From:

Biomass as Fuel in Small Boilers

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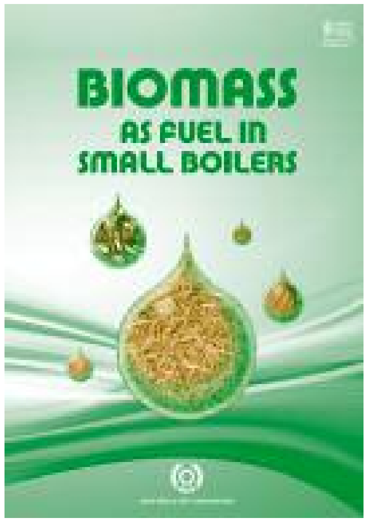

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APO WORLD CONFERENCE ON GREEN PRODUCTIVITY

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FOREWORD

The cost of fossil fuels has risen rapidly recently, and most Asian Productivity Organization (APO) member countries depend upon imports, thereby increasing overall business costs. Small and medium enterprises (SMEs) in the region are therefore under tremendous pressure to cut costs and be more competitive to survive. At the same time, millions of tons of biomass in the form of rice husk, waste wood, coconut shell, horticultural and agricultural waste, palm oil waste, organic solid waste, bagasse, etc. are generated in the Asia-Pacific region, which could easily be utilized in boilers as an energy source replacing fossil fuels. As most SMEs in Asia depend on industrial boilers for the steam required in their production processes, the use of biomass in place of nonrenewable fuel such as coal, diesel, fuel oil, etc. would result in cost savings and reduction in emissions including emissions of the greenhouse gases responsible for climate change.

Some industries in the region have already started using biomass as an energy source and have successfully made profits. The use of biomass also provides environmental benefits in terms of stabilizing CO_2 emissions, which would otherwise contribute to global warming. To promote the use of biomass in industrial boilers, the APO in association with the ASEAN Foundation carried out a project on Reusing Biomass Waste in Industrial Boilers for Energy Recovery for the Greater Mekong Subregion Countries. In 2008, a similar project was implemented for the APO member countries in the SAARC region. More than 300 professionals received training and information on the use of biomass in industrial boilers through workshops and national programs under these projects. At the time of publication, four more national programs were planned for March 2009 targeting 200 professionals in Pakistan, Nepal, Bangladesh, and Sri Lanka.

The manual Biomass as Fuel in Small Boilers is an outcome of the regional workshops on biomass unitization in industrial boilers organized in Lahore, Pakistan, in August 2008. The manual covers basic information on the characteristics of biomass, logistic aspects, and biomass energy conversion technologies and describes methods for retrofitting coal/oil-fired boilers for biomass use including the cost economics. It aims at enhancing the understanding of boiler users and managers from SMEs of the use of biomass as fuel and the operation and maintenance of biomass boilers.

Based on the feedback received during APO biomass boiler-related projects, the majority of SMEs in the region would be interested in changing to the use of biomass as fuel. It is hoped that this manual will prove to be of practical use to such SMEs, providing them with the relevant information to plan their approach, comprehend key requirements for such a change, and thereby promote biomass as fuel in the region.

Shigeo Takenaka
Secretary-General

Tokyo, April 2009

1. INTRODUCTION TO BIOMASS AS FUEL

1.1 BIOMASS AS FUEL

Biomass, the oldest form of renewable energy, has been used for thousands of years. However, with the emergence of fossil fuels, its relative share of use has declined in recent years. Currently some 13% of the world's primary energy supply is from biomass, though there are strong regional differences. Developed countries derive around 3% of their energy from biomass, while in Africa the proportion ranges between 70% and 90%.

With the adverse environmental effects of fossil fuels on the environment (such as climate change) coming to the forefront, people everywhere are rediscovering the advantages of biomass.

The potential benefits of biomass include:

- Reducing carbon emissions if managed (produced, transported, used) in a sustainable manner;
- Enhancing energy security by diversifying energy sources and utilizing local resources;
- Reducing the problem of biomass waste management;
- Possible additional revenues for the agricultural and forestry sectors.

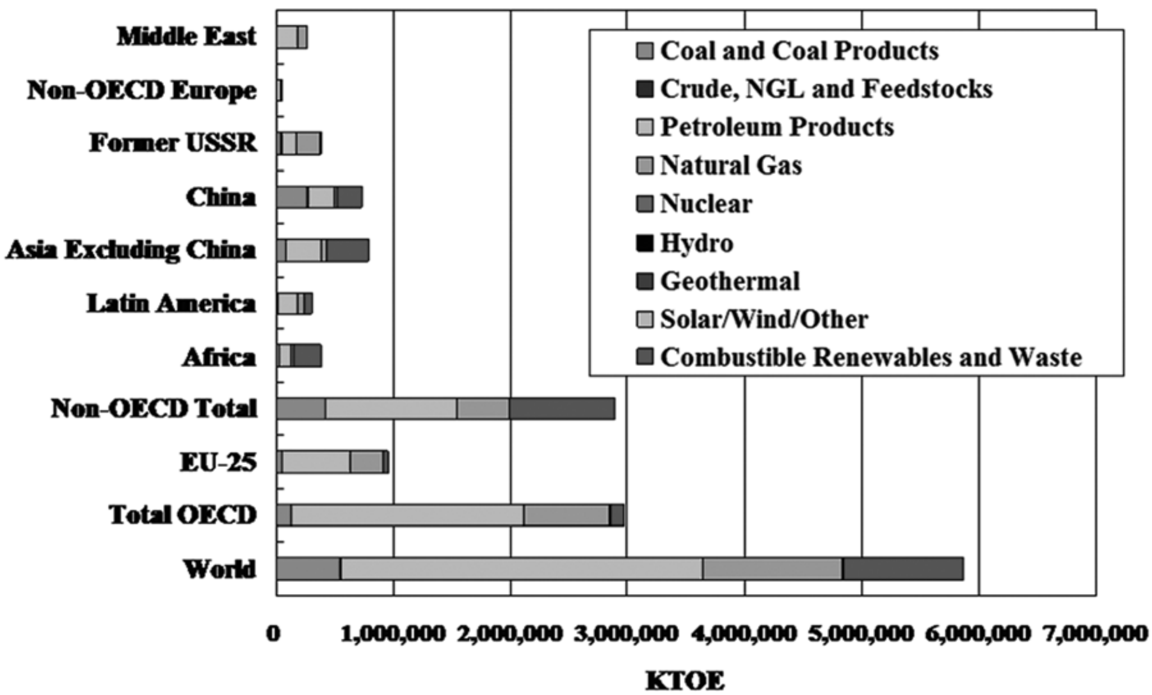

Figure 1-1 Primary energy consumption of various world regions

Source: International Energy Agency (IEA) Non-OECD Countries Energy Balance 2003

Biomass energy accounts for around 14% of total primary energy consumption. This bold figure hides a major disparity between the developed world and the developing world. Estimates of the amount of energy that can be supplied from biomass also vary widely, but according to some estimates, by 2050 biomass could provide as much as 50% of global primary energy supply.

1.1.1 Biomass as carbon-neutral fuel

The use of biomass as a fuel is considered to be carbon neutral because plants and trees remove carbon dioxide (CO_2) from the atmosphere and store it while they grow. Burning biomass in homes, in industrial processes, for energy generation, or for transport activities returns this sequestered CO_2 to the atmosphere. At the same time, new plant or tree growth keeps the atmosphere's carbon cycle in balance by recapturing CO_2.

This net-zero or carbon-neutral cycle can be repeated indefinitely, as long as biomass is re-grown in the next management cycle and harvested for use. The sustainable management of the biomass source is thus critical to ensuring that the carbon cycle is not interrupted.

In contrast to biomass, fossil fuels such as gas, oil, and coal are not regarded as carbon-neutral because they release CO_2 which has been stored for millions of years, and because they cannot be stored or sequestered.

1.1.2 Sources of biomass as fuel

There are a variety of biomass residues available around the world. The most important of these are crop residues, but there are significant quantities of forestry residues and livestock residues as well, which can also be used to produce energy.

Most of the world's crops generate biomass residues that can be used for energy production.

- Wheat, barley, and oats all produce copious amounts of straw, which has traditionally been burned. Approximately 1–2 billion T of crop residues may be burned annually.
- Rice produces both straw in the fields and rice husks at the processing plant; both of these can be conveniently and easily converted into energy. Recent legislation has made straw burning illegal in some parts of the world. Since the straw must still be removed from fields, such legislation could make it cost-effective to convert these residues into energy.
- When maize is harvested, significant quantities of biomass remain in the field. Much of this needs to be returned to the soil, but when the harvested maize is stripped from its cob the latter remains, constituting more biomass which can easily be converted into energy on-site.
- Sugar cane harvesting leaves harvest "trash" in the fields, while processing produces fibrous bagasse. The latter is a valuable source of energy.
- Harvesting and processing of coconuts produces quantities of shell and fiber that can be utilized.
- Peanuts leave shells, which are a great source of biomass energy.

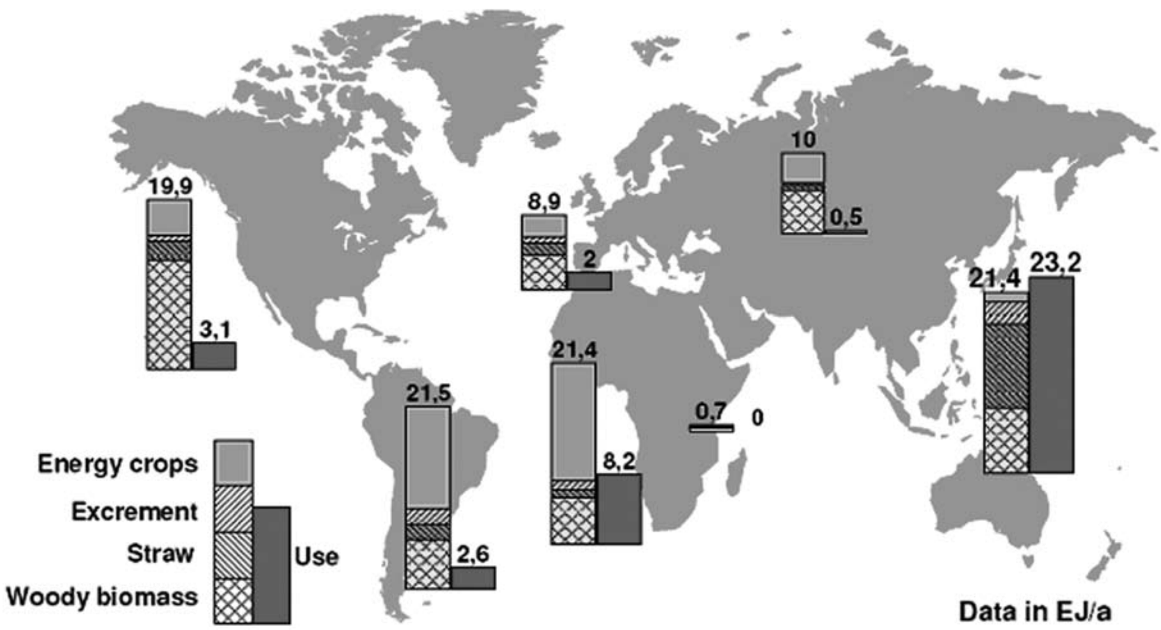

Figure 1-2 Regional Distribution of Various Sources of Biomass and Their Use in EJ/annum

Quantifying the amounts of each of these crops is rather difficult. One estimate is shown in Table 1-1, where the total residue from the four major crops listed is equivalent to 32EJ (exajoule). Another estimate puts the total of crop residues at 65EJ, while yet another, from 1993, suggested that utilizing only 25% of the waste from the world's main agricultural crops could generate 38EJ.

Table 1-1 Residue from major crops in EJ (1987)

Region	Maize straw	Wheat straw	Rice husks	Bagasse	Total
Africa	0.48	0.25	0.20	0.54	1.47
US and Canada	2.95	1.93	0.13	0.19	5.20
Latin America	0.71	0.38	0.29	3.58	4.94
Asia	1.74	3.65	8.96	3.19	17.54
Europe	0.61	2.39	0.04	0.00	3.04
Oceania	0.23	2.26	0.06	0.22	2.77
Total	6.72	10.86	9.68	7.72	31.98

The values in Table 1-1 also suggest that Asia produces the largest quantities of agricultural residues, although there is potential across all the continents. However, mere availability of the residue does not guarantee its use.

Table 1-2 Biomass varieties presently used in South Asian countries

Agricultural and Farm Biomass	Agro-industrial Biomass	Forest Residues and Plantation
Babul stems	Coffee husks	Firewood
Chili stalks	Bagasse	Forest residues
Coconut husks	De-oiled bran	Julie flora
Coconut pith	Groundnut husks	Other woody biomass chips
Corncobs	Groundnut shells	
Cotton stalk	Rice husks	
Maize stems	Sawdust	
Mango residues		
Mustard stalks		
Palm leaf		
Prosopis		
Rai stems		
Sugarcane trash		
Tamarind husks		
Til stems		
Casurina branches and fruit		

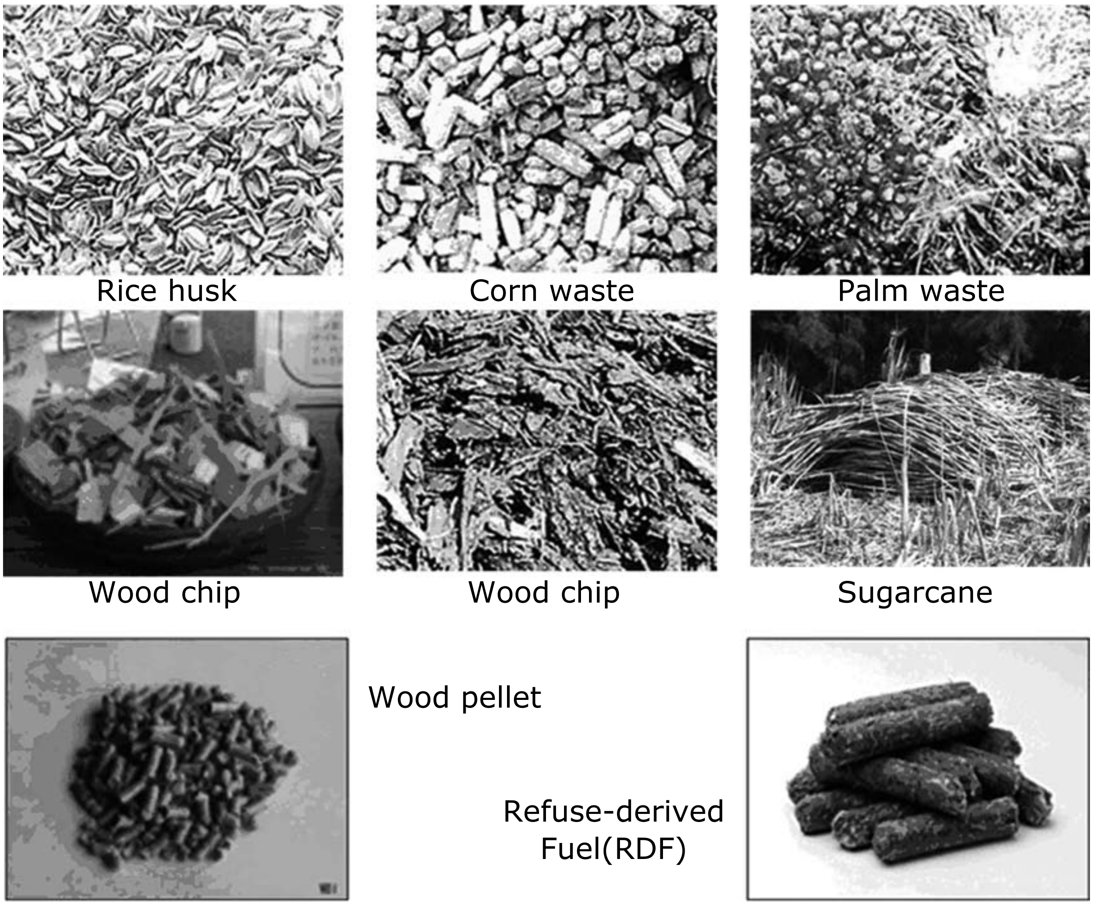

Figure 1-3 Various biomass energy sources

1.2 CHARACTERISTICS OF DIFFERENT BIOMASS FUELS

Figures 1-4 and 1-5 show the chemical composition and heating values for different types of biomass which can be used as fuel in boilers. Computing heating efficiency accurately requires calculating both the composition of biomass and the thermal efficiency of the boiler, using direct as well as indirect methods.

Fuel	C	H	O	N	S	Ash	Higher Heating Value
	Wt%						MJ/dry-kg
Pittsburgh coal	73.3	5.3	10.2	0.7	2.8	7.6	30.4
Wyoming coal	70.0	4.3	10.2	0.7	1.0	13.8	33.5
Wood	52.0	6.3	40.5	0.1	0.0	1.0	20.9
Pine bark	52.3	5.8	38.8	0.2	0.0	2.9	20.4
Bagasse	47.3	6.1	35.3	0.0	0.0	11.3	21.2
Raw garbage	45.5	6.8	25.8	2.4	0.5	19.0	16.4
Cow dirt	42.7	5.5	31.3	2.4	0.3	17.8	17.2
Rice chaff	38.5	5.7	39.8	0.5	0.0	15.5	15.4
Straw	39.2	5.1	35.8	0.6	0.1	19.2	15.2

Figure 1-4 Element omposition and heating value of various fuels

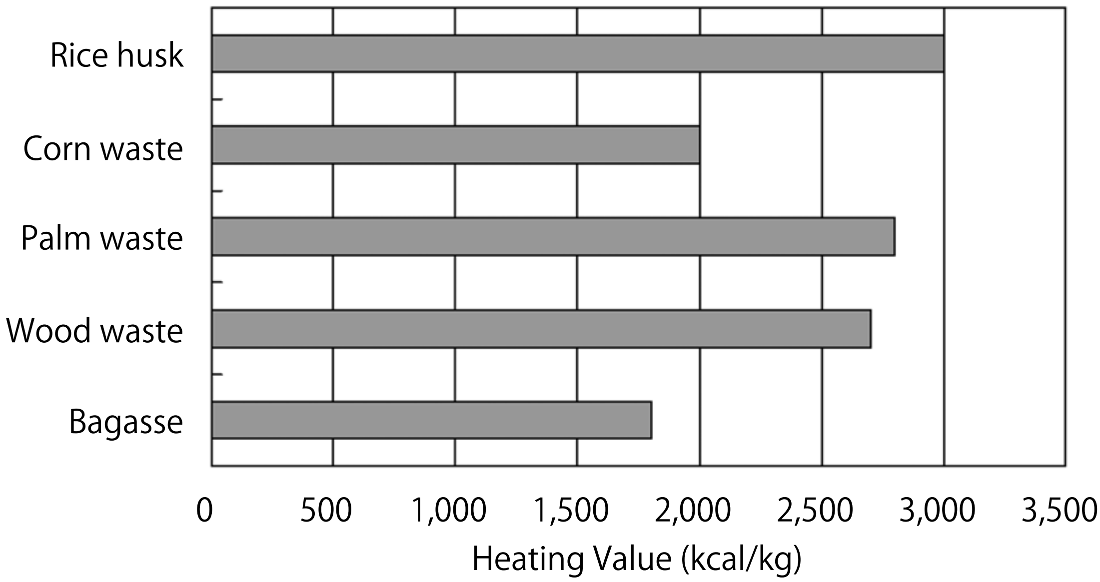

Figure 1-5 Biomass fuel heating value

2. BIOMASS PREPARATION, STORAGE, HANDLING, AND CONVERSION TECHNOLOGIES

2.1 AVAILABILITY OF BIOMASS

It is well known that biomass availability is highly influenced by crop patterns and regional variations of weather and seasons. Added to these factors is the diffused availability of biomass, which makes collection and transport a difficult and costly task. These factors impose constraints on the total quantity of biomass that can be made economically available to industry. If an industry is going to use biomass as fuel in a boiler, the following factors should be taken into account.

- Even before biomass began to be used for boilers, it was being used by local industries, hotels, and rural populations to meet their thermal energy requirements due to the increasing cost of fossil fuels.
- All the biomass available in a region is not accessible at a reasonable price.
- The supply of biomass changes with every season and every year based on crop patterns and weather conditions such as floods and droughts.

2.2 FUEL COLLECTION AND LOGISTICS

With the increased cost of fossil fuel and the low cost of steam produced by biomass-fired boilers, more industries will switch over to biomass firing in their boilers. In some South Asian countries the situation has changed to the extent that manufacturers are looking for agricultural or forest residue (woody biomass) that can be burned in their boilers. One of the main reasons is the haphazard way biomass is collected. Normally the availability of biomass varies from region to region, and the participation of village communities is essential to ensure a regular supply of biomass. The module in Figure 2-1 is proposed for biomass collection and logistics.

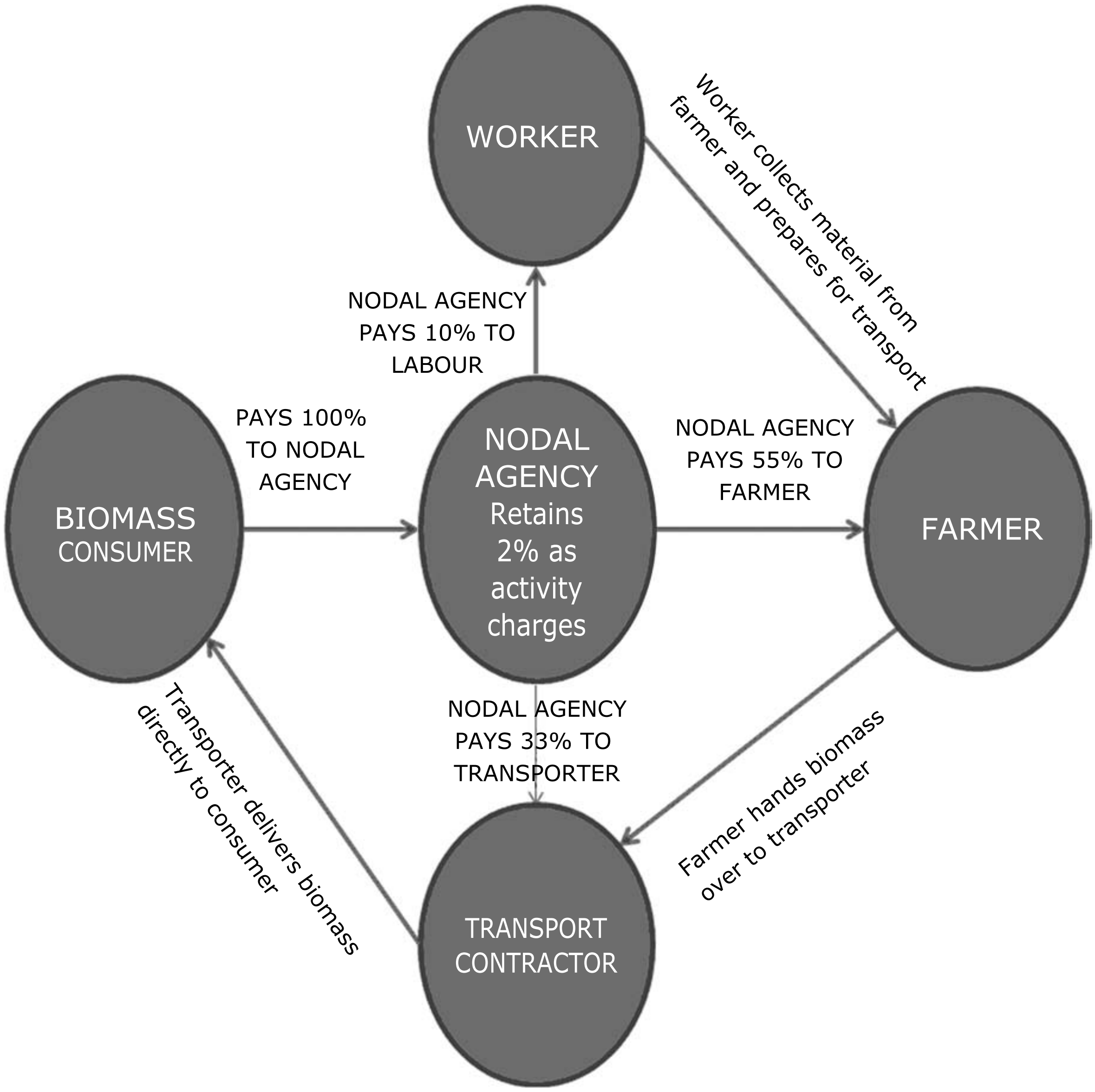

Figure 2-1 Logistics of biomass collection

It is difficult to ensure availability of any particular type of biomass throughout the entire year. A variety of types of biomass necessitate different types of collection and handling equipment. Most of the common biomass fuels, such as Cajurina branches, cotton stalk, husks, sugar cane trash, spent coffee waste, coconut, etc., require special types of handling machines, which add up to additional capital investment.

The major problem is the low bulk density of biomass fuels, which results in lower tonnage per vehicle, spillage from open lorries or trucks, and higher transportation cost. The transportation cost constitutes a significant portion of the landed cost of biomass. Therefore, care should be taken to use baling for loose biomass in order to minimize extra transportation expense.

2.3 STORAGE, HANDLING, AND PREPARATION OF BIOMASS

Most biomass users have no sheltered space in which different types of biomass can be safely stored and protected from the vagaries of the weather. The propensity of biomass fuel to decay/decompose with time, when exposed in open yards, puts a limit on fuel inventory. This means that users have to make substantial efforts to secure to biomass for their operations on a regular basis, as they cannot store large amounts of biomass.

It would be beneficial to build sheltered storage yards, where loss of biomass due to decay can be reduced. Storage sheds need to be built and appropriate tools used for stacking and reclaiming.

2.3.1 Need for multiple preparation and handling equipment

A biomass-fired boiler user can no longer afford the luxury of using a single fuel throughout the year. It has become quite normal to use multiple types of biomass fuel. This has made it necessary to deploy the special equipment that is required for preparation of biomass before it is fed to the boiler. Examples of such equipment are listed below.

- Sizing equipment (chopping) for woody biomass
- Saw cutter and wood chipper for woody biomass like juliflora
- Chippers for making palm bunches into fibrous material for ease of firing
- Chipper for making coconut fronds into smaller pieces or powder
- Rotary shredding machinery for bushy biomass like jute sticks, cotton stalks, Casurina branches, etc.
- De-oiled bran crusher
- Shredders
- Screens
- Briquette making (yet to be tried)
- Sieving machines for coir pith
- Dryers for moisture removal by air drying
- Drying: natural (solar) drying
- Conveying equipment (belt, drag chain, bucket, pneumatic)

The need for multiple types of biomass preparation and handling machinery is illustrated through the following examples.

- Casurina branches and coconut fronds can be cut and chipped with a single machine, but that same machine is not suitable for woody types of biomass like Julie flora, coconut trunks, dead mango trunks, etc.
- For hard woods (Julie flora and dead mango trunks) and biomass with large cross-sectional area (trunks of coconut and other trees), the preparation involves cutting and chipping into small pieces, which require a different type of equipment like a drum cutter or a saw mill.

- Separate conveyers have to be used for rice husk and woody biomass (Julie flora chips), as they have to be fed at different locations and in different ways.
- Screw feeders, used for conveying rice husk, cannot be used for sugar cane trash, as the trash would roll around and jam the screw.
- Many types of biomass are collected directly from fields, which potentially adds external impurities like mud, sand, and unknown chemicals. It has been observed that typically the moisture content ranges between 25% and 38%.
- While sun drying is a simpler process than air drying, it has its own constraints:
  - A large floor area is required where the biomass can be spread to provide the maximum exposed surface area.
  - There is the unfortunate situation that when there is bright sun there is no biomass and the reverse.
  - The enormous amount of labor required for handling, transporting, and stacking pushes up the cost of the fuel beyond the capacity of the production unit. Most types of biomass have the peculiar characteristic that only about the top 2 inches of thick material dries up while the inner mass does not dry. This calls for periodic restacking/disturbing of the heaps of biomass, calling for extra labor and raising other costs.
- While some of the production units were observed trying to use waste gases for this preliminary drying, they faced the problem of huge capital investment for the appropriate equipment.

2.4 BIOMASS ENERGY CONVERSION TECHNOLOGIES

There are a number of ways of converting biomass into heat energy. The simplest approach is to burn the biomass in a furnace, exploiting the heat generated to produce steam in a boiler. This approach, often called direct firing, is the most widespread means of deriving heat from biomass. It is also generally rather inefficient, though new technologies will be able to improve efficiency significantly.

A more advanced approach is biomass gasification. This employs a partial combustion process to convert biomass into a combustible gas. The gas has a lower energy content than natural gas. Nevertheless, it can be used in the same way as natural gas. In particular, it can provide fuel for gas turbines and fuel cells. Biomass gasification is still in the development stage, but it promises high efficiency and may offer the best option for future biomass-based power generation.

An intermediate option for exploiting biomass is to mix it with coal and burn it in a coal-fired power station. In the short term this may offer the cheapest and most efficient means of exploiting biomass. Finally, there are a number of specialized methods of turning biomass wastes into energy. These include digesters, which can convert dairy farm waste into a useful fuel gas, and power stations that utilize chicken farm litter, which they burn to generate electricity.

The following conversion technologies are commonly used in boilers:
1. Step grate furnace
2. Stationary grate furnace
3. Stoker combustion
4. Suspension combustion
5. Fluidized bed combustion

2.4.1 Step grate furnace

The simplest tool for direct firing of biomass with a smoke boiler is a step grate furnace. Biomass such as rice husks, peanut shells, groundnut shells, coffee husks, and sawdust can be easily burned in a step grate furnace. Such materials can be placed in a small-capacity boiler with up to 2 tons/hour steam generation capacity. The step grate furnace concept is generally used in cases of retrofitting for oil/coal fired boilers. The side sectional view of a step grate furnace is depicted in Figure 2-2.

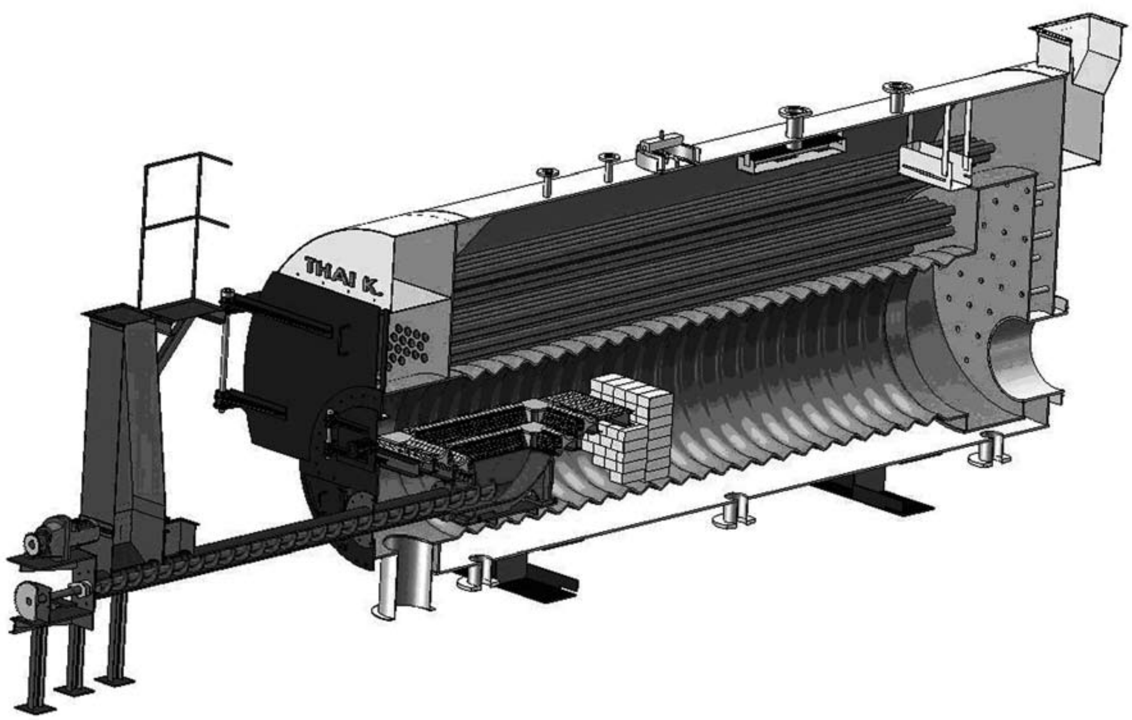

Figure 2-2 Side sectional view of step grate furnace

2.4.1.1 Advantages of the step grate furnace

- It is easy to install with local resources.
- Low capital investment is required.

- It is easy to switch over from oil/coal-fired boiler to biomass.
- Not much technical skill is required for boiler operation.
- Dust emission level is low compared to other biomass combustion systems such as fluidized bed or stoker firing.

2.4.1.2 Disadvantages of the step grate furnace

- The small boiler gives only up to 2 tons/hour of steam generation.
- A manual fuel firing system is used.
- Distribution of fuel on the grate step is uneven.
- It is difficult to control the air-to-fuel ratio because mixing of fuel and air is not uniform.
- The equipment operates at high excess air levels.
- There is a high percentage of unburnts in the ash.
- The thermal efficiency of a step grate boiler is in the vicinity of 50–60%.
- The furnace normally operates on natural draft.

2.4.2 Stationary grate furnace

The stationary grate furnace is commonly used in boilers where biomass sizes are big and have higher moisture content. Biomasses such as wood, stems, forest residue, casurina branches and fruits, and coconut husks can be easily burned in a stationary grate furnace. The grates are made of cast iron, and combustion air is supplied from the bottom. The air gap in the grate varies from 25 to 40 mm depending upon the type of biomass. Such types of grates are used for a boiler with capacity for 5 ton/hr of steam generation.

2.4.2.1 Advantages of the stationary grate furnace

- It is easy to install with local resources.
- Biomass with different sizes and moisture contents can be fed into the same furnace.
- Maintenance cost is low.
- The furnace can be retrofitted from an existing coal-/oil-fired boiler with an external furnace.
- It can operate on natural or forced draft.

2.4.2.2 Disadvantages of the stationary grate furnace

- Mostly manual feeding of fuel is required.
- Bed thickness of biomass on the grate is uneven.
- Improper mixing of fuel and air can result in higher levels of excess air and poor combustion efficiency.
- Manual cleaning of ash results in reduction of furnace temperature.

2.4.3 Stoker combustion

The step grate or stationary grate furnace represent the traditional method of biomass burning. However, their basic operation can be improved by introducing a moving grate or stoker, which allows continuous removal of ash so that the plant can be operated continuously. Fuel can also be spread more thinly on the grate, encouraging more efficient combustion.

The first stoker grate for wood combustion was introduced by the Detroit Stoker Co. in the 1940s. In this type of furnace, combustion air still enters below the grate of a stoker burner. This flow of air into the combustion chamber helps cool the grate. The air flow and consequent grate temperature determines the maximum operating temperature of the combustor. This, in turn, determines the maximum moisture content allowable in the wood fuel if combustion is to proceed spontaneously.

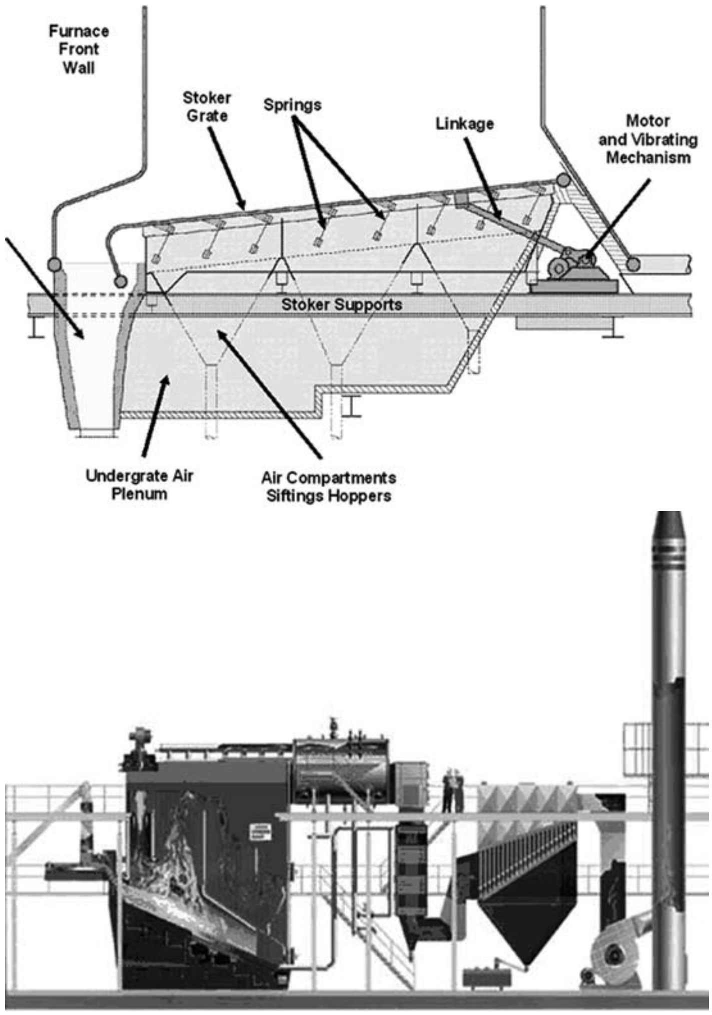

Figure 2-3 Fuel bed stoker combustion (Overfeed vibrating incline grate stoker)

Refinements of the basic stoker grate such as inclined grates and water-cooled grates can help improve overall performance and make the operation less sensitive to fuel moisture. Nevertheless, stoker combustors are still relatively inefficient, with boiler efficiencies of 65%–75% and overall efficiencies of 20%–25%.

2.4.4 Suspension combustion

Most modern coal-fired power stations burn pulverized coal, which is blown into the combustion chamber through a specially designed burner. The burner mixes air with the powdered coal, which then burns in a flame in the body of the combustion chamber. This is suspension combustion and in this type of plant there is no grate. Finely ground wood, rice husk, bagasse, or sawdust can be burned in a similar way.

Suspension firing requires a special furnace. The size and moisture content of the biomass (wood) must also be carefully controlled. Moisture content should be below 15%, and the biomass particle size has to be less than 15mm. Suspension firing results in boiler efficiency of up to 80% and allows a smaller-sized furnace for a given heat output.

However, it also requires extensive biomass drying and processing facilities to ensure that the fuel is of the right consistency. It also demands special furnace burners. A small number of plants designed to burn biomass in this way have been built. The technology is also of great interest as the basis for the co-firing of wood or other biomass with coal in pulverized coal plants.

2.4.5 Fluidized bed combustion

Aside from suspension firing of wood, the most efficient method of directly burning biomass is in a fluidized bed combustor (FBC). This is also the most versatile since the system can cope with a wide range of fuels and a range of moisture contents.

The basis for an FBC system is a bed of an inert mineral such as sand or limestone through which air is blown from below. The air is pumped through the bed in sufficient volume and at a high enough pressure to entrain the small particles of the bed material so that they behave much like a fluid.

The combustion chamber of a fluidized bed plant is shaped so that above a certain height the air velocity drops below that necessary to entrain the particles. This helps retain the bulk of the entrained bed material towards the bottom of the chamber. Once the bed becomes hot, combustible material introduced into it will burn, generating heat as in a more conventional furnace. The proportion of combustible material such as biomass within the bed is normally only around 5%.

There are different designs of FBC system which involve variations around this principle. The most common for biomass combustion is the circulating fluidized bed which incorporates a cyclone filter to separate solid material from the hot flue gases that leave the exhaust of the furnace. The solids from the filter are re-circulated into the bed, hence the name.

The fluidized bed has two distinct advantages for biomass combustion:

First is the ability to burn a variety of different fuels without affecting performance. Second is the ability to introduce chemical reactants into the fluidized bed to remove possible pollutants. In FBC plants burning coal, for example, limestone can be added to capture sulphur and prevent its release to the atmosphere as sulphur dioxide. Biomass tends to contain less sulphur than coal, so this strategy may not be necessary in a biomass plant.

A fluidized bed boiler can burn wood with up to 55% moisture. One specialized application is in plants designed to burn chicken litter, the refuse from the intensive farming of poultry.

Of the five different types of combustion technologies discussed above, the FBC technology is best suited for a range of small and medium-scale boilers (say more than 2 T/hr steam generation). With technological advancements the FBC boilers give efficiency of as high as 80–82% and can be used for a wide variety of fuels.

2.4.6 Comparison of different types of biomass conversion technologies

Table 2-1 compiles a quick comparison of different types of biomass conversion technologies commonly used worldwide.

Table 2-1 Comparison of different types of biomass conversion

Technology Parameters	**Step Grate/ Stationary Grate Combustion**	**Stoker Combustion**	**Suspension Combustion**	**Fluidized Bed Combustion**
Grate	Fixed / stationary grate	Fixed or moving grate	No grate or moving grate	No grate
Fuel Size	Different fuel sizes can be used	Uneven fuel size can be used	Preferable for high % of fins in the fuel	Uniform size fuel in the range of 1 to 10 mm.
Bed Temperature	1250–1350 ℃	1000–1200 ℃	1250–1350 ℃	800–850 ℃

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Combustion	It is difficult to maintain good combustion because: - Air fuel mixing is not proper; - Bed height is stationary, resulting in clinker formation; - Avoiding air channel is difficult; - Due to intermittent ash removal system it is difficult to maintain good combustion.	Combustion is better with an improved version of pile combustion. Since most of the fuel is burned in suspension, the heavier mass falls on the grate. If the system has a moving grate the ash is removed on a continuous basis and therefore the chances of clinker formation are lower.	It is similar to stoker combustion, but since the fuel size is small and even, the combustion efficiency is improved as maximum amount of fuel is combusted during suspension.	Best combustion takes place in comparison with the other types since the fuel particles are in fluidized state and there is adequate mixing of fuel and air.
Moisture	High moisture leads to bed choking and difficult combustion conditions.	Combustion condition not very much disturbed with 4–5 % increase in moisture.	Same as stoker combustion.	It can handle fuels with high moisture condition up to 45–50% but high moisture in the fuels is not desirable, and adequate precautions should be taken in the design stage itself.

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Draft Conditions	Natural draft / forced draft/ balanced draft	Forced draft / balanced draft	Balanced draft	Balanced draft
Maintenance	Not many maintenance problems.	Frequent problems due to movement of grate.	Variation in fines in fuel leads to delayed combustion thereby affecting the boiler tubes.	Erosion of boiler tubes embedded in the bed is quite frequent.

3. BIOMASS-BASED FLUIDIZED BED COMBUSTION (FBC) BOILERS

3.1 INTRODUCTION TO FBC BOILERS

Traditional grate fuel firing systems have several limitations and hence are techno-economically unviable to meet the challenges of the future. FBC has emerged as a viable alternative as it has significant advantages over conventional firing systems.

FBC offers multiple benefits, such as compact boiler design, flexibility with fuel used, higher combustion efficiency, and reduced emissions of noxious pollutants such as SOx and NOx. The fuels burned in these boilers include coal, washery rejects, rice husks, bagasse, and other agricultural wastes. The fluidized bed boilers have a wide capacity range: 0.5 T/hr to over 100 T/hr.

3.2 MECHANISM OF FLUIDIZED BED COMBUSTION

When evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles remain undisturbed at low velocities. As the air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream, and the bed is then called "fluidized."

With further increase in air velocity, there is bubble formation, vigorous turbulence, rapid mixing, and formation of a dense defined bed surface. The bed of solid particles exhibits the properties of a boiling liquid and assumes the appearance of a fluid — a "bubbling fluidized bed."

At higher velocities, bubbles disappear, and particles are blown out of the bed. Therefore, some number of particles have to be re-circulated to maintain a stable system, which is called a "circulating fluidized bed." This principle of fluidization is illustrated in Figure 3-1.

Fluidization depends largely on the particle size and the air velocity. The mean velocity of solids increases at a slower rate than does the gas velocity. The difference between the mean solid velocity and mean gas velocity is called slip velocity. Maximum slip velocity between the solids and the gas is desirable for good heat transfer and intimate contact. If sand particles in fluidized state are heated to the ignition temperatures of fuel (rice husk, coal, or bagasse), and fuel is injected continuously into the bed, the fuel will burn rapidly and the bed will attain a uniform temperature.

Fluidized bed combustion (FBC) takes place at about 840℃ to 950℃. Since this temperature is far below the ash fusion temperature, melting of ash and associated problems are avoided. The lower combustion temperature is achieved because of a high coefficient of heat transfer due to rapid mixing in the fluidized bed and effective extraction of heat from the bed through in-bed heat transfer tubes and the walls of the bed. The gas velocity is maintained between minimum fluidization velocity and particle entrainment velocity. This ensures a stable operation of the bed and avoids particle entrainment in the gas stream.

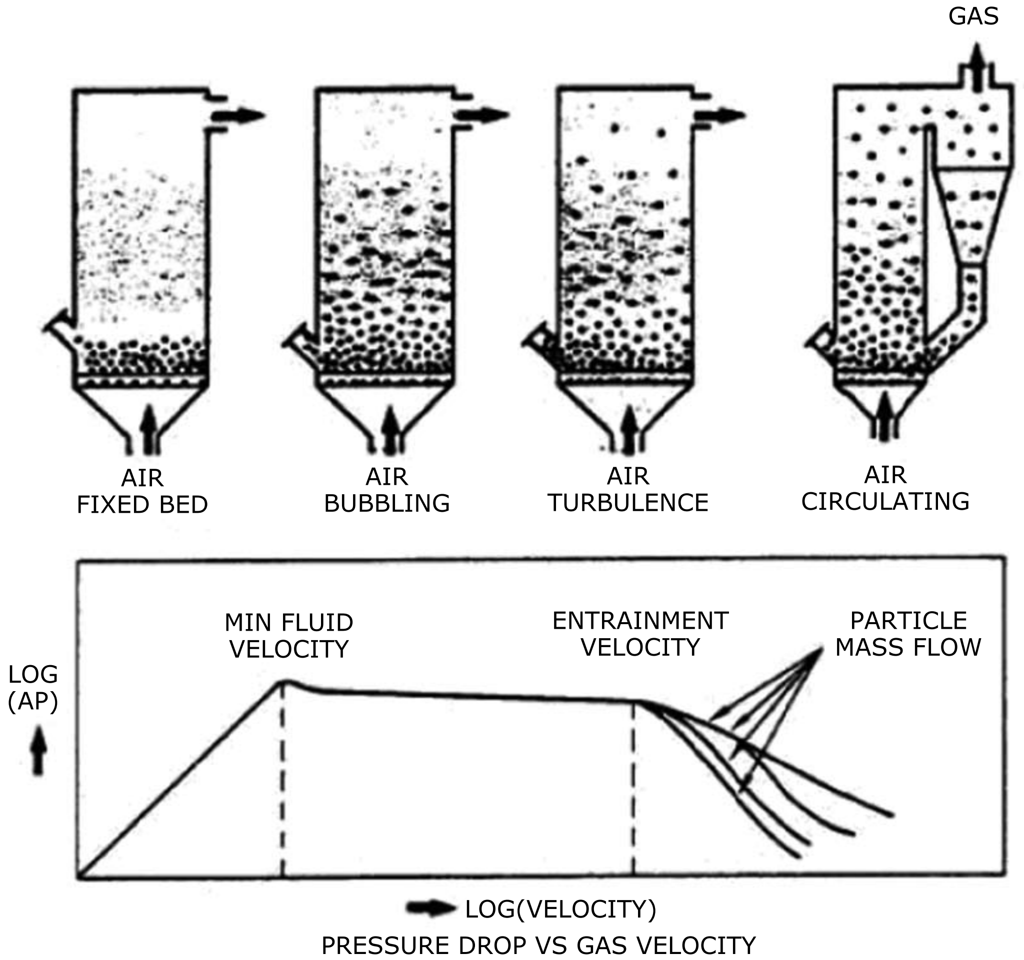

Figure 3-1 Principles of fluidization

As the velocity of a gas flowing through a bed of particles increases, a value is reaches when the bed fluidizes and bubbles form as in a boiling liquid. At higher velocities the bubbles disappear; the solids are rapidly blown out of the bed and must be recycled to maintain a stable system.

Any combustion process requires three "T"s: Time, Temperature, and Turbulence. In FBC, turbulence is promoted by fluidization. Improved mixing generates evenly distributed heat at lower temperature. Residence time is many times higher than conventional grate firing. Thus an FBC system releases heat more efficiently at lower temperatures. Since limestone can also be used as particle bed (as when fuel with sulphur content is used), control of SOx and NOx emissions in the combustion chamber is achieved without any additional control equipment. This is one of the major advantages over conventional boilers.

3.3 ADVANTAGES OF FBC BOILERS

- High efficiency: FBC boilers can burn fuel with a combustion efficiency of over 95% irrespective of ash content. FBC boilers can operate with overall efficiency of 84% (±2%).
- Reduction in boiler size: High heat transfer rate over a small heat transfer area immersed in the bed results in overall size reduction for the boiler.
- Fuel flexibility: FBC boilers can be operated efficiently with a variety of fuels. Even fuels like flotation slimes, washer rejects, agro waste can be burned efficiently. These can be fed either independently or in combination with coal into the same furnace.
- Ability to burn low-grade fuel: FBC boilers give a rated output even with an inferior quality fuel. The boilers can fire coals with ash content as high as 62% and having calorific value as low as 2,500 kCal/kg. Even carbon content of only 1% by weight can sustain the fluidized bed combustion.
- Ability to burn fines: Coal containing fines below 6 mm can be burned efficiently in an FBC boiler, something that is very difficult to achieve in conventional firing systems.
- Pollution control: SO_2 formation can be greatly minimized by addition of limestone or dolomite for high sulphur coals (3% limestone is required for every 1% sulphur in the coal feed). Low combustion temperature eliminates NOx formation.
- Low corrosion and erosion: The corrosion and erosion effects are less due to lower combustion temperature, softness of ash, and low particle velocity (around 1 m/sec).
- Easier ash removal; no clinker formation: Since the temperature of the furnace is in the range of 750–900°C in FBC boilers, even coal of low ash fusion temperature can be burned without clinker formation. Ash removal is easier as the ash flows like liquid from the combustion chamber. Hence less manpower is required for ash handling.
- Less excess air; higher CO_2 in flue gas: The CO_2 in the flue gases will be of the order of 14–15% at full load. Hence, the FBC boiler can operate at low excess air: only 20–25%.
- Simple operation, quick start-up: High turbulence of the bed facilitates quick start-up and shutdown. Full automation of start-up and operation using reliable equipment is possible.
- Fast response to load fluctuations: Inherent high thermal storage characteristics can easily absorb fluctuation in fuel feed rates. Response to changing load is comparable to that of oil-fired boilers.
- No slagging in the furnace; no soot blowing: In FBC boilers, volatilization of alkali components in ash does not take place and the ash is not sticky. This means that there is no slagging or soot blowing.

- Provision of automatic coal and ash handling system: Automatic systems for coal and ash handling can be incorporated, making the plant easy to operate comparable to oil- or gas-fired installations.
- Provision of automatic ignition system: Control systems using microprocessors and automatic ignition equipment give excellent control with minimum supervision.
- High reliability: The absence of moving parts in the combustion zone results in a high degree of reliability and low maintenance costs.
- Reduced maintenance: Routine overhauls are infrequent and high efficiency is maintained for long periods.
- Quick responses to changing demand: FBC can respond to changing heat demands more easily than stoker-fired systems. This makes it very suitable for applications such as thermal fluid heaters, which require rapid responses.

3.4 BOILER WATER TREATMENT

Most of the boiler operations in small and medium-scale industries pay little attention to water quality. Producing quality steam on demand depends on properly managed water treatment to control scale deposition on tubes and avoid corrosion problems. Deposits and corrosion result in efficiency losses and may result in boiler tube failure. In order to maintain the desired quality of water, several different water treatment techniques are commonly used for boiler operation. These are listed in Table 3-1.

3.4.1 Internal water treatment

Internal treatment is carried out by adding chemicals to the boiler to prevent the formation of scale by converting scale-forming compounds to free-flowing sludge, which can be removed by blow-down. Specialists must be consulted to determine the most suitable chemical to be used for internal treatment in each case.

3.4.2 External water treatment

External treatment is used to remove suspended solids, dissolved solids (such as calcium and magnesium ions, which are major causes of scale formation), and dissolved gases (oxygen and carbon dioxide). The external treatment processes available are ion exchange; demineralization, reverse osmosis, and de-aeration. Before any of these are used, it is necessary to remove suspended solids and color from the raw water, because these may contaminate the resins used in the subsequent treatment sections. Table 3-1 given lists the various boiler treatment processes

Table 3-1 Boiler treatment processes

S.No	Process	Treatment
1.	Ion-exchange process (softener plant)	The hardness of water is removed as the water passes through a bed of natural zeolite or synthetic resin.
2.	Demineralization	Demineralization is complete removal of salts by using cation resin, which exchanges the cations in the raw water with hydrogen ions, producing hydrochloric, sulphuric, and carbonic acid. Carbonic acid is removed in degassing lower than water is passes through an anion resin which exchanges anions with the mineral acid (e.g. sulphuric acid) and forms water.
3.	De-aeration	In de-aeration, dissolved gases such as oxygen and carbon dioxide are removed by pre-heating boiler feed water with steam before it enters the boiler.
4.	Reverse osmosis	This process is used where the TDS level of feed water is very high. Normal small fire tube boilers do not use this system because the limit for TDS level in the boiler drum is high.

Treatment of boiler feed water is essential even from the point of view of boiler safety. The degree of treatment of boiler feed water is dependent on the pressure of the steam which is generated. The higher the pressure of the steam to be generated, the greater is the degree of treatment required. Table 3-2 gives the recommended boiler water limits for different levels of pressure.

Table 3-2 Recommended boiler water limits

Factor	Up to 20 kg/cm^2	21–40 kg/cm^2	41–60 kg/cm^2
TDS, ppm	3000–3500	1500–2000	500–750
Total iron dissolved solid ppm	500	200	150
Specific electrical conductivity	1000	400	300
Phosphate residual ppm	20–40	20–40	15–25
pH at 25 °C	10–10.5	10–10.5	9.8–10.2
Silica (max) ppm	25	15	10

3.5 BOILER BLOW-DOWN

When water is boiled and steam is generated, dissolved solids that were contained in the water remain in the boiler. After a period of time their solubility in water is exceeded and they are deposited from the solution. Above certain levels of concentration, these solids encourage foaming and cause carryover of water into steam. The deposit also leads to scale formation in boiler tubes and reduces efficiency, localized heating, and tube failure. It is therefore necessary to control the level of concentration of the solids and this can be achieved by the process known as blow-down, in which a certain amount of water from the boiler is blown off. The maximum amount of total dissolved solids (TDS) concentration permissible in various types of boilers is shown in Table 3-3.

Table 3-3 Recommended TDS levels for various boilers

	Boiler Type	**Maximum TDS (ppm)**
1.	Lancashire	10,000 ppm
2.	Smoke and water tube boilers (12 kg/cm^2)	5,000 ppm
3.	Low-pressure water tube boiler	2000–3,5000 ppm
4.	Package and economic boiler	3,000 ppm
5.	Coil boilers and steam generators	2000 (in the feed water)

Note: Refer guidelines specified by manufacturer for more details

3.5.1 Blow-down calculations

The quantity of blow-down required to control boiler water solids concentration is calculated using the following formula:

$$\text{Blow-down (\%)} = \frac{\text{Feed water TDS x \% Make-up water}}{\text{Maximum Permissible TDS in Boiler Water}}$$

If maximum permissible limit of TDS in a package boiler is 3000 ppm, percentage that makes up water is 10%, and TDS in feed water is 300 ppm, then the percentage of blow-down is given as

$$= \frac{300\text{x}10}{3000}$$

$$= 1\%$$

If boiler evaporation rate is 3000kg/hr, then the required blow-down rate is

$$= \frac{3000 \times 1}{100}$$

$$= 30 \text{ kg/hr}$$

3.5.2 Benefits of blow-down

Good boiler blow-down control can significantly reduce treatment and operational costs, in the form of:

- Lower pre-treatment costs;
- Less make-up water consumption;
- Reduced maintenance down time;
- Increased boiler life;
- Lower consumption of treatment chemicals.

3.6 OPTIMIZING EXCESS AIR AND COMBUSTION

For complete combustion of every kg of rice husk fuel, 4.69 kg of air (in theory) is needed. In practice, mixing is never perfect; a certain amount of excess air is needed to complete combustion and ensure release of the entire amount of heat contained in the fuel. If far more air than what is required for completing combustion were allowed to enter, additional heat would be lost in heating the surplus air to the chimney temperature. This would result in increased stack losses. Less air than is required would lead to incomplete combustion and smoke. Hence, there is an optimum excess air level for each type of fuel.

3.6.1 Control of air and analysis of flue gas

In actual practice, the amount of combustion air required will be much higher than what is optimally needed. Therefore some of the air gets heated in the furnace boiler and leaves through the stack without participating in the combustion.

Chemical analysis of the gases is an objective method that helps in achieving finer air control. By measuring carbon dioxide (CO_2) or oxygen (O_2) in flue gases by continuous recording instruments of Orsat apparatus or portable fyrite, the excess air level as well as stack losses can be estimated with the graph as shown in Figure 3-2. The excess air to be supplied depends on the type of fuel and the firing system. For optimum combustion of fuel, the CO_2 or O_2 in flue gases should be maintained at 14–15% in case of CO_2 and 2–3% in case of O_2. But excess air depends upon the type of biomass and normally excess air level is high in biomass fuel as compared to coal, oil or natural gas.

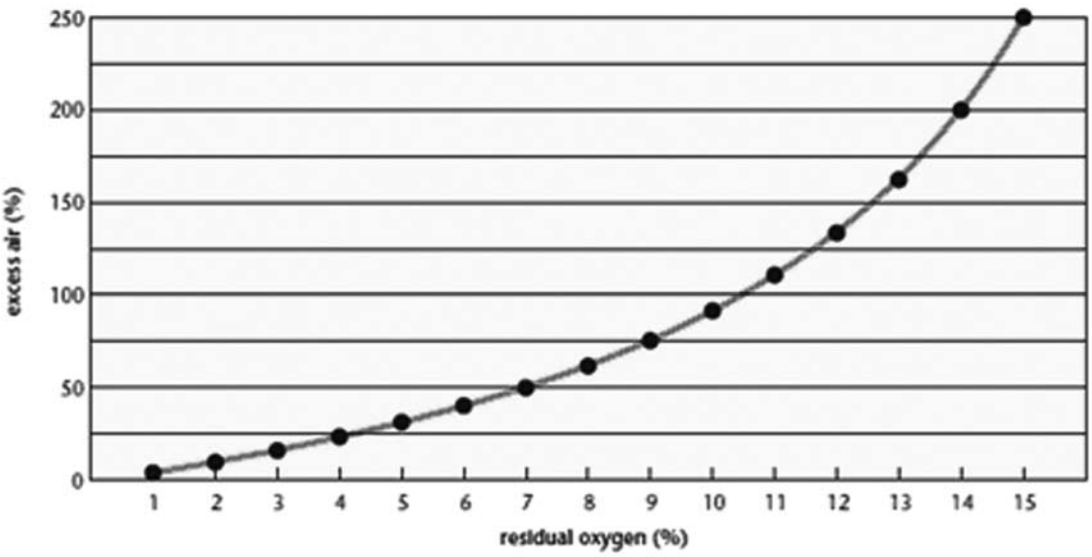

Figure 3-2 Relationship between excess air and oxygen

3.7 SOME TECHNICAL PROBLEMS WITH BIOMASS BOILERS

Biomass is a cheap and clean source of energy. If it is used judiciously, entrepreneurs can reduce the cost of steam generation and at the same time reduce greenhouse gas emissions. In order to avoid operational problems with biomass fed boilers, the following areas need attention:

- Uneven spreading of biomass fuel on boiler grate can lead to secondary combustion in the super-heater zone, resulting in overheating of super-heater tubes and fluctuations in steam pressure.

  Due to troublesome flow characteristics of biomass in bunkers, some operators feed the biomass directly from the top of the boiler with conveyors, leading to uneven distribution. Also, since the bunkers (which serve as reserve capacity to smoothen the variations in flow from the conveying system), are bypassed, furnace loading and combustion are not uniform, resulting in fluctuating steam parameters and generator output.
- Frequent erosion of super-heater and economizer coils can occur, due to high silica content in the biomass.
- High extraneous matter in biomass (sand and mud) causes tube fouling and fluidized bed to be drained more frequently, with resultant heat loss.
- Carbon and dust coating of boiler tubes results in lowering of steam temperatures, especially during soot blowing.
- Pesticides used during cropping add to tube failure frequencies; potassium is a particular danger.

- Corrosion of heating surfaces (coils) is a big issue. Such is the uncertainty of their wellbeing that many plants are compelled to stock at least one bundle, as a spare, at all times, thus increasing their holding costs. There are instances where the super-heater coil bundle was replaced at least once in the span of a year.
- Corrosive constituents in biomass badly affect boiler internals, especially the super-heater tubes. Chloride content in certain types of biomass (like cotton stalk, 8–9%) can combine with sodium and potassium in the-high temperature region to aggravate the corrosion process. (Many plant operators are using types of biomass whose constituents they do not fully know. It is only by trial and error that they are gaining insight into which types of biomass they should avoid.)

  Some boilers which are using Red Gram husk/twigs as fuel are facing corrosion problems at the cold ends (i.e., secondary super-heater and economizer tubes), due to the sulfur content of the Red Gram.
- The biomass fuel mix fed to the boiler, in quite a few cases, contains a combination of 7 to 6 biomass types. Each biomass has a separate air-to-fuel ratio, and it is only with difficulty that the operators manage to set a workable air–fuel ratio. In spite of their efforts, the excess air is much higher than desired. Fluidized Bed Combustion is felt to be a better choice.
- High moisture content in the biomass causes frequent jamming of the fuel in feeders, leading to fluctuations in steam pressure and temperature.
- High moisture content in the biomass also leads to plugging and choking of closely spaced heating surfaces. This situation is further aggravated by the super-heater tube coil with very close spacing, probably the result of an desire to achieve a compact design.
- Due to biomass fuel size variation, the occurance of unburnts in flue gases and bottom ash is high, resulting in lower efficiency and also variation in steam pressure and temperature.
- Inadequate height of the furnace and close pitch of the tubes lead to higher back-end temperatures, especially in the convection zones. High flue gas exit temperatures resulting in lower boiler efficiencies are the result.
- Absence of biomass feed rate measurement mechanism leaves little room for accurate assessment of heat rate/efficiency. Providing a weighting mechanism is difficult on account of different biomass fuel mixes being used with different (and low) bulk densities. This aspect needs to be studied in detail to develop viable technology solutions.
- Degradation of biomass during storage in exposed ambient wet atmosphere leads to loss of heat value. Loss of material due to windage and carpet loss, coupled with loss of heat value on account of decay (inherent biomass characteristics), can cause an error in assessment of input fuel energy (as the input heat is customarily evaluated based on received biomass quantities and GCV).

- Higher than required heating surfaces result in boilers operating at part load and lower efficiencies.
- High auxiliary power consumption (APC) is a frequent problem.
- Condensation of moisture on the colder surfaces of the ESP bottom end leads to choking of dust in the ESP hopper and subsequent ESP failures. This can be mitigated by incorporating/operating ESP hopper heaters.

4. PERFORMANCE EVALUATION OF BIOMASS BOILERS

The performance of boilers declines over time due to poor combustion, heat transfer surface fouling, and poor operation and maintenance. Even for a new boiler, deteriorating fuel quality, water quality, and other factors can result in poor boiler performance. Boiler efficiency tests help us to determine the deviation of a particular boiler's efficiency from the highest level of efficiency and to target problem areas for corrective action.

4.1 BOILER EFFICIENCY

The thermal efficiency of a boiler is defined as the percentage of heat input that is effectively utilized to generate steam. There are two methods of assessing boiler efficiency:

1. The Direct Method: Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel.
2. The Indirect Method: Where the efficiency is the difference between the losses and the energy input.

4.1.1 Direct method

This is also known as "input-output method" due to the fact that only the use fuel output (steam) and the heat input (i.e. fuel) are required for evaluating the efficiency.

$$\eta = \frac{\text{Heat Output}}{\text{Heat Input}}$$

This efficiency can be evaluated using the formula Parameters to be monitored for the calculation of boiler efficiency by direct method are:

- Quantity of steam generated per hour (Q) in kg/hr;
- Quantity of fuel used per hour (q) in kg/hr;
- The working pressure (in kg/cm^2 (g) and superheat temperature (°C), if any;
- The temperature of feed water (°C);
- Type of fuel and gross calorific value of the fuel (GCV) in kcal/kg of fuel,

$$\text{Boiler efficiency}(\eta) = \frac{Q \times (hg - hf)}{q \times GCV} \times 100$$

where, hg – Enthalpy of saturated steam in kcal/kg of steam
hf – Enthalpy of feed water in kcal /kg of water

Example:

Find the efficiency of the boiler by the direct method with the data given below:

- Type of boiler = Rice husk-fired
- Quantity of steam generated = 7.5 TPH
- Steam pressure (gauge)/temp. = 10 kg/cm^2;180°C
- Quantity of rice husks consumed = 1.8 TPH
- Feed water temperature = 65°C
- G.C.V. of rice husks = 3200 K.Cal/kg
- Enthalpy of feed water = 65 K.Cal/kg
- Enthalpy of steam = 660 K.Cal/kg

It should be noted that the boiler may not generate 100% saturated dry steam, and there may be some amount of wetness in the steam.

$$\text{Boiler efficiency}(\eta) = \frac{7.5\times(660-65)}{1.8\times3200}\times100$$

$$= 77.47\%$$

4.1.1.1 Advantages of direct method:

- Plant staff can evaluate quickly the efficiency of a boiler;
- Few parameters are required for computation;
- Few instruments are needed for monitoring.

4.1.1.2 Disadvantage of direct method:

- It does not give clues to the operator as to why system efficiency is lower;
- It does not calculate the losses accountable for various efficiency levels.

4.1.2 Indirect method

There are several reference standards for on-site boiler testing using the indirect method. One is British Standard, BS 845: 1987; the US Standard is 'ASME PTC-4-1 Power Test Code Steam Generating Unit'.

The indirect method is also called the heat loss method. Efficiency can be arrived by subtracting the heat loss fractions from 100. The standards do not include blow-down loss in the efficiency determination process. A detailed procedure for calculating boiler efficiency by the indirect method is given below. However, it may be noted that energy managers in industries prefer simpler calculation procedures.

The principal losses that occur in the boiler are:

- Loss of heat due to dry flue gas
- Loss of heat due to moisture in fuel and combustion air
- Loss of heat due to combustion of hydrogen
- Loss of heat due to radiation
- Loss of heat due to unburnts

Of the above, loss due to moisture in fuel and the loss due to hydrogen combustion are dependent on the fuel, and cannot be controlled by design.

The data required for calculation of boiler efficiency using indirect method are:

- Ultimate analysis of fuel (H_2, O_2,S, C, moisture content, ash content)
- Percentage of oxygen or CO_2 in the flue gas
- Flue gas temperature in °C (Tf)
- Ambient temperature in °C (Ta) & humidity of air in kg/kg of dry air.
- GCV of fuel in kcl/kg
- Percentage combustible in ash (in case of solid fuels)
- GCV of ash in kcal/kg (in case of solid fuels)

Solution:

Theoretical air requirement =

$[(11.43\times C)+\{34.5\times(H2-O2/8)+(4.32\times S)\}]/100$kg/kg of fuel

$$\text{Excess Air Supplied (EA)} = \frac{\%\ O2}{(21-\%O2)} \times 100$$

Actual mass of air supplied / kg of fuel (AS) = $\{1+EA/100\}\times$theoretical air *i. Percentage heat lost due to dry flue gas*

$$\% \text{ heat loss due to dry flue gas} = \frac{m \times C_p \times (Tf - Ta) \times 100}{\textit{GCV of Fuel}}$$

m = mass of dry flue gas in kg/kg of fuel
m = (mass of dry products of combustion/kg of fuel) + (mass of N_2 in fuel on 1 kg basis) + (mass of N_2 in actual of air we are supplying)
C_p = Specific heat of flue gas (0.23 kcal/kg)

ii. Percentage heat loss due to evaporation of water formed due to H2 in fuel

$$\% \text{ heat loss due to hydrogen in fuel} = \frac{9 \times H2 \times \{584 + C_p(Tf - Ta)\} \times 100}{\textit{GCV of Fuel}}$$

Where, H_2 – percentage of H_2 in 1 kg of fuel
C_p – specific heat of superheated steam (0.45 kcal/kg)

iii. Percentage heat loss due to evaporation of moisture present in fuel

$$\% \text{ heat loss due to moisture in fuel} = \frac{M \times \{584 + C_p(Tf - Ta)\} \times 100}{\textit{GCV of Fuel}}$$

Where, M – % moisture in 1 kg of fuel
C_p – specific heat of superheated steam (0.45 kcal/kg)

iv. Percentage heat loss due to moisture present in air

% heat loss due to moisture in air

$$= \frac{AAS \times \text{humidity factor} \times \{584 + C_p(Tf - Ta)\} \times 100}{\textit{GCV of Fuel}}$$

C_p – specific heat of superheated steam (0.45 kcal/kg) *v. Percentage heat loss due to unburnts in fly ash*

% heat loss due to unburnts in fly ash

$$= \frac{\text{Total ash collected per kg of fuel burnt} \times \text{GCV of fly ash} \times 100}{\textit{GCV of Fuel}}$$

vi. Percentage heat loss due to unburnt particles in bottom ash

% heat loss due to unburnts in bottom ash

$$= \frac{\text{Total bottom ash collected per kg of fuel burnt} \times \text{GCV of bottom ash} \times 100}{\textit{GCV of Fuel}}$$

vii. Percentage heat loss due to radiation and other unaccounted losses

The actual radiation and convection losses are difficult to assess because of particular emissivity of various surfaces, its inclination, its flow pattern, etc. In a relatively small boiler, with a capacity of 10 TPH, the radiation and unaccounted losses could amount to between 1% and 2% of the gross calorific value of the fuel, while in a 500 MW boiler, value between 0.2% to 1% are typical. The loss may be assumed appropriately depending on the surface condition.

$$\text{Efficiency of boiler } (\eta) = 100-(i + ii + iii + iv + v + vi + vii)$$

Example:

The following are the data collected for a typical rice husk-fired boiler. Find the efficiency of the boiler by the indirect method.

- *Type of boile*r	: Rice husk
- *Ultimate analysis of rice husk*	
Carbon	- 38.5%
Hydrogen	- 5.7%
Oxygen	- 39.8%
Nitrogen	- 0.5%
Sulphur	- 0%
G.C.V.	- 3200 K.Cal/kg
Moisture in fuel	- 8%
Ash in fuel	- 15%
GCV of bottom ash	- 900 K.Cal/kg
GCV of fly ash	- 650 K.Cal/kg
Ratio of bottom ash to fly ash	- 80:20
Percentage of oxygen in flue gas	- 7%
Flue gas temperature	- 200°C

- Ambient temperature - 30 °C
- Humidity of air - 0.018 kg/ kg of dry air

Solution:
Step 1) Find the theoretical air requirement

$[(11.43\times C)+\{34.5\times(H2-02/8)+(4.32\times S)\}]/100$kg/kg of fuel

$= [(11.43\times38.5)+\{34.5\times(5.7-39.8/8)+(4.32\times0)\}]/100$

= 4.65kg of air / kg of rice husk

Step 2) Find the percentage of excess air supplied

$$\text{Excess Air Supplied(EA)}=\frac{\%\ 02}{(21-\%02)}\times100$$

$$\text{Excess Air Supplied(EA)}=\frac{7}{(21-7)}\times100$$

= 50%

Step 3) Find the actual mass of air supplied

Actual mass of Air supplied / Kg of fuel

$= [1+EA/100]\times\text{Theoretical Air}$

$= [1+50/100]\times4.65$

= 6.97 kg of Air/kg of R.H

Note: In order to make the calculation simple, the flue gas mass is taken as actual mass of air supplied for combustion.

Step 4) Find the losses

i. Dry flue gas loss

$$\%\text{ heat loss due to dry flue gas} = \frac{m\times C_p\times(Tf-Ta)\times100}{\textit{GCV of Fuel}}$$

$$\%\text{ heat loss due to dry flue gas} = \frac{6.97\times0.23\times(200-30)\times100}{3200}$$

= 8.5 %

ii. Heat loss due to evaporation of water formed due to H_2 in fuel

$$\text{\% heat loss due to hydrogen in fuel} = \frac{9 \times H2 \times \{584 + C_p(Tf - Ta)\} \times 100}{\textit{GCV of Fuel}}$$

$$\text{\% heat loss due to hydrogen in fuel} = \frac{9 \times 0.57 \times \{584 + 0.45(200 - 30)\} \times 100}{3200}$$

$$= 1.06 \ \%$$

iii. Heat loss due to moisture in fuel

$$\text{\% heat loss due to moisture in fuel} = \frac{M \times \{584 + C_p(Tf - Ta)\} \times 100}{\textit{GCV of Fuel}}$$

$$\text{\% heat loss due to moisture in fuel} = \frac{0.12 \times \{584 + 0.45(200 - 30)\} \times 100}{3200}$$

$$= 2.47\%$$

iv. Percentage heat loss due to unburnts in ash

GCV of bottom	= 9000 Kcal/kg
Amount of bottom ash in 1 Kg if RH	= 0.8 x 0.15
	= 0.12 kg
Heat loss in bottom ash	= 0.12 x 900
	= 108 kcal/kg of fuel
% heat loss in bottom ash	= 108 x 100/3200
	= 3.375%
GCV of fly ASH	= 650 kcal/kg
Ratio of bottom ash to fly ash	= 80 : 20
Amount of fly ash in 1 kg of fuel	= 0.2 x 0.15
	= 0.03 kg
Heat loss	= .03 x 650
	= 19.5 kcal/kg of RH
% heat loss in fly ash	= 19.5 x 100/3200
	= 0.6 %

Unaccounted losses such as radiation convection, carbon monoxide, and humidity in air are estimated as 2.5 %.

Total heat loss	= 8.5+1.06+2.47+3.375+0.6+2.5
	= 18.5%
Boiler efficiency	= 100−18.5
	= 81.5%

5. RETROFITTING OF COAL-/OIL-FIRED BOILER WITH BIOMASS AND CHECKLIST FOR ENHANCED BOILER EFFICIENCY

5.1 BOILER RETROFITTING

With the escalating cost of fossil fuel, most enterprises in small and medium-scale industries, using coal or oil for steam generation, are keen to switch over to biomass fuel to reduce steam generating cost. Acquiring a new biomass boiler requires high investment and is difficult for small enterprises. Most small-scale industries are interested in retrofitting measures, with which they can adapt an existing boiler for switching over from fossil fuel to biomass. One of the major drawbacks of fuel substitution in an existing boiler is de-rating, or reduced steam generation capacity, of a retrofitted boiler. The de-rating factor depends upon the type of boiler. For example, in an oil-fired package boiler, the biomass combustion chamber is designed externally, and the de-rating factor will be larger than for boilers where the furnaces is installed internally, as in the case of a stationery grate water tube boiler.

The heat transfer rate in a boiler is a combination of radiation and convection, which constitute 30% and 70% respectively. As the radiation heat transfer increases, boiler steam generation capacity also improves. This is one of the major problems in fire tube boilers, where radiation heat transfer is affected due to the external furnace. Sometimes the de-rating factor is as high as 25−30%.

The other factor in de-rating is the slow combustion press for small tyoes of biomass with uneven size and higher moisture content, such as woody mass, bagasse, etc. Burning this type of fuel in a small boiler requires high excess air and reduced flame temperature.

The de-rating factors also accelerate due to manual removal of ash in most biomass burn boilers (particularly in stationary grate furnaces), where the combustion air supply is on which cools down furnace temperature.

Table 5-1 depicts the selection of types of furnaces for different boilers for retrofit.

Table 5-1 Selection criteria for boiler retrofit

S. No	Type of Boiler	Furnace Selection for Retrofit	Remarks
1.	Vertical fire tube small boiler up to 1 Tons/hr capacity	Stationary and step grate furnace	• Mostly coal is used in this type of boiler. In the same stationary grate, wood can be burned, and there will be little de-aeration in steam generation capacity. • For rice husk-type biomass, external step grate furnace is recommended.
2.	Stationary grate coal-fired water tube boilers up to 5 Tons/hr capacity	Stationary grate, spreader stocker, fluidized bed	• Biomass having large sized pieces can be easily burned in stationary grate. • Biomass of fine particles such as rice husk/sawdust can be used for suspension firing. Furnaces should have sufficient combustion volume. • For uniform and small sized biomass, a fluidized bed furnace is one of the most efficient retrofits. In this system, boiler can have an efficiency level of 80±2%.
3.	Oil-fired fire tube package boiler	Step or suspension grate external furnace	• In oil-fired package boiler the combustion volume inside the boiler is the limitation. In such cases external furnace can be designed for biomass burning. Provision may be made for regular cleaning of fire tube.
4.	Chain grate spreader stocker coal-fired boiler	Spreader stocker suspension firing	• Biomass can be easily fed with spreader stocker in boiler furnace. Steam generation capacity of boiler will be reduced. • Major modification will be required if the same boiler is redesigned for fluidized bed combustion. Efficiency will be higher in FBC as compared to spreader stocker.

5.2 ECONOMICS OF CHANGE

The example given below illustrates the cost of changing an oil-fired boiler to a rice husk-fired boiler.

COST ECONOMICS OF REPLACING SMALL OIL-FIRED BOILER WITH RICE HUSK-FIRED BOILER

BOILER OPERATING PARAMETERS

- Steam generation capacity	- 2 TPH
- Saturated steam pressure	- 10 Kg/cm^2
- Heat content of steam	- 660 K.cal/kg
- Feed water inlet temperature	- 60°C
- Daily operating hours	- 24
- No. of days/year	- 300
- Efficiency of oil fired boiler	- 82%
- Efficiency of rice husk fired boiler	- 70%
- Cost of fuel oil	- USD500/ton
- Cost of rice husk	- USD40/ton
- G.C.V. of fuel oil	- 10,000 K.cal/kg
- G.C.V. of rice husk	- 3,200 K.cal/kg
- Cost of 2 T/hr rice husk boiler	- USD50,000/-

A. Fuel Oil Consumption

- Boiler operating time per year = 24 x 300 = 7200 hrs
- Annual steam production = 2T/hr x 7200 = 14,400 T/yr
- Heat requirement for producing 14,400 tons steam
  =14,400x10^3 x (660−60)
- Heat Input= Heat Output/Boiler Efficiency
  = 864 x 10^7 / 0.82
  = 1053.6 x 10^7 K.cal.
- Oil equivalent (G.C.V. of oil=10000 K.cal/kg)
  = 1053.6 x 10^7 /10,000
  = 1053.6 tons
- Cost of fuel oil (USD500/T) = 1053.6 x 500
  = USD526,800

B. Rice Husk Consumption

- Heat requirement for producing 14,400 tons steam
  = 864 x 10^7 K.cal
- Heat Input = 864 x 10^7 / 0.70
  = 1234.3 x 10^7 K.cal.
- Rice Husk equivalent (G.C.V. of Rice Husk
  = 3200 K.cal/kg)
  = 1234.3 x 10^7 / 3200
  = 3857 tons
- Cost of rice husks (USD40/ton) = 3857 x 40
  = USD154,280

- Fuel savings = 526,800−154,280
  = USD3,72,520
- Investment for purchase of new rice husk-fired boiler
  = USD50,000
- Simple payback period = 1.6 months

5.3 CHECKLIST FOR ENHANCING BOILER EFFICIENCY

5.3.1 Periodic tasks and checks outside of the boiler

- All access doors and plate work should be maintained airtight with effective gaskets.
- Flue systems should have all joints sealed effectively and be insulated where appropriate.
- Boiler shells and sections should be effectively insulated. Is existing insulation adequate? If insulation was applied to boilers, pipes, and hot water cylinders several years ago, it is almost certainly too thin even if it appears in good condition. Remember, it was installed when fuel costs were much lower. Increased thickness may well be justified.
- At the end of the heating season, boilers should be sealed thoroughly, internal surfaces either ventilated naturally during the summer or very thoroughly sealed with tray of desiccant inserted. (This is only applicable to boilers that will stand idle between heating seasons.)

5.3.2 Safety and monitoring

- Explosion relief doors should be located and/or guarded to prevent injury to personnel.
- Safety valves should have self-draining discharge pipes terminating in a safe location that can be easily observed.
- Installed instruments should be maintained in working order and positioned where they can be seen easily.
- Provide test points with removable seal plugs in the flue from the boiler, to enable flue gas combustion tests to be carried out.
- Do you check boiler combustion conditions periodically? CO_2 or O_2 readings and exit temperatures can be obtained using relatively inexpensive portable equipment. Adjusting combustion by optimizing the fuel/air ratio costs nothing and can lead to substantial savings.
- Do you monitor exit temperatures? There should be a steady rise between boiler flue-duct cleaning intervals, and this should not be allowed to exceed, say, 40°C. Try to clean based on temperature indications, rather than on the calendar.

- If you have more than one boiler, do you isolate boilers which are in excess of load requirements? Automatic flue isolation should be used, if possible, to prevent excessive purging by chimney draughts during idle periods.
- In multi-boiler hot water installations, are the boilers hydraulically balanced to ensure proper sharing of the load?
- Consider fitting heat exchangers/recuperators to flues; these can recover 5−7% of the energy available.

5.3.3 Boilers: Extra items for steam-raising and hot-water boilers

- Check regularly for buildup of scale or sludge in the boiler vessel; or check TDS of boiler water each shift, but not less than once per day. Impurities in boiler water are concentrated in the boiler, and the concentration has limits that depend on type of boiler and load. Boiler blow-down should be minimized, but consistent with maintaining correct water density. Recover heat from blow-down water.
- With steam boilers, is water treatment adequate to prevent foaming or priming and consequent excessive carryover of water and chemicals into the steam system?
- For steam boilers: Are automatic water level controllers operational? The presence of interconnecting pipes can be extremely dangerous.
- Have checks been made regularly on air leakages around boiler inspection doors, or between boiler and chimney? The former can reduce efficiency; the latter can reduce draught availability and may encourage condensation, corrosion, and smutting.
- Combustion conditions should be checked using flue gas analyzers at least twice per season, and the fuel/air ratio should be adjusted if required.
- Both detection and actual controls should be labelled effectively and checked regularly.
- Safety lock-out features should have manual re-set and alarm features.
- With boiler plant, ensure that the fuel used is correct for the job. With solid fuel, correct grading or size is important, and ash and moisture content should be as the plant designer originally intended.
- Ensure that the boiler operators are conversant with the operational procedures, especially any new control equipment.
- Have you investigated the possibility of heat recovery from boiler exit gases? Modern heat exchangers/recuperators are available for most types and sizes of boiler.
- Do you check feed and header tanks for leaking make-up valves, correct insulation, or loss of water to drain?

- The boiler plant may have originally been provided with insulation by the manufacturer. Is this still adequate with today's fuel costs? Check on optimum thickness.
- Keep a proper log of boiler house activity so that performance can be measured against targets. When checking combustion, etc., with portable instruments, ensure that this is done regularly and that load conditions are reported in the log.

5.3.4 Water and steam

- Water fed into the boilers must meet the specifications given by the manufacturers. The water must be clear, colorless, and free from suspended impurities.
- pH values of 8 to 10 retard forward action or corrosion. pH less than 7 speeds up corrosion due to acidic action.
- Dissolved O_2 should be less than 0.02 mg/l. Its presence with SO_2 causes corrosion problems. CO_2 level should be kept very low. Its presence with O_2 causes corrosion, especially in copper and copper-bearing alloys.
- Water must be free from oil: it causes priming.

5.3.5 Boiler water

- Water must be alkaline: within 150 ppm of CaCO3 and above 50 ppm of CaCO3 at pH 8.3.
- Total solids should be maintained below the value at which contamination of steam becomes excessive, in order to avoid cooling over and accompanying danger of deposition on super heater, steam mains, and prime movers.
- Water treatment plants suitable for the application must be installed to ensure water purity, and a chemical dosing arrangement must be provided to further control boiler water quality. Blow-downs should be resorted to when concentration increases beyond the permissible limits stipulated by the manufacturers.
- Alkalinity is not to exceed 20% of total concentration. Boiler water level should be correctly maintained. Normally, 2 gauge glasses are provided to ensure this.
- Operators should blow these down regularly in every shift, or at least once per day where boilers are steamed less than 24 hours a day.

5.3.6 Blow-down (BD) Procedure

A conventional and accepted procedure for blowing down a gauge is as follows:

1. Close water lock
2. Open drain cock (note that steam escapes freely)

3. Close drain cock
4. Close steam cock
5. Open water cock
6. Open drain cock (note that water escapes freely)
7. Close drain cock
8. Open steam cock
9. Open and then close drain cock for final blow-through

The water that first appears is generally representative of the boiler water. If it is discolored, the reason should be ascertained.

5.3.7 Boiler periodic checklist

Table 5-2 lists the items that must be periodically checked as part of boiler maintenance.

Table 5-2 Items to be used for checking boilers

System	Daily	Weekly	Monthly	Annual
BD and water treatment	Check that BD valves do not leak. BD is not excessive.		Make sure solids do not build up.	
Feed water system	Check and correct unsteady water level. Ascertain cause of unsteady water level, contaminant overload, malfunction, etc.	Check controls by stopping the feed water pump and allow control to stop fuel.		Condensate receiver, deaerator system pumps.
Flue gases	Check temperature at two different points.	Measure temperature, compare composition at selected firings, and adjust recommended valves.	Same as weekly. Compare with previous readings.	Same as weekly. Record references.

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Combustion air supply			Check that adequate openings exist in air inlet. Clean passages.	
Burners	Check that controls are operating properly. May need cleaning several times a day.	Clean burners, and pilot assemblies; check condition of spark gap of electrode burners.	Same as weekly.	Same as weekly; clean and recondition.
Boiler operating characteristics		Observe flame failure and characteristics of the flame.		
Relief valve		Check for leakages.		Remove and recondition.
Steam pressure	Check for excess loads which will cause excessive variation in pressure.			
Fuel system			Check pumps, pressure gauges, transfer lines. Clean them.	Clean and recondition system.
Belts for gland packing			Check for damages. Check gland packing for leakages and proper compression.	

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Air leaks on water side and fire side surfaces				Clean surface as per manufacturer's recommendation annually.
Air leaks				Check for leaks around access openings and flame.
Refractories on fuel side				Repair.
Electrical system		Clean panels outside.	Inspect panels inside.	Clean, repair terminals and contacts, etc.
Hydraulic and pneumatic valves			Clean equipment; oil spillages to be arrested and air leaks to be avoided.	Repair all defects and check for proper operation.

5.3.8 Boiler Do's and Dont's

Do's

1. Conduct soot blowing regularly.
2. Clean blow-down gauge glass once a shift.
3. Check safety valves once a week.
4. Blow down in each shift, to requirement.
5. Keep all furnace doors closed.
6. Control furnace draughts.
7. Clear and discharge ash hoppers every shift.
8. Watch chimney smoke and control fires.
9. Check auto controls on fuel by stopping feed water for short periods occasionally.
10. Attend to leakages periodically.
11. Check all valves, dampers, etc. for correct operation once a week.
12. Lubricate all mechanisms for smooth working
13. Keep switchboards neat and clean and indication systems in working order.
14. Keep area clean and dust-free.
15. Keep firefighting arrangements in readiness always. Rehearsals should be carried out once a month.

16. All log sheets must be truly filled out.
17. Reset the FD fan if ID fan trips.
18. CO_2 or O_2 recorder must be checked/calibrated once in three months.
19. Traps should be checked and attended to periodically.
20. Quality of steam and water, should be checked once a day, or once a shift as applicable.
21. Quality of fuel should be checked once a week.
22. Keep sub heater drain open during start-up.
23. Keep air cocks open during start and close.

Dont's

1. Don't light up torches immediately after a fireout (purge).
2. Don't blow down unnecessarily.
3. Don't keep furnace doors open unnecessarily.
4. Don't blow safety valves frequently (control operation).
5. Don't over-flow ash hoppers.
6. Don't increase firing rate beyond that permitted.
7. Don't feed raw water.
8. Don't operate boiler blindfolded.
9. Don't overload boiler as a practice.
10. Don't keep water level too high or too low.
11. Don't operate soot blowers at high loads.
12. Don't trip the ID fan while in operation.
13. Don't look at fire in furnace directly; use tinted glasses.
14. Avoid thick fuel bed.
15. Don't leave boiler to untrained operators/technicians.
16. Don't ignore unusual observations (sound change, change in performance, control difficulties); investigate.
17. Don't skip annual maintenance.
18. Don't prime boilers.
19. Don't allow steam formation in economizer (watch temperatures).
20. Don't expose grate (spread evenly).
21. Don't operate boiler with water tube leaking.