ENERGY POTENTIAL OF INVASIVE PLANTS

IN SRI LANKA

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Abstract

Invasive Alien Species (IAS) is a great threat to biodiversity in many of the natural ecosystems in Sri Lanka. Water hyacinth, Prosofis juliflora, Mimosa pigra, Lantana camara and Panicum maximum are found to be the most critical IAS plants which are threatening in lakes, Bundala, Mahaweli catchment, Udawalawa and island wide respectively. With the drawbacks of launched controlling mechanisms those of physical, chemical and biological, there is a much necessity for initiating more sophisticated program with the participation of public, especially rural community where there will be more benefits for them.

As far as the Sri Lankan energy balance is concerned about 45% comes from biomass while rest from imported petroleum (45%), hydro (8%) and unconventional renewables. About 25% of the imports expenditure is accounted for petroleum imports. On the other hand, the demand for fuel wood is increasing due to rapid industrialization and it will be always questionable whether the existing feed stocks are sufficient. Further, currently identified biomass species such as Gliricidia, Ipil, Eucalyptus and etc are not the best as far as the annual yield is concerned.

Learning from the nature, has been a key scenario in invention and development. IAS itself shows the characteristics which are suitable for dedicated energy crops those of high yield, low nutrition requirement and survival in mild environmental conditions. The two IASs; Guinea grass and Arundo donax, were analyzed to be used as energy feedstock. Their perennial nature along with high yield as high as 75 tons per hectare provide evidence their suitability as energy plants.

Guinea grass was further tested in an updraft gasifier and the flame was not stable for a long time but only for 6 to 7 minutes. The performances were different from batch to batch where gas analysis showed that it was composed with around 11% combustibles. In trial 2 sample, 50% of nitrogen suggests that the presence of oxygen is low and hence, the unaccounted 18% could be composed with tars which were not detectable by used column in GC analysis. Further, the heterogeneous nature of feedstock along with the uneven compaction caused uneven combustion throughout the cross section and height. Hence it was suggested again that the homogeneous nature of feed material is a crucial factor in gasification.

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ERJC Bandara

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1.0 INTRODUCTION

1.1 Background

People (Society), Planet (Environment) and Profit (Economic) have emerged as the key parameters of the theory of sustainability which is referred as the Triple Bottom Line (TBL) or Trilemma (Yoda, 1995) as well. The Earth is composed with Atmosphere, Hydrosphere and Geo-sphere where there are lots of natural ecosystems and manmade systems, referred as built environment, embedded in it. Each living species, from unicellular creature to giant mammals (fauna) and from algae to giant trees (flora), does a silent job in building up the environment and ensuring the sustainability of it.

Since the dawn of time, but prior to the development of modern science and technology (industrial revolution during 18th and 19th century) or invention of fossil fuels (19th century), the life on earth happened to be in absolute balance. However, during last couple of centuries when humans took command over the nature and when powerful/rich nations took command over the poor, the sustainable existence was challenged. For instances, climate change, depletion of ozone, glazier erosion, sea level rise, severe weather conditions (floods and prolong drought) economic recessions, poverty and ethnic and political conflicts in many countries, clearly reciprocate the situation where even humans themselves have endangered.

Flora, especially green plants, is the primary food provider (Photosynthesis by harvesting sun’s radiation energy) (Beadle & Long, 1985) in the food chains and have been evolved throughout millions of years into thousands of verities adopting different climatic and soil conditions (Chaloner, 2003) and so have the fauna.

With the evolution & development of man, plants have been used for Agricultural (direct human food or animal feed), Energy and Ornamental purposes. As man developed their own territory, natural ecosystems were cleared and redesigned for their dwelling and agriculture. In this altered environment, some flora tended to behave differently showing some excessive growth and spreading over other economically valued plants, lately declared as Weeds (McNeely, 2001). Due to the increased transportation and colonialism/world wars, plants were subjected to move in between countries and different ecosystems for economic & aesthetic purposes or sometimes those trespassed to foreign territories accidentally attached to machineries, animals and etc. Even though many of the introduced species were beneficial, within few decades, some of them became threatening to native plants and are known as Invasive Alien Species (IAS) (McNeely, 2001). The lost of biodiversity is the major impact of IAS and it is said that it seconds only to the clearing off of natural ecosystems for agriculture and other infrastructure developments. Hence IAS challenges the sustainability of Environment.

Like majority of other nations, Sri Lanka, as well, has been struggling with IAS since the 20th century and yet to come up with sophisticated controlling mechanisms. In one hand, lots of physical, biological and chemical initiatives have been launched in both built environments and natural ecosystems and number of legislations followed by actions plans have also been brought forward, on the other.

The combustion of fossil fuels along with its uneven geographical distribution has caused the global warming and lots of political violence in between nations respectively. These factors have catalyzed the interest in developing renewable energy sources and improving/inventing the conversion processes. Biomass is known as one of the oldest source of energy while hydro, solar and wind give considerable contribution. However, when it comes to biomass, its low energy density, bulkiness, handling difficulty and non-user friendly physical existence (high moisture) make it essential the upgrading of raw fuel by means of various processes such as gasification, pyrolysis, anaerobic digestion, fermentation and etc. Further, it has been emphasized that the renewable energy alone cannot meet the sustainability, but conversion efficiencies should also be improved.

As Sri Lanka's energy balance is concerned, household cooking and industrial thermal applications are highly depended on biomass energy (Sustainable Energy Authority, 2010), where as a share of total, biomass accounts for approximately 45%. Most of the biomass cooking stoves in Sri Lanka are having low thermal efficiencies and the stove emissions are having lots of respiratory health effects. However, the national economic growth of 6% - 8% per annum (Central Bank of Sri Lanka, 2010) has resulted in improved living conditions of citizens followed by switching household cooking from fuel wood to LPG (Joseph, 2011). Despites to that, the growing population along with rapid industrialization have caused an increased demand for biomass continuously. Larger fraction of the imported fossil fuels is consumed by transportation and electrical power generation (Sustainable Energy Authority, 2010) and the expenditure on fossil fuel imports as a share of total imports is touching 25% (Central Bank of Sri Lanka, 2010). Energy policy of the country has also highlighted the necessity of alternative indigenous energy sources where even a separate ministry has been established recently.

1.2 Statement of the problem

IAS tends to be a burning dilemma in Sri Lankan context where chemical and biological programs are not selective which will, in turn, effect on native species as well. Even though the physical removal mechanism is labor intensive, at the end of the day, lots of lignocellulose biomass is left behind where dumping is yet again a challenging undertaking.

As a country, Sri Lanka should be keen on enhancing the national energy security and reducing the expenditure on fossil fuel import. Minimizing of switching of house hold cooking from fuel wood to LPG and redirect LPG users towards fuel wood will be a key step in reducing the foreign fuel dependency. However, the existing biomass cooking stoves are neither efficient enough nor user friendly to commercialize in between both higher and lower income community.

Further, with the existing economic development, manufacturing and services industry will also have a tendency to bloom in the coming years which will generate a huge demand for fuel wood. Hence, extracting of every possible biomass feed stocks with minimum or zero impact to the environment will be crucial.

On the other hand, the living of the far rural villages is still very poor where majority of them are small scale famers or self employees such as brick making, coconut fiber based products and etc. Therefore, it is vital to improve their economic conditions to proceed ahead as a nation. Further, the household cooking is done by women and it is a crucial necessity to come up with a solution for the health issues related to the emissions of traditional fuel wood cooking stoves.

1.3 Research problem

The research is targeting on generating a link between disposing of IAS with biomass energy utilization. Further, it focuses on the fill the drawbacks of traditional biomass cooking stoves with high efficient gasifier stoves.

1.4 Research objectives

Prioritizing of invasive plants is discussed followed by characterization of selected IAS and their components as biomass energy feed stocks. Adoptability of thermo-chemical and bio-chemical mechanisms to process selected IAS matter into secondary fuels is critically analyzed and enhanced researches are carried out to validate the suitability of the gasification technology for cooking with a physical demonstration.

By introducing the cooking stove, the participation of public community (especially the rural community) for the control of IAS is aimed while improving their quality of living along with the economic conditions.

1.5 Research limitations

The analysis was narrowed down to two species and those were selected according to the significance of existence in Sri Lanka. During the gasifier operation, air flow rate was the only controlled variable and the system designing was having the drawback of inability for continuous feeding where much more improvements is needed for the real world usage. The packing density of the material within the gasifier hopper could be varied from batch to batch. As the experiment was carried out for prolong period, the composition (moisture content) could be varied throughout the batches. Further, only updraft gasification with air as the oxidation agent was tested. Gas cleaning and tar cracking were not carried out as the gasifier/gasifier stove was designed for the thermal energy generation for cooking purposes, but not as an engine fuel or electricity generation.

1.6 Research gaps

Gasification of grass leaves in gasifier cooking stoves has had limited interest in the research arena and very few evidence are found in literature.

1.7 Thesis outline

Chapter 01 carries the background for the research and how the research objectives were generated.

Chapter 02 in this thesis is focused on the literature review about invasive plant, their evolution as invasive and global management programs & institutional framework. Identified and future potential invasive plant species and mitigations practices which have been launched in Sri Lanka are also discussed in this chapter. This chapter also depicts recent energy data of Sri Lanka and literature on biomass conversion mechanisms into secondary fuels.

In chapter 03, the research methodology is explained including, characterization of selected invasive plant species as fuels (calorific value, drying curves and etc.) and design & fabrication of small scale updraft Gasifier along with its operation.

Chapter 04 depicts the Results and Discussion while chapter 05 and 06 are included with Conclusion and future research topics subsequent to this project respectively.

2.0 LITERATURE SURVEY

2.1 Invasive Alien Species (IAS)

2.1.1 Biodiversity

Due to the long geological and evolutionary history, the earth consists with highly diversified species of plants, animals, and micro-organisms in different continents and various ecosystems (McNeely, 2001). Biological diversity means the full range of variety and variability within and among living organisms and the ecological complexes in which they occur and encompasses ecosystem or community diversity, species diversity and generic diversity (Cho et al, 2008) which is further described in the table 2.1.

Table 2.1: - Definitions of components of biodiversity

Generic diversity	Combination of different genes found within a population of a single species, and the pattern of variation found within different populations of the same species
Species diversity	variety and abundance of different types of organisms which inhabit an area
Ecosystem diversity	variety of habitats that occur within a region, or the mosaic of patches found within a landscape

Biodiversity boosts ecosystem productivity, where each species, no matter how small, has an important role to play. It helps for the sustainability of natural ecosystems such as nutrition storage, provides numerous resources such as food & medicine and social benefits such as tourism (Christie et al, 2012).

Loss of biodiversity in both flora and fauna is a widely spread and deeply discussed topic within all the nations generally. There are hundreds of species in IUCN red list which have been categorized as endangered in extinction from the earth. The factors could be either man made or natural. Extinction of dinosaurs from the earth is a natural phenomenon (at least not manmade) while extinction of natural forestry (i.e. Amazon) for agricultural purposes is manmade. Even though the agricultural lands have the possibility of categorizing under forestry (i.e. rubber plantations), the drawback of loss of biodiversity cannot be addressed. The IASs are having similar characteristics of threat for the loss of biodiversity of a particular ecosystem which only seconds to the degradation of natural habitats (Yakandawala, 2011). However it is also important to recognize that biography is dynamic and contents of ecosystems undergo continuous changes due to various factors such as climate change (McNeely, 2001).

2.1.2 Biodiversity of Sri Lanka

Compared to its small size, Sri Lanka is having a broad biodiversity (ecosystem diversity) due to its topographic and climate heterogeneity as well as coastal influence. The existing ecosystems within the island can be categorized into four main sub groups as, Marine or coastal ecosystems, Natural forest ecosystems, Natural and semi-natural grassland ecosystems and Inland wetland ecosystems (Gunathilake et al, 2008). Further details are attached under annexure 01.

2.1.3 Invasive Alien Species (IAS)

Native Species; a species, subspecies or low taxon living with its natural range (past or present), including the area which it can reach and occupy using its own legs, winds, wind/water born or other dispersal systems, even if it is seldom found there (McNeely, 2001).

Alien Species (non-native, non-indigenous, foreign, exotic); a species, subspecies, or lower taxon introduced outside its past or present distribution; includes any part, gametes, seeds, eggs or propagules of such species that might survive and subsequently reproduce.

Invasive Alien Species can be defined as an alien species whose establishment and spread threaten ecosystems, habitats already existing there or species with economic or environmental harm (Wijesundara, 2008).

Due to the geographical barriers in between continents, countries or regions (oceans, mountains or deserts), the transition of flora & fauna was not dominant during early stage. Oceanic islands and other geographically isolated ecosystems often have their own suites of species, many found in nowhere else which is called as endemic species.

About 20% of the world’s flora is made up with insular endemics found on only 3.6% of the land surface area (McNeely, 2001). This framework provides the basis for defining the concept of native & alien species.

With the gradual development of transport sector, humans managed to overcome the geographical barriers and it expanded the travelling, settling down at different newly found countries, trading and military invasions which enhanced the shifting of flora & fauna along with. The bulk movements of floral species originated with the European colonial periods. Some flora has been purposely introduced to colonized regions as food intensive to the military people (wheat, potato), some as economic valued crops (tea, cocoa), as animal feeds (grass verities) and some as ornamental plants (Water hyacinth) for their home gardens while other few verities has moved accidently by means of military or agricultural equipment and cattle or other farming beings. But the invasiveness was observed surprisingly because people who introduced were not aware about possible negative ecological ramifications involved. Sometimes secondary alien species are introduced for the controlling of invasive species where those too can be emerged as invasive in years later. And with the time, finally some of the IAS might show native characteristics where a greater attention should be given when removing/controlling those IAS.

Once IAS rooted in a particular location within a country, it can be spread across by means of wind, water bodies (rivers/irrigation channels), equipment, human activities and creatures like birds, creating adverse ramifications in global trade, settlement patterns, agriculture, economics, health, water management, climate change, genetic engineering and many other fields and concerns (McNeely, 2001).

Alien species can be discussed in both broader (transition across country borders) and narrow (trespass in between local ecosystems) scale. In contrast, even native species could be invasive once those species gets more adaptation to the changing factors like climate, soil nutrition, hydrology, fauna and etc. But, alien species is more threatening to become invasive because of the speedup spreading over native species resulting loss of biodiversity, generating socio-economic problems and sometimes even health hazards. And it is said that the spread of invasive plants is more dominant in altered lands by humans such as agricultural lands, water reservoirs or by roads.

Even though the intention of some of the introduced plants was economic factors, some of those have become invasive later on. Hence it is essential to calculate the environmental cost over economic beneficial cost whenever an alien species is introduced in to a newer ecosystem. A case study is attached in Appendix 02.

2.1.4 Threatening IAS in world

Table 2.2: - Most threatening IAS in the World (Invasive Species Specialist Group, 2010)

Acacia mearnsii	*Ardicia elliptica*	*Arundo donax*
Cecropia Peltata	*Chromolaena Odorata*	*Chincona pubescens*
Clidemia hirta	*Eichhornia crassipes*	*Euphorbia esula*
Polygonum cuspidatum	*Hedichium gardnerianum*	*Hiptage benghalensis*
Imperata cylindrica	*Lantana camara*	*Mimosa pigra*

2.1.5 Global IAS programs

Scientific Committee on Problems of the Environment (SCOPE)

This program was launched during 1982 & 1988 with the contribution of large number of scientists and a document was prepared about the nature of invasive species problem. The outcome of the program was published as number of books such as "Biological Invasions, A Global Perspective". Although this was scientifically sophisticated, it didn't deliver any strategic approach for the managers for the management of invasive species (Mooney, 1999).

Global Invasive Species Program (GISP)

Addressing the drawbacks of previous programs, along with the partners from UNEP (United Nations Environment Program), IUCN (International Union for the Conservation of Nature) and CABI (Commonwealth Agricultural Bureau International), a newer program; Global Invasive Species Program (GISP), has launched which is more comprehensive giving tools for understanding as well as dealing with invasive species. This effort differs substantially from previous program in that it will engage the many constituencies that are involved with the problem including natural and social scientists, educators, lawyers, resource managers and people both industry and government (Mooney, 1999).

2.1.6 IAS control

Volunteering campaigns (short duration programs of removing plants by manual or simple tools) of eradication of invasive species have been carrying out by NGOs, Private and governmental bodies where some of those were successful as a short term outcome but none of them were sustainable. On the other hand removal of invasive plants alone doesn't make any sense of recovering the ecosystem the way it existed prior to the invasion (or simply restore). Hence there should be a well studied biological/ecological approach in controlling invasive plant species and it should be emerged as a management program rather than mere an eradication campaign because it is vital to protect intact ecosystem from invasion while keeping the affected system restored.

In contrast, more sophisticated approaches such as biological or chemical controlling mechanisms should be subjected to comprehensive analysis in order to make out the adaptability for a particular ecosystem because a particular mechanism for a particular invasive species in a particular ecosystem might be not productive for the same species in another ecosystem. On the other hand there are two major draw backs. First is that the controlling mechanism has every chance of effecting the native species too as the mechanism applies in more general to the ecosystem but not as selective to particular invasive species. Second, in biological controlling, introduced newer species can be invasive in later in the same ecosystem or any other.

Adhering to the ecological solutions instead of technological is supposed to be more reliable and sustainable in managing and controlling invasive species because technological will lead to newer problems which may require additional technological solutions where there will be no ending.

2.1.7 IAS in Sri Lanka

In the Sri Lankan context, large or average grown trees are less susceptible to become invasive while small trees, herbs, shrubs, grasses, creepers and aquatic weeds are dominant. According to the current knowledge almost all invasive alien plants in Sri Lanka are vascular plants (Wijesundara, 2010) and some of the species like *Cuscuta* can be parasitic as well. The following table 2.3 summarizes the identified IAS in Sri Lanka.

Table 2.3: - IAS in Sri Lanka

Invasive Species	Distribution	Affected Ecosystem
Annona glabra	Lowland Wet Zone	Coastal lagoon marshes
Salvinia molesta	Island-wide	Tanks, Ponds, Marshes, Streams
Eichhornia crassipes	Island-wide	Tanks, Ponds, Marshes, Streams
Lantana camara	Island-wide	Scrubland, Degraded open forests
Ulex europaeus	Montane Zone	Montane Forests, Wet pathana grasslands
Eupatorium riparium	Montane Zone	Montane forests
Panicum maximum	Island-wide	Wastelands, dry patina grasslands, agricultural lands
Cestrum aurantium	Montane Zone	Montane forests
Prosopis juliflora	Arid Zone	Thorn scrublands
Opuntia stricta	Arid Zone	Thorn scrublands
Clidemia hirta	Lowland Wet Zone	Rainforests
Swietenia macrophylla	Lowland Wet Zone	Forest edges
Mimosa invisa	Lowland Wet Zone	Forest edges
Dillenia suffruticosa	Lowland Wet Zone	Forest edges
Mimosa pigra	Intermediate Zone	Riparian areas
Leucaena leucocephala	Intermediate Zone	Dry-mixed evergreen forests
Clusia rosea	Sub-montane Zone	Rocky outcrop forests
Parthenium hysterophorus	Dry & Intermediate	Fallow fields, marshy areas
Wedelia trilobata	Wet & Intermediate	Forest edges
Myroxylon balsamum	Wet & Intermediate	Dry-mixed evergreen forests
Alternanthera philoxeroides	Island-wide	Fallow fields, marshy/riparian areas
Hydrilla verticillata	Island-wide	Streams, canals & marshes

The picture of introduction of alien plants to Sri Lanka runs thousands of years back to the introduction of our most venerated tree, the sacred “Bo” tree (Sri Maha Bodhi) at Anuradhapura (Wijesundara, 2010). Even the main export agricultural product crops in Sri Lanka; tea, rubber, coconut, cocoa, coffee and etc, were deliberately introduced alien species which still contribute to the national economy. Except the economically valued flora, many other ornamental plant species were introduced during the colonial period as ornamental plants through the collaboration of Royal Botanical Garden of Peradeniya (See Appendix 03). However, many of the introduced species have later become invasive as those were let free into natural ecosystems.

One of the best examples for accidental or non-deliberate introductions of an invasive plant is the Congress weed (*P. hysterophorus*). This plant was believed to have entered the northeast of the country in the late 1980's through goats imported from India (Jayasuriya, 2001). Seeds of this particular species have also entered the island along with seeds of onion and chilly imported from India as a contaminant.

Salvinia molesta is supposed to be introduced as educational material. *Mimosa pigra* has been introduced to strengthen the Mahaweli river bank in 1980s. *Panicum maximum*; one of the noxious weed (Ranwala et al, 2011), has been introduced as cattle feed pasture in 1801 A.D. (Wisumperuma).

Nevertheless some plants show invasive characteristics after a considerable time since the first introduction. For example, the Guinea grass (*Panicum maximum*) was not considered as a weed in 1908 even though it is believed to have been introduced around 1801-1802 (Ranwala et al, 2011)

2.1.8 Institutional framework for IAS in Sri Lanka and IAS management/ control

There are some legislation enacted in Sri Lanka to facilitate prevention, control and management of invasive species such as Water hyacinth ordinance No 4 of 1909, The plant protection ordinance 1924, Fauna & Flora Protection Act, Seed Act of the department of Agriculture 1999 and 2003.

A National Action Plan for the Control of IAS in protected areas has been formulated in 2007 by Ministry of Environment (ME) as a part of the addendum to the biodiversity conservation of Sri Lanka. Attached to the program, a National Invasive Species Specialist Group (NISSG) has also been appointed. Number of workshops and symposia has been conducted by the biodiversity secretariat of ME to increase awareness of public community about adverse impacts of IAS (Wijesundara, 2008).

Department of Agriculture (DOA) is engaged in biological control of *S. molesta* using the weevil *Cyrtobagus salviniae*. Further DOA has been using bio-control agents *Neochetina eichhorniae* and *N. bruchi* to control *E. crassipes*.

DOA has implemented a chemical controlling program for *E. crassipes* in northwestern province in collaboration with irrigation department.

A joint project of ME, DOA, universities and governmental & non-governmental organizations has been carrying out in controlling *P. hysterophorus* where a special gazette notification was released in prohibiting movement of materials contaminated with any part of *P. hysterophorus* from the infested areas.

ME together with DOA implemented a year program of management of aquatic weeds in 2005/2006 having funded of FAO.

Department of Wild Life Conservation (DWLC) has launched a program to manage the spread of *P. juliflora* and *O. dillennii* in Bundala national park.

But some of the eradication came out with complications due to having interaction with the wildlife during their existence in a particular ecosystem. For example, eradication program of *Ulex europaeus* were aborted due to the fact that endemic lizards and amphibians use this plant as a protection from their natural enemies. Similarly eradication of *L. camara* from Udawalawa National park has also encountered practical difficulties.

On the other hand eradication of some other species is affected by conflicts in the policies. Forest department is promoting planting of *C. rosea* in Knuckles range as a fire prevention measure while DWLC promoting planting or maintaining *P. maximum* as a food source for elephants.

2.2 Energy in Sri Lanka

2.2.1 World energy balance

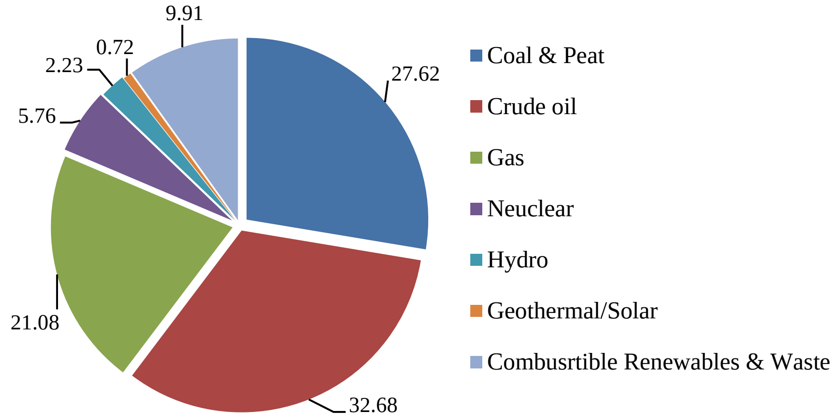


Figure 2.1: World energy Balance as at 2010 (International Energy Agency, 2012)

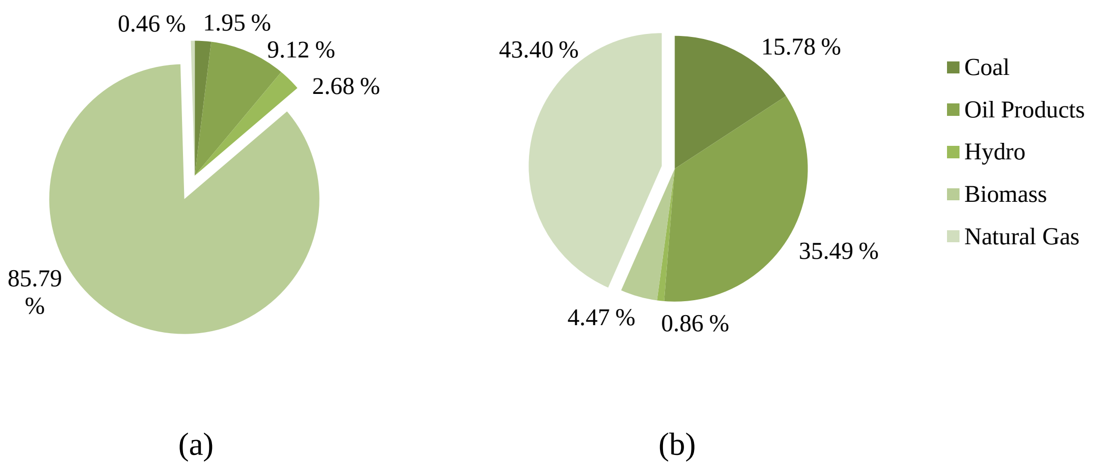


Figure 2.2: (a) Energy balance of Nepal as at 2009, (b) Energy balance of Malaysia as at 2009 (International Energy Agency, 2010)

The above figure 2.1 illustrates the energy balance for the world as a total even there can be considerable divergences in between countries though. But still, biomass renewable combustibles account for 10% share of the total which is sensible (There are lots of statistics available for energy account as per the whole world where the percentage value of biomass is varying in the range of 9% to 13%). The following figure 2.2 depicts the uncharacteristic energy generation between a developing country and a developed country.

2.2.2 Sri Lankan energy balance

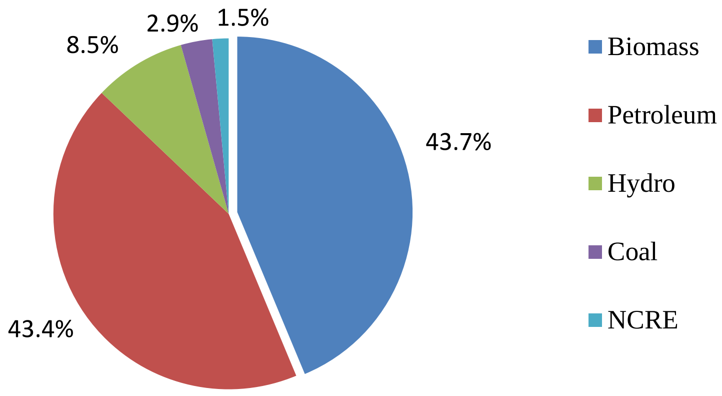


Figure 2.3: Primary Energy Supply in Sri Lanka in 2011/percentage for the total of 11034.3 TOE*1000 (Sustainable Energy Authority, 2010)

Looking into the figure 2.3, Sri Lankan energy profile is quite different from both Nepal and Malaysia; those are dominant with biomass and fossils respectively, which shows the features of a developing economy. Approximately 54% of the energy comes from indigenous renewable sources composed with hydro, biomass, solar and wind. The rest is coming from fossils, those of petroleum and coal having contribution of 43.4% and 2.90% respectively.

The total utilization of indigenous energy resources is limited due to technological, socio-economic and political reasons. All the fossils are imported to the country. Even though it has found the availability of crude in North-West Sea, those are still to explore and extract. Electrical generation is powered by petroleum, coal, hydro, solar photovoltaic and wind.

Largest energy consuming sector is the household, commercial and other sector, using a share of 48.0% of the country’s total energy demand. Transport sector share of energy consumption, which is mainly met through liquid petroleum, accounted for a share of 27.6%, while the industrial sector accounts for 24.4%.

2.2.3 Energy patterns of Sri Lanka

The rural domestic cooking is still running on biomass energy where LPG is dominant in urban sector; may be due to lack of biomass supply, compacted housing (less space) and aesthetic factors like black smoke. Kerosene is also a popular energy source especially in up hills for cooking and domestic lighting where kerosene is marketed at a subsidiary price.

The electrification of the country has been achieving the saturation level and grid connected coverage is approximately 91% where another 3% coverage is achieved by off-grid renewable energy sources (solar, wind, mini hydro).

Diesel & Petrol fuel the transportation even there are few LPG driven vehicles though. This is the limiting factor in reducing the fuel imports because transportation consumes a greater portion which is having less or no sophisticated substitutes.

When it comes to the industrial sector, they are fueled by both grid electricity and either biomass or fossil fuels; diesel, furnace oil or coal. Refer Appendix 04 for detailed energy statistics.

2.2.4 Energy production and distribution in Sri Lanka

Even though there are proven oil reserves in Mannar basin, those are yet to extract and hence all the fossils including petroleum and coal are imported by now. Liquid petroleum is imported as both crude oil and refined products where Ceylon Petroleum Corporation (CPC) owns the sole refinery in Sri Lanka. Liquid product distribution network is operated by CPC and Lanka Indian Oil Corporation (LIOC). LPG is imported and distributed by two companies, Litro Gas Lanka Limited and Laugfs Gas PLC. For coal, There is no any authorized agent and private sector themselves import the required quantities.

Electricity generation is achieved by both private sector and governmental organization. Ceylon Electricity Board (CEB) owns the governmental power plants and both CEB and Lanka Electricity Company (LECO) are in process of distribution. After mid 90s, a significant involvement of private sector organizations in power generation could be observed. The composition of the electricity generation sources has been subjected to gradual changes from hydro, hydro-oil mix to hydro-oil-coal mix.

As far as biomass is concerned, home gardens alone provide the majority of the house hold cooking fuel wood demand. Dedicated energy plantations, inter cropped energy plants (in coconut and tea plantations), agro-industrial waste (bagasse and peeled cinnamon sticks), wastes from timber industry (sawdust), seasonal uprooting and pruning of long term agro plants (rubber and tea) and forestry supply the industrial biomass supply. Individuals and private sector organizations facilitates the wood supply chain network.

2.2.5 Biomass cook stoves in Sri Lanka

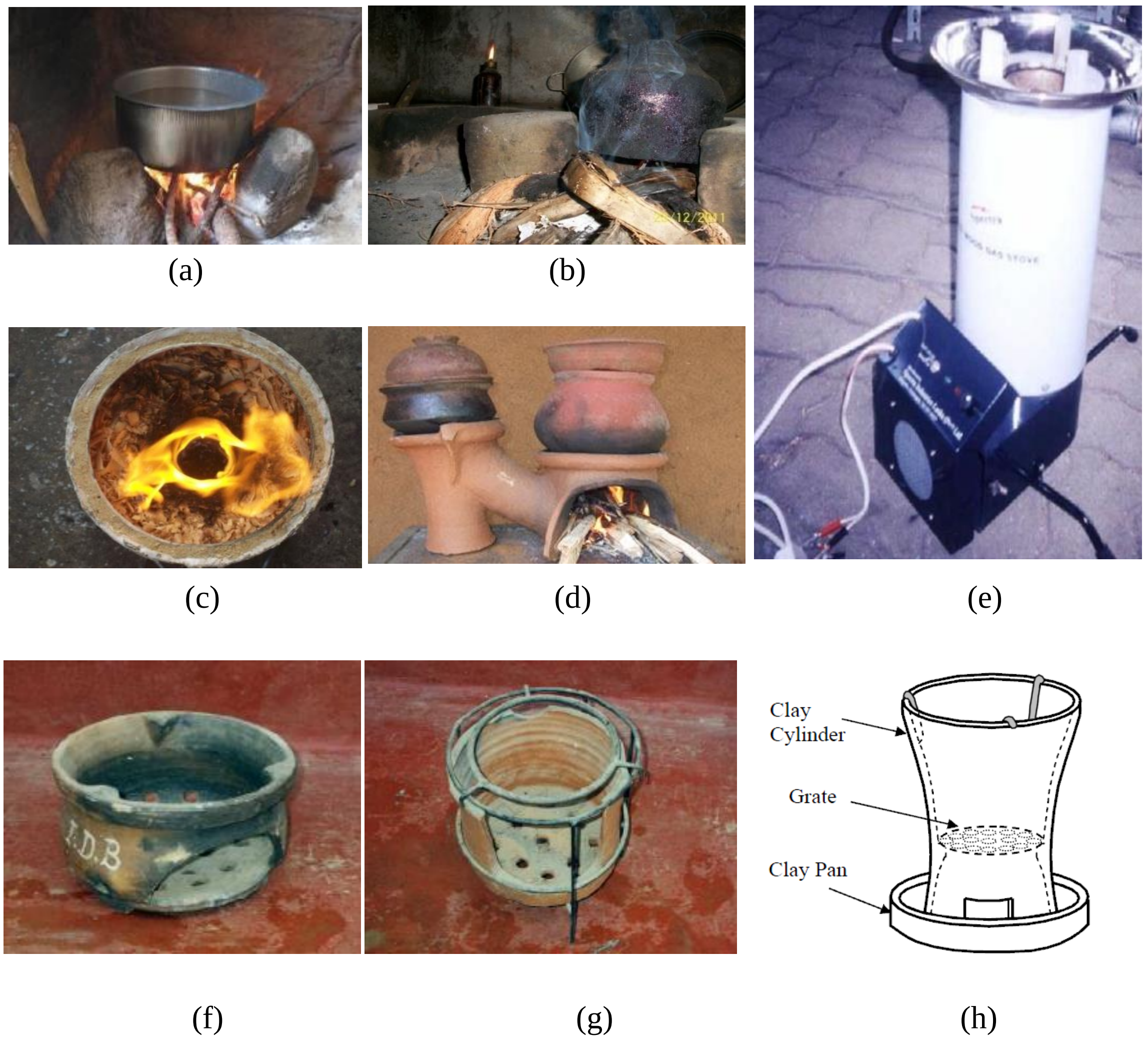


Figure 2.4 - Wood cooking stoves in Sri Lanka, *(a) - Traditional 3 stone stove, (b) - Traditional U shaped semi closed stove, (c) - Sawdust stove, (d) - Anagi stove, (e) - NERDC gasifier stove, (f) - IDB stove, (g) - NERDC stove, (h) CISIR charcoal stove*

About 80% of the total wood consumption is occupied for the cooking purposes and hence it is vital to improve the wood cooking stove performance. Fuel wood, sawdust, coconut husk and paddy husk are the major feed stocks involved where the demand is fulfilled by home gardens in many situations. However, U shaped stove is the highly used type and even though the thermal loses has cut off to a certain extent, other drawbacks, those of combustion inefficiency, fire hazard, difficulty in fire controlling, continuous attention and respiratory health risks, are still there (Perera & Sugathapala, 2002)

Anagi cook stove was developed by Industrial Development Board (IDB) and has been popular due to its improved efficiency compared to traditional cook stoves followed by durability and as it comes in a readymade package which could be installed in no time. National Engineering Research and Development Center (NERDC) has developed a high efficient gasifier cooking stove, which however did not approach commercial level though.

The energy efficiencies of the available biomass cooking stoves are in a range of 8% to 30%. The traditional three stone stoves are having the minimum value of 8% while Anagi and NERDC stoves are having efficiencies of 18% and 27% respectively.

2.2.6 **Energy Policy of Sri Lanka** (Siyambalapitiya, 2001)

This energy policy document was generated in the form of a "*Report of the National Committee to Formulate the National Energy Policy of Sri Lanka"* in 1997 by the ministry of Irrigation & Power. Few initiations had been taken by the Natural Resources, Energy and Science Authority (NARESA) (currently the national science foundation - NSF) in early 80's though.

The energy policy is divided in to ten elements as (1) providing the basic human energy needs, (2) reducing Dependence on imported energy and diversifying energy sources, (3) choosing the optimum mix of energy sources, taking into consideration the ability to influence demand on source types, (4) optimization of the operation of available energy resources (hydroelectricity, biomass, solar, wind, oil), (5) conserving energy resources and eliminating wasteful consumption in the production, distribution and use of energy, (6) developing and managing forest and non-forest fuel wood resources, (7) adopting an appropriate pricing policy and ensuring price stability, (8) ensuring continuity of energy supply, (9) increasing the content of local Manufacture, fabrication, construction and value addition in energy supply and utilization areas, (10) establishing the capability to develop and manage the energy sector.

2.2.7 Cost of Energy Imports in Sri Lanka

The following table 2.4 contains the cost on energy import of Sri Lanka.

Table 2.4: - Petroleum Importing Statistics (Central Bank of Sri Lanka, 2010)

Energy Imports						
Year	**2007**		**2008**		**2009**	
Item	Tons x 1000	Rs. Millions	Tons x 1000	Rs. Millions	Tons x 1000	Rs. Millions
Crude Oil	1938	113584	1853	143159	2066	111715
Refined	2216	150390	2145	202144	2098	126148
LPG	156	12027	144	15301	146	12153
Share As Per Total Imports						
	US$ millions					
Total Imports	11296.5		14008.4		10206.6	
Petroleum imports	2500.7		3368.2		2166.6	
Share	22.10%		24.00%		21.20%	

2.2.8 Future Energy Prospects and Biomass Energy Trends in Sri Lanka

Biomass, hydro, solar and wind are the indigenous energy sources within the country and all of them are renewable. The expenditure on fossils gives a clear indication that there is a challenging task left that is to enhance the energy security and save foreign reserves. Further, the same idea is reciprocated by the national policy as well.

With the development of the country at a rate of 6-8% annually, the energy demand of all the sectors, those of electricity, petroleum and biomass, has increased.

With the commencement of Upper Kotmale hydro project, Sri Lanka will be running off with potential major hydro facilities totaling an installed capacity of 1355 MW while there is few hundreds of mini-hydro installation remaining (Ferdinando, personal contact). Looking into the future, 10% of the electrical generation is targeted to be achieved via renewable energy sources including biomass, wind and mini hydro by 2016 and 20/20 (20% electricity generated with non-conventional renewable energy sources by 2020) is a further long term target. However, coal tends to be the fossil fuel based thermal energy conversion source with the 300 MW installations at Norochchole which will be extended to 900 MW.

However, there is no any specific renewable energy target in the transport or industrial sectors. The petroleum consumption in transportation shows a continuous growing and so will be in the future. In contrast, biomass is more demanding than fossils in industrial thermal energy generation where even the existing petroleum users in the industrial arena are shifting to biomass. Nevertheless, households tend to shift to LPG but recent statistics show an increased wood consumption due to increased population. Hence, as a total, the biomass demand within the country is increasing where the supply chain side should be reinforced with the development of conversion technologies followed by equipment fabrication.

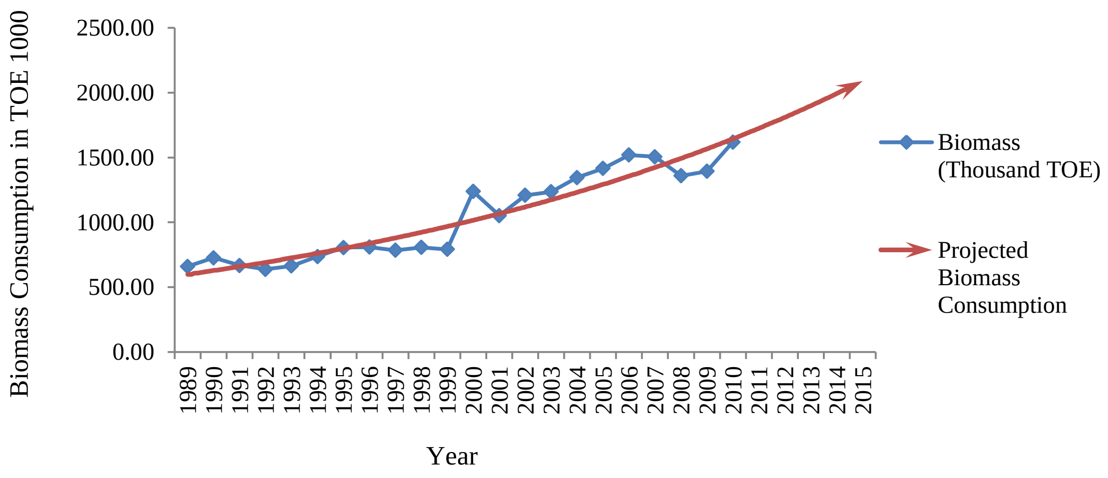


Figure 2.5: - Projected values of total biomass consumption of Sri Lanka (SEA, 2010)

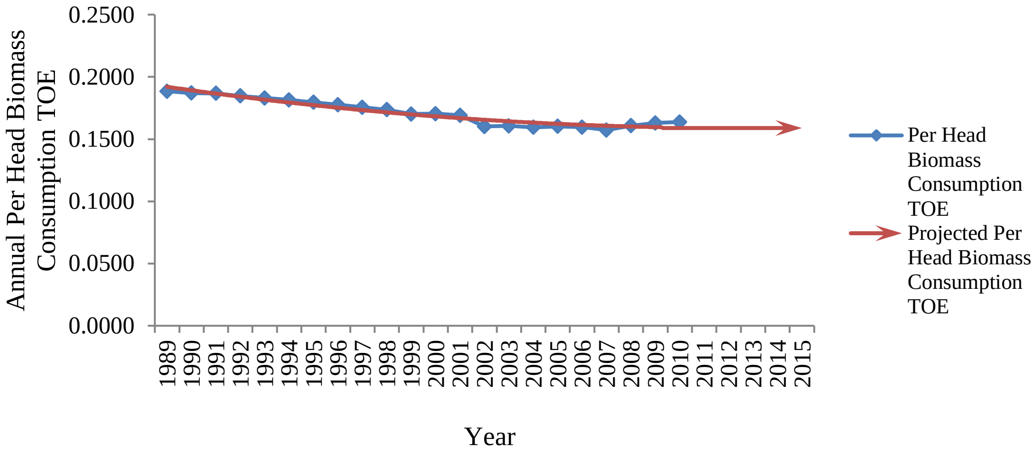


Figure 2.6: - Decreasing per capita house hold biomass consumption and projected values (SEA, Department of Census and Statistics, 2010)

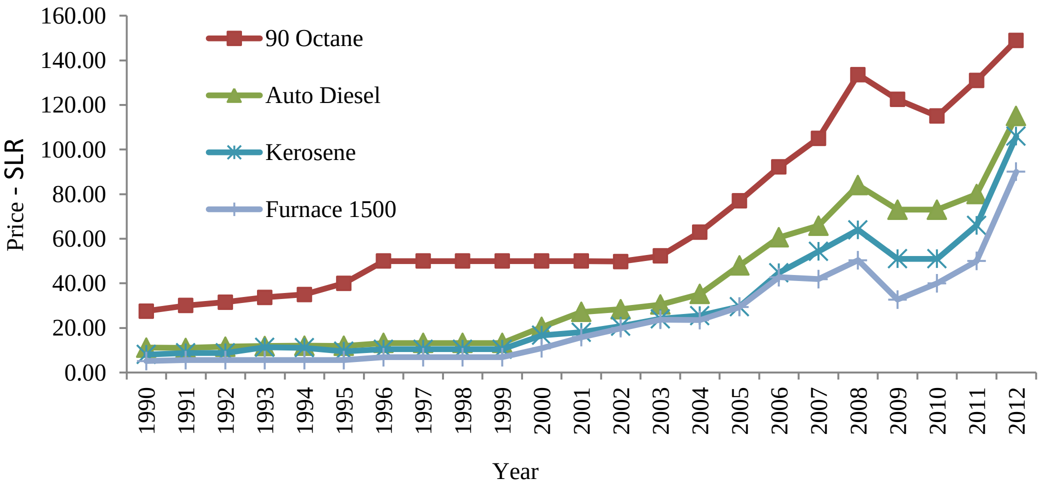


Figure 2.7: - Increasing petroleum process in Sri Lanka

Sustainable Energy Authority is the key driver of renewable energy sector and recently, a separate ministry was also formed for renewable energy (Ministry of Environment and Renewable Energy).

2.3 Biomass Energy

2.3.1 Sustainability, atmospheric CO2, climate change and renewable energy

Sustainability is having a balance system of Economic, Environment and Social conditions (Triple Bottom Line) where sustainable development can be broadly defined as living, producing and consuming in a manner that meets the needs of the present without compromising the ability of future generations to meet their own needs. It has become a key guiding principle for policy in the 21st century. Worldwide, politicians, industrialists, environmentalists, economists and theologians affirm that the principle must be applied at international, national and local level (John Twidell & Tony Weir, 1986).

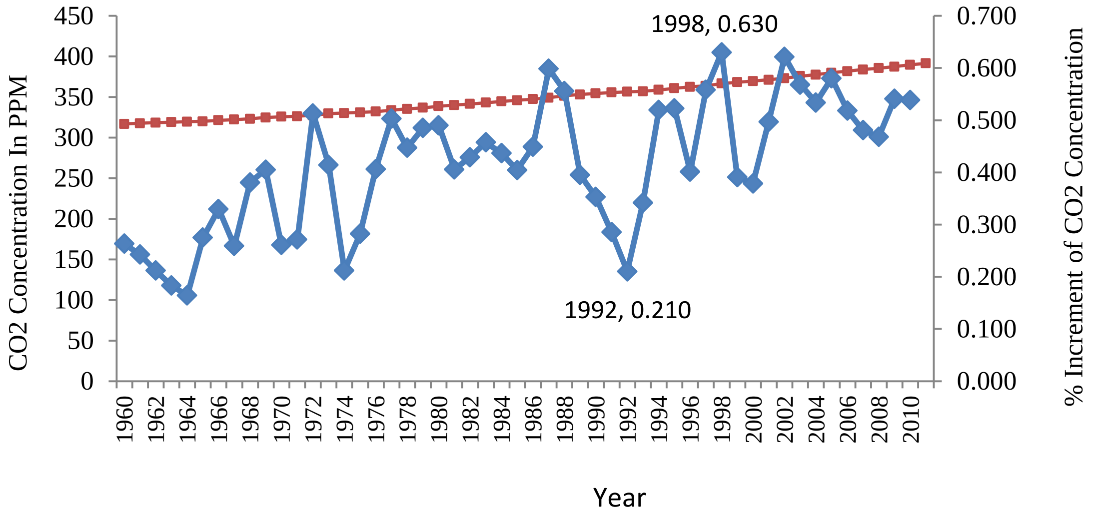


Figure 2.8: - Increasing CO2 concentration in atmosphere

Food and Agricultural Organization of the United Nations believes that current deforestation rate is approximately 13 million hectares (including 6 million of hectares of primary forests) per year even the rate of deforestation has achieved a remarkable decline since mid 90's and existing forest coverage is estimated to be approximately 4 billion hectares (31% of the total land area). Forest biomass carbon storage is estimated to be 289 Giga tones and deforestation reduces this stock converting them into other forms such as atmospheric CO2 (FAO, 2010).

Increased using of fossil fuel resources and deforestation along with other GHG emissions have caused in increasing global temperature; one of the key future challenges on earth. Hence "Renewable Energy" has become a key runner in overcoming above issues (Anu Kauriinoja, 2010).

Renewable energy can be defined as "energy obtained from the continuous or repetitive currents of energy recurring in the natural environment (Twidell and Weir, 1986), or as "energy flows which are replenished at the same rate as they are used (Sorensen, 2000). Ideally, a sustainable or renewable energy source is,

- One that is not substantially depleted by continued use
- Does not entail significant pollutant emissions or other environmental problems
- Does not involve the perpetuation of substantial health hazard or social injustices

United States, China, Germany and Brazil are the leading nations having higher number of renewable energy system installation (REN21, 2011). Solar thermal, solar photovoltaic, wind mills, mini/micro hydro, geothermal, and biomass are the key renewable energy sources.

2.3.2 Biomass

Table 2.5: - Biomass categories

Sugar	sugarcane, sugar beet, sweet sorghum, sugar manufacturing waste (molasses)
Starch	corn, wheat, cassava, food industry waste
Fat	palm, Jatropa, algae, food industry waste (used oil)
Lignocellulose	forestry residues, agricultural residues (straws and husks), timber industry waste (saw dust), bagasse, perennial grass, dedicated plantations

Every component which stems out from flora and fauna including microorganisms can be considered as biomass and the energy derived is termed as biomass energy. It does not matter that from where in the food chain we extract the biomass, but green plants, via photosynthesis, are the sole primary food provider to the living beings. However, those synthesized matters are stored in various forms within plants themselves such as sugars, starch, oils and lignocelluloses and converted into various other chemicals at downstream of the food chain. Dung from farms, industrial waste from meat processing facilities and microbial sludge from waste water treatment units are the major sources of fauna based biomass. The global production of plant biomass, where 90% of it is composed with lignocellulose, is 200 x 10^9 tons per year and about 20 x 10^9 tons remain potentially accessible (Szczodrak and Fiedurek, 1996). Hence the lignocelluloses tend to be the upcoming biomass source.

As CO2 is absorbed back by green plants during photosynthesis, the biomass energy systems are said to be CO2 neutral unless the energy consumption in transportation and pre-processing is concerned. Apart from that, the same phenomena is a way of CO2 capturing and storing where ocean is the other responsible agent for the CO2 sequestration. Moreover, on one hand, biomass is beneficial in enhancing the energy security of non oil producing country and improving the rural economy on the other.

In contrast to the positive outcomes, there are number of identified drawbacks related to biomass energy systems. Firstly, the utilization of edible feed stocks such as starch, sugar or oil and employing the land for energy plantations have caused for the rise of world food price directly. Further, it has triggered the deforestation, especially in countries like Brazil, which has become a huge threat to the biodiversity and consequently the environmental sustainability.

2.3.3 Chemical composition of lignocelluloses

The biomass is composed with mainly Carbon, Hydrogen and Oxygen with minor fraction of nitrogen followed by minerals. There can be trace amounts of sulfur as well. These elements together make four major organic compounds, those of cellulose, hemicelluloses, lignin and crude protein (Pan & Sano, 2002). Cellulose is the crystalline fraction of the material where it is believed to be the most abandoned natural polymer, composed with repetitive glucose units, on earth and it is the building block of plant cell walls. In contrast, hemicellulose, which is again a polymer, is composed with repetitive C-5 sugars, those of pentose, mannose and arabinose. Lignin acts as the bonding agent between cellulose which gives the rigidity for wood. The compositions of these compounds can be varied from species to species. The ash content is also varied from species to species which is mainly composed with CaO, MgO, K_2O and many other minor mineral oxides.

2.3.4 Perennial grass and invasive plants as energy feed stocks

Klass, 2004, clearly provides the evidences that perennial grasses like Panicum maximum and Napier grass generate much more lignocellulosic feed stocks compared to hard woods like Poplar or Willow. USA and Canada are leading countries which have undertaken number of researches in developing grasses such as Switchgrass and Miscanthus as energy crops. Those are having lots of advantages over hard wood where the interest is even higher as feed stocks for second generation liquid biofuels manufacturing. Besides from second generation that, perennial grasses have attained interest in co-firing with coal fired power plants.

Capability of mechanized harvesting, reducing soil erosion, enhancing soil structure (high sub-terrestrial carbon sequestration), high yield over wide range of geographies (specially C4 photosynthesis cycle grasses), low water and nutrient requirement (can be grown in marginal lands, less fertilizer requirement), high resistant to pest attacks (less agro-chemicals requirement) are identified positive facts for perennial crops. IAS is having many of the features that a biomass energy crop should have, including above features followed by resistance to continuous removal of plant material.

2.3.5 Biomass to energy conversion

The conversion technologies are dependent on the composition of the feed stocks and more over end user requirement. Moisture content is vital too.

High concentrated/pure sugar and starch based feed stocks are more desired to be converted into ethanol or butanol via bio-chemical (hydrolysis and fermentation) methods which has acquired a growing interest as a liquid bio-fuel, a substitute for gasoline. In contrast, less concentrated streams are subjected to anaerobic digestion to produce biogas. Fat matters are more likely to be transferred into bio-diesel through a chemical conversion which has emerged as a diesel substitute.

The Conversion of solid biomass materials has a precise objective to transform a carbonaceous solid which is originally difficult to handle, bulky, hydrophilic, vulnerable to biodegradation, poor flowability, heterogeneous and low energy concentration into the fuels having physico-chemical characteristics which permit economic storage and transferability trough pumping systems. As far as the lignocelluloses, the largest biomass feed stock on the Earth, are concerned, there are number of technologies to convert them directly into energy or secondary fuels. Even though the liquefaction and fermentation is being tested for lignocellulose, it is yet to peep into the commercial scale. Hence, as the secondary fuel synthesizing technologies are concerned, gasification seems to be the simplest and well established technology in worldwide since a long time back. However, still, 97% of the biomass energy systems are using the direct combustion as it is the simplest technology known for thousands of years.

2.3.6 Fuel characteristics for thermal conversion of lignocelluloses

The contents of carbon, hydrogen and oxygen which are the main components of solid biofuels are of special relevance for the gross calorific value. The hydrogen content also determines the net calorific value. The fuel nitrogen content is responsible for nitrogen oxide formation and should not exceed 0.6% w/w in dry matter (DM). Sulfur is one of the elements responsible for deposit formation, corrosion, and aerosol and sulfur oxide emissions. Sulfur concentration should be lower than 0.1% w/w in the DM. Chlorine as well is involved in corrosion, deposit and aerosol formation. Furthermore, it causes hydrogen chloride and dioxin and furan emissions. Chlorine content should be kept under 0.1% w/w in the DM. The ash content influences the choosing of appropriate combustion technology, deposit formation, fly ash emissions, ash storage and utilization/disposal. Major ash forming elements are aluminum, calcium, iron, potassium, magnesium, sodium, phosphorus, silicon, and titanium. They are of relevance for the ash melting behavior, deposit formation, and corrosion.

Main physical fuel properties are calorific value, moisture content, particle size, bulk density, ash melting behavior. The calorific value first of all depends on moisture content, decreasing linearly with rising moisture content (McKendry, 2002). Furthermore it is negatively correlated to the ash content. With every 1% increase in ash concentration, the heating value of the fuel decreases by 0.2 MJ per kg of DM (Jenkins et al., 1998).

2.3.7 Biomass gasification overlook

Gasification, as it name depicts, a technology which produces a combustible gas called “Syn-Gas” or “Producer-Gas” by means of partially oxidation of solid biomass which can be used as either combustion fuel in IC engine/gas turbine/boiler or feed stock for chemical synthesis (Makendry, 2002). Theoretically, process converts biomass into combustible gas that ideally contain all the energy originally present in biomass but having practical efficiencies of 60%-90% (Reed & Das, 1988).

Gasification, at their outbreak during the industrial revolution, has been used to produced gas termed as "town gas" for lighting (Mayer, 1988). Bischaf has patented the first commercial gasifier in 1839 while initial steps for IC engine operation have been taken at 1881 (Stassen and knoef, 1993) and was a popular vehicle energizing device during World War II as a transportation fuel, especially in German military (Rowland, 2008). But during the post war period, the popularity of producer gas industry declined due to economical access of fossil fuels. But with the energy crisis of 1970s, biomass gasification was re-invented as an economical renewable energy source (Loewer et al, 1982).

Generally, gasification is capable of running with any kind of biomass feed stock, but the equipment should be tailor made (at least the gasifying section) (Reed & Das, 1988) as per various feeding materials & their physical existence such as wood chips, saw dust, bagasse, paddy husk, paddy straw and many other. Further feed stocks having moisture content less than approximately 50% (less than 20% is the best recommended) are more desirable for gasification or in generally terms, for thermal conversion (Makendry, 2002). Main advantage of the gasification over direct combustion is that it is having more controlled combustion hence more controlled energy extraction with having less combustion residue (ash) and air pollution.

In compared to the LPG, the producer gas is having low calorific value and less consistency in the composition of the gas and consequently the energy output. Further it is uneconomical to store producer gas in a compressed liquid state (economical in storing and transportation) as it contains around 50% of N_2 gas. Therefore it should be consumed at the time of production and at a place nearby.

2.3.8 Chemistry and thermodynamics of gasification

Theoretical equation for the gasification as follows.

$$CH_{1.4}O_{0.6} + 0.2\ O_2 \longrightarrow CO + 0.7\ H_2$$

Unfortunately, as the energy content of the components of right hand side is greater than that of the left hand side, thermodynamically, forward reaction is impossible unless otherwise thermal energy is supplied from an external source (Reed & Das, 1988). In general practice, some additional oxygen/air is supplied in order to achieve the excess energy needed where CO_2 & H_2O will present in syn-gas in consequence. Hence, the above equation gets re-arranged as given below.

$$CH_{1.4}O_{0.6} + 0.4\ O_2 \longrightarrow 0.7\ CO + 0.3CO_2 + 0.1\ H_2O + 0.6\ H_2$$

Basic reactions of a gasification system are given below.

$C + 0.5\ O_2 \rightarrow CO$ +111 MJ/kmol

$C + 1.0\ O_2 \rightarrow CO_2$ +394 MJ/kmol

$CO + 0.5\ O_2 \rightarrow CO_2$ +283 MJ/kmol

$H2 + 0.5\ O_2 \rightarrow H_2O$ +242 MJ/kmol

$C + CO_2 \rightarrow 2\ CO$ -172 MJ/kmol (Boudouard reaction)

C + H2O → CO + H2 -131 MJ/kmol (Water gas reaction)

C + 2H2 → CH4 +75 MJ/kmol (Methanation reaction)

CO + H2O → CO2 + H2 +41 MJ/kmol (Shift conversion reaction)

CH4 + H2O → CO + 3H2 - 206 MJ/kmol (Steam methane reforming reaction)

2.3.9 Gasifying mediums

Gasifier systems could primarily be distinguished according to the gasifying media used those of air, oxygen, steam or CO_2. Atmospheric air is used in many cases where the producer gas gets diluted with Nitrogen (approximately 50%) which causes for reduced heating value for around 4-7 MJ/Nm^3 in turn. If Oxygen is used as the gasifying medium, the calorific value of the producer gas could be raised to a value of 12-28 MJ/Nm^3 and however oxygen is rarely used in the commercial level. Steam employed systems produce gas having a heating value in between while containing more H_2 in it which is a more attractive alternative for air. Supercritical water has also been tested as a medium for gasification where the producer gas is rich with H_2 and CH_4. When CO2 is used, it reacts with the char to produce CO and however the reaction rate is very low.

2.3.10 Syngas

The syn- gas composition is 50-54% N2, 17-22% CO, 9-15% CO2, 12-20% H2, 2-3% CH4 and high molecular weight chars (FAO, 1986). On an average 1 kg of biomass produces about 2.5 m3 of producer gas at S.T.P. In this process it consumes about 1.5 m3 of air for combustion (33% of stoichiometeric air for complete combustion). The gas composition highly proportional to the gasification medium and it is richer with hydrogen when steam is used. Further equivalence ratio also has a significant effect on the producer gas composition. The following figure clearly depicts the fact.

2.3.11 Classification of Gasifier Systems

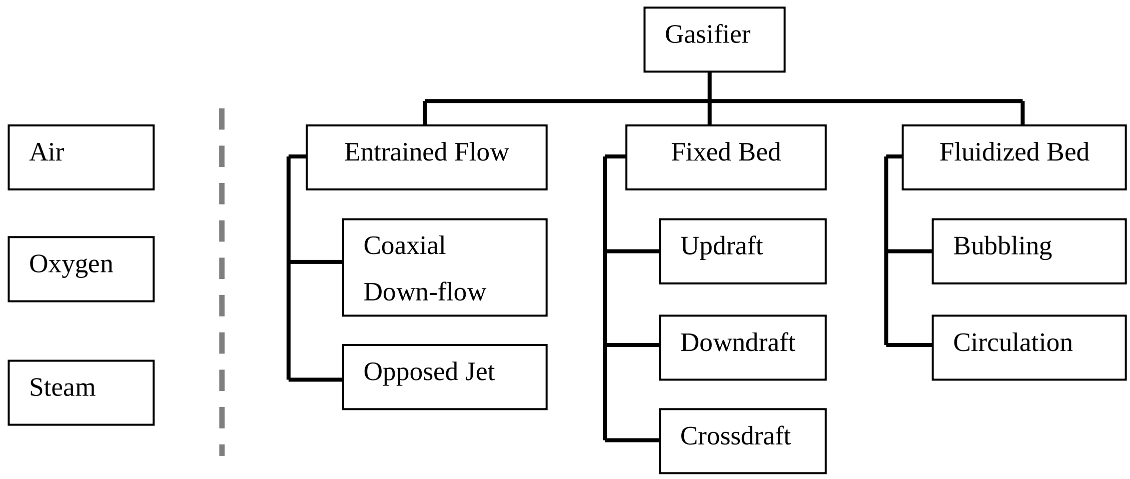


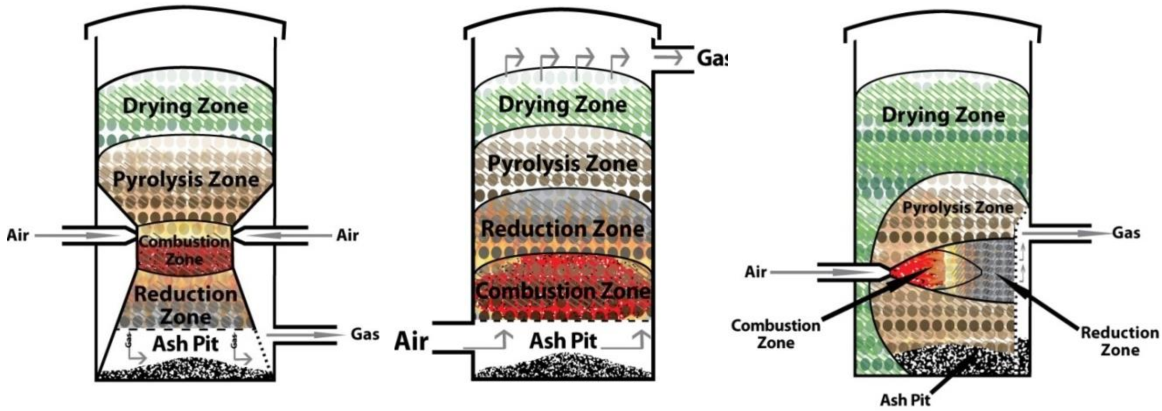
Figure 2.9: - Gasifier classification

2.3.12 Fixed Bed Gasification

Fixed Bed Gasifiers can be categorized in to 3 main processes as Up-draft, Down-draft and cross draft (according to gas flow) which is believed to be suitable for small & medium scale units in contrast to the Fluidized Bed which is more focused on large scale applications.

Downdraft systems have a co-current flow of air and biomass where the design can be either having throat or throat less. Zones are drying, pyrolysis, combustion and reduction respectively from the top and heat for the drying and pyrolysis zones flows as radiation energy or through conduction. Throat systems are more sensitive to shape & size uniformity of feed stocks in contrast to the throat less systems. Nevertheless both systems are more operable with smaller size feed stocks. Main advantage of downdraft systems in general that the presence of tar in the outlet gas is as less as 0.05 kg tar/ kg gas (Tiwari et al, 2006) as gases released (water vapor, tar & other minor compounds) in drying and pyrolysis zones is subjected to complete cracking in combustion zone. Due to the same reason, downdraft units are not good at high moisture feed stocks.

Updraft systems are counter-current systems where biomass is fed from the top and air is blew from the bottom. Starting from the top, the zones are drying, pyrolysis, reduction and combustion respectively. As the combusted gas passes through all the zones carrying thermal load as convective flows, a better heat exchange can be achieved which will lead to high thermal efficiencies. While having the advantage of handling high moisture feed stocks, it is highly disadvantageous of being large amounts of tar presence in syn-gas around 10 – 20%.



(a) (b) (c)

Figure 2.10: - Classification of fixed bed gasification, (a) – downdraft, (b) – updraft, (c) – cross draft

Average gasifier efficiency lies between 60% & 70% (Rajvanshi, 1986) and highly depends on the gasifier design and the fuel characteristics. Downdraft systems are utilized in both engine operation and thermal applications while utility of updraft systems are narrowed down to thermal application unless proper downstream processing is installed to remove tar. Availability of particulate matter in syn-gas is also considerably low in updraft as biomass holding section acts as a filtering media which will intern result minimum gas cleaning. Thermal energy carryover with the gas is again less in updraft. Presence of high ash can cause operational drawbacks due to slagging. According to the FAO, 1986, the hottest part of the gasifier should be maintained above 700°C.

Drying

The drying zone lies at the top of the reactor where fuel wood is fed into the gasifier. The main function of this zone is to drive off the moisture in the form of water vapor from the wood and in the same time it acts as a temporary storage section which is commonly known as wood hopper. The rate at which drying takes place depends on the surface area, temperature and the internal diffusivity of wood particles, and the temperature, velocity and relative humidity of the surrounding air (Buekens & Schoeters 1986).

Drying occurs below 120°C and the necessary heat is transferred by conduction through wood particles or radiation in a downdraft system. In contrast, heat is transferred to the drying section in a updraft system by means of direct contact of hot producer gas (convection). This heat transfer is not fast enough to remove all the water inside the particle in the drying zone due to the low thermal conductivity of wood which is in the range of 0.006 - 0.011 W/m K. Thus drying is not confined to this region and it occurs in the primary pyrolysis zone as well.

Pyrolysis

The pyrolysis zone lies below the drying region. When fuel wood is heated to 200°-600°C in the absence of air/oxygen, the wood initially breaks down into oil vapor (tar), char (primary char) and gas (primary volatiles). The release of volatiles begins at 250°C (Reed & Das 1988) and this process is known as primary pyrolysis. Oil vapor generated near the surface of small particles can escape into the gas phase before being cracked into secondary tar (Reed, 1981). But these oil vapors are cracked at high temperatures (above 600°C) to form reformed gas such as hydrocarbons, mainly methane, and this process is called secondary pyrolysis.

For larger particles, the longer escape path provides more time for cracking the tars thus resulting in higher char production. Pyrolysis converts 95 to 80% of original mass into liquid phase products such as water, tars and oils, and gaseous phase products including, CO, CO_2, H_2 and hydrocarbons, leaving 5 to 20% of highly reactive char (Reed & Markson, 1983). The product stream's compositions and distribution of the pyrolysis process depends on factors such as the composition of the feed, heating rate, temperature, residence time of gaseous components and particle size (Buekens & Schoeters 1986).

Combustion

The existence of the combustion zone differs between updraft and downdraft. In an updraft designing, combustion zone lies below the reduction zone while it is wiser versa in a downdraft. Oxygen in input air reacts with char produced in the pyrolysis zone and produces combustion gas (CO2) and water vapor. Combustion of char is very rapid and the reaction is exothermic which results in a rapid rise in temperature. The temperature in this zone varies from 800°-1100°C (Reed, 1981). Heat produced from char combustion is the main heat supplier to the other regions of the gasifier. The hot combustion gas and water vapor produced in the combustion zone are next drawn into the gasification zone.

Reduction

This zone lies at the bottom of the downdraft gasifier where it lies above the combustion zone in an updraft design. The surrounding gases such as carbon dioxide and water vapor initially react with the char particles at their outer surface. Then the zone of reaction moves into the solid. This is known as diffusion of gas down the pore towards the centre of the particle. Then absorption of these gases and the surface reaction takes place. Finally desorption of product gases such as carbon monoxide and hydrogen takes place on the pore wall. These product gases are also known as synthesis gas. A portion of the hydrogen combines with carbon to form methane. These reactions are endothermic and they cause the temperature to decline from 1500° to 600°C in the gasification zone.

2.3.13 Tar Formation during gasification

Compared to the coal gasification, one of the major issues arising during biomass gasification is the tar formation. The main biomass characteristic relevant to this phenomenon is lower fixed carbon with high moisture and volatile matter content. Tar is a complex mixture of condensable hydrocarbons comprising single-ring to 5-ring aromatic compounds plus other oxygen containing hydrocarbons and complex polyaromatics. These tars are classified further as primary, secondary and tertiary and relevant details are tabulated below.

However, there are other classifications of tars as well such as according to the molecular weight as well.

As far as the quantity of tar produced is concerned, updraft is the worst having an approximate value of 100 g/Nm3. Fluidized design is having an intermediate level of 10 g/Nm3 where downdraft has found to be the best of having the least tar production at an average value of 1 g/Nm3.

The presence of tar can cause operational problems because of the possible formation of aerosols, soot formation due to re-polymerization and interaction of tar with other contaminants such as fine particles. In addition, heavy tars may condense on cooler surfaces downstream which can lead to blockage of particle filters and fuel lines. Hence, it is vital to remove tar or process them into non-condensable components, for gasification technology to be attractive.

Reduced tar content in the producer gas could be achieved by either primary methods that is inside the gasifier or secondary methods that is in a separate unit after gas is synthesized. Primary methods include appropriate selection of operating parameters, proper gasifier design and use of bed additives or catalysts. Secondary methods are mechanical removal in cyclones or electrostatic filters, thermal cracking, plasma cracking and catalytic cracking.

2.3.14 Micro Gasification/Gasifier Cooking Stoves

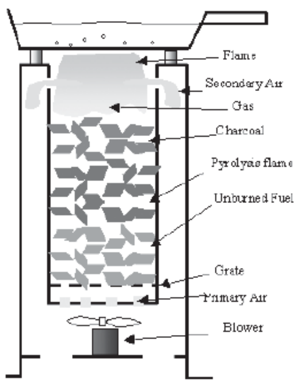


Figure 2.11: - Micro Gasifiers

Micro-gasification is mainly targeted to be used as cooking stoves with minimum mechanical devices and simpler operation as a batch reactor. To be a successful stove, it should satisfy four basic parameters, those of fuels for the heat, combustion to obtain the heat, applications of the heat, and human factors such as costs, cooking preferences/traditions, and user-friendliness. The latter two factors could be varied from place to place and culture to culture respectively.

Due to the initial introducing heat, volatiles come out form the wood as a smoke and it starts burning as the combustion air is supplied. For over a hundred years scientists and engineers have known that combustion of biomass is cleaner when the air is well mixed with only combustible gases, instead of having the combustion occur in zones where solid fuel is still present. The creation of combustible gases that are separate from the combustion of those gases is a clearly distinguishing characteristic of a true "gasifier."

The existing simple stoves use sticks of wood where it makes uncomplicated situations as far as the fuel and combustion are concerned, but it is still to deal with the shortcomings of poor complete combustion characteristics and emissions. In contrast all the above parameters are violated whenever a different kind of fuel, other than sticks, has to be used. The answer is micro gasification, where there are lots of successful research outputs found in literature.

Above figures, left; typical arrangement of a gasifier cooking stove and right; Dr Tom Reeds designing, illustrates the micro gasification. It clearly separates the primary and secondary air where it is not achieved in a traditional stove. Thomas D. Reed and Paul Anderson have been working on micro gasification and have developed several models such as TLUD and AVUD.

2.3.15 Biomass gasification in Sri Lanka

As biomass is and tends to be the dominant indigenous renewable energy, it is vital to develop both biomass supply and conversion technologies. Besides from the direct biomass fired boilers, biomass gasifiers have attained a growing interest during early 2000s and reached the maximum during 2007 to 2009 as a result of the rise in petroleum prize.

Prior to the commercial scale, there were few small scale units installed by NGOs in far rural villages for electrical power generation where no grid connection was available.

Later, few companies such as Heyles and EnerFab put hand into gasification where numbers of units were installed in the following years in factories and especially in hotel sector for thermal energy generation. However, few electrical power generation units of few kilowatts were also installed (i.e. Meemure and Kakkapalliya). Almost all the equipments were imported from India and Ankur gasifiers have been popular.

Preferred feed stocks are Gliricidia, Cinnamon, and Ipil Ipil which are chipped to 6 inches in length and no diameter higher than 2 inches. The optimum moisture content is supposed to be 20% or lower. However, uncertainty in continuous supplying of the fuel wood has been a huge barrier for the growing popularity of the gasifiers.

NERDC has been the pioneer research and development center for gasification designing and Swedish technology has been adopted. Several other research institutes, such as the University of Moratuwa, the University of Peradeniya, the Coconut Research Institute and the Tea Research Institute, are also involved with studies related to gasifiers, but up to now these efforts have been mainly limited to feasibility studies and field testing rather than technology development. Out of many designing systems in Sri Lanka, the gasifier cook stove marked the only success in commercial level.

3.0 Materials and Methods

3.1 Fabrication of Pilot Scale Gasifier

The Purpose of the construction of gasifier is to analyze the suitability of few invasive plant materials such as Guinea Grass and Arundo donax (Wijesundara, 2008) as feed stocks in order to develop this as an alternative solution for the invasive plant management in Sri Lanka which is giving a compromise solution.

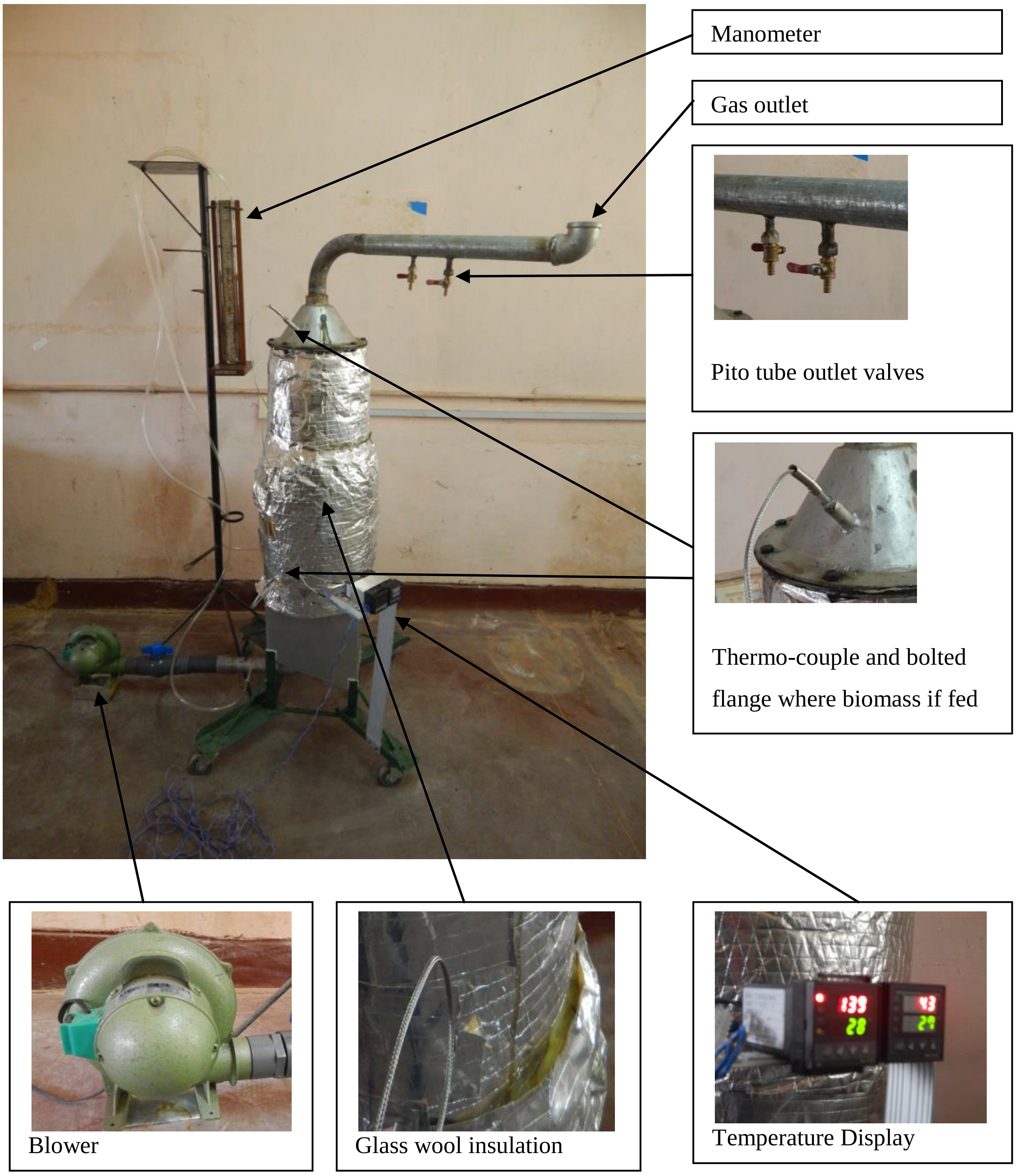
Many of the gasifiers are having the drawback of chipping the feed stock wood in to manufacture specifications (Miles, 1992). Preparation of wood chips according to the specifications has disadvantages such as electricity consumption, human labor needs, dust collection, noise production and accidents (Reed, 2005). Hence, either grass or softwoods having tiny stems are selected as feed stocks to be used without preprocessing into chips but as bundles having a same diameter to the gasifier section.

The hearth area dimensions were selected as per the Handbook of Biomass Downdraft Gasifier Engine System, Solar energy research institute, Golden, Colorado, 1988 and by the work of Patil and Rao (1993).

The gasifier system is composed with body (combustion zone plus hopper), ash collection box, blower assembly, support assembly and measuring facilities for temperature, flow rate and pressure.

As this is designed to be used at household level, the unit was equipped with minimum mechanical parts. Hence the unit was designed for batch wise operation. The size of the equipment was selected as suitable for the household use and more over, according to the available literature on gasifier cooking stoves. Diameter was selected as 200 mm where height was 800 mm and this is to facilitate required gas flow rate and half an hour operation in between successive feedings.

The body of the gasifier was fabricated with mild steel 200mm, schedule 40 pipe. Topmost closer was designed as a conical end to minimize the flow disturbance and gas outlet was provided with a 1.5 inch GI pipe. Pipe fittings for the instrumentation and inlet air were welded to the gasifier body using arc welding. The fixing of auxiliaries was done as either 4 mm thick mild steel and bolted flange connections or threaded



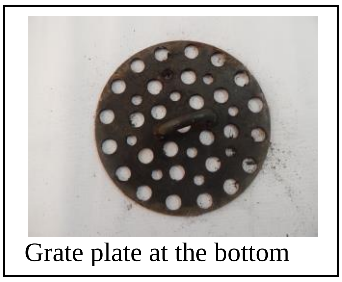


Figure 3.1: - Gasifier and Components

connections. Flanged connections were equipped with air tight gaskets made out of asbestoses fabric.

Ash collection box was made out of 2.5 mm thick mild steel sheets where the bottom plate of the box was designed having a taper to one side with a 2” x 2” opening as it facilitates ash removal (manual) and introducing the initiating fire. Air inlet pipe made out of GI and having a diameter of 1.5 inch was fixed to the bottom of the ash box.

Single phase (230 V), 1 kW induction motor blower was used to supply the combustion air. Blower was selected having a higher capacity in order to optimize the air flow. The blower outlet and air inlet to the gasifier was connected via a flexible horse in order to prevent the transfer of vibration and as the blower was a general purpose facility of the department of Chemical & Process Engineering. A 2 inch flap controlled valve was installed in after the blower to facilitate the control of combustion air. Blower was installed at inlet side because the unit was not equipped with gas cleaning units (if blower was fixed in the suction side, dirt might accumulate inside the blower housing) and available blower was a low temperature (if it was fixed in suction side, blower should have been a high temperature one as out gas was at few hundreds of centigrade) tolerance one.

The gasifier was insulated with 100mm glass wool insulation to a two third height from the bottom of the body and 50mm thick glass wool for the topmost one third in order to prevent the heat dissipation from the surface. Any excess heat loss would reduce the overall efficiency and efficiency of reduction and pyrolysis reactions.

L-angle supporting structure was facilitated with caster wheels as testing was intended to carry out outer side to the building premises (due to any CO leakage).

Temperature measuring devices, K-type thermocouples manufactured at Mega Heaters Private Limited with display units, were installed along the gasifier chamber in order to measure temperatures of combustion zone and outlet syngas.

Pitotube units were installed inlet and outlet in order to measure the gas flow rates and pressure drop across the biomass bed. Pitotube openings to the out were equipped with valves and connected to manometers with flexible tubes.

3.2 Sample Collection

As high sensitive electronic digital balance couldn't be used on site, a less sensitive (to nearest 1 g) balance was used for the field measurement. The balance was calibrated prior to the weighing.

Whenever the plant contains different distinguishable components such as leaves & stem in guinea grass, the sample was prepared as a collective sample representing all those sections. Approximately 500g sample was measured at an accuracy of nearest 1g with the calibrated balance. Then the sample was stored in a sealed polythene package (package weight was measure prior) having labeled the Date/time, Location (GPS coordinates), weight and average age of the plant.

3.3 Gasifier Operation

Dried guinea grass were weighted and introduced into the gasifier chamber in small quantities. Then the fed material was compacted manually at each step of feeding to increase the bulk density. No any controlled parameter was monitored to measure the level of compaction, but to the satisfaction to our intuition.

Next, the top cover with the gas pipe attached was fixed to the main body with carbon steel nuts and bolts where a gasket was placed in between to prevent any gas leakage. Grease was applied prior in both sides of the gasket to prevent stitching into flange. Gas collection port was attached to the sampling bag via flexible horses and kept the valve shut.

Then the power supply for the blower and temperature controllers was switched on.

Bottom ash removing opening was opened and blower was switched on. Then the biomass was ignited by inserting a candle through ash removing opening and the combustion temperature was monitored to identify the commencement of combustion followed by closing the opening. Combustion temperature and outlet gas temperature were monitored where a continuous flame had been introducing at the gas outlet. Gasifying air supply was adjusted accordingly and the flow rates were monitored.

Once the outlet gas stream tended to combust with a blue flame continuously, gas sampling port valve was opened and let the bag filled with producer gas. Sampling bag was fully evacuated by pressing with hand prior and valve was closed followed by tightening the valve at the sampling bag in order to prevent the leakage.

3.4 Producer gas analysis

Gas was analyzed by "Shimadsu GC – 2014" Gas chromatography at NERDC. The distinguishable compounds/elements were N_2, CO, H_2, CO, CH_4 and C_2H_4. The available column did not support the detecting of O2 or tar.

Figure 3.2: - Gas Chromatography

3.5 Moisture content of Guinea Grass

The oven was calibrated for 100 – 120 C with a calibrated thermometer.

The collected sample was measured at the laboratory along with the package and sample weight was calculated. The percentage loss of weight was calculated. A smaller representative sample about 25g was selected and measured with a calibrated scale at an accuracy of 0.01g. Then the reading was corrected as it gives the fresh sample reading with the use of above calculated weight loss percentage.

Then the moisture content was measured according to ASTM D 2016, Oven drying test method. The testing was carried out in Energy Laboratory, Department of Chemical & Process Engineering, University of Moratuwa, Sri Lanka.

3.6 Proximity Analysis

Samples were prepared as representative of all leaves and stems for herbaceous where only woody part was taken for woody species. Prepared samples were dried at 105 C for constant weight to remove moisture and kept at a decicater until transferred for the furnace.

The muffle furnace was calibrated at 600 C. Then, the dried samples were placed in crucibles. Furnace was switched off and heated up to 600 C. Ceramic crucibles were used and those were thoroughly washed and oven dried prior to used. An electronic scale having an accuracy of 0.001 g was used.

For volatile matter, the samples were kept for 7 minutes under 600 C and weighed. Then for ash, the samples were heated for 45 minutes under 600 C and weighed. Fixed carbon was calculated by the difference.

3.7 Calorific Values

Whenever the plant contains different distinguishable components such as leaves & stem in guinea grass, the sample was prepared as a collective sample representing all those sections.

Samples were subjected to drying under atmospheric conditions and the moisture content was measured at the same time of the calculation of calorific value, ASTM D 2016, Oven drying test method.

The calorific values were calculated at Holcim, GeoCycle Laboratory, Puttlam using model IKA C5003 Bomb Calorimeter (Adiabatic method).

Standards: - DIN 51900 – 3, ASTM E-(711-87)

Figure 3.3: - Bomb Calorimeter

3.8 Thermo Gravimetric Analysis

The thermo gravimetric analyses were done for both Arundo and Guinea in both oxygen and oxygen free environment. The tests were carried out in material testing laboratory at Sri Lanka Institute of Nanotechnology (SLINTEC).

The instrument used was, TGA instruments Q600 and the used ramp was 10 C per minute.

Samples were dried and cut into small pieces about 2 mm to 6mm. Testing samples were not powered because; it was supposed to maintain the real physical state which we were used in gasification experiments.

Figure 3.4: - TGA instruments Q600

4.0 Results and Discussion

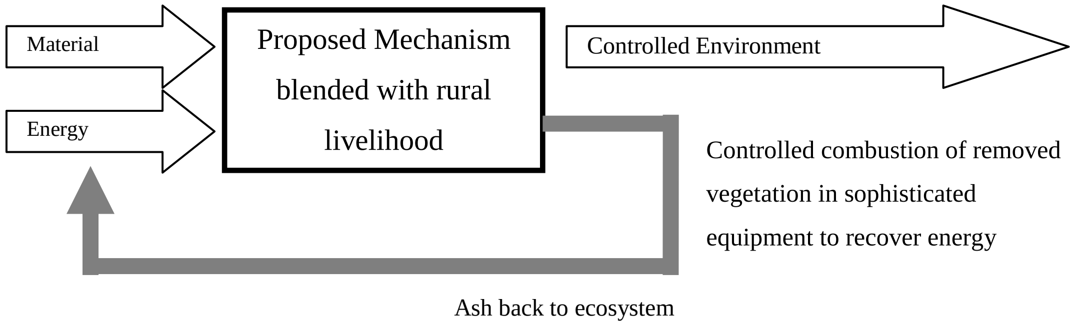


Figure 4.1: - Graphical overview of the research objective

4.1 Discussion with Experts of IAS Control Workshops

The following content is composed with the discussions with two genius in National IAS program followed by the discussions have had during the UNDP funded project of Strengthening capacity to control the introduction and spread of Invasive Alien Species in Sri Lanka.

4.1.1 Discussion with experts

According to Person "A", many launched programs did not attained high success rates. Many projects were short term and site specific where those have not been sustained in long term. Further, in some locations, IAS has embedded into the natural ecosystems and caused for the extinction of the existed inhabitant flora. On the other hand, few others have integrated into ecosystems where some faunal species have got used to depend upon those. Therefore it is a crucial task controlling the IAS and the word "IAS management" is more interested than "IAS eradication". Biological and Chemical controlling mechanisms are challenging because chemical mechanisms are not selective other than applying for plants individually where biological controlling is having every possibility of becoming introducing plants invasive later.

However, there are few success stories of managing IAS but those are self managing mechanisms integrated with rural livelihoods. The best example is *Arundo donax* which is locally known as *Apala*. It had been a cumbersome plant in Nuwaraeliya and Badulla districts where it later attained an interest as supporting sticks for vegetables such as beans. Consequently, by now days, that plant is self regulated where many farmers are even maintaining small cultivars for their own usage and business purposes. Each sticks sales at a prize of 3.00 LKR. Other example is Ipil Ipil which is currently being used as a fuel wood crop, especially in gasification. This plant has made its major habitats in Putlam district and can be seen in island wide.

Expert "B" In contrast to the idea of IAS control with getting integrated with rural livelihoods, it is having the critical adverse effect of trying of cultivation those crops for economical purposes where *Arundo donax* is a good example of that. Therefore the process should be well analyzed prior to launch. Further there are some industrial applications where IAS biomass is used as feedstock and utilization of Water hyacinth in recycle paper manufacturing is one of the best examples.

4.1.2 GEF project on "Strengthening Capacity to Control the Introduction and Spread of Invasive Alien Species in Sri Lanka" – One day workshop on "Stakeholder Consultation on Best Practice of Demonstration of IAS Control" (21st February 2013 at Taj Samudra, Colombo).

This is a project has started on 2010 and runs for a period of 5 years having a total budget over 5 million US$. The project is funded by both Government and GEF/UNDP where it deals with both floral and faunal IAS. This project intends to address the present gaps in controlling the introduction and spread of invasive species in the country by addressing barriers through appropriate policy intervention, coordination, economic instruments, legislation and information. The project outputs can be listed as follows.

- Legislation a national IAS policy followed by drafting a national IAS strategy and action plan
- Developing protocols based on IAS risk, early warning and blacklisting in use
- Generating a database with all relevant information which is open to public
- Granting the researches to come up with the existing gaps of IAS control
- Demonstration sites for eradication, controlling and conversion of IAS biomass into valuable products

At the beginning of the workshop, the findings and outcomes of the completed activities of the project was delivered. A tool for prioritizing of IAS in Sri Lanka had been developed based on Ecological and Socio Economic impacts, Invasive Potential, Distribution and Management Aspects. According to the prioritized list, Guinea grass has attained the 1st place and however, next 4 species, those of Eichhornia crassipes, Lantana camara, Mimosa pigra, Prosopis juliflora, have been selected to be addressed under the project. The major reason for not selecting Guinea grass is because it has grown in abandoned open land or areas of public dwellings such as by roads where the selected crops are having more threats in wildlife or forestry reserves. Again a criterion for prioritization of geographic areas for management of selected IAS has been developed under following key points.

- Areas that harbor one or more prioritized IAS for management
- Area of high ecological, cultural and economic significance
- Sites that supports local livelihoods
- Areas affected by IAS with implications on human health and well being
- Areas with easy access to implement control mechanisms
- Areas with other socio economic factors that facilitate management

According to above criterion, the selected sites for above 4 species are Bellanvila/Aththidiya sanctuary, Udawalawa national park and Hambanthota, Mahaweli middle catchment and Bundala national park respectively.

Eichhornia is supposed to remove manually or mechanically and use in biogas production in situ. Consultation of universities and experts will be acquired and the constructions will be handed over to private personals. Biological control is also under consideration as a long term plan.

Both Prosopis and Mimosa are intended to control by utilizing it as an energy plant and get participated the public. A number of small societies will be formed and they will grant the access permission to selected areas while having a continuous monitoring of their work and what they remove. Nevertheless, there is an ongoing program of removing Prosopis at Bundala national park and used in dendro power generation. The removal is done by means of mechanical devices and the project seems devastating as it removes the entire crop coverage without following any restoration program.

More options were suggested for controlling of Lantana and the public participation will be stimulated as similar to above. Tiny sticks are supposed to use in manufacturing baskets and similar items where larger stems can be developed as fuel wood source. Few researches of extracting chemicals from lantana leaves were also suggested as a project component.

4.2 Developing a flow diagram for IAS control

Most of the researches published about invasive plants up to now in Sri Lanka are enclosed with identification of potential species and the threats to the adhering ecosystem or native species. Further there are few studies about prioritizing the invasive species and approaches for the eradication of those species as individuals. In contrast, flow chart in figure xxx gives a comprehensive road map to select the most suitable method of controlling adhering to type of existence, extent of existence and characteristics of biomass components of that particular species.

At the very first of the flow diagram, existing plants are filtered according to the biodiversity loss or economical loss terms. There are numerous studies to analyze the invasiveness characteristics of a particular flora and many of them have already identified and listed along with existing areas and current & potential risks. However, there should be a continuous monitoring system to identify any new coming species showing invasive characteristics.

During the next stage, selected plants should be classified according to whether those are existed in forestry and wildlife reserves or out of reserves. Because, 1) public involvement is hard to achieve for reserve areas but highly productive in outside reserve areas, 2) Same eradication/management procedures cannot be applied for both reserved or outside reserved areas even for the same species. Then the flora is subjected to classify as terrestrial and aquatic. In many cases of Sri Lanka, aquatic plants are capable of harvesting mechanically and those removed biomass can be subjected biochemical conversions to derive secondary fuels, developed as pulp for paper or analyzed to recover valuable chemicals whenever possible.

Terrestrial IAS makes the controlling procedures complex and hence, in the following stage, distribution of the plants should be well analyzed followed by the quantification.

For these, it is vital to generate distribution maps as GIS database using remote sensing of satellite images. However, it is really hard to remote sense the low dense populations and those existing under the upper canopy. Therefore random field observations should be carried out to discover any hidden population.

For control burning, those mainly applied within reserves, the understanding of the weather patterns is crucial and dry seasons with lower wind speed days are preferred. A crew should be in alert to control the fire in any case of emergency whenever the fire catches the unwanted segments. In some cases, chemical applications are necessary to wipe out the upcoming plants due to roots and unburned seeds after the control fire eradication. Low density and narrowly distributed areas within reserves can be treated with manual removal and burning at the site. These areas can again be treated with chemical methods and application should be done individually per each tree.

During the transportation of mechanically or manually harvested biomass within reserves, safe containers should be employed to avoid dropout of any plant component (seeds, forage, roots ant etc.) along the path. Further, prior to the preparation of transport road within the reserves, those should be mapped in the same distribution map as having minimum exposure to the intact neighborhoods. When the biomass is to be harvested as larger volumes, it is vital to charge those with an economic value which will in turn give a recovery on investment. Whenever those are supposed to utilize after removal, search on the literature is important to identify the possible utilization methods. Testing on the properties (proximity analysis, calorific value, TGA, chemical composition, fiber content and etc.) are another crucial work which should be carried out prior. Along with the available literature, research and development should be performed in order to comply with the local technology and community.

Figure 4.2: - IAS control flow diagram

4.3 Selection of IAS and Potential Uses

According to the latest classification, Panicum maximum (Guinea grass), Eichhornia crassipes (Water hyacinth), Prosopis juliflora (Kalapu andara), Mimosa pigra (Jodha nidikumba), Lantana camara (Gandapana) are the leading IAS in Sri Lanka. All Lantana, Prosopis and Mimosa generate woody biomass and utilization of wood in combustion for thermal energy generation is a well established technology. However, all these three show their existence in forestry or wildlife reserves and hence the getting participated the public for eradication process is rather a difficult or cumbersome long process. Water hyacinth, as an aquatic species, is more desired in biological conversions to process either biogas or second generation bio-ethanol.

Guinea grass is a perennial grass which is the most distributed IAS island wide. In contrast to above three terrestrial species, Guinea grass is highly grown in outside the reserves which makes the environment easy for the public to get involved with the eradication process. Further, even though studies on Guinea grass are not found that much, there are a large number of researches attached to the Switch grass which is having more resemblance with Guinea grass.

Arundo donax, which is locally known as Apala and grown by the upcountry dwellings, had once been declared as an IAS which is currently used as supportive sticks for vegetables like bean. Even though Apala has not been eradicated, it has well managed within certain boundaries due to the utilization by agricultural community. In contrast to the current usage, this is regarded as a very good perennial plant to be grown an energy plant where there are number of researches can be found in literature.

Even though both of them are currently categorized under IAS, those are having a very good potential of being energy crops in the future under controlled cultivation. The literature data proves that both of above selected plants have a higher annual biomass yield compared to Gliricidia and Ipil which are popular in Sri Lanka as energy crops.

4.3.1 Guinea grass

Currently, Guinea grass is rarely used for any other except as a cattle or goat feed. However, once the plants matured, those cannot be used even as a cattle feed. The main controlling methods in used are cutting, burning or application of chemicals.

Guinea grass as a bio-ethanol raw material

In contrast to the woody biomass, perennial grass plant matter and agricultural residue straw is more desirable as a raw material for bio-ethanol production since its low content of lignin which cannot be fermented. Further, its enhanced hydrolysis rate and reduced pre-processing energy requirement reduces the energy footprint of the process. However, the hemicelluloses content of the perennial grass is comparatively higher than that of the woody biomass. Therefore hemicelluloses fermentation technology, which is currently in between research level and industrial level, should be developed to achieve economically profitable bio-ethanol. As Sri Lanka is suffering from foreign dependency of gasoline, second generation bio-ethanol or bio-butanol from plant residues of Guinea grass will reinforce the national economy and strengthening the economies along with quality of livings of rural low income communities simultaneously.

Guinea grass as a co-firing agent with coal

Biomass co-firing with coal is a developing technology where it enhances the combustion efficiency with improved flame stability (due to high volatile fraction of biomass) and reduces the emissions. Switchgrass has been tested successfully in USA for co-firing in power plants. Ceylon Electricity Board (CEB) is having a target on restructuring the power generation profile with 20% renewable in 2020, those are from solar, wind, hydro and biomass. On the other hand, currently CEB is shifting from oil to coal for power generation. Hence, introducing biomass co-firing with coal will be a good alternative approach (other than sole biomass based power generation) in achieving 20% by 2020 and Guinea grass will be a good candidate.

Guinea grass for paper and pulp

Similarly to the above two scenarios, the literature for paper and pulp from perennial grass is available for switchgrass. It has found that switchgrass has shown good performance in terms of quality of fiber and paper properties. In the Sri Lankan context, there are two paper manufacturing facilities at Embilipitiya and Valachchena which uses rice straw as the raw material. But the data makes evidence that the Embilipitiya mill had never achieved its designed target of processing 30,000 MT of rice straw annually, but only one third of it. Hence, it will be a huge outcome if guinea grass could be used for the rest of 20,000 MT. As Guinea grass is vastly grown in Monaragala area, the supply chain will also be within economic levels.

Guinea grass for household cooking

It is very clear that biomass should be consumed or processed at an adjacent facility to the harvest in order to the process to be economical. This can be achieved for both bio-ethanol processing and paper pulp by installing small or medium scale facilities adjacent to the cultivars or grown areas after optimizing for the minimal transportation. However, the other option of using in coal power plant as a co-firing agent needs increased transportation.

Hence, at the end of the day, the best way of utilizing guinea grass is designing to energize the household cooking stoves. But the main issue with Guinea grass as a source for traditional cooking stoves is its high rate of combustion due to high surface area. Thus, it needs control combustion where a gasifier cooking stove can do the job. Gasifier cooking stoves are outdoing with other additional benefits such as improved efficiency and low smoke. The major problem arises when plant matter needs the pre processing to compact as Guinea grass is having a low bulk density.

4.3.2 Arundo donax

Figure 4.3: - Arundo donax as vegetable supporting sticks

Arundo donax is also popular as a plant due to its high yield. It is also demanding as a bio-ethanol feedstock and co-firing agent with coal. Apart from those, it has been tested as a low cost raw material in activated carbon production. However, currently those are being used as supportive sticks for vegetable plants such as beans. Therefore, once used sticks can be used for the energy generation or other applications.

4.4 Plant characteristics

4.4.1 Guinea grass

Figure 4.4: - Guinea grass grown in abandoned lands by Gampola and the distribution was much dense.

The newer plants could be emerged by seeds, stolon roots, crown or adventitious roots. Daughter shoots from roots or crown of the mother plants are called as tillers. Seeds seemed to be better in cultivars or initial invasion of spare lands whiles tillers seemed to be dominant in naturally grown areas. The numbers of tillers were found to be high in wet climatic zone with compared to dry zone which consequently make the wet zone distributions denser. This is due to because roots tend to grow vertically downwards to catch the water in dry zones. In contrast, roots tend to grow more horizontally in wet zone as water is available near by the surface of the soil layer which will in turn generates more tillers.

Flowering could observed as early as 2 to 3 months and fully mature in 6 months time, however a plant can stay about a year before completely die away. Unlike in the cultivars from seeds, plants of all the ages could be seen in naturally grown areas.

For the yield measurement, crops were not grown in control environment due to its invasive nature. Hence the samples were collected from the existing areas composed with all the ages of plant’s life cycle, from before flowering, flowering stage to totally mature. As the samples were weighed at the place and just after the harvest, there is a possibility of the value being deviated from the exact due to presence of water. Dry matter content was calculated assuming 80% moisture in fresh samples. Further, there are two identified verities of guinea grass in Sri lanka, those of Tall/Medium verity (3.5 maximum height) and Shorter verity (1.5 maximum height). During the sample collection, it made sure to extract from Tall/Medium verity as it is the most common throughout the island.

Table 4.1: - Plant Characteristics of Guinea

Location (WGS 84)	No	Fresh Weight (kg/m2)	Height (mm)	Panicle Length (mm)	No of Panicle branches	No of nodes	Stem/leaves weight ratio
8 14 54 N /79 48 51 E	1	14.50	2000	550	33	13	1.85
	2	31.00	2500				
6 54 08 N/80 55 07 E	3	15.50	1900	575	27	7	2.67
6 50 11 N /81 04 19 E	4	25.29	1700	580	26	7	4.80
06 48 16 N / 81 05 53 E	5	16.14	2000	670	26	7	3.14
06 45 33 N / 81 16 21 E	6	21.20	2000	675		7	
06 44 46 N/81 18 45 E	7	19.16	1825	650		8	
06 46 49N/ 81 17 55E	8	41.10	1900	650	25	6	
06 41 39 N/ 81 06 34E	9	32.00	2100	600	32	11	2.17

The content of the following graph clearly shows that the Guinea grass yield varies over different regions and it doesn’t show any pattern over climatic zones. The yield of these naturally grown cultivars seems entirely depending on the site specific characteristics such as water availability, soil nutrition, the way site is maintained (self maintaining with die matured plants and decaying at the same place or timely removal away of biomass feedstock from grown sites) and etc. As an example, the sample 3 was extracted from a cliff and the weight is relatively low. The most recent reason can be either lack of water and nutrition or both of them. On the other hand, sample 1 and 5 were extracted from by the roads and there evidences that the cut biomass had been removed away. This continuous removal of biomass from the site carries away soil nutrition along with them which might be the reason for reduced yield. Sample 8 and 9 was harvested from an abandoned “hena” lands which showed an increased yield. Many of the above samples were collected from dry zone, especially from Monaragala district, and the yield seems to be higher than that of the sample from wet zone. The main reason could be that the samples were harvested on February which is supposed to be the latter days of the rainy season that is North-East monsoon, starting from December.

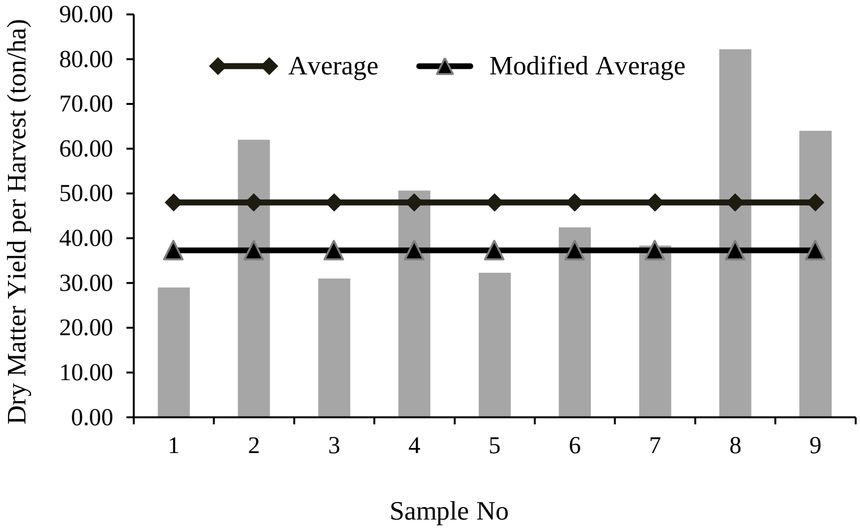


Figure 4.5: - Variation of yield of Guinea with the location

The above graph gives the Yield per harvest and it is capable of harvesting twice a year. Having processed all the raw data together, it gives the following data,

Annual Average Yield	-	96 ton/ha
Standard Deviation	-	36.4
Relative Standard Deviation	-	37.94%

The annual yield is an extremely high value compared to current interested energy plants of Gliricidia and Cinnamon those having annual yields of 28 ton/ha (13% moisture) and 27 ton/ha (13% moisture) respectively. Further, it is still a higher yield when compared to guinea yield found in literature that of 49 t/ha. 37.94% Relative standard deviation shows the deviated nature of sample data. Therefore sample 3, 8 and

9 were considered as out liars and calculation was preceded without those three figures which gave an average annual yield of 74.5 ton/ha with a SD value of 8.2.

Hence, the above data attests that Guinea grass is far more suitable as an energy crop compared to traditionally known Gliricidia, as far as the yield is concerned, which has been declared as the 4th plantation crop in Sri Lanka after tea, rubber, and coconut.

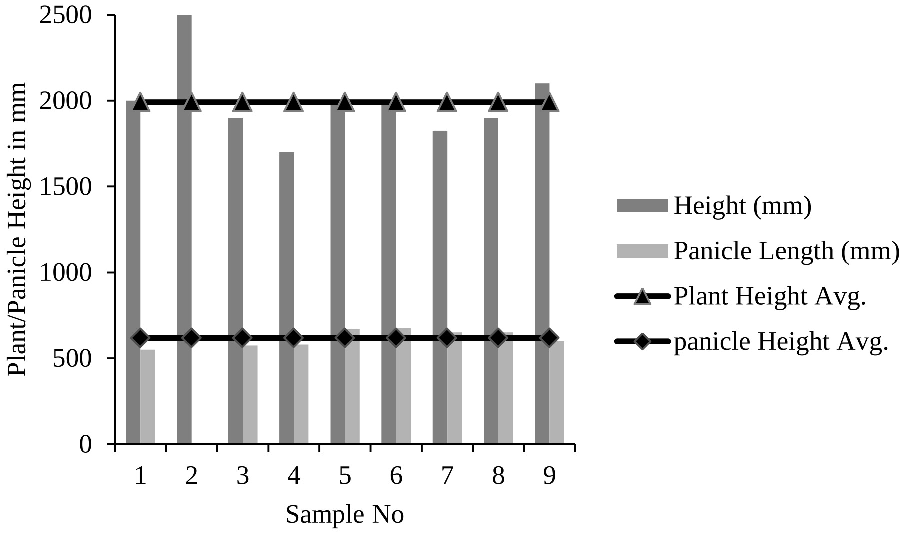


Figure 4.6: - Height variation of Guinea with location

Height was measure for the most matured plant in the collected sample and according to the above table, it also shows some uncharacteristic behavior with an average value of 1990 mm, SD of 223 and relative SD of 11.22%. However, by observation, it was clearly noticed that the plants grown in continuously removed sites were shorter comparatively. When it comes to the panicle length (length from last node to the top of panicle), it seemed that length is lesser in wet zone and in contrast number of nodes are reasonably high in wet zone samples. Sample SD of panicle length is 48.1 while relative SD is approximately 7%.

Stem to leaves ratio is another morphological character which is highly depend on the age of the plant. At the early stage, there is not a stem and with the aging, the weight of the stem becomes significant. The stem/leave ratios calculated for collected sample are not showing any pattern because the age of the sample plants were not known.

However, the measurements were taken for the most matured plants in the sample collected. However, the development of the stem/leave ratio was analyzed from the samples extracted from university premises.

Sample No	Description
1	Before Flowering
2	Flowers just erupted
3	Seeds fully developed
4	Seeds fallen

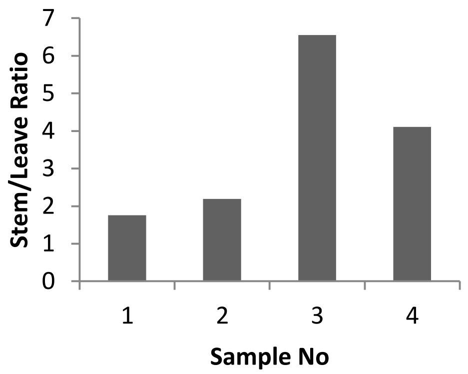


Figure 4.7: - Leave to stem ratio of Guinea

1, 2 and 3 sample data convinces that the increment of the ratio with the age. However, the variation of the values between 3 and 4 cannot be argued in a proper manner.

4.4.2 Arundo donax

Table 4.2: - Plant characteristics of Arundo

Sample	Height (mm)	Diameter (mm)	Weight (g)	Age
1	3650	17.50	450	3-4 months
2	4100	25.45	1000	3-4 months
3	4000	22.27	930	3-4 months

Even though it had been once regarded as an IAS, currently, it is being used as vegetable sticks where each stick values 3.00 rupees. These are used maximum for three times before discarding. Due to the existing demand, there is a tendency to maintain cultivars of these in sparsely used lands or margins of the agricultural plantations. The plants emerge from newer tillers and the most specific characteristic is not having flowers/seeds of the variety which could be seen here in Sri Lanka. Therefore the spreading of the plant is limited with compared to guinea grass unless anyone move it purposely to another site. In contrast to the guinea grass, almost all the cultivars were owned by a villager and hence free removal of samples were not easy where prior permission was needed. “Boragas” was the sample collected village and it was from a cultivar by Nuwaraeliya Welimada road.

As the plants are continuously removed, the age of the plants was almost same. At the particular cultivar, there were average140 plants per square meter. Assuming the 75% of water content, average yield per hectare per year is 100 tons which is a reasonably high value. Plant height does not show huge variation. The stem structure is having more resemblance with structure of bamboo species. However some significant variation could be observed of stem diameter, especially in natural cultivars. The most recent reason which could be observed was the plant density of the individual spots of the cultivars that is the plant diameter changes within shorter distances within the same cultivars. The upcoming tillers having much space to grow, where the sunlight is easy to catch, grow with a higher diameter.

4.5 Proximity analysis

The proximity analysis data for six IAS species in moisture free basis are given in the following table 4.3.

Table 4.3: - Proximity analysis of selected IAS

Species	Volatile %	Fixed Carbon %	Ash %
Panicum maximum	69.72	24.31	5.96
Arundo donax	76.00	21.5	2.50
Lantana camara	77.42	17.20	5.96
Ipil	83.56	12.08	4.36
Prosofis juliflora	81.82	15.91	2.27
Mimosa pigra	78.30	19.06	2.64

All the woody biomass is having higher percentage of volatile matter compared to perennial grass, those of Panicum or Arundo. Ipil contains the highest volatile matter content among all and it has been one of the proper feedstock for gasifiers in Sri Lanka.

However, the ash content of Ipil is higher which causes the significant drawback of ash melting and clinker formation. Both Prosofis and Mimosa are having reasonably low ash content along with considerable volatile fraction which are encouraging facts for gasification or combustion in more general. In contrast, as a perennial grass, Guinea is having highest ash content of 5.6 followed by lowest volatile fraction of 69.72. However, Arundo shows much lower ash content with demanding volatile fraction of 76.00. Hence, Arundo seems better with compared to Guinea.

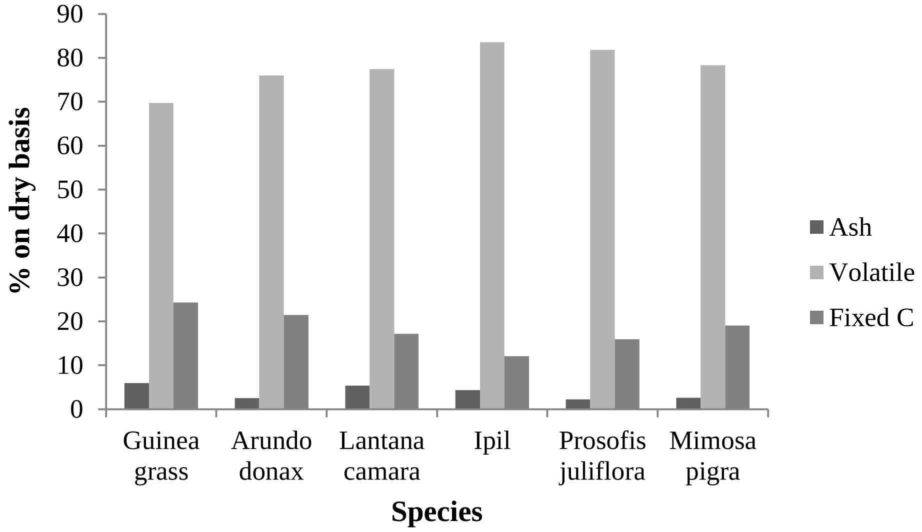


Figure 4.8: - Comparison of components of selected IAS

However, things are quite different from updraft to downdraft. As discussed in literature review, updraft systems carry away the volatile tars along with the producer gas. Hence, whenever the biomass is having a higher volatile fraction, the tar content of generated producer gas could be high. So, looking into the proximity analysis, Guinea grass and Arundo donax are more desired in updraft gasification. Ash melting is not that much a dominant factor in updraft gasification.

In both cases, those of updraft and downdraft, Arundo donax seems better as far as the proximity analysis is concerned though it is less interesting for downdraft as far as the char characteristics are concerned.

4.6 Calorific Values

For Arundo Donax, calorific value testing was carried out only for the stems as the weight of the leaves were insignificant. In contrast, calorific value for both leaves and stems were analyzed separately for Guinea grass. Further, calorific values for some other IAS, those of Lantana, Prosofis, Mimosa and Ipil, were analyzed as those were hard wood varieties which could be used in thermal energy generation and Ipil is even being used by now. The calorific values along with moisture content are given below.

The typical gross calorific values lie between 15MJ/kg to 20 MJ/kg for wood or biomass. Arundo donax and mixed sample of Guinea grass, that is proportional content of stems and leaves, show an increased calorific value compared to other samples. The above data lies between the ranges of the values in literature. However, the calorific values of hard wood are supposed to be greater than softwood or herbaceous. This is mainly because of the high lignin content of hardwood compared to others. But the data shows the characteristics other way around. The Ipil and Mimosa samples were not matured and that could be the most recent reason for the lower heating value. Further, heating value reduces with the increasing ash content too.

Table 4.4: - Calorific values of selected IAS

Species	GHV (MJ/kg)	Moisture %	NHV
Arundo donax	17.52	10.5	15.42
Lantana camara	15.65	13	13.29
Guinea grass (mix)	17.10	9	15.34
Guinea grass (stem)	15.60	13.5	13.16
Guinea grass (leaves)	15.22	13	12.93
Prosofis juliflora	15.09	10.7	13.20
Ipil	15.20	11.2	13.22
Mimosa pigra	15.06	13.4	12.71

4.7 Drying Characteristics and Storage

Drying test was carried out at university premises under solar. No any sophisticated equipment was used as the normal practice of drying wood is under direct sunlight.

The following figure 4.10 shows dried guinea grass samples in non-weathered and weathered conditions. The pictures themselves shows the difference and weathered sample had severely decayed while the other had not. Therefore storing the guinea grass under weathered conditions is not that much suitable and during the first 3 months it showed approximately 3% of weight loss during one handling (untie the bundle, relaxing the material and tie again). Arundo did not show any distinguished weight loss during handling. However, the guinea grass showed high rate of drying, where a layer around 2 inches was dried to 25% moisture within 2 days.

(a) (b)

Figure 4.9: - Drying of Guinea under weathered (b) and non-weathered (a) conditions

4.8 TGA Test

The TGA was done for both Guinea and Arundo in both N_2 and O_2 environment which are illustrated in above figures from 4.11 to 4.14. The graphs are plotted for both temperature versus weight loss percentage and derivative of prior graph. For both species, plots in N_2 environment are less complex compared to those are for O_2 environment.

In figure 4.8, a weight loss of 9.0% could be observed up to 117°C for Arundo which is the amount of moisture. Then there was no any significant weight loss up to 165°C. It has started a slow weight loss in 170s of °C which could be assumed as the start point of pyrolysis and it was increasing.

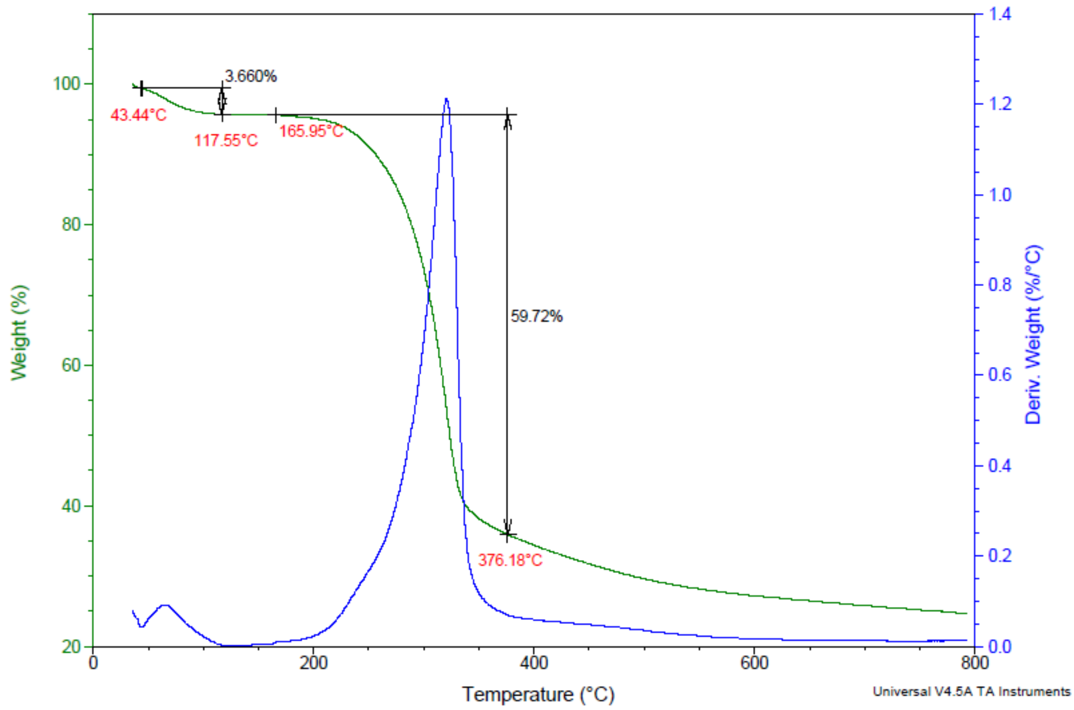


Figure 4.10: - TGA of Arundo in Nitrogen Environment

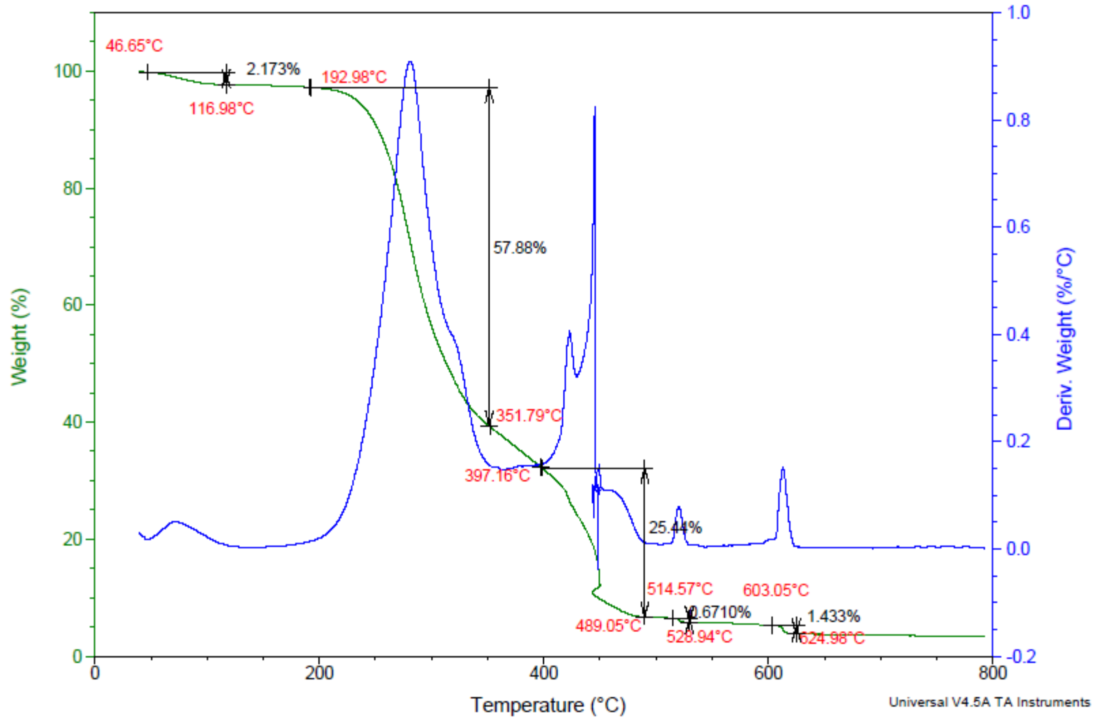


Figure 4.11: - TGA of Arundo in Oxygen Environment

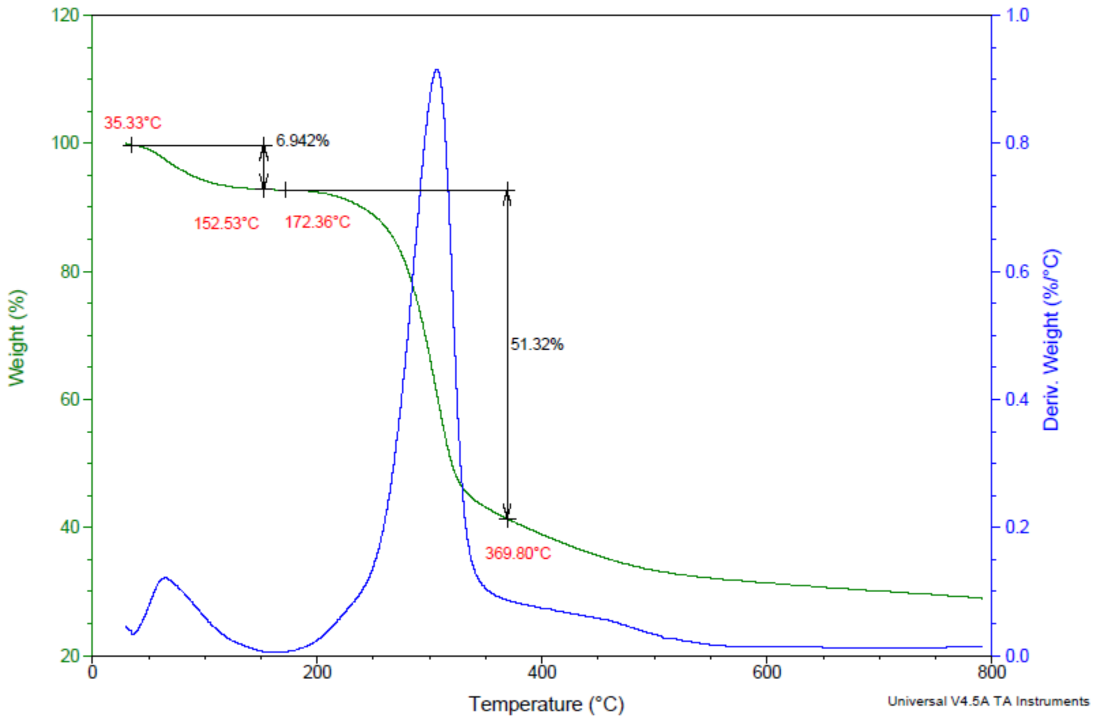


Figure 4.12: - TGA of Guinea in Nitrogen Environment

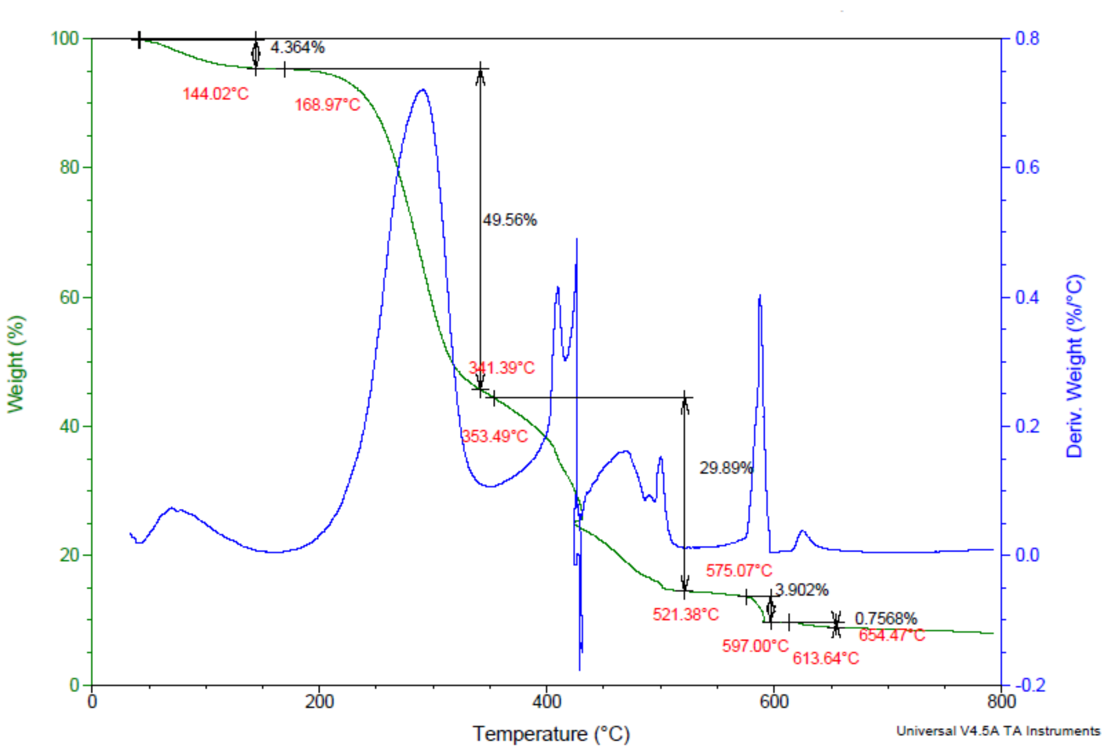


Figure 4.13: - TGA of Guinea in Oxygen Environment

A rapid devolatization has started from around 250°C and continued up to 340s of °C where the peak rate of 1.2% per °C was observed at approximately 325°C and. During this rapid devolatization period, about 55% loss of the original weight could be observed. There is another distinguished phase between 340°C to 475°C which is having a slow rate and having a weight loss of 17%. From 475°C to 800°C, a slow and reducing weight loss rate was observed. The weight loss during last phase is approximately 7% and the remaining 25% of the material is the cumulative fractions of fixed carbon and ash.

In contrast, for guinea, as depicted in figure 4.10, first phase of weight loss has continued up to 152°C and weight loss percentage is 7%. Initiation of devolatization could be observed in 170s of °C which is similar to Arundo and the rapid rate has continued to 340S with a peak rate of 0.95 % per °C at 300°C. Hence the peak rate is comparatively low compared to Arundo and the total loss of weight during this period was about 47%. The next distinguished phase runs up to 475°C with a weight loss of 10%. Finally, the total weight has reduced to 30% when it was heated up to 800°C

4.9 Selection of suitable gasifier system

The main objective of this design is to be utilized as a household appliance for cooking fed with grasses. Hence it should be more user friendly and less complex to operate as, in Sri Lanka, cooking is carried out by women whom having less or no technical comprehension. Further, handling of biomass from field to the final utilization in the gasifier is supposed to be performed by individuals without any intermediates in the supply chain. Therefore, except drying, other pre-processing techniques such as chipping, grinding or pelletizing is cumbersome and would not be sustainable. In one hand, measuring parameters such as moisture content prior to feeding is not viable and it would be advantageous if the gasifier is versatile for diversified feedstock, on the other. Hence, the design should be addressed all of above outcomes for the system to be attractive and sustainable.

The fluidized-bed gasification is more complex compared to fixed-bed as fluidized-bed gasifiers should be equipped with high pressure blowers and additional auxiliaries such as cyclones to recover non-reacted biomass particles while removing ash from the out gas stream. Further, dried grass cannot be used as it is, but grinding or chipping is needed prior. Therefore, fluidized-bed is less suitable as a cooking stove.

Comparing the fixed-bed designing, down-draft and up-draft are more popular and lots of literature is available. However, down-draft is composed with increased mechanical devices such as char removal rotors and additional attachments like cyclone separator where it makes less user friendly and frequent maintenance. On the other hand, in a down-draft system, a char bed should be maintained below the combustion to facilitate the reduction reactions. With the grass as the gasifier feed material, it is found to be very difficult to maintain char and to maintain char in granular profile. Further, down-draft systems are less interested in handling high moisture feed material as it consumes lots of energy to evaporate water which should be available at the downstream char bed for the reduction reactions. Moreover, in a downdraft gasifier, the nozzle section diameter in hearth is a critical parameter and consequently, it creates limitations for the range of operation load. Again the throat area is always subjected to high temperature (combustion zone) and with the applied weight of the biomass storage, throat tends to deformed, corroded or burnt unless high quality materials are used.

Instead, majority of these drawbacks could be addressed with up-draft systems. High moisture feed is supportive as water evaporates during drying (most top zone) and escapes along with producer gas without encountering the combustion zone or reduction zone. Feed material, stored in the hopper section, works itself as a filtering media which trap the particles and as the feed is grass, the filtering is even better. The grate, a perforated plate which holds the feed material, could be made out with low cost mild steel as it always gets cool down with supply air. At the end of the day, because of its simplicity, versatility and target on household use (gasifier cooking stove), fixed bed updraft gasification configuration was selected.

4.10 Gasifier Performances

4.10.1 Trial 01

At the very first, gasifier had been insulated with ¼” asbestos rope and the gasifier operation was not successful where the flame was inconsistent. It was supposed that the insulation was not thicker enough and lots of heat dissipated from the body. Further, it seemed that high quantity of tar presence in the gas.

Figure 4.14: - Tar formation

4.10.2 Trial 02

Additional insulation was provided using glass wool while keeping the initial asbestos insulation as it is. The flame could be maintained continuously after approximately 7 minutes from the startup and the gas temperature was at 60s of Celsius. A continuous flame existed for approximately 6 minutes and then the flame disappeared.

The gasifier flame was mostly reddish color where some sections were yellowish and bluish. The presence of red color indicates that the flame temperature lies around 800C which is reasonable for cooking. On the other hand this reddish color could be due to presence of tiny particles in the gas stream. However, combustion air, both primary and secondary comes from the around atmosphere, but not pre-mixed.

The operation time of 6 minutes per batch is too small for practical use. However the system was operated at a higher flow rate and operation time could be increased with lower air flow. But the main advantageous factor came across was that the system could be operated in a wide range on flow rates. This is highly outstanding compared to wood chip fixed bed gasification because those cannot be operated from largely deviated flow rates than designed. The main reason could be limited reaction surface area for wood chips and non-reacted combusted gas passing trough. However, when it comes to grass leaves, it produces huge surface area which facilitates the reaction rate to be high enough for an increased rate of air flow.

Figure 4.15: - Gasifier flame

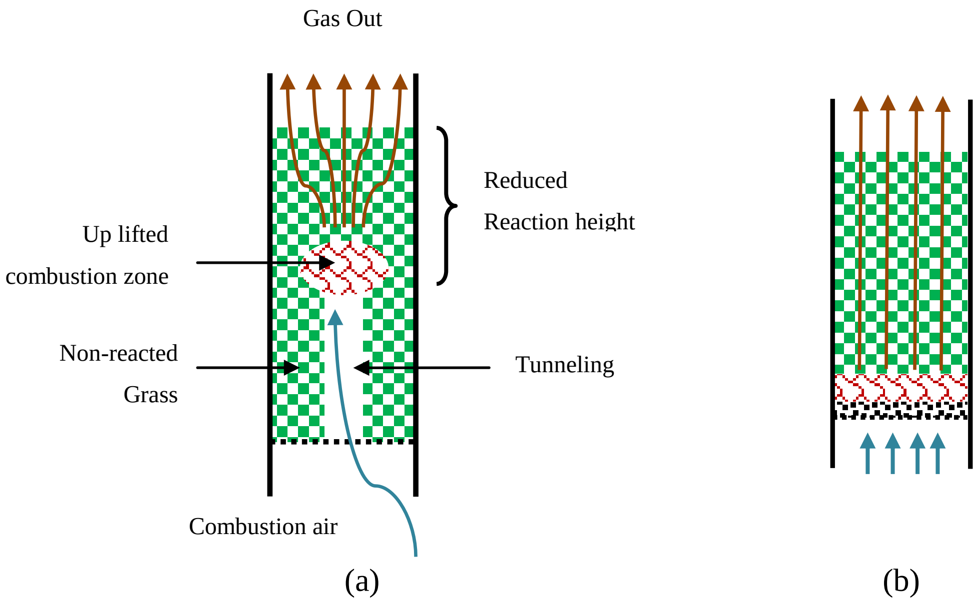


Figure 4.16: - Burning behavior inside the gasifier (a) – practical situation (b) - expected

After the trial run, the top cover was dismantled and remaining feed grass and internal sections, especially grate area were observed. Any ash melting was not observed and this might be due to reduced temperature of operation. No any deformation of grate was observed and recent reasons could be either low temperature or the cooling effect of fresh air passing through.

The combustion patterns/path was observed by analyzing removed feed grass after combustion. It was interesting to see that all the cross section had not burnt. Grass near the walls did not show any proof of combustion and instead combustion had take place in narrow channels generating tunnel like structure from around the center. This could be due to high compaction of grass near walls because the compaction was done manually with a iron rod. See into figure 4.17 for a graphical review of above phenomena and for expected operation.

This could be the reason for lower operation period of the system because once it cleared a tunnel towards the top, all the air supply follow that and time for the reactions are reduced. These tunnels form along the most lightly packed sections and this proves the facts in the literature that homogeneity of the feed material is crucial in biomass gasification. Non homogeneous feed creates a non homogeneous fuel bed and the gas passes through the minimum resistant path, especially in up-draft systems, leaving densely packed regions intact. In this designing packing is not equal all over the cross section and height. Further, material itself is not homogeneous because it contains both stems and leaves. Leave parts has shown quick burn compared to stems. Even during the field observation, the areas subjected to burn showed similar characteristics that the stems had remained not burnt, here and there.

Figure 4.17: - Burning patterns inside the gasifier

4.10.3 Trial 03

The next idea was to take the necessary actions to prevent the tunneling from bottom to top of the gasifier. Three intermediate layers of 75mm thick coconut husk pieces were introduced to break the guinea grass bed. One layer was laid right at the bottom to prepare a combustion zone which spread all over the cross section of the reactor where another two in the upstream in preventing the channeling.

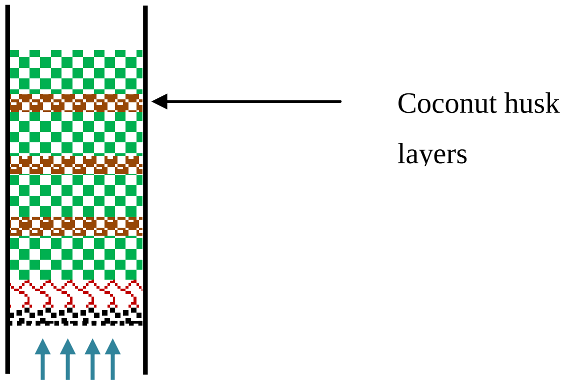


Figure 4.18: - Gasifier bedding with coconut husk layers

A continuous flame could not be obtained. There were two main parameters which could have affected, those of difference in compaction (as it was done manually) or changes in chemical composition due to a prolong period of storing since trial two. The guinea grass leaves had deteriorated where those broke into small particles making a dusty environment.

Gas temperature rose up to 80 C during the operation and it seemed hard to measure the actual temperature of the combustion zone. This could be due to, in one hand the sensor was installed as its tip position right at the inner surface of the reactor and combustion did not acquire total cross section on the other. Further, as the fuel does not flow downwards, the combustion zone moves up along the reactor with the time.

4.8.4 Gas Analysis

However, during the inconsistent flame conditions, a gas sample was collected and analyzed. The following table gives the gas composition.

Sample 01 was for mono bed of guinea grass while sample 02 was for where coconut husk layers were placed along the reactor. By looking into both results, there were not any improvements by introducing coconut husk layers. However, the quality of the feeding material was comparatively degraded for the second one which could also affect the reduced gas quality.

Table 4.5: - Producer gas analysis

Component	Volume %	
	Trial 02	**Trial 03**
Hydrogen (H_2)	2.553	0.283
Nitrogen (N_2)	53.171	61.180
Carbon monoxide (CO)	6.630	5.579
Carbon dioxide (CO_2)	17.449	13.689
Methane (CH_4)	2.295	1.260
Ethane (C_2H_6)	0.123	0.000

Sample 01 contained only 11.6% of the combustible gasses which is around one third of a typical producer gas stream. In contrast there are 18% of the total remained undetected. The used column in the GC was not standardized to detect tars or oxygen and therefore this undetected amount could be either one of above or a mix of both. However, saravankumar, 2007, has stated that the char content in a typical updraft gasifier could be in between 10 to 30%.

Comparing sample 01 and 02, the sample 02 should surely contain some excess amount of oxygen because its nitrogen content has increased while the reduced CO_2 generation. This could be due to the tunneling and then air might not have sufficient time for the reactions. Oxygen cannot be present in a producer gas stream if the gasifier is working properly and it makes the argument that there are certain malfunctions.

During the observation of reacted biomass after the operation, no clear zones of either pyrolysis or combustion were figured out. It could be judged that the temperature inside the reacted might not had been sufficient for gasification reactions. A properly working gasifier gas contains around 10% of CO2 where, here, it seems a bit higher and it suggests that the reduction reactions (gasification) have not occurred. Therefore the presence of CO might be due to pyrolysis reactions.

As far as the gas combustion is concerned, the volume/molar percentages of CO, H_2 and CH_4 are under the minimum individual flammability limits those of 12.5%, 4% and 5% respectively. This factor along with the high CO_2 concentration might be the reason for inconsistent flame conditions. However there was 11.6% of cumulative quantity of CO, H2 and CH4 where those 18% of undetected fraction could contain a certain combustible tar fraction.

5.0 CONCLUSION

The energy production is a crucial factor in Sri Lanka with the non-existence of petroleum resources. Looking into the energy distribution patterns, the liquid petroleum is mainly consumed by the transportation sector which is hard to address unless liquid fuels such as bio-diesel or ethanol is synthesized. On the other hand, there is a growing demand for biomass in industrial sector where it will be a challenging task to come up with the asking demand with the existing biomass feed stocks. Hence, it will be vital to developed high yield varieties which are suitable for different geographical and climatic regions (i.e. rainfall, soil, elevation, steep or flat and etc.). Gliricidia has been declared as an energy plant which is also considered as the 4th plantation crop in Sri Lanka. But as far as the yield is concerned, it is not the best. Further the tendency of shifting of cooking from biomass to LPG should be reversed by introducing user friendly and high efficient cooking stoves.

On the other hand, IAS is also becoming threatening when it comes to the biodiversity. Number of ecosystems in both terrestrial and aquatic such as Udawalawa, Bundala, and Aththidiya has already been invaded. The employed chemical and biological solutions have not been sustainable and physical removal process has got the every chance of being successful if an economic value could be charged over removed biomass. Participation of rural public will be more attractive and make use of that biomass within domestic/small scale level for thermal energy generation (cooking, brick manufacturing) or manufacturing (woven baskets, recycle paper) will be suitable rather than industrial scale involvement because they need large quantities which will in turn adversely affect the particular ecosystem.

Out of number of IAS, Guinea grass and Arundo donax seem good alternatives because of their high yield and regularity. Arundo is suitable in hills while guinea is growing almost all over the island wide below 1500m contour. Controlling of spreading of Arundo is quite easy as it does not generate any seed. In contrast, guinea should be well managed and harvesting should be done prior to seed maturation in order to prevent the spreading. Besides their high yields, guinea grass is a better option for soil carbon sequestration while giving a contribution in preventing soil erosion. Calorific values are within the range of hardwood of both Guinea and Arundo and as usual, Guinea contains more ash with respect to Arundo and other IAS. Hence Arundo seems far good compared to Guinea.

The other main objective was to analyze the capability of gasifying Guinea grass without pre-processing unless drying. Pelletizing and briquetting consumes more energy and it is hard to make those in household level. Due to the low bulk density, the operation time of a batch is relatively low which is observed as about 10 to 20 minutes. Hence batch wise operation is inconvenient unless two units are available. Without pelletizing, it is hard to design a continuous system.

On the other hand, the gasifier performances were highly deviated from batch to batch and hence it cannot be recommended as a cook stove fed with guinea without further R & D. The Guinea is composed with both leaves and stem part where it is not homogeneous. During the observation of feed material after the operation, it was found that those two sections (leaves & stem) had burnt in different nature. This non homogeneity of physical state and combustion characteristics along with low bulk density caused the tunneling upward which drastically reduced the gas quality and operation time. Hence, this again suggests what is in literature that is; homogeneity of feed is a crucial factor in gasification.

6.0 FURTHER STUDIES

Both Guinea grass and Arundo should be tested under control environmental and geographical regions as mono cropping or intercropping. Then, a cultivation map should be developed according to region wise and season wise.

Guinea and Arundo could be analyzed for co-firing at Holcim or Coal power plants.

Guinea grass is a good alternative as a fiber source for paper manufacturing and hence, properties should be analyzed to understand the usability in rural recycle paper production. Further, the fiber alone should be analyzed for crystalinity and hence to use as a filler materials in various industries (dry rubber manufacturing).

These types of plants are currently being tested as feedstock for second generation bio-ethanol in USA. Hence both Guinea and Arundo could test for ethanol production via hydrolysis-fermentation path or gasification-fermentation path.

Gasifier could run with process feedstock of Guinea such as briquettes and further, amount of char generation should be well analyzed because it is a vital factor in bio chemical conversion of synthesis gas.

Pyrolysis and torrefaction are other suitable processing techniques where the left char could either be used as energy feedstock or activated carbon manufacturing.

REFERENCE

Beadle, C.L., Long, S.P. 1985, Photosynthesis - is it limiting to biomass production? *Biomass*, 8, 19-168

Buekens, A.G., Schoeters, J.G., 1986, European experience in pyrolysis and gasification of solid waste, *Conservation & Recycling*, 9, 253-269

Central Bank of Sri Lanka, 2011, *Annual Report*

Ceylon Petroleum Corporation, 2010, *Statistical Report*

Chaloner, W.G., 2003, The role of carbon dioxide in plant evolution, *Evolution on planet earth*, 65-83

Christie, M., Fazey, I., Cooper, R., Hyde, T., Kenter, O.J., 2012. An evaluation of monetary and non-monetary techniques for assessing their importance of biodiversity and with developing economies, *Ecological Economics*, 83, 67–78

Cho, W., Bae, D., & Kim, H.S., 2008, Economic Valuation Methods of Biodiversity, *Environ. Eng. Res.*, 13, 41-48

Ferdinando M.M.C., Gunawardana R.J., Electricity Generation from Renewable Energy in Sri Lanka: Future Directions, Ceylon Electricity Board

Food and Agricultural Organization, 2010, [Online] Global Forest resources assessment 2010; key findings, Available at, *http://foris.fao.org/static/data/fra2010/KeyFindings-en.pdf*

Food and Agricultural Organization, 1986, *Wood Gas As engine Fuel*, FAO Forestry Department (ISBN 92-5-102436-7), [Online] Available at, *ftp://ftp.fao.org/docrep/fao/t0512e/t0512e00.pdf*

Gunathilake, N., Pethiyagoda, R., Gunathilake, S., 2008, Biodiversity of Sri Lanka, *J. Natn. Sci. Foundation of Sri Lanka*, 36, 25-62

International Energy Agency, 2012, [Online] World Energy Balance of 2010, Available at, *http://www.iea.org/statistics/statisticssearch/report/?country=WORLD&product=balances&year=2010*

Invasive species specialist Group, 2012, [Online] Global Invasive Species database, Available at,

http://www.issg.org/database/species/search.asp?st=100ss&fr=1&str=&lang=EN

Jayasuriya M., 2001, New invasive weed in Sri Lanka, *Parthenium hysterophorus* L., *proceedings of the silver jubilee seminar series of the postgraduate institute of agriculture*, University of Peradeniya, Sri Lanka

JenkinS, B.M., Baxter, L.L., Miles, T.R., 1998, Combustion Properties of Biomass, *Fuel Processing Technology*, 54, 17-46

Joseph, P.G., 2011, Market and Economic Study of the Biomass Energy Sector in Sri Lanka, *Report submitted to United Nation's Industrial Development Organization*.

Kauriinoja A., 2010, *Small scale biomass to energy solutions for northern periphery areas*, Master's thesis, University of Oulu

Klass, D.L., 2004, Biomass for Renewable Energy and Fuels, *Encyclopedia of Energy*, 1

Loewer, O.J, Black, R.J., Brook, R.C., Ross, I.J., Payne, F., 1982, economic potential of on-farm biomass gasification for corn drying, *transactions of ASAE*, 779-784

McNeely, J.A., 2001, An introduction to human dimensions of Invasive Alien Species, *The Great Reshuffling*, Cambridge, IUCN Publications Services Unit, 5-20.

Makendry, P., 2002, Energy Production from biomass (part 1) – overview of biomass, *Bioresource technology*, 83, 37-46

Makendry, P., 2002, Energy Production from biomass (part 2) – Conversion technologies, *Bioresource technology*, 83, 47-54

Mooney, H.A., Hobbs, R.J., 2000, *Invasive Species in a Changing World*, Island Press, Washington DC, USA

Pan, X., Sano, Y., 2005, Fractionation of wheat straw by atmospheric acetic acid process, *Bioresource Technology, 96 (11)*, 1256-1263

Perera, K.K.C.K., & Sugathapala, A.G.T., 2002, Fuel wood fired cook stoves in Sri Lanka and related issues, *Energy for Sustainable Development,* 6, 85-94

Rajvanshi, A.K., 1986, Biomass gasification, *Alternative energy in agriculture,* 2, 83-102

Ranwala, S., Marambe, B., Wijesundara, S., Silva, P., Weerakoon, D., Atapattu, N., Gunawardena, J., Manawadu, L., AND Gamage, 2011, Post-entry risk assessment of Invasive Alien flora in Sri Lanka; present status, gap analysis and most troublesome alien invaders, *23rd Asian-Pacific Weed Science Society Conference*, The Sebel Cairns, 26-29

Reed T.B., Das A., 1988, *Handbook of biomass downdraft gasifier engine system,* Solar energy research institute, Colorado

Renewable energy policy network for the 21st century (REN21), 2011, Renewables *2011-Global status report,* [Online] Available at

http://www.ren21.net/REN21Activities/GlobalStatusReport.aspx

Rowland, S., 2008, Designing & testing of a small scale updraft gasifier for gasification of eastern redcedar, Oklahoma state university, Master's thesis

Siyambalapitiya, T., 2002, A review of energy policy in Sri Lanka and its implementation, *Energy for sustainable development,* 6, 5 - 13

Stassen, H.E.M., Knoef, H.A.M., 1995. UNDP small scale biomass gasifier monitoring program – final findings, *Energy for sustainable development*, 2, 41 – 48

Sustainable Energy Authority of Sri Lanka, 2011, Sri Lanka Energy Balance 2010

Szczodrak, J., & Fiedurek, J., 1996, "Technology for conversion of lignocellulosic biomass to ethanol", *Biomass and Bioenergy* 10, 367-375

Tiwari, G., Sarkar B., & Ghosh, L., 2006, Design parameters for a rice husk throat less gasifier reactor, *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development*, 8

Twidell, J., Weir, T., 1986, *Renewable energy resources, Second Edition*, Taylor & Francis, New York & Oxon

Wijesundara, S., 2008, Major invasive plant species in different climatic zones of Sri Lanka, *Proceedings of the National Symposium on Invasive Alien Species*, 15-21

Wijesundara, S., 2010, Invasive alien plants in Sri Lanka, Invasive Alien Species in Sri Lanka – strengthening capacity to control their introduction and spread, 27-38

Sorensen, B., 2000. *Renewable Energy (Second Edition)*, Academic Press

Yakandawala, D., Yakandawala, K., 2011, Hybridization between native and invasive alien plants; An overlooked threat to the biodiversity of Sri Lanka, *Cey. J. Sci. (Bio. Sci.)* 40, 13-23

Department of Census and Statistics of Sri Lanka, 2010, *Statistical Report*

Yoda, S. 1995. *Trilemma; three major problems threatening world survival,* Tokyo, Central Research Institute of Electric Power Industry

APPENDIX

Appendix 01: - Biodiversity of Sri Lanka

Plant Species	Total No of Species (Endemic)	Vertebrate	Total No of Species (Endemic)	Invertebrate	Total No of Species (Endemic)
Flowering Plants	3771 (927)	Mammals	91 (16)	Bees	148 (21)
Gymnosperms	1 (0)	Birds	482 (33)	Ants	181 ( )
Ferns & Fern allies	314 (59)	Reptiles	171 (101)	Butterflies	243 (20)
Mosses	561 (63)	Amphibians	106 + (90+)	Spiders	501 ( )
Liverworts	227 ( )	Fishes	82 (44)	Land Snails	246 (204)
Freshwater Algae	560 + ( )			Dragon Flies	120 (57)
Fungi	2260 + ( )			Crabs	51 (51)
Lichens	661 ( )			Shrimps	23 (07)

Table A.1.1: - Species Diversity of Sri Lanka

Aquatic Ecosystem Diversity	Present Extent (ha)	Terrestrial Ecosystem Diversity	Present Extent (ha)
Costal Ecosystems		Natural Forest Ecosystems	
Coral Reefs	N/A	Tropical Lowland Rain Forests	141506
Sea Grass Beds	23819	Tropical Sub-montane Forests	68616
Salt Marshes	33573	Tropical montane Forests	243886
Mangroves	12189	Tropical Moist Evergreen Forests	1090981
Sea Shores/Beeches	N/A	Tropical Dry Mixed Evergreen Forests	464076
Mud Flats	N/A	Thorn Scrub Forests	N/A
Lagoons & Estuaries	158017		
Sand Dunes	7606	Natural Grassland Ecosystems	
		Dry Patanas	65000
Inland Aquatic Systems		Damanas	10000
Fresh Water Marshes	10000	Wet Patanas	N/A
Rivers/Streams, Riverine Forests	22435	Savannas	N/A
Reservoirs	170000	Thalavas	N/A
		Villu	N/A

Table A.1.2: - Ecosystem diversity of Sri Lanka

Appendix 02: - Case study of how newly introduced species come out as invasive later on with huge economic losses

A good illustration of the issue is the Nile perch (Lates niloticus) which was introduced into Lake Victoria for economic reasons. It has led to the extinction of dozens, perhaps hundreds, of species of cichlid fish endemic to the lake, and has led to deforestation around the lake because firewood is needed to dry the oily perch; forest clearing in turn is leading to siltation and eutrophication, thus adding additional pressure to the continued productivity of the lake (which is also infested with invasive water hyacinth). While the Nile perch fishery in Lake Victoria generates up to US$400 million per year in export income, relatively few people living around the lake earn these economic benefits. Tons of perch end up on the plates of European diners, while protein malnutrition is a major problem around the lake (WRI, 2000). Great economic benefits are flowing to a few people from this IAS, but none of the money is being spent on managing the considerable economic and ecological costs imposed on the poor, or on the Lake Victoria ecosystem. The economics of the marketplace have proven more powerful than the ethics of equitable distribution of benefits".

Appendix 03: - IAS introduced by Royal Botanical Garden of Sri Lanka

Family	Species	Country of Origin	Year of Introduction
Asteraceae	*Ageratina riparia*	Mexico	1905
Asteraceae	*Tithonia diversifolia*	Mexico	1851
Clusiaceae	*Clusia rosea*	West Indies	1866
Dilleniaceae	*Dillenia suffruticosa*	Borneo	1882
Fabaceae	*Myroxylon balsamum*	Venezuela	1870
Fabaceae	*Prosopis juliflora*	Tropical America	1880
Fabaceae	*Ulex europaeus*	Europe	1888
Iridaceae	*Aristia ecklonii*	Guatemala	1889
Melastomataceae	*Clidemia hirta*	Tropical America	1894
Melastomataceae	*Miconia calvescens*	Mexico	1888
Polygonaceae	*Antigonon leptopus*	Tropical America	1870
Pontederiaceae	*Eichhornia crassipes*	Hong Kong	1905
Solanaceae	*Cestrum aurantiacum*	Cape of Good Hope	1889
Verbenaceae	*Lantana camara*	Tropical America	1826

Appendix 04: - Detail Energy statistics of Sri Lanka