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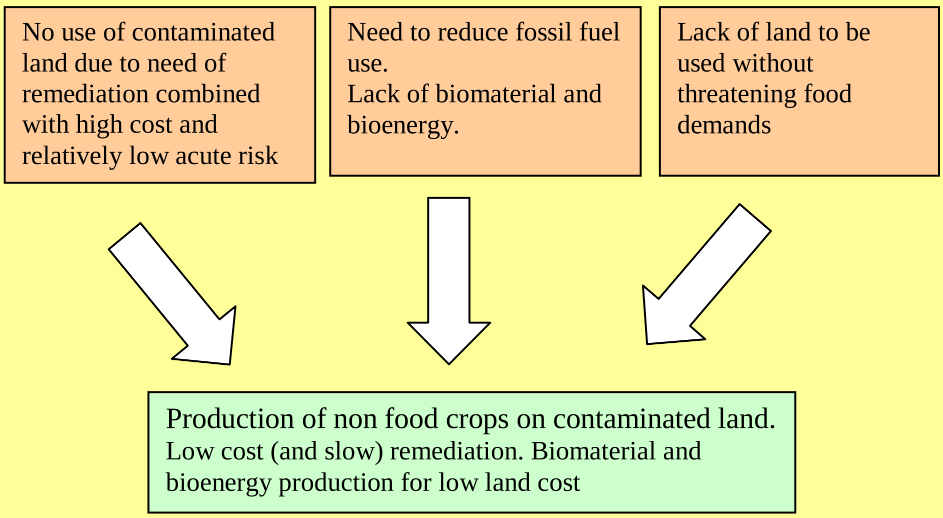

Biofuel and other biomass based products from contaminated sites – Potentials and barriers from Swedish perspectives

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ISSN ISRN	1100-6692 SGI-VARIA--09/599--SE
Dnr SGI Proj.nr SGI	1-0711-0824 13702

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PREFACE AND ACKNOWLEDGEMENT

The work performed in this report is part of the Rejuvenate Project. The aims of the full Rejuvenate project are to:

- explore the feasibility of a range of possible approaches in order to combine risk based land management (RBLM) with non-food crop land-uses and organic matter re-use as appropriate,
- identify a "matrix" of potential opportunities worthy of further development in the UK, Germany and Sweden and in a wider European context, and
- assess how verification of their performance might be carried out and identifying what requirements remain for future research, development and demonstration.

Here results are presented based on interviews and literature surveys on the triggers and stoppers for non food crop on contaminated land in Sweden. The report is a first step to explore the feasibility of a range of possible approaches to combine RBLM with non-food crop land-uses and organic matter re-use as appropriate in a Swedish context. The focus of the report is on the treatment of contaminated land by phyto-remediation and on biofuel cultivation. Phyto remediation implies that plants, fungi or algae are used to remediate, control or increase the natural attenuation of contaminants. Depending on the contaminating species and the site conditions, the best potential type of phyto remediation method varies. The biofuel part focuses on the context for cultivation and use in general from an ethical, economic and political perspective in relation to a Swedish context. The report also includes a first estimate of potential marginal land for biofuel production in Sweden.

Identified stakeholders are owners of contaminated land (all types including municipalities, mining industries, pulp and paper industries, chemical industries, small enterprises, refineries and oil industry, petrol stations (SPIMFAB), Landfill organisation (RVF), fuel producers at different levels and regulators, especially Swedish EPA, municipalities and county administration boards.

An environmental impact assessment, including carbon balance estimates, has also been done within the frame of the project. The results from the Swedish case studies, including a petrol contaminated site and a site contaminated with a mix of metals and organic compounds, are presented in a separate report "Environmental impact assessment biofuel production on contaminated land – Swedish conditions" by Suer et al., 2009. The results presented in this report and the environmental assessment are incorporated with the parallel ongoing work in the UK and Germany into the main result of the Rejuvenate project. A summary and the digested results are presented in the Rejuvenate final report by Bardos et al., 2009.

Rejuvenate was funded, under the umbrella of an ERA-Net Sustainable management of soil and groundwater under the pressure of soil pollution and soil contamination (SNOWMAN), by the Department for Environment Food and Rural Affairs and the Environment Agency (England), FORMAS (Sweden), SGI (Sweden) and Bioclear BV (Netherlands), all gratefully acknowledged.

SUMMARY

The work performed in this report is part of the Rejuvenate Project. The aims of the full Rejuvenate project are to explore the feasibility of a range of possible approaches to combine risk based land management (RBLM) with non-food crop land-uses and organic matter re-use as appropriate; identify potential opportunities worthy of further development in a wider European context; assess how verification of their performance might be carried out and identify what requirements remain for future research, development and demonstration.

In this report, results are presented based on interviews and literature surveys on the triggers and stoppers for non food crop on contaminated land in Sweden. The report also includes a first estimate of potential marginal land for biofuel production in Sweden.

The report is a first step to explore the feasibility of a range of possible approaches to combine risk based land management (RBLM) with non-food crop land-uses and organic matter re-use as appropriate in a Swedish context. The focus of the report is on the treatment of contaminated land by phyto-remediation and on biofuel cultivation.

Contaminated marginal land

In Sweden, like all other countries in Europe, areas of land have been degraded by past use. Such previously developed land includes areas affected by mining, fallout from industrial processes such as smelting, areas elevated with contaminated dredged sediments, former landfill sites and many other areas where the decline of industrial activity has left a legacy of degraded land and communities. The extent of contamination may not be sufficient to trigger remediation under current regulatory conditions, and there may be little economic incentive to regenerate the affected areas.

An ideal solution would be a land management approach that is able to pay for itself. Biomass from coppice or other plantations has long been seen as a possible means of achieving this goal. Phyto remediation offers a low cost method for remediation of areas that are not candidates for conventional regeneration. The optimal conditions for phyto remediation are large land areas of low or mediate contamination. Phyto remediation is also suitable to prevent spreading of contaminants, for example in green areas such as in cities, as waste water buffer and small size remediation areas with diffuse spreading.

Phyto remediation to remediate, control or increase the natural attenuation of contaminants

Phyto remediation implies that plants, fungi or algae are used to remediate, control or increase the natural attenuation of contaminants. Depending on the contaminating species and the site conditions the best potential type of phyto remediation method varies. In Appendix 2 of this report, various phyto remediation methods (remediation, control or increased natural attenuation) are shown together with a brief description of the species convenient for each method. The advantages in using phyto remediation are for example low remediation cost, less transportation, less use of land for landfill, less use of other new resources etc. Phyto remediation can also be a useful complement to more conventional remediation methods. For example very high contaminated masses can be excavated and site areas with lower concentrations are phyto remediated.

More recently there has been an increasing interest in the management of risks from an ecological perspective. In addition, a wider range of non-food crop options are increasingly feasible, including bioenergy products as well as higher value “bio-feedstocks”. This approach also contributes to policy goals related to renewable energy, the beneficial re-use of organic wastes and potentially carbon management. It may provide a means of restoring economic activity and overcoming issues of blight, opportunity for rapid enhancement of landscape and long term recovery of local land values and may integrate well with mixed projects, e.g. with some reuse for built development and some for amenity.

Bioenergy

Bioenergy is defined as energy produced from organic matter of biomass. Through modern technology, cellulosic ethanol, biogas and heat from straw and poplar etc, the energy gain can be large. The energy production may also strengthen co-product industries and create related jobs in the process. From a global climate perspective, this is an appealing solution, where the energy is home grown, created by renewable resources combined with new jobs and development opportunities.

The most common fuels made from biomass are Synthetic Natural Gas (SNG), DME, ethanol, methanol, and Biomass-To-Liquid (BTL), which is a synthetic fuel with fuel properties as conventional diesel. A summary of the present level of development, advantages and disadvantages are shown in Table 1 in Appendix 3.

A particular concern regarding bioenergy, however, is the land-use conflict between food production, non-food production and habitat. In parallel with this concern an increasing interest in food safety and concerns over contamination impacts on food production exists. A possible resolution is to preferentially grow non-food crops on contaminated areas. A schematic description of how marginal low risk contaminated land can be used to meet increasing demands for bioenergy, and how bioenergy does not threaten food demands, is presented in Figure S:1.

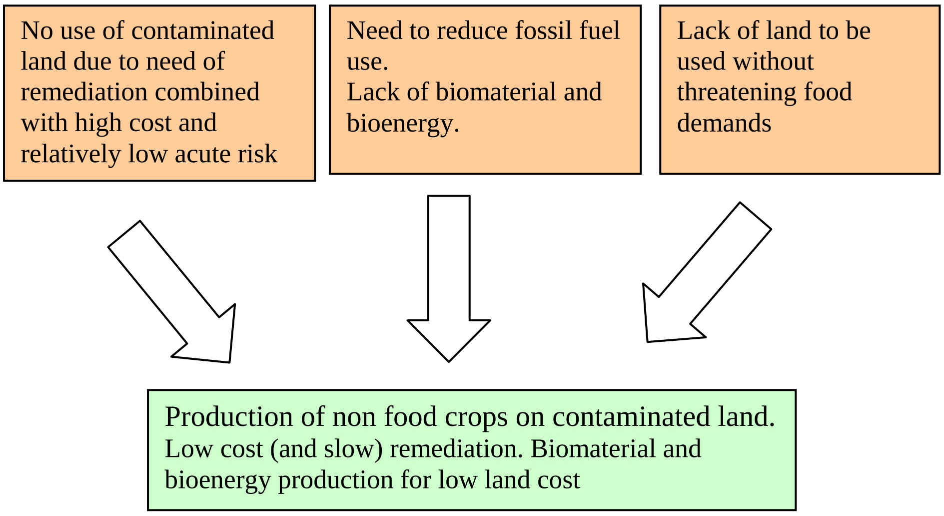


Figure S:1. The increasing demands of bioenergy require land not threatening food demands, the use of marginal low risk contaminated land offers a possible solution.

Together with other alternative land and biomass sources, such as agricultural and municipal waste, the combination with other energy production alternatives such as sun and wind, and not at least less and more efficient energy use, may work together towards more sustainable energy consumption and production.

Potential marginal land for biofuel production

In this study the maximum arable area of the potential contaminated sites in Sweden was assessed. In this context, arable area is defined as an area that can be used for growing biomass (e.g. for production of biofuels) or that can be phyto-remediated or contained and stabilized through a plantation. The assessment of the arable area was mainly based on data collected from the Swedish data base MIFO[1].

The total area of contaminated sites has been estimated to 3000 km^2, which is about 0.7% of the size of Sweden. The total *arable* area of contaminated sites in Sweden was estimated to almost 800 km^2. This is about 0.2% of the size of Sweden and constitutes 26% of the total contaminated area. It has to be noted that this is a first estimate based on several assumptions and should thus be seen just as a first attempt to estimate the maximum arable area of contaminated land in Sweden

Environmental impacts of biofuel on marginal land

Environmental impacts of biofuel cultivation on contaminated land depend on site specific conditions. In this project a carbon balance and a life cycle assessment have been performed for two different contaminated sites. In the investigations, Willow cultivation at the contaminated sites has been compared to more traditional remediation methods and as alternatives to other cultivation areas for bio fuel production. One site is the former oil depot and the other is a site with metals being the dominating contaminants. The results of Willow cultivation instead of more traditional remediation methods are very promising regarding both the carbon footprint and the other environmental impacts investigated.

Opportunities and barriers for biofuel cultivation on contaminated marginal land

Opportunities

The environmental negative impacts, from local to global scale, especially for second generation biofuels, are low.

To achieve EU directive goals (existing and future) all available land for biofuel production will be needed. The fuel demand in Europe is so large that any land area used for crop production will be of interest.

From a broad environmental perspective the use of contaminated land for biofuel production can be a sustainable solution, as the production *i)* does not compete with food production, *ii)* reduces the fossil fuel use and *iii)* stabilises or remediate the contaminated land.

The costs, both the phyto remediation and biofuel raw material cultivation, are regarded as low among the interviewed stakeholders.

[1] *Metodik för Inventering av Förorenade Områden* (*Methodology for inventory of contaminated areas).*

Barriers

Knowledge about phyto remediation methods and projects in Sweden is rare, and the results from the phyto remediation projects are not yet fully available. Consequently, there are no good examples showing the benefits, costs and timescales.

The present legislation and praxis is based on total concentrations left in the soil and not based on soil functionality or risk based land management.

In Sweden, areas of highest priority for remediation are sites with very high contaminant concentrations. Such sites are in urgent need of remediation and the contamination level is high, and thus there is risk of phyto toxicity. Furthermore, in areas of exploitation interests, i.e. non marginal land areas, other faster solutions than phyto remediation are prioritized due to the time perspective.

Another "stopper" regarding biofuel from waste and contaminated land is the handling and regulations concerning rest-, and co-products such as sludge and ashes. Despite regulations it would be useful to have an increased knowledge about the fate of the contaminants.

Many technical challenges remain including the development of better and cheaper catalysts, improvements in current technology for producing high quality biodiesel, use of non-fossil based solvents, conversion of the rest-, and co-products to useful products.

Here only the investment costs of biofuel plants have been considered. The investment costs is a barrier, but the biofuel demand may be high enough to reduce this barrier. Not included in this study, are the site owners view on investment costs for biofuel production. In general for biofuel production nearby customers and the site area are crucial.

In summary:

- Biofuel production on contaminated land could prove an economic incentive for phyto-remediation of contaminated sites, and at the same time provide land for biofuel cultivation that does not compete for food production.

- Biofuel production on contaminated soil is positive for the sustainability, as the production does not compete with food production, reduces the fossil fuel use, create employment opportunities, and provide low-impact treatment of contaminated sites.

- A first estimate of the maximum arable contaminated area in Sweden is 800 km^2, 25% of total contaminated area and 0.2% of Sweden's area.

- The main barriers are found in legislation and praxis, with priority for high contaminated concentrations and question marks concerning rest-, co-products.

SAMMANFATTNING

Denna sammanställning utgör en del av ERA-NET Snowman projektet Rejuvenate. Målen med Rejuvenate är att:

- undersöka genomförbarhet och lämplighet av att kombinera riskbaserat handhavande (Risk based land management, RBML) av förorenade områden med odling av grödor som inte skall användas för livsmedelsproduktion utan till exempel för biobränsle
- identifiera en ”matris” av möjligheter som det är värt att arbeta vidare med i England, Tyskland, Sverige och ett vidare europeiskt perspektiv
- bedöma hur man skall utföra en verifiering av olika möjliga lösningars prestanda samt identifiera vilka ytterlige behov som kvarstår avseende forskning, utveckling och demonstrationsbehov.

I denna rapport presenteras resultat från ett svenskt perspektiv. Resultaten baseras på intervjuer och litteraturstudier av faktorer som kan trigga, respektive motverka, odling av grödor på förorenad mark i Sverige. I rapporten presenteras också en första bedömning av potentiell yta som kan vara möjlig att användas för biobränsle på förorenad mark i Sverige.

Rapporten är ett första steg för att undersöka genomförbarhet och lämplighet att kombinera RBML av förorenade områden med odling av grödor och återanvändning av organiskt material i ett svenskt perspektiv. Rapporten fokuserar på att man åtgärdar förorenad mark genom fytosanering och odling av biobränslegrödor.

Förorenad mark lämplig för odling av biobränsle

I Sverige, liksom i andra Europeiska länder, finns mycket mark som har minskat i värde eller bara nedklassats till följd av dess tidigare användning. Sådan mark kan t ex vara påverkad av tidigare gruvdrift eller annat förorenat industriområde, förorenade sediment, soptippar, deponier m m. Många av dessa områden har med tiden minskat eller helt avslutat sina aktiviteter. Ansvarsfrågan kan var otydlig och föroreningar har lämnats kvar i marken. Föroreningsgraden kan vidare vara för låg för att behöva åtgärdas baserat på befintlig lagstiftning, praxis och prioriteringar av områden för sanering och det finns få eller inga ekonomiska incitament för en sanering.

En ideal lösning för sådan mark skulle kunna vara en riskbaserad förvaltning som samtidigt kan betala för sig själv. Biomassa från energiskog på sådan mark har sedan länge setts som en möjlighet att uppnå detta mål. Fytosanering erbjuder en billig saneringsmetod av områden som inte är av intresse för konventionell sanering. Optimala förhållanden för fytosanering är stora landområden med en låg eller medelmåttlig föroreningsgrad. Fytosanering är också lämplig för att förebygga spridning av föroreningar, exempelvis genom gröna områden i städer, som buffert för avloppsvatten och för sanering på mindre områden med diffus föroreningsspridning.

Fytosanering för att sanera, kontrollera eller öka den naturliga saneringen

Med fytosanering avses att växter, svampar eller alger används för att sanera, kontrollera eller öka den naturliga saneringen av föroreningar. Vilken fytosaneringsmetod som är mest lämplig är beroende av typ av föroreningar och platsspecifika förhållanden. I Appendix 2 till denna rapport redovisas olika fytosaneringsmetoder (sanering, kontroll eller ökad naturlig sanering) tillsammans en kortfattad beskrivning av vilka grödor som är lämpliga för respektive metod.

Fördelarna med fytosanering är till exempel låg saneringskostnad, mindre markanvändning för deponering, mindre användning av resurser såsom vatten, jord och energi. Fytosanering kan vara ett lämpligt komplement till mera konventionella saneringsmetoder. Till exempel kan man inom ett och samma område schakta bort de riktigt förorenade massorna men odla biobränsle på de områden där föroreningsgraden är lägre.

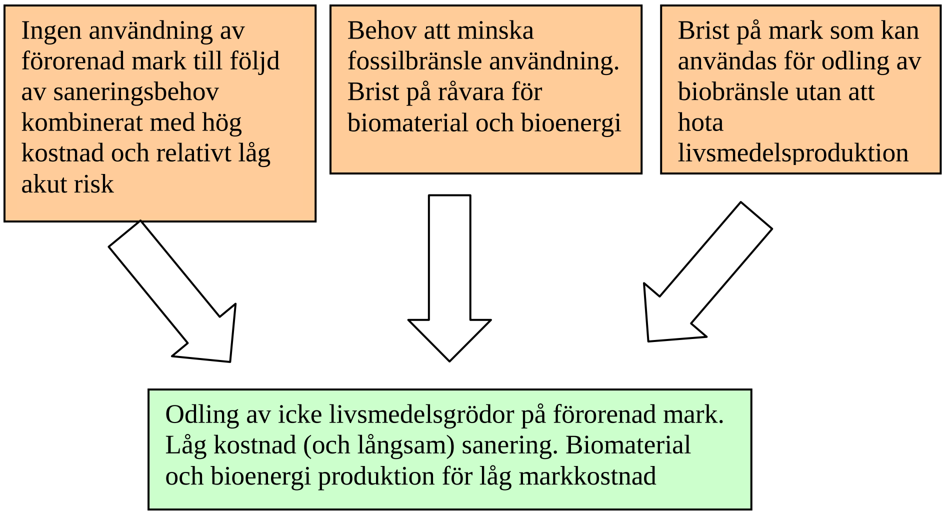
Nyligen har det blivit allt större intresse kring riskhantering ur ett ekologiskt perspektiv. Det kommer också i allt större utsträckning fram fler växter för icke livsmedelsanvändning. Dessa kan användas för biobränsleproduktion men också för andra ändamål såsom tillverkning av plast eller fibermaterial. Detta kan medverka till att uppnå politiska mål relaterade till förnyelsebar energi, återanvändning av organiskt material och förbättring av kolbalansen. Det kan också bidra till förbättrade möjligheter att återställa eller förbättra en regions ekonomiska aktiviteter och förutsättningar, att förbättra landskapet och bidra till en långsiktig lokal och regional återhämtning.

Bioenergi

Bioenergi definieras som energi som producerats från biomassa. Genom modern teknologi, cellulosa etanol, biogas och värme från stråmaterial och energiskog såsom salix eller popplar etc kan nyttan ur energisynpunkt vara stor. De mest vanliga biobränslena är syntetisk naturlig gas (SNG), DME, etanol, metanol och BTL (Biomass-To-Liquid) som är ett syntetiskt bränsle med bränsleegenskaper som konventionell diesel. I Appendix 3 till denna rapport ges en summering av dagens utvecklingsnivå, fördelar och nackdelar med olika biobränslen.

Bioenergiproduktion kan, om grödorna odlas på ett hållbart sätt, bidra till att stärka biproduktindustrier och skapa arbeten som är relaterade till processen. Ur ett globalt klimatperspektiv är detta en tilltalande lösning med hemodlad energi, producerad med förnyelsebara resurser som kombineras med nya arbets- och utvecklingstillfällen.

En speciell svårighet som kan vara ett bekymmer med bioenergi är, emellertid, att det finns en konflikt mellan livsmedelsproduktion, icke livsmedelsproduktion och livsmiljö. Samtidigt finns en ökad medvetenhet och intresse för matens kvalitet och föroreningars inverkan på livsmedelsproduktionen. En lösning som borde kunna vara att föredra är därför att odla icke livsmedelsgrödor på förorenad mark. En schematisk presentation hur förorenad mark kan användas för att möta de ökade behoven av bioenergi och samtidigt motverka hotet av odling av bioenergi på mark som kan användas för livsmedelsproduktion ges i Figur S:1.



Figur S:1 *Ökade behov av bioenergi och behov av mark för odling av biogrödor som inte hotar livsmedelsodling gör att odling på förorenad mark kan vara en möjlig lösning.*

Tillsammans med andra alternativa markområden och biomasskällor, som till exempel organiskt avfall, och tillsammans med andra energiproduktionsalternativ, som sol och vind, och inte minst genom en minskad och mer effektiv energianvändning kan en mer hållbar energikonsumtion och produktion uppnås.

Tillgänglig mark för odling av biobränsle grödor

I denna rapport ingår en studie som bedömt maximal yta förorenad mark som kan vara möjlig att använda för odling av biobränsle. I denna bedömning innefattas förorenad mark som ur platsspecifikt perspektiv kan användas för att odla grödor och mark som kan fytosaneras, stabiliseras eller kontrolleras genom odling av grödor för biomassa produktion. Som grund för studien har MIFO[2]databasen använts.

Totala ytan förorenad mark har bestämts till 3000 km^2, vilket är ca 0.7% av hela Sveriges yta. Den totala odlingsbara ytan förorenad mark i Sverige har bestämts till närmare 800 km^2. Detta är ca 0.2% av Sveriges yta och utgör 26 % av den totala förorenade ytan I Sverige. Det måste påpekas att detta är det första försöket att göra en sådan bestämning och att den baseras på ett flertal antaganden. Det är därför viktigt att se bestämningen som just ett första försök att bestämma den maximal odlingsbara ytan på förorenad mark i Sverige.

Miljöpåverkan av biobränsle på förorenad mark

Miljöpåverkan på biobränsleodling på förorenad mark beror av platsspecifika förhållanden. Inom detta projekt har en bedömning av kolbalans och en livscykel(LCA)-baserad bedömning gjorts för två olika förorenade områden. I denna bedömning har Salix odling på de förorenade områdena jämförts mot mer konventionella saneringsmetoder och som alternativ till biobränsleodling på annan plats. Det ena området var en tidigare oljedepå och det andra var ett område förorenat med både metaller och organiska ämnen. Resultaten från dessa studier (kolbalans och LCA) visar på att odling av Salix istället för mer konventionella saneringsmetoder är mycket lovande såväl avseende kolblalansen som övrig miljöpåverkan som analyserades.

[2] *Metodik för Inventering av Förorenade Områden*

Potentialer och barriärer för biobränsleodling på förorenad mark

Potentialer

Den negativa miljöpåverkan är låg (gäller framförallt andra generationens biobränsle)

För att dagens, och kommande, EU mål skall uppnås kommer all tillgänglig mark att behövas för odling av biobränslegrödor.

Ur ett brett miljöperspektiv kan odling av biobränslegrödor på förorenad mark vara en hållbar lösning eftersom 1) produktionen tävlar inte med livsmedelsproduktion, 2) det minskar användningen av fossila bränslen 3) det stabiliserar, kontrollerar eller bidrar till sanering av förorenad mark

Kostnaderna för fytosanering, innefattande även kontroll och stabilisering, och odling av biobränsleråvara på förorenad mark anses som låga av de personer som intervjuats inom projektet.

Barriärer

Kunskap om fytosaneringsmetoder och projekt, innefattande även kontroll och stabilisering, i Sverige är relativt sällsynt och resultaten från de fytosaneringsprojekt som påbörjats är ännu inte helt tillgängliga. Det finns således inga goda exempel som visar på fördelar, kostnader och tidsaspekter.

Dagens regelverk och praxis baseras på uppmätta koncentrationer och koncentrationer som skall uppnås i marken och inte markens funktionalitet eller riskbaserad förvaltning och hantering av marken.

Bland de statligt finansierade saneringsprojekten i Sverige prioriteras de objekt som har hög föroreningsgrad. Sådana objekt är dels i behov av mycket snabba saneringsåtgärder och dels, eftersom föroreningsgraden är hög, föreligger risk för fyto-toxicitet. I exploateringsintressanta områden är behovet av snabb sanering stort oavsett föroreningsgrad, varför fytosanering inte heller i flertalet privatfinansierade projekt är intressant med hänsyn till tidsperspektivet.

En av de barriärer många av dem som intervjuats nämner är att man känner sig osäker på vilka krav som föreligger, och som kommer att föreligga, kring hantering av bi och restprodukterna från biobränlseproduktionen. Man påpekar att oavsett regelverket vore det värdefullt att få en ökad kunskap kring föroreningarnas öde vid odling av biobränslegrödor på förorenad mark.

Det finns många tekniska/ekonomiska utmaningar såsom utveckling av billiga katalysatorer och utveckling av teknologin för att producera till exempel hög kvalitativ biodiesel, icke fossilbaserade lösningsmedel och för omvandling av biprodukterna till meningsfulla produkter.

I denna studie har endast investeringskostnader för biobränsleanläggningar beaktats. Investeringskostnaden är en barriär, men biobränsleefterfrågan kan bli så stor att detta inte utgör en väsentlig barriär. I denna studie har däremot inte investeringskostnader för markägarna ingått. Generellt gäller dock att biobränsleproduktion nära kunder och en tillräckligt stor markyta är av stor betydelse för att minska betydelsen av kostnaden för investeringen.

Sammanfattningsvis:

- Odling av biobränslegrödor kan öka de ekonomiska incitamenten för fytosanering av förorenad mark och samtidigt medverka till biobränsle utan att konkurrera med ytor som behövs för livsmedelsproduktion.

- Odling av biobränslegrödor på förorenad mark är positivt ur hållbarhetssynpunkt eftersom den inte tävlar med livsmedelsproduktion, minskar användningen av fossila bränslen och kan bidra till att upprätthålla arbetstillfällen och har en ringa miljöpåverkan vid hantering av förorenade områden

- En första bedömning av ytan odlingsbar förorenad mark är ca 800 km^2 eller 0.2% av hela Sveriges yta.

- Den största barriären för odling av biobränslegrödor på förorenad mark är att lagstiftningen inte gynnar sådan hantering av marken, praxis, brist på goda exempel och osäkerhet avseende hantering av bi- och restprodukter.

1 INTRODUCTION

1.1. Marginal contaminated land

In August 2007 the European Environment Agency (EEA, 2007) concluded that soil contamination requiring clean up is present at approximately 250000 sites in the EEA member countries, according to recent estimates based on a number of Member States. This number is expected to grow. Although the data is very variable from country to country, the Agency continues “Potentially polluting activities are estimated to have occurred at nearly 3 million sites (including the 250000 sites already mentioned) and investigation is needed to establish whether remediation is required. If current investigation trends continue, the number of sites needing remediation will increase by 50% by 2025.” A considerable share of remediation expenditure, about 35% on average, comes from public budgets. Although considerable efforts have been made already, the Agency concludes that it will take decades to clean up a legacy of contamination. In Sweden the potential number of contaminated sites is estimated to 70 000 (Swedish EPA, 2008b) The majority of these sites have not been investigated and the average site area is not estimated.

In Europe are areas of land which have been degraded by past use that are not easy candidates for conventional regeneration, or for which conventional regeneration may not be the most sustainable approach for example because of issues of scale (size of the impacted area). Such “marginal land” included areas affected by mining, fallout from industrial processes such as smelting, areas elevated with contaminated dredged sediments, former landfill sites and many other areas where the decline of industrial activity has left a legacy of degraded land and communities (Bardos et al., 2001). The extent of contamination may not be sufficient to trigger remediation under current regulatory conditions, and there may be little economic incentive for redevelopment or regeneration of the areas affected.

In some countries (e.g. the UK and Germany) some of this land has been managed with “soft” restoration, e.g. to grazing or “country parks. In the Netherlands a number of areas have been elevated by the addition of sediments and may have problems of contamination for which conventional remediation is unsuitable. In Sweden the priority has tended to be on “intensive” approaches to sites in urban regions, and other degraded land has tended to be left alone.

1.2. Phyto remediation – remediation, control and natural attenuation

An ideal solution would be a land management approach that is able to pay for itself. Biomass from coppice or other plantations has long been seen as a possible means of achieving this goal. While a number of biomass remediation projects have been supported, these have tended to rely on using phyto-extraction as a risk management approach.

Phyto remediation offers a cheap method for remediation of areas not candidates for conventional regeneration. The optimal conditions for phyto remediation are large land areas of low or mediate contamination (McCutcheon et al., 2003). Phyto remediation also is suitable for maintenance of an area to prevent spreading for example in green areas such as in cities, as waste water buffer and small size remediation areas with diffuse spreading (McCutcheon et al., 2003).

More recently there is increasing interest in the management of risks from an ecological perspective. In addition, a wider range of non-food crop options are increasingly feasible including bioenergy products as well as higher value “bio-feedstocks”. This approach also contributes to policy goals related to renewable energy, the beneficial re-use of organic wastes and potentially carbon management. It may provide a means of restoring economic activity and overcoming issues of blight, opportunity for rapid enhancement of landscape and longer term recovery of local land values and may integrate well with mixed projects, e.g. with some reuse for built development and some for amenity.

1.3. Bioenergy

Bioenergy is defined as energy produced from organic matter of biomass (Steenblick et al., 2007). Modern bioenergy technologies, producing heat, electricity and transport fuels are advancing rapidly.

1.3.1 Rapid development

The rapid development of modern bioenergy offer a broad range of opportunities, but it also entails trade-offs and risks. Experience with the associated economic, environmental, and social impacts is limited, and the types of impacts will depend largely on local conditions and on policy frameworks implement to support bioenergy development (Steenblick et al., 2007). Thus the economic environmental and social impacts of bionenergy development must be assessed carefully before deciding if and how rapidly to develop the industry and what technologies, policies, and investments strategies to pursue (Steenblick et al., 2007).

Bioenergy is capable of being converted into virtually any energy service: electricity; process heat (cooking and drying); various forms of mechanical power and steam production etc. It is also largely independent of the short-term supply fluctuations that are typical with wind and solar energy (Steenblick et al., 2007).

However, bioenergy production, such as some fuel production from corn, may be as carbon dioxide intensive as gasoline and therefore not resulting in any or modest net reduction of green house gas emissions (e.g. Farrell et al., 2006; Pimentel et al., 2007; Rydberg, 2007; Ulgiati, 2001). By the modern technology, other crops (e.g. cellulosic ethanol, electricity, biogas and heat from straw and poplar) and efficient energy use and delivery systems such as district heating the gain can be much larger (e.g. Adler et al., 2007; Börjesson, 2007; Rydberg, 2007). By modern technology systems waste can be converted into a wide range of productive uses, for example in the production of cellulosic ethanol, wood pellets and briquettes used for heating, biodiesel derived from animal fats and biogas from wet agricultural waste, sewage sludge, landfill methane and as also discussed in this project utilise and remediate contaminated land. The energy production also may strengthen co-product industries and creating related jobs in the process (Steenblick et al., 2007).

From global climate perspective this is an appealing solution, where the energy is home grown, created by sun and water fuelled photosynthesis, combined with new jobs and development opportunities (e.g. Farrell et al., 2006; Pacala et al., 2004; Steenblick et al., 2007). For example with oil production already in decline in many nations, greater biofuel use could hep bring the oil market into balance and greatly reduce oil prices, modern bioenergy can also help meet the needs of the 1.6 billion people worldwide who lack access to electricity in their homes, and the 2.4 billion who rely on straw, dung and other traditional biomass fuels to meet their energy needs (Steenblick et al., 2007). Locally produces bioenergy can provide energy for local agricultural, industrial and household used, in some instances at less that the cost of fossil fuels (Steenblick et al., 2007).

The fast development of biofuel technology includes the use and development of genetic modified plants (Bülow et al., 2007; Hermann et al., 2007; Schmer et al., 2008). Genetic modified organisms (GMO) offers opportunities but also risks. Here, only the impacts on bioenergy production, which in general benefit from such a development, are regarded. The risks, and benefits, related to GMO are complex and need its own review and risk assessments and consequently are omitted here.

1.3.2 EU strategy biofuels

In EU about 21% of the total green house gas emissions are estimated to be from the transportation sector (Commission of the European communities, 2006). In the opening months of 2007, the European Union stepped up its energy and climate change ambitions to new levels (Commission of the European communities, 2008). The Commission put forward an integrated package of proposals calling for a quantum leap in the EU's commitment to change."[1] A political consensus grew up in support of this approach, with the support of the European Parliament and the Member States at the 2007 European Spring Council. This culminated in agreement on the principles of a new approach and an invitation to the Commission to come forward with concrete proposals, including how efforts could be shared among Member States to achieve these targets (Commission of the European communities, 2008):

- an independent EU commitment to achieve at least a 20% reduction of greenhouse gases by 2020 compared to 1990 levels and an objective for a 30% reduction by 2020 subject to the conclusion of a comprehensive international climate change agreement;
- a mandatory EU target of 20% renewable energy by 2020 including a 10% biofuels target

In January 2008 three key policy proposals implementing the agreed energy and climate package were proposed (Commission of the European communities, 2008):

(a) a proposal for a Directive on the promotion of renewable energy,
(b) a proposal for amending the EU Emissions Trading Directive reviewing the EU emissions trading system (EU ETS),
(c) a proposal relating to the sharing of efforts to meet the Community's independent greenhouse gas reduction commitment in sectors not covered by the EU emissions trading system (such as transport, buildings, services, smaller industrial installations, agriculture and waste).

In April 2008 the EEA Scientific Committee made public an opinion on the environmental impacts of biofuel use in Europe (EEA, 2008). The Scientific Committee recommended a new, comprehensive scientific study on the environmental risks and benefits of biofuels, and that the EU target to increase the share of biofuels used in transport to 10% by 2020 should therefore be suspended. The European Parliament called in July 2008 for the EU to lower its targets for developing biofuels, through boost harmful emissions and drive up food prices, in favour of cleaner power sources for transport with the aim to make renewable sources account for between eight and 10 per cent of transport energy sources, with biofuels to account for just half of this share, i.e. four per cent in 2015 (Commission of the European communities, 2006). In Figure 1 the European fuel use development is presented as a roadmap for the targets.

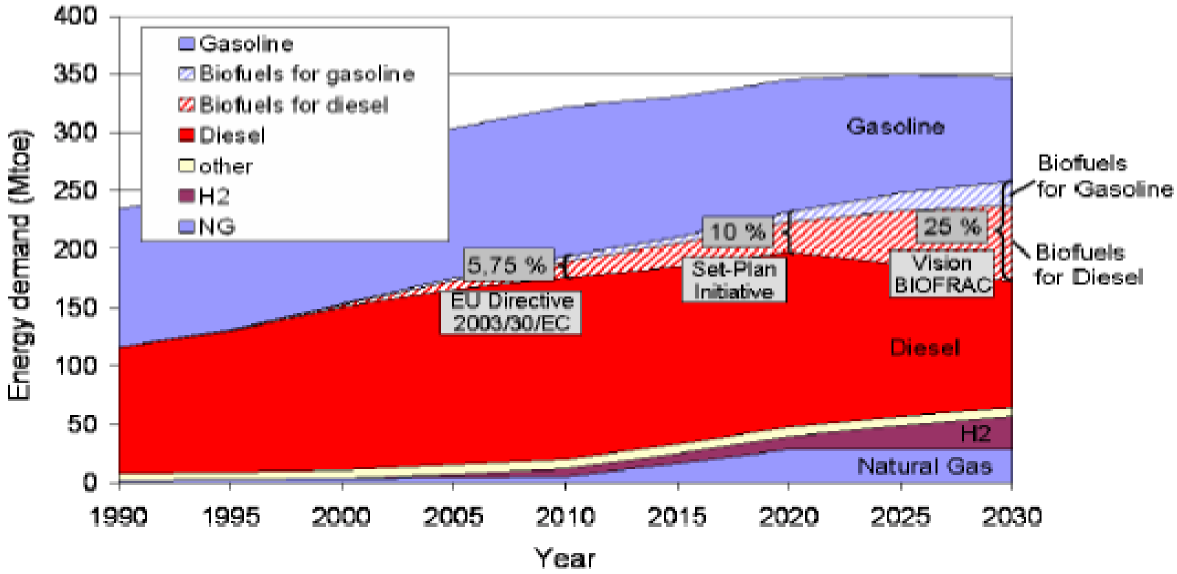


Figure 1. The Fuel Roadmap for Transport European Union. Source: via Sören Erksson, Preem Refinery (2008) from Biofuels TP-WG3.

1.3.3 Biofuel – need of land

It can be worth nothing, one of the major driving forces for the development towards use of fossil fuels instead of biofuel, was the land use areas needed for the latter. For example, the land area needed using biomass instead of the real use of coal in England around 1800 would correspond to the total area of England and Wales together (Bergqvist et al., 2007).

The land use needed to supply 5% of energy demand by transport in 2001 in UK today has been estimated to range between about 10% of UK arable land (for ethanol from sugar beet) up to about 45% land use for wheat straw to ethanol; of the UK's total land area of 24.25 Mha, 6 Mha is arable land and 2.4 Mha is forest (Woods et al., 2003 in Defra, 2005). The net energy balance of the system is not taken into account estimating these figures, so although some of the feedstocks use less land, the overall energy balance can be poor. Available information and estimates make it clear that there is no realistic prospect to become self-sufficient in biofuels for transport for anything more than low replacement levels in UK (The Royal Society, 2008)

Similarly, an exchange of the energy need by Swedish transport sector, excluding sea traffic, by 10% (i.e. 10% of 92 TWh) by ethanol from wheat would demand all the agriculture land in use in Sweden today, i.e. 3 million hectare (30 000 km^2) based on that 1 hectare wheat theoretically results in 36 000 kWh (Bülow et al., 2007; Rydberg, 2007). Corresponding land area needed for production of dimetylether (DME) instead of ethanol would be 20 000 km^2 based on relative relation of well-to-tank energy efficiency estimates for producing ethanol versus DME (Semelsberger et al., 2006). In Sweden the total annual use of fossil fuel is 130 TW accordingly corresponding to a land area need of 450 000 km^2 for ethanol (Rydberg, 2007) and around 300 000 km^2 for the more energy efficient DME. Technological developments along the supply chain will, however, impact the land use needed. For example, improving crop yield per hectare and improving conversion efficiency will provide a greater final yield of biofuel, which will use less land. There are also other available resources such as oil plants, and the large sources of municipal solid waste (MSW) and rest products from farming.

According to the manual for willow cultivation (Lantmännen et al., 2007) compiled by Gustafsson, Larsson and Nordh, SLU Uppsala, on behalf of Lantmännen Agroenergi AB/Salix, Örebro, the production of woodchips from Salix grown on normal ground amount to 8 – 10 ton dry matter per hectare annually which corresponds to 4-5 m^3 of oil. The energy quota for growing Salix is high compared to other crops. The energy consumed during the process is only about 5% of the production of heat and electricity.

1.3.4 Manure, compost and municipal waste – additional resources

Globally, rest products from farming correspond to around a sixth of today's primary energy production (oil, coal etc.)(Formas, 2007). MSW has great potential to become a significant energy resource in all countries. If successfully integrated into feedstock supply systems, MSW could provide year round feedstock supply and address a significant waste disposal problem. About half the content of MSW is organic, and origins from food and packaging. Estimates of the bioenergy potential of these wastes depend strongly upon assumptions about economic development and consumption of materials. However, a city of one million people could provide enough feedstock to produce about 430,000 litres of ethanol per day, enough to meet the needs of 360,000 people (at per capita fuel use similar to current rates in France) (Worldwatch Institute, 2006). Efficient utilisation of this resource could be important in a country like the UK, where there is a relatively limited availability of arable land to grow plants (The Royal Society, 2008).

It is crucial to optimise the use of scarce resources and minimise the negative consequences such as less exploiting of rain forests and other valuable eco systems. A variety of non fossil fuel production methods are of great importance as well as increased energy efficiency, which reduce the use of all scarce resources. Consequently, there is a need of a new radical technical development (Formas, 2007; Scharlemann et al., 2008).

1.3.5 Biofuel & marginal contaminated land

A particular concern regarding bioenergy is the land-use conflict between food production, non-food production and habitat. In parallel with this concern is an increasing interest in food safety and concerns over contamination impacts on food production (Van-Camp et al., 2004).

A possible resolution is to preferentially grow non-food crops on contaminated areas (Bardos et al., 2008). A schematic description of how marginal low risk contaminated land can be used to meet increasing demands of bioenergy, and bioenergy not threatening food demands, is presented in Figure 2.

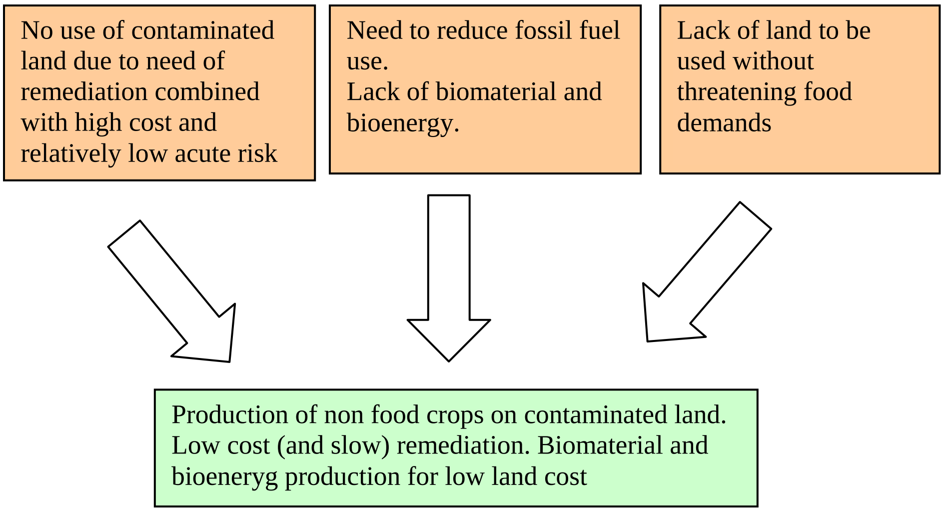


Figure 2. The increasing demands of bioenergy and bioenergy require land not threatening food demands, the use of marginal low risk contaminated land offers a possible solution.

Together with other alternative land and biomass sources, such as agricultural and municipal waste, the combination together with other energy production alternatives such as sun and wind, and not at least less and more efficient energy use, may work together towards more sustainable energy consumption and production.

An ideal solution would be a land management approach that is able to pay for itself. Biomass from coppice or other plantations has long been seen as a possible means of achieving this goal. While a number of biomass remediation projects have been supported, these have tended to rely on using phyto-extraction as a risk management approach (Riddel-Black, 1998). More recently risk management approaches linked to containment, stabilisation and perhaps biodegradation have begun to be seen as better options for phyto-remediation that avoid the transfer of contaminants into biofuel fractions (Bardos et al., 2008). In addition, a wider range of non-food crop options are increasingly feasible including bio-diesel (oil seed rape), bioethanol (straw, wood, and grains) and fibre crops (e.g. hemp, flax) as well as higher value bio-feedstocks (e.g. pharmaceutical precursors, flavourings) (The Royal Society, 2008).

The growth of poplar, willow or other bioenergy products may under some conditions also create a value to the landscape (Aronsson et al., 2007). This has for example been experienced by the Copenhagen Malmö Port, CMP, in Malmö (Åkesson, 2008). Here a poplar alley was designed and constructed to create a barrier prohibiting spreading of oil contaminants from the soil to the sea (Figure 3). The neighbours reacted very positive. Today they contribute to expand the poplar alleys of esthetical reasons. CMP are also interested in further plantations of similar barriers in Malmö and Copenhagen to prohibit the spreading of contaminants and dusting from the bulk harbour (Åkesson, 2008).

Figure 3. Map of Malmö oil Harbour and Åke Åkesson, CMP, at the poplar alley.

2 MARGINAL LAND IN SWEDEN

2.1 Available contaminated land for non food crop cultivation

In Sweden the potential number of contaminated sites is estimated to approx. 70 000 (Swedish EPA, 2008b). All these sites have not been investigated and the average site area is not estimated. Therefore, only a rough estimate of available land can be done, based on available information and experience of remediation projects. In this project a first attempt has been done to estimate also the arable area of marginal contaminated land in Sweden. The procedure is described below and the full procedure of the land bank estimate is presented in Appendix 1.

2.1.1 Definition of marginal land (contaminated sites, brownfield, landfill)

In Sweden, like all other countries in Europe, areas of land have been degraded by past use. Such previously developed land includes areas affected by mining, fallout from industrial processes such as smelting, areas elevated with contaminated dredged sediments, former landfill sites and many other areas where the decline of industrial activity has left a legacy of degraded land and communities.

In Sweden the priority has tended to be on "intensive" approaches to sites in urban regions, and other degraded land has tended to be left alone. The extent of contamination may not be sufficient to trigger remediation under current regulatory conditions, and there may be little economic incentive to regenerate the areas affected. In this land bank assessment all such land is regarded as marginal land.

2.1.2 Inventory and classification of contaminated land

In order to enable for consistent and accurate assessments of contaminated sites in Sweden, the Swedish EPA has developed a methodology of surveying contaminated sites; MIFO (*In Swedish: Metodik för Inventering av Förorenade Områden*). The methodology is divided in to two phases; 1) orientation studies and 2) general surveys. In the first phase, data is collected using available information from maps and archives combined with impressions gained from site visits and interviews. The second phase consists of an on-site recognisance with sampling at strategically selected points. Further description of the methodology can be found in the report by Swedish EPA (Swedish EPA, 1999).

In the so called MIFO-model the inventoried contaminated sites are divided into different branches. A *branch* describes the type of activity that has been ongoing on the site (e.g. gas station, dry cleaning, sawmills, landfill etc.). *Contaminated sites* refers to any land fill, land, groundwater or sediment showing concentrations of pollutants that are significantly elevated above background levels, due to local emissions. A contaminated site is referred to as an *object* in the data base.

The inventory work is conducted by local and regional authorities. All collected data are complied in regional data bases. The compiled data in the regional data bases are once a year reported to the Swedish EPA, who evaluate and fuse the data into a national progress report. At the time of this study a national database, including all inventory data, does not exist, however, such a data base is under development.

2.1.3 Quality of available information

The aim of this task was to assess the maximum arable area of the potential contaminated sites in Sweden. In this context, arable area is defined as an area that can be used for growing biomass (e.g. for production of biofuels or for other non food purposes) or that can be phytoremediated or contained and stabilized through a plantation. The assessment of the arable area was mainly based on data collected from the Swedish data base MIFO.

Sweden comprises 21 counties, which are in turn divided into municipal areas. All 21 County Administrative Boards have there own MIFO-database and in some counties the municipal authorities also contributes to the inventory with own databases. Since it would be too time-consuming to go through all these databases, the MIFO-data base of The County Administrative Board of Skåne was chosen to serve as a general model for the assessment of mean areas of the different branches (MIFO, 2008).

As the MIFO data base does not include the area of the contaminated sites, five objects (=five contaminated sites), within each branch, were randomly selected from the MIFO database of The County Administrative Board of Skåne. For each object the following data was collected:

1. The area of the site (*in Swedish: fastighetens area*)
2. The use of land on the site (*in Swedish: markanvänding på objektet*)
3. The use of land in close conjunction to the site (*in Swedish: markanvändning inom påverkansområdet)*

The mean area of each branch was then calculated. In addition the relative standard deviation of each determined mean value was also calculated. For branches that had less than five registered objects, all inventoried objects were used. For these branches the mean area was assessed from the available information (i.e. n=<5). In addition, 16 branches did not contain any inventoried objects at all. The mean area of these branches has been assessed by expert estimates (advanced experience based guessing) through interviews with persons well experienced with the method of surveying contaminated sites (Svensson, 2008).

It must be noted that the calculation is based on reported areas of the sites, were the branches have conducted their activities, and not the actual contaminated area of the site. The calculation is based on information from 71 branches (of total 82). 11 of the branches have low priority within the work of MIFO or should be inventoried by other agencies, or “surveyors” than the County Administrative Board (e.g. the Swedish military authorities or the Swedish Rail Administration). Due to lack of information about objects within these branches they were excluded from the calculation. In total 40 226 objects were registered on the 71 branches (Nilsson, 2008).

2.1.4 Statistics about land bank

Based on the expert estimates and the information from the 71 branches, the potential area for non food crop cultivation on marginal land in Sweden was estimated taking into account also the suitability such as the arable part of the site. To take into consideration how the use of the land may affect the potential of cultivation, a ”mean arable site factor”, k_{site}, was assessed for each branch. For example, a site containing buildings and housings would probable be less fit for cultivation than an industrial site. Also taken into account was how the potential of cultivation may be affected by the use of land in close conjunction to the site, and thus a ”mean arable conjunction factor”, $k_{conjunction}$, was assessed for each branch. For further details and information see Appendix 1.

The total arable area of contaminated sites in Sweden was estimated to up to 778 km^2, this is about 0.2% of the size of Sweden. The total area of contaminated sites was estimated to 2936 km^2, which is about the same size as 0.7% of the size of Sweden. According to this first estimate, the arable area constitutes 26% of the total contaminated area of Sweden. Again we want to point out that the estimate is based on the reported area of the site (the area reported by land owner) where the branches have conducted their activities and not the actual contaminated area of the site. Thus, the calculation is rather an overestimation than an underestimation of arable area of reported contaminated sites, and should thus be seen just as a first attempt to estimate the maximum arable area of contaminated land in Sweden. Furthermore, it must also be kept in mind that this calculation is based only on 71 branches of in total 82. The 11 excluded branches had all together 2994 reported objects in the progress report of 2008 (Nilsson, 2008). The total sum of reported object was 43220. Thus, about 7% of all reported objects are excluded from our estimation of branch areas, and consequently this may affect the result.

Despite large uncertainties, the results indicate that there is a significant potential area available for cultivation of Biofuel or other non food crops in Sweden. According to this first land bank estimate attempt, the potentially available marginal contaminated land constitutes up to some percents of the land needed for bioenergy solely compensating the national fossil fuel in use today. Bioenergy from marginal land, combined with other biomass sources such as agricultural and municipal waste, other energy production alternatives such as sun and wind and not at least less and more efficient energy use, may work together towards more sustainable energy consumption and production

2.2 Contaminated land management – Praxis and legislation

In Sweden, any land with concentrations obove background level, polluted by a point source, is a contaminated area according to risk assessment practice. Thus, treated landfill and treated contaminated sites with pollution left in the soil are included, but not areas from mining or smelter fallout, unless they pose a significant risk to human health and are defined as contaminated area according to the Environmental Code (MB: SFS 1998:808).

According to the Swedish Environmental Code (SFS 1998:808), chapter 10, contaminated land is an environmental damage that constitutes a significant risk due to the soil pollutants. The risks can be on people’s health, significant negative effects on surface or ground water quality, or that it significant damages or hampers the existence of protected animals or plants, or the habitat for such a species in a certain area.

Chapter 10 in the MB therefore covers land areas, where there is a need of remediation in order to counteract the significant negative effects on health or water quality. For example, according to MB chapter 10 5§, there is an obligation to carry out measures that prevents further damage on the environment and risk for people's health, to ensure that contaminated land no longer constitutes any significant risk for people's health and to restore the environment to what it would have been without the actual damages on water, protected species and their habitats. There is also an obligation to compensate for lost environment values prior restoring, or to compensate these values in other ways if restoration is not possible. The compensating measures comprise additional improvement of protected natural habitats, and protected species or waters, either on the damaged site or elsewhere.

Cultivation, of non food crop for bioenergy or other purposes, on land areas covered by MB chapter 10 consequently must have the aim to restore the land, i.e. the first priority is remediation and the second cultivation of bio fuel or other bio materials. The cultivated plants must thus be chosen and adapted so the soil quality at the site is increased.

The risk assessment praxis developed in Sweden is based on a guide line value model, developed at the Swedish EPA (Swedish EPA, 1997), where the land area is regarded as potentially contaminated if the concentrations in the soil or water are above the natural background levels. Only point sources are included in this model and consequently diffuse anthropogenic pollutants are excluded. According to the Swedish EPA (Swedish EPA, 1999) a contaminated site is the synonymous to a remediation object. This includes any area, landfill, soil, groundwater or sediment that is contaminated and the concentration significantly exceeds local/regional background levels.

Restricted areas

If a land or water area is seriously contaminated, then land use restrictions, or other safety measures, are needed. The County administration board shall thus declare the area an environmental risk area according to MB chapter 10 § 15. In such declaration the pollutant's health and environmental risks, the contaminant level, the conditions for spreading and the sensitivity of the surrounding environment shall be considered ((SFS 1998:808) chapter 10 § 15).

The County administration board can in the decision prescribe measure of clear management character. According to MB chapter 10 § 17, when an area is declared environmental risk area, the County administration board shall decide about restrictions in land use, or if other measures are wanted by the land owner those shall be joined with demands or be concealed by an explanation to the authority. This include for example excavating, other soil works, changed land use, and other measures that can imply increased spreading of contaminants and that future restoration measures are hampered. However, as the area is regarded as risk area according to MB chapter 10 there is a need of restoration.

The Swedish plan and building law, PBL (SFS 1987:10), should be an instrument for RBLM. At present, however, PBL only covers exploit areas and not marginal land areas. To our knowledge there are no Swedish legislative instruments available for restricted land use, such as RBLM for bio crop production at sites where the cultivation not is related to remediation, i.e. phyto remediation, of the contaminated site.

3 PHYTOREMEDIATION – REMEDIATION, CONTROL OR INCREASED NATURAL ATTENUATION

The optimal conditions for phyto remediation are large land areas of low or mediate contamination (McCutcheon et al., 2003). Phyto remediation also is suitable for maintenance of an area to prevent spreading, in green areas such as in cities, as waste water buffer, small size remediation areas with diffuse spreading (McCutcheon et al., 2003). Phyto remediation implies that plants, fungi or algae are used to remediate, control or increase the natural attenuation of contaminants. Depending on the contaminating species and the site conditions the best potential type of phyto remediation method varies.

3.1 Non Food Crop remediation

The use of marginal contaminated land for production of a revenue generating crop, such as coppiced willow, is not a new idea. The use of short rotation willow coppice for the restoration of metal contaminate land by harvesting metals from soils in biomass that could be used in energy production, using sewage sludge to assist tree establishment, was for instance considered in FP5 project BIORENEWAL (Riddell-Black et al., 2002). In FP6 project BIOPROS the use of short rotation coppice for supporting the re-use of sewage sludge on metal contaminated land was examined (Aronsson et al., 2007). However, this approach to managing contaminated marginal land has not been widely adopted because of concerns over the transmission on heavy metals, both in the harvested biomass, and through mobilisation in dissolved organic matter from added organic matter (Punshon et al., 1997), and the very long treatment times and uncertain performance of the technique for metal removal from soil. These have been insurmountable barriers in many countries, not least because the harvested biomass might need to be treated as a waste (Bardos et al., 2001) and burned in a waste incinerator directive compliant facility. Nonetheless, the Flemish regulator OVAM (Openbare Vlaamse Afvalstoffenmaatschappij) is pushing ahead with developing phyto-extraction as a potential solution for metal contaminated arable soils in the Kempen area. As a consequence recent demonstrations of phyto-based techniques, such as the ones disseminated, tested and developed within the European LIFE project DIFPOLMINE (Jacquemin, 2006), have been centred on “stabilisation” of marginal contaminated land to reduce its environmental impacts and improve its appearance and functionality as habitat.

Interest in non-food crop cultivation of contaminated marginal land has, however, been heightened in recent times, rather than diminishing. Two factors have driven this increasing interest: 1) the development of revenue opportunities from a wider range of bio-energy and bio-feedstock opportunities; and 2) the increasing recognition that restoration to habitat/open space, while laudable, creates a long term financial liability for land management for (generally) local public authorities in areas of poor income. The latter is not seen as financially sustainable in the long term, leaving open the risk that land management might cease. Solutions to this problem are required. For example, in the UK the Land Restoration Trust (The Land Restauration Trust, 2004) was formed with the mission to take on and manage the legacy of sites damaged by industrial use that would not otherwise be regenerated. It sought to pay for this by a financial mechanism, where those surrendering land to it also paid a “dowry” which would be invested. The investment proceeds would pay for the long term management of its land portfolio. A revenue generating approach for marginal land that can run in parallel with risk management could reduce site management costs considerably (Andersson-Sköld et al., 2008; Bardos et al., 2008).

It is time to extend the plant based reuse of contaminated marginal land debate beyond phyto-extraction based methods. There are two dimensions to this move, the first is in terms of land management, and the second is recognition of the broader range of low input long term, so called “extensive” treatments that can take place in conjunction with non-food crop production (Andersson-Sköld et al., 2008; Bardos et al., 2008). Below a description of a broadened perspective of phyto remediation is reviewed.

3.2 Methods and plants

Depending on the contaminating species and the site conditions the best potential type of phyto remediation method varies. In Appendix 2 various phyto remediation methods (remediation, control or increased natural attenuation) are shown together with a brief description of which species being convenient for each method. In Appendix 2 also the most convenient plants for each method, and the advantages and disadvantages are briefly described. Below a summary of advantages and disadvantages with phyto remediation, also including control and enhanced natural attenuation, is given.

3.3 Advantages and disadvantages

3.3.1 Advantages

- Low cost (see for example Table 1).
- In situ and thereby less transportation (Marmiroli et al., 2003) and possibly other lower environmental costs, such as use of land for landfill, use of other new resources for reuse of the previous contaminated land etc.
- The soil is kept serviceable and after remediation, of e.g. cadmium, the agricultural use for crop production can be re-continued or started (Suthersan, 2002).
- The method can be used more successfully than remediation based on pumping techniques in low permeable soils (Suthersan, 2002).
- Phyto remediation can be a useful complement to more conventional remediation methods. For example very high contaminated masses are excavated and the land with less high concentrations are phyto remediated (Suthersan, 2002).

Table 1. Example of costs (per ton contaminated soil, Sweden) for various remediation methods (from Andersson and Persson, 2007).

Treatment	**Cost per ton contaminated soil (€)**
Phyto remediation (increased rhizodegradation	7–30
In-situ bioremediation	35–100
Soil ventilation	15–160
Soil wash	55–150
Stabilisation	160–250
Extraction with solvent	250–300
Combustion	140–1000

3.3.2 Disadvantages

- Phyto remediation is relatively slow and therefore not always applicable.
- The conditions (soil type, pH, salinity, contaminant and other toxin concentrations) must be at a level the plants can tolerate (Huang et al., 1997; Marmiroli et al., 2003; Suthersan, 2002).
- The long remediation time makes it hard to predict the total project cost (McCutcheon et al., 2003).
- Still, 2008, there is little experience and few good examples available
- The growth climate dependence makes it difficult to draw conclusions for other locations based on available experience. Cold climate may for example imply need of longer time needed for remediation (Suthersan, 2002). This has, however, not been able to be shown such as in a comparison study of south (Skåne) versus further north (700 km) in Sweden (Lundström et al., 2003),
- Remediation is limited to the soil depth the vegetation can influence and root depth data for various plants is site specific and also generic information can be difficult to find (Suthersan, 2002).
- The lack of good examples and experience makes public and key stake holders insecure (Marmiroli et al., 2003).
- Phyto extraction may create hazardous waste, which must be handled according to current directives and laws (Suthersan, 2002).
- Plants containing high contaminant concentrations can be toxic for grazing animals (Suthersan, 2002).

3.4 Example sites and experience of bioremediation

3.4.1 Karlstad – Preem[3]

In this example study previously performed by Sonja Blom, phyto-remediation with *Salix Viminalis* was used as an enhancement to the biodegradation of hydrocarbons (HC) and to prevent lateral migration. The study was a low budget field study and unfortunately no continues sampling program was performed. Therefore the results presented have no scientific value, but are to be seen as a preliminary program to study the possibility of phyto-remediate HC contaminated sites in cold climate.

The site, shown in Figure 4, is a former oil storage site located in Karlstad Sweden and was chosen because the level of contamination was moderate, being about 5000 mg petroleum hydrocarbons per kg dry matter at about ¼ of the area and around 1000 mg petroleum hydrocarbons per kg dry matter at about ¾ of the site. The site area, which is owned and previously used by Preem, is 9000 m^3. The surrounding upstream groundwater current was at the time the experiment started a wooded area, protecting the site from any potential additional contamination. The soil consists of sand, gravel and stones of variable size. The groundwater level, as well as the most contaminated soil, is located about 0.5 to 1.5 m below the ground surface making the contaminants within reach of the root systems of *Salix Viminalis*.

[3] The literature basis for the site remediation: Chaudhry, Q., Blom-Zandstra, M., Gupta, S. and Joner, E. J. (2005). "Utilising the synergy between plants and rhizosphere microorganisms to enhance breakdown of organic pollutants in the environment" Environmental Science and Pollution Research, 12, 34-48.

Figure 4. Phyto remediation Preem oil depot, Karlstad.

In order to find the clone with the extensive root system, laboratory experiments were conducted with tree different clones of *Salix Viminalis* that were cultivated in soil from the location. The clone that had proportionally largest root system in comparison to over ground parts was chosen. This clone is called *Tora* and comes from Svalöv-Weibull in Sweden. The reduction of HC in soil was tested in continuous flow system in a small scale laboratory study. The reduction seemed to have a correlation to the organic carbon content being 1020 mg per kg dry matter in a container with 3% organic carbon and 580 mg per kg dry matter in a container with 2% organic carbon. During the time the plants were cultivated (one month) in the container, the root length gained was about 1m.

In 2001 *Salix Viminalis* (12000 cuttings) were planted. The distance between plant rows were about 60 cm and the distance between the plants in each row about 30 cm. The cuttings were irrigated during the first two growth seasons and cut and fertilized in 2002. Establishment of the *Salix* required one season except for the most contaminated area, were the plant roots did not penetrate more that 10 cm to the soil in 200,1 but were established in 2004. The seasonal sprout growth in 2001 was 0.5–1 m. In 2004, when the plantations were harvested for the fist time, several plants had grown 2–5 m. In summer 2008 the plants were fully grown.

Because only scare initial measurements were done in the beginning of the study, only approximate estimates can be made of the reduction of contamination level. The results from the site suggest a 30% reduction of contamination during the first 6 years of cultivation. Unfortunately, the protecting forest around the site was cut down during 2006, resulting in change in groundwater flow. Measurements done in ground water in 2008 suggest that contaminated groundwater now flows into the area. The results of the study thereby indicate that the cultivation of *Salix Viminalis* reduces the contamination level at the site (up to approx. 30%), but also that the clean cut of the wooded surrounding have impact of the spreading and possibly also the leaching of contaminants. This is relevant also regarding the harvesting procedure of wood cultivated on contaminated land, i.e. the harvesting at contaminated sites need to be done in a way that clean cutting is avoided.

The results suggest that phyto remediation can be a cost-effective remedial method for HC contaminated sites in Sweden and that *Salix Viminalis* is well suited for phyto remediation in Swedish climate. The establishment of the *Salix Viminalis* at the most contaminated area was slow, but the plants adapt to the conditions and can contribute to the future remedial process.

The land owners impression and experience

According to the land owner one of the major advantages with the phyto remediation is the low remediation cost (Hägglund, 2008). As petrol stations and depots are taken out of use, the land is remediated. During 2007 Preem performed remediation projects for about SEK 35 million (~€ 3.5 million). Another advantage is that the use of contaminated land for energy production may make less pressure on agricultural and other less marginal lands, which instead could be used for other purposes and products than fuel only (Hägglund, 2008).

Preem in total has 22 depots in Sweden, among those around 10–15 are likely to be suitable for phyto remediation. The depot area varies between 10 000–20 000m^2. Among those, around 25% of the area may be suitable for harvesting, i.e. for combined bio remediation, or bio-stabilization, and bioenergy production, which possibly can contribute further to the economical advantage under conditions when the area is large enough and there are nearby customers.

Similar contaminated areas are available for depots owned, or used by, Statoil, Shell, OK Q8, Hydro, NDAB (2 depots), SCT, VOPAK, Nordic Storage and Almer Oil. Hägglund, estimates these land areas in total of the same magnitude as in total for Preem, adding up to an area of 100,000 m^2 land, suitable for combined bioremediation, or stabilization, and biomass production to be harvested for production of energy or other products (Hägglund, 2008).

3.4.2 Gunnebo castle

Another small scale low budget phyto-remediation project was conducted by (Seiler et al., 2006) in close cooperation with Gunnebo Castle close to Göteborg, Sweden. The remediation project at Gunnebo is shown in Figure 5.

In 2004 a program was started at Gunnebo Castle to re-establish the castle and the surrounding gardens to the state they were at 1700. Reestablishment of the kitchen garden was part of this program.

The kitchen garden was to be ecologically farmed and it was important to analyze the soil content of contaminants including heavy metals before cultivation. At the end of mars 2004 soil samples were collected from the top soil layer (0 to 30cm below the soil surface) in the kitchen garden. The pooled samples were taken over the whole kitchen garden area. The average soil content of lead was 80 mg per kg dry matter and cadmium 0.4 mg per kg dry matter, both levels being equal to the upper limit for soil used for production of food in Sweden. Although it still was possible to cultivate food crops in the garden it was considered favourable to reduce the content of these two metals. The content of other contaminants was well below the upper limit for cultivation of food crop.

Based of reference literature (Gawronski et al., 2003; Greger, 2004; Huang et al., 1997; Seiler et al., 2006; Tassi et al., 2003) *Lupinus albus*, *Brassica juncea* and *Nicotina Glauca* were selected for phyto remediation at Gunnebo. The selection was based on the results in the reference literature, showing that these species were tolerant to the metals present and due to that they suited well to the back to 1700 program. Additional species that were planted due to compability with the program Gunnebo back to the 1700 and due to that they are fast growing and therefore had the potential to take up trace elements from the soil to larger amount of biomass were *Zea mays* and *Phacelia tanacetifolia*. Also *Amorpha fruticosa* was planted at the site.

The plants were collected after the first growing season. Only the parts above soil of the plants were sampled. The plats were dried and the metal content was analyzed (Table 2).

Following the first growing season both the content of lead and cadmium in the soil were reduced to levels well below the upper threshold level for food production in Sweden. *Lupinus albus* and *Nicotina Glauca* both accumulated cadmium. No other accumulator effects were seen. The reduction of lead and cadmium can be explained by ordinary plant uptake of these metals, but also due to increased organic content in the soil due fertilization.

Table 2. Measured initial metal soil concentrations and plant content after one year at Gunnebo castle phyto-remediation project.

Lead (mg/kg dry matter)	**Soil concentration**	**Plant content after**
Lupinus albus	66.6	0.03
Bassica juncea	35.3	0.89
Nicotina Glauca	45.1	0.60
Zea mays	34.9	0.57

Cadmium (mg/kg dry matter)	**Soil concentration**	**Plant content after**
Lupinus albus	0.23	0.76
Bassica juncea	0.17	0.07
Nicotina Glauca	0.18	0.53
Zea mays	0.13	0.14

Gunnebo slott odlas tungme

tt utanför Göteborg
å tillbaka sin 1700-tals
e byggnaderna och
apas enligt bevarade
gar. Men när det var
yngsta delen av kök-
isade den sig innehålla
Odla bort dem löd

scarsson

bak, majs, brun senap och
säsongen är över ska de ha
ly och kadmium och lag-
både bladmassa, rot och

rden åter kunna användas
d annat ätbara produkter

i en säsong till, berättar
projektträdgårdsmästare.
n paus i sin utbildning till
kt vid lantbruksuniversitet i
delta i arbetet med att åter-
ården vid Gunnebo Slott.

Figure 5. Phyto remediation Gunnebo Castle kitchen garden.

3.4.3 Malmö oil harbour[4]

Malmö oil harbour is located 2 km from the former Öresund sea shoreline and the whole area has been filled in order to become part of the harbour area (Figure 3). Most part of the filling material consists of bottom sand and sediments from Öresund.

The topsoil (about 0-5m below ground level) consists of sand and gravel and stones of variable size. According to interviews also waste material may occur in the topsoil layer. Below this level the soil is likely to be former sea bottom, consisting of clay. Oil is present in the soil in concentrations between 2000 and 6000 mg per kg dry matter, but concentrations up to 24,000 mg per kg dry matter have been measured. Only a few groundwater samples have been analyzed and, among those, concentrations up to 1800 mg per litre have been measured in the harbour area. Also heavy metals are found within the harbour area, but the concentrations are generally low.

Within the harbour area, the contaminated sites are all still in use and plantations on top of the contamination is not possible.

Tree different alternatives were investigated for in situ remediation within the harbour area.

- “Pump and treat“, where contaminated ground water would be pumped to the unused area south of the storage sites. The method has previously been used for treatment of organic solvents, petrochemical hydrocarbons and nutrients (Trapp et al., 2001).
- Poplar ally, with ground vegetation of grass or cleaver below, with the aim to create a hydrological barrier between the contaminated area and the sea. Poplars are commonly used for phyto-remediation of contaminated soil (D. Glass Associates Inc., 1999)
- Planting of vegetation to the wastewater basing, following oil separation. Suggested plants were *Ceratophyllum demersum*, *Myriophyllum verticillatum*, *Myriophyllum spicatum*, *Persicaria amphibia*, *Potamogeton perfoliatus* and *Elodea canadensis*.

The “Pump and treat” was rejected due to alternative future plans for the suggested planting area. No plants have yet been planted in the wastewater basing. The poplar ally was however planted in 2005.

Today poplar ally is established at the site and offers a visible barrier with esthetical dimensions making the oil harbour area less industrial. The project has yield a lot of positive attention both among the personal and the visitors to the harbour. Many of the clients have donated poplar tress to the ally that now has been extended also to the other side of the harbour basing.

3.4.4 Landfills – Sweden

Swedish landfills

The total number of Swedish landfills, i.e. landfills that takes more than 50 ton of municipal waste, was 192 sites in the year 2003. The number of landfill sites that used plants for leachate treatment was 37 sites (RVF, 2004a). The amount of waste on the landfills was

[4] Literature basis for this site:D. Glass Associates Inc. (1999) "U.S. and international markets for phytoremediation 1999-2000". D. Glass Associates Inc., R245-001 http://www.mindbranch.com/listing/product/R245-001.html, Trapp, S. and Karlson, U. (2001). "Aspects of phytoremediation of organic pollutants" Journal of Soils and Sediments, 1, 37-43.

3 765 000 ton of which 475 000 ton was household waste. The total amount of waste on the landfills, since the start of the landfills, was 205 million m^3 and the total area of the landfills amounted to approximately 25 km^2. The amount of landfill gas extracted from the waste amounted to 443 GWh.

The amount of leachate treated was 8 million m^3, mostly treated in municipal sewage treatment plants. The amount of leachate were irrigation of grass or trees was at least a part of the treatment was approximately 0.9 million m^3.

Since 2002 there is a ban on landfilling of combustible waste, and since 2005 there is a ban on landfilling organic waste. This, together with other measures against landfilling such as a landfill tax, has led to a decrease in the amount of waste to landfills. In the year 2007 a total of 4 717 300 ton of waste were collected (Avfall Sverige, 2007). 40 880 ton consisted of hazardous waste, 1 737 720 ton were recovered, 561 000 ton were biologically treated, 2 190 980 ton underwent thermal treatment with energy recovery. Only 18 600 ton were landfilled.

The number of active landfills 2007 amounted to 140 sites. The total amount of waste landfilled was 1 994 000 ton of which the household waste amounted to 186 000 ton. The decrease of the organic waste landfilled has led to a decrease in the landfill gas extracted from the landfills. The amount from 60 active landfills with gas extraction amounted in the year 2007 to 290 GWh.

Vegetation on landfill

A variety of grasses and trees are used at Swedish landfill sites to reduce pollutants in the leachate. In the fist place the plants are used to enhance the evapotranspiration and decrease the amount of leachate that has to be treated. Secondly the plants ability to bind nitrogen in the leaves and wood are used. It is well known that the plants can take up and bind other pollutants, but this is not commonly used actively at the sites. The harvest of the wood is seen as an extra advantage, but the intentions with the plantations are not maximize the growth of the wood.

Different species are used in different ways. One way is to let them grow in dams and ponds with leachate water. Mostly pondweed is used. Grass or trees can grow either on top of the landfill or in fields nearby. Among the grasses species as Perennial Ryegrass, Fescue (*Festuca*), *Dactylis glomerata* (Cocksfoot or Orchard Grass or Cocksfoot Grass), timothy (*Phleum pratense*), Wood bluegrass (*Poa nemoralis*) and Reed canary grass (*Phalaris arundinacea*) are used. Among the trees, Salix has been used frequently and sometimes trees that grow naturally in the vicinity have been irrigated with leachate water. In recent year's experiments with other species, for example hybrid aspen have been carried out. Salix is normally harvested each third to each fifth year, and the wood is used as a fuel. The intention with the use of hybrid aspen is to let it grow to its full length and use the wood for other purposes.

Treatment of leachate has been described in many reports. In RVF report D2007:07 (RVF, 2007) it is described that some plant and animal species have the ability to take up metals and organic pollutants from soil or water. This knowledge is important when assessing the risk for environmental impact and for assessing the possibilities to treat polluted water.

There are a number of species, including grasses, willow and birch, that could be of interest to test to treat polluted water with respect to metals and PAH (e.g. (Berndes et al., 2004; El-Gendy et al., 2006; Nehnevajova et al., 2007; Parrish et al., 2006; Samake et al., 2003; Wislocka et al., 2006)). For example, experiments in laboratory and pilot scale on the uptake in *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce) from sewage showed that the plants are capable to decrease several indicators of water quality to levels low enough to allow the water to be used for irrigation of trees (Zimmels et al., 2006). A deeper survey and tests in pilot scale are suggested to be carried out with specific leachates and site conditions or for more generic conditions in Swedish climate. Despite site specific conditions to be considered there are some general aspects of interest. For example a study carried out to create a basis for a calculation/assessment model ("partition limited model") for uptake of PAH (phenanthrene and pyrene). The study, carried out on *Lolium perenne (*Perennial Ryegrass) grown in soil and in water, showed that there was a good correlation between the model and reality. Further, the uptake from water showed to be higher than from soil with the same concentrations (Gao et al., 2004). Of generic interest is also a model developed to simulate phytoextraction/rhizofiltration of soil polluted with metals and sewage water (Verma et al., 2006).

Experience of vegetation on landfill

The experience of vegetation on landfills is that growing plants on landfills is not without problems as summarised in "Damage on plants watered by landfill leaching water"(RVF, 2006). Studies were carried out during 2004 and 2005 on MERAB's landfill site in Rönneholm and SYSAV's landfill sites in Hedeskoga and Måsalycke in the south of Sweden. The aim of the project was to get a deeper understanding of the causes of the problems with the plants and to get a well functioning vegetation system with as great evapotranspiration as possible. The results can be used as a basis for modifying the system to suit the plants used. Experiments have been carried out with two types of plants, the grass Reed canarygrass and the herb Japanese Knotweed (*Fallopia japonica*), and the results have been compared with the Salix "Tora" The results show that the pH value in the soil is higher than in normal soil, probably due to a high pH value in the leachate. A high pH value can lead to a lack of some nutrients in the plants. Measures should be taken to lower the pH value in the soil to the more normal value between 5.3 and 6.5.

The nitrogen content in the plants is twice as high as normal, which leads to a relative lack of other nutrients. Concerning metals there is a lack of Fe, Cu and Ni in the plants. The nitrogen content of the leachate should be lowered before it is used for irrigation, alternatively complementary fertilizing should be carried out to balance the amount nitrogen.

The soil was very wet du to too mush irrigation. This could lead to a shortage of oxygen at the roots which can cause the death of plants or a decrease in growth. This could also contribute to green house gas emissions such as dinitrogen monoxide and methane.

Damaged plants cause a decrease in evapotranspiration which correlates directly to the decrease of the area of the leaves. Reed canarygrass seems to be the most tolerant to saturated soil of the tested species. The irrigation should be regulated depending on the climate and with regard to whether the area has been newly harvested. If the leachate is spread on the leaves, this can cause mechanical damage and precipitation of less soluble salts or algae. Thus spreading of leachate beneath the leaves is recommended.

A manual for treatment of leachate from landfills with plants has been worked out at Avfall Sverige (the Swedish Association for Waste Management) (RVF, 2004b). The dimensioning of the systems is made on basis of the hydraulic circumstances and on basis of nitrogen reduction. Other pollutants do normally not influence the system.

Use of vegetation from landfills

At the NÅRAB landfill site. Hyllstofta, Salix as well as hybrid aspen is used. The fuel from the Salix plants is combusted in a combustion plant for waste. This is due to economic reasons and not environmental risks. On other sites the harvest is usually carried out by a contractor who mixes the chips with other chips from other sources to obtain an even quality. At the NÅRAB site there have been no questions about the origin or the pollution content of the fuel. The hybrid aspen which grows outside the area of the actual landfill is intended to grow to its full length and used for more advanced purposes than fuel (Waldemarsson, 2008).

The situation has similarities with the situation concerning fertilizing Salix on normal ground with sewage sludge. The question about origin and content of pollutants has not, yet, been raised.

Personal at the Hedeskoga landfill site confirm the experiences from NÅRAB. Nobody has asked for origin or metal content of the fuel. The wood is harvested each third or fourth year by a contractor who sells it on the market. The waste company does not pay for the harvesting, but on the other hand the contractor eventually gets the profit. The main purpose of the plantation is the reduction of leachate that has to be treated (Lindén, 2008).

The plants are harvested each third to each fifth year. Under good conditions the harvest would amount to 6–9 ton per hectare for grass and to 10–12 ton per hectare for Salix.

The area for plants on top of the actual landfill may decrease in the future. The legislation demands advanced top covers in order to prevent water from entering the landfill, and the sealing liners now being constructed may be damaged by roots. Salix also produce a thick cover of leaves causing the death of the lower vegetation, which in turn makes the soil more vulnerable to erosion, especially at the sloops of the landfill. Erosion on landfills due to vegetation may be increased or decreased depending on which plant is cultivated where (Klug et al., 2008).

From a controlling point of view it is favourable to harvest crops regularly as it gives a good opportunity to monitor the capping at the same time.

3.4.5 Further examples

Both in Sweden and around Europe also additional phyto remediation projects are going on. One of the projects referred to in Rejuvenate at an early stage is one of the UK sites, i.e. the Markham Willows project (Bardos et al., 2009 (in prep)) and in appendix 2 references to other national and international phyto remediation test sites are given.

4. BIOENERGY

4.1 Different types of bioenergy

There are several types of bioenergy such as heat and electricity, and biofuels such as biogas, plant oil methyl esters, ethanol and methanol. The process for production can be physical, chemical or biological such as oil pressing, chemical reaction, fermentation or anaerobic digestion. The bioefuels produced by those processes are sometimes referred to as first generation biofuels.

There are also synthetic biofuels sometimes termed as second generation biofuels. This term, however, is also used for fuels made from biomass resources, which are not edible and are thus not competitive to food production. A third definition of second generation fuels referrers to the use of ligno-cellulosic plants as a raw material (Jungbluth et al., 2008).

For the production of synthetic fuels first synthesis gas is produced from the biomass by means of gasification[5]. In principle several types of biomass including wood and cellulose or lignin containing plants can be used as a raw material. Different types of synthetic fuels can be produced in this type of processes. The same process can also be used with bio and fossil fuel resources such as the production of GTL (gas to liquid), using natural gas or coal-to liquid (CTL). The most common fuels made from biomass are (Jungbluth et al., 2008):

- BTL: Biomass-To-Liquid. A synthetic fuel with fuel properties as conventional diesel
- SNG: Synthetic Natural Gas. A possible replacement of natural gas
- DME: A fuel with similar properties as LPG (liquid petroleum gas)
- Ethanol
- Methanol

Below a short description of each method is given and Table 1 in Appendix 3 a summary of the present level of development, advantages and disadvantages is shown. In Figure 6 a flow chart of a conventional combustion system as described by Shuck (Schuck, 2006) is shown.

[5] Gasification is a process that converts coal, petroleum, or biomass, into carbon monoxide and hydrogen by reacting the raw material at high temperatures with a controlled amount of oxygen and/or steam. The resulting gas mixture is called synthesis gas or syngas and is itself a fuel. The advantage of gasification is that using the syngas is more efficient than direct combustion of the original fuel. Syngas may be burned directly in internal combustion engines, used to produce methanol and hydrogen, or converted via the Fischer-Tropsch process into synthetic fuel. Gasification relies on chemical processes at elevated temperatures >700°C, which distinguishes it from biological processes such as anaerobic digestion that produce biogas, see section 4.1.4).

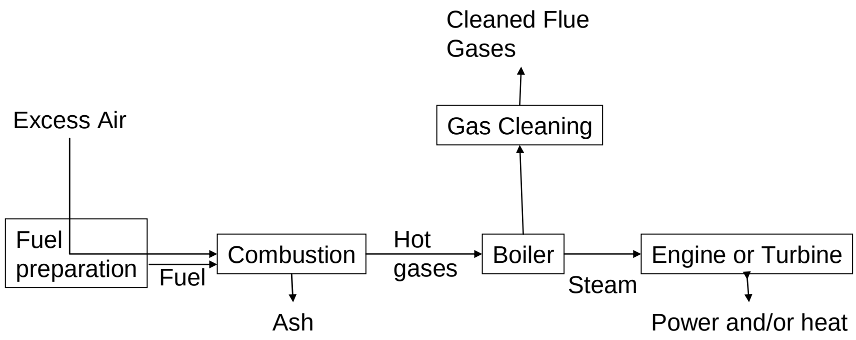


Figure 6. Flow chart of a conventional combustion system (based on Figure 2 in (Schuck, 2006)).

4.1.1 Ethanol production through fermentation of grain and forest material

Production

Ethanol can be produced from a raw product containing sugar or starch. In Europe, wheat, barley and sugar beats are mostly used in the ethanol production (Grahn, 2007). The grain is transported to the plant where it is cleaned and then stored. The production starts with grinding of the grain to flour fraction, thereafter water and enzymes are added causing the starch to break down. To the sugar solution yeast is added which starts the fermentation. During the fermentation ethanol and carbon dioxide is formed from the sugar. Distillation and further separation then part the ethanol from the draff (mask) and excessive water. The produced draff is rich in protein and can be used as animal food after it is dried (Grahn, 2007).

Level of development

Agroetanol in Norrköping, Sweden was built in 2001 and produces 50 000m^3 ethanol per year equivalent to 0.29 TWh. It is estimated that 30% of today's consumption of petrol and diesel could be substituted by ethanol. In those calculations the greatest part of raw material will come from the forest but, to increase the Swedish production of ethanol, grain is now used.

The trends in the world concerning raw material and production volumes differ. In Sweden wheat is the most common raw material and the fuel has a low admixture of ethanol. Brazil produces 15 million m^3 ethanol per year that is used in a 26% admixture. In Brazil sugar canes is the raw material. Corn is the main raw material for ethanol production in the USA. About 10 million m^3 ethanol per year is produced (2004). The admixture is 10%.

The second generation production of ethanol, which is under development, is formed through fermentation of forest material. In Sweden there is a pilot plant in Örnsköldsvik and perhaps a full scale demonstration plant will be built. Commercial production of ethanol from forest material is discussed in other cities, such as Umeå and Sveg, as well (Skogsindustrierna, 2007).

At present, summer 2008, among the larger fuel producers sugar cane from Brazil is used for ethanol production (Eriksson, 2008).

4.1.2 Biogas production through digestion of plants

The same assumptions for digestion of sludge and organic waste as for digestion of forage crops are assumed.

Production

Biogas is formed when organic material is degraded by microorganisms in an anaerobic environment. This is a natural process that occurs in for example wetlands and landfills, where the organic fraction is high enough. The composition of the biogas depends on the substrate, but the main components are methane and carbon dioxide. In (bio) reactors biogas is commercially produced from organic waste and/or crops such as forage crop. The reactor has to be airtight, isolated, stirred and provided with some kind of heating system. When the biogas is formed it is taken out via the top of the reactor and can then be used for heat, electricity or, after upgrading, vehicle fuel (Energimyndigheten et al., 2008).

Level of development

There are several commercial biogas production facilities in Sweden; at waste water treatment plants, industries, landfills and waste management stations and some smaller at local farms.The total annual biogas potential in Sweden is estimated to 14 TWh, and of that 7.2 GWh comes from cultivated land. In this estimation10% of Sweden's arable land is to be cultivated with a mix of plants (FramTidsbränslen AB, 2005).

How to calculate the environmental impact from production of biogas is not easy. Analyses of the systems have to be done and there need to be measurements that quantify the amount of gas leaking from the facilities. Then technique has to develop to minimize the leakage (Berglund et al., 2002). According to (Berglund et al., 2002) the full potential for biogas production is not reached yet. The coefficient of utilization could increase by 30%. At some locations there is a problem with the digested sludge. It might contain contaminants so the farmer does not want to use it on the fields.

It is estimated that by 2010 the amount of fuel gas in forms of biogas will increase from today's 226 GWh to 1040 GWh. Of that 250 GWh will be produced from cultivated plants (FramTidsbränslen AB, 2005).

4.1.3 Firing of fuel from crops normally grown on arable land

Production and level of development

Cultivation of Salix is commercial in Sweden and is most often used at heating plants or combined power and heating plants. Since the demand of Salix is larger than the production there is a potential to expand the cultivation.

There is no commercial industry for Reed canarygrass in Sweden today, but there is research aiming at refining species suitable for production of bioenergy. Due to a high content of ash, compared to other biofuels, Reed canarygrass is best suited for large facilities with an automatic handling of the ashes. Compared to firing of wood pellets and forest fuels the emissions in forms of sulphur and nitrogen are higher from firing of Reed canarygrass. In Finland Reed canarygrass is burnt together with peat since a part of the sulphur (from the peat) is trapped in the ashes (Bioenergiportalen, 2008).

Straw is mostly used at smaller farms and, in some cases, at district heating plants. The straw is fired either in packs or in smaller pieces. The supply of straw is in direct correlation to the cultivation of grain and oil plants. It is estimated that 10 times the today production could be burnt for production of heat and electricity, in Sweden. In Denmark, the production is 15 times the Swedish one (Bioenergiportalen, 2008).

Firing of fuel from crops, normally grown on arable land, and grain takes place in small pan at the farm, a larger pan that can produce enough energy for a school or similar, or at a district heating plant. Firing of fuel from crops normally grown on arable land and grain produces a lot of ashes that has to be taken care of. The ashes can also cause problems in the pan if it melts (Bioenergiportalen, 2008).

4.1.4 Gasification of biomass

Production

Synthetic gas (methane and hydrogen) can be formed from biomass, waste or black liquor. There are several techniques for gasification of biomass, but the main step is where the raw material is burnt and gas is formed. Depending on the gasification temperature different by-products are formed. Lower temperatures, about 800°C, result in high concentrations of methane, tar and dust. Higher temperatures, about 1200°C, decreases the amount of tar and dust but the ashes in the biomass melts at these temperatures (FramTidsbränslen AB, 2005). After production the gas is cleaned. The synthetic gas is then further processed into dimethylether, methanol, synthetic diesel or hydrogen gas.

Level of development

There are no commercial plants for gasification in Sweden (FramTidsbränslen AB, 2005). Even if several plants exist it is hard to produce synthetic gas of good quality that can be used for production of fuel. In Germany, some pilot plants have managed to do this.

4.1.5 Esterification of rape seeds

Production

The first step in the production is to separate the oil from the seeds. In smaller plants this is done by cold pressing and in larger production sites warm pressing is used, since this increases the amount of oil extracted. The rest-products from the pressing are rape-expeller or raps flour which can be used as animal food. It is also possible to digest the expeller in a biogas plant. After the extraction the oil is cleaned by filtering, sedimentation or centrifugation. Methanol and a catalyst such as caustic soda, NaOH, are added to the oil. The mixture is heated and through continuous stirring reaction takes place. Raps methyl ester, RME, and glycerol are produced. Since glycerol is heavier than methyl ester it can be tapped from the bottom of the tank. The methyl ester is then cleaned from excessive amounts of methanol, neutralized, desalted and filtered. The RME can be stored in tanks for at least a year (Bioenergiportalen, 2008).

Level of development and geographical differences

The first commercial plant in Sweden was built in 2006, in Karlshamn, by “Ecobränsle”, and produces 40 000 ton RME per year. In 2007, Perstorp Stenungsund built a RME production plant planning to produce 60 000 ton RME per year in the beginning and then increase to at least the double. In Sweden, the raw material for RME is mostly rape seeds, while fish oil is most common in Norway. In the southern parts of Europe, soya beans and sunflower oil are usually used whereas fry oil is the most common raw material for RME in the US (Bioenergiportalen, 2008).

4.2 Implementation and trends of bioenergy

In Sweden, biomass constituted more than 18% of the total energy production 2007. The main biomass sources are (Formas, 2007):

- wood (wood, bark, saw dust and energy forest)
- pulping liquor and pine tree oil from the pulp industry (tall oil pitch)
- peat
- waste
- ethanol (pure to the industry and for mixing in 95 octane petrol and other fuels E85 and E92)

There are several national initiatives and activities promoting bioenergy and other alternatives to fossil fuel. Below some examples of the present ongoing activities are listed:

- Heat and electricity
  - Renewable electricity certificates
  - Aid for conversion from electric and oil-fired heating system
  - Aid for energy efficiency and renewable energy in public places
- Climate investment programmes
- Phase out fossil fuel

These examples of ongoing promoting activities are further described in Appendix 4. In Appendix 4 also examples of ongoing small and regional scale activities and development at various locations is presented.

The Swedish government recently declared its intention to phase out fossil fuels in the transport sector by 2020. To achieve this goal, it will be necessary to improve energy efficiency and to design and implement feasible strategies for transition to renewable fuels. Based on this goal, Robèrt et al. (Robert et al., 2007) investigated the potential for a full transition to domestically produced biofuels in the transport system of the city of Stockholm by 2030, without exceeding the proportional share of national bioenergy assets. The objectives were to test the potential of biofuels assets in Sweden and to explore the potential for energy efficiencies in the transport system after the peak of fossil oil production. The following three aspects were included in the analysis: *i)* the potential for domestic production of biofuels without exceeding the capacity of Swedish agriculture and forests (~10% of forest land and 30% of agricultural land could be redirected to biomass production), *ii)* the potential for alternative technological developments (hybrid cars, hydrogen powered fuel technology etc.) considering that these technologies will probably be more cost-effective than conventional cars within 10-15 years and *iii)* urban mobility, modelling traffic scenarios to estimate the potential for policy measures (traffic tolls, zero-cost transport, etc.) considering a tripled fuel price and technological breakthrough. It also permits to quantify the rebound effects of energy efficient vehicles (e.g. increases in private car transport).

The study by Robèrt et al. (Robert et al., 2007) shows that as much as 40% reduction in transport fuel demand may be achieved by a combine-strategy (50% increase in fuel prices, traffic tolls, free public transport, mechanisms to decrease car ownership, technological improvements) in the particular case of the transport sector in Stockholm in 2030. The study highlights *i)* that efficiency assessments are crucial in the planning process in order to keep competition with forest industries and the vital need for food to a minimum, and *ii)*that biofuels are a serious candidate as a substitute for fossil fuels in order to reduce energy use and greenhouse gas emissions from the transport sector. Furthermore, during a transition period, biofuels would play an essential strategic role since they constitute a renewable energy platform for both the present infrastructure, as well as for various optional future renewable fuel solutions (Robert et al., 2007).

5 AVAILABLE ADDITIONAL RESOURCES – RECYCLED MANURE, COMPOST AND MUNICIPAL WASTE

5.1 Sewage sludge

Wastewater (sewage) sludge comes from sewage treatment plants, private wastewater wells or other devices that treat sewage from households and settlements. Wastewater sludge can also occur in other kinds of treatment works, for example within the food industry (Swedish EPA, 2008a).

Since the 1st of January 2005 it’s illegal to landfill wastewater sludge. Landfilling, however, is an alternative if the sludge has been treated, for example by composting (Swedish EPA, 2008a).

The wastewater sludge contains valuable nutrients and it’s preferable to regain these to the soil. A goal for recycling phosphor is described in one of the Swedish national environmental objectives (Number 15 – Good Built Environment, (Miljömålsrådet, 2008)). The aim is to recycle 60% of the phosphor compounds in the sludge to the soil before year 2015, and half of it should be regained to arable land (Swedish EPA, 2008a).

Every year about 1 000 000 ton wastewater sludge is produced in municipal sewage treatment works. If water is not included the weight is about 240 000 ton and half of it is organic material, i.e. the sewage sludge in Sweden is 120 000 ton dry weight organic matter. Additional sludge comes from the private wastewater wells. Today about 5-10% of the sludge is recycled to arable land or forests, this means about 6 000-12 000 ton dry weight organic material. The rest is burned or used in construction works, for example noise reducing embankments along motorways (Avfall Sverige, 2007).

5.2 Compost

Biological treatment includes both composting and digestion. Composting means biological decomposition of organic material during the presence of oxygen (aerobic process), transforming the material into carbon dioxide and water. Digestion is the process when organic material is decompose without the presence of oxygen (anaerobic process) forming the material into a gas (biogas). The gas contains mainly methane and carbon dioxide (Swedish EPA, 2008a).

During 2007, the total amount of biological treated waste in Sweden was about 870 000 ton. This includes 561 000 ton household waste (which corresponds to 11% of the total household waste) and 167 000 ton waste from food industry. This lead to the production of 336 100 ton of digested organic material was produced during biofuel production from other sources than sewage sludge. At 30% dry substance, this corresponds to roughly 100 000 ton dry substance. Decomposed material is a long-term working soil improver and it is often used in gardens, parks and in different land constructions. The material can be certified through SPCR[6] 152 and SPCR 120 (Avfall Sverige, 2007).

[6] SPCR is an abbrevation of Swedish certification rules (In Swedish: SP:s (Statens Provningsanstalt) CertifieringsRegler). SPCR 152 –compost, SPCR 120 sewage sludge

Almost all (96%) digested biofuel waste and composted waste is at present recycled back to arable land or to gardens. The Swedish municipalities aim to double the capacity for biological treatment within a few years. A national objective is that 35% of all household waste should be treated biologically in the year 2010 (Avfall Sverige, 2007), so the amount of organic material available for soil improvement will increase.

5.3 Stable manure

The spread of stable manure are regulated by legislation. Which soil type and what part of the country are two factors that control when to spread the manure. Also the total amount of phosphor in the manure is an important factor (Jordbruksverket, 2009)

Stable manure means manure produced during the indoor period. During the grazing period all urine and manure are directly regained to the soil (Bioenergiportalen, 2008).

6 BIOENERGY FROM CONTAMINATED LAND

6.1 "Biofuel problems are contaminated land's opportunity – or contaminated land is a biofuel solution"

Non-food use of contaminated marginal land use, combined with a low intensity agronomic approach that emphasises the use of secondary materials like compost, has a wide range of benefits such as carbon management. A sequestration effect may arise from increasing soil carbon levels (for example from bio charcoal or added organic materials and root exudates) and standing crop biomass. It is possible that this effects will diminish over time if the land-use subsequently changes. However, it is also possible for some sites with poor quality (or nonexistent) soil cover, that the addition of organic matter with the non-food crop cultivation will make a self sustaining improvement to soil carbon levels. The permanence of the carbon sequestration and risk management effects may be linked, so that their management is interlinked. The extent of the carbon sequestration opportunity may be greatest for marginal land with absent or highly degraded soil cover (Andersson-Sköld et al., 2008).

6.2 Emissions and net energy from different bio raw material

6.2.1 Net energy

In Figure 7 an estimate of the net energy production from different raw materials per raw material production surface area is shown. The net energy depend on the need of energy in the production steps (growth, the steps of conversion to fuel) and the net energy that can be used in the energy production step. Semelsberger et al. (Semelsberger et al., 2006) has for example estimated that DME is the most favourable bio-based product based on the net energy. Also regarding the net carbon dioxide emissions, DME is at present the most efficient fuel (Eriksson, 2008). There is, however, an ongoing development and new solutions are becoming more efficient.

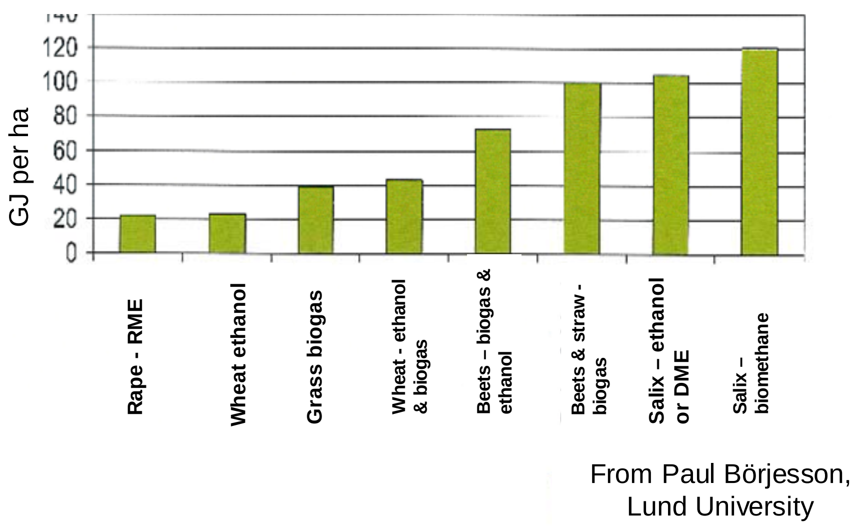


Figure 7. Net energy production from different raw materials per surface area (produced by Paul Börjesson, Lund Univeristy)

A normal forest in Sweden can take up 5-10 ton carbon dioxide per hectare and years. The carbon is stored in the tree (biomass) and is transferred gradually to the ground (soil) via the roots and falloff (Grelle, 2008). When biomass is taken out both the uptake and degradation is changed in the remaining forest. The Swedish University of Agricultural Sciences (SLU) points out that it is not easy to estimate the carbon storage in a forest. However, with modern measuring technique SLU today measures flows of carbon dioxide in the atmosphere above forests and can thereby direct estimate the forest's net uptake or emission of carbon dioxide to the atmosphere. Based on such estimates the net uptake has been estimated for some out take alternatives by Grelle (Grelle, 2008) .

Final felling, the most common harvest technique for forestry, leaves open surfaces with hardly any vegetation left. The carbon storage is used up (degraded, oxidised) to carbon dioxide in the atmosphere, and it takes many years before the new planted forests to become a net sink for carbon dioxide (Grelle, 2008).

A storm felled forest is probably the worst-case scenario, since it causes destruction on almost all wealth vegetation, and the ground are broken up due to fallen roots. As a result, the coal in the soil can easily be oxidised and emitted as carbon dioxide to the atmosphere. A storm felled forest can lead to approximately twice as much CO_2 emissions compared to an ordinary final felling (Grelle, 2008) .

According to the studies by SLU, outtake of biomass from a forest through thinning hardly seems to affect the forest carbon balance (Grelle, 2008). The reason is that in spite of a reduced number of trees, the remaining trees in the forest take up as much CO_2 as the forest prior the outtake, since the reduced uptake competition favours the remaining vegetation. Depending on the use of the material taken out, the harvested biomass can either preserve coal for many years by, for example be bound in a wooded house, and sooner or later replace fossil fuels by to be used as bio-energy (Grelle, 2008) .

The carbon balance from cultivation on contaminated land further depends on site specific conditions. In this project a carbon balance has been estimated for two different contaminated sites as alternatives to other cultivation areas and for other remediation alternatives than bio fuel production. The assessments are made for hypothetical alternatives at two contaminated case study areas in Sweden. One site is the former oil depot described in section 3.4 the other is a site with metals being the dominating contaminants. The results are very promising regarding the carbon footprint from biofuel cultivation instead of more traditional remediation methods. For further details and information see (Suer et al., 2009c).

7 ENVIRONMENTAL IMPACTS

7.1 Environmental consequences of soil contamination and remediation

Contaminated land may have acute or long term consequences on the environment, but also every contaminated soil treatment leads to consequences for the environment. Not only local eco-toxicity and human health, but also other aspects varying from global warming, acidification, eutrophication, ozone, habitat and biodiversity and social factors are affected by the soil remediation strategy (e.g. (Suer et al., 2009a; Suer et al., 2009c), and references therein). Even in situ biological soil remediation measures may have an overall negative impact worse than doing nothing and leaving the contamination in the soil. Most often, however, there usually is from an environmental perspective a more beneficial in situ biological alternative available (Suer et al., 2009c)

There are some LCA perspective based studies of remediation projects (e.g. (Bouwman et al., 2002)(Bender et al., 1998; Diamond et al., 1999; Johnsen et al., 2000; Owens, 1997; Page et al., 1999; Ribbenhed et al., 2002; Schenck, 2001; Vignes, 1999; Volkwein et al., 1998; Volkwein et al., 1999), and in Sweden LCA has been used to compare different remediation technologies (Andersson-Sköld et al., 2007; Lind et al., 2004; Ribbenhed et al., 2002; Suer et al., 2009b). According to those investigations, in situ bioremediation can be the best, but also the worst, remediation alternative from an environmental holistic perspective, depending on method used and site specific conditions (Suer et al., 2009b).

In addition, there is general a large room for improvement in everyday remediation, since the holistic environmental aspects are often ignored completely today. Even a sketchy review of the environmental impact can indicate which techniques to avoid, and where there is potential for improvement. Such a review should consider the entire chain, a life cycle perspective, of the remediation. Within this project, both a sketchy and more detailed environmental assessments have been performed. The assessments are made for hypothetical alternatives at two contaminated case study areas in Sweden. The study covers a more classical LCA perspective and a sketchy life cycle framework based assessment of alternative remediation alternatives. At one site the alternatives regarded are *i)* cultivation of willow, *ii)* dig and landfill and *iii)* monitored natural attenuation, at the other the alternatives investigated are *i)* cultivation of *Salix Viminalis* and *ii)* establishment of a park. For further information see Suer et al. (Suer et al., 2009a; Suer et al., 2009c).

7.2 Environmental consequences of bioenergy and biofuel

Today the global use of fossil fuel is more than ten times the bioenergy and the total production of fossil fuels are still increasing (Berndes et al., 2007). One major risk when increasing the use of bioenergy is that there globally is not enough biomass to compensate the today’s use of fossil fuel. There are potential resources of increasing the amount of bioenergy from by- and rest-products, waste etc. For example manure can be used for digestion and biogas production, which in turn also reduces methane emissions normally released from dung-wells.

According to Börjesson (Börjesson, 2007) the environmental risks in general and the green house gas emissions are less by planting energy forests, e.g. perennials such as Willow (*Salix)* and *Poplar,* instead of annual plants, due to for example less need of fertilisers.

The environmental consequences are limited using energy forest. For example, when using the forestry harvest by-products, such as branches and tops, the nutrients are removed. However, this can be compensated by returning the ashes or other rest- and by-products from the energy production process. Adding nitrogen will further increase the carbon uptake and energy production by increasing the biomass production up to 50% in comparison to the energy needed for the nutrient production. The use of branches and tops may even reduce the nutrient leaching and acidification in Southwest of Sweden(Börjesson, 2007). While adding an alkaline fertiliser, such as ash, to naturally acid forest soils, such as in North of Sweden and Norway may severely disturb the kinetics of the natural biogeochemical cycles of many elements (Reimann et al., 2008).

According to a recent study by Zah et al. (Zah et al., 2007) 21 out of 26 biofuels reduce the green house gas emissions by more than 30% compared to gasoline. However, 12 out of these 26 biofuels (including US corn ethanol, Brazilian sugar cane ethanol and soy diesel and Malaysian palm oil diesel) have greater total environmental costs than fossil fuels (Zah et al., 2007). Among the remaining five out of the 26 biofuels, some have no net reduction or even higher total green house gas emissions than gasoline (Zah et al., 2007). According to the study by Zah et al. biofuels that are by far the best are those produced from residual products, such as bio waste or recycled cooking oil, as well as ethanol from grass or wood (Zah et al., 2007). Despite theoretical environmental benefits, Mazzoleni et al. (Mazzoleni et al., 2007) points out the importance of stringent quality testing in biofuel production in order to benefit also in carbon monoxide and hydrocarbon emissions.

The study by Zah et al. (2007) shows that depending on grain, growth and energy production conditions, the environmental benefits using biofuel instead of fossil fuel vary. However, even when only including first generation biofuels there are environmental benefits for many of the biofuels included in the study. Therefore it has to be noted, that if the study by Zah et al. (2007) had included the so called second generation biofuels, such as breakdown of plant cellulose or lignin, which can be produced from non-food plants grown on marginal land or algae cultivated in aqua culture, the benefits could include a larger group of beneficial crops with even more pronounced total environmental benefits than in the present study (Hill et al., 2006).

Schmer et al. (Schmer et al., 2008) carried out a lifecycle analysis for the production and use of ethanol from switchgrass. This indicated that, on average, using bio ethanol from switchgrass is nearly carbon neutral if carbon sequestration in the soil is included in the model and if the waste biomass is also used to produce energy. Further improvements will be possible, through the use of genetic engineering techniques as well as improvements in processing technology.

Another environmental cost that varies among biofuels is trace gas emissions, such as nitrous oxide emissions related to fertilisation. The nitrous oxide emissions using corn or canola for ethanol production may result in worse contribution to global warming than burning fossil fuels (Crutzen et al., 2008). Other environmental impacts concern use of pesticides, possible invasiveness of some species used in biofuel production and water consumption (UNEP, 2008).

Additionally, changes in the carbon content of soils, or in carbon stocks in forests and peat lands related to bioenergy production, might offset some or all the green house gas benefits

(Steenblick et al., 2007). This can, however, be compensated. One way to get more carbon into soils is by spreading biodegradable organic wastes such as crop residues, farmyard manure, sewage sludge and compost onto agricultural land. There are risks for methane emission, and the amount depends on methods and site specific conditions why the net carbon balance result has to be assessed. Combining soil and waste management in this way directs carbon to the soil where it can be captured and has the added benefit of reducing the amount of waste that goes to landfill. Estimates of the contribution this method could make to carbon capture range from 2-20 million ton of CO_2-eq per year, due to regional differences in soil, management practices and climatic conditions (Marmo, 2006).

Within this project a carbon balance (carbon footprint) assessment has been performed for the same sites and conditions as in the contaminated site environmental assessment, the carbon footprint investigation includes cultivation of *Salix Viminalis* at the contaminated sites and at more common agricultural sites. For further information see Suer et al. (Suer et al., 2009c).

7.2.1 Land use and biodiversity

One of the greatest environmental risks with production of bioenergy or biofuel is the potential impact on land used for feedstock production and harvesting (particularly virgin land or land with high conservations value). A negative impact on such land will have associated effects on habitat, biodiversity, water, air and soil quality and may also reduce the net effect on carbon dioxide emission reductions (Bala et al., 2007; Laurance, 1999; Righelato et al., 2007; Scharlemann et al., 2008; Steenblick et al., 2007).

A study by Russi (Russi, 2008), using Italy as a case study, suggest that it may not be worth investing in biodiesel. First generation crops, such as wheat and rye, have particularly high environmental impacts and the gains using those crops would, according to this study, be small and the impacts on the land and soil would be of concern. Nevertheless, according to an EEA Technical report (EEA, 2007) Europe has the space to increase the amount of crops grown as bioenergy resource.

To mange the increase in land used to grow crops for bioenergy, however, requires measures and safeguards to protect environmental quality. This includes that:

- at least 30 per cent of agricultural land area should be devoted to environmentally oriented farming by combining organic farming and high nature value farmland (rich biodiversity);
- at least 3 per cent of agricultural land should be set aside as ecological compensation areas to halt the loss of bird populations by providing non-cropped habitats and maintain links between zones between lands such as Natura 2000;
- crops and crop mixes should be chosen for optimum environmental benefits;
- a higher share of biomass coming from perennial sources, including grassland and short rotation coppice;
- certain types of land, e.g. olive groves and permanent grassland, shall not be converted to arable energy crops;
- improvements are required in the technology used to convert biomass to energy;
- biomass crops should not require irrigation or intensive use of pesticides or fertilisers;
- crops should be planted to increase farmland diversity and avoid monoculture (EEA, 2007).

In a recent report by Rowe et al.(Rowe et al., 2009) short rotation coppice crops for biofuel (e.g. willow and poplar) have the potential to increase biodiversity, however not as efficiently as natural woodland or grassland. It further needs carefully planned planting density and location, and the introduction of plants that are preferred by nesting bird could help to maximise the benefits (Rowe et al., 2009).

Under conditions where the bioenergy is produced in a sustainable way, the use and production may be the most important tool to handle today's energy and environmental problems (Hillring et al., 2007; Steenblick et al., 2007). However, measures to ensure sustainability of bioenergy will be needed. Such measures include matching of crops with local conditions, good agricultural management practises and development of local markets that provide the energy poor with modern energy services (Achim Stiener in (Steenblick et al., 2007)) or as Carol Werner (Executive director, The Environmental and Energy Study Institute, Washington, D.C., February 7, 2008), concludes in the Testimony, U.S. Senate, Committee on Energy and Natural Resources: "*I feel that it is important to stress that renewable fuels are one piece of the solution to transportation emission, but no a complete solution. Renewable fuels will be ONE part of a larger strategy, but so will increase vehicle fuel efficiency, expanded public transport, and "smart growth" practices /enabling more transit, biking and walking). … There already is a backlash against substantial increased production of renewable fuels. Concerns over the fuel vs. food debate and ecosystem degradation would be bolstered if the United States were to try to replace 140 billion gallons of gasoline and 9 billion gallons of diesel used annually. Instead, a vision of integrated low-carbon sustainable renewable production must be combined with other technologies to reduce the amount of transportation fuel needed for a long term solution on climate change*."

7.3 By- and rest-products – Environmental impacts

According to the energy producers interviewed in this study (Eriksson, 2008; Johansson, 2008; Sandstedt, 2008; Ådal, 2008) there should be no problems connected using contaminated land for bioenergy production. For example, no regulations should be needed for crops grown on land, contaminated with only non persistent organic compounds, since these compounds are either degraded prior uptake in the crop or converted to less harmful substances in the biofuel production process.

Biofuel cultivation on metal contaminated land should in principle not cause any health or environmental problems (Ribbing, 2008). There are at present no evident restrictions and in worst case the ash has to be treated as hazardous waste instead of reused. It is, however, much cheaper if it can be used as forest fertiliser. However, the alternative, excavation and landfilling, is not cheaper (Ribbing, 2008).

There are both environmental risk and benefits using the ash as fertiliser. For example, the use of wood ash as fertiliser can introduce high levels of toxic trace elements to the forest surface soil. Though, under some conditions there are environmental benefits using ash on anthropogenic acidified land, such as Southwest of Sweden, since the alkaline ash reduces the acidification of the soil (Skogsstyrelsen, 2007).

At present other potential utilisation of metals in the ash, such as metal enrichment, is being discussed (e.g. (Karlfeldt, 2006)). It may also be possible to fractionate the heavy metals into certain ash fractions or to bind the metals in the ash (Reimann et al., 2008). However, both the net environmental and economical costs can be high. Investigations must be performed to assess the environmental impacts.

In a similar way as ash, sludge or other by- and rest-products may also either by reused on site, elsewhere, or treated as hazardous waste.

According to the interviews performed within this project, the major barriers for cultivation on metal contaminated land are the uncertainties related to the handling of these by-, and rest-products (Eriksson, 2008; Johansson, 2008; Sandstedt, 2008; Ådal, 2008).

At present, the economical biomass value is higher for energy use, than for the pulp and paper value. Sawdust is today used for pellet production, rather than particle board production. In addition, wood that has started rotten, (including storm wood), is nowadays used for energy production (Ribbing, 2008).

The total environmental impact of biofuel cultivation on contaminated land depends on the handling of by and rest-products, as well as on the full cultivation chain. The environmental impacts are site specific and depend on:
the site conditions;

- the crop and its fate after harvest;
- the type of facility used in the transformation from crop to fuel or other materials.

The full chain is important in the risk- and environmental assessments and consequently must be included to achieve a robust basis for decision. Within the Rejuvenate project, one of the major results is a decision support tool for such a complete assessment. The decision framework is described in Bardos et al. (Bardos et al., 2009 (in prep)). Moreover, for sustainable solutions there must be economical and social benefits. These aspects are also included in the decision framework by Bardos et al. (2009).

8 SOCIAL AND ECONOMICAL ASPECTS

Regional environmental, social and economical aspects are of importance for a local and regional sustainable development. This includes the ability for industry and other enterprises to survive in the region. For all companies their good will, which depends on the general opinion, is of importance (Eriksson, 2008; Hägglund, 2008). Among the public the awareness, ethical aspects and social aspects in a global perspective are becoming more and more important and thus must be regarded as important also for the company. According to the larger energy producers interviewed in this project, i.e. Göteborg Energi and Preem, the use of contaminated land for the crop production is of no concern as long as the ethical and other general demands are fulfilled (Eriksson, 2008; Hägglund, 2008) .

In this chapter some general social and economical aspects of bioenergy are discussed.

8.1 Sweden

Among the regional aspects is a well working market. Sweden has a fully commercial biofuel market. In 2005, Sweden's total supply of biofuels amounted to approx. 112 TWh. Most of these fuels are produced domestically and include:

- ligneous fuels (wood, bark, chips and wood from short rotation forestry),
- spent liquor (by-products of chemical pulp production),
- peat,
- waste (industrial waste, refuse, etc.)
- and a smaller quantity of agricultural raw materials.

These fuels are mainly used within the forestry industry for heat (district heating and small houses) and to produce electricity.

Part of the bioenergy production in Sweden is from mixed household waste and forestry rest products from other European countries, especially Germany and Netherlands (Formas, 2007). Some Swedish cities, such as Linköping and Göteborg, supply all their habitants by heat energy produced from waste. In Linköping also biogas is produced. In Göteborg such a facility is about to start (Sandstedt, 2008). There is an increase of waste as energy resource, and as Kaj Andersson from the sustainability office of the City of Göteborg says: Waste is to become hard currency as the prices of fossil fuel and other raw materials are increasing (Kennedy, 2008). Kaj also points out that the waste produced in Göteborg not will cover all energy needed. Together with other, yet regarded as alternative energy sources, such as wind, it can compensate the today's use of fossil fuel.

Using bioenergy as a backup, or supplemental energy source, can help companies reduce losses due to power outages and/or fuel disruptions. In Finland and Sweden, most of the process energy in chemical pulp mills comes from recovered pulping liquor, and sawmill and wood material industries have become fully energy self-sufficient mainly through the use of bark and sawdust. In both countries, the surplus wood from these industries fuels pulp mills, district heating plants, and even service industries and households (using wood pellets from upgraded sawdust) (Ericsson et al., 2004; Steenblick et al., 2007).

In Sweden, as well as in the rest of EU, and globally, the transport sector is considered to be one of the most difficult to manage regarding greenhouse gas emissions. In particular, emissions from road traffic account to 21% of the total CO_2-equivalents in the EU, and this figure is expected to increase. The Swedish government recently declared its intention to phase out fossil fuels in the transport sector by 2020. To achieve this goal, it will be necessary to improve energy efficiency and to design and implement feasible strategies for transition to renewable fuels

The increased and increasing demand of bioenergy is a driving force to find new land for energy production. For example the large energy producers such as Preem and Göteborg Energi are interested in all raw material products independent of land grown on (Eriksson, 2008; Sandstedt, 2008; Ådal, 2008).

8.2 The bioenergy chain

To create and maintain the bioenergy value chain, all players must operate in synchrony to deliver the product. This can be a challenge when new industries are developing and when costs, benefits and interests of actors within the chain differ. Thus, parallel support for the whole value chain must be considered. This challenge will increase as the numbers of actors increase. In general, large-scale, vertically integrated operations have logistical and economy-of-scale advantages. But in many, especially developing countries, industry is characterised by Small Middle Size Enterprises (SME). There are, however, numerous examples of successful co-operative structures, where several independent SME biomass producers work together to supply larger facilities or markets. The development benefits of bioenergy are enhanced dramatically when more people own more of the value-added chain (Steenblick et al., 2007). A general conclusion given by UN (Steenblick et al., 2007) is that regardless the scale of the production, the more involved farmers are in the processing, and use of biofuels, the more likely they are to share the benefits." (Steenblick et al., 2007)

Forestry-based bioenergy, such as the derived from wood pellets and wood chips, can create new opportunities for SME. In general, forest products and perennials will play an important role in the future of bioenergy (Steenblick et al., 2007).

The expansion of liquid biofuel production could affect food security at the household, national and global levels. The effects may be positive or negative, depending on the situation. For instance, whether a country or household is a net buyer or seller of energy services and food products will fundamentally influence whether biofuels will be beneficial or detrimental to their welfare. Considerations will vary depending on the type of fuel, country specific policies, setting (urban or rural), farming system, and food security context. To an extent, the food security risks associated with biofuels are the mirror image of the opportunities (Steenblick et al., 2007). As second-generation technologies based on lignocellulosic feedstock become commercially viable, this will lessen the possible negative effects of land and resource competition on food availability (Bülow et al., 2007; Steenblick et al., 2007).

8.3 Global

One of the perceived needs in industrial countries and the EU is to maintain indigenous food production capacity (food security), along with the benefits of environmental services that are derived by land management, for example soil and watershed protection, biodiversity management, visual amenity have prompted many western governments to subsidise indigenous farming and forestry activities (Steenblick et al., 2007). Although such subsidies have become increasingly controversial, the subsidised land management remains likely for the foreseeable future (Steenblick et al., 2007).

At the global level, the UN Food and Agricultural Organisation (FAO) have predicted that biofuels may provide 25% of the world's energy needs over the next 15 to 20 years (Steenblick et al., 2007). A potentially significant benefit of a new sustainable biofuels market in the EU, from which developing countries could stand to benefit, could be that it would help to create economic conditions which would assist in securing international sustainability standards for agricultural products more widely (House of Commons, 2007).

Biofuel may be the most important tool to solve the energy- and the environmental problems of the 21st century, presupposed that the fuel is sustainably produced and transported (Hillring et al., 2007; Steenblick et al., 2007). However, already today there are severe signs of potential non sustainable production systems. For example, biofuels have forced global food process by up to 75% according to a study by the Internal World Bank (Chakrabortty, 2008). According to the Word Bank study rapid income growth in developing countries such as China and India has not lead to large increases in global grain consumption and was not a major factor responsible for the large price increase and even successive draughts in Australia have had marginal impacts. Instead, the study argues, that the EU and US drive for biofuels has had by far the biggest impact on food supply and process. “Without the increase in biofuels, global wheat and corn stocks would not have declined appreciable and price increases due to other factors would have been more moderate” (Chakrabortty, 2008). The study argues that production of biofuels has distorted food markets in thee main ways. First, it has diverted grain away from food for fuel, with over a third of US corn now used to produce ethanol and about half of vegetable oils in EU going towards the production of biodiesel. Second, farmers have been encouraged to set land aside for biofuel production. Third, it has sparked financial speculation in grains, driving process higher up (Chakrabortty, 2008). According to the Guardian (Chakrabortty, 2008) biofuels derived from sugarcane, which Brazil specialises in, have not had such a dramatic impact on the prizes.

The picture is complex; there is a need to reduce green house gas emissions, but sustainable (economically, socially and environmentally) solutions are needed. Liquid biofuel growth has already begun to raise the prices of corn and sugar, the worlds leading agricultural feedstock. The ability of various bioenergy types to reduce greenhouse gas emissions varies widely, and where forests are cleared to make way for new energy crops, the emissions can even be higher than those for fossil fuels (Steenblick et al., 2007). According to UN (Steenblick et al., 2007) new policies have to be enacted in order to protect threatened lands, secure socially acceptable land use and steer bioenergy development in a sustainable direction. If such actions are omitted, the environmental and social damage could in some cases outweigh the benefits” (Steenblick et al., 2007).

However, successful bioenergy industries bring significant job-creation potential, with positions that include highly skilled science, engineering, and business related employments; medium-level technical staff; low-skill industrial plant jobs; and unskilled agricultural labour. Because the vast majority of bioenergy employment occurs in farming, transportation and processing most of these jobs would be created in rural communities where underemployment is a common problem. The construction and operation of these facilities generates additional rural economic activity, since the weight and volume of most biomass crops usually makes it necessary to locate collection and conversion facilities close to where feedstock is grown.

Jobs are being created in bioenergy agro-industries in rich and poor countries alike. In some cases, however, large –scale, mechanised farming may display worker and poor labour conditions are associated with some large-scale-agricultural plantations. The shift to biomass production for bioenergy will make it necessary to address these issues. (Steenblick et al., 2007)

While strong agricultural economies are prerequisites to a strong biofuels industry, the bioenergy sector could benefit from efforts that take its specificities into account (Steenblick et al., 2007). A few international initiatives are already seeking to realise such benefits such as the International Bioenergy Partnership (IBEP[7]), the Global Bioenergy Partnership (GBEP[8]), the BioFuels Initiative of UNCTAD[9] and the Global Village Energy Partnership (GVEP)[10]."

8.4 Environmental, social and economical consequences of other vegetable non food products

There are arguments that both fossil oil and non-food crops should be used for other purposes than energy production, such as plastics, packing-, interior fitting-, building-, fibre- and other materials. Industrial biotechnology already has much to offer. Recent advances in fermentation technology have lead to increased productivity and yields and the industry expects further substantial progress by using genetically modified microorganisms, for example the plants them selves may be the future factories. With biotechnology advances in the future, the researchers suggest that worldwide CO_2 savings in the range of 500–1000 million ton per year are possible (Bülow et al., 2007; Hermann et al., 2007). At present 15% of the vegetable oil production is used for industrial purposes rather than energy. Also, there is at present research, development and improvements of plants of interest for industrial use in addition to vegetable oils. Sugar for example, can in addition to being fermented to ethanol also be fermented or other products such as lactates and propanediols useful raw materials for plastic industry. The sugar produced both from sugar cane as in Brazil or sugar beets, one of the plants most efficient transforming solar energy to sugar by photosynthesis, as in Sweden can be used (Bülow et al., 2007).

Bioplastic

Polylactic-acid-based plastics (PLA) is considered a promising natural alternative to petroleum-based thermoplastics like polypropylene because PLA has comparable tensile strength and other mechanical properties, but is biodegradable. PLA composites range from nondurable goods such as water bottles, cups and packaging, to lightweight indoor-construction materials such as wallboard, tabletops and pressed furniture.
PLA still is costlier because of the complex processes required to derive it from fermented corn sugars, but there is an ongoing development towards less costly production. For example

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[8] GBEP has the mandate of facilitating a global political forum to promote, marketing, and use of green fuels, with particular focus on developing countries.

[9] The BioFuels Initiative of UNCTAD aims to provide access to sound economic and trade policy analysis, capacity building activities, consensus-building tools, and assessments of the potential individual developing countries to engage in the emerging biofuels market

[10] the Global Village Energy Partnership (GVEP) supports and help developing countries set up energy action plans and assisting with the associated studies and demand analyses. It has also started to provide financial support, capacity building, and technical assistance to energy SMEs in developing countries

the ARS National Center for Agricultural Utilization Research (NCAUR) in USA is working on a project to convert sugar beet pulp into a specialized filler material for PLA.

In Sweden the sugar beet offers large opportunities. The sugar production is 50 ton per hectare (Bülow et al., 2007). There is at present a high demand and ongoing development towards larger harvests and more cold and dry resistant sugar beets. There is ongoing development and research towards more efficient production of plastics from the sugar beets.

The amount of energy for the whole chain production of bioplastics compared to traditional fossil oil based production is not yet clarified, and it also depends on which plastic. One advantage is that also plastics with the same properties as can be produced by fossil fuel, can be produced by vegetation and within the plant it self (Bülow et al., 2007).

Wood houses

There are in total less green house gas emissions from houses made of wood compared to concrete when the wood rest products are used for heat instead of fossil fuel according to a study of a house in Växjö, built in 1994 after the reallowance of building wooded framework buildings in Sweden 1994 (Gustavsson, 2007). The multifamily house has four levels and a total living area of 1 190 m2. A similar concrete framework house was analysed based on estimated project designing and costs. Both houses give the same service for the people accommodated and they have the same energy consumption while in use. The difference between the houses is the framework material and the subsequent differences such as sound insulation. That the base is wood does not mean the house only being wood and vice verse, for example the ground is also in this house made of concrete and the concrete house doors may be of wood. The house with wooden framework results in less green house gas emissions due to four reasons: *i)* the wood production demands less energy than concrete production, *ii)* rest products from the wood production can be used for energy production, *iii)* carbon is stored in the wood acting as a carbon sink iv) cement production emits carbon dioxide. The estimated cost is lower for the wood based than the concrete based house (Gustavsson, 2007).

Hemp

Hemp (*Cannabis sativa L.*) is an annual herbaceous crop which depending on its handling and its agro-ecological aspects can supply up to 12 ton of dry matter and 2 ton of seed per hectare (Lloveras et al., 2006)(González-Garcia et al., 2006). Hemp has many advantages such as weeds suppresser, crop free from diseases, improving soil structure and no pesticide consumption which makes it useful for fibre production and hemp grown for paper pulp is one of the highest yielding and least intensive crops to cultivate (González-Garcia et al., 2006).The main problem with hemp is the alternative potential use as a drug and the related health and social aspects and the complexity regarding regulations that can be related to growth of hemp also for other purposes.

9 OPPORTUNITIES AND BARRIERS IN SWEDEN

9.1 Based on literature review

A general barrier in Sweden is that excavation is the most commonly applied remedial solution (e.g. (Örberg). Today there are few alternative solutions available in Sweden, which results in high price levels and few opportunities to select techniques with respect to least negative environmental impact. Whereas alternative remediation techniques are developed in other countries, the application is limited in Sweden in contrast to for example the Netherlands (Örberg). One of the major differences between Sweden and the Netherlands is that in general in the Netherlands a wider range of different remediation techniques are available and tested which also results in more good examples. A stopper for using, for example in situ methods, is that using the Swedish practice and regulations it is hard to estimate when the remediation goal is reached. Furthermore, in situ remediation demands long term monitoring programs, which are being avoided as far as possible in public funded projects in Sweden. The main reason for this is probably that the grants being allotted on yearly basis (Örberg). Also in private funding remediation projects in general long –term monitoring programs are avoided, mainly because most of those are performed in exploit areas, since there is a high exploit demand and excavation often is a natural part of the building planning e.g. underground parking etc. (Andersson-Sköld et al., 2006).

One of the main reasons why phyto remediation not is used is due to the way the sites chosen for remediation are prioritised (Andersson et al., 2007; Örberg). The areas of highest priority for remediation are in class 1 and 2, i.e. the sites with very high contaminant concentrations. At those sites there is a high risk of phyto toxicity, where the method would not work and if working at all, the time for remediation would be very long and in addition only these sites are considered for governmental funding (Swedish EPA in (Andersson et al., 2007)). In exploiting areas, in general faster remediation is needed or requested. Consequently the areas where phyto remediation could be used are not of high priority for remediation neither by regional or national authorities or private investors. The areas where phyto remediation could be used are remote and not highly contaminated and the remediation time span is long.

Another limiting factor in Sweden for phyto remediation is that often only one remediation method is used for a full site. This limits the use of phyto remediation also at the sites of high priority to a higher degree than necessary. In Netherlands, for example, several different approaches are applied within the same site due to the differentiation of the pollution (Örberg). Experience from the Netherlands show that an integrated or combined remediation approach is often more efficient than using one single technique. In Netherlands different techniques are combined for remediation of for example hot spot, source and plume areas and also a combination of excavation and in-situ and active and passive techniques are applied. In addition monitoring is a crucial art of the remediation work in the Netherlands (Örberg).

Applying such differentiated remediation also in Sweden would offer large opportunities and land areas available for phyto remediation and stabilisation to be used as bio fuel. The planting could both be in the less polluted parts of the contamination site. Monitoring would be needed, but to a less degree than a full site in situ remediation. This more differentiated remediation would consequently allow phyto remediation as part of the solution also on priority areas and for green areas in cities.

Another stopper is that the environmental code ((SFS 1998:808), MB 13, 12 §) demands authorisation for planting gene modified organisms and there are restrictions regarding transport and plantation of gene modified plants (SFS 2007:273).

9.2 Based on interviews

Within this project interviews were performed with stakeholders to find barriers and potentials and advantages of biofuel, and other non food crop, cultivation on marginal contaminated land. Below the results from these interviews are presented. In section 9.2.1 the land owners perspectives are presented. Among those, the cultivation on contaminated land is regarded as a remediation methodology and can involve phyto extraction, but could in principle also be control. In section 9.2.2. the energy producers perspectives are presented.

9.2.1 Land owners

Barriers for phyto-remediation

The most pronounced barrier for phyto-remediation is the lack of good examples. The remediation project of the former oil depot in Karlstad (described in section 3.4.1.), may, however, become a door opener and similar projects are very likely to take place in Sweden in the future (Hägglund, 2008).

Advantages of phyto-remediation

Phyto remediation is very cost efficient compared to other conventional remediation techniques (Hägglund, 2008; Åkesson, 2008).

Phyto-remediation offers a cost efficient environmental benefit and can also contribute to esthetical values (as was seen in the Malmö oil harbour project, described in section 3.4.1.3, where a poplar alley was designed and constructed to create a barrier prohibiting spreading of oil contaminants from the soil to the sea) (Åkesson, 2008).

9.2.2 Bioenergy producers

Barriers for bioenergy production on contaminated land

The word remediation would make the by- or co-products, especially if mixed with fertilisers, unattractive on the market. Consequently, the word remediation must be avoided in relation to the produced products. This can be solved using some other, still honest and relevant, term for the products. The exact term needs to be thoroughly decided prior use (Johansson, 2008).

There is a lack of knowledge regarding which type of crops can be technically and cost efficient handled (e.g. straw and Salix have high content of chlorine and thereby causes corrosion. Today very few Swedish energy plants exists that can handle such crop. In Denmark, on the contrary, both small and larger plants can handle straw) (Sandstedt, 2008).

One stopper is that the technique in use is governed by tradition and moreover, is most often fuel specific, i.e. the energy plants are in general developed for just one type of raw material. To adapt to a larger variety of raw materials further development and investments have to be demanded (Sandstedt, 2008).

The limitation at smaller plants is that the costs related to develop the plant to be able to efficiently separate the fertiliser for various uses, i.e. landfill, forest and agricultural reuses, are at least today far too high. Future market and demands may, however, alter this situation (Johansson, 2008).

There is a lack of knowledge regarding the emissions that may be created in the combustion process of contaminated plant- and wood-material. Examples to be regarded are which species are emitted to air, which products are formed in the ash and can the air emissions be treated with a scrubber etc. Those aspects can be clarified including the uptake of various crops, known facts about the combustion rests and emissions, under different conditions. The achieved knowledge in such a review thereafter must be related to regulations, guideline values and the political views of today, e.g. is it allowed to mix the ash, is there a wish to mix the ash or the fuels, is it more political correct to dig and dump, is it more political correct to re-use, etc. Other useful information would include available steering tools such as taxes etc. to reach the political goals within the organisation, examples of plants and techniques available to reach those goals. The political demands are both internal, i.e., within the organisation, but to a higher extent external, i.e. the customers and legislative demands on the organisation and its activities (Sandstedt, 2008).

Landfill is expensive, i.e. any costs such as taxes, or other charges related to the by- or rest-products is a stopper. To what extent it is a stopper, depends on the cost and available reuse possibilities (Sandstedt, 2008). Solutions for re-use at the site or as fertiliser in parks and other green areas, agricultural or forest, or other ways to treat (e.g. metal enrichment, landfill) rest-products such as sludge and ash has to be found (Eriksson, 2008).

Directives, regulations and guidelines regarding the classification of by- and rest-products, such as ash and fertiliser product, are regarded, as a limitation for plant development towards use of biomass from contaminated land as raw material in the production. At present, there is a debate concerning how ashes from different combustion plants can be utilized as construction materials or other recovery. This means uncertainties regarding how to utilize ashes and other waste products. To minimise this barrier the regulations must be clear. If the regulations are clear, even with low guideline values, future plant development would be considered. Under todays conditions, the regulations are unclear and therefore such investments are not seriously considered (Eriksson, 2008; Johansson, 2008; Ribbing, 2008; Ådal, 2008). Contaminated land is a complex branch regarding liability and responsibilities. The energy producers want to avoid risks for disputes and legal cases (Ådal, 2008).

Opportunities for bioenergy production

Any increase in available raw material with high gas potential such as sugar beet, corn, clover and Lucerne is very positive for a smaller biogas plant (Johansson, 2008). Larger Swedish energy producers such as Göteborg Energi and Preem are in principle interested in all raw material and neither of the organisations have any demands on the land where it comes from (Eriksson, 2008; Sandstedt, 2008; Ådal, 2008).

The investment costs related to use of bio based raw material with high gas potential in addition to today’s use of agricultural waste is not regarded as a development barrier. The market demands are steadily increasing (Johansson, 2008).

The site areal and the produced amount of biofuel can be of any size. There are no limitations, neither upwards or downwards, i.e. the fuel is wanted wherever it origins from on the condition that it does not have any impact on the operation of the plant. However, the area of the site is of course relevant to the site owner, in view of the fact that the investment must be realistic in relation to the area. For bio cultivation the site need to be both of an appropriate sizeand nearby customer if to be used for energy production. If, the cultivation is done only for remediation or control, the size is less limiting (see for example section 3.4.1 and (Suer et al., 2009c)).

Ethical demands really favour the use of contaminated land for the production of the biomass according to all stakeholders interviewed (Eriksson, 2008; Hägglund, 2008; Sandstedt, 2008; Ådal, 2008)(Åkesson, 2008)

The organic raw materials presently used by larger energy plants in Sweden, are municipal waste, wood chips and pellets. The wood chips and pellets are from Sweden or imported from Canada. Today there is a request, however, to find more nearby produced raw material and thus also biomass grown on contaminated land is interesting. Furthermore, Göteborg Energi, can see a potential in, and may initiate, crop (i.e. raw material) production and one can consider such production on contaminated land (Ådal, 2008).

Landfilling is expensive. Therefore, if the biomaterial, can be mixed with less contaminated material prior the fuel is produced, and thereby fulfils the regulations as forest fertiliser, such fuel is very useful (Sandstedt, 2008).

Of interest are also other solutions, where the by- and rest-products treatment is not related to any costs. For example crops with high contaminants are potentially interesting for use as material for metal enrichment (Ribbing, 2008; Sandstedt, 2008; Ådal, 2008).

Potential triggers, but also potential stoppers, are non governmental organisations NGOs. The Swedish Society for Nature Conservation (Naturskyddsföreningen) is pro biofuel, but their opinion on use of contaminated land for the production is not yet known. It will be of importance what their views are, i.e. whether they regard biofuel production on contaminated land as a threat, or express any other negative attitude, or if the they will regard it as a resource.

10 CONCLUSIONS ABOUT TRIGGERS AND STOPPERS

10.1 Triggers

Demand of renewable energy sources

To achieve EU directive goals (existing and future) all available land for biofuel production will be needed. The directive goals favour both climate objectives and to become independent of crude oil from outside EU. The fuel demand in Europe is so large that any land area used for crop production will be of interest.

Well working market and infrastructure for biofuels in Sweden

In Sweden the use of biomass, especially for energy production, is relatively well developed and there is an existing market and infrastructure system which makes it easy for new raw material producers to utilise it.

Sustainable solution

From a broad environmental perspective the use of contaminated land for biofuel production can be regarded as a sustainable solution, as the production *i)* does not compete with food production, *ii)* reduces the fossil fuel use and *iii)* stabilises or remediate the contaminated land.

Cheap

The costs are among the interviewed stakeholders regarded as low, both for phyto remediation and biofuel raw material cultivation. In addition, the cost for a combination of phyto remediation with biomass based production of fuel or other products, is regarded as very low among the interviewed stakeholders.

Goodwill

In general, the use of biofuel from contaminated land is regarded as environmentally beneficial. The environmentally negative impacts, all on a local to global scale are low, especially for a second generation biofuel. This is also in agreement with the carbon footprint investigation and life cycle assessment performed in this project (Suer et al., 2009c).

10.2 Stoppers

Remediation priorities

One of the main reasons why hardly any phyto remediation is used in Sweden is that the areas of highest priority for remediation are sites with very high contaminant concentrations. Such sites are in urgent need of remediation and the contamination level is high, and thus there is risk of phyto toxicity. In general, only such highly contaminated sites are considered for governmental funding (Andersson et al., 2007; Örberg).

Due to the time perspective, in areas of exploitation interests, i.e. non marginal land areas, other faster solutions than phyto remediation are prioritized.

Lack of good examples

The knowledge about phyto remediation methods and projects in Sweden are rare, and the results from the phyto remediation projects are not yet fully available. Consequently, there are no good examples showing the benefits, costs and timescales.

Legislation
The present legislation and praxis is based on total concentrations left in the soil and not based on soil functionality or RBLM.

Restrictions on rest-, co- or by-products
The most important “stopper” to be solved regarding biofuel from waste and contaminated land is the handling, i.e. regulations, of rest-, by- and co-products such as sludge and ashes.

Biofuel technology
Many technical challenges remain including the development of better and cheaper catalysts, improvements in current technology for producing high quality biodiesel, use of non-fossil based solvents, conversion of the by-products to useful products.

Investment cost
Here only the investment costs of biofuel plants have been considered. The investment costs are stoppers, but the biofuel demand may be high enough to reduce this barrier. Not included in this study, are the site owners view on investment costs for biofuel production. In general for biofuel production nearby customers and the site area is crucial (see (Suer et al., 2009c)).

Knowledge
Despite regulations, it would be of great help to have a rough knowledge about the fate of the contaminants. This includes the fate of the contaminant in the soil under various climatological and geological conditions for various plants. Additionally, knowledge about the uptake, deposit and concentrations of contaminants in the plants is needed. Furthermore, a review of what happens with the contaminants in the combustion process and which methods to use to trap the contaminants (filters, scrubbers etc.) is needed, together with information on the occurrence of different contaminants and their concentrations in different rest-, by- or co-products. This knowledge would be of great importance for further development of strategies, regulations, guidelines and in decisions taken about the potential for biofuel grown on contaminated soil.

The interviewed stakeholders express that one barrier is the economic uncertainties related to how to handle contaminated waste or by-products such as sludge and ashes. Economically suitable solutions would solve this problem. For example, a demand for cheap products for use in constructions etc. would be of economical interest. Ongoing research, together with an increased awareness of more sustainable reuse of products and waste products may increase the demands for such production, which also has to be implemented as acceptable use and production routes.

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Appendix 1

Arable area of potential contaminated sites in Sweden

Anja Enell, Ola Wik, Yvonne Andersson-Sköld

Introduction

In Sweden, like all other countries in Europe, areas of land have been degraded by past use. Such previously developed land includes areas affected by mining, fallout from industrial processes such as smelting, areas elevated with contaminated dredged sediments, former landfill sites and many other areas where the decline of industrial activity has left a legacy of degraded land and communities. The extent of contamination may not be sufficient to trigger remediation under current regulatory conditions, and there may be little economic incentive to regenerate the areas affected.

In Sweden the priority has tended to be on "intensive" approaches to sites in urban regions, and other degraded land has tended to be left alone. The amount of land remaining degraded over the long term remains a matter of concern as the degradation remains a blight on local populations, and there are strong quality of life, social and political arguments for some form of action.

An ideal solution would be a land management approach that is able to pay for itself. Biomass from coppice or other plantations has long been seen as a possible means of achieving this goal. Besides phyto-remediation approaches, risk management approaches linked to containment and stabilisation have begun to be seen as new options. There is also increasing interest in the management of risks from an ecological perspective. In addition, a wider range of non-food crop options are increasingly feasible including bio-diesel (oil seed rape), bioethanol (straw, wood, grains) and fibre crops (e.g. hemp, flax) as well as higher value "bio-feedstocks". The combination of a wider range of risk management approaches with the emerging broad range of non-food uses of land offers great potential for low (or no) cost risk based land management that is stable and sustainable.

In this study, a first attempt to assess the arable area of contaminated land in Sweden was made. The aim of the study was to assess the maximum arable area of the potential contaminated sites in Sweden. In this context, arable area is defined as an area that can be used for growing biomass (e.g. for production of biofuels) or that can be phyto-remediated or contained and stabilized through a plantation.

Methodology

The assessment of the arable area was mainly based on data collected from the Swedish data base MIFO. In order to enable for consistent and accurate assessments of contaminated sites in Sweden, the Swedish Environmental Protection Agency (Swedish EPA) has developed a methodology of surveying contaminated sites; MIFO (*In Swedish: Metodik för Inventering av Förorenade Områden*). The methodology is divided in to two phases; 1) orientation studies and 2) general surveys. In the first phase, data is collected using available information from maps and archives combined with impressions gained from site visits and interviews. The second phase consists of an on-site recognisance with sampling at strategically selected points. Further description of the model can be found in the report by Swedish EPA (1999).

Nomenclature

In the MIFO-methodology for the inventory, the contaminated sites are divided into different branches. A *branch* describes the type of activity that has been ongoing on the site (e.g. gas station, dry cleaning, sawmills etc.). In total there are 82 different branches in MIFO.

Contaminated sites refers to any land fill, land, groundwater or sediment showing concentrations of pollutants that are significantly elevated above background levels, due to local emissions. A contaminated site is referred to as an *object* in the data bases of MIFO.

Assessed mean areas

The inventory work is conducted by local and regional authorities. All collected data are complied in regional data bases. The compiled data in the regional data bases are once a year reported to the Swedish EPA, who evaluate and fuse the data into a national progress report. At the time of this study a national database, including all inventory data, does not exist, however, such a data base are under development.

Sweden comprises 21 counties, which are in turn divided into municipal areas. All 21 County Administrative Boards have there own MIFO-database and in some counties the municipal authorities also contributes to the inventory with own databases. Since it would be too time-consuming to go through all these databases, the MIFO-data base of The County Administrative Board of Skåne was chosen to serve as a general model for the assessment of mean areas of the different branches (MIFO, 2008).

Five objects (=five contaminated sites), within each branch, were randomly selected from the MIFO database of The County Administrative Board of Skåne. For each object the following data was collected:

1. The area of the site (*in Swedish: fastighetens area*)
2. The use of land on the site (*in Swedish: markanvänding på objektet*)
3. The use of land in close conjunction to the site (*in Swedish: markanvändning inom påverkansområdet)*

The mean area of each branch was then calculated:

$$BMA = \frac{\sum_{1}^{n} Site\ Area}{n} \qquad (1)$$

BMA = Branch Mean Area
n = numbers of objects

In addition the relative standard deviation of each determined mean value was also calculated. For branches that had less than five registered objects, all inventoried objects were used. For these branches the mean area was assessed from the available information (i.e. n=<5). In addition, 16 branches did not contain any inventoried objects at all. The mean area of these branches has been estimated through interviews with persons well experienced with the method of surveying contaminated sites (Svensson, 2008).

To take into consideration how the use of the land, at objects within a specific branch, may affect the potential of cultivation of that land, a ”mean arable site factor”, k_{site}, was assessed for each branch. For example, a site containing buildings and housings would probable be less fit for cultivation than an industrial site. The assessment of this factor was done based on collected data (under paragraph 2 given above) and on guesses on how arable these objects would be (MIFO, 2008 and Svensson, 2008). For each description of the “use of land” the factor k_{site} was given a value between 0 and 1. Estimated (guessed) values of k_{site} for different “use of land” are given in table 1. In addition, a mean value of k_{site} for each specific branch was calculated (based on the collected data from MIFO).

Moreover, to take into consideration how the potential of cultivation may be affected by the use of land in close conjunction to the site a ”mean arable conjunction factor”, $k_{conjunction}$, was assessed for each branch. This factor is used for taking into account how the potential of cultivation will be affected by the site’s location. The potential of cultivation is probable higher at the countryside than if the site is located in the middle of a city. This factor was assessed based on collected data (under paragraph 3 given above) and on guesses on how arable these sites would be (MIFO, 2008 and Svensson, 2008). For each description of the “use of land in close conjunction to the site” the factor $k_{conjunction}$ was given a value between 0 and 1, and a mean value of $k_{conjunction}$ for each specific branch was then calculated. Estimated (guessed) values of $k_{conjunction}$ for different descriptions of “use of land in close conjunction” are given in table 1.

Table 1. Estimated vales of ”mean arable site factor”, (k_{site}) and ”mean arable conjunction factor”, ($k_{conjunction}$).

The use of land on the site/in close conjunction to the site	k_{site}	$k_{conjunction}$
Urban areas/Buildings/Housings	0.1	0.1
Public garden/area of preserved land/parks	0.1	0.1
Area of recreation or outdoors activities	0.75	0.75
Industrial land	0.5	0.5
Agriculture land	1	1
Forest	1	1
Pasture	1	1
Meadow of shore	1	1
Rail road station	0.1	0.1
Airport	0.01	1
Others	0.3	0.3

The total arable area of a specific branch (*ABA*) was calculated as:

$$ABA = BMA * k_{site} * k_{conjunction} * total\ branch\ objects \qquad (2)$$

ABA = Arable Branch Area
k_{site} = the arable factor of the site (a factor between 0 and 1) (see table 1)
$k_{conjunction}$ = the arable conjunction factor (a factor between 0 and 1) (see table 1)
total branch objects = number of reported objects registered on a branch in the national progress report 2008 (Nilsson, 2008)

The total arable area of Sweden was then assessed through:

$$TAA = \frac{\sum_1^j ABA}{Nbr_{objects}} * TOTNbr_{sites} \qquad (3)$$

TAA = Total Arable Area
j = numbers of branches (=71)

$Nbr_{objects}$ = 40 226
$TOTNbr_{sites}$ = 70 000

The above calculation is based on information from 71 branches (of total 82). 11 of the branches have low priority within the work of MIFO or the inventory should be done by others than the County Administrative Board (e.g. the Swedish military authorities or the Swedish Rail Administration). Due to lack of information about objects within these branches they were excluded from the calculation. In total 40 226 objects were registered on the 71 branches (Nilsson, 2008) and the Swedish EPA has estimated the total number of contaminated sites in Sweden to about 70 000 (Swedish EPA, 2008).

Results and discussion

Example of calculation of BMA

The *BMA* (together with the relative standard deviation, *RDS*) and *ABA* of all 71 branches is given in Table 3. The results of the calculation of the branch "Production of pesticides" is given as an example below (in table 2 and in text):

Table 2. Calculation of branch mean area for the branch "Production of pesticides"

Production of pesticides		
Area of object (m2)	The use of land on the site	The use of land in close conjunction to the site
1530	Buildings/Housings	Urban areas/Buildings
5152	Industrial land	Industrial land
3080	Industrial land	Urban areas
2288	Urban areas/Buildings	Urban areas/Buildings
8040	Urban areas/Buildings	Urban areas/Buildings
BMA (SD)		
4018 ± 2623	n=5	
RSD: 65%		

Calculation of k_{site} and $k_{conjunction}$ for the branch "production of pesticides" using data in table 1 and 2:

$$k_{site} = \frac{(3*0.1+2*0.5)}{5} = 0.26$$

$$k_{conjunction} = \frac{(0.5+4*0.1)}{5} = 0.18$$

The reported number of objects within this branch was 38 at the time of the study (Nilsson, 2008). The arable branch area was then calculated using the above data and Eq. 2:

$$ABA = 4018*0.26 \quad *0.18 \quad *38 = 7146\,\text{m}^2$$

Total arable area

The total arable area of contaminated sites in Sweden was estimated to 778 km^2 (using Eq. 3). This is about 60% of the size of Öland, (an island of the South Swedish east coast) or 0.2% of the size of Sweden. The total area of contaminated sites was estimated to 2936 km^2, which is about the same size as the Swedish county Blekinge or about 0.7% of the size of Sweden. Due to this calculation, the arable area constitutes 26% of the total contaminated area of Sweden. However, it must be noted that this calculation is based on reported areas of the sites, i.e. the area were the plants, industries or other branches have conducted their activities, and not the actual contaminated area of the site. Thus, the calculation is rather an overestimation than an underestimation of arable area of reported contaminated sites, and should thus be seen just as a first attempt to estimate the maximum arable area of contaminated land in Sweden.

Furthermore, it must also be kept in mind that this calculation is based only on 71 branches of in total 82. The 11 excluded branches had all together 2994 reported objects in the progress report of 2008 (Nilsson, 2008). The total sum of reported object was 43220. Thus, at least (may be higher depending on reporting frequency), about 7 % of all reported objects are excluded from our estimation of branch areas, and consequently this may have affected the final result.

Table 3. The BMA (together with the relative standard deviation, RDS) and ABA of all 71 branches (names of branches are only given in Swedish).

Branch	BMA (m2)	RSD (%)	n=	ABA (m2)
Bensinstation	3 401	62	9	1 474 521
Bilskrot	3 136	53	5	1 639 089
Bilvårdsanläggning	2 491	51	5	2 649 256
Elektroteknisk industri	19 351	110	4	436 838
Framställning av bekämpningsmedel	4 018	65	5	7 146
Färgindustri	6 018	127	5	106 398
Förbränningsanläggningar	11 494	31	2	739 639
Garveri	19 942	152	5	426 717
Gasverk	10 040	82	5	88 207
Gjuteri	3 336	68	5	270 568
Glasindustri	83 997	127	2	718 170
Grafisk industr	5 413	74	3	584 345
Gruva/upplag	50 400	91	5	76 522 320
Gummiproduktion	3 987	82	4	220 960
Industrideponi	65 500	74	2	20 521 969
Järn-, stål- och manufaktur	285 455	132	3	50 382 749
Kemtvätt	740	31	5	15 948
Livsmedelsindustri	356 432	135	2	15 290 911
Massa och pappersindustri	436 012	127	4	15 247 340
Oljedepå	21 196	174	5	1 398 962
Plywood-Spånskivetillverkning	133 622	31	2	918 651
Sekundära metallverk	46 818	154	3	176 243
Skjutbana	80 000	35	2	74 070 000
Sågverk	67 398	83	5	51 653 980
Tillverkning av plast- polyuretan	8 834	12	2	208 924
Tillverkning av stenkolstjära eller koks	35 092	115	2	75 799
Tillverkning av tegel och keramik	90 333	74	4	6 492 648
Träimpregnering	27 655	124	5	1 627 740
Varv	35 355	70	5	2 059 429
Verkstadsindustri	60 343	192	5	32 874 794
Ytbehandling av metaller	15 407	139	5	2 626 943
Ytbehandling av trä	10 287	76	5	716 691
Övrig oorganisk kemisk industri	3 765	65	5	57 016
Övrig organisk kemisk industri	6 085	78	5	75 688
Övrigt	17 200	172	5	10 321 940
Bilfragmentering	3000		0	6 000
Ferrolegering	20000		0	12 000
Fiberskivetillverkning	100000		0	487 500
Flygplats	1000000		0	1 440 000
Grafitelektrodindustri	3000		0	750
Kloralkali	240000		0	660 000
Kloratindustri	100000		0	100 000
Olyckor	1000		0	4 230
Sediment	10000		0	102 000
Textilindustrin	20000		0	1 362 000
Tillverkning av trätjära	2000		0	162 000
Tillverkning av tvätt och rengöringsmedel	10000		0	162 000
Avloppsreningsverk	7500		0	2 396 250

Betning av säd	1000	0	436 000
Fotografisk industri	2000	0	3 240
Krematorier	1500	0	8 168
Ackumulatorindustri	26 023	1	35 131
Anläggning för miljöfarligt avfall	216 100	1	32 090 850
Betongindustri	6 060	1	310 575
Brandövningsplats	800	1	44 000
Framställning av bindemedel	13 700	1	23 975
Impregnering	15 000	1	2 550
Läkemedelsindustri	30 000	1	585 000
Mineralullsindustri	584 240	1	1 460 600
Motorbanor	60 000	1	2 976 563
Oljegrus- och asfaltsverk	13 224	1	1 094 286
Oljeraffinaderi	133 000	1	399 000
Plantskola, handelsträdgård	6 210	1	1 633 230
Primära metallverk	1 074 391	1	22 562 211
Sjötrafik-Hamnar	13 183	1	970 928
Tank- och fatrengöring	5 955	1	50 618
Tillverkning av krut- och sprängämnen	69 956	1	1 836 345
Tillverkning av plast-polyester	68 620	1	233 308
Tillverkning av takpapp	11 735	1	2 934
Ytbehandling med lack, färg eller lim	11 000	1	731 500
Tryckeri	2 500	0	7 600
		SUMMA (m2):	447 091 878

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Swedish EPA, 1999. Metodik för inventering av förorenade områden: Bedömningsgrunder för miljökvalitet. Rapport 4918. (in Swedish).

Svensson, 2008. Personal communication with Paul Svensson, the Swedish geotechnical institute (SGI), December 2008.

Appendix 2

Phyto remediation methods, advantages and disadvantages

Yvonne Andersson-Sköld based on information in Andersson and Svensson, 2007.

Table appendix 2. Phyto remediation methods, advantages and disadvantages (based on information given in Andersson and Svensson, 2007)

Method	Convenient plants	Advantages	Disadvantages
Phyto extraction: Contaminants are taken up by the plant material and can be extracted when harvested Convenient for Metals (PCB DDE)	Salix, corn (maize) and poplar are in general regarded as good for deep contaminants. May need to mix different species to complement each other. Known Pb[1]: corn > poplar (highly contaminated, pH ~ 4), opposite less contaminated pH > 4 Sareptamustard+EDTA very efficient Cd[2]: Salix very efficient, there are available techniques to Swedish EPArate Cd from the ash, but most often not used Hg:[3] Salix, wheat, sugar beet, rape, white clover are not efficient Zn, Cu[4]: Salix (optimal pH 4.9)	The biomass from the extraction can be used as a resource (EPA 2000) The amount of biomass to be handled is less than the corresponding amount of soil Combustion of biomass containing metals, produces ash of lower volume than the soil to be handled on landfill	The biomass must be harvested and transported from the site, and metals have to be taken care of Metals can be phyto-toxic for plants It is difficult to move from laboratory to field and remediation (the accumulation probably being less in field than in the laboratory) It can be difficult to find plants with enough translocation of the contaminants
Hyper accumulators[5]	Ni : ~300 species known Co, Cu, Se, Zn ~20 species known	Accumulates high concentrations	Often small plants with short roots: difficult to harvest, do not reach deep contaminants Risk of spreading by lose leaves Risks for animal intake
Phyto "open cast mining"[6]	Zn, Cu, Ni, Co > 20%, in ashes commercially interesting for enrichment, gold > 17 ppm in plant(mass): Serapta mustard+ammonium tio cyanate	Remediation as above and reuse of metals without mining	
Phyto degradation / Phyto transformation: The contaminants are taken up by the plant in where they are degraded or the plant enzymes degrade the contaminants in the root zone. Organic compounds with ability to be taken up by the plant e.g. TNT, MTBE, TCE[7], CN[8]	Plants with large root system and high amount of enzymes able to degrade organic compounds such as poplar 7	Completely independent of microbes and therefore can be used in highly contaminated soils [9]	Potential toxic intermediates (metabolites) Difficult to proof degradation

[1] Komarek et al., 2007
[2] Aronns and perttu, 2000, Perttu et al., 2003, Berndes et al., 2004, Dimitriou and Aronsson, 2005
[3] Wang and Greger, 2004 Greger et al., 2005, Wang and Greger, 2006
[4] Keller, 2006
[5] Brooks 1998 in Rockwood et al., 2001
[6] Kumar et al., 1995, Andersson et al., 1998, Chaney et al., 2000
[7] Burken, 2003, Pilon-Smits 2005)
[8] Ebbs et al., 2006, Larsen och Trapps, 2003(uptake FeCn), Trapp in Andersson and Svensson 2007
[9] EPA 2000

Increased rhizo degradation: The roots changes the soil structure to increase the air conditioning, emit compounds stimulating the microorganism flora and chemical conditions for increased natural attenuation (both chemical and by microbes) in the root zone. Organic compounds not taken up by plants such as BTEX, PAH, chlorinated hydrocarbons,…..9	The roots changes the soil structure to increase the air conditioning, emit compounds stimulating the microorganism flora and chemical conditions for increased natural attenuation (both chemical and by microbes) in the root zone. PAH: Salix > poplar > ash[10]	In situ degradation Low cost, no harvesting No risk of spreading to other sites Can be used on species where K_{ow} are to high to be taken up by plants	The time to develop a large root system The root depth is limited Can not be sure the area always will be more clean than without the plants The microbes may use the root emissions rather than the contaminants as carbon source May need additional fertiliser (both plant and microbes)
Rhizo filtration: Contaminants in water are concentrated in the plant material or precipitate. The compounds can either be used as nutrients or extracted when harvested.[11] Metals, hydrophobic organic compounds and radio nuclides[11]	Salix and poplar very efficient, also tested are sarepta mustard, sun flower, Lemna minor [11, 12]	No need of translocation to buds since the full plant can be harvested The remediation is done in water, thereby the contaminants are more bio available Both terrestrial and aquatic plants can be used More easy to design Good agreement between field and laboratory investigations Reduced:[13] sludge production, amount of precipitation chemicals, energy use, commercial nutrients, transports, leaching of nutrients to recipients	pH may need regulations continuously9 the water flow needs to be controlled[9] the plants may need pre-planting[9] the season and weather may have impacts on the result [9]
Phyto stabilisation: The plants are used to stabilise the contaminated ground by reducing erosion and infiltration. The contaminants can also be precipitated, (thereafter) adsorbed or absorbed in the plant roots or rhizosphere. Can be an option in mining rest sites. Metals (As, Cu, Hg, Zn, Cr, Pb), potential also organic compounds[14]	Poplar, grass[15]	The soil does not need removing Low costs and low ecological disturbances Enhanced ground recovery when the soil is covered by plants No need of landfill	The contaminant still left in the soil The soil may need high amounts of nutrition or other treatments Uptake and translocation in the plant must be avoided The root exudates, nutrients and contaminant level must be controlled to avoid leaching Should be regarded as a temporary solution

[10] Spriggs, 2005
[11] Dushenkov, 1997, Pivetz, 2001, Suthersan, 2002, Prasad and Freitas, 2006,
[12] Carman and Crossman, 2001, Miretksky, 2004, Waldermarson in Andersson and Svensson, 2007
[13] LindoffCommunications 2004, Rosenquist in Andersson and Svensson, 2007
[14] Cunningham, 1995, Salt et al., 1995, Suthersan, 2002
[15] Smith and Bradshaw, 1979, Pierzynski et al., 1994 in Carman and Crossman, 2001

Phyto evaporation: Contaminants are taken up by the plant, transported up in the plant and evaporated to the atmosphere[16] Organic compounds: high water soluble and evaporative (TCE, NDMA, MTBE)[17] Inorganic compounds: As, Se, (Hg)	Poplar, rape, cauliflower, lucern (Medicago sativa)[18]	The contaminants can be transformed to less toxic metabolites (e.g. Hg) The evaporated contaminants can be further degraded in air (e.g. photolysed)	The contaminants, or toxic metabolites (e.g. vinyl chloride from TCE), evaporates to the atmosphere Contaminants or toxic metabolites can be accumulated in the vegetation
Hydraulic control: An (more) up going direction of the ground water due to plant transpiration, reducing the leaching and spreading from the contaminated area. All species easily leached and non phyto toxic levels[19]	Salix and poplar very efficient (high transpiration, deep roots)[19] Grass, high transpiration, landfill cover Example Holte previous gas production (CN, tar, phenols and oil) outside Copenhagen (3 types of poplars), cost 11 M DKr instead of conventional 20 M Dkr.[20]	Trees can, in contrast to conventional pumps, make use of water in low permeable soils Plants root system allow contact with a larger soil volume than conventional pump systems[16] Spreading of contaminants is reduced, despite not being in contact with the root system No need of plant uptake, only need of high transpiration	Relative large area is needed for planting to achieve an effective hydraulic barrier The time needed for deep roots and large biomass to develop Climate, e.g. seasonal variations, influence the effectiveness Fluctuations in groundwater demand plants tolerating roots in saturated soil
Phyto covering: Plants are planted on landfills to stabilise the soil and reduce the infiltration reducing the leaching from the landfill and increasing the rhizo degradation. Most (all) contaminants since no contact plant-contaminant, most convenient organic compounds stimulating natural attenuation	Poplar, Salix and grass[16] (Sweden not allowed > 50l/m^2 penetration[21] demands combining with conventional method)	In contrast to conventional land fill covering, the method does not reduce but increase the natural attenuation process, thereby reducing the gas production[22] Passive gas emission is allowed in contrast to conventional covering[22] Control of landfill cover penetration is not needed Trees and other plants makes habitat for birds and other animals Minimise erosion Cheaper than conventional methods (both remediation and control)[22]	Maintenance and control may be needed[22] Natural succession may result in other plants than planted[22] Surface water may reach the waste[22] Risk for not wanted plant uptake of contaminants[22] The design has to be site specific and adapted to local climate[22] Risk for exposure due to fallen trees (storms etc)[22] Difficult to make use of produced gas[22]

[16] EPA 2000
[17] Burken and Schnoor, 1998, Ma and Burken, 2003, Collins et al., 2006, Yu and Gu, 2006
[18] EPA, 2000, Zayed et al., 2000, Hong et al., 2001
[19] Suthersan, 2002, Schnoor, 2002
[20] Thygesen och Trapp, 2002, Press-Kristensen and Trapp, 2003, Trapp in Andersson and Svensson, 2007

Increased rhizo degradation: The roots luckrar upp, air, emit compounds stimulating the microorganism flora and chemical conditions for increased natural attenuation (both chemical and by microbes) in the root zone. Organic compounds not taken up by plants such as BTEX, PAH, chlorinated hydrocarbons,…..9	The roots luckrar upp, air, emit compounds stimulating the microorganism flora and chemical conditions for increased natural attenuation (both chemical and by microbes) in the root zone. PAH: salix > poplar > ash[23]	In situ degradation Low cost, no harvesting No risk of spreading to other sites Can be used on species where Kow are to high to be taken up by plants	The time to develop a large root system The root depth is limited Can not be sure the area always will be more clean than without the plants The microbes may use the root emissions rather than the contaminants as carbon source May need additional fertiliser (both plant and microbes)
Rhizo filtration: Contaminants in water are concentrated in the plant material or precipitate. The compounds can either be used as nutrients or extracted when harvested.[11] Metals, hydrophobic organic compounds and radio nuclides[24]	Salix and poplar very efficient, also tested are sarepta mustard, sun flower, Lemna minor [11, 25]	No need of translocation to buds since the full plant can be harvested The remediation is done in water, thereby the contaminants are more bio available Both terrestrial and aquatic plants can be used More easy to design Good agreement between field and laboratory investigations Reduced:[26] sludge production, amount of precipitation chemicals, energy use, commercial nutrients, transports, leaching of nutrients to recipients	pH may need regulations continuously9 the water flow needs to be controlled[9] the plants may need pre-planting[9] the season and weather may have impacts on the result [9]

[21] Rihm, 2002
[22] Carman and Crossman, 2001, EPA, 2000
[23] Spriggs, 2005
[24] Dushenkov, 1997, Pivetz, 2001, Suthersan, 2002, Prasad and Freitas, 2006,
[25] Carman and Crossman, 2001, Miretksky, 2004, Waldermarson in Andersson and Svensson, 2007
[26] LindoffCommunications 2004, Rosenqusit in Andersson and Svensson, 2007

Phyto stabilisation: The plants are used to stabilise the contaminated ground by reducing erosion and infiltration. The contaminants can also be precipitated, (thereafter) adsorbed or absorbed in the plant roots or rhizosphere. Can be an option in mining rest sites. Metals (As, Cu, Hg, Zn, Cr, Pb), potential also organic compounds[27]	Poplar, grass[28]	The soil does not need removing Low costs and low ecological disturbances Enhanced ground recovery when the soil is covered by plants No need of landfill	The contaminant still left in the soil The soil may need high amounts of nutrition or other treatments Uptake and translocation in the plant must be avoided The root exudates, nutrients and contaminant level must be controlled to avoid leaching Should be regarded as a temporary solution
Phyto evaporation: Contaminants are taken up by the plant, transported up in the plant and evaporated to the atmosphere[29] Organic compounds: high water soluble and evaporative (TCE, NDMA, MTBE)[30] Inorganic compounds: As, Se, (Hg)	Poplar, rape, cauliflower, lucern (Medicago sativa)[31]	The contaminants can be transformed to less toxic metabolites (e.g. Hg) The evaporated contaminants can be further degraded in air (e.g. photolysed)	The contaminants, or toxic metabolites (e.g. vinyl chloride from TCE), evaporates to the atmosphere Contaminants or toxic metabolites can be accumulated in the vegetation
Hydraulic control: An (more) up going direction of the ground water due to plant transpiration, reducing the leaching and spreading from the contaminated area. All species easily leached and non phyto toxic levels[32]	Salix and poplar very efficient (high transpiration, deep roots)[19] Grass, high transpiration, landfill cover Example Holte previous gas production (CN, tar, phenols and oil) outside Copenhagen (3 types of poplars), cost 11 M DKr instead of conventional 20 M Dkr.[33]	Trees can, in contrast to conventional pumps, make use of water in low permeable soils Plants root system allow contact with a larger soil volume than conventional pump systems[16] Spreading of contaminants is reduced, despite not being in contact with the root system No need of plant uptake, only need of high transpiration	Relative large area is needed for planting to achieve an effective hydraulic barrier The time needed for deep roots and large biomass to develop Climate, e.g. seasonal variations, influence the effectiveness Fluctuations in groundwater demand plants tolerating roots in saturated soil

[27] Cunningham, 1995, Salt et al., 1995, Suthersan, 2002
[28] Smith and Bradshaw, 1979, Pierzynski et al., 1994 in Carman and Crossman, 2001
[29] EPA 2000
[30] Burken and Schnoor, 1998, Ma and Burken, 2003, Collins et al., 2006, Yu and Gu, 2006
[31] EPA, 2000, Zayed et al., 2000, Hong et al., 2001
[32] Suthersan, 2002, Schnoor, 2002
[33] Thygesen och Trapp, 2002, Press-Kristensen and Trapp, 2003, Trapp in Andersson and Svensson, 2007

Phyto covering: Plants are planted on landfills to stabilise the soil and reduce the infiltration reducing the leaching from the landfill and increasing the rhizo degradation. Most (all) contaminants since no contact plant-contaminant, most convenient organic compounds stimulating natural attenuation	Poplar, Salix and grass[16] (Sweden not allowed > 50l/m^2 penetration[34] demands combining with conventional method)	In contrast to conventional land fill covering, the method does not reduce but increase the natural attenuation process, thereby reducing the gas production[35] Passive gas emission is allowed in contrast to conventional covering[22] Control of landfill cover penetration is not needed Trees and other plants makes habitat for birds and other animals Minimise erosion Cheaper than conventional methods (both remediation and control)[22]	Maintenance and control may be needed[22] Natural succession may result in other plants than planted[22] Surface water may reach the waste[22] Risk for not wanted plant uptake of contaminants[22] The design has to be site specific and adapted to local climate[22] Risk for exposure due to fallen trees (storms etc)[22] Difficult to make use of produced gas[22]

[34] Rihm, 2002
[35] Carman and Crossman, 2001, EPA, 2000

Appendix 3

Brief summary of biofuel methods/techniques and the level of development, advantages and disadvantages

Alexandra Angelbratt

Table 3:1 Biofuel methods and techniques, level of development and advantages and disadvantages.

Method / Technique	Product after further processing	Level of Development	Energy Efficiency	Sensibility for Contaminants	Advantages	Disadvantages
Fermentation of wheat and barley to ethanol and carbon dioxide (Europe).[1]	Ethanol.	In Sweden and international production of ethanol out of grain is commercial. Ethanol from forest material is under development.**Fel! Bokmärket är inte definierat.** Agroetanol 2001. Europe (wheat + sugar beets), Brazilian (sugar canes), USA (corn).[2]	energy balance= energy outcome/energy input = 1.31-2.05[3]; =1.2-2[Fel! Bokmärket är inte definierat.]**Fel! Bokmärket är inte definierat.**		Both grain and forest mass can be used in the process.**Fel! Bokmärket är inte definierat.**	Lack of grain **Fel! Bokmärket är inte definierat.** and thereafter lack of forest material.**Fel! Bokmärket är inte definierat.**
Production of Biogas through anaerobic digestion of plants (forage	Methane -> LNG / CNG Electricity and heat.	Production of biogas only from forage crop is not economically good. The cultivated material can not compete with the free waste from landfills etc.**Fel!**	energy balance= energy outcome/energy input = 2.12-2.33**Fel! Bokmärket är inte**	Contaminants in the plants cause problems when the sludge is to be	Cultivation of different species decreases the need for pesticides. Forage crop can improve the structure	Lack of raw material.**Fel! Bokmärket är inte definierat.** [7]

[1] www.agroetanol.se, 2008-02-27
[2] www.svebio.se, 2008-02-27, Fokus Bioenergi nr 8 2004, Biodrivmedel
[3] Sammanställning och analys av potentialen för produktion av förnyelsebar metan (biogas och SNG) i Sverige, Svenskt Gastekniskt Center, reviderad 2005, (Table fr Börjesson 2004)
[4] www.svebio.se, 2008-02-27, Fokus Bioenergi nr 4 2004, Åkerbränslen
[5] www.bioenergiportalen.se, 2008-02-28

crop etc)[4]		**Bokmärket är inte definierat.** Today there is one large biogas plant in Sweden that produces biogas from forage crop Svensk Växtkraft AB in Västerås.[5] There are 31 upgrading plants in Sweden (2006)[6]	**definierat.** 60 % of the energy content of the raw material can be extracted.**Fel! Bokmärket är inte definierat.**	returned to the field rather than during the digestion process.	of the earth and increase the crop yield.**Fel! Bokmärket är inte definierat.** Climatically good if the leakage of methane during production and handling is minimized.**Fel! Bokmärket är inte definierat.**	The process is sensitive for disturbances. The raw gas is expensive to store and transport.**Fel! Bokmärket är inte definierat.** Leakage of methane is a problem.[8]
Firing of fuel form crops normally grown on arable land (Salix, Reed canarygrass, straw) and grain.	Electricity and heat.**Fel! Bokmärket är inte definierat.**	Cultivation of Salix is commercial in Sweden.**Fel! Bokmärket är inte definierat.** The market for Reed canarygrass is undeveloped but there is research going on aiming at refining species suitable for bio energy production.**Fel! Bokmärket är inte definierat.** In Sweden some district heating plant and several farms uses straw for energy production. In Denmark the use of straw is widely spread.**Fel! Bokmärket är inte definierat.**	1 ton dry Salix-biomass yields about 5 MWh.**Fel! Bokmärket är inte definierat.** 1 ton dry Reed canarygrass biomass yields about 5 MWh.**Fel! Bokmärket är inte definierat.**	Salix can accumulate cadmium and caesium. Therefore it is important with a good gas cleaning.**Fel! Bokmärket är inte definierat.**	A well maintained Salix cultivation can last for about 30 years.**Fel! Bokmärket är inte definierat.** If Reed canarygrass is burnt together with peat the ashes accumulate some of the sulphur.**Fel! Bokmärket är inte definierat.** The nutrients are by harvest time relocated to the roots of the Reed canarygrass. This decreases the removal of nutrients from the field and facilitates the burning of the grass. Straw is a by product and requires little extra work. Grain of lower quality can be used by the farmer for local energy production.**Fel! Bokmärket är inte definierat.**	Firing of fuel form crops normally grown on arable land and grain produces a lot of ashes that has to be taken care of. The ashes can also cause problems in the pan if it melts. Lack of Salix.**Fel! Bokmärket är inte definierat.** Related to the market price Reed canarygrass is not cost effective to cultivate.**Fel! Bokmärket är inte definierat.**
Gasification of biomass.**Fel! Bokmärket är**	Dimetyleter (DME), methanol,	Yet no commercial plants for this method.**Fel! Bokmärket är inte definierat. Fel! Bokmärket är**	More energy can be obtained out of a given amount of		Several different biomasses can be used in this process. In the production phase the energy	Methanol is poisonous and corrosive to the engine.

[6] Persson Margareta, 2006, Exposé of New Technology in the Biogas Area
[7] Grahn Maria, Drivmedel till fordon, Fysisk resursteori, Chalmers
[8] Blinge, Sörheim, Djupström, 2004, Alternativa och förnybara bränslen - en scenariobeskrivning runt framtida utveckling, Institutet för transportforskning

inte definierat.	synthetic diesel, hydrogen gas.**Fel! Bokmärket är inte definierat.**	**inte definierat.** Pilot plant by 2010 and perhaps a full scale plant by 2015 (SWE). **Fel! Bokmärket är inte definierat.**	biomass as methanol then as ethanol.**Fel! Bokmärket är inte definierat.**		effectiveness will be higher and the costs lower compared to production of petrol/diesel.[9]	Hydrogen gas requires a new production system.**Fel! Bokmärket är inte definierat.** The method is restrained by available technology and risk capital.**Fel! Bokmärket är inte definierat.**
Esterification of rape seeds with methanol and caustic soda (NaOH).**Fel! Bokmärket är inte definierat.**	Rape methyl ester (RME).	The first commercial plant in Sweden was built 2006 in Karlshamn. 2007 Perstorp built a RME facility in Stenungsund. Before that only local small scale plants. In Europe RME is the most common biofuel.**Fel! Bokmärket är inte definierat.**			The process is quite simple.**Fel! Bokmärket är inte definierat.**	Cultivation, fertilizing and harvesting of rape requires a certain amount of energy.**Fel! Bokmärket är inte definierat.** Lack of rape seeds. To get profitability in the process the rest products must be taken care of. **Fel! Bokmärket är inte definierat.**

[9] Sundsvall Demonstration Plant Förstudie för produktion av Fischer Topsch Diesel

APPENDIX 4

Examples of ongoing activities and research promoting bioenergy and other alternatives to fossil fuel

Yvonne Andersson-Sköld

CONTENTS

1 SWEDISH INITIATIVES AND ACTIVITIES PROMOTING NON FOSSIL FUEL

In Sweden, biomass constitutes more than 18% of the total energy production (Energiläget 2007, Formas, 2007). The main biomass sources are wood (wood, bark, saw dust and energy forest), pulping liquor and pine tree oil from the pulp industry (tall oil pitch), peat, waste and ethanol (pure to the industry and for mixing in 95 octane petrol and other fuels such as E85 and E92).

1.1 Swedish examples on national level

There are several national initiatives and activities promoting bioenergy and other alternatives to fossil fuel. Below some examples of ongoing activities for the promotion of bioenergy are described. These include heat, electricity and biofuel.

1.1.1 Heat and electricity

Among activities promoting bioenergy and other alternatives to fossil fuel, for heat and electricity are:

- Renewable electricity certificates
- Aid for conversion from electric and oil-fired heating system
- Aid for energy efficiency and renewable energy in public places
- Local climate investment programmes

Renewable electricity certificates

In 2003, a system of electricity certificates was introduced on the Swedish market to promote the production of electricity from renewable sources, including from biomass and waste. The certificate is a market-based system that replaces Swedish State aids and subsidies, which previously existed to promote the development of renewable energy. The cost is now paid by the electricity user instead. The producers of renewable electricity receive an electricity certificate for each megawatt-hour of electricity produced. All electricity consumers are required to purchase a certain number of certificates in relation to their consumption, a so-called quota requirement. Up to 2006 about 5 TWh of renewable electricity per year had already been produced (Swedish Parliament, 2006).

Aid for conversion from electric and oil-fired heating systems

In 2006, the Parliament of Sweden approved to introduce two new conversion aids for owner-occupiers of small houses with an oil-fired heating system or direct-acting electric heating. The purpose of the aid was to stimulate the use of renewable energy sources, district heating or individual heating from biofuels, heat pumps and solar heating. Apart from that, the government has passed a resolution on the detailed rules in two ordinances: Ordinance SFS 2005:1256 on aid for converting from oil-fired heating systems in residential buildings; as well as Ordinance SFS 2005:1255 on aid for converting from direct-acting electric heating in residential buildings (Swedish Parliament, 2006).

Aid for energy efficiency and renewable energy in public places

On 14 April 2005, the Government of Sweden approved the new aid for energy investments in public places. The owners of buildings with premises where public activity is undertaken can receive aids of up to 30% of the costs of investing in energy efficiency and converting to renewable energy sources, including bioenergy. To install photovoltaic systems, aid is granted for up to 70% of the costs. In total, the Government has directed SEK 2 billion towards the aid, of which SEK 100 million is expected to be used for installing photovoltaic systems (Swedish Parliament, 2006).

Local climate investment programmes

The development of local climate targets is an important part of the work of forming a sustainable society. State aid towards local climate investment programmes (klimat investerings program, KLIMP) was a Swedish programme which aimed to stimulate districts, companies and other actors to make long-term investments that reduced the greenhouse effect. The effort originates from the bill "Sweden's climate strategy" (prop. 2001:02/55) in which almost SEK 900 million was allocated for the years 2002-2005. KLIMP has contributed to achieving the Swedish climate target by decreasing the emission of greenhouse gases, strengthening the local climate work and collecting and spreading knowledge and experiences on climate investments. Investments in renewable energy and bioenergy have been included in such local climate investment programmes (Swedish Parliament, 2006).

1.1.2 Renewable fuel

In December 2005, the obligation to provide renewable fuels was introduced in Sweden (Swedish parliament, 2006, Act (2005:1248)). The Act stipulates that from the 1st of April 2006 and onwards, the largest petrol stations must sell renewable fuels, such as ethanol or biogas, with the purpose to reduce carbon dioxide emissions by improving access to renewable fuels. Petrol stations selling more than 3 000 cubic metres of petrol or diesel per year are covered first. The requirements will then gradually be defined up to 2009 when they will apply to those points of sale that annually provide 1 000 cubic metres, or more, of conventional fuels.

In order to avoid one-sided support for a particular technical solution, a State aid has also been introduced for measures to promote the distribution of renewable fuels. This aid means that persons who make investments in order to provide renewable fuels, under the Act 2005: 1248 concerning the obligation to provide renewable fuels, can receive a subsidy of up to 30% of the total cost of the measure (the investment cost). The subsidy may not, however, exceed the investment cost minus the lowest cost needed to fulfil the requirement (standard cost). The aid was introduced to some extent to facilitate also the more expensive alternatives such as investments in biogas filling stations (Swedish Parliament, 2006).

Use of biofuel in Sweden

The biofuels widely used in Sweden are bioethanol, rapeseed methyl ester (RME) and biogas. Very small quantities of some other types of biofuels are also used. The total quantity of biofuels, as regards energy content, which on the market replaced petrol and diesel for transport, amounted to less than 3% in 2005. In the same year, almost 92% of the supplied quantity of petrol contained 5% low admixture of ethanol. This means that Sweden now finds itself in a situation where almost all supply of petrol (except unleaded 98-octane) contains a low admixture of ethanol. There are no vehicle-related barriers to having a low admixture of up to 10% ethanol in fuel for cars in the existing vehicle fleet. Instead, it is the EU Directive on fuel quality that is at present limiting the low admixture to only 5%. With a possible amendment to this EU Directive and a continued tax exemption for ethanol, the amount of low admixture for ethanol may be expected to rise.

RME is used both as a 2% low admixture in diesel and as pure RME. During 2005, slightly more than 10% of the supplied quantity of diesel contained a low admixture of RME, which is about the same proportion as in 2004. The recently implemented amendment to the Swedish legislation means that up to 5% RME can be mixed with diesel from August 2006. The amount of biogas sold to the transport sector increased in 2005 by about 25% to about 0.16 TWh (Swedish Parliament, 2006).

In 2005, ethanol accounted for almost 87% of biofuel use, calculated in terms of energy volume. Most bioethanol, around 90%, is used for admixing with petrol, but the volumes used in pure, or almost pure form, are also increasing.

In Sweden ethanol is produced from grain by Agroetanol and from by-products of paper pulp production by SEKAB, in Örnsköldsvik. The sharp increase in imported ethanol, already noted in 2003 and 2004, has continued. Imported ethanol constitutes about four-fifths of Sweden's total use of ethanol in fuels and in 2005 came mainly in the form of sugar-cane ethanol from Brazil. The price of the imported ethanol is between SEK 3-5 per litre (including customs duties). The cost of Swedish production, which is based on cereals, is reported to be about SEK 5 per litre (Swedish Parliament, 2006).

At the end of 2005, there were about 4.1 million private cars on the road in Sweden. Of these, about 94% ran on petrol and about 5% on diesel. Thus, private cars operated on any other kind of fuel represented less than 1%. During 2005, the number of registered private cars that can be operated using biofuels as a first or second fuel increased greatly. The number of light vehicles equipped to run on biogas/natural gas or petrol increased from 4 519 in 2004 to 6 500 in 2005. The total number of buses and lorries powered by natural gas or biogas also increased from 780 2004 to 900 by end of 2005. (Swedish Parliament, 2006)

Several Swedish cities have invested in biogas as a fuel for local buses. During 2005, there were biogas buses operating in eleven cities and there will gradually be more. In connection with this, filling stations for private cars have also been established and the increased accessibility is also increasing the number of these vehicles. This can be seen, for example, in Linköping, Kristianstad and Trollhättan, where the total number of private cars powered by vehicle gas has greatly increased over the last few years The number of public filling stations for natural gas and biogas increased from 47 to 75 and the number of public filling stations for RME was 21. In June 2006, there were a total of 415 filling stations in Sweden that supplied one or more biofuels, namely biogas, Ethanol E85 or RME (Swedish Parliament, 2006).

1.2 Swedish examples – small scale production local level

In addition, to the above stated generic national actions to promote and produce sustainable energy production, there are at present, in Sweden, several local and regional scale ongoing activities. In the following sections, several examples of such small scale sustainable energy production are given, together with examples of activities planned in a near future.

1.2.1 Biofuelled electricity production and district heating

An electricity and heat producing power station (Riskulla, kraftvärmeverk, KVV), Mölndal located at the south border of Göteborg, is at present under production. The plant, which will be a biofuel based district heating, electricity and heat production plant, is to be started 2009/2010. The total local annual electricity production will be 130 000 000 kWh which corresponds to the complete annual household demand in the city of Mölndal. The spill heat will be transported and used by the citizens. The district heat deliveries will be approx 50 000 000 kWh, enough to heat 25 000 normal size houses (villas) (Mölndal Energi, 2008).

A similar district heating plant is to be started, in 2008, in Sundsvall. The Sundsvall district heating plant (Fjärrvärmeverk, Sundsvall Energi), will be fuelled by bio pellets producing 2 500 MWh per year (Mannheim Swartling, 2008).

1.2.2 Vehicles run by biogas

July 17^{th} 2008, the first tractor driven by biogas in Sweden was shown. The vehicle has been developed in the Netherlands, and according to the producers they do not know any other examples world wide. The technique makes it possible to use manure from the farms as fuel. This tractor runs to 75% on biogas and 25% diesel (SVT, 2008).

Another city in Sweden will run the buses on biogas. From 2009 all city buses in Örebro will be run by locally produced biogas. (SVT, 2008)

1.2.3 Manure

New plants using manure (dung, fertiliser) to produce biogas are set up at two farms in Vårgårda and Herrljunga, both in the south west of Sweden. At the two farms the animals produce around 2 million tonne manure annually. The aim is to use this to produce biogas (methane) in smaller digestion plants at each farm. The methane will thereafter be transported in a pipeline system to larger collectors. One of the farmers in charge, Tobias Kullingsjö, estimates the development costs to around 50 million SEK (~ € 5 million) (Hellström, 2008).

1.2.4 Seaweed

In Ystad, by the very south coast of Sweden, there are plans to start biogas production from smelling seaweed. A small pilot has shown that the production worked perfect. Annually hundred thousands tonne seaweed is cleaned from the coastal beaches, today it is waste just thrown away, now the plan is to use it for biogas production (Skånskan, 2008).

1.2.5 Sugar beet

Gotland together with the south of Sweden and Mälardalen was already in1998 shown to be suitable for Swedish biogas production, due to large agricultural areas, large animal production and large amounts of waste and small population (Nordberg et al., 1998). Not until today, however, the first biogas production project is about to start on Gotland. The production will be based on sugar beet. The areas in use will be 2 000 hectares (of the total Gotland area of 87 000 hectares) producing gas corresponding to 8 000 cubic meters oil or 12% of the total demand of diesel and petrol on Gotland (Helagotland, 2008).

1.2.6 Tall oil

In Sweden, forest products, such as tall oil, pine branches and tops, offer large potentials for further development. At present, 100 000 tonne rape seed oil is annually produced (Bülow & Stymne, 2007). This corresponds to less than a third of the fatty acids in the pulp and paper industry from pine, and consequently tall oil offers a large potential for Swedish oils production. Sweden is the globally largest pulp and paper producer, however, the annual production of tall oil only reaches 2 million tons. Gene modifications, e.g. by developing Salix or poplar to contain more oil, (i.e. in the same quantities as some trees in Mongolia that already today containing up to 10% oil) could increase the production (Swedish pine contains only 1% oil). The potential result would thus be a Swedish annual production of 60 million tonne oil. The advantages with oil from pine and other trees are the low energy demands and other costs related to the production. The amount produced would correspond to 15% of the vehicle fuel demand in Sweden today (Bülow & Stymne, 2007).

1.2.7 Sewage sludge addition

Corrosion has been shown to be a major problem in biogas production units, due to many bio raw products containing potassium, sodium and chlorine, forming alkali chlorides under combustion. A potential solution is simultaneous combustion of sewage sludge which has been shown to reduce the corrosion related to biomass burning in a fluidised bed boiler (Elled, 2008). The corrosion is hindered due to the sewage sludge’s high content of sulphur, which forms potassium or sodium sulphate in the combustion process, and the ash from the sewage sludge contains compounds binding the alkali chlorides. The chloride forms hydrogen chloride gas which can be purified (removed) from the exhaust (Elled, 2008). Furthermore, heavy metals are according to the experiments performed by Elled (2008) readily bound to the sewage sludge ash.

2 EUROPEAN EXAMPLES

One of the driving forces for the development towards non fossil fuel is the European directives and strategies described in the main report. Below some examples of practical ongoing activities are presented. There is a fast development all over Europe and the number of activities is increasing rapidly.

For example all over Europe biogas and biodiesel buses are taken in use or being planned for in urban communities. An example is that in the summer 2008, buses running on biodiesel (B100) was launched in the United Kingdom. An early example of biogas buses is the Lille Metropolis, Urban Community, Biogas Buses Project, which had the first pilot production unit for biogas operational since April 1995. The biogas is of good quality (Methane: 97,5%, H_2S: 2 ppm and H_2O: 3 ppm), which makes the reliability of the gas buses comparable with biofuel buses. The cost per kilometre is equal to, or less than, that for diesel buses and the emissions are for most pollutants, i.e. non methane volatile hydrocarbons, nitrogen oxides, particulates less than from the diesel buses (Lille, 2008).

There is an increasing interest in European sugar for biofuel production. For example in June 2007, the first bioethanol plant in the UK was opened by Food and Farming Minister Jeff Rooker. The plant is run by British Sugar in Wissington. The sugar factory's combined heat and power plant also provides energy for the bioethanol plant, ensuring that bioethanol produced delivers 60% lifecycle carbon savings compared with ordinary petrol. The plant will be converted to the production of biobutanol. The plant will continue to use locally grown sugar beet as the feed stock and the biobutanol produced will be blended with petrol in the UK (British Sugar, 2006).

Furthermore, other facilities are under construction, or in planning, for example using feedstocks from wheat. An example is the bioplant to be built by Associated British Foods plc ("ABF"), BP and DuPont. The plant will initially produce bioethanol, however, the partners will look at the feasibility of converting it to biobutanol once the technology is available (GNN, 2008).

3 NON EUROPEAN ACTIVITIES – EXAMPLES

There are several ongoing non European activities promoting biofuel for heat, energy and other purposes. In a report published by UN, (2007), several examples of successful bioenergy projects are presented. One example is the Dutch-Nepalese Biogas Support Programme. Since the programme started, 1995, more than 120 000 biogas plants have been installed in Nepal. Thereby providing approximately 3% of Nepalese homes with the benefits of fuel for lighting and cooking as well as reduced levels of indoor air pollution. Moreover, because roughly 72% of the biogas plants connect to latrines, human health risks have been reduced and sanitation improved on a large scale (UN 2007).

Another programme described in the report by UN, (2007), is the Dutch-Vietnamese cooperation which was initiated in 2003. It was built on the Nepalese experience by implementing a Biogas Programme for Vietnam's animal husbandry sector. The programme won an Energy Awards in 2006. Through the programme approximately 25 000 biogas plants have been built benefiting more than 100 000 people in 20 provinces. The cooperation aims to establish a commercially viable domestic biogas sector and focuses on quality assurance and the training of end users, biogas construction teams and technicians. Vietnamese households use the biogas for cooking and use the bioslurry residues as crop fertilisers and fish feed. Health improvements include reduced indoor air pollution and odour as well as improved latrines, sanitation and stable facilities. In addition, the use of biogas has freed women and children from burden related to housework and firewood collection while also reducing deforestation (UN 2007).

Further examples of energy self-sufficiency and even selling power to the grid comes from the sugar industries of Australia, Brazil, Guatemala, India, Mauritius and several other countries. These industries serve as models for the 80 sugar cane-growing developing countries in which residues from sugar cane production and processing represent a vastly underutilised energy resource (UN 2007).

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