1 Introduction

The area of degraded tropical land with potential for rehabilitation amounts to approx. 2.000 million ha, while deforestation and desertification continue, ruining soil, decreasing biodiversity and aggravating world hunger. Indebtedness of tropical countries and economic pressure constrict a sustainable management of resources – therefore socioeconomic development must parallel any land rehabilitation effort.

World consumption of primary energy has exceeded 400 EJ/year. Possible effects of global warming are starting to show. Oil and natural gas may be depleted before 2040 resp. 2065. Military conflicts for fossil energy resources already increase. Presently biomass is the only competitive alternative energy source, conforming to established technology and available on a substantial scale. The greatest energy demand, however, comes from industrial countries, while major biomass potentials are found in the tropics. Consequently there is a high risk of competition between energy demand, nature conservation and world feeding. A synergistic solution, seizing the complementary needs of land rehabilitation and bioenergy production is recommended in this study.

Table 1: Plant Species for Land Rehabilitation and Bioenergy

<table>
<thead>
<tr>
<th>Species</th>
<th>Ecological Requirements</th>
<th>Reported Biomass Yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>leguminous trees</td>
<td>&gt; 20°C; rainfall 700-4400 mm/year</td>
<td>15-40</td>
</tr>
<tr>
<td>Calliandra calothyrsus</td>
<td>pH 4.5-8.0, low fertility demands</td>
<td>19-31</td>
</tr>
<tr>
<td>Leucaena leucocephala</td>
<td>&gt; 25°C; rainfall 650-1500 mm/year</td>
<td>7-14</td>
</tr>
<tr>
<td>Acacia auriculiformis</td>
<td>&gt; 26°C; tolerates poor soils, sand dunes, extended dry seasons, wide range of pH</td>
<td>6-30</td>
</tr>
<tr>
<td>Cassia siamea</td>
<td>rainfall 350-450 mm/year, sandy, saline or alkaline soils</td>
<td>1-26</td>
</tr>
<tr>
<td>perennial C4-grasses</td>
<td>&gt; 14°C; rainfall 250-400 mm/year</td>
<td>2-85</td>
</tr>
<tr>
<td>Pennisetum purpureum</td>
<td>pH 4.5 &amp; 2; tolerates drought, fire, monsoon</td>
<td>19-31</td>
</tr>
<tr>
<td>Cenchrus ciliaris</td>
<td>&gt; 13°C; rainfall 250-750 mm/year, pH 5.5-8.2</td>
<td>19-31</td>
</tr>
</tbody>
</table>

2 Coproduction of Food and Bioenergy on Rehabilitated Land

Coproducing food and fuel on rehabilitated land minimises opportunity costs, and optimises utilisation of resources. Agroforestry is a common example for multifunctional ecosystems, producing food, energy and other commodities. A study by the FAO (1995) states that average woodfuel productivity of agroforestry systems in Asia is 13-19 t/ha·year in the humid resp. half of that in the subhumid tropics.

Agroforestry systems are suitable for land reclamtion and allow sustainable management. In various environments an important function is assumed by leguminous trees, which add nitrogen and organic matter to the system, provide erosion control and shelter for smaller crops, can be browsed by livestock, and are major producers of woody fuel. Costs of reforestation, e.g. in India (1996), are quoted in the range of 600,- € / ha.

Perennial grasses that follow the C4-photosynthetic pathway have a high water efficiency, can provide good erosion control and high biomass production in semi-arid or dry regions. Food use is possible by temporal grazing.

Table 1 indicates the biomass potential of some species suited for land rehabilitation as well as for coproduction of food and bioenergy. Traditional biomass utilization is mostly inefficient (combustion). Conversion to high grade fuels could release an energy surplus.

3 Conversion of Biomass into Ethanol and Hydrogen

Combustion engines for ethanol are state of the art, infrastructure requirements are low, and the biochemical production pathway allows recirculation of organic residues. Ethanol production from lignocellulosic biomass like wood or straw (Figure 1) promises a decline in resource consumption and costs.

Hydrogen is the energy carrier of the future. It represents the interface of all solar energy sources (storage by electrolysis) and potentiates clean energy of highest efficiency by the use of fuel cells. The gasification of lignocellulosic biomass (Figure 1) is the most cost-efficient solar production pathway of hydrogen.

Total auxiliary energy required for conversion, transport, etc. is in the range of 1.5% (EtOH) to 6% (H2) of the biomass input. Variable costs for production and distribution are estimated at 150,- € per tonne ethanol resp. 700,- € per tonne hydrogen. A sales revenue for fuel applications of 350,- € per tonne ethanol resp. 1300,- € per tonne hydrogen can be expected. Both numbers account for a gross revenue of 60,- € per tonne biomass. Investment costs for conversion plants will be in the range of 0.5 mill. (EtOH) to 0.7 mill. (H2) € / MW, depending on the economy of scale.

4 Impact and Recommendation

As illustrated in Figure 2 by a sample calculation, the on-site production of high grade fuels from biomass coproduced with food on degraded tropical land entails multiple benefits:

- Funding of land rehabilitation by revenue from energy production
- Soil restoration and increase of biodiversity
- Substantial reduction of CO2-emissions
- Self-supply of local population, additional income and regional development
- Economic production of clean renewable energy
- Promising return on investment

For the exploitation of this win-win-situation more detailed information is required. The concept of a preliminary project is given in Table 2.
References

Aufforstungen als kosteneffiziente Klimaschutzmaßnahme im Rahmen einer internationalen Zusammenarbeit zwischen Deutschland und Indien
Tagung der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaus, Braunschweig

Energy plant species
James&James, Braunschweig

High Performance Gasification with the Two-Stage Gasifier

Estimating areas of degraded tropical lands requiring replenishment of forest cover
The International Tree Crops Journal 5, S. 31-61

Woodfuel productivity of Agroforestry Systems in Asia
FAO, Field Document No. 45, Bangkok

Mahendrawaria, C.P.; Kumar, A. (2000)
Prospects of biomass production in wastelands: growth and productivity of selected tree species in Rajasthan
1st World Conf. on Biomass for Energy and Industry, Sevilla, 5-9 Jun 2000, pp. 315-317

Poetsch, J. (2002)
Chancen der energetischen Nutzung holzartiger Biomasse mit Brennstoffzellentechniken
Master-Thesis, Georg-August-Universität Göttingen, Institut für Agrartechnik

Wyman, C.E.; Bain, R.L.; Hinman, N.D.; Stevens, D.J. (1993)
Ethanol and Methanol from cellulosic biomass