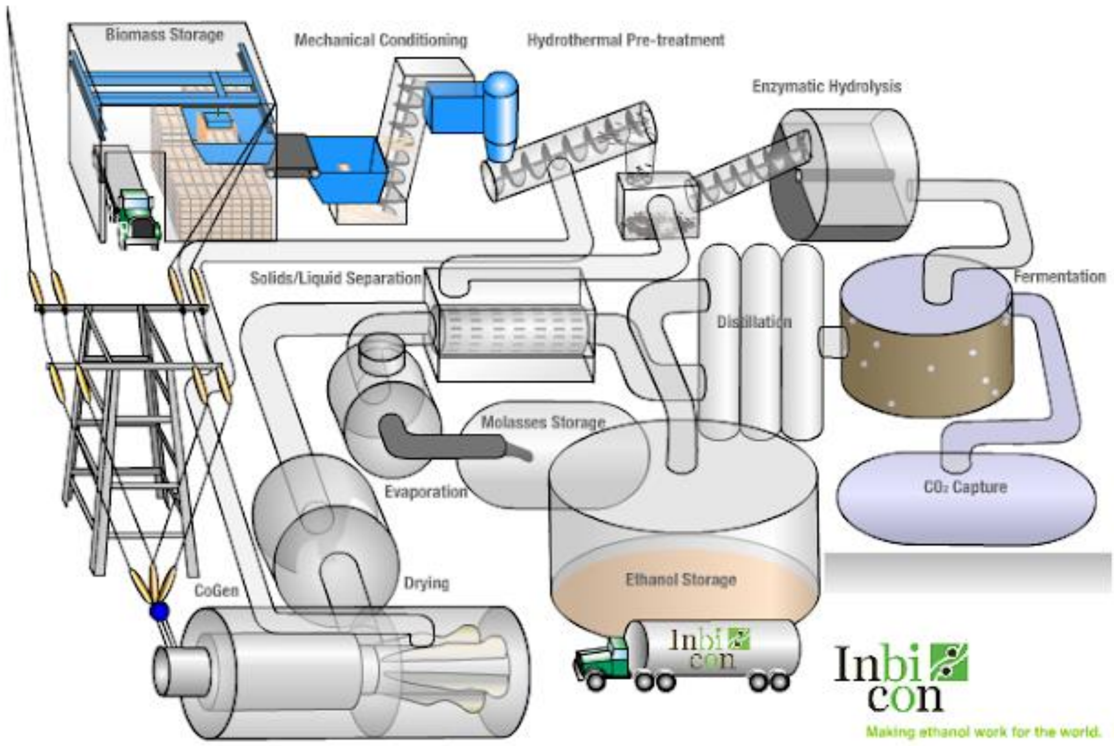
Appendix I


Biomass Storage
Mechanical Conditioning
Hydrothermal Pre-treatment
Enzymatic Hydrolysis
Solids/Liquid Separation
Fermentation
Distillation
Molasses Storage
Evaporation
CO2 Capture
Drying
CoGen
Ethanol Storage
Inbicon
Making ethanol work for the world.

Appendix II

Oil plant	latin name	Seed Yields (kg/ha)	Oil yields (kg/ha)	Oil content (%)	flowering	max height	Growth
Sunflower	*Helianthus annuus*		900-1000		july - september	300	annual
Canola	*Brassicaea napus*	2500-6600		30-48	May - August	120	annual
Hemp	*Cannabis Sativa*				July	250	annual
Castor	*Ricinus communis L.*	1500-3500	600-2000	40-55	July - September	150	perennial
Lesquerella	*Lesquerella fendleri*	800-2300	220-380	22.5-25	June - July	80	perennial
Jathropa	*Jahtropha curcas*	1250-5000	450-2250	35-45	October	600	perennial
Lunaria	*Lunaria annua*	2000-2500	600-1000	30-40	May - July	600	annual
Safflower	*Carthamus tinctorius*	2600-4000	560-1000	21-22	August - October	100	annual
Creeping Thistle	*Cirsium arvense*						

Lignocellulose plant	latin name	Biomass Yield	elements	Growth	flowering	max height
Sundangrass	*Sorghum spp.*	Phytostabilization	Cd, Ni, Cu, Pb & Zn	annual		240
Vetiver Grass	*Vetiveria zizanioides*	Rhizofiltration	mineral oils C10-C50, PAH's	perennial	May - June	300
Narrowleaf cattail	*Typha angustifolia*	Rhizofiltration	As, Cd, Cr, MN, Ni, Fe Cu Pb, Zn, Perchlorate	perennial	June - July	300
Hybrid Silvergrass	*Miscanthus x Giganteus*	Phytoextraction	Cu, Zn, Ni	perennial	April - May	300
Hybrid Poplars	*Populus hybrids*	Phytodegradation	PAH's	perennial	April - May	1500
Diamond Leaf Willow	*Salix spp.*	Mycroremdiation	mineral oils C10-C50, PAH's	perennial	April - May	2500
Switchgrass	*Panicum virgatum*	Phytoextraction	Pb and Cd	perennial		180
Reed Canary Grass	*Phalaris arundinacea*	Rhizofiltration		perennial	July - September	150
Creeping Thistle	*Cirsium arvense*			perennial	July - September	90

Appendix III: Contaminations in the soils of Shell-Pernis (design location)

According to the research of Tauw (2019) the area of Shell Pernis has heavily polluted topsoils, subsoils and contaminated groundwater. The amounts of contaminants are described in mg/kg dry matter soil and are compared to **their background value, intermediate values and exceeding value**, which can be found in table 1. Within the topsoil, slightly increased values have been detected of the following heavy metals; Cu, Co, Cd, Hg, Pb, Zn and PAHs, Aromas (Toluene & xylene) and Mineral oils (C10-C40) and highly increased values for the pollutant Cu.

In the subsoils slightly increased amounts of Cd, Cu, Co, Hg, Ni, Pb, PAHs (10) and Mineral oils (C10-C40) are found. Whereof Cu, Co, Pb, Zn and Mineral oils (C10-C40) exceed the intermediate values and Zn and Mineral oils (C10-C40) exceed the intervention values. The groundwater target values are exceeded of Ba, Mineral oils (C10-C40) and xylene. Barium, likewise, exceeds the background values, however this is a mineral that naturally occurs with higher concentrates in groundwaters.

Based on the information retrieved from the assessment, different bioremediation techniques and their accompanying plants will be selected in order to generate a clean subsurface. The most present and therefore the most important pollutants that are detected are; Zn and Mineral oils (C10-C40) following with Copper, Cadmium, Cobalt and Lead.

Pollution		Bovengrond		Ondergrond		Grondwater	
	abbrev.	mg/kg	overschrijding	mg/kg	overschrijding	ug/L	overschrijding
Cadmium	Cd	1,47	Achtergrond	6,6	Tussenwaarde	370	-
Barium	Ba	254	-	600	-	<0,2	Tussenwaarde
Cupper	Cu	126	Tussenwaarde	152	Tussenwaarde	<2	-
Cobalt	Co	10,8	Achtergrond		Tussenwaarde	<2	-
Mercury	Hg	0,85	Achtergrond	3,67	Achtergrond	<0,05	-
Led	Pb	110	Achtergrond	308	Tussenwaarde	<2	-
Zinc	Zn	368	Achtergrond	1203	Interventie	<2	-
Nickel	Ni	23,6	Achtergrond	37,3	Achtergrond	<3	-
PAH's					Achtergrond	<10	-
Aromaten	Tolu & Xylenen				Achtergrond		Achtergrond
Mineral oil C10-C40				52000	Interventie		Achtergrond

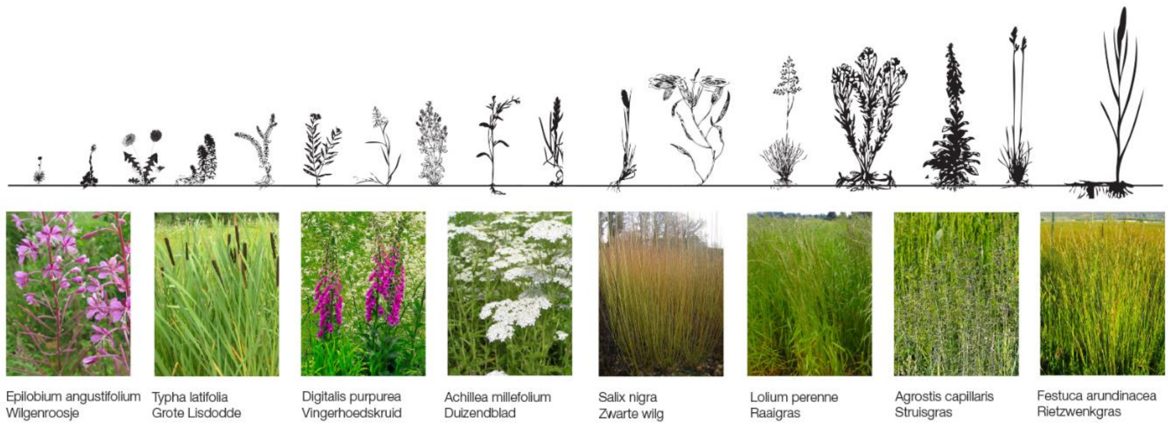
Appendix IV: List of Phytoremediation species

Commonn Name	*Scientific name*	technique	elements	Growth	flowering	max height	layer
Sundangrass	*Sorghum spp.*	Phytostabilization	Cd, Ni, Cu, Pb & Zn	annual		240	grass
Kidney Fetch	*Anthyllis vulnerarial*	Phytoextraction, hyperaccumulator	Zn	perennial	June - September	90	herbaceous
Penny Cress	*Thlaspi caerulescens*	Phytoextraction	Cd, Pb, Zn, Mn	perennial	April - June	60	herbaceous
Vetiver Grass	*Vetiveria zizanioides*	Rhizofiltration	mineral oils C10-C50, PAH's	perennial	May - June	300	grass
Narrowleaf cattail	*Typha angustifolia*	Rhizofiltration	As, Cd, Cr, MN, Ni, Fe Cu Pb, Zn, Perchlorate	perennial	June - July	300	grass
Sunflower	*Helianthus Annuus*	Rhizofiltration	PAH's, Cu, Zn, Ni	annual	July - September	300	herbaceous
Viola	*Violacaea calaminaria*	Hyperaccumulator	Cd, Zn, Pb	annual	May - June	50	soil covers
Black Willow	*Salix nigra*	Mycroremediation, Rhizofilration	mineral oils C10-C50, PAH's	perennial	April	1200	Shrub
Halleri Cress	*Arabidopsis halleri*	Hyperaccumulator		perennial	May - June	30	herbaceous
Brown Seed Mustard	*Brassicaea juncea*	Phytoextraction, rhizofiltration	Cd, Cr, Cu, N, Pb, Zn	annual	June - August	100	herbaceous
Water Hyacinth	*Einchhornia crassipes*	Rhizofiltration	Hg, Zn, Pb	perennial	May - September	80	soil covers
Hybrid Silvergrass	*Miscanthus x Giganteus*	Phytoextraction	Cu, Zn, Ni	perennial	April - May	300	grass
Hybrid Poplars	*Populus hybrids*	Phytodegradation	PAH's	perennial	April - May	1500	canopy tree
Willow	*Salix spp.*	Mycroremdiation	mineral oils C10-C50, PAH's	perennial	April - May	2500	canopy tree
Canola	*Brassicaea napus*	Hyperaccumulator	Zn, Pb, Ni	annual	May - August	120	herbaceous
Hemp	*Cannabis Sativa*	Hyperaccumulator	Pb, Zn, Mg, Cd, Cu, Co	annual	July	250	herbaceous
Castor	*Ricinus communis L.*	oil plant	N, Pb, Cd	perennial	July - September	150	shrub
Jathropa	*Jahtropha curcas*	phytoextraction	Al, Cr, Mn, Fe, Cu	perennial	October	600	tree
Switchgrass	*Panicum virgatum*	Phytoextraction	Pb and Cd	perennial		180	grass
Reed Canary Grass	*Phalaris arundinacea*	Rhizofiltration		perennial	July - September	150	grass

Appendix IV: Case studies towards recreational landscapes on polluted industrial sites

De Ceuvel, Amsterdam, the Netherlands

Size:	4 470m2
Year:	2014
Architects:	DELVA Landscape Architects, Metabolic
Former use:	Shipyard
Current Use:	Restaurant, Living Lab, Office area.
Costs:	5000€



The polluted areas are separated into three classifications: heavily polluted, medium polluted and light polluted. The heavily polluted areas were designed to serve for biomass production, since the overall time for the remediation could take up to 60 years. In these areas mainly willow trees were planted as they have a high caloric value and can serve as biomass for the incinerator. Other areas where the pollution is medium to slightly present in the soils, plants are used to rehabilitate the ground. In the final result of the plantation plan a relation is drawn between the extend of pollution and esthetic aspects of the landscape.

The surviving plants after several years are the mature Willows, Poplars and several grasses. From 2016 onwards, the invading species on site have been monitored and researched for their potential benefits in phytoremediation. The plants with recognized accumulating properties are frequently sown. Soil contamination is no long the bigger issue in the area but has become a sustainable catalysator. According to UrbanGrowth NSW (2018) the project of De Ceuvel is the only project in Europe that utilizes bioremediation in its purest form. The effectiveness of the socio-economic aspects becomes visible through the fact that the abandoned shipyard developed into a thriving sustainable hub for the local community.

Sources:

1. Ware, S., Johnstone, C., Sparks, K., Allan, P., Bryant, M., Murray, A. (2018). Power Plants. Phytoremediation Gardens. Stage One Report. NSW Government, Landcom: Sydney, Australia.
2. De Ceuvel. (2019). Sustainability retrieved from https://deceuvel.nl/en/about/sustainable-technology/

Wester park, Amsterdam, the Netherlands

Size:	135 000m2
Year:	2004
Architects:	Kathryn Gustafson & Francine Houben
Former use:	Gas facility and storage
Current Use:	Recreational Park, Leisure, culture and office area.
Costs:	31 million €

The design question for the Westergasfabriek park was written out as a competition in 1997 with the means to transform the heavily polluted site of a former Gas facility in Amsterdam into a recreational facility, subject to the rehabilitation of the site. From the mid-1800s the gas facility provided gas for domestic use and street lamps, however when natural gas was discovered in the 1960s, all facilities were shut down. During this period the soils became heavily polluted with toxins (e.g. tar, cyanide and asbestos). Afterwards, the site facilitated as storage, from 1981 it was rezoned into a recreational area and at 1989 it became of historical interest. In the design new and old and technical and natural artefacts are combined. The remains of the gasholders and stelcon paving is up until today still visible.

Sources:

3. Ware, S., Johnstone, C., Sparks, K., Allan, P., Bryant, M., Murray, A. (2018). Power Plants. Phytoremediation Gardens. Stage One Report. NSW Government, Landcom: Sydney, Australia.
4. Da Silva, G. (2015). *Westegasfabriek Park goes from Polluted Gas Factory to an Award Winning Design*. Land8: Landscape Architects Network Retrieved from https://land8.com/westergasfabriek-park-goes-from-a-polluted-gas-factory-to-an-award-winning-design/

BP Parklands, Sydney, Australia

Size: 250 000m2
Year: 2004
Architects: McGregor Coxall
Former use: Industrial Storage Tanks
Current Use: Recreational and Environmental space
Costs: 3,4 million €

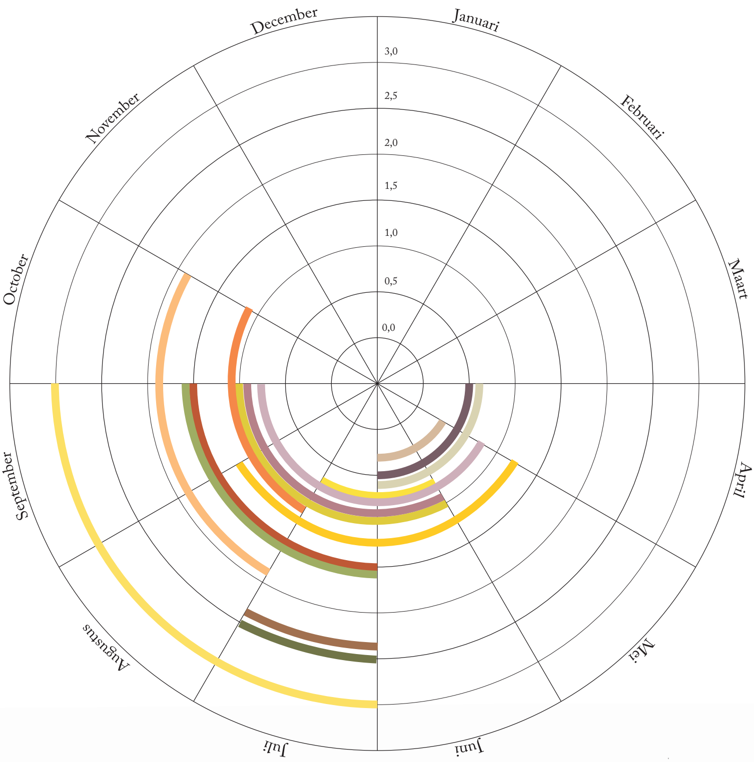
Parkland is designed to be self-sustaining, to reconnect Sydney's residents with its major waterways and to provide educational and recreational opportunities for visitors. Yearly, over 2.5 million people visit the place for different **recreational and leisure purposes,** and the space gives opportunity for nearly 20.000 children to follow **environmental education programs** The area was in former use of different industries including the BP fuel storage, these activities contaminated the site with large amounts of industrial and commercial wastes. The area exists of a range of industrial relics including pipework, excavated danstone cliffs, bund wall and footings and **provides habitat** for over 180 native bird species. According to the NSW (2018), the design connects the historical artefacts of the site, and at the same time contrasting them against a modern framework. Since 2005, the project has won five awards in landscape design.

The design incorporates **phytoremediation planting as well as a stormwater collection an filtration system,** which is constantly cleaning the polluted area. In total, over 55.000 provenance-sourced indigenous plants are used for the rehabilitation of the site. Unfortunately the information about on tracking of the effects of the bioremediation or which plants are implemented to decontaminate the site is not accessible to the public.

Sources:

1. Zeunert, J. (2017). *Landscape architecture and environmental sustainability: Creating positive change through design*. Bloomsbury Publishing.
2. Ware, S., Johnstone, C., Sparks, K., Allan, P., Bryant, M., Murray, A. (2018). Power Plants. Phytoremediation Gardens. Stage One Report. NSW Government, Landcom: Sydney, Australia.

Appendix VI: Rehabilitating plants for polluted soils and sustainable production landscapes



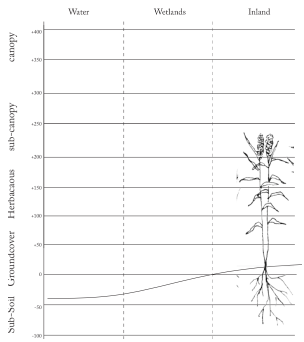
Specifications

Common Name: Sundangrass
Technique: Phytostabilization
Pollutants: Cd, Ni, Cu, Pb, Zn
Sort: Grass
Height: 240 cm
Habitat: Wetlands

Explaination

Sorghum is a genus of flowering plants in the grass family Poaceae. Seventeen of the 25 species are native to Australia, with the range of sWome extending to Africa, Asia, Mesoamerica, and certain islands in the Indian and Pacific Oceans

Landscape positioning



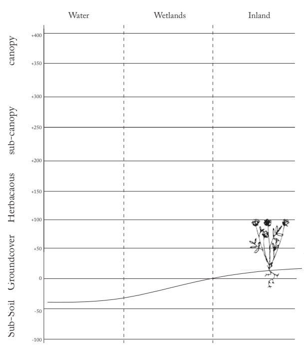
Specifications

Common Name:	Kidney Fetch
Technique:	Phytoextraction, hyperacumulator
Pollutants:	Zn
Sort:	Herbacaous
Height:	90 cm
Habitat:	Inland
Growth:	Perennial
Flowering:	June - Sept.

Explaination

Anthyllis Vulneraria L. is a herbacaous plant that is spread throughout Europe and North Africa. The plant usually appears in dry sitiations and sea cliffs. It can handle light sandy and medium clay soils and prefers a PH neutral or alkaline soils. It cannot grow in shaded areas. The plant is reknown for attracting wildlife and bees, moths and butterflies. Another advantage of the Anthyllis vulneraria L. is that it is able to fix nitrhogen

Landscape positioning



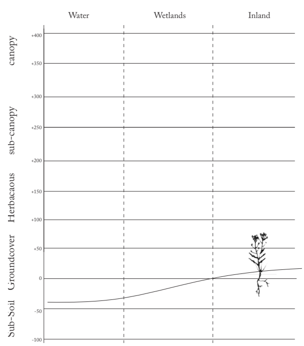
Specifications

Common Name: Penny Cress
Technique: Phytoextraction
Pollutants: Zn
Sort: Herbacaous
Height: 40 cm
Habitat: Inland
Growth: Perennial
Flowering: April - June

Explaination

Penny Cress grows well in light sandy, loamy, clay soils. It tolerates acid, neutral an basic alkaline soils and grows in semi shade or no shade. It is native to the mountains of central and southern Europe.

Landscape positioning



Vetiveria zizanioides L.

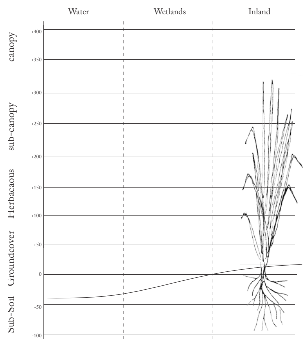
Specifications

Common Name:	Vetiver Grass
Technique:	Rhizofiltration
Pollutants:	mineral oils C10-C50, PAH
Sort:	Grass
Height:	Up to 300 cm
Habitat:	Water, dry soil
Growth:	Perrenial
Flowering:	May - June

Explaination

Vetiver grass can grow in many conditions dry soils, sandy, loamy and clay soils. Besides they provide for erosion-control, pesticide tolerance & removal of metal acculmulation. The plant can resist high velocities of water up to 5 m/sec.and ist is drought and fire resistant. At last, vetiver grass removes nitrates, and phosphates frem the soils and the essentail oils can be used for market products.

Landscape positioning



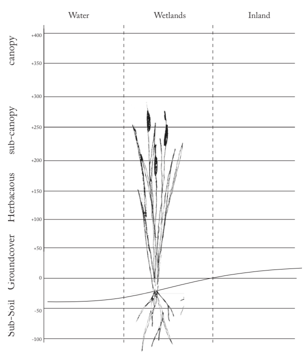
Specifications

Common Name:	Narrowleaf Cattail
Technique:	Rhizofiltration
Pollutants:	As, Cd, Cr, Mn, Ni, Fe, Cu, Pb, Zn
Sort:	Grass
Height:	300 cm
Habitat:	Wetlands
Growth:	Perrenial
Flowering:	June - July

Explaination

Narrowleaf Cattail stands in wetlands with water up to 15 cm deep. They grow well in brackish conditions and light sandy, loamy and heavy clay soils. In addition, the grass attracts wildlife.

Landscape positioning



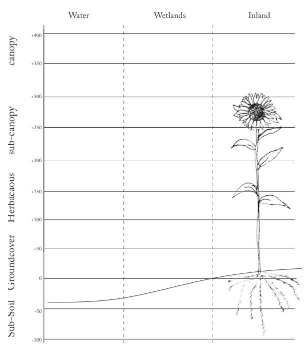
Specifications

Common Name:	Common Sunflower
Technique:	Phytoextraction Rhizofiltration
Pollutants:	PAH, Cu, Ni, Zn
Sort:	
Height:	300 cm
Habitat:	Inland
Growth:	Annual
Flowering:	July - September

Explaination

The Common Sunflower grows at a fast rate up to 300 cm. It accumuates nitrates and is reknown for attracting wildlife. It grows in light sandy, medium loamy and heavy clay soils. Either acid, neutral and basic alkaline soils are environmnets where the sunflower will grow. It prefers no shade or semi-shading and grows well in moist soils but tolerates drought.

Landscape positioning



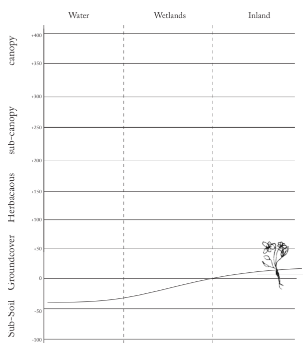
Viola Boashanensis

Specifications

Common Name:	Viola
Technique:	Hyperaccumu lating
Pollutants:	Zn, Cd, Pb
Sort:	Soilcovers
Height:	50 cm
Habitat:	Inland
Growth:	Annual
Flowering:	May - June

Explaination

Landscape positioning



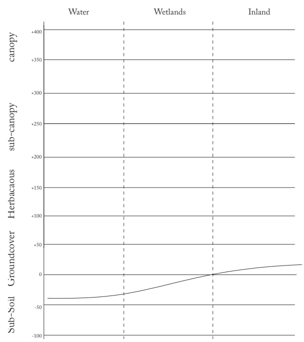
Specifications

Common Name:	Black Willow
Technique:	Mycoremediation
Pollutants:	Mineral Oils, PAHs
Sort:	Shrub
Height:	1200 cm
Habitat:	Wetlands
Flowering:	April

Explaination

Salix Nigra is fast growing, but relatively short lived. The shrub-succeeds in most soils including wet and flooded soils. The tree can be used for papermaking and basket and furniture making. Besides is the woody plant good for erosion control and a great product for biomass energy

Landscape positioning



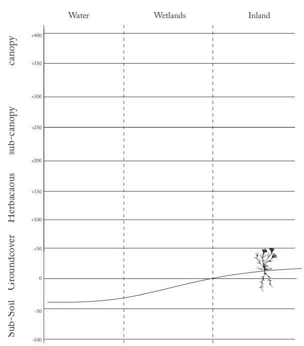
Specifications

Common Name:	Halleri Cress
Technique:	Hyperaccumulator
Pollutants:	Zn
Sort:	Herbaceous
Height:	30 cm
Habitat:	Inland
Growth:	Perrenial
Flowering:	May - June

Explaination

The plant is found in the northern hemispheres. It is very tollerant to heavy metal contaminated soils and a hyperaccumulator for Zn.

Landscape positioning



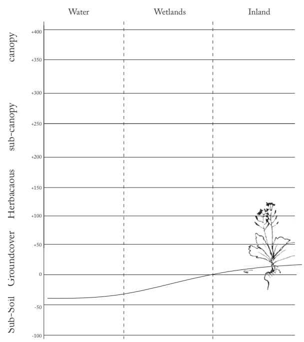
Specifications

Common Name:	Brown Seed Mustard
Technique:	Phytoextraction, rhizofiltration
Pollutants:	Cd, Pb, Zn, N, Cr, Cu
Sort:	Herbaceous
Height:	80 cm
Habitat:	Inland
Growth:	Annual
Flowering:	June - August

Explaination

The borwon seed mustard is one the most well renown plants for bioremediation, as it has a high tolerance for heavy metals and a hyperacculumator for different heavy metals such as lead and zinc. The plant is also used for its mustard taste and for medi-cines. It can grow in many soil types and occurs naturally from Northern Europe to Asia.

Landscape positioning



Eichhornia crassipes

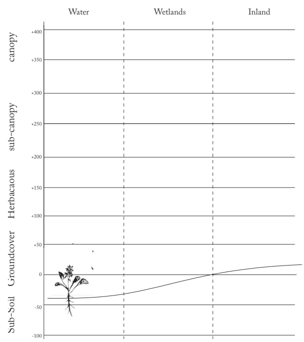
Specifications

Common Name:	Water Hyacinth
Technique:	Rhizofiltration
Pollutants:	Pb, Hg
Sort:	Groundcover
Height:	30 cm
Habitat:	water/ponds
Growth:	Perennial
Flowering:	May - September

Explaination

The Water Hyacinth is an excellent source of biomass and is often cultivated for the use in wastewater treatment. The biomass can be harvested after and dried plants can be used as fertilizer and plant mulch. It requiers greenhouse protection in the winter. Besides it fixated nitrogen.

Landscape positioning



Miscanthus x Giganteus

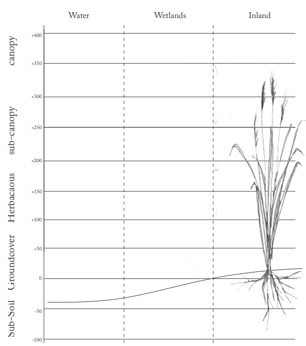
Specifications

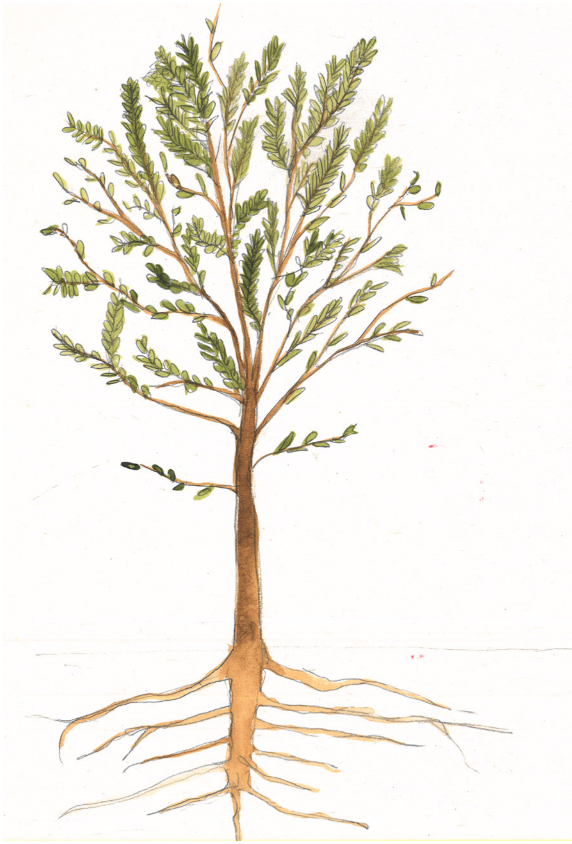
Common Name:	Miscanthus
Technique:	Phytostabilization
Pollutants:	Zn
Sort:	Grass
Height:	400 cm
Habitat:	Inland/wetland
Growth:	Perennial
Flowering:	April - May
Harvest:	spring

Explaination

Miscanthus is a woody rhizomatous C4 grass. They are characterized by rapid growth up to three meters tall during the third or fourth year of production. The plant was first introduced in Europe in the 1930ies and is now well established, around 40 forms and cultivars are available. It is used as industrial crop for non-food in materials, chemicals and energy. At last, tha plant is an excellent windbreak and popular ornamental

Landscape positioning





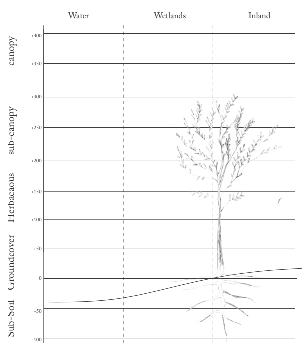
Specifications

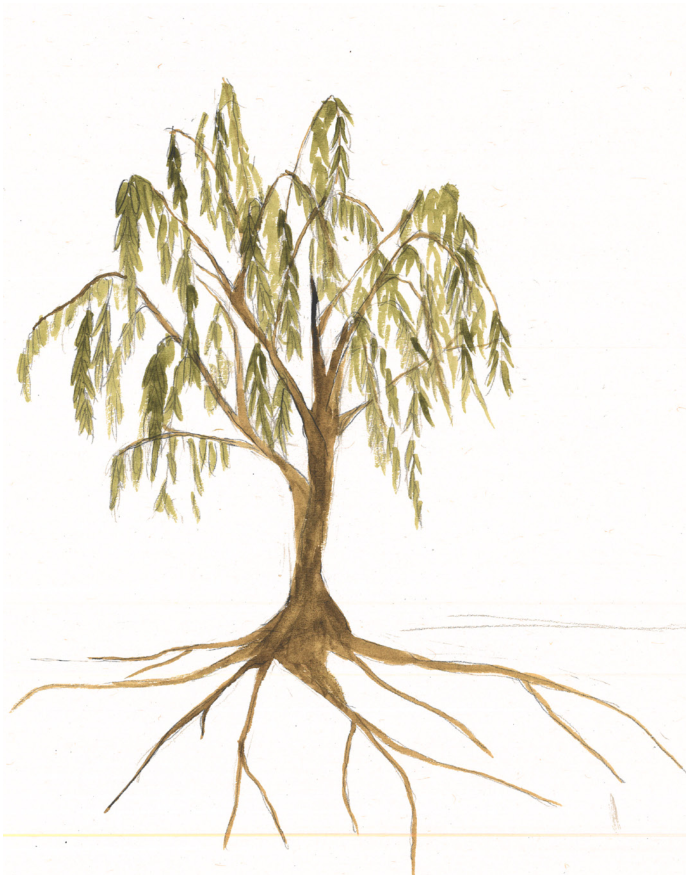
Common Name:	Poplar, Aspen
Technique:	Phytodegradation
Pollutants:	Mineral Oils, PAHs, PCB
Sort:	Tree Canopy
Height:	1500 - 5000 cm
Habitat:	Inland
Flowering:	April - May

Explaination

Hybrid Populus spp. is a fast growing species from the same family as the willow Salicaceae. It likewise succeeds in most soils including wet, flooded soils and maritime conditions. The tree is known for its rapid bioaccumulation and provides resources for energy, materials an chemicals. Besides is the tree good for erosion control and wind breaks and living trellis.

Landscape positioning





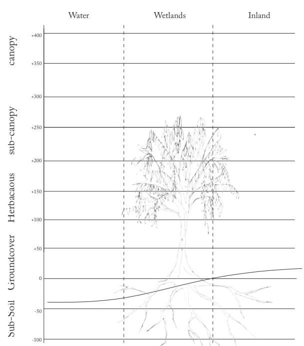
Specifications

Common Name: White Willow
Technique: Mycoremediation
Pollutants: Mineral Oils, PAHs
Sort: Tree Canopy
Height: 2500 cm
Habitat: Waterfront
Flowering: April - May

Explaination

Salix spp. is a fast growing species and succeeds in most soils including wet, flooded soils and maritime conditions. The tree can be used for papermaking and basket and furniture making. Besides is the tree good for erosion control and a great product for biomass energy.

Landscape positioning



Brassica napus

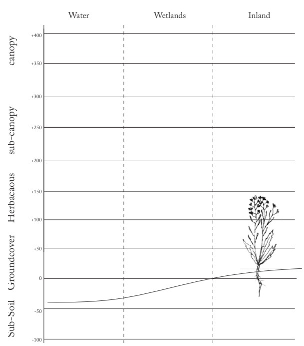
Specifications

Common Name:	Canola
Technique:	Phytoextraction
Pollutants:	Zn, Pb, Se
Sort:	herbacaous
Height:	120 cm
Habitat:	Inland
Flowering:	May - August
Growth:	Annual/Biennial

Explaination

The seed of the canola is good for making oil, which can be used for lubricant, soap, polyamide fibres and resins, and as a vegetable wax substitute. The seed husks are used in plastering walls. The sprouted seed can be used in salads. Besides it has bioremdiating properties much like Brassica juncea. The plant succeeds in very alkaline to very acids soils and in dandy, loamy and cloay soils.

Landscape positioning



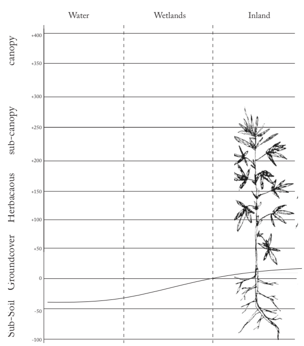
Specifications

Common Name:	Hemp
Technique:	Hyperaccumulator
Pollutants:	Pb, Zn, Mg, Cd, Cu, Co
Oil content:	49%
Sort:	Herbacaous
Height:	2500 cm
Growth:	Annual
Habitat:	Inland
Flowering:	July

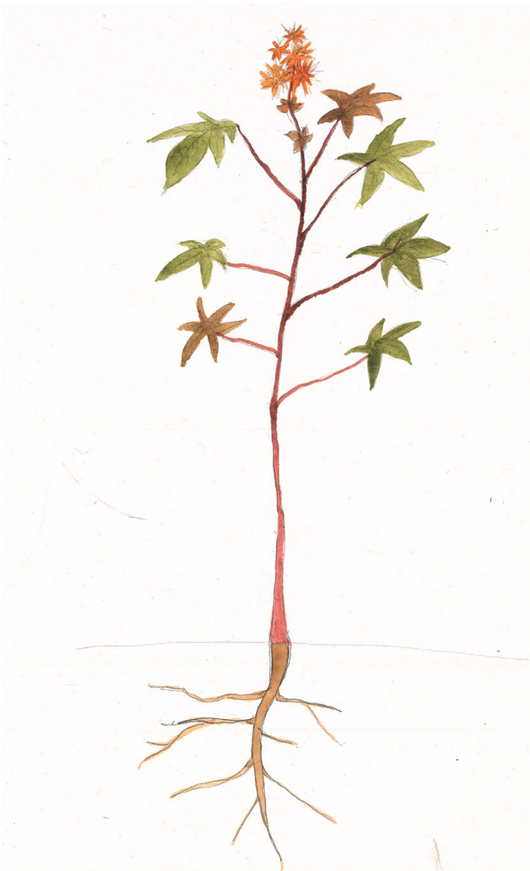
Explaination

Cannabis Sativa L. is a widespread species occuring in various habitats ranging from sea levels to temperate alpine foothills. It is an annual herb that is cultivated at low cost and low environmental impact. The oil from the seeds can be used for soap, paints, varnishes. Fibre is obtained from the stem and can be used for making robe, fabrics etc. Besides it is an excellent phytroremediating agent for heavy metals.

Landscape positioning



Ricinus Communis L.



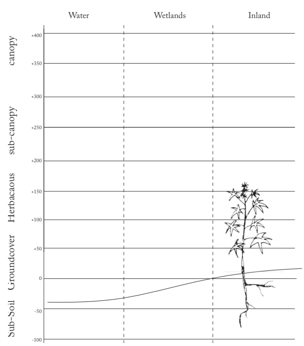
Specifications

Common Name:	Castor Seed
Technique:	Oil Plant
Oil content:	40-55%
Seeds (kg/ha):	1500 - 3500
Oil (kg/ha):	600 - 2000
Sort:	Shrub
Height:	150 cm
Habitat:	Inland
Flowering:	July - September
Harvesting:	October

Explaination

Castor seed is a tropical plant which is cultivated around the non-edible oilseeds. world for its oil. It cannot tolerate temperatures below 15 degree. It is suitable to grow in light sandy, medium loamy and heavy clay soils. The plant is very poionous. The oil can be used for the production of soaps, polishes, flypapers, painting and varnishes, coating fabrics and lubricants.

Landscape positioning



Lesquerella fendleri

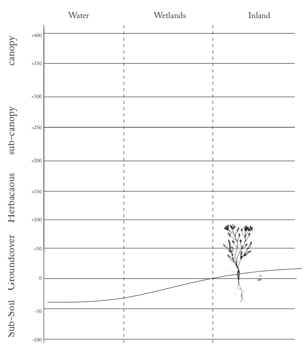
Specifications

Common Name:	Lesquerella
Technique:	Oil Plant
Oil content:	22.5-25%
Seeds (kg/ha):	800 - 2300
Oil (kg/ha):	220 - 380
Sort:	Shrub
Height:	80 cm
Habitat:	Inland
Flowering:	October
Harevsting	June - July

Explaination

A few species are improved through breeding, having oil contents up to 39 percent, this gives huge possibilities for the future of the lesquerella in the oil production. The lubricants can be used for plastic, waxes, resins, lubricants, cosmetics and coatings. It usually lives above sea level but is not demanding on soil quality and irrigation.

Landscape positioning



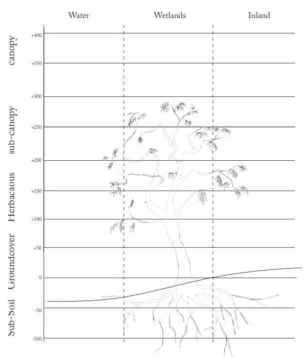
Specifications

Common Name: Black Locust
Technique: SRC
Biomass Yield: 220 - 380
Sort: Tree
Height: 2500 cm
Habitat: Inland
Flowering: June

Explaination

The black locust is a tree noted for attracting wildlife, nitrogen fixation and its toleration for atmospheric pollution. It is widely used for windbreaks, shelterbelts and for the proiduction of woody biomass for energy. The bark is used for paper making and a substitude for silk and wool. The tree also provides erosion control . The plant also attracts bees and butterflies due to its fragant flowers.

Landscape positioning



Jahtropha curcas

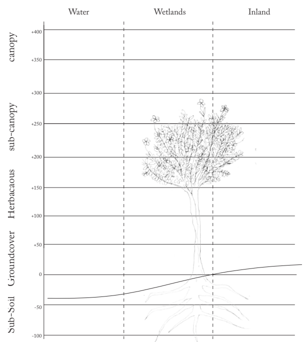
Specifications

Common Name: Jahtropha
Technique: Oil Plant
Oil content: 35-45%
Seeds (kg/ha): 1250 - 5000
Oil (kg/ha): 450 - 2250
Sort: Shrub
Height: 600 cm
Habitat: Inland (tropical)
Growth: Perennial
Flowering: October

Explaination

A multipurpose, drought resistant plant which is widely distributed in the wild and cultivated in many southern countries. It has the ability to grow on poor soils , wherefor mariginal land can be used. Reduces wind and water erosion and runoff. The plant grows quick and is easy to establish. The oil can be used for kerosene, diesel and other fuels. It can handle strong winds but no maritime exposure and is frost tender.

Landscape positioning



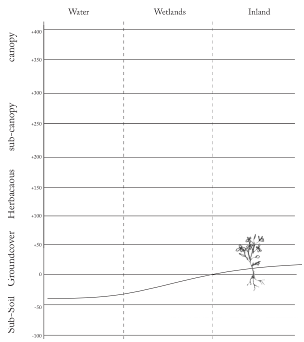
Specifications

Common Name:	Lunaria
Technique:	Oil Plant
Oil content:	30 - 40%
Seeds (kg/ha):	2000 - 2500
Oil (kg/ha):	600 - 1000
Sort:	Shrub
Height:	90 cm
Habitat:	Inland
Growth:	Annual/biennial
Flowering:	May - July

Explaination

Lunaria annua is a plant native to southern Europe and west Asia, but well adapted to northern Europe countries. The oil of the plant can be used by the oleochemical industries for the production of lubricants, additives and pharmaceutical products. The plant grows in a fast rate and is noted for attracting wildlife and is pollinated by bees. It grows in sandy, loamy and clay soils and tolerates acid and alkaline soils.

Landscape positioning



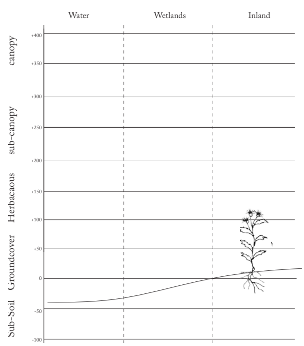
Specifications

Common Name:	Safflower
Technique:	Oil Plant
Oil content:	21 - 22%
Seeds (kg/ha):	2600 - 4000
Oil (kg/ha):	560 - 1000
Sort:	Shrub
Height:	100 cm
Habitat:	Inland
Growth:	Annual
Flowering:	May - October

Explaination

Safflower can grow naturally in very poor and alkaline soils. An edible oil is obtained from the seed, which can be used for lighting, paint, linoleum, and wax clothes. Besides it can be used as a diesel substitute.

Landscape positioning



Panicum virgatum L.

Specifications

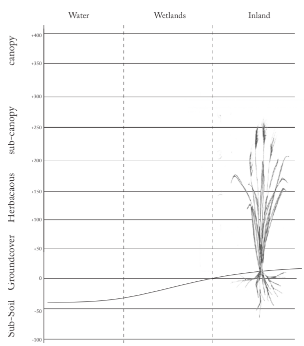
Common Name: Switchgrass

Technique:	Phytoextraction (to the root system whilst preventing the translocation to the aireal mass)
Pollutant:	Pb, Cd
Sort:	Grass
Height:	180 cm
Habitat:	Inland
Growth:	Perennial

Explaination

Switchgrass can grow naturally in poor soils, it is used as ground cover to control erosion and it is a usefull energy substitute. It has low fertilization and herbicide requierments and is a fast growing species and can tolerate drought and maritime exposure. The plant is sometimes used as windbreak in crop fields and is a valuable soil-stabilization plant. The plant has the potential to produce 400 L ethanol per ha compared to 270 for sugarcane and 160 for corn.

Landscape positioning



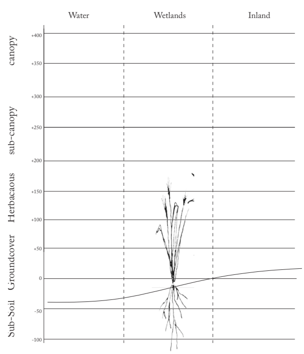
Specifications

Common Name:	Reed canarygrass
Technique:	Rhizofiltration
Sort:	Grass
Height:	150 cm
Habitat:	Wetlands
Growth:	Perennial
Flowering:	July - September

Explaination

Reed canary grass grows well in temperate climates and can tolerate many types of soils. It is one of the highest yieling grasses with annual yields ranging from 8 – 20 p/ha, thus a hugh potential as biomass. Besides the grass type is goof for erosion control, noted for attracting wildlife and one of the main species used for water purification treatment systems for grey water and sewage effluent of industrial sources

Landscape positioning



Cirsium arvense

Specifications

Common Name:	Creeping Thistle
Sort:	Herbacaous
Height:	90 cm
Habitat:	Inland
Growth:	Perennial
Flowering:	July - September

Explaination

The Creeping Thistle is plant that grows at a fast rate and seeds from August to October. The specie is pollinated by bees, flies, moths and butterflies. It is suitable for light sandy, medium loamy and heavy clay soils. It is extremely tolerante to PH as it is suitable for acid, neutral and alkaline soils. It cannot grow in shaded areas and preferes moist soils. The thistle seeds can be used for bioplastic production.

Landscape positioning