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Heating Applications of Bio-pellet to Enhance Utilization of Renewable Energy in the APEC Region

APEC Energy Working Group /
Expert Group on New and Renewable Energy Technologies

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Produced by
Seng-Rung Wu, Ph.D., Principal Researcher
Green Energy and Environment Research Lab.
Industrial Technology Research Institute
Bldg. 64, 195, Sec. 4, Chung Hsing Rd.,
Chutung Hsinchu 31040, Chinese Taipei

ITRI Industrial Technology Research Institute

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace, Singapore 119616
Tel：(65) 68919 600
Fax：(65) 68919 690
Email：info@apec.org
Website：www.apec.org

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Executive Summary

The world energy supply is facing a diverse and broad set of challenges. Owing to the development of industrial civilization and the rapid increase in population, the fossil fuel reserves on earth have been consumed rapidly. The over-reliance on the use of fossil fuels has led to not only environmental pollution but also global climate change. Concerns over climate change related to carbon emissions are affecting governmental and company policies and strategies. Combined with other drivers, these factors are putting increased focus on sustainable fuels made from biomass.

Bio-pellets are sustainable bio-fuels which can be categorized into white pellet (pelletized from biomass) and black pellet (pelletized from torrefied biomass), both having the characteristics of being "carbon neutral" and clean combustion that they are effective alternatives to replace the fossil fuels in industrial combustion and power plant applications. There are two major markets for bio-pellets, the industrial pellets used as a substitute for coal in large utility power stations and the premium heating pellets used in pellet stoves and pellet fueled central heating systems. Global wood-pellet production increased from 19.5 million tons in 2012 up to 28.6 million tons in 2016, with average annual growth rate of about 10%. In 2016, industrial usages on bio-pellets and household usages on premium heating pellets have accounted for 50.4% and 49.6%, respectively. The demands of industrial pellets will grow rapidly in the future due to policies driven by each country for substituting some coals into bio-pellets for power plant applications.

Policies driven by each country for bio-pellet applications, either by Fit-in-Tariff (FIT) or Renewable Portfolio Standards (RPS), increase the bio-pellets utilization in substitution for coal in power plants, significantly reducing the carbon dioxide emission from fossil fuel. In Europe, UK has the world's largest biomass firing power program which contributes 5.6% electricity production in 2017. In Asia, Korean RPS mandates an increasing percentage of power generated from renewable sources increased to 10% in 2024. Wood pellet imports to Korea has almost tripled over the past three years. Korea is now the largest importer of wood pellets in Asia. The FIT of ¥21/kWh for 20 years in Japan has led to 8 GW of renewable energy capacity being added since 2012. Co-firing wood pellets for large utility pulverized coal boilers have been increased from 80,000 tons in 2012 up to expected 500,000 tons in 2017 and are expected to be increased significantly in the future in Japan.

Most enterprises especially in the APEC's developing economics are SMEs, relying on firing fossil fuel with boilers to obtain heating required for the manufacturing process. It is difficult for SMEs to use modern green energy, especially the wind power and solar PV, due to the limited space available. A project is conducted in Chinese Taipei to utilize white leadtree for the bio-pellet applications to SMEs' packaged boiler. The white leadtree is one of the 100 worst invasive species and is a very common species in APEC economics. Although the high ash and chorine contents of white leadtree make it unqualified for household premium heating pellets, white-leadtree pellets are applicable to industrial packaged boilers equipped typically with air pollution control devices. Boiler efficiency reaches 89.6% in white-leadtree pellet-fired packaged boiler.

A win-win strategy of eradiation of white leadtree for bio-pellet production is not only good for land environment but also beneficial to climate environment by providing SMEs carbon-neutral bio-pellet for packaged boiler applications. Another win-win strategy for both bio-pellet fuel manufacturers and boiler end users of SMEs is proposed. EPP (Equivalent Pellet Price) is the selling price of white-leadtree pellet based on the same dollar can buy the same heating values of bio-pellet or natural gas fuels. SMEs can cut down the cost of fuel and hence increase their competitiveness when the white-leadtree pellet fuel is sold at 90% of EPP. Although bio-pellet fuel manufacturers generate lower profits, they still enjoy a decent calculated 12.4% IRR and greater market share in return.

An APEC Workshop on Bio-pellet Production, Handling and Energy Utilization was held in Tokyo, Japan on 24-25 October, 2017. More than 68 bio-pellet scientists and engineers from 11 APEC member economies and 1 non-APEC economy, representing academia, industry, and government agencies, gathered in Tokyo to discuss the bio-pellet technologies and applications. The substantial interest in this workshop, evidenced by the diversity of participants, demonstrates the vital importance of this topic to APEC member economies. Several comments are made and action plans are suggested concerning the bio-pellet applications over the presentations and discussions in the workshop.

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Acronyms

APEC	Asia-Pacific Economic Cooperation
ASTM	American Society for Testing and Materials
BFB	Bubbling Fluidized Bed
CEN	European Committee for Standardization
CER	Certified Emission Reductions
CHP	Combined Heat and Power
CFB	Circulating Fluidized Bed
COP	Conference of the Parties
DIN	Deutsch Industry Norm
EN	European Standard
ENSO	El Nino Southern Oscillation
EPP	Equivalent Pellet Price
EV	Electric Vehicle
FBC	Fluidized Bed Combustion
FC	Fuel Cell
FCV	Fuel Cell Vehicle
GHG	Green House Gases
HV	Heating Value
HHV	Higher Heating Value
IEA	International Energy Agency
INDCs	Intended Nationally Determined Contributions
IUCN	International Union for Conservation of Nature
ISO	the International Organization for Standardization
ITRI	Industrial Technology Research Institute
LCA	Life Cycle Analysis
LHV	Lower Heating Value
NT$	New Taiwan Dollar
PCC	Pulverized Coal Combustor
PFI	Pellet Fuels Institute
PV	Photovoltaic
REC	Renewable Energy Certificate
REN21	Renewable Energy Policy Network for the 21st Century
SMEs	Small and Medium Enterprises
SOFC	Solid Oxide Fuel Cell
TILF	Trade and Liberalization Fund

UNFCCC	United Nations Framework Convention on Climate Change
US$	United States Dollar
VAT	Value-Added Tax
VOC	Volatile Organic Compounds

1. Recent Advances in Bio-pellet Technologies and Applications

1.1 Global biomass energy status

Since crude oil was discovered in the nineteenth century, it helped develop industry and commerce rapidly. Owing to the development of industrial civilization and the rapid increase in population, the energy reserves on earth have been consumed rapidly, and fossil fuels are becoming serious issues. Furthermore, the over-reliance on the use of fossil fuels will also lead to environmental pollution and global warming problems in addition to the rapid exhaust of fossil fuels.

With the global attention on the issues of energy supply, carbon reduction and environmental sustainability, the worldwide countries have taken different policies or measures (mandatory or voluntary carbon reduction) to comply with the global carbon reduction trend, and to actively develop carbon footprint, carbon tax, carbon rights trading and other mechanisms. The United Nations Framework Convention on Climate Change (UNFCCC) 21st Conference of the Parties (COP21), held in Paris, France, in 2015, passed the historic Paris Agreement and the 195 participating countries agreed to control greenhouse gas emissions, so that global average temperature will rise no more than 2 degrees Celsius, and will strive to control within the target of 1.5 degrees Celsius. Most of the countries are committed to expanding the usages of renewable energy and enhancing energy efficiency through the Intended Nationally Determined Contributions (INDCs) [1].

Bioenergy has a “carbon neutral” characteristic and is a kind of energy source that can replace fossil fuels. As to the acquisition of bioenergy, we can transform biomass materials into high-quality solid, liquid or gaseous biomass fuels through conversion technology, and apply to existing infrastructure to achieve the required energy (thermal or electrical). Moreover, biomass materials are the only reliable sources of organic carbon and biofuels [2,3], which can be converted into heat and electricity for buildings and industrial processes or converted to gas or liquid fuels used for transportation purposes. This flexibility is unique among a variety of forms of renewable energy that it is a highly valued alternative energy. Therefore, countries worldwide have been actively planning on developments of biomass fuels, biomass heat/electricity, etc.

According to the International Energy Agency (IEA), the world’s total primary energy supply was about 13,699 Mtoe in 2014, and bioenergy accounted for about 10.3% of the world’s total primary energy supply, which was only less than coal, oil and natural gas that it was the world's fourth largest energy supply category [4]. In addition, the REN21 data indicate that bioenergy supply has been increasing 2% annually since 2010, and would provide 60 EJ primary energy supply in 2015. As to the final energy consumption, bioenergy accounts for 14% of the total energy consumption. If we compile statistics from the usage sectors, bioenergy accounted for 2%, 2.8%, 7.2% and 29.6% for global electricity, transportation, industrial heat applications and living/commerce sector (heat supply) respectively. Such data have shown bioenergy's contributions to heat supply of final energy demands, which are far more than the usages in electricity or transportation. Among them, solid biofuel is the major source of bioenergy in the heating supply and power applications, the supply ratios were 77% and 71% [1].

Bio-pellet is one of the sources of solid biofuel. Bio-pellet refers to the use of lignin as a binder under certain conditions of temperature and pressure, compressing loose farming or wooden biomass materials such as wood chips, straws, branches and bamboo chips into rod-shaped, massive or pellet formed fuels of energy density equivalent to medium bituminous coal [5], which have advantages for storage, transportation, ease of usage, being clean and environment friendly and high combustion efficiency. Moreover, its pollutant emission of NO_x, SO_2 and particulates in the boiler combustion applications is lower than that of burning coals. Therefore, the use of bio-pellets is one of the effective ways to achieve efficient and clean energy usages, and has received wide attention recently.

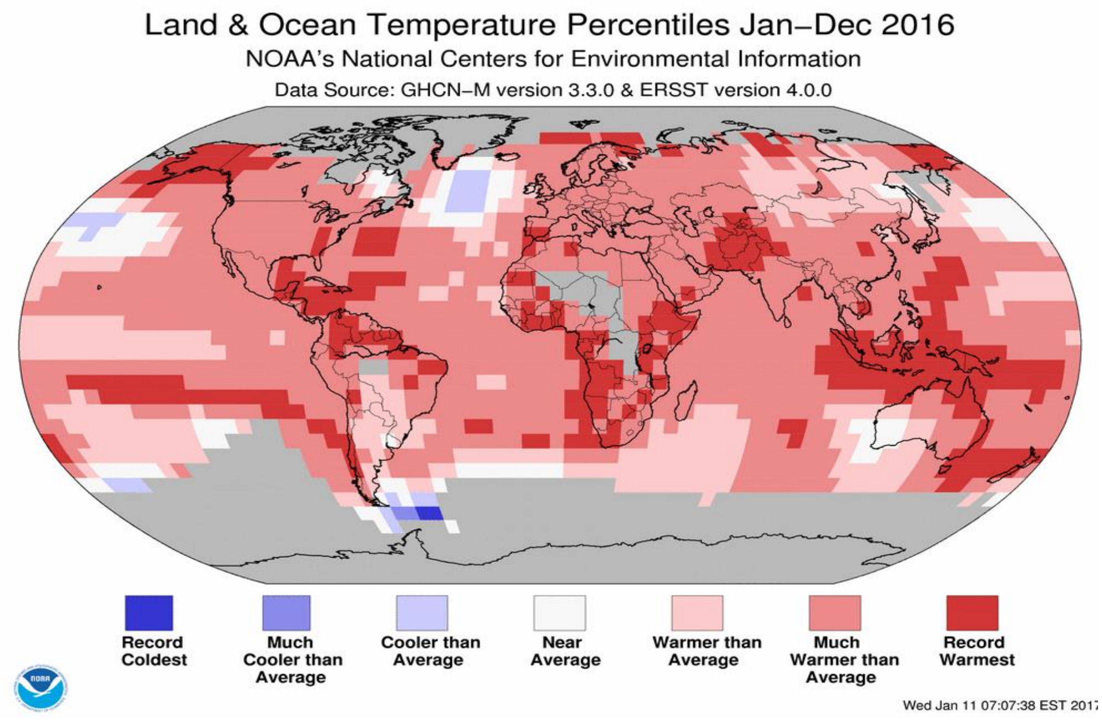
In 1976, during the world oil crisis, the first wood bio-pellet patent came out in the United States, and was applied to small-scale regional thermal applications [6]. Moreover, with the fossil fuel prices ramping up year by year, it facilitated the developed countries' applications of bio-pellets in industries, and in turn drove the industries of bio-pellet related technologies forward. Since 1990, the use of wood pellets has soared in European countries of Sweden, Denmark, Austria, etc. [7]. In 1995, an international symposium on biomass pelletizing technology was held in India to broadly promote the international exchanges and developments of biomass pelletizing technology.

By the end of 2005, there were 285 large-scale bio-pellet plants (mainly wood pellet plants) in the world with more than 4.2 million tons of production annually. Among them, the American regions have produced 1.1 million tons and European region 3 million tons [8]. As to the individual countries, Sweden's approximate 1.4 million tons bio-pellet annual production and 1.7 million tons annual consumption have been ranked the #1 of the world. The global wood pellet market has kept on rapidly expanding after that, and the wood pellet production has been steadily increasing at a growth rate of 10% per year. By the end of 2016 the world wood pellet production was about 28.6 million tons, which has been used to replace coal for industrial boilers, and also for boilers/burner fuel usage purposes for regions and household heat-supply [9]. Among them, the industrial sector have consumed about a total of 14.4 million tons of pellet fuels.

In view of the global trend for carbon reduction, bio-pellets have the characteristics of “carbon neutral” and clean combustion that it is an effective approach for replacing fossil fuels in industrial combustion applications. Therefore, this Chapter collects information about the technical developments on manufacturing of the bio-pellets, combustion applications in existing boiler, and to introduce about wood-pellets’ application cases in various regions of the world.

1.2 Global bio-pellet market outlook

Ever since the Industrial Revolution, new types of manufacturing methods have replaced traditional manpower and animal forces to improve the efficiency of production, and have changed the human life. However, the revolution of science and technology have also impacted the environment more and more seriously, such as the environmental issues of greenhouse gas effect, ENSO, etc., have emerged gradually. Figure 1.1 shows the circumstances concerning changes of average temperatures in various cities of the world in 2016, and from which we can see that the majority areas of the earth are in a warming state that exceeds the average temperature. Therefore “how to slow down the warming of the earth” has gradually become a common concern nowadays. Among them, the use of renewable energy such as co-firing of bio-pellets is an effective measure to alleviate greenhouse gas emission. The application of bio-pellets thus has gained much attention.



Source [10]

Figure 1.1 World average temperature change record

The global production of wood-pellets has grown significantly over the past decade, and it can be seen from Figure 1.2 that global wood-pellet production increased from 19.5 million tons in 2012 up to 28.6 million tons in 2016, with the annual growth of 13.5%, 15.4% 3.3% and 5.9% respectively and average annual growth rate of about 10% [11]. Nevertheless, the annual growth rate of wood pellets slightly slowed down due to the sharp decline in oil prices during the period of 2014-2015 (Figure 1.3).

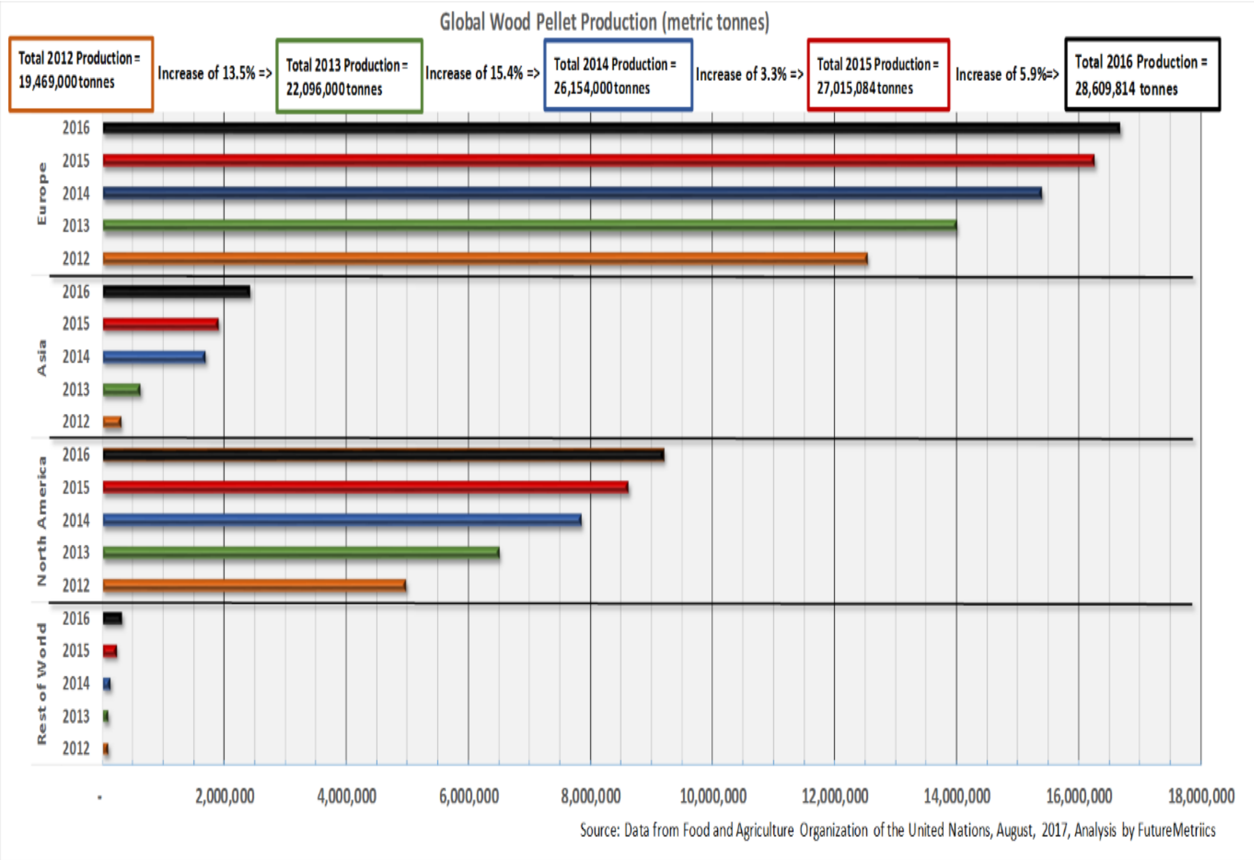
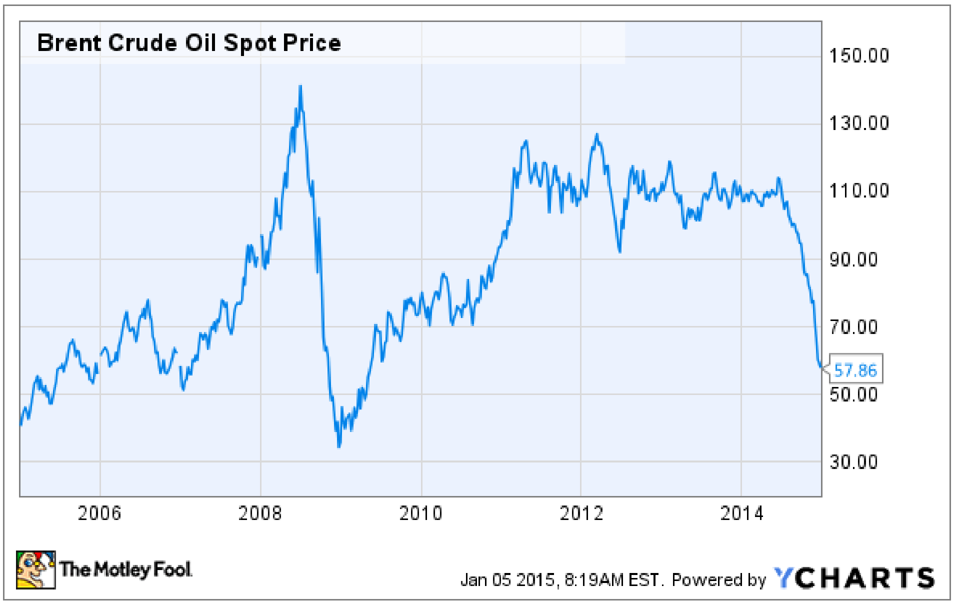


Figure 1.2 Global wood pellet production



Source [12]

Figure 1.3 Brent crude oil price

In terms of wood-pellet production, Europe is the region of the world with the largest production capacity. Take 2016 for example, the whole global wood pellet production was about 28.6 million tons, and the European region has contributed a total of 55%. Among them, Germany was the biggest production country with annual production of about 2 million tons, while Sweden, Latvia and Austria were the second, third and fourth largest wood pellets producers in that region. The American region was the second largest region in the world for wood pellet production. Its annual production accounted for 32% of the total global production with the USA as the main producer. As to the pellet production in Asian region, it accounted for 5.3% of the total global production, and the main production countries were the Southeast Asian countries and China.

In general, the global wood-pellet applications can be divided into two aspects of industrial applications and household applications. In 2016, industrial usages on bio-pellets have accounted for 50.4%, which are mainly to replace the coal in thermal power plants, to reduce carbon emissions and to mitigate greenhouse effects. The household usages on premium heating pellets have accounted for 49.6%, which are mainly used in pellet stoves and pellet fueled central heating systems as shown in Figure 1.4 [11]. The premium heating pellets are for household applications and the quality requirements are higher than what from the industrial sector.

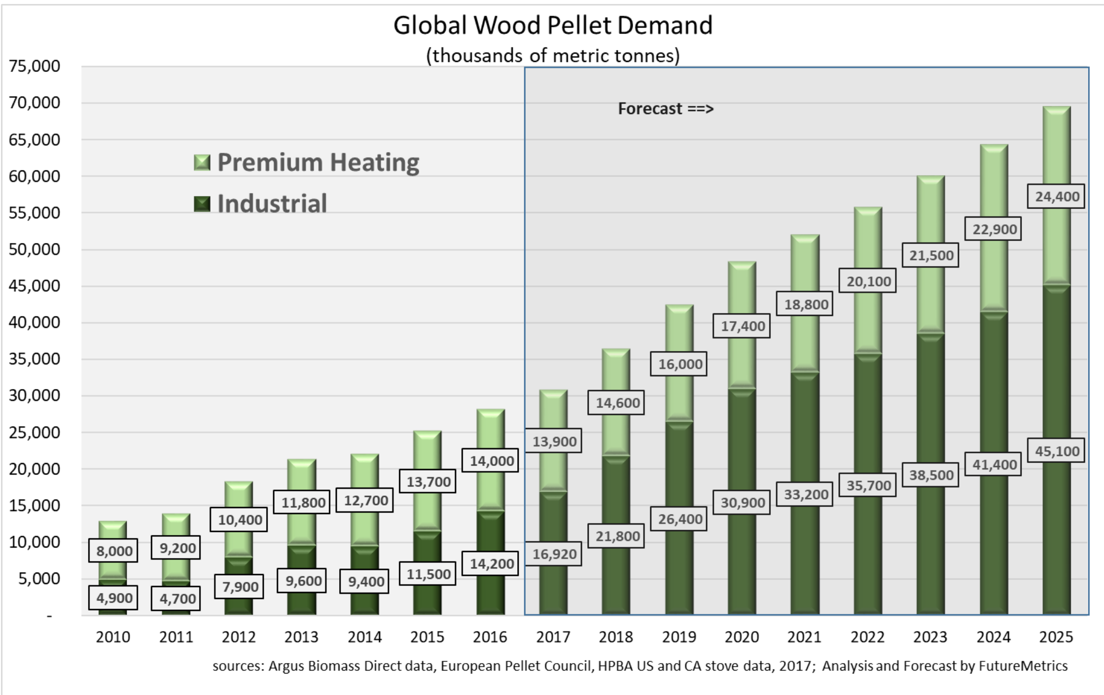


Figure 1.4 Global wood pellet demand

The industrial pellet market is expected to grow rapidly (Figure 1.5) mainly due to the policy requirements of some countries to mitigate carbon dioxide emission by substituting some coal into bio-pellet for power plant applications. Figure 1.6 shows the premium heating pellet markets which are driven by economics when lowest cost of heating fuel is available for household [11].

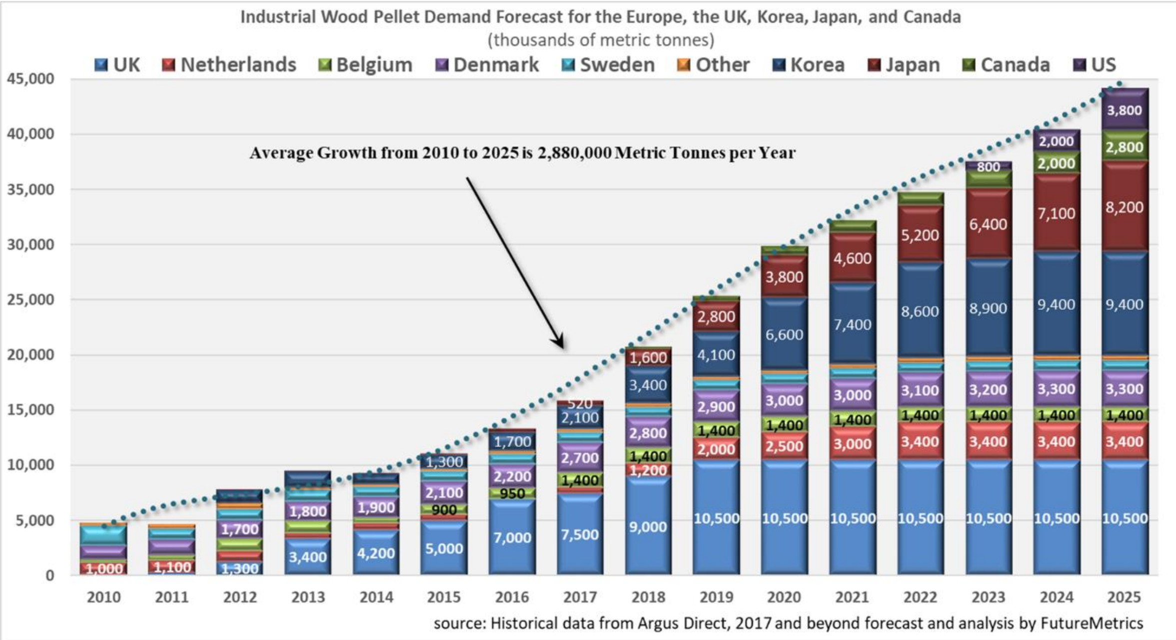


Figure 1.5 Industrial pellet market

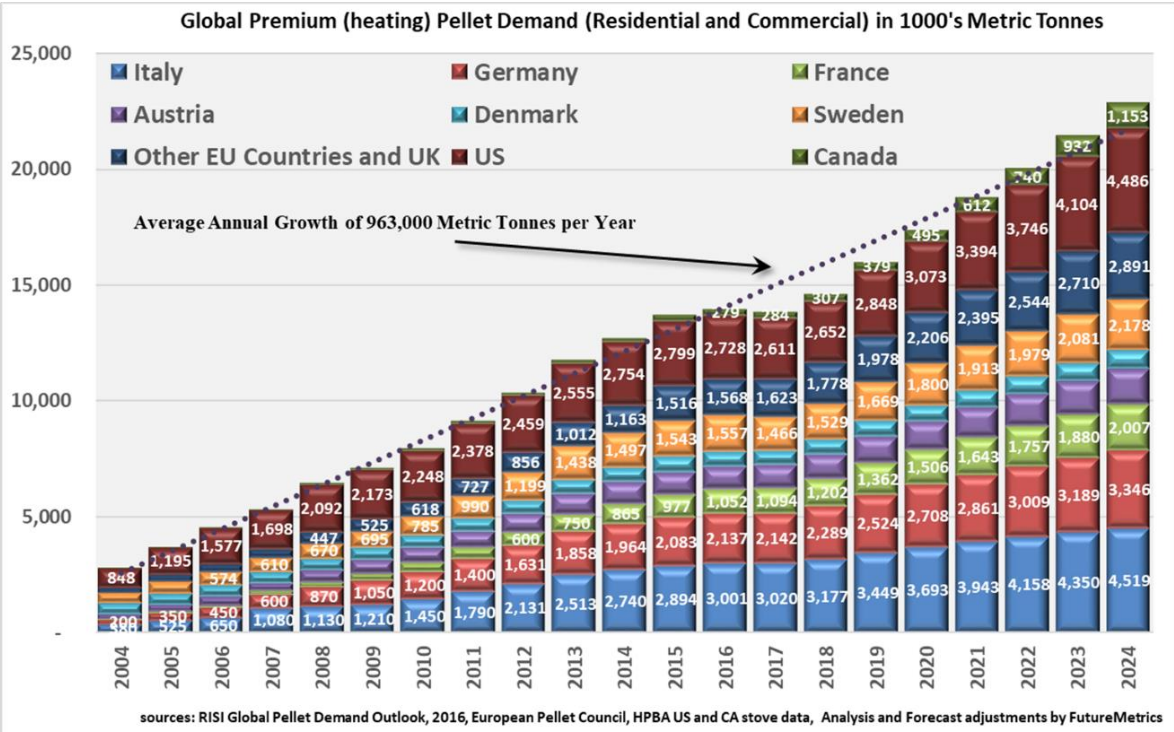
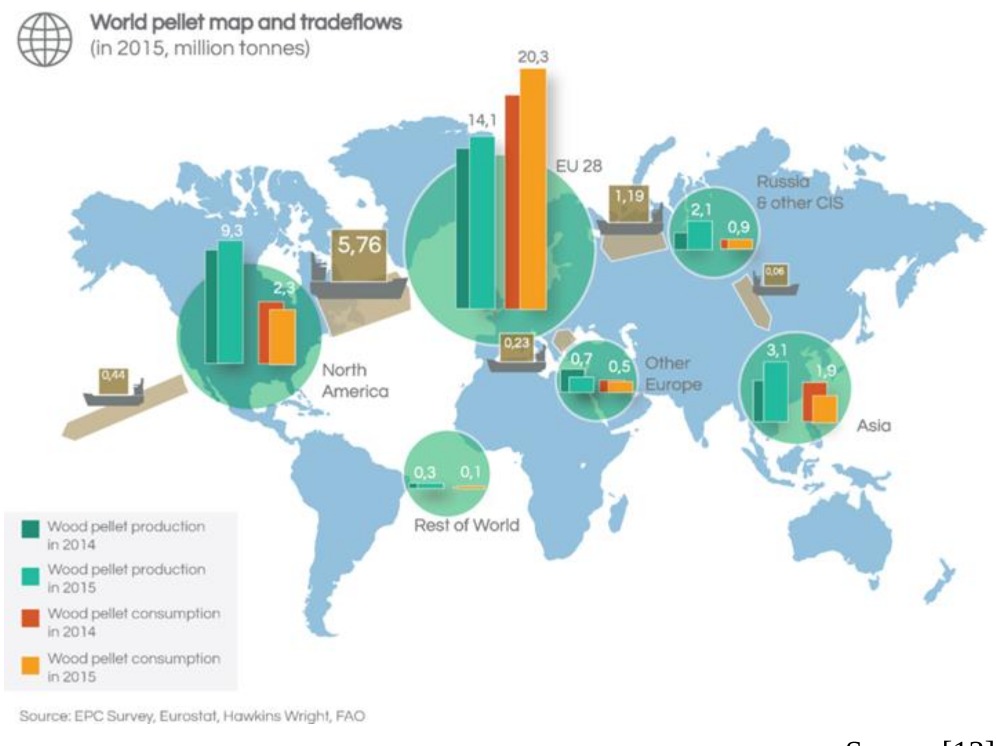


Figure 1.6 Premium heating pellet market

In terms of demand for wood-pellets, the European market is constrained by the EU’s energy policies which have asked that power companies comply with regulations that "20% of electricity generated must be from renewable energy", and thus resulted in the continual growth of wood pellets year after year. Take the case of 2015 for example (Figure 1.7), the global demand for wood pellets was about 26 million tons with the demand for the European market was 78%, or about 20.3 million tons, and its production was about 14.1 million tons only. Europe needed to import a lot of wood pellets to meet its needs, particularly the United Kingdom and Italy which were the two countries with biggest demands. Among them UK mainly imported bio-pellets for electricity purposes, while Italy was to use them for generating heat. As to the wood pellets production of the northern America, it was 9.3 million tons in 2015 with its domestic demand of 25% over its throughput, which was equivalent to 2.3 million tons, and the remaining 75% was exported to either Europe or Asia to consume the remaining capacity. The market demand of Asia has reached 1.9 million tons or so in 2015, and of which Korea, Japan, and China were the countries with the highest demands for wood-pellets.



Source [13]

Figure 1.7 World pellet map and trade flows

The heat-purpose wood pellet market has been affected in recent years due to warm winter and low oil prices and the current market is showing an oversupply. However, as various countries keep on promoting policies for higher proportion of wood-pellet co-firing for power generation gradually, the power plant would entirely use wood pellet for fuels, or increase the proportion of wood pellets in combustion, therefore the demand of wood pellets will expand as well. For example, the British Drax power plant, Japan's Shinchi power plant, Korea's Southeast power plant, and the Netherlands RWE's Amer power plant are the power plants known for using wood-pellets at high co-firing percentages, and there are plans for establishing more such power plants, or to increase the co-firing percentages. The demands from global wood pellet markets are quite promising.

1.3 Biomass for wood-pellet productions

For manufacturing wood-pellets, we shred the wood into particles, remove excess moisture by heating, densify the various materials into pellets of cylindrical shapes for usages of different purposes. Comparing to logs, coal or other fuels, wood pellets have following advantages:

- Density is usually greater than 640kg/m^3.
- Suitable for automatic feeding system.
- Can be used for fireplaces or boilers.
- Can be used for different scales of heating purposes.
- Easy to handle, store and transport.
- Combustion characteristics, such as calorific value, are higher than the original raw materials.

In general, the structure of wood material would be more compact and solid after it is pelletized; the energy density will be upgraded, and will have higher adaptability and stability coping with fundamental facilities' treatments and storage. Particularly the ash and metal contents in most of the wood-pellets are low, thus resulting in less fouling, scaling, corrosion, etc. on the combustion equipment. So far, wood-pellets have been regarded as the better form for solid particle fuel applications.

As various kinds of bio-pellets will have different kinds of fuel characteristics under different circumstances, we therefore must choose appropriate pellet fuels according to different application areas. In the early days, the raw material sources of wood pellets were mainly sawmill residue, such as debris, sawdust or shavings. As they are already of very small sizes and in most cases, are dry materials, they are of ideal raw materials for producing wood pellets.

Wood pellet producers have begun to search for additional types of wood pellet raw material alternatives to keep the medium and long-term raw material supply chains stable in view of the wood pellet market expansion due to the power plant throughput increase or policy restriction issues in Europe or North America in recent years. According to the classification of DIN EN 14961-1, for the regard of wood-pellet production, the raw materials used can be categorized according to the adaptation in different markets.

- Wood pellets suitable for small consumer markets.
- Wood pellets suitable for medium-sized consumer market and a wider range of power generation demands.
- Others, such as the wood pellets used in large power plants, as well as the wood pellets made from other agricultural waste.

Figure 2.1 has listed the potential raw materials suitable for the production of wood pellets for different market uses [14]. Among them, the waste or remaining sapwood of the wood industry process may come from a combination of different parts of the trees (including trunks, branches, bark, etc.) , and they are now comprehensively used as the raw materials of wood-pellets with potential accounted for about 50%. As to roots, flowers, wild fruits, fruit flocks and other parts, since they are not suitable for the production of raw materials in pelletizing, they have been listed as unusable raw materials in various countries. In addition, in order to satisfy the future consumption increase on wood pellets, and to expand the available raw materials for producing wood pellets, biomass crops from forestry, agriculture and others have also been considered as the potential raw materials gradually for the production of pellet fuels.

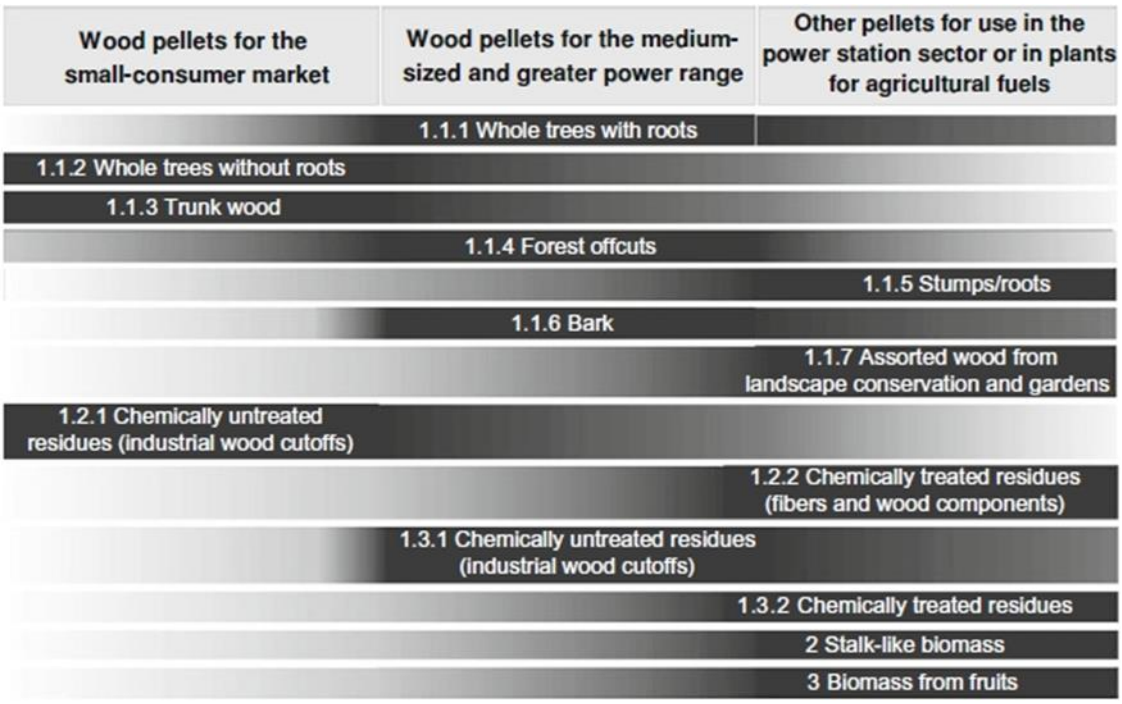


Figure 1.8 Qualitative allocation of biogenic solid fuels (DIN EN 14961-1) according to potential input flows for determining pellet potentials

1.4 Wood-pellet standards

There are many specifications for wood pellets in the world, such as EN*plus* and DIN*plus* standards in the Europe, ASTM, CAN*plus* and PFI standards in the North America and ISO standards all over the world. Figure 1.9 shows the applicable areas of the various specifications [15].

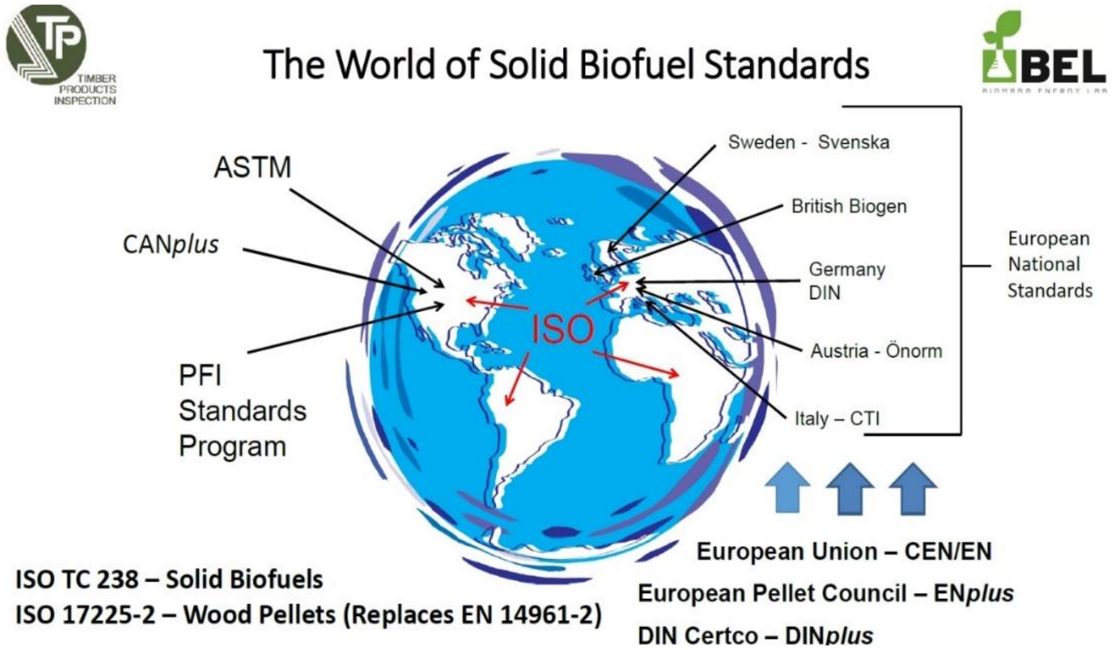


Figure 1.9 The world of solid biofuel standards

The specification formulation of pellet fuels began in the mid-1980s in Europe and the United States when the manufacturers and users of heating equipment began to ask for the specifications of their fuels, and many European countries, such as Germany, Sweden, Austria, Italy, France, Denmark, Finland, the Netherlands, the United Kingdom and other countries have adopted the old coal testing standards until the early 1990s. In the late 1990s, European countries such as Austria, Sweden, the United Kingdom, France and Denmark, passed the use of so-called "Universal European Solid-State Pellet Fuel Standard" (CEN), and then the ISO standards which were of the implementation of pellet fuel CEN upgrades were launched in 2008. In 2000, the American Pellet Fuels Institute (PFI) began a standardization program for the regulations of the bio-pellets, and to stipulate levels of the pellet fuels. In 2012, Europe and Canada established EN*plus* and CAN*plus* wood pellet certificate standards respectively for assuring the quality of the pellets, and the various standards are as follows:

1.4.1 EN*plus* and CAN*plus*

The EN*plus* and CAN*plus* are the same quality seal account for the whole wood pellet supply chain – from production to delivery to the final customer, therefore ensuring high quality as well as transparency. Table 1.1 shows the detail EN*plus* A1, EN*plus* A2 and EN*plus* B three bio-pellet specifications. EN*plus* is widely used in the Europe. Table 1.2 shows the detail CAN*plus* A1, CAN*plus* A2 and CAN*plus* B three bio-pellet specifications. CAN*plus* is used in Canada.

Table 1.1 EN*plus* specifications

Property	Unit	EN*plus* A1	EN*plus* A2	EN*plus* B	Testing standard [11]
Diameter	mm	6 ± 1 or 8 ± 1			ISO 17829
Length	mm	3,15 < L ≤ 40 [4]			ISO 17829
Moisture	w-% [2]	≤ 10			ISO 18134
Ash	w-% [3]	≤ 0,7	≤ 1,2	≤ 2,0	ISO 18122
Mechanical Durability	w-% [2]	≥ 98,0 [5]	≥ 97,5 [5]		ISO 17831-1
Fines (< 3,15 mm)	w-% [2]	≤ 1,0 [6] (≤ 0,5 [7])			ISO 18846
Temperature of pellets	°C	≤ 40 [8]			
Net Calorific Value	kWh/kg [2]	≥ 4,6 [9]			ISO 18125
Bulk Density	kg/m^3 [2]	600 ≤ BD ≤ 750			ISO 17828
Additives	w-% [2]	≤ 2 [10]			-
Nitrogen	w-% [3]	≤ 0,3	≤ 0,5	≤ 1,0	ISO 16948
Sulfur	w-% [3]	≤ 0,04	≤ 0,05		ISO 16994
Chlorine	w-% [3]	≤ 0,02		≤0,03	ISO 16994
Ash Deformation Temperature [1]	°C	≥ 1200	≥ 1100		CEN/TC 15370-1
Arsenic	mg/kg [3]	≤1			ISO 16968
Cadmium	mg/kg [3]	≤ 0,5			ISO 16968
Chromium	mg/kg [3]	≤10			ISO 16968
Copper	mg/kg [3]	≤10			ISO 16968
Lead	mg/kg [3]	≤10			ISO 16968
Mercury	mg/kg [3]	≤ 0,1			ISO 16968
Nickel	mg/kg [3]	≤10			ISO 16968
Zinc	mg/kg [3]	≤100			ISO 16968

[1] ash is produced at 815 °C
[2] as received
[3] dry basis
[4] a maximum of 1% of the pellets may be longer than 40mm, no pellets longer than 45mm are allowed.
[5] at the loading point of the transport unit (truck, vessel) at the production site
[6] at factory gate or when loading truck for deliveries to end-users (*Part Load Delivery* and *Full Load Delivery*)
[7] at factory gate, when filling pellet bags or sealed *Big Bags*.
[8] at the last loading point for truck deliveries to end-users (*Part Load Delivery* and *Full Load Delivery*)

Table 1.2 CAN*plus* specifications

Property	Unit	CANplus A1	CAN*plus* A2	CAN*plus* B	Testing Standard
Diameter	mm	6 ± 1 or 8 ± 1			ISO 17829
Length	mm	3.15 < L ≤ 40 4)			ISO 17829
Moisture	w-% 2)	≤ 10			ISO 18134
Ash	w-% 3)	≤ 0.7	≤ 1.2	≤ 2.0	ISO 18122
Mechanical Durability	w-% 2)	≥ 98.0 5)	≥ 97.5 5)		ISO 17831-1
Fines (< 3,15 mm)	w-% 2)	≤ 1.0 6) (≤ 0.5 7))			ISO 18846
Temperature of pellets	°C	≤ 40 8)			n/a
Net Calorific Value	kWh/kg 2)	≥ 4.6 9)			ISO 18125
Bulk Density	kg/m³ 2)	600 ≤ BD ≤ 750			ISO 17828
Additives	w-% 2)	≤ 2 10)			n/a
Nitrogen	w-% 3)	≤ 0.3	≤ 0.5	≤ 1.0	ISO 16948
Sulfur	w-% 3)	≤ 0.04	≤ 0.05		ISO 16994
Chlorine	w-% 3)	≤ 0.02		≤0.03	ISO 16994
Ash Deformation Temperature1)	°C	≥ 1200	≥ 1100		CEN/TC 15370-1
Arsenic	mg/kg 3)	≤1			ISO 16968
Cadmium	mg/kg 3)	≤ 0.5			ISO 16968
Chromium	mg/kg 3)	≤10			ISO 16968
Copper	mg/kg 3)	≤10			ISO 16968
Lead	mg/kg 3)	≤10			ISO 16968
Mercury	mg/kg 3)	≤ 0.1			ISO 16968
Nickel	mg/kg 3)	≤10			ISO 16968
Zinc	mg/kg 3)	≤100			ISO 16968

1) ash is produced at 815 °C
2) as received
3) dry basis
4) a maximum of 1% of the pellets may be longer than 40mm, no pellets longer than 45mm are allowed.
5) at the loading point of the transport unit (truck, vessel) at the production site
6) at factory gate or when loading truck for deliveries to end-users (Part Load Delivery and Full Load Delivery)

1.4.2 PFI standards

The PFI standard program is the bio-pellet standard used in pellets market in U.S. PFI standard is very similar to DIN*plus*, EN*plus*, and CAN*plus*. Only a bio-pellet producer can apply for certification, but all can reference ASTM standards. The PFI Fuel Grade is showed as Table 1.3.

Table 1.3 PFI Fuel Grade specifications

Fuel property	PFI Premium	PFI Standard	PFI Utility
Normative Information-Mandatory			
Bulk Density, lb/cubic foot	40.0-48.0	38.0-48.0	38.0-48.0
Diameter, inches	0.230-0.285	0.230-0.285	0.230-0.285
Diameter, mm	5.84-7.25	5.84-7.25	5.84-7.25
Pellet Durability	≧96.5	≧95	≧95
Fineness, %(at the mill gate)	≦0.5	≦1	≦1
Inorganic Ash,%	≦1	≦2	≦6
Length, % (>1.5 inches)	≦1	≦1	≦1
Moisture, %	≦8	≦10	≦10
Chloride, ppm	≦300	≦300	≦300
Heating Value	N.A	N.A	N.A

1.4.3 DIN*plus*

The DIN refers to Deutsch Industry Norm. DIN*plus* certification scheme for high quality wood pellets plant was firstly developed by DIN CERTCO in 2002. It is developed on the base of the German DIN 51731 certification and the Austrian ÖNORM M 7135 certification. DIN*plus* contributed the promotion of the residential pellet market in Germany today. The DIN*plus* is showed as Table 1.4.

Table 1.4 DIN*plus* specifications

Parameter	Unit	DIN plus	DIN 51731	Ö NORM M 7135
Diameter	mm	4~10	4~10	4~10
Length		<5xD	<50mm	<5xD
Bulk density	kg/m^3	>1.12	1.0-1.4	>1.12
Heat value	MJ/kg	>18	17.5-19.5	>18
Moisture content	%	10	12	10
Abrasion	%	<2.3	/	<2.3
Ash content	%	<0.5	<1.5	<0.5
Chlorine content	%	<0.02	<0.03	<0.02
Sulfur content	%	<0.04	<0.08	<0.04
Nitrogen content	%	<0.3	<0.3	<0.3
Heavy metals	%	regulated	regulated	Not regulated

1.4.4 Others

Some other pellet standards are also used in the Europe. Such as ÖNORM M 7135 in Austria, NF Granules Bio combustibles in France, Pellet Gold in Italy etc. After EU established, EU-28 all use EN*plus* for wood pellet standards.

1.5 Compositions of biomass on wood-pellet quality

Pellet fuels are products made from shredding biomass raw materials, pressed and formed with or without the addition of extra binders. From the technical point of view, almost all solid biomass materials can be used as raw materials for pelletizing, while it requires structure stability of the raw materials, uniform distribution of particles, and appropriate moisture contents and chemical compositions to produce good quality bio-pellets. Therefore, the molecular structures and chemical compositions of the biomass materials have decisive influences on the pelletizing process and the quality of bio-pellets. In addition, the moisture contents of the biomass raw materials also have certain influences on the manufacturing of the pellets and their quality. The important raw material properties that affect pellet quality are discussed as follows:

1.5.1 Molecular structure

In terms of chemical composition, the biomass contains a large amount of carbohydrates, consisting of about 90% carbon and oxygen, 6% hydrogen and other elements. Chemical composition will affect the calorific value, C, O and H can be decomposed with the release of energy (heat) to form carbon dioxide, water and other by-products. The molecular structure of the woody biomass material is mainly composed of macromolecular polymeric materials, including polysaccharide polymers (cellulose and hemicellulose) and lignin, accounting for about 95%, and the remaining composition ratio consists of a variety of extracts (such as resin, fat, starch, sugar, protein and inorganic substances). Table 1.5 lists the distribution of cellulose, hemicellulose and lignin in typical wood [14].

Table 1.5 Typical distribution of cellulose, hemicellulose and lignin in wood

Wood type	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Hardwood	40-44	15-35	18-25
Softwood	40-44	20-32	25-35
Pine	26.4	44.7	18.6
Eucalyptus	27.7-25.9	49.5-57.3	13.1-16.8
Black Wattle	17.9-21.2	63.9	12.7

The molecular structure of cellulose contains about 48% of the carbon, lignin contains about 64% of the carbon, while it is usually difficult to estimate on the chemical composition of hemicellulose because of the big differences in its structures. The differences in cellulose, hemicellulose and lignin compositions will affect the carbon contents of the biomass materials, and the differences in carbon contents will also affect the dry basis calorific values. Therefore, biomass materials containing higher carbon ratios have higher calorific values.

1.5.2 Cellulose

As cellulose contains a large amount of hydrophilic functional groups, the contents of cellulose have certain influences on the absorption and removal of moisture. The higher the contents of cellulose in the biomass raw materials, the longer it takes to remove moisture during drying. In addition, cellulose contains carbon components, which is one of the main heat sources in wood-pellets. The amount of cellulose contained in the biomass raw materials will affect the calorific value of the wood-pellets.

1.5.3 Hemicellulose

Hemicellulose has an amorphous phase structure that promotes moisture absorption. Therefore, just like cellulose, the proportion of its content will have certain influences upon the dryness of the biomass materials. In addition, hemicellulose has the characteristics of swelling and adhesion, which are also important factors for pelletizing of biomass materials. The carbonaceous component in hemicellulose, also one of the caloric sources of wood-pellets, will affect the calorific value of wood-pellets.

1.5.4 Lignin

Lignin will come up with arching and adhesive effects during the pelletizing compression process that it is a natural adjuvant for biomass pelletizing, and it may help increasing the mechanical strength of wood pellets. Moreover, lignin contains hydrophobic functional groups that it may prevent moisture adherence from happening with it distributed over the surface of the bio-pellets. However, as lignin will gradually lose its adhesion under the temperature of higher than 150℃, therefore do pay attention to the temperature control during the pelletizing process to avoid loss of its adhesion characteristics which results in pelletizing failure. Furthermore, the carbon content of lignin is higher than what in cellulose and hemicellulose, so that the higher the lignin content, the higher the calorific value of bio-pellets.

1.5.5 Starch and sugar

Starch and sugar have the characteristics of adhesion that they are also natural adhesive aids in the biomass pelletizing process. They play the role of adhering with other raw materials in order to enhance the mechanical strength of the pellets, so that fractures are less possible to happen in the movement operations. Furthermore, the addition of grain, starch or molasses can also increase the raw material lubrication in the pelletizing process, and can reduce the energy consumption during the pelletizing process. Therefore, some pellet manufacturers will add potato flour or starch in order to have full adhesion of raw materials to help pelletizing forming.

1.5.6 Fat and oil

The fat and oil components in the raw materials contribute to a lubricating function for the manufacturing of the bio-pellets that can reduce energy consumption in the pelletizing process and increase the processing capacity of the pelletizer. However, for the bio-pellets, the characteristics of easier slide will reduce the firmness and their mechanical strength.

1.5.7 Resin and wax

The resin and wax ingredients inside the biomass materials are both natural compression aids that can strengthen the bonding strength between raw materials and thus enhance mechanical strengths of the pellets. Moreover, resin and wax also consist of hydrophobic structures that, just like lignin, they can prevent the bio-pellets from being affected by the moisture in the surrounding air, and to improve the stability of the particles. However, the waxy protection layer of grain which is similar to the cereal fiber-like material will downgrade the raw material pelletizing that it is necessary to choose the appropriate pelletizing technology.

1.5.8 Inorganic matters

The inorganic matters in the biomass materials mainly affect the ash contents and their compositions. The ash content of the raw materials do not affect the pelletizing process, while the ash contents of the biomass pellets are important factors which affect the pellet applications. High ash content and the alkali metals (such as potassium and sodium) in the ash may increase the slagging and fouling formation in the combustion chambers of the pellet boilers, and may even lead to operational failures of the combustion furnaces. In addition, the less the ash contents of the biomass pellets, the longer the intervals of the ash discharges, and the lower the operating costs of the combustion furnaces. Another reason for controlling the ash contents of the biomass pellet is that high levels of ash may result in emission of pollutant particulates in the combustion process. Therefore, for bio-pellets, the lower the inorganic material contents in the raw materials, the better, so as to avoid the operational issues of the pellet combustion equipment.

1.5.9 Moisture contents

In case moisture contents of the raw materials are too low, that would result in difficulties in the pelletizing process. Therefore, the appropriate amount of water will be added to the raw materials with moisture contents of too-low levels to increase their formability. For pellet fuels, an increase in moisture contents would downgrade the properties of physical and mechanical strength, and would make the pellets susceptible to wear. Moisture content will affect the storage of raw materials and pellets (microbial production, storage loss, spontaneous combustion), pellet weights and their calorific values. When the pellets are burning, a portion of the heat would be used for vaporizing the water, thus the actual output heat will be reduced. The evaporative heat is about 2,400kJ/kg. When the moisture content is 10%, the heat generated by the combustion will be reduced by 11.2%. When the moisture content is 30%, the heat generated by the combustion will be reduced by 33.6%. Moreover, the higher the moisture contents, the more black smoke is also prone to be generated during the burning of the pellets, and thus result in environment impacts. Therefore moisture contents have important influence on the combustion quality of the pellets.

1.6 Bio-pellet productions

Pelletizing or briquetting means to compress the various type of biomass wastes such as wood chips, straw, rice husk, sawdust, etc., which are originally of loose, finely divided, amorphous raw materials under certain action pressure into a larger density of granular-shaped, rod, block and other shapes of densified fuels. The bio-pellets are of uniform sizes with typical diameters of less than 5mm, particles density obviously larger than what prior to compression that it may be up to 1.2~1.4g/cm^3 with volume shrink 75% to 90%. They can improve the disadvantages of inconvenience resulted from collection, storage and uses due to the reasons of raw material dispersion, loose body density and low energy density, and become evenly-sized, density and strength increased, well-operational and combustion characteristics improved fuels with better commercial values and market potential.

1.6.1 Bio-pellet's raw materials

The manufacturing production of bio-pellets mainly takes biomass materials of agriculture and forestry waste as raw materials for feeding into the manufacturing process. In Europe, America and other countries the raw materials for bio-pellet manufacturing are mainly wood and wood chips, which are from saw milling plants and sawdust byproducts produced by wood-making processes. With the rapid increase in demand for bio-pellets, large commercial pellet manufacturers have also started using wood logs (about 5-30% of deciduous trees and 70-95% of coniferous wood) for raw materials by way of crushing and drying treatments to ensure sufficient raw material supply is available for manufacturing bio-pellets. In addition, there are manufacturers that use straw as raw materials to produce bio-pellets, which are mainly used in industrial boilers for replacing the use of coal fuels.

1.6.2 Principles of bio-pellet forming technologies

The principles of bio-pellet forming can be divided into three steps: consolidated filling, surface deformation and destruction and plastic deformation. The biomass raw materials are usually loose, crushed, and have larger porosity on the structures which make the density smaller. During the pelletizing process with external force, the structure particles start to move and re-organized, the distances between each other are thus shortened and result in denseness. As the pressure increase further, the relative displacements and elastic deformation between the particles are more obvious, and the surface is deformed and destroyed. When the external pressure is applied further, the plastic deformation generated from the stress will make the porosity to reduce further, the contract areas between the particles increase significantly, and then complex mechanical meshing and intermolecular bonding force would occur.

In order to maintain the shape and strength of particles, to prevent pellet rebounds from happening to destruct the bonding force in pelletizing, appropriate amount of binder to participate is necessary in the pelletizing compression process. The binder may be an internal component of the raw materials or an extraneous substance to enhance the adhesion between the particles for increasing the strength of the pellet products. According to the composition of the biomass materials, lignin is generally considered to be the best intrinsic binder which contributes to binding formation of biomass pellets during the wood materials' compression manufacturing process. Therefore, there are a variety of woody raw materials (including hardwood and cork) available to mix for best lignin contents to achieve suitable forming proportion [16]. In addition, the biomass materials contain resin, wax, etc. that they are also of natural binders, and are able to help bonding in the process of compression formation. All in all, for raw materials with high contents of lignin the bonding can be achieved by way of softening through compression and heating for plastic deformation, and to maintain pellet shapes. As for raw materials of low lignin contents, we can add a small amount of inorganic, organic and fiber-based adhesives such as molasses to strengthen the binding capacity of raw material particles, and improve the strength of pellet products in the process of compression formation [17].

1.6.3 Manufacturing process of bio-pellets

The biomass pelletizing process is shown in Figure 1.10, which includes the serial steps of drying, grinding, mixing, pelletizing, cooling and packaging, etc. However, depending on conditions of moisture contents and particle diameters, appropriate treatment adjustments must be made accordingly to facilitate unification in the pelletizing process. For the grass biomass materials with less lignin contents, they are not able to provide sufficient binders in pelletizing, and it will be even worse for pelletizing after some time of placement with too much moisture vaporized. For this regard, small amount of water or steam can be applied to soften their fibers, and that should help such materials' formation [18]. If recycled woods are used as the raw materials, they must go through sorting process to remove the unsuitable matters first. The sorting facility includes magnets, and screen, etc.

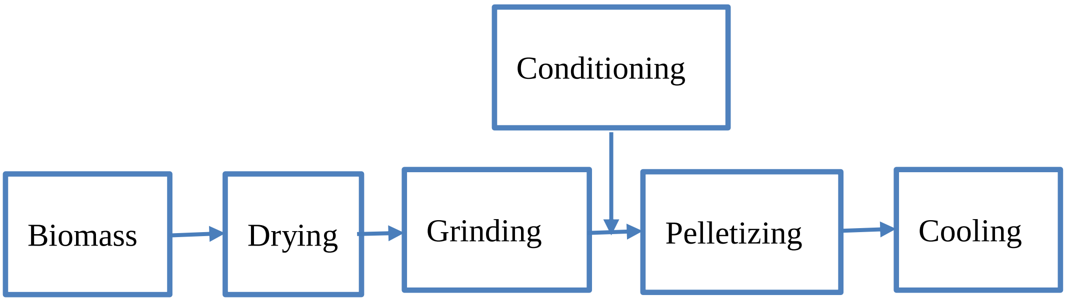
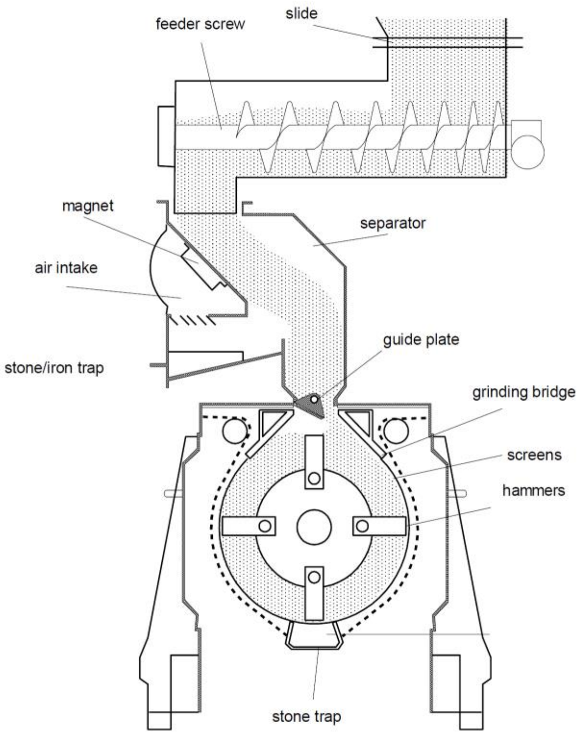


Figure 1.10 Biomass pelletizing process

After a pellet factory receives the raw materials, a pre-treatment must be made first on the wood raw materials, and then the wood logs and branches are cut into small pieces not more than 40mm in diameter for delivering to the subsequent drying equipment. In order to produce high quality wood-pellets, wood raw materials must maintain 12-15% moisture content; they must be dried in case the moisture has exceeded, otherwise it will be difficult for the formation process afterwards. The most common dryer in commercial pellet plants is the rotary kiln dryer, which is the most cost-effective option. For the use of recycled-woods for pellet raw materials, they need to go through sorting process to remove unsuitable matters such as stones and metal particles to avoid subsequent mechanical failures with crushers. The common sorting equipment includes magnets and screens, etc. [16].

Prior to pelletizing, the raw materials need to be crushed to appropriate sizes. Normally the raw materials for making wood-pellets must be of 5 mm or less in diameter to conform to the die holes of the pelletizer. Therefore, it is standard procedure that the dried raw materials will go through grinding process for even sizes. The grinding of raw materials can be done using different types of grinders, where the hammer mills (Figure 1.11) are the most commonly used grinders [19]. Although the grinding power consumption of roller mills are taking less power than hammer mills, but their mechanical durability is obviously worse, therefore they are not suitable for pelletizing application.



Source [19]

Figure 1.11 Hammer mill

In order to increase the adhesion of the raw materials during the pelletizing process, and to improve the mechanical durability of the pellets, the raw materials themselves can be conditioned in several ways before entering the pelletizing process, including the addition of steam to adjust the moisture contents of the raw materials, and the addition of binders, additives and so on. The optimum moisture content for each raw material and pelletizing process is different. According to the experience of the manufacturers, the optimum moisture content of the standardized wood pelletizing is about 12%, the moisture content of the herbaceous biomass materials are slightly higher, about in the range of 14-15% [20,21]. Not only do these have the advantage of adjusting optimum moisture content, the addition of steam to be setup according to the moisture also has a secondary positive effect, which is to preheat the materials, adjusting the raw materials temperature to about 70 ℃, so that the lignin inside the raw materials are easy to micro-plasticize and separate, and thus facilitate binding and forming [16,17,22]. In addition, the addition of binders, such as starch residue, molasses and pyrolysis oils, can improve the stability of the pellets and also reduce the energy requirements of the pelletizing process [17].

There are many ways for biomass pelletizing, and we may broadly divide pelletizing process into three main types of cold compression pelletizing, hot compression pelletizing and carbonization pelletizing [23]. Cold compression pelletizing, also known as wet compression pelletizing, is commonly used in fiber-typed raw materials with high moisture contents. The fibers are normally soaked for few days under normal temperature to improve their characteristics for ease of formation with compression, and they can be divided into two types of open style material feeding and close style material feeding. The hot compression pelletizing is currently the most widely-adopted pelletizing technology. This way of pelletizing is to compress the biomass at fixed temperature. With respect to whether the materials are heated prior to the pelletizing machines or inside the pelletizing machines, they can be categorized as preheated hot compression pelletizing and non-preheated hot compression pelletizing. Carbonization forming is to have biomass materials going through carbonization or partial carbonization, and then add a certain amounts of binders to form through mixing and squeezing, or to pelletize the loose biomass materials in the pelletizing machines first, and then put them into the carbonization furnace for carbonization treatment.

The cooling treatment is a very important step in pellets' production processes. The pellets, which went through the pelletizing process will reach higher temperatures due to the friction between raw materials and the die holes and high-temperature moisture release during the squeezing process that their temperature may exceed 90℃. During this period of time, the lignin is still in a softened state, which requires air to cool down the pellets, so as to reduce the heat stress and solidify the lignin ingredient on the pellets surfaces [16,24,25]. Counter-current air cooling towers have advantages on both energy efficiency and cost that they are widely used [26]. After cooling treatment the pellets will go through vibrating screening process to make the finished pellets evenly shaped in their dimensions, and then to remove dusts and recycle powdery materials for preventing transport and combustion operation issues, and finally, re-package for storage.

1.6.4 Types of pelletizing machines

The current pelletizers for biomass are of three types of screw extrusion press pelletizers, piston punch pelletizers and roller press pelletizers. Among them the roller press pelletizers may divide into flat-die pelletizers (Figure 1.12) and ring-die pelletizers (Figure 1.13). The ring die pelletizers have adopted ring-shaped dies, die holes are evenly radiating in the radial directions with large operation contact areas. They have many die holes, and all the points on contact lines along the ring dies and press wheels are with the same tangential speed. They have advantages of high productivity, low energy consumption, etc. and have become the mainstream technologies in Europe, the United States, Japan and other developed countries nowadays [17].

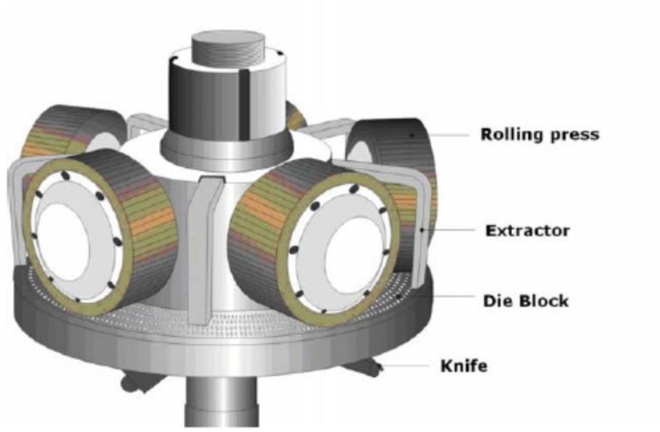
Source [27]

Figure 1.12 KAHL Co. flat die pelletizer

Source [28]

Figure 1.13 Anyang Energy Machinery Co. ring die pelletizer

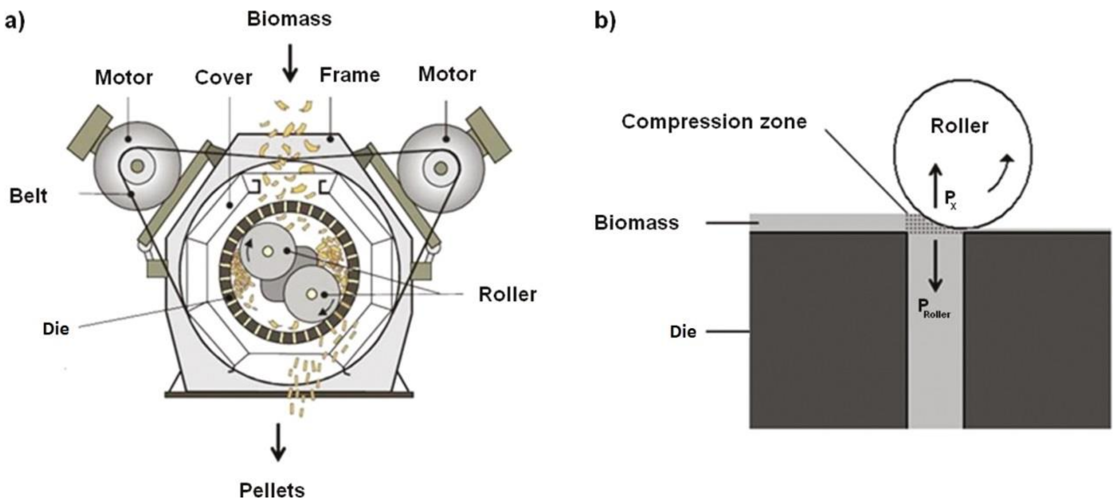
Operation principle of flat-die pelletizers: the materials inside the machines are squeezed and compressed by the rollers, and are forced and extruded out through the steel flat die holes (Figure 1.14). The extruded pellets are cut under the templates, and thus cylindrical-shaped pellets are obtained. The pellets are of 2-10mm in diameters, and the formation rate is greater than 95%.



Source [16]

Figure 1.14 Diagram of the plane type die

Operation principle of ring die pelletizer: raw materials are fed into the inside of the ring dies, going through rolling press for continual rolling and squeezed into the ring die holes for pelletizing (Figure 1.15). During the pelletizing process the operational pressure reaches 50~100Mpa with the formation rate of ≧95%. The raw materials under high pressure compressing would deform, their temperature would go up, and the temperature may reach up to 100-120℃. For achieving the moisture contents (the moisture content requirement is around 12 to 15%), many materials need to be dried before being used for pelletizing.

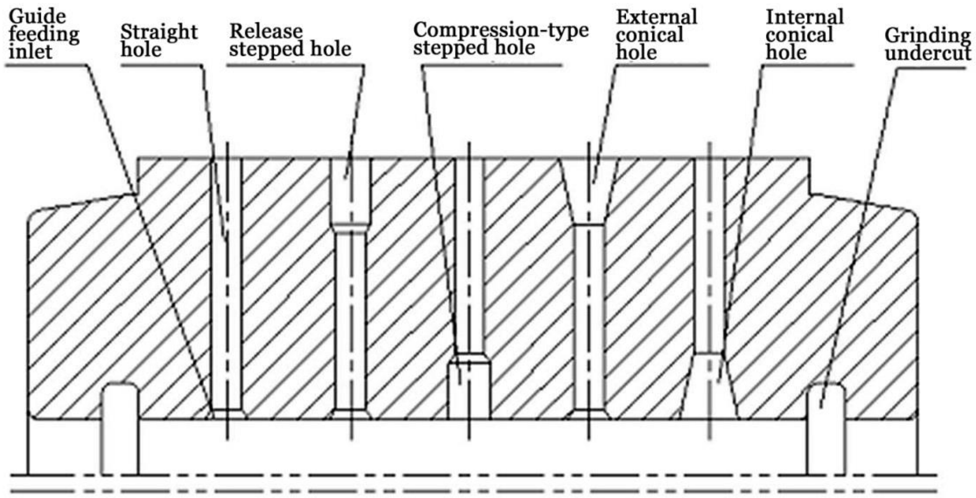


Source [29]

Figure 1.15 (a) Working principle of a ring die pellet press and (b) showing how biomass is compacted by the roller in the compression zone

Ring dies are the key parts of the pelletizing machines that they have direct influences on quality. They are also the major consumable parts of the pelletizing machines, and the expenses of ring dies account for more than 25% of the entire production facilities' maintenance costs. The characteristics of ring dies, reasonable usages and effective maintenance, are extremely important for the pelletizing processes.

The common ring-typed die holes have different structures of straight holes, stepped holes, external conical holes and internal conical holes, etc. The stepped holes are divided into release-typed ladder hole (commonly known as pressure relieve hole or release hole) and compression ladder hole, as shown in Figure 1.16. Different types of die holes are suitable for different types of raw materials or different ingredient ratios of raw materials. Die hole diameters can be customized according to requirements with 3-25mm ranges. The 6mm diameter dies are commonly used in the United Kingdom [16].



Source [30]

Figure 1.16 Ring-typed die hole structure

The compression ratio of ring die is referring to the ratio between a die hole's effective length vs. the ring die hole's minimum diameter, which is also called Length/Diameter (L/D) ratio. It is an index reflecting to pelletizing compression strength, the bigger the compression ratio, the more solid the pellets are. Concerning the selection of the compression ratio of ring die, it is based on the types and characteristics of the raw materials for different choices. Generally, the L/D ratio of 4-5 will be suitable for wood materials, and L/D ratio of 6-9 will be better choices for high-fiber, herbaceous plants and rice stalk category. Roughness is also an important index for benchmarking the quality of ring dies. Under the same compression ratio, the larger the roughness value is, the bigger the extrusion resistance is, thus the more difficult the material discharge will be, and the appropriate roughness value should be between 0.8 and 1.6.

1.6.5 The operational factors that affect the pelletizing of bio-pellets

The factors that affect the pelletizing of the biomass raw materials are raw material types, moisture contents, particle sizes, pelletizing pressure and die shapes/dimensions and so on. The raw material types not only affect the production yield and operational parameters such as energy consumption, but also directly affect the quality characteristics of density, strength and calorific value of the pellets. If the wood raw materials have high lignin contents, it has bonding effects under heating condition, and is easier to pelletize. As to fiber plants, since they are weakly bonded that they are not easy to pelletize. The particle sizes of the raw materials affect the quality of pelletizing, and also affect the formation efficiency and the energy consumption. In general, raw material with smaller particle sizes is easier for compression than the larger ones. During the pelletizing process, the moisture contents of raw materials must be appropriate. The steam will be difficult to be drained out during the pelletizing process if the moisture contents are too high, and the pellet quality will be affected. On the contrary, the pelletizing will be difficult if the moisture contents are too low. Normally the raw materials' moisture contents will be requested to be 12-15%. Formation pressure is of the fundamental condition for biomass pelletizing that the raw materials may create plastic deformation for pelletizing and to overcome the friction between the biomass materials and dies only if sufficient pressure has been applied. Therefore, the pressure ratings also directly relate to the die shapes and dimensions.

1.7 Black pellet productions

Bio-pellets are sustainable bio-fuels which can be categorized into white pellet (pelletized directly from biomass) and black pellet (pelletized from torrefied or steam explosive biomass), both having the characteristics of being "carbon neutral" and clean combustion that they are effective alternatives to replace the fossil fuels in industrial combustion and power plant applications. Previous section discusses the productions of white pellet. In the following section productions of black pellet are discussed.

Black pellets are biomass processed by pre-treatments of torrefaction or steam explosion before pelletization. Black pellets enable energy-efficient upgrading of biomass into commodity solid biofuels with favorable properties in view of logistics and end-user [31].

- Favorable properties include high energy density, better water resistance, slower biodegradation, good grindability, good flowability, homogenized material properties.
- Cost savings in handling and transport, advanced trading schemes possible, capex savings at end-user (e.g. outside storage, direct co-milling and co-feeding), higher co-firing percentages and enabling technology for gasification-based biofuels and bio-chemicals production.
- Applicable to a wide range of lignocellulosic biomass feedstock.

Prospective features of black pellets (torrefied wood pellets and steam explosive pellets) are compared with biomass (wood chips), white pellets (wood pellets), charcoal and coal, which is illustrated in Table 1.5 [31].

Table 1.5 Comparison of prospective features of black pellets with other solid biofuels and coal.

	Wood chips	Wood pellets	Torrefied wood pellets	Steam expl. pellets	Charcoal	Coal
Moisture content (wt%)	30 – 55	7 – 10	1 – 5	2 – 6	1 – 5	10 – 15
LHV (MJ/kg db)	7 – 12	15 – 17	18 – 24	18.5 – 20.5	30 – 32	23 – 28
Volatile matter (wt% db)	75 – 85	75 – 85	55 – 80	72	10 – 12	15 – 30
Fixed carbon (wt% db)	16 – 25	16 – 25	20 – 40	ND	85 – 87	50 – 55
Bulk density (kg/l)	0.20 – 0.30	0.55 – 0.65	0.65 – 0.75	0.73-0.75	0.18 – 0.24	0.80 – 0.85
Vol. energy dens. (GJ/m³)	1.4 – 3.6	8 – 11	12 – 19	~15	5.4 – 7.7	18 – 24
Hygroscopic properties	Hydrophilic	Hydrophilic	(Moderately) Hydrophobic	Hydrophobic	Hydrophobic	Hydrophobic
Biological degradation	Fast	Moderate	Slow	Slow	None	None
Milling requirements	Special	Special	Standard	Standard	Standard	Standard
Product consistency	Limited	High	High	High	High	High
Transport cost	High	Medium	Low	Low	Medium	Low

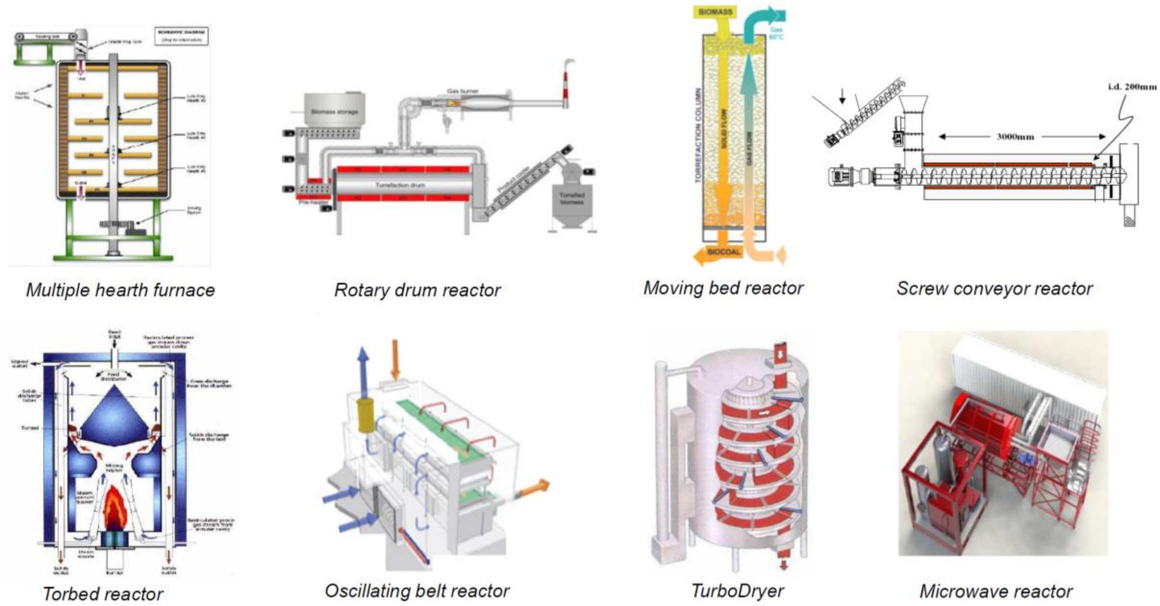
Abbreviations:
db = dry basis
LHV =Lower Heating Value
sources: ECN (table, fig.1, 3), Pixelio (fig. 2, 6), Valmet (fig. 4), OFI (fig. 5), ISO/TC 238 WG2 (table)






1.7.1 Torrefaction process

Torrefaction is a thermochemical treatment of biomass at 200 to 300°C. It is carried out under atmospheric conditions and in the absence of oxygen. In addition, the process is characterized by low particle heating rates < 50°C/min. During the process the biomass partly decomposes giving off various types of volatiles. The final product is the remaining solid, which is often referred to as torrefied biomass, or torrefied wood when produced from woody biomass. Most of the volatile components is decomposed from hemicellulose of biomass. The volatiles are partially driven off and can be combusted for pre-drying biomass or further heating the torrefaction reactor. Figure 1.17 shows various reactors for torrefaction processes.

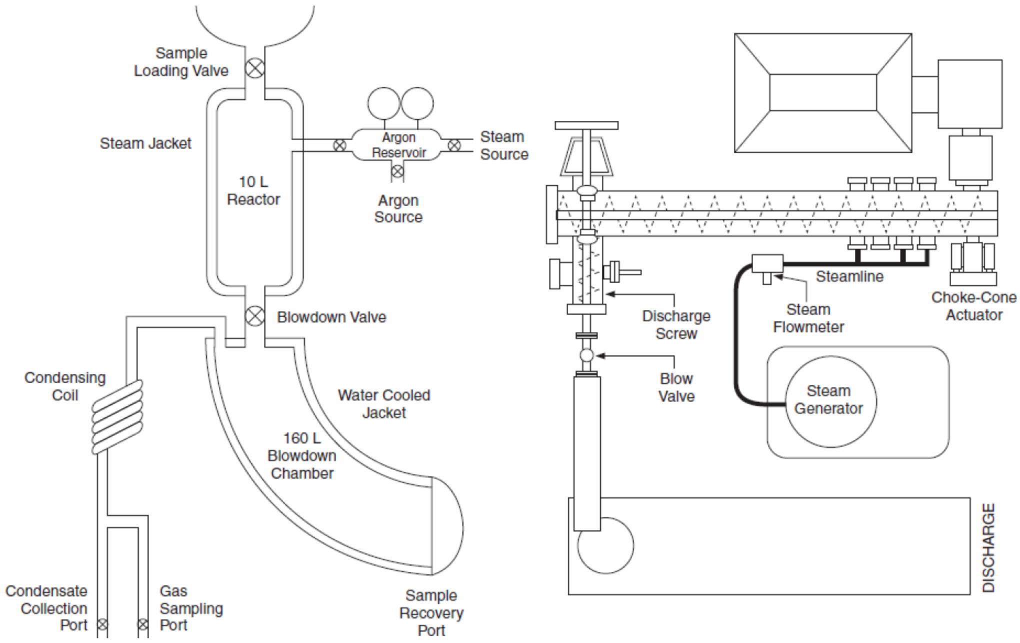


Source [31]

Figure 1.17 Various types of reactors for torrefaction processes

1.7.2 Steam explosion process

There are fewer steam explosion developers than for torrefaction. The current steam explosion reactors for biomass are of two types of batch reactor and continuous reactor as shown in Figure 1.18. For steam explosion, biomass is pre-dried and impregnated with steam at 10-35bar and 180-240°C, followed by explosive decompression to atmospheric pressure in a reactor. Fibers are ruptured to pulp. Lignin is softened and distributed across pulp surface. After post-drying, pelletization of steam explosive biomass is ease because of soften lignin used as a binder. Typically steam explosion process has higher mass yields than that of torrefaction, but steam explosive biomass also contains more oxygen [31].



Batch process (Turn et al., 1998) Continuous process (Heitz et al., 1990)

Both figures reproduced from (Melin, 2013)

Source [31]

Figure 1.18 Reactors for steam explosion processes

1.8 Bio-pellet storage and handling

In view of the increasing household/commercial heating, industrial process heating and the electricity usages for bio-pellets, more and more attention has been paid on considerations on storage and operational safety of solid biomass fuels [32]. The IEA Bioenergy Task 32 focuses on the safety importance of production, trade and applications concerning solid biomass fuels. A manual has been co-edited by experts of four different tasks from IEA Bioenergy Agreement that illustrates the risk issues associated with solid biomass fuel supply chain as well as the reference of safety measure requirements for operation, storage and transport [33].

1.8.1 Bio-pellet storage

Due to the seasonal fluctuations in productions and demands of bio-pellets, the pellet producers and intermediate suppliers need a lot of storage space. As for most end users from industrial heating and electricity generation, sufficient storage spaces for pellets are also required for coping with unexpected fuel supply shortages and to ensure of the supply capacity. Because the bio-pellets are sensitive for moisture absorption, they would swell and cause breakage of pellet structures when they are exposed to rains. Moreover, high moisture would accelerate microbial degradation and may result in dangerous conditions of self-heating and self-ignition. Therefore, bio-pellets are always kept indoors, and silo and flat storage are the most widely adopted.

Silos require less space than flat storage sites, and the filling and discharge of the pellets can be easily operated with a screw conveyor, which is the most common way of storing pellets. The pellet silos typically have two different types, including silos with tapered bottom and silos with flat bottom. A vertical silo with a tapered bottom can be discharged by the gravity drainage through tunnel and the conveyor belt. The vertical silo with a flat bottom utilizes circulating auger for feeding into the drainage tunnel that is located at the center for emptying. The silos with tapered bottom are widely used for the storage of cereal-based agricultural products. They are also widely used for pellet storage. As to silos with flat bottom, the required spaces are less due to their flat structure, so that the construction costs are cheap, while such silos require more maintenance and longer emptying time.

Flat storage sites are used for bulk storage and storage of large quantities of pellets. They are commonly used in pellet manufacturers, intermediate storages at ports and large-scale storage (such as power plant sites). In such storage sites, the pellets emptying, feeding system (power plant site) of the boilers, or follow-up transports for trucks, ships or rail vehicles are carried out by front loaders. While using front loaders to move the pellets, there are risks from powders and dust generation that special attention must be paid to dust explosion and health risks.

1.8.2 Bio-pellet handling

The operations of bio-pellets mainly include feeding and transports. During the operations the pellet will break due to the impacts of external forces that result in pellet breakage and generation of powder and dusts, therefore we must pay attention to the overall risks on which operations are involved. Although there are many international standards for pellet manufacturing (such as EN 14961-1) to ensure that producers are producing high-quality and wear-resistant pellet fuels, but this problem cannot be completely avoided.

There are many different ways of pellet transportation. Among them the pellet transports between the storage containers and the transport vehicles include the pneumatic pump and the conveyor. The pneumatic pump delivery may result in pellet damages due to pressure (pellet speed) being too high, sharp turns in the transport pipeline and potential impact portions. If a conveyor is used for transports, it should be carried out with minimum wear and damage for the solid biomass fuels' regard, including minimizing transmission distances, preventing from multiple cross-transmission and high dropping operations, and also pay attention to avoid moisture absorption of the pellets.

For the transports of pellet fuels, depending on their transport distances, we may choose using trucks, trains or ships. Trucks are usually used for short-distance transports and trains are used for longer distances, while ships are used to transport large quantity of pellets directly to the end users, or to transport the pellets to the ports for unloading and then to distribute to smaller transport vehicles. During the periods of pellet transport loading, unloading, and internal operations the risks of dust generation, ignition, and explosion must be minimized. Precautionary measures are taken such as using spark detection and fire extinguishing systems to avoid overheating or burning caused by fine powder generation and pellet wears.

The entire supply chain of bio-pellets, from the pelletizing plant to the user side, is likely to see particle wear and dust generation problems. In order to prevent the formation of fine powders and dusts, the operations of pellets should be as mild as possible. More operation steps will cause more pellets cracks. For the operation of the bio-pellets, the pellet cracks are positively correlated with the number of impacts and the impact forces (i.e., drop heights). The drop heights and the number of falling drops should be minimized to reduce the mechanical impact of the pellets.

1.8.3 Common storage and handling problems of bio-pellets

The bio-pellet storage and handling problems caused by degradation depend on the types, sizes, compositions and moisture contents of the bio-pellets. The major problems that may happen during bulk storage and handling of bio-pellets include self-heating and self-ignition, off-gassing, dust accumulation and microbiological hazards, etc.

(a) Self-heating and self-ignition

In a closed storage environment, self-heating could happen on bio-pellets due to oxidative reactions or microbial degradation. The self-heating developments of bio-pellets caused by microbial degradation are highly correlated with moisture contents [34], and the oxidative reactions normally decrease due to the longer storage time.

Therefore the fresher the bio-pellets are, the higher the moisture contents will be, and the greater the risks of self-heating are. Also because of the poor heat transfer internally and the insulation characteristic of bio-pellets, the heat is accumulated inside the bio-pellets, and may result in the happening of self-ignition.

In addition, fire disasters and explosions caused by catching fire may happen throughout the entire supply chain of bio-pellet production and delivery, including production plants, transport vehicles, operation facilities and users' premises. The sources for catching fire can be divided into sparks generated by contacts between external metal fragments or stones and the bio-pellets, or caused by overheating due to high friction components of machines such as motors, conveyor belts, and bearings, etc. Improper maintenance and cleaning on the equipment, may accumulate dusts and powders, thus will increase the risks of fire and dust explosion. There are measures for reducing these risks, including impurity removal (such as stones and metals) from bio-pellets, and the installations of spark detectors and fire extinguishing systems during transport, to periodically inspect conveyor belts and bearing conditions to avoid overheating, and to remove dusts and other debris. In addition, the use of anti-static electricity and fireproof materials on conveyor parts, and to have the conveyors properly grounded can also reduce the risks of catching fire externally.

(b) Off-gassing and oxygen consumption

Bio-pellets will consume oxygen and release CO and CO_2 in the chemical oxidation and microbial reaction processes. CO and CO_2 are odorless and can be lethal at low concentrations, and hypoxia can cause operator suffocated to death. In addition, the bio-pellets contain a variety of volatile organic compounds (VOC), namely unsaturated hydrocarbon compounds, esters, ethers and aldehydes. These VOCs can be evaporated from the bio-pellets and in some cases may gather and accumulate to certain concentrations which may cause health and safety hazards. Thus, the personnel should not enter a closed bio-pellet storage tank prior to being ventilated with fresh air.

(c) Dust accumulation

Bio-pellets are apt to release a lot of dust during the treatment and operation processes, particularly the bio-pellet dust usually has low density and high resistance coefficient characteristics that they can be easily dispersed in the air. The dust particles in the air constitute a major health risk to whomever comes in contact with it, mainly by way of inhalation. Bio-pellet dusts mainly affect the eyes, lungs and respiratory system, the inhalation of excess particle dust can cause irritation on the eyes, lungs, nose and respiratory system. Repeated exposure for long periods of time may easily cause allergic reactions and serious diseases.

The second greatest risk which bio-pellet dust may cause is dust explosion. Because the surface areas of the dust is relatively large in comparison to their mass, and that makes dust a flammable bulk material. Depending on the bio-pellets' types, sizes and shapes, the explosive suspensions are formed at different mass/oxygen ratios. These explosive mixtures can be ignited by electro static discharges, rubbing or hot surface contacts and result in fatal damages.

(d) Microbiological hazards

The bio-pellets are made of natural biomass, so that the raw materials will have different types of potential microorganisms present, such as fungi and bacteria. The risk of microbiological hazards in the bio-pellets depend on the nature of the biomass materials, i.e. sizes, compositions, moisture contents and temperature. When the fungus grows on the biomass materials, it can digest the biomass materials and grow rapidly to form large communities that cause the biomass to rot and produce toxins, i.e. mycotoxines. Moreover, they can be released into the air with the dust. The fungal spores and toxins can cause respiratory tract irritation and allergic reactions that we should avoid inhalation and direct contacts.

1.8.4 Safety and precautionary measures for storage and operation of biomass pellets

Indoor storage of bio-pellets requires a series of safety measures to overcome the problems of self-heating, dust generation and bio-pellet off-gassing issues. Improper handling on bio-pellets storage may lead to serious damages and risks of the operators' health and even worst the human life.

According to Safety Manual of IEA Bioenergy Task 32 for the production and utilization of solid bio-pellets, the followings are normally recommended as safety and precautionary measures to prevent bio-pellets self-heating and self-ignition from happening [33].

- Avoid bulk storage and transportation in case you are not sure whether the bio-pellets have the tendency of self-heating.
- Pay attention to the risks of self-heating and self-ignition inside large storage spaces.

- Avoid storing bio-pellets with moisture contents exceeding 15%.
- Avoid mixing different types of bio-pellets in a storage tank.
- Avoid mixing bio-pellets with different moisture contents.
- Avoid the presence of large amounts of fine powders in the bio-pellets.
- Measure and monitor the temperature distribution and gas compositions in the storage tanks.
- Prepare gas injection facilities at the bottoms of the tanks to prevent fires from happening.
- Particle storage facilities must be equipped with appropriate ventilation-control measures to remove carbon monoxide and carbon dioxide.

Fire operations for large warehouses are complex and expensive jobs. In the event of fires, especially when bio-pellets are stored in the tanks, it must be noted that in many cases water cannot be used for extinguishing. The bio-pellets will quickly absorb moisture and expand to about 3 to 4 times their original sizes to form a very hard pie-structure that it will be difficult to remove them from the tanks, and may result in silo ruptures. Moreover, self-heating usually occurs at deep-inside of the tank that it is difficult to reach the fire source. Usually nitrogen, carbon dioxide gas and foam, are more suitable options to choose from for fire extinguishing at the pellet silos.

In a closed storage environment, the pellets may result in self-heating due to microbiological and/or chemical reactions. Due to the poor internal heat transfer in bulk mass and the adiabatic nature of the bio-pellets, the internal heat accumulation may lead to spontaneous combustion. The main factors that affect the temperature of the pellet silos are the ambient temperatures, moisture contents, humidity gradients, volumes and storage densities. Therefore, it is also necessary to monitor the temperatures, exhaust gases and moisture contents of the bio-pellet silos. In addition to continuously monitor the temperatures through the embedded sensors, the equipment may also be included with the detection functionality for the physical readings of carbon monoxide, hydrocarbon, radiant heat and smoke, and which are the precursors of overheating [34]. In addition, the oxidation of the pellets will also generate gases of carbon dioxide, carbon monoxide, aldehydes and methane, etc. The generation of these gases will deplete oxygen in the silos. When the external ambient temperatures are lower than the internal storage temperatures the storage silos can cool down the bio-pellets and conduct gas exchanges at the same time. In general, the temperature inside the silo should be kept below 45°C and, when the temperature is too high (>80°C), an emergency response procedure should be started to discharge the pellets, to relocate the pellets to different reservoirs or outside, to eliminate hot spots and to cool down the pellets [32].

The gases generated in the tightly packed bio-pellet silos are of threats to the operators' life, and necessary measures should be taken to avoid the contact with the operators. For opening up and getting into the silos, strict operation procedures can be setup through ventilation systems, gas monitoring and warning signs to ensure the safety of the operators.

1.9 Bio-pellet co-firing in existing boilers for electricity or CHP

Based on the positive results of studies concerning co-firing of coal with bio-pellet over the years, together with the stringent environmental regulations adopted by various countries in response to climate change, boiler users have been actively co-firing bio-pellets in their existing coal-fired boilers [35]. Bio-pellets (mainly wood-pellets) have been popularly applied as solid fuel in household heating and regional heat supply in Europe and the United States. The developments in high efficient combustion equipment are quite matured and the thermal efficiency of the bio-pellet combustion boilers of the heat supply systems in residential area and schools can reach above 90% [5]. In this report, we focus on the combustion application technologies of bio-pellets on existing power plant boiler or industrial boilers, including the co-firing technologies of bio-pellets on coal-fired boilers and the pellet burner applications on oil-fired and gas-fired boilers.

The co-firing of bio-pellets and coals has the advantages of technology maturity, high thermal efficiency, low equipment investment and ease of material storage/transports and handling. Bio-pellet fuels have three ways of co-firing applications while applied on coal-fired boilers:

- Direct co-firing: The bio-pellets are treated via the same or different grinding and feeder equipment, and then combined with coal into the same boiler for combustion, while the coal and bio-pellets may use the same burner or individual ones. There will not be specific equipment cost with this approach that it is the most direct and cost-effective way of co-firing, and is the most widely adopted way of co-firing.
- Indirect co-firing: This approach is to establish another bio-pellet gasifier. The bio-pellets are gasified into syngas firstly, and then conduct such syngas into the coal-firing boilers for burning. Since the syngas have been pre-purified, therefore the pollution impacts of combustion can be minimized.
- Parallel co-firing: This approach is to establish a separated bio-pellet fired boiler, and then the steam generated from bio-pellet boiler is fed into the coal-fired boiler steam system for use. This approach has used a separated bio-pellet boiler

that allows maximum utilization of bio-pellets, but is typically used for reuse on the by-products of paper mill (e.g., bark, waste wood) [36].

Concerning the direct and indirect co-firing of bio-pellets with the coal-fired boilers there are five approaches to combine into the piping or equipment of the existing coal-fired boilers as shown in Figure 1.19 [17,19,35,36]. The approaches 1 through 4 in Figure 1.19 are of direct co-firing systems. The approach 5 is indirect co-firing of bio-pellet with coal.

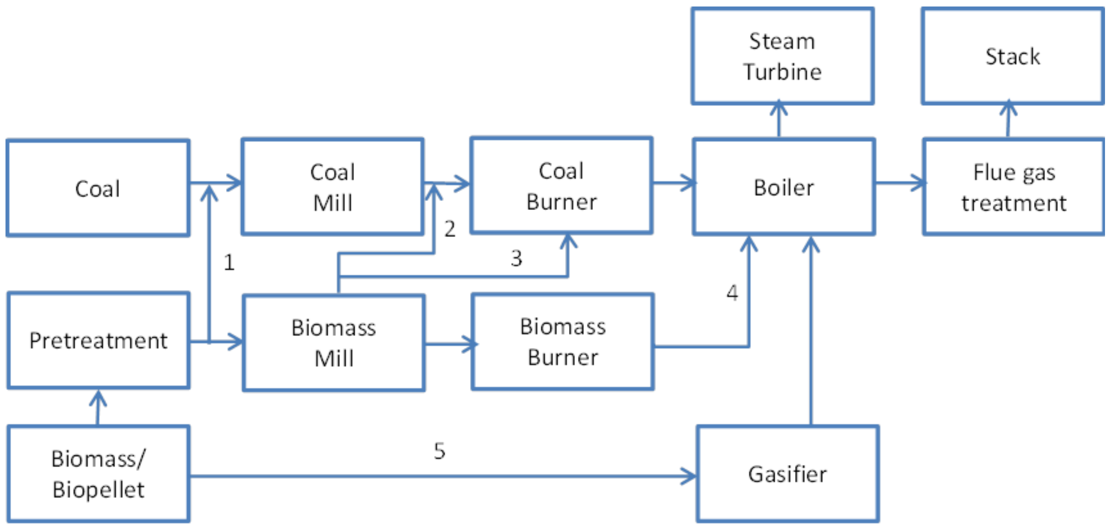


Figure 1.19 Direct and indirect bio-pellet co-firing approaches at coal-fired boiler

The approach 1 shows that the bio-pellets have pre-mixed with coals, going through grinders for grounding, and then get into the pulverized coal combustion system for burning. Because the approach 1 has low investment cost, and the required retrofit time for co-firing facilities modifications can be controlled within a reasonable range, it is what many power plants have chosen for the first time. However, as the calorific values of the bio-pellets are less than that of coal, heat input into the boilers will be greatly reduced if high proportion of bio-pellet is co-fired with coal. Therefore from operation point of view the bio-pellet proportion (calorific basis) of such co-firing approach is at most 5-10% (5 to 6%, or less, is more common) [36]. However when co-grinding fuels with different characteristics, we must pay attention to the primary air temperature of the pulverizer to avoid safety issues such as spontaneous combustion or explosion, etc.

The approach 2 requires establishing additional bio-pellet grinding mill. The ground bio-pellet powders are sprayed into the existing pipelines between the coal mills and the burners through pneumatic conveying equipment. This type of co-firing will not affect the heat input into the boilers. The UK's Drax plant have had success in this type of co-firing.

The approach 3 has higher costs and risks than approach 2. Likewise, approach 3 requires additional bio-pellet grinding mills. But some bio-pellets with special characteristics may result in risks of blocking the pulverized coal pipelines, therefore it is necessary to have the ground powders directly sprayed into the modified burners through pneumatic conveying equipment.

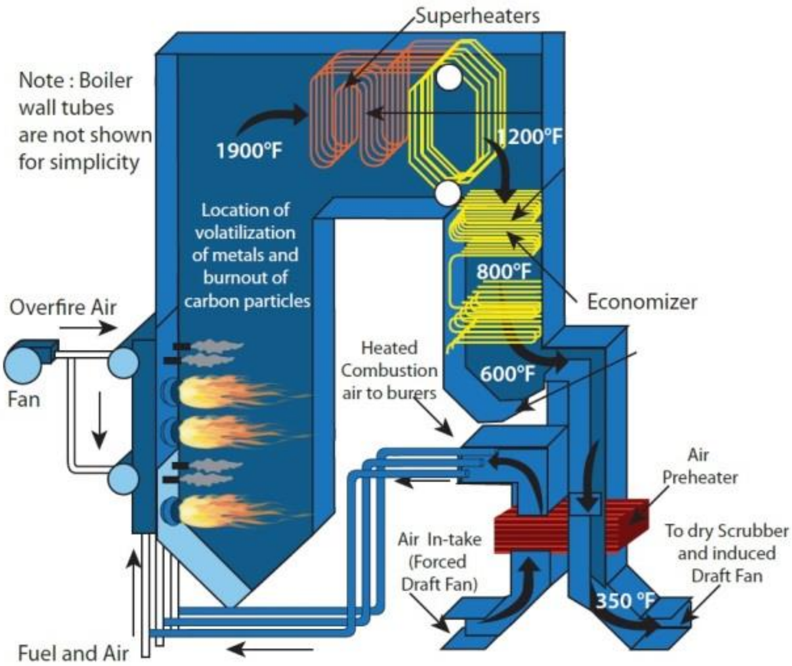
The approach 4 is to maintain the existing coal-firing capabilities that additionally dedicated bio-pellet burners are added to the existing boiler. This approach similarly requires additional bio-pellet grinding mills. The ground bio-pellet powders are directly sprayed into the dedicated bio-pellet burners through pneumatic conveying equipment. In general, the installation of dedicated bio-pellet burners has been considered as an expensive and relatively high-risk co-firing approach.

The approach 5 is of an indirect co-firing system. It is mainly to gasify the bio-pellets, and then mixes the syngas generated together with the coal and are fired in the existing boilers. But the gasifiers, syngas cleaning equipment and tar treatments are more expensive than the other approaches.

The effort of IEA Bioenergy Task 32 has been continuously made to collect data on cases of co-firing of coal and biomass fuels in existing coal-fired boilers, and has established a co-firing database. It provides data of the backgrounds of the co-firing plants, ways of co-firing, boiler types and capacities, co-firing proportions, fuel types, etc. According to the recent investigations of actual co-firing cases, there are 247 cases in the world that have used co-firing biomass fuels as alternative fuels [37]. It indicates that they are mainly distributed in Europe and the United States. Most of the co-firing cases are in Finland with a total of 78 cases followed by the United States 39 cases, Germany 26 cases, United Kingdom 20 cases, Demark 16 cases, Sweden 15 cases, Australia 8 cases, etc. Most of the investigated cases are of power plants that belong to the public sector, however the combined heat and power cases in the industrial sector also account for a significant percentage. It is obvious that the industrial application of biomass fuel co-firing is getting more and more attention.

Usually the existing coal-firing technologies are used in most of solid biomass materials' co-firing cases. The coal-fired power plant facility is suitable for the co-firing of biomass fuels and coals without too much the need for new professional technologies and function modifications. In the typical combustion technologies of coal-firing, it is generally divided into three types of pulverized coal combustor (PCC), fluidized bed combustor (FBC) and stoker/grate combustor [35]. According to the case analysis of the bio-pellet co-firing in coal-fired power plants in the United States, pulverized coal combustor has accounted for the largest percentage, which is 77.1% followed by the stocker combustor, accounting for 12.3%, and the fluidized-bed combustor also accounts for 10.6 % [38].

Figure 1.20 shows the pulverized coal combustion boiler which is a commonly used technique for converting coal and other petrochemical fuels into thermal energy. Normally the fuels are pulverized into fine powders, and then blown with controlled air into the boilers for uses. When the PCC boiler is used for co-firing, some studies have confirmed that NO_x emission could be significantly reduced. However, the applications of this kind of combustion technology require high-quality fuels with ground particle diameter range of 50-70μm, the moisture contents cannot be greater than 20wt%, and that also limits the applications of PCC technology on co-firing of coal and biomass.

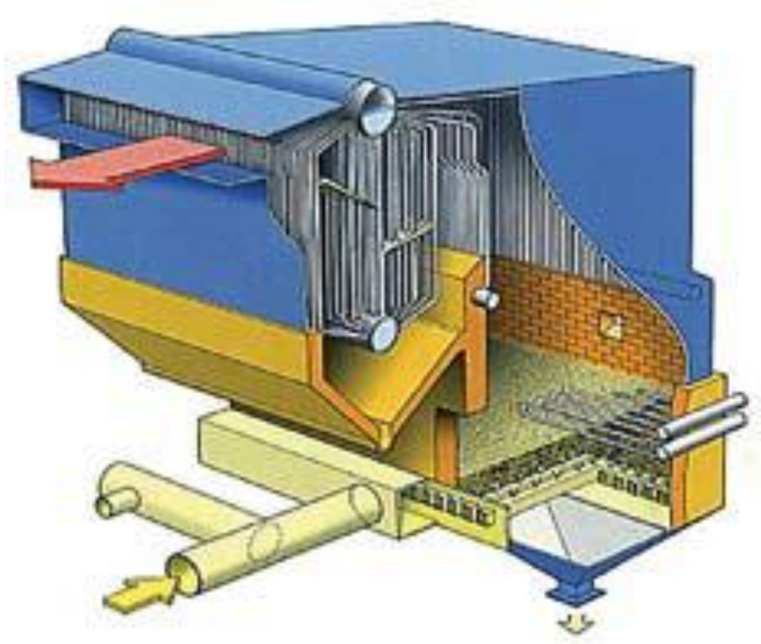


Source [35]

Figure 1.20 Pulverized coal combustor

In comparison with the fluidized bed combustors and stoker/grate combustors, the PCCs are less affected by deposition problems such as slagging, fouling, and corrosions due to high concentrations of potassium and chlorine contained in the biomass materials, etc. The risks of slagging, fouling and corrosions in the bio-pellet co-firing can be reduced by selecting the correct co-firing technologies and co-firing fuels. Moreover, pretreatment with acid, water or ammonia, etc. to remove the alkali metal and ash in the biomass materials beforehand also may effectively reduce the possibility of corrosion resulted from deposition formation. Such pretreatments are even more important particularly when herbal raw materials are used that their alkali metal contents are high. Although the washing pretreatment will increase the production cost of the biomass fuels, the maintenance cost for the combustion boiler system could be significantly reduced.

Fluidized bed combustion as shown in Figure 1.21 can be divided into circulating fluidized bed (CFB) and bubbling fluidized bed (BFB) according to the gas speeds. The fluidized bed combustion is designed to operate at high temperatures, ranging from 800 ℃ to 900℃ with lower NO_x and SO_x emissions comparing to other combustion technologies. By way of fluidized sands' evenly mixing with the fuels internally the fluidized bed boilers are of suitable co-firing reactors. Fuels of lower grades such as wood residue of forestry industry, wood chips of the industrial waste, and the solid waste from cities all can be utilized in FBC boiler systems. When the fluidized bed combustion boilers are operated in a direct co-firing mode, the overall combustion efficiency is less sensitive to the rate of increase in the co-firing proportion of the biomass fuels. Moreover, fluidized bed combustion boilers can process biomass materials with higher moisture contents (10-50%) and larger size (<72 mm) pellets than pulverized coal boilers.



Source [35]

Figure 1.21 Fluidized bed bio-pellet boiler

The combustion air in the fluidized bed flows upwards, which mixes the bio-fuels with the bed sands in a suspended way. As the combustion air velocity increases, more fluid properties are obtained. In contrast to the fuel particles' speeds, the BFB combustion boilers are normally operated under lower air velocities, but the CFB combustion boilers have been designed to have extremely high gas velocities that the fuels and bed sand particles could be brought away from the combustion chambers, and these bed sand particles will be separated in the cyclone separator, and then recycled back to the combustion bed.

The packed bed combustion systems utilize stoker or grate combustors as shown in Figure 1.22, and have been designed to supply fuels to the moving grates under steady air controls. During its operation, the bio-pellets are driven by the grate, and are burned steadily. The larger bio-pellets burn directly on the grate, and the smaller bio-pellets are scattered by the grate and burn in the air. Stoker/grate combustors can burn different types of fuels, such as peats, coals, or biomass of different sizes (up to about 3cm), such as straws or woody residue. These features have made stoker/grate combustors suitable for co-firing of coal with biomass fuels. However, such boiler system still has some technical disadvantages such as low thermal efficiency, tendency to easily sinter on the furnace walls, and the cost constraints to remove ashes from the flue gas. Although such boiler systems have low operating and maintenance costs, their low thermal efficiency has constrained the widespread use of such boiler systems, comparing to FBC and PCC.

Source [35]

Figure 1.22 Stoker/grate bio-pellet boiler

The comparison and applicability of the above co-firing technologies on existing boilers are summarized in Table 1.6 [39].

Table 1.6 Applicability of various co-firing techniques on existing boilers

Co-firing technologies	Technology applications
BFB	•It has wide ranges of operational conditions applicable for wood biomass material and a variety of waste fuel co-firing. •The allowed bio-pellet sizes are of <80mm and the co-firing ratio is of 80% (heat base) that it has better control on pollutant emissions, and is mostly utilized on applications of medium-scale regional heat supply and steam/electricity co-generation plants.
CFB	•Similar to BFB, but the gas velocities inside the CFB are higher than which of BFB. The bio-pellet sizes applicable ranges are of <10mm with allowed co-firing ratio of 60-95% (heat base). •It is mostly utilized on applications of large-scale regional heat supply and steam/electricity co-generation plants.
Stoker/Grate	•It generally refers to the packed-bed boilers, and they have been applied on RDF co-firing and waste co-firing. •They allow broader types of biomass materials with bio-pellet sizes applicable range of <30mm. •The allowed co-firing ratio is 3~70% (heat base) that the pollution controls may not meet the expectations of economic benefits.
PCC	•It is applicable for the co-firing with pre-ground biomass fine powders. The ground particle range of 50-70μm with allowed moisture contents to be under 20%. •This type of boiler allows co-firing ratio of 1-40% (heat base). There are many co-firing references and experiences about such combustion technologies, which are applied in commercial power plants in Europe and the USA.

1.10 Bio-pellet combustion in existing industrial boiler

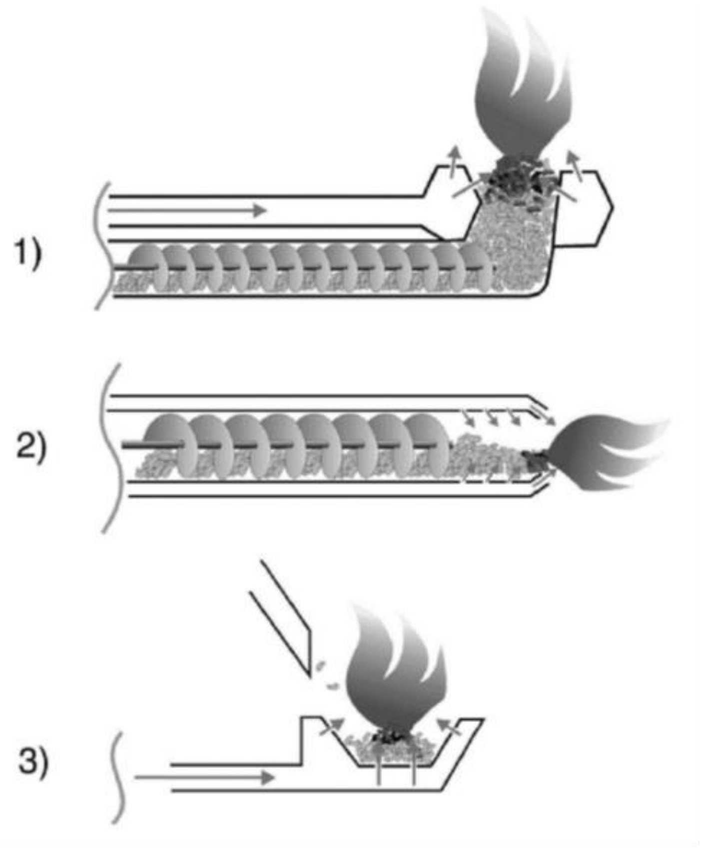
Wood-pellets have the features of ease of ignition, high energy density and carbon neutral fuels, etc. They can substitute coal and other fossil fuels for applying in the civilian areas of cooking and heating and in the utility areas of power generation, combined heat and power, and other industrial applications. Wood-pellet burner is a mature combustion device that has used wood pellets as its fuels. It is a systematic equipment which can be continuous firing and automatically controlled. It is widely applied in small-scale equipment such as hot stoves and heating furnaces and medium-sized bio-fuel boilers, etc. The applications of wood pellet burners in the European countries are quite mature especially in Sweden.

Features and advantages of wood-pellet burners are as follows:

- Low cost: Wood pellet burners use bio-pellets for energy sources that reduce the fuel costs for 30-60% as compared to heavy-fuel-oil or natural-gas fired burners.
- High combustion efficiency: Wood-pellet burners have adopted semi-gasified combustion and tangent swirl-flow type air distribution design that the combustion efficiency can reach up to more than 96%.
- Stable and reliable operation: The wood-pellet burner can avoid backfire phenomenon under slightly positive pressure operation.
- Low carbon and environment friendly: The bio-pellet combustion features low SO_x and NO_x, and it is easy to meet the air pollutant emission standards.
- Save operation labor: The wood-pellet burners are mostly designed with automatic feeders for bio-pellets that their operations are automatically controlled and can be done by a single operator.

The bio-pellets are of uniform sizes that continual combustion can be conducted through automatic feeding. The use of high efficiency combustion equipment can obviously upgrade the bio-pellet boilers' efficiency that typically can achieve above 86%. The bio-pellet boilers have a variety of models, and their ways of classifications are different. Typical wood-pellet burners generally consist of feeding system, ignition system, air distribution system, combustion chamber, bottom ashes cleaning system and automatic control system, etc.

According to the ways of wood pellets feeding, we may roughly categorize the wood-pellet burners into three types of underfed burners, horizontally fed burner and overfed burner, as shown in Figure 1.23 [40].



Source [40]

Figure 1.23 Wood-pellet burners: (1) underfed burners; (2) horizontally fed burner and (3) overfed burner.

The underfed burners use screw feeding devices which are under the burner to feed the pellet fuels into the combustion chambers. The primary air follows the bio-pellet feeding devices or the small holes on the combustion beds to get into the combustion chambers, and the secondary air gets into the combustion chambers through the air holes located at the upper side. The ashes left from burning of such burners will be squeezed by the incoming pellet fuel and fall into the ash collection devices down below.

The principles of the horizontally fed burners are similar to that of the underfed burners which also use the screw feeding devices to feed the pellet fuels into the combustion chambers, but this type of burners require additional ash collection devices. Míguez et al. [41] has conducted statistical analysis on 995 sets of wood-pellet burners, and he concluded that the horizontally fed burners are commonly selected for bio-pellet feeding with larger capacity burners.

The overfed burners are the most widely used and are usually used in boilers or stoves. There are pellet-descending channels on the inner walls of the overfed burners. The pellet fuels drop from the channels down into the combustion chambers for burning, the primary air together with the hot air needed for automatic ignition are guided inside from the bottom of the combustion chambers, and the secondary air holes are located at the walls of combustion chambers. Usually, blowers have been used to provide combustion air, and to facilitate the heat exchange between the inner combustion chamber and the surrounding air. The grates have been designed with either manual or automatic movements to facilitate the ashes' falling down into the ash collecting devices conveniently.

The advantages and disadvantages of the three feeding modes of bio-pellet burners are shown in Table 1.7.

Table 1.7 Comparison of feeding modes of bio-pellet burners

Type of pellet feeding mode	Advantage	Disadvantage
Underfed	• The pellets do not have much influence on the combustion layer, thus the combustion process is stable.	• Backfire is more possible to happen after long combustion, or in the later period of the combustion.
Horizontally fed	• The pellets do not have much influence on the combustion zone, thus the combustion process is stable.	• Has higher risk of having backfire, needs additional ash-clearing device.
overfed	• The combustion chamber is separated from the fuel compartment, the risk of backfire is reduced and the feeding control is more accurate.	• When the pellet falling, the combustion zone will be interfered, and that may result in incomplete combustion on more pellets.

Source [5]

Ignition approaches of wood pellet burners can be categorized into two types of contact ignition and non-contact ignition according to the relative positions of the ignition devices and bio-pellets. Contact ignition refers to the cases when the ignition elements contact fuels that the energy is transferred to the pellets by way of conduction directly, thus it has the advantages of high ignition efficiency and small energy loss. The most common approach of contact ignition is mainly resistance rod ignition. Non-contact ignition refers to the cases when ignition elements are not in direct contacts with the fuels that the energy generated by the ignition elements is transmitted to the fuels by convection. This approach has the advantages of good control, simplicity and convenience that it mainly includes two types of resistor ignition and electronic ignition.

Because bio-pellets have characteristics of high volatility that they ignite easily, and the burning time is short. Moreover the melting points of their ashes are low thus may easily results in slagging during the combustion process. In terms of small-scale burner, the combustors are small, thus the bio-pellets are not easy to burn completely, resulting in incomplete combustion and causing more smokes and low combustion efficiency. In order to have the pellets to burn more completely, approaches on combustion chamber and air distribution must be taken for the burners, such as using rotating combustion chamber and secondary air distribution mechanism. Such measures can improve the combustion efficiency, decrease flue gas emissions, and can reduce slagging from happening [42].

The controls of pellet burners mainly have two types. The first type is semi-automatic control, of which the pellet burner is a separate unit capable of working with standard boilers, and the bio-pellet feeding, ignition and combustion are all automatically controlled, but the thermal output can only be set as full output (100%) or half output (50%). This type of control is more commonly adopted in the Swedish-made burners. The pellet burners of the second type control modes handle automatic controls on material feeding, ignition, combustion and ash cleaning. Their thermal outputs can be adjusted and controlled within a certain range (30~100%) that it is easier to use, and they are more commonly used in the pellet burners of Austria, Denmark, etc.

For small- and medium-scale enterprises, small wood-pellet burners are ideal substitutes for fuel oil and gas burners. To use such small wood pellet burners may reduce emissions of harmful gases, save limited fossil fuel resources, and can also reduce the operational costs of the boilers. In Nordic countries, it is very common to replace the existing oil-fired burners with wood pellet burners (Figure 1.24) [40]. In this case, the pellet burner designs should cope with the boilers accordingly. If the burner flames are too long, that might touch the cold boiler wall surfaces and cause smoke and high emissions of hydrocarbons, and result in low combustion efficiency. In addition, the flue gas velocities of the wood pellet burners are higher than that of the fuel-oil-fired burners, so that the retention time of the flue gas in the boilers may be shorter, and which will result in excessive flue gas outlet temperature and emissions of unburned materials. For revamping the fuel-oil-fired burners to pellet burners, the thermal outputs of the pellet burners should be slightly smaller than the corresponding fuel-oil-fired burners' outputs. Although it implies that consumers can get a little less of thermal outputs, but pragmatically the fuel-oil-fired boilers' design capacities are usually more than their normal heat supply ratings, therefore it will not cause any boiler operation issues.


Source [43]

Figure 1.24 Pellet burner for industrial boiler

The biggest difference in operation between a bio-pellet boiler and a conventional fuel-oil-fired/gas-fired boiler is the time required for the boiler to startup and to stop. For using fuefl-oil-fired/gas-fired boilers, the on/off operations of the burners are rather fast that the combustion inside the burners' combustion chambers may start or stop simultaneously at the moment when the fuel and air supply starts or stops. However, for the bio-pellet boilers, the pellets are supplied at steady rates, and their combustion in the combustion chambers are continued as long as the pellets and air remain there, until either bio-pellets or air have been consumed fully. As a result, bio-pellet boilers require longer start and stop times than the conventional fuel-oil-fired/gas-fired boilers [16]. In addition, the ash contents of the pellets are higher than that of fossil fuels such as fuel oil and natural gas. Therefore, the pellet boilers require regularly removal on ash inside the combustion chambers and fly ash inside the flue pipes.

1.11 Bio-pellet utilizations in North America

The United States and Canada are the world's leading producers of wood pellets with their nameplate production capacities of more than 13.7 million tons and 4 million tons respectively in 2016 [44]. Operation capacities of the United States and Canada are 60% and 50%, respectively. Among them, approximately above two-thirds of their output is sold abroad, and one-thirds is kept for domestic use. Table 1.8 shows major export and import countries in North America, Europe and Asia [11]. Currently the United States and Canada dominate the trade in industrial wood pellets into Europe, the United Kingdom and Japan.

Table 1.8 Global major export and import countries of wood pellets.

	Net Imports by Region (major import and export countries) - negative indicates net exports				
Region	2013	2014	2015	2016	2017 (forecast)
Europe and UK	4,866,320	5,655,327	6,669,874	7,407,511	8,570,000
Canada	-1,615,638	-1,607,239	-1,597,847	-2,252,201	-2,320,000
US	-2,730,078	-3,835,747	-4,368,301	-4,537,378	-5,220,000
Japan	79,052	92,539	232,060	346,518	670,000
S. Korea	484,668	1,849,639	1,469,184	1,716,346	2,530,000
Vietnam	-157,226	-742,794	-1,022,809	-1,254,955	-1,490,000
		source: Argus Direct, September 2017, Analysis and 2017 forecast by FutureMetrics			

The increase of wood pellet production and consumption within Canada is mainly driven by international demand as well as potentially new domestic policies. Coal power accounts for roughly 10% of Canada's total greenhouse gas emissions. The federal government has announced plans to phase out the use of coal-fired electricity in Canada by 2030 as part of its overall clean-energy strategy [44]. Especially in Ontario, a number of assessment projects have been implemented, and have successfully completed a variety of bio-pellets and coals' co-firing tests and demonstrations. According to the statistics of IEA Bioenergy Task 32 database, 46 biomass fuel co-firing facility cases, either at demonstration stages or in commercial operations, have been set up in 2013 in North America, seven of them are located in Canada, all in Ontario and are owned and operated by the Ontario Power Plant (OPG). In these cases where seven power plants of pulverized coal boilers are co-firing with bio-fuels, a total of four power plants have used wood pellets as co-firing fuel.

Since 2003, because of the negative view about coal combustion, Ontario's overall coal-fired power generation capacity has been reduced by 40% to decrease air pollution from coal-fired emissions. It is anticipated that such a change will result in a reduction of nearly 300,000 tons of carbon dioxide emissions in Ontario, which is almost equivalent to the emissions of 7 million vehicles. Public utilities such as the Ontario Power Plant are actively endeavoring to add more renewable energy sources such as biomass and wind energy, as well as natural gas power plants. Furthermore, similar renewable power projects also have been included into other provinces' renewable energy policy implementation plans.

In the United States, although there are many operation cases of biomass co-firing, most of them are still at the demonstration stages of different boiler types. Because of the lack of favorable encouragements and policy incentives in the past, utility companies in the

United States are still in lack of the willingness on biomass co-firing for commercialized scales. The main drivers for wood pellet consumption in the U.S. have been regional price competitiveness with residential heating oil and propane as well as replacements of fuelwood burners with respect to comfort and automatic feed-in. Renewable Portfolio Standards (RPS) mandates the production of renewable electricity, including bio-power, but wood pellets are usually not used in bio-power facilities due to price [44]. However, according to the new environmental policies and regulatory requirements, the power sector has started to have interests in biomass, waste and recycled fuels for the applications of power generation and steam/electricity co-generation's regard.

Many utility companies in the United States and Canada have begun to use different bio-fuel types, co-firing technologies and co-firing ratios to conduct co-firing plans of biomass and coals (Table 1.9). Among them, at least four co-firing programs have utilized wood pellets as co-firing fuels. The co-firing approaches which these utility companies have chosen include the following:

- To burn the biomass at low proportion under the circumstances that almost no modification on the existing equipment is made.
- To make an upgrade on the existing equipment, and to burn the biomass at higher co-firing proportions.
- Convert/revamp the existing coal-fired burners and co-fire with the biomass fuels.
- Convert/revamp the overall power plant, and use biomass fuels for co-firing.
- Use torrefied wood pellets for co-firing. The goal is to achieve a higher proportion of co-firing in the existing co-firing system, or to completely replace coal combustion with biomass fuels, and to restart the entire plant operation.

Table 1.9 Co-firing activities in North America

Location	Plant name	Owner	Co-fired fuel
Bakersfield, California	Mount Poso Cogeneration Plant	Red Hawk Energy	Agricultural and residential waste
Boardman, Oregon	Boardman Plant	Portland General Electic	Torrefied wood or other biomass
Portsmouth, New Hampshire	Schiller Station	Public Service Co. of NH	Wood
Cassvile, Wisconsin	E.J. Stoneman	DTE Energy	Wood
Hawaii	Hu Honua Station	Hu Honua Bioenergy, LLC	Agricultural residue
Ashland, Wisconsin	Bay Front Station	Xcel Energy	Wood waste from forest harvesting
Madison, Wisconsin	Charter St. Heating Plant	University of Wisconsin	Various biomass fuels
Albany	Mitchell Steam Generating Plant	Southern Company	Woody biomass
Shadyside, Ohio	R.E. Burger Plant	First Energy Corp.	Various biomass fuels
Ontario, Canada	Lakeview Station	Ontario Power	Agricultural residue and wood pellets
Ontario, Canada	Lambton Station	Ontario Power	Agricultural residue and wood pellets
Ontario, Canada	Nanticoke Station	Ontario Power	Agricultural residue and wood pellets
Ontario, Canada	Atikokan Station	Ontario Power	Agricultural residue and wood pellets

Source [39]

Atikokan Station, an Ontario Power Plant (OPG) in Canada, stopped the operation of its originally 205 MW coal-fired pulverized boiler in 2012. This near 30-year-old boiler system was established in 1985, and was revamped to entirely wood pellets based for extending the boiler’s operation lifetime. This power plant has been re-launched in Sept. 2014 that consumes 900,000 tons of wood-pellets annually, and is the biggest wood-pellet power plant in North America.

1.12 Bio-pellet utilization in EU

The EU has set up a new target for GHG emission reductions in 2014, which will reach 40% reduction by 2030 vs. 1990. It will promote the co-firing of biomass in the industrial sector, especially in power plants. According to the statistics of the IEA Bioenergy Task 32, about two-thirds of the existing biomass co-firing cases are located in Europe, and are mostly commercial power plants. The co-firing cases of biomass and coals in Europe in 2017 are Finland 78 cases, Germany 26 cases, United Kingdom 20 cases, Denmark 16 cases, Sweden 15 cases, etc.

1.12.1 EU

In Europe, most of the biomass co-firing cases are on the public coal-firing power plant basis, which include Drax, Ferrybridge, Fiddler's Ferry, etc. in UK, Avedøre, Amager, Enstead, etc. in Denmark, Rodenhuize, Les Awirs, Ruien, etc. in Belgium, and Amer, Borselle, Gelderland, Maasvlakte in Netherlands. In addition, many other countries also have power plant co-firing plans such as Finland, Sweden, Germany and other European countries [45].

Among the co-firing biomass fuels, the most widely used are the wood-pellets. In Denmark, the Avedøre power plant's unit 2 boiler has a capacity of 800MWth which has utilized wood pellets to replace coals and co-fired with heavy fuel oil and natural gas. Among them the wood-pellets have contributed 80% of power generation.

1.12.2 UK

As to UK, it has gradually achieved the goal of bioenergy development plan by importing bio-pellets, establishing dedicated system for biomass fuels, having its existing coal-fired facilities utilize biomass fuels, etc., and that can even be used as reference for biomass co-firing promotions. Bio-pellets firing power plants contribute 5.6% of UK's electricity in 2017. Among them, the British Drax power plant is of the world's largest biomass fuel co-firing program that plans to modify six coal-fired boilers for co-firing or wood-pellet dedicated system. So far two 630 MW wood pellet fuel dedicated systems have been in operation, and the other four 630 MW systems for wood-pellet fuels are still under assessments. The project has made Drax to become the world's largest green power producer from being the world's largest carbon emitter. In addition to the implementation of the biomass co-firing program, Drax power plant also invested in wood-pellet production plants in the United States in 2013, and has produced wood pellets in 2015 to ensure that there is no worry for pellets supply.

In addition, the Eggborough company in the UK has three 500 MW power plants to use biomass fuels in 2016 which demands for 5.2 million tons annually. The RWE Lynemouth is planning a 420 MW power plant of dedicated wood-pellet fuel system. The annual demand for wood-pellets has been estimated to be 1.4 million tons [46]. The UK biomass power generation plans are as shown in Table 1.10.

Table 1.10 UK Wood pellet power generation and demand

Power plant	Capacity (MW)	Wood pellet demand (million tons)
Drax Power	6×660	7.5 to 10
Eggborough	3×500	5.2
RWE Lynemouth	420	1.4
MGT Power	CHP	1.2
Helius Energy	New bio-energy plant	0.4
E.ON Ironbridge	Old unit	1
Total	-	14

Source [46]

1.13 Bio-pellet utilization in Asia

The wood pellet is an emerging market in Asia especially in Japan and Korea. Japan and Korea are the two big import countries of wood pellets in the Asia. Currently, the United States and Canada dominate the trade in industrial wood pellets into Japan. Some of Japan wood pellets are also imported from Russia. Viet Nam and Malaysia dominate the wood pellet trade into Korea.

1.13.1 Japan

Japan's is the single largest importer of LNG, second largest importer of coal and third largest importer of oil in the world. After the Fukushima nuclear disaster, Japan domestic resources can satisfy only 9% of energy requirements. Other than depending upon fossil fuel energy, Japan is actively looking for energy support from renewable energy.

By 2020 all of Japan's major utilities will be required to decouple generation from transmission and distribution. Once decoupled, the FIT of ¥21/kWh for 20 years in Japan may be extended to the major utilities for renewable energy. Co-firing wood pellets for large utility pulverized coal boilers will take off quickly since little or no modification is needed to co-fire at low ratios. FIT program has led to 8 GW of capacity being added since 2012. Increased demand for industrial wood pellets can be foreseen. Figure 1.25 shows the increased import of wood pellet in Japan since 2012 [11]. The operation, construction and planning of Japan biomass power plants after the implementation of FIT of 8 GW for the renewable energy on 1 July 2012 is shown in Figure 1.26 [47].

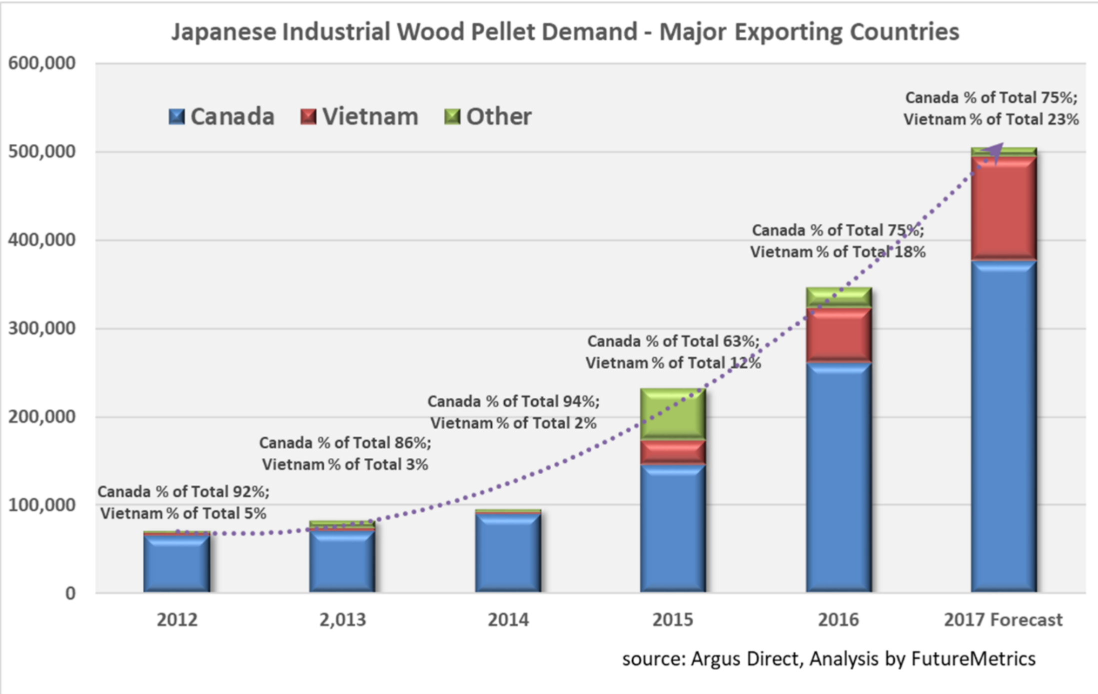


Figure 1.25 Japanese industrial wood pellet demand

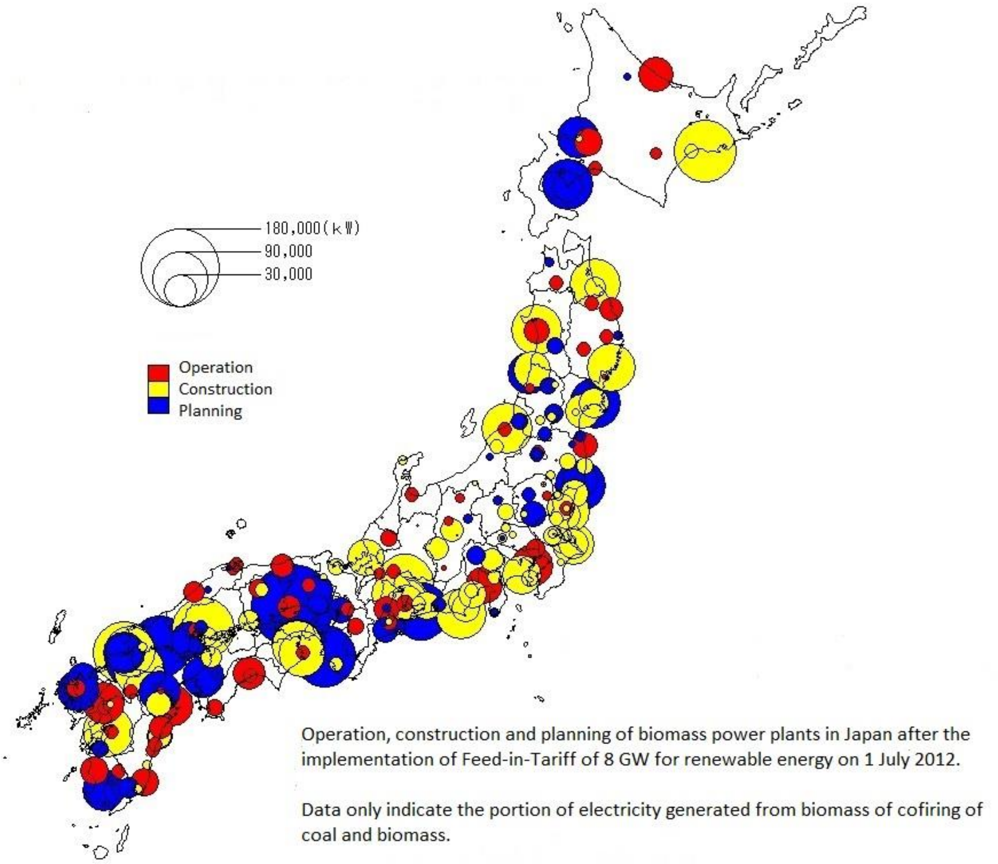


Figure 1.26 Operation, construction and planning of Japan biomass power plants.

In japan there are several biomass power plants. Recently, since the incentive of FIT of ¥21/kWh for 20 years, Sumitomo Corp. has made public plans to construct a 50MW wood biomass power plant in Sakata City, Yamagata Prefecture through its wholly owned subsidiary Summit Energy Corp. Sumitomo already owns and operates two other biomass power plants, the 50MW Ltoigawa Biomass Power Plant, which came online in 2005, and the 75MW Handa Biomass Power Plant, which is slated to begin commercial operation in 2017.

1.13.2 Korea

Korea relies on fossil fuel imports for about 97% of its primary energy consumption. In 2014, Korea was the fourth-largest global coal importer. A renewable portfolio standard (RPS) for Korea became effective in 2012. Korea's RPS mandates an increasing percentage of power generated from renewable sources. The required proportion of power from renewables increases to 10% in 2024 [48]. Utilities must buy Renewable Energy Certificate (REC) or pay a fine of 150% average REC price if they do not meet the RPS. Wood pellet imports to Korea has almost tripled over the past three years, from 400,000 tons in 2013 to more than 1,400,000 tons in 2016. Figure 1.27 shows the increase of imported wood pellets since 2012 [11]. The wood pellets are mainly imported from Viet Nam, Malaysia and Canada. Korea is now the largest importer of wood pellets in Asia.

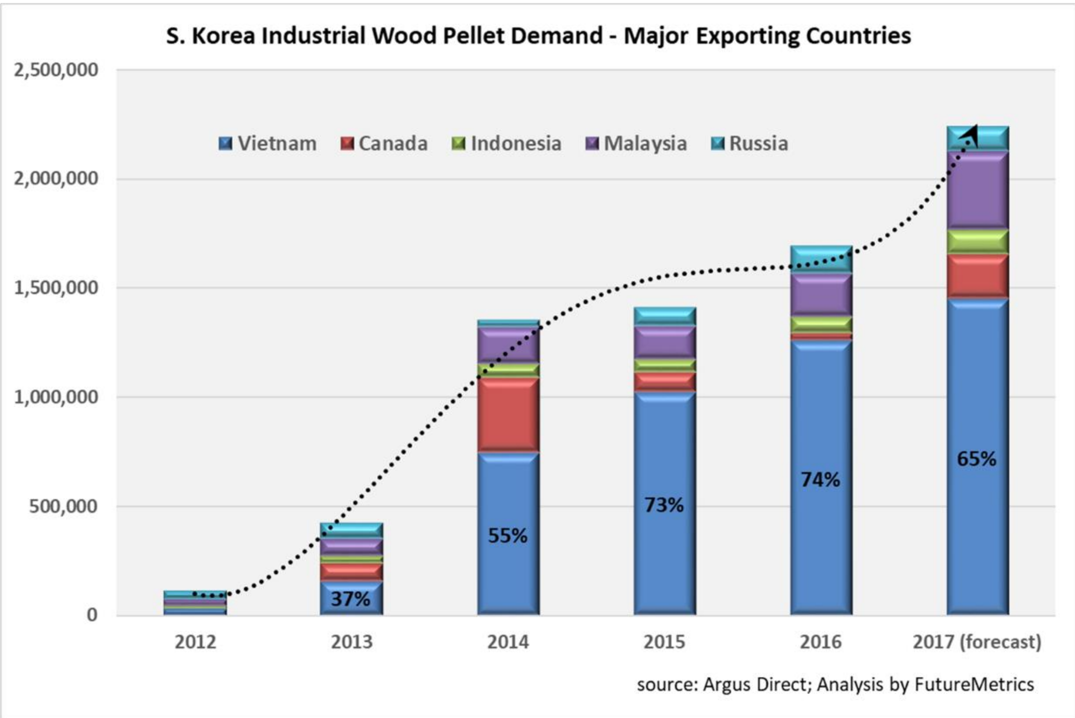


Figure 1.27 Korea industrial wood pellet demand

1.13.3 China

There is major uncertainty regarding the Chinese markets for pellet fuel both in terms of potential demand and in terms of how much pellet fuel could be produced domestically. On one hand, China has very limited forest resources for producing wood pellets. On the other hand, they have almost unlimited agricultural wastes that could be made into pellet. The 2016 to 2020 five-year plan in China has explicit support for pellets. If China were to embrace co-firing of wood pellets, even at modest ratios, the internal demand would be very large. China will probably be the largest market of bio-pellets in next few decades [9].

1.13.4 Chinese Taipei

Chinese Taipei relies on fossil fuel imports for about 98% of its primary energy consumption. Renewable energy accounts for only 4.8% in 2016 and will increase rapidly to 20% in 2025. Various FIT programs are employed to solar farm, wind power and biogas electricity to promote the renewable energy applications. Since 2014, Chinese Taipei’s import of wood pellets has increased significantly for the domestic industrial heating applications. The wood pellets are used for replacing fossil fuel in industrial packaged boilers. Several demonstration tests of using domestic bio-pellets made from bamboo and eco-hazard plant of white leedtree for packaged boilers were conducted. Results show that the boiler efficiencies were the same as that of the fossil fuel boilers and the boiler emissions of SO_x and NO_x of firing bio-pellets were lower than that of fossil fuel boilers.

2. White-leadtree Pellet Production and Combustion in a Packaged Boiler

2.1 White leadtree

White leadtree (Leucaena leucocephala) is a small fast-growing mimosoid tree native to southern Mexico and northern Central America (Belize and Guatemala), but is now adapted throughout the tropics [49]. Common names of the white leadtree include jumbay, river tamarind, Subabul, and white popinac [50]. The white leadtree is used for a variety of purposes, such as firewood, fiber and livestock fodder.

The white leadtree is a highly invasive species in the arid parts of Chinese Taipei; Hong Kong, China; China; the Hawaiian Islands; Indonesia; Malaysia; Viet Nam; the Philippines; Australia; South America and Europe [51]. The white leadtree is considered one of the 100 worst invasive species by the Invasive Species Specialist Group of the IUCN Species Survival Commission [52].

2.2 Small-and-medium enterprises

Most enterprises especially in the APEC's developing economics are small-and-medium enterprises (SMEs), relying on firing fossil fuel with boilers to obtain heating required for the manufacturing process. It is difficult for SMEs to use modern green energy, especially the wind power and solar PV, due to the limited space available. The white leadtree, one of the 100 worst invasive species, is a very common species in APEC economics and is detrimental to ecology. To get rid of the white leadtree and to utilize this invasive plant are important issues in APEC's developing economics. After removal of the white leadtree, cultivating native, fast-growing plants like eucalyptus or others in the arid areas can be considered for the sustainability of feedstocks for the bio-pellet fuel. In this section, after getting rid of the white-leadtree, the demonstration and utilization of bio-pellets, made from the white leadtree, in packaged boilers of SMEs for green energy applications are discussed.

2.3 White-leadtree distribution in Chinese Taipei

Native to Central and South America, Hawaii-type white leadtree (Figure 2.1) was introduced into Chinese Taipei by the Dutch some 400 years ago. In 1976, the large-sized Salvador-type white leadtree was introduced into Chinese Taipei as some private enterprises intended to develop the paper industry. However, the plan was aborted after evaluation. The white leadtree has three major types, i.e. Hawaiian, Salvador and Peru types. The Hawaiian type has extraordinary capability to withstand dryness and is highly adaptable to habitats. The tree can reach 5 meters, and blooms and fruits all year around. The Salvador type is a large-sized species. It can grow to 17 meters in just 6 years and has a diameter at breast height of 28 centimeters. The thin bark and high volume of wood make the Salvador-type white leadtree ideal for producing paper pulps and being used as firewood and industrial fuel. It is therefore called an "energy tree" [53].

Figure 2.1 White leadtree plant

The white leadtree has many advantages. It is fast growing, capable of producing high quality wood, used as livestock fodder, easy to sprout even after cutting, etc. However, the properties such as fast growth, easy propagation and high adaptability to environment give the white leadtree the capability to invade bare lands in large quantity. It's hard for other plants to survive in the places where the white leadtree grows. As a dominant species, the white leadtree has done serious damage to the ecosystem in Chinese Taipei. For example, the large-scale propagation of white leadtree has become a very serious issue for Kenting National Park. The situation is similar at the Taroko Gorge National Park. Currently, the Hawaii-type white leadtree plants are spreading throughout the Hengchun Peninsula and occupying many farm lands that were used for growing sisal or other agricultural crops. Many abandoned agricultural lands are also invaded by the white leadtree. The lands along the coastline and the roads to the west of Kenting National Park are the most severely invaded areas. Figure 2.2 shows the white leadtree infested forests in Chinese Taipei's mountains. Figure 2.3 displays the distribution of the white leadtree in Chinese Taipei [53].

Figure 2.2 Invasion of the white leadtree in Chinese Taipei mountain

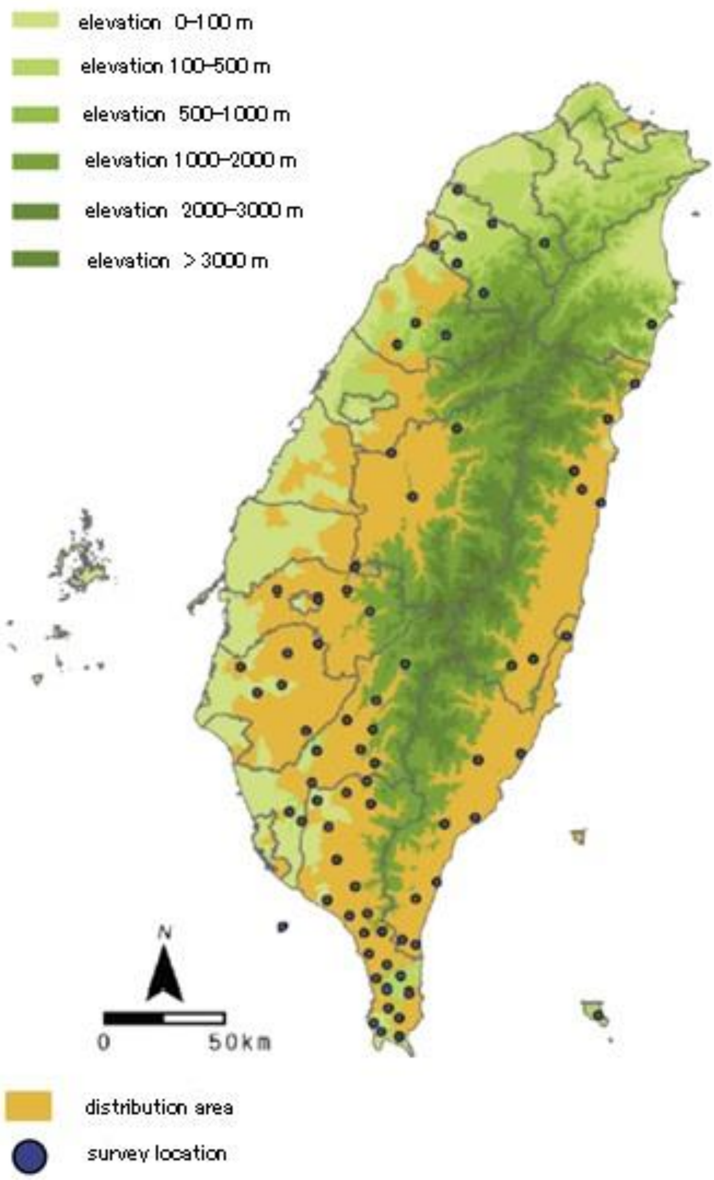


Figure 2.3 Distribution of the white leadtree in Chinese Taipei

There are no clear statistics about the number of the white leadtree in Chinese Taipei yet. Highly populated areas of the white leadtree in Chinese Taipei are mostly in the east and south regions of Chinese Taipei, i.e. south of Taimali, Taitung County and south of Fangliao, Pingtung County, respectively. In this study, the white leadtree material used by the packaged boiler comes from the Hengchun Peninsula which is located at south of Chinese Taipei. Trees of Chinese Taipei native species, such as the acacia confusa and others, are planted in the forest land areas (Figure 2.4) after the white leadtree plants are eradicated.

Figure 2.4 Trees of Chinese Taipei native species are planted after the white leadtree plants are eradicated.

2.4 White leadtree preparation

The white leadtree to make the bio-pellet fuel comes from the mountain area of Hengchun Peninsula. The Forestry Bureau hires private companies to uproot the white leadtree plants in the wilderness, remove the branches and leaves, and then transport the timbers to the log yard for storage as shown in Figure 2.5.

Figure 2.5 White leadtree log yard

The pulverization process is as follows: the white leadtree timbers are first transferred from the log yard (Figure 2.5) to the feeding preparation area (Figure 2.6) and then loaded onto the feeding platform. Manual inspection is carried out on the logs. The logs that are crooked or too long may hamper the feeding and pulverization process (Figure 2.7) hence appropriate trimming is needed.

Figure 2.6 Feeding preparation area for white leadtree logs

Figure 2.7 Manual trimming of logs unsuitable for feeding

Used to pulverize the white leadtree, drum slicer is a specialized equipment for chopping timbers. Drum slicer can be used to chop logs, branches, bamboo and other non-wood fibrous stalks. It is an essential equipment used in making paper, fiber boards and wood board processing. The wood chips produced by the drum slicer are uniform in length and thickness and have clean cut surfaces. The drum slicer can be used to chop various raw materials.

A drum slicer is composed of parts such as base, feeding platform, conveyor belt (Figure 2.8), upper and lower feeding rolls (Figure 2.9), knife roll (Figure 2.10), hydraulic system, etc. Multiple knives can be installed and mounted on the knife roll with specially-made bolts and pressure blocks. To accommodate different thicknesses of raw materials, the upper feeding roll assembly is capable of moving up and down within a certain range with the help of the hydraulic system. The chips cut off from the logs are discharged from the bottom of the machine.

Figure 2.8 Feeding platform and conveyor

Figure 2.9 Logs being fed into upper and lower feeding rolls

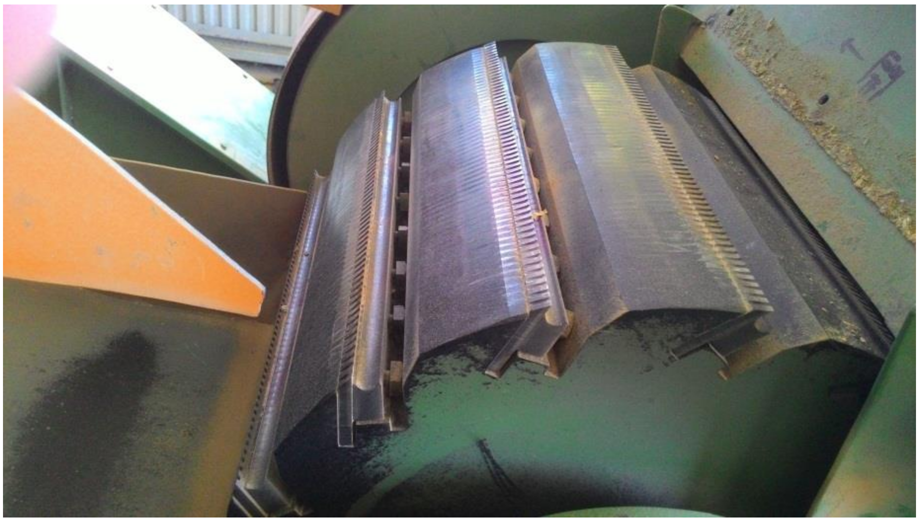


Figure 2.10 The cutting knives installed on the knife rolls of drum slicer

The white leadtree logs from conveyor belt are fed between the upper and lower feeding rolls, which push the logs into the drum slicer at a steady speed. The wood chips then fall into screw conveyor below. The white leadtree particles separated by a vibrating screen (Figure 2.11) are discharged through the screw conveyor (Figure 2.12).

Figure 2.11 Vibrating screen

Figure 2.12 White leadtree particles

The pulverized white leadtree particles are transferred to storage pit (Figure 2.13) of the packing system by loader shove. The screw conveyor raises the particles so that they can be dropped into the bulk bags for packing (Figure 2.14). The packed bulk bags (Figure 2.15) are then carried by trucks to the next stop, the bio-pellet fuel manufacturing plant.

Figure 2.13 The storage pit of the white leadtree packing system

Figure 2.14 The white leadtree particles packed into bulk bags on truck

Figure 2.15 Packed bulk bags of the white leadtree

2.5 The manufacturing of the white-leadtree pellet fuel

The pelletization results of the white-leadtree pellets are influenced by the water content of the pulverized particles. Drying process is therefore needed to control the water contents of the white-leadtree particles before pelletization. Measurements of the water contents of the white-leadtree particles are carried out on the random samples of bulk bags. The results reveal that the water contents of the white-leadtree particles lie between 23.50～38.69 wt%. Table 2.1 shows the details of sampling analysis of water content.

Table 2.1 The sampling analysis of water content of white-leadtree particles

Water content of white-leadtree particles (%)				
Bulk bag #	Measurement 1	Measurement 2	Measurement 3	Average
#50	21.97	24.09	24.45	23.50
#52	23.98	24.09	24.45	24.17
#58	39.52	38.55	37.99	38.69
#60	34.06	33.67	35.41	34.38

Since the water content of the white-leadtree particles is higher than that required by the pelletization condition of making bio-pellet fuel, the drying process is needed to control the water content. The white-leadtree particles are first unpacked from the bulk bags and fed into the storage hopper (Figure 2.15) by using a loader shovel. Then the conveyor transfers the particles to the pulverizer (Figure 2.16), which is used to control the sizes of the white-leadtree particles before pelletization. Tests of water content of the pulverized white-leadtree particles are carried out on the production line in order to determine the time and temperature of the drying process.

Figure 2.16 White-leadtree particles fed into storage hopper by loader shovel

Figure 2.17 Pulverization of the white leadtree and particle size adjustment

Pneumatic conveying dryer, as shown in Figure 2.18, is used to dry the white leadtree particles. Pneumatic conveying dryer is widely used in the drying process of the particle materials. The air is sent by an air blower into the burner for heating. The heated air is then sent to the inside of the pneumatic conveying dryer. Wet particles are added into the pneumatic conveyor dryer. The high-speed and heated air flow will speed up the drying process for the wet particles and evenly diffuse them in the air flow. The wet particles are dried up by the air flow in the process of conveying.

Figure 2.18 Vertical-tube pneumatic conveyor dryer

The advantage of the pneumatic conveyor dryer is that the solid particles are highly diffused and float in the air flow so that the surface areas of heat transfer and mass transfer between gas and solid phases are greatly increased. The high air flow speed (20~40m/s) also increases the relative speed between gas and solid phases. Not only is the heat transfer area increase but also the heat transfer coefficient of the particles is raised.

After pulverization, the white-leadtree particles are transported by conveyor into pneumatic conveyor dryer (Figure 2.19) for drying. The water content of the particles is controlled at 16% (Figure 2.20) approximately.

Figure 2.19 Pneumatic conveyor dryer

Figure 2.20 Online water content measurements of dried white-leadtree particles

The process of pelletization begins once the white-leadtree particles are dried to the expected water contents. The pelletizing process of bio-pellets is directly influenced by the material properties and water content. Too high or too low water content will fail the pelletization. When the water content of the particles is too low, the pelletization will not be successful due to the lack of softener and lubricant that are required in the compressing process. On the other hand, the pelletizing condition deteriorates when the water content is too high.

When the water content of particles is too low or too high, the white-leadtree particles in the pelletizing chamber will be pressed into cakes and cannot be pushed out through the forming dies. The blocked forming dies will lead to the rising stress of the machines and equipment, an electrical overload and even the breakage of the safety pin that is used to protect pellet forming machine. It is learned for the past experiences that effective pelletization can only be achieved when water content is controlled in the range of 10% to 30%. With water content below 10%, the success ratio of bio-pellet's pelletization drops drastically.

As introduced in Chapter 1 there are two types of pelletizing machines, the flat-die pelletizer and the ring-die pelletizer. The horizontal-type ring-die pelletizer, as shown in Figure 2.21, is chosen to manufacture the white-leadtree pellets in this study. Driven by the main shaft, the ring-die pelletizer starts to rotate. The clamping roller is driven to rotate by the friction force of the feed-in biomass particles. The white-leadtree particles are fed into the pelletizing chamber, which are evenly distributed on the ring die. The ring die in the pelletizer rotates and drives the clamping roller to rotate at the same time. The white-leadtree particles are pressed between the ring die and the clamping roller and then gradually pushed through the ring-die holes. The gradually formed white-leadtree pellets are pushed out of the ring-die holes and then cut into the desired length by a scrape knife out of the ring-die chamber. Figure 2.22 shows a horizontal-type ring-die pelletizer.

Figure 2.21 Ring die of the horizontal-type ring-die pelletizer

Figure 2.22 Horizontal-type ring-die pelletizer

The pellet fuel used by the bio-pellet burner are normally 8mm (or above) in diameter for easy stack-up in the burner, where the partial combustion and partial gasification processes take place. Bio-pellet fuel can be cut into different lengths in the manufacturing process as required. Figure 2.23 displays the sizes of the white leadtree pellet fuel. They are 10mm in diameter and the lengths range from 30 to 50mm.

Figure 2.23 The sizes of the white-leadtree pellets

Industrial analysis (on moisture, ash, fixed carbon and volatile matter), element analysis (on carbon, hydrogen, oxygen, nitrogen, sulfur, chlorine) and heating analysis are carried out for white-leadtree pellet. Table 2.2 shows details of sampling analysis results.

Table 2.2 Analysis of the white-leadtree pellet

Analysis	Item	White-leadtree bio-pellet	Test method
Proximate analysis (wt.%)	Moisture	7.16±0.07	NIEA R213.21C
	Ash	1.83±0.06	NIEA R205.01C
	Volatile	75.01±1.06	CNS 10823
	Fixed carbon	16.00	
Ultimate Analysis (dry and ash free basis wt.%)	Carbon	43.69±1.21	NIEA M403.01B
	Hydrogen	5.88±0.22	
	Nitrogen	0.88±0.14	
	Sulfur	N.D.	
	Chlorine	0.17±0.02	NIEA M402.00C NIEA W415.53B
	Oxygen	40.39	NIER R125.02C
Heating value (MJ/kg)	HV (dry basis)	18.23±0.88	NIEA R214.01C
	HHV	16.93	
	LHV	15.41	

Note：5-time averaged sample analysis

Currently, Chinese Taipei has not established the standards for bio-pellet fuel yet. Table 2.3 lists the standards governing bio-pellet fuel [51], including Austrian (ÖNORM M1735), Swedish (SS 187120 and SS 187121), German (DIN 51731) and EU (proposed CEN/TS 14961). The comparison of the properties of the white-leadtree pellets (Table

2.2) and German DIN 51731 standard (Table 2.3) reveals that the heating value and other properties comply with the German standards. However, the ash and chlorine contents are higher than the German DIN 51731 standards. Therefore, air pollution prevention equipment needs to be installed when the white-leadtree pellets are used to fire boilers.

Table 2.3 Bio-pellet fuel standards of Austria, Sweden, Germany and EU

Specification	**Austria** ÖNORM M7135		**Sweden** SS 18 71 20			**Germany** DIN 51731 / DIN plus			**CEN** CEN/TS 14961:2005 Annex A
	Wood pellets	Bark pellets	Group 1	Group 2	Group 3	5 size classes [cm]			
Origin									Chemically untreated wood without bark
Size	- Pellets : 4 - 20 mm Ø max.100 mm lg.	-Briketts: 20 -120 mm Ø max. 400 mm lg.	max. 4 Ø**)	max. 5 Ø	max. 6 Ø		Length	Ø	D06 ≤ 6 mm ± 0,5 mm and L ≤ 5 x Diameter D08 ≤ 8 mm ± 0,5 mm and L ≤ 4 x Diameter
						HP1	>30	>10	
						HP2	15-30	6-10	
						HP3	10-15	3-7	
						HP4	<10	1-4	
						HP5	<5	0,4-1	
Bulk density			≥ 600 kg/m³**)	≥ 500 kg/m³	≥ 500 kg/m³				Recommended to be stated if traded by volume basis
Fines in % <3mm			≤ 0,8	≤ 1,5	≤ 1,5				F1.0 ≤ 1,0 % F2.0 ≤ 2,0 %
Unit density	≥ 1,0 kg/dm³	≥ 1,0 kg/dm³				1-1,4 g/cm³			
Moisture content	≤ 12 %	≤ 18 %	≤ 10 %	≤ 10 %	≤ 12 %	<12 %			M10 ≤ 10 %
Ash content	≤ 0,5 % *)	≤ 6,0%*)	≤ 0,7 %	≤ 1,5 %	>1,5 %	< 1,5 %			A0.7 ≤ 0,7 %
Calorific value	≥ 18,0 MJ/kg*)	≥ 18,0 MJ/kg*)	≥ 16,9MJ/kg ≥ 4,7 kWh/kg	≥ 16,9MJ/kg 4,7 kWh/kg	≥ 16,9MJ/kg 4,7 kWh/kg	17,5 - 19,5 MJ/kg ***)			16,9 MJ/kg 4,7 kWh/kg
Sulphur	≤ 0,04 %*)	≤ 0,08 %*)	≤ 0,08 %	≤ 0,08 %	anges	< 0,08			S0.05 ≤ 0,05 %
Nitrogen	≤ 0,3 %*)	≤ 0,6%*)				< 0,3			N0.3 ≤ 0,3 % N0.5 ≤ 0,5 % N1.0 ≤ 1,0 % N3.0 ≤ 3,0 % N3.0+ > 3,0 % (actual value to be stated)
Chlorine	≤ 0,02%*)	≤ 0,04%*)	≤ 0,03%	≤ 0,03%	anges	< 0,03			Recommended to be stated in category: CL 0.03 CL 0.07 CL 0.10 CL 0.10+ (if CL>0.10 % the actual value to be stated)
Arsenic						<0,8 mg/kg			
Cadmium						<0,5 mg/kg			
Chromium						<8 mg/kg			
Copper						<5 mg/kg			
Mercury						<0,05 mg/kg			
Lead						<10 mg/kg			
Zinc						<100 mg/kg			
EOX, extractabl.org. halogens						<3 mg/kg			
Fines. bevor delivery to costumer	max. 1 %					max. 1 %			
Additives	max. 2 % only natural		to be stated						< 2w-% of dry basis. Only products from the primarily agricultural and forest biomass that are not chemically modified are approved to be added as a pressing aids. Type and amount of additive has to be stated.
Ash melting point			temperatur to be stated						
Durability									DU97.5 ≥ 97,5

*) of dry basis **) at factory ***) witout ash and water

2.6 Combustion test of the white-leadtree pellet

In this bio-pellet burning test the white-leadtree pellet fuel is used with an industrial packaged boiler equipped with a bio-pellet burner. The sizes of the white-leadtree pellet fuel selected are shown in Figure 2.24. They are 10mm in diameter and the lengths range from 30 to 50mm. The properties of the pellet fuel are shown in Table 2.2 above.

Figure 2.24 White-leadtree pellets

The steam packaged boiler, originally natural gas fired, used in the burning test of white-leadtree pellets is shown in Figure 2.25. Due to the high cost of natural gas and CO_2 emission problem, the steam boiler was retrofitted in August 2015 by replacing the natural gas burner with a bio-pellet fuel burner (Figure 2.26). The main body of the boiler is re-used for cost reduction. The steam boiler has an evaporation rate of 7,200 kg/hr, heat transfer area of 147.97 m^2 and heat output of about 4,320,000 kcal/hr.

Figure 2.25 Packaged boiler fired with natural gas

Figure 2.26 Horizontal-type bio-pellet burner

Typical packaged boiler uses bio-pellet burner with a combined partial combustion and partial gasification process. The bio-pellets are partially combusted first in the burner that provide the heat for the follow-up gasification process of bio-pellets. The syngas generated by gasification in the burner is then introduced into the packaged boiler to replace natural gas or heavy fuel oil to produce steam energy that can be utilized in the heating manufacturing process. There are normally two types of bio-pellet burners, *i.e.* vertical type burner and horizontal type burner, and most of them adopt fixed bed design. A horizontal, fixed-bed bio-pellet burner, as shown in Figure 2.26, is used in this test. Horizontal bio-pellet fuel burner has the advantages such as a more even gasification and ease of ash discharge. However, it takes more floor area than a vertical burner does.

The combustion test of white-leadtree pellet is carried out with the steam boiler in the factory manufacturing process. The test must not interfere with the production process of the factory. The white-leadtree pellets are unloaded from bulk bags into the hopper of bio-pellet feeder and then fed into the pellet fuel burner by a screw feeder (Figure 2.26). The bottom of the fixed-bed burner is a furnace grid that is used to contain and support the white-leadtree pellet fuel. It also allows the ash created from the combustion of pellet fuel to pass through and be discharged.

The white-leadtree pellet fuel is ignited, burned and gasified on the furnace grid of the fixed-bed burner. Pilot flame is established by a small amount of combustion and appropriate adjustment of air intake in the burner. Increase air intake and the white-leadtree pellet fuel slowly and observe the flames in both fixed-bed burner and boiler furnace. Increase the proportion between the white-leadtree pellet fuel and air until the flames reach the desired height, width and brightness in the boiler. The procedure of the combustion test of bio-pellet fuel with boiler is shown in Figure 2.27.

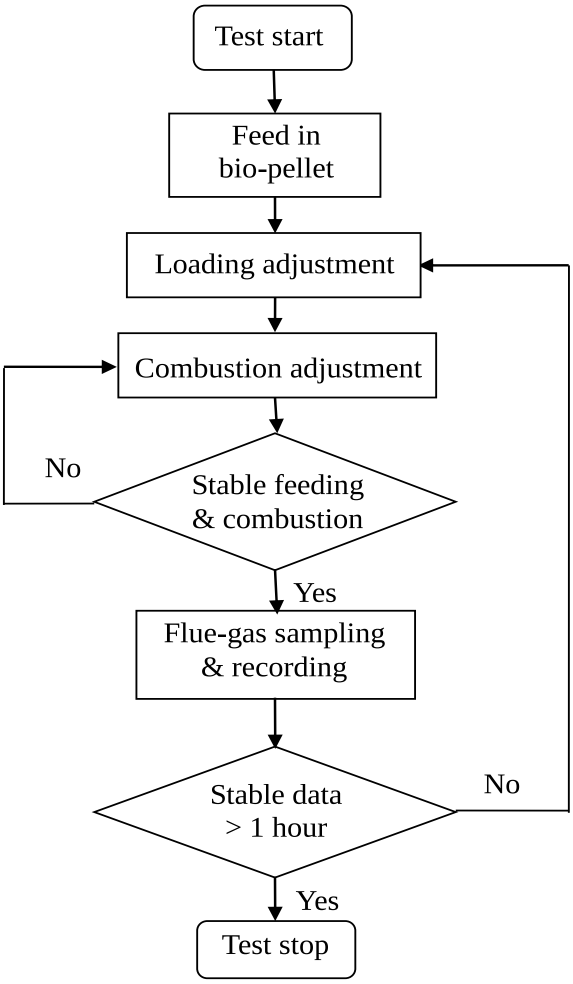


Figure 2.27 Test procedure of the white-leadtree pellet fired in a packaged boiler

Figure 2.28 shows the bio-pellet burner and packaged boiler. The nameplate operation data and capacity of the boiler are shown in Table 2.4. The items in the combustion test of the white-leadtree pellet fuel include observation of gasification flames, adjustment of combustion fuel/air ratio and investigation of flame stability. Once the burning of white-leadtree pellet reaches stable condition and a stable steam pressure of the boiler is maintained, flue-gas emission measurement is carried to check if the exhaust flue-gas of the boiler meet the Standards for Emission of Air Pollutants for Stationary Air Pollution Sources. The boiler efficiency is then calculated after the boiler operation is stable.

Figure 2.28 Bio-pellet steam packaged boiler

Table 2.4 Operation data of bio-pellet burner and boiler

Boiler type	Normal operation pressure	Equivalent evaporization	Burner capacity
Fire tube boiler	8.0 kg/cm^2	7,200 kg/h	4,320,000 kcal/h
Max. operating pressure	Heating surface	Bio-pellet feeding rate	Combustion control
10 kg/cm^2	147.97m^2	8~10 kg/min	Fuel/air area ratio

When the combustion and steam pressure of the boiler becomes stable, a flue gas analyzer is used to measure the contents of exhaust gases, such as oxygen (O_2), carbon monoxide (CO), nitric oxide (NO_x) and sulfur dioxide (SO_x). By feeding the appropriate amount of pellet fuel and adjusting the air intake, different ratios of air to white-leadtree pellet fuel can be experimented in order to find the optimum conditions of oxygen (O_2) and carbon monoxide (CO) in the boiler exhaust flue-gas, *i.e.* optimized excess oxygen with less carbon monoxide and no black smoke come out of the boiler chimney.

Most of the white-leadtree pellets are 30~50mm long. Some smaller pellets may be created in the process of pellet packing, transportation and download to the burner. When the white-leadtree pellet is burned in the boiler furnace, investigations of outlines and tips of the flames is carried out through the inspection hole of the boiler. Flames with no sparks falling down to the boiler furnace are observed, indicating an ideal condition of combustion in the boiler. Generally speaking, this white-leadtree pellets fired in the boiler produce stable-shaped and bright flames.

After the operation of the boiler is appropriately adjusted, an eight-hour white-leadtree pellet combustion test is carried out. Table 2.5 shows the test data of boiler exhaust gases during a one-hour test period. On average, the exhaust gases contain 2.3% of O_2, less than 0.1% of CO, 18.3% of CO_2, 76.6 ppm of NO_x (@6% O_2) and 6.1 ppm of SO_x (@ 6% O_2). The average temperature of exhaust gases is 212℃. The test data of the exhaust gases reveals that burning the white-leadtree pellet has a near-zero emission of SO_x, which is around 6.1 ppm (@ 6% O_2) on average. This analysis data coincides with the results in Table 2.2 that sulfur is not detectable in the analysis of white-leadtree pellet fuel.

Table 2.5 Flue-gas analysis of packaged boiler firing white-leadtree pellet

Time	Steam pressure (kg/cm^2)	O_2 (%)	CO (%)	CO_2 (%)	NO_x (ppm@6%O_2)	SO_x (ppm@6%O_2)	Flue-gas temperature
13:28	3.6	2.2	N.D	18.4	64.0	8.5	212
13:38	3.8	2.2	N.D	18.5	62.1	9.3	210
13:48	3.8	2.3	N.D	18.3	78.8	7.4	216
13:58	3.9	2.2	N.D	18.5	90.0	2.7	212
14:08	3.8	2.1	N.D	18.6	84.0	5.2	210
14:18	3.8	2.2	N.D	18.2	92.3	1.9	215
14:28	3.8	3.1	N.D	17.3	65.4	7.8	212
Average (1 hour)	3.8	2.3	N.D	18.3	76.6	6.1	212

Note：N.D. (<0.1%)

The air fuel ratio of the boiler is 1.12 and boiler efficiency is calculated to be 89.6%, based on the heat loss method described in the Chinese Taipei national standard for boiler, CNS 2141 B1025 (Calculation method of boiler efficiency for land use).

3. Economic Feasibility Study of Utilizing White-leadtree Pellets Instead of Fossil Fuel for Boiler Application

Before carrying out the economic feasibility study of utilizing white-leadtree pellets instead of fossil fuel for boiler application, a bio-pellet fuel manufacturing facility has to be chosen in order to decide the cost of building a bio-pellet plant. As described in Chapter 1, Review of the Recent Advances in Bio-pellet Technologies, there are mainly two kinds of bio-pellet fuel pelletizers, i.e. flat-die and ring-die pelletizers. Ring-die pelletizers can be further categorized into vertical-type and horizontal-type ones.

In Chapter 2, White-leadtree Pellet Production and Combustion in a Packaged Boiler, a horizontal-type ring-die pelletizer (Figure 2.22) is chosen to produce white-leadtree pellet and its feasibility has been proven. Therefore, the cost estimation of bio-pellet plant building in this chapter is also conducted based upon the use of the horizontal-type ring-die pelletizer.

White leadtree logs have to be sun dried properly after being cut down from the woods in order to reduce the moisture content. A shredder is then used to pulverize the logs into particles. These particles are sometimes difficult to be pelletized due to their high moisture content. Therefore, a dryer must be used to dehydrate the white leadtree particles to an appropriate extent before pelletization.

Pneumatic conveying dryer and rotary-kiln dryer are the most widely used particle drying equipment. The former is often used for fast drying of a smaller amount of wood particles (like the dryer used in Chapter 2). To dry wood particles in larger quantities, a rotary-kiln dryer is preferred. The economic feasibility assessment in this chapter is focused primarily on the mass production of white-leadtree pellet fuel. The cost estimation of plant building is thus based on the rotary-kiln dryer of choice.

3.1 White-leadtree pellet fuel

Since no bio-pellet fuel standard has been established in Chinese Taipei yet, the target moisture content of white-leadtree pellet to be produced is set at 12wt% by adopting the German DIN51731 standard (see Table 2.3 in Chapter 2). According to Table 2.2, the higher heating value (HHV) of white leadtree pellet fuel is 16.93MJ/kg at 7.16wt% moisture content. A conversion based on that will show that the heating value of white-leatree pellet fuel is 16.05MJ/kg at 12wt% moisture content.

To evaluate the production cost of white-leadtree pellet fuel, an estimation of the amount of moisture reduction for white-leadtree particles in the drying process must be carried out first. According to the analysis described in Chapter 2, the average moisture content of white-leadtree particles after drying and before pelletization is 16wt% and the moisture content after pelletization is 7.1wt% (see Table 2.2). It is learned from the pelletization experiences from Chapter 2 that the white leadtree particles will be further heated and dehydrated in the pelletizer so that a 20wt% moisture content in the particles is acceptable to successfully produce pellets with 12wt% moisture content, which is the German DIN standard to be met.

Based on the analysis in Chapter 2, the moisture content of white-leadtree particles after pulverization and before drying is 30wt%. The cost evaluation of dehydrating white-leadtree particles in the designed bio-pellet fuel plant is based on 30wt% and 20wt% of moisture content before and after dehydration, respectively. The heating value of white leadtree bio-pellet fuel produced is 16.05MJ/kg with 12wt% moisture content.

3.2 White-leadtree pellet fuel plant

A bio-pellet fuel plant can achieve higher economic benefits with a greater production capacity. To increase the output, a bio-pellet fuel plant can have more than one production line. In this chapter, one production line is used as the basis to conduct the economic feasibility study of white-leadtree pellet fuel plant. If the economic benefit of a plant with only one production line is satisfactory, it can still be further improved by adding more productions lines to increase the production capacity.

The production capacity of the bio-pellet fuel plant is planned based on the production capacity of a conventional bio-pellet fuel production line, which is three tons per hour. The plant operates with three teams of workers on two eight-hour shifts for 330 days per year. It produces 1,320 tons of bio-pellet fuel per month. The pellets are 8mm or 10mm in diameter, with 12wt% moisture content.

Figure 3.1 and Figure 3.2 show the flow diagram and equipment layout of one production line of a bio-pellet manufacturing plant. A typical bio-pellet production line is composed of the coarse shredding system, heating system, drying system, fine shredding system, pelletizing system, pellet cooling system and pellet packaging system. These facilities cost NT$ 30,500,000, which equals US$ 1,000,000 given an exchange rate of 1US$=NT$ 30.5.

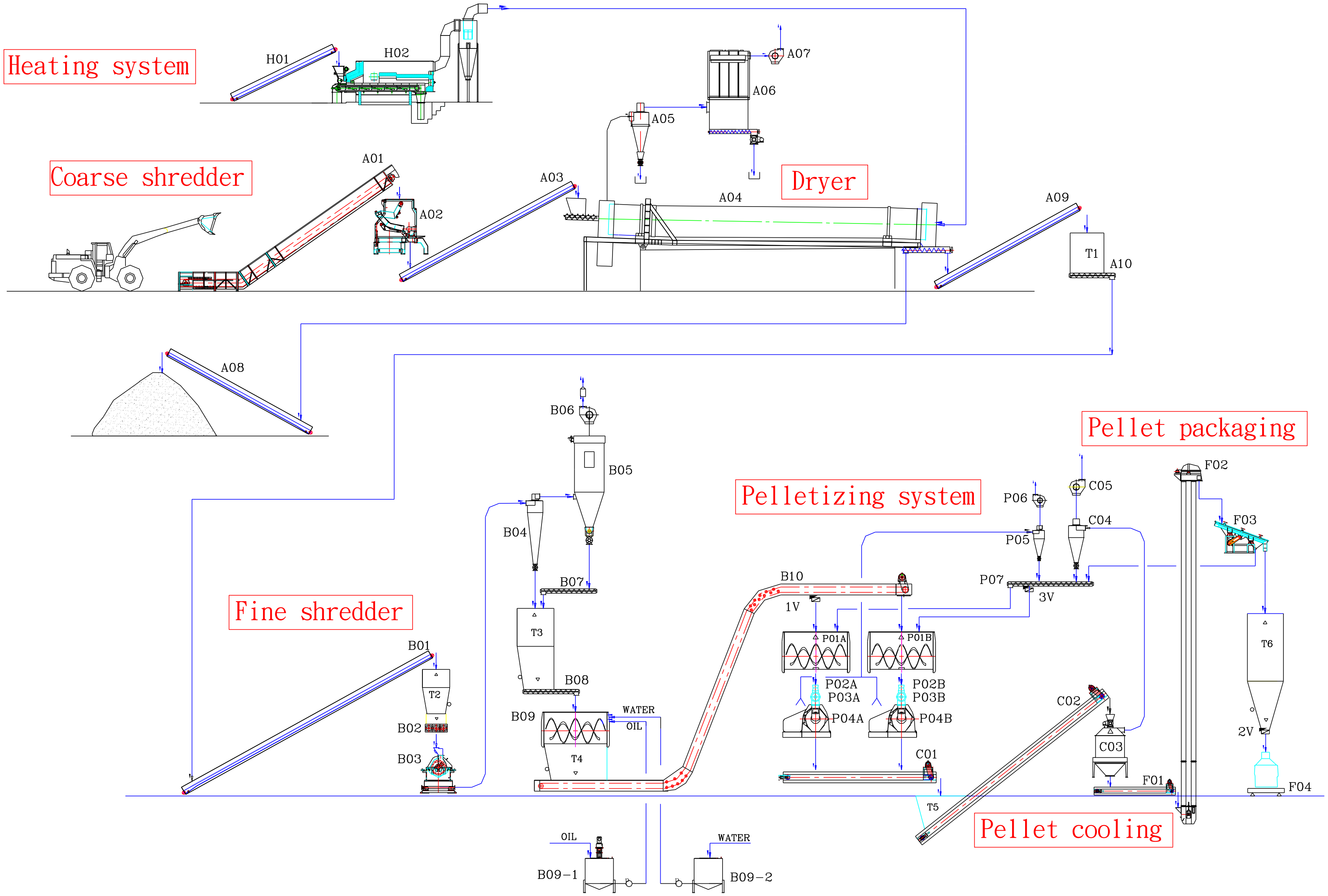


Figure 3.1 Flow diagram of a bio-pellet manufacturing plant

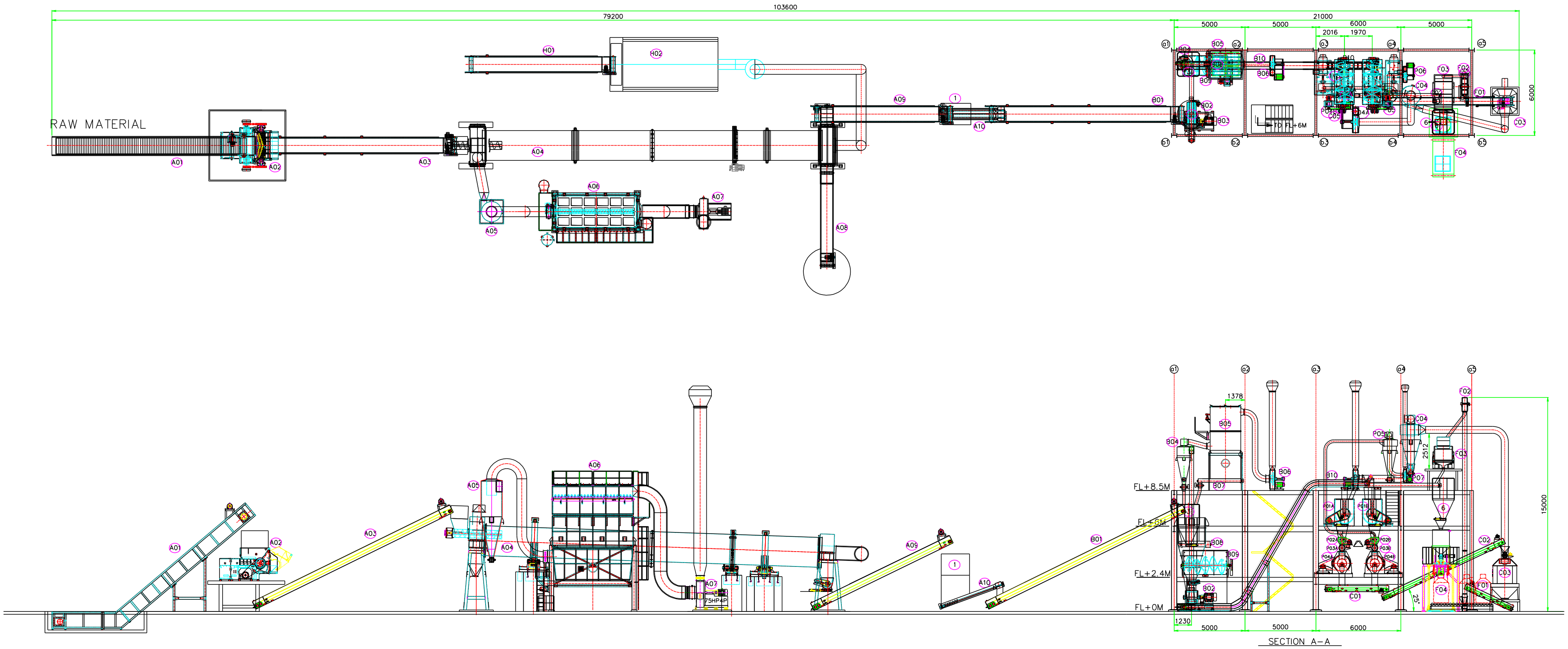


Figure 3.2 Layout and side view of a bio-pellet manufacturing plant

3.3 Business model of bio-pellet supply

As shown in Figure 3.3, the bio-pellet packaged boiler used by smallest and medium enterprises (SMEs) comprises a bio-pellet feeder, bio-pellet burner and boiler main body. To retrofit the fossil-fuel (*e.g.* natural gas, diesel and heavy fuel oil) fired boilers into a bio-pellet packaged boiler, a new bio-pellet feeder must be added and the original burner must also be replaced with a pellet burner in order for the boiler to work. The main body of the boiler can still be used so that the cost of equipment change can be reduced.

Figure 3.3 Bio-pellet packaged boiler

If the SMEs boiler users have a high demand for bio-pellet fuel and are willing to sign long-term contracts (over three years) with the bio-pellet fuel suppliers, it will give the deal-seeking suppliers incentives to absorb the extra costs resulting from replacing the bio-pellet burner and adding a pellet feeder, which means that the costs will be in turn included into the selling price of bio-pellet fuel. For the costs of plant building, in addition to the costs of the plant and bio-pellet fuel production equipment, the economic feasibility study in this chapter must also take into consideration the costs of the bio-pellet feeder and burner. Take the 7.2-ton steam boiler used in Chapter 2 for example, the bio-pellet feeder and burner cost about US$ 42,000 (NT$ 1,280,000). The actual total costs will be calculated based on how many feeders and burners are needed to consume the 1,320 tons of bio-pellet fuel per month.

3.4 The cost of white-leadtree feedstock

The white leadtree is a competitive and invasive species. The costs of acquiring white-leadtree feedstock start from cutting/harvesting, collection and transportation. There are two types of prices available when white-leadtree feedstock is bought by a bio-pellet plant. Normally the price of white-leadtree feedstock includes the costs of cutting, collecting to log yard for sun drying and another 30 km delivery to the bio-pellet fuel plant. The first type of white-leadtree price includes only the costs of collection and transportation but not cutting. Because the white-leadtree trees are invasive species and mix with the local high-value trees, to harvest the high-value trees the white leadtree tress must be eradicated. Cost of cutting white-leadtree trees is included in the cost of harvesting the high-value trees. The purchase price of this type of white-leadtree feedstock is 22.95US$/ton (700NT$/ton). The other type of purchase price is 75.41US$/ton (2,300NT$/ton), which includes the costs of cutting, collection and transportation since they are not passed on to other activities.

The bio-pellet plant is planned based on the production capacity of three tons per hour. The plant operates with three teams of workers on two eight-hour shifts for 330 days per year. The white-leadtree particles are dried so that the moisture content can decrease from 30wt% to 20wt%. The plant is capable of producing 1,320 tons of bio-pellet fuel per month. The pellets produced are 10 mm in diameter, with 12wt% moisture content.

The following three cases are evaluated in the economic feasibility study of white-leadtree pellet fuel. In cases 1 and 2, the purchase price of white-leadtree feedstock is 22.95US$/ton (700NT$/ton) and 75.41US$/ton (2,300NT$/ton), respectively, and the moisture content is 30wt%. A win-win strategy is proposed in case 3. The cost estimations of plant building and the respective economic benefits of the three cases are discussed below.

3.5 Case 1 (white-leadtree feedstock of 22.95US$/ton)

In this case, the purchase price of white-leadtree feedstock is 22.95US$/ton (700NT$/ton) and moisture content is 30wt%. The annual amount of white-leadtree feedstock required by a bio-pellet plant that is capable of producing 1,320 tons of bio-pellet fuel per month is calculated as shown in Table 3.1.

Table 3.1 Annual feedstock and production yield of white-leadtree pellet plant

	Item	value	Remark
1	Facility operating day	330day/year	Daily operating time 16 hours
2	Feedstock required	19,913ton/year	Moisture content 30wt%
3	Bio-pellet yield	15,840ton/year	Bio-pellet yield 1,320 ton/month

Table 3.2 lists the costs of facility and white-leadtree pellet plant, plus the total costs of pellet feeder and burner. The costs of facility and pellet plant are US$ 1,000,000 (NT$ 30,500,000) and US$ 133,115 (NT$ 4,060,000) respectively. As described earlier in section 3.4, the bio-pellet fuel supplier is responsible for the cost of refitting the natural gas fired boiler, i.e. adding pellet feeder and burner. Table 3.1 also estimates how many 7.2-ton steam boilers can be fired by the bio-pellet fuel of 15,840ton/year and thus the total costs of pellet feeders and burners can be calculated. It is assumed that 60% of the total cost of facility, plant, pellet feeder/burner is paid with a loan from the bank with an annual interest rate of 2%.

Table 3.2 Costs of facility and others of white-leadtree pellet plant

	Item	Cost (NT$)	Remark
1	Facility	30,500,000	As the facility shown in Figure 3.1
2	Plant	4,083,750	Plant area 15m x 45m，construction fee NT$ 6,050/m^2
3	Pellet feeder/burner	2,393,600	Plant pellet production provides 1.87 sets of pellet boiler consumption annually
4	Interest	443,728/year	items (1+2+3) x loan 60% x 2% interest rate
5	Feedstock	13,939,100/year	Moisture content 30wt%
6	Fuel for drying feedstock	520,100/year	Chain stocker, wood fuel 743 ton/year, NT$ 700/ton
7	Electricity	7,392,000/year	Electricity consumption 400 kW, NT$ 3.5/kWh
8	Water	0	No water consumption

Labor cost is shown in Table 3.3. One plant manager and six operators (three teams of operators, two operators for each shift, two eight-hour shifts in a day) are needed.

Table 3.3 Employee salaries of white-leadtree pellet plant

	Item	Staff	NT$/month/staff	NT$/year	Remark
1	Plant manager	1	50,000	700,000	Annual salary 14 months
2	Operators	6	30,000	2,520,000	3 teams for 2 shifts (2 operators per team), annual salary 14 months
	Total			3,220,000	

Table 3.4 shows the calculation of the per-ton production cost of white-leadtree pellet fuel. The cost includes feedstock, utility, labor, maintenance, insurance and taxes, overhead, etc. The production cost of white-leadtree pellet is 59.54US$/ton (1,816 NT$/ton) based on 22.95US$/ton (700NT$/ton) purchase price of white-leadtree feedstock and 20 years of operating period of the plant. The total cost of the plant is the sum of the costs of bio-pellet manufacturing facility, plant and pellet feeder/burner. Maintenance and insurance/tax account for 2% and 1.5%, respectively, of the total cost of the plant. Overhead is 20% of labor cost.

Table 3.4 Production cost of white-leadtree pellet plant (case 1)

Item	Consumption		Consumption of pellet per kg	Unit cost (NT$)	Cost per year (NT$/year)	Cost of pellet per ton (NT$/ton)
Raw materials		3,771.4 kg/h	1.257 kg/kg	700/ton	13,939,094	880
Utility	water & chemicals	0 ton/h	0 kg/kg	10/ton	0	0
	wood fuel for heating	140.7 kg/h	4,030 kcal/kg	700/ton	520,101	33
	electricity	400.0 kw	0.133 kWh/kg	3.5/kwh	7,392,000	467
	waste water	0 kg/h	0 kg/kg	10/ton	0	0
	solid waste	0 kg/h	0 ton/kg	8,000/ton	0	0
Variable operating cost					21,851,196	
Labor	Table 3.3				3,220,000	203
Maintenance	2% of cost of facility, plant, pellet feeder/burner in Table 3.2				739,545	47
Insurance & tax	1.5% of cost of facility, plant, pellet feeder/burner in Table 3.2				554,660	35
Overhead	20% of labor cost				644,000	41
Fixed operating cost					5,158,207	
Total operating cost					27,009,403	1,705
Annual plant cost	Plant operation 20 years				1,760,826	111
Total investment					28,770,229	1,816

The bio-pellet plant is planned based on the production capacity of three tons per hour. The purchase price of white leadtree feedstock is 22.95US$/ton (700NT$/ton). As shown in Figure 3.4, the components of production cost and their respective ratios are: bio-fuel feedstock 48.4%, electricity 25.7%, labor 11.2%, annual plant cost 6.1%, maintenance 2.6%, overhead 2.2%, insurance and tax 1.9%, heating fuel 1.8%. Of them, the cost of white-leadtree feedstock is the largest component of the total cost.

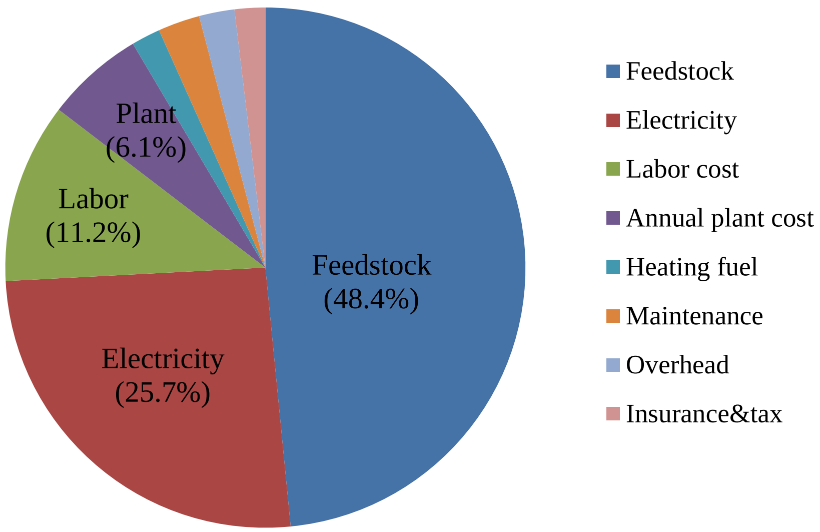


Figure 3.4 Production cost ratio of white-leadtree pellet (case 1)

The white leadtree used to produce bio-pellet fuel has a 30% moisture content. Table 3.5 shows the calculation of discounted cash flow method based on the assumption of 15% of internal rate of return (IRR), where discount factor $1/(1+IRR)^n$ at the n^{th} year. 60% of the total cost of facility, plant, pellet/burner is paid with a loan from the bank with an annual interest rate of 2%. The plant is expected to operate for 20 years. The 10-year straight-line accelerated depreciation method is used to calculate the value of the plant. Sales tax rate (VAT) is 17%. Based on the figures above, the selling price of white-leadtree pellet fuel is set at 77.38US$/ton (2,360NT$/ton).

Table 3.5 Discounted cash flow of sale of white-leadtree pellet (case 1)

Year	Sale of pellet (NT$)	Factory depreciation	Operating cost (NT$)	Loan interest	Pre-tax income (NT$)	Sales tax (17%)	Net income after tax (NT$)	Discount Factor	Net present value (NT$)
1	37,382,400	3,361,577	27,009,403	443,728	6,567,692	1,116,508	5,451,184	0.8696	4,740,160
2	37,382,400	3,361,577	27,009,403	443,728	6,567,692	1,116,508	5,451,184	0.7561	4,121,878
3	37,382,400	3,361,577	27,009,403	443,728	6,567,692	1,116,508	5,451,184	0.6575	3,584,242
4	37,382,400	3,361,577	27,009,403	443,728	6,567,692	1,116,508	5,451,184	0.5718	3,116,732
5	37,382,400	3,361,577	27,009,403	443,728	6,567,692	1,116,508	5,451,184	0.4972	2,710,202
6	37,382,400	3,361,577	27,009,403	443,728	6,567,692	1,116,508	5,451,184	0.4323	2,356,697
7	37,382,400	3,361,577	27,009,403	443,728	6,567,692	1,116,508	5,451,184	0.3759	2,049,302
8	37,382,400	3,361,577	27,009,403	443,728	6,567,692	1,116,508	5,451,184	0.3269	1,782,002
9	37,382,400	3,361,577	27,009,403	443,728	6,567,692	1,116,508	5,451,184	0.2843	1,549,567
10	37,382,400	3,361,577	27,009,403	443,728	6,567,692	1,116,508	5,451,184	0.2472	1,347,449
11	37,382,400	3,361,577	27,009,403	443,728	6,567,692	1,116,508	5,451,184	0.2149	1,171,695
12	37,382,400		27,009,403	443,728	9,929,269	1,687,976	8,241,293	0.1869	1,540,357
13	37,382,400		27,009,403	443,728	9,929,269	1,687,976	8,241,293	0.1625	1,339,441
14	37,382,400		27,009,403	443,728	9,929,269	1,687,976	8,241,293	0.1413	1,164,731
15	37,382,400		27,009,403	443,728	9,929,269	1,687,976	8,241,293	0.1229	1,012,809
16	37,382,400		27,009,403	443,728	9,929,269	1,687,976	8,241,293	0.1069	880,704
17	37,382,400		27,009,403	443,728	9,929,269	1,687,976	8,241,293	0.0929	765,829
18	37,382,400		27,009,403	443,728	9,929,269	1,687,976	8,241,293	0.0808	665,939
19	37,382,400		27,009,403	443,728	9,929,269	1,687,976	8,241,293	0.0703	579,077
20	37,382,400		27,009,403	443,728	9,929,269	1,687,976	8,241,293	0.0611	503,545
Total			540,188,055	8,874,564	161,608,031	27,473,365	134,134,665		36,982,359

In Chapter 2, White-leadtree Pellet Production and Combustion in a Packaged Boiler, the burning test is carried out with the boiler fired with white-leadtree pellet fuel instead of natural gas. In this section, the prices of natural gas and pellet fuel will be compared and the expected maximum selling price of white leadtree pellet fuel is calculated.

The heating value of natural gas is 37.8 MJ/m^3 [55] and the selling price of natural gas for industrial use in Chinese Taipei is 0.3725US$/$m^3$ (11.3602NT$/$m^3$) [56]. Based on the heating value and selling price of natural gas, the heating value of natural gas 1 US$ can buy can be calculated. Assume the heating value of white-leadtree pellet fuel 1 US$ can buy is the same as that of natural gas. The heating value of the white-leadtree pellet fuel is 16.05MJ/kg (moisture content 12wt%) and we can therefore calculate the equivalent pellet price (EPP) of white-leadtree pellet fuel. That is, in order to replace natural gas, white-leadtree pellet fuel must have the maximum selling price no greater than EPP, otherwise white-leadtree pellet fuel has no competition with natural gas. Figure 3.5 shows that the EPP of white-leadtree pellet fuel can be acquired from the various selling prices of natural gas. The red dotted line indicates that when the selling price of natural gas is 0.3725US$/$m^3$ (11.3602NT$/$m^3$), the EPP of white-leadtree pellet fuel is 159.41 US$/ton (4,862 NT$/ton).

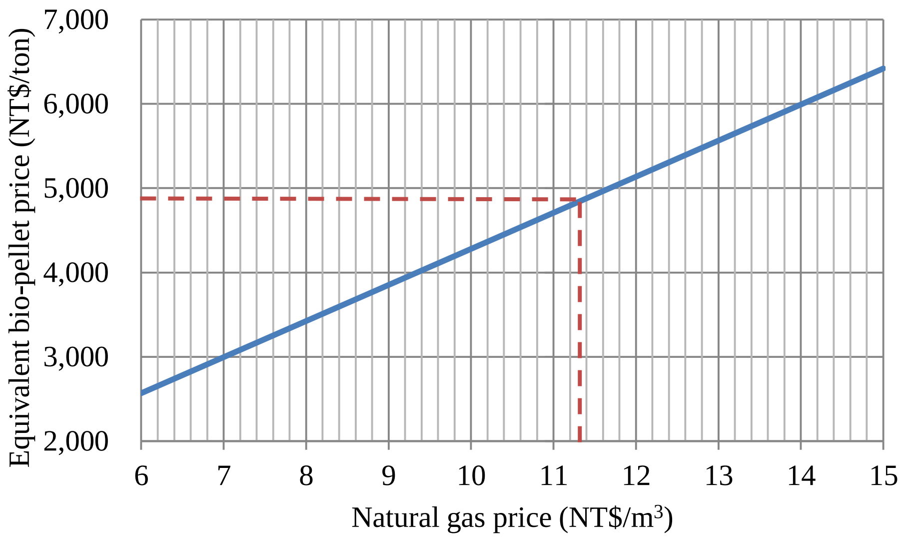


Figure 3.5 Equivalent bio-pellet price vs. natural gas price

The selling price of the white-leadtree pellet fuel is set at 77.38US$/ton (2,360NT$/ton) based on the following conditions: 22.95US$/ton (700NT$/ton) purchase price of white-leadtree feedstock, 20 years of operating period of the plant, 10-year straight-line accelerated depreciation of the plant, VAT (sale tax rate) of 17%, a loan of 60% of the total cost of facility, plant and pellet feeder/burner and IRR=15%. Compared to Figure 3.5, the selling price is lower than the EPP of white-leadtree pellet, which is 159.41 US$/ton (4,862 NT$/ton). In other words, under the premise that the heating value of the fuel 1 US$ can buy is the same, the selling price of white-leadtree pellet is more competitive than that of natural gas, which is 0.3725US$/m^3 (11.3602NT$/m^3).

When the maximum selling price of white-leadtree pellet fuel is set at EPP of 159.41 US$/ton (4,862NT$/ton), the maximum allowed purchase price of white-leadtree feedstock is estimated based on the following conditions: 20 years of operating period of the plant, 10-year straight-line accelerated depreciation of the plant, VAT of 17%, a loan of 60% of the total cost of facility, plant and pellet feeder/burner and IRR=15%. As shown in Figure 3.6, the maximum allowed purchase price of white-leadtree feedstock is 85.836US$/ton (2,618NT$/ton) and the red dotted line represents the EPP of white-leadtree pellet fuel. That is, as long as the purchase price of white-leadtree feedstock is lower than 85.836US$/ton, the selling price of white-leadtree pellet fuel produced is more competitive compared to that of natural gas, which is 0.3725US$/m^3 (11.3602NT$/m3).

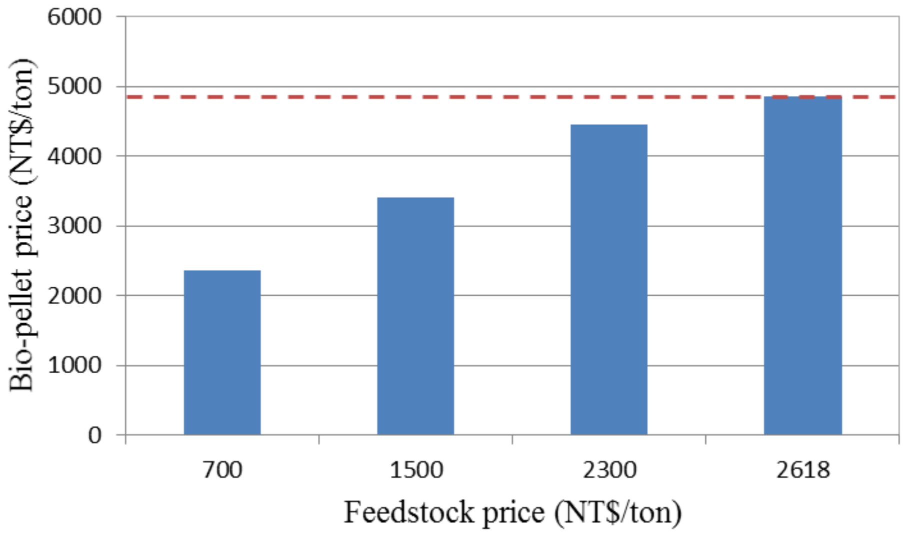


Figure 3.6 Analysis of feedstock price vs. bio-pellet selling price

3.6 Case 2 (white-leadtree feedstock of 75.41US$/ton)

The purchase price of white-leadtree feedstock is increased greatly from 22.95US$/ton (700NT$/ton) to 75.41US$/ton (2,300NT$/ton) when the price, in addition to the costs of collection and transportation, also includes the cost of cutting of white-leadtree trees.

Figure 3.6 indicates that as long as the purchase price of white-leadtree feedstock is kept under 85.836US$/ton (2,618NT$/ton), the selling price of white-leadtree pellet fuel is relatively competitive compared to that of natural gas. The estimation of the production cost and selling price of white leadtree pellet fuel is presented below.

The purchase price of white-leadtree feedstock with a 30% moisture content is 75.41US$ (2,300NT$/ton). The plant is expected to operate for 20 years. Based on the figures above, the production cost of white-leadtree pellet fuel is 127.97US$/ton (3,903 NT$/ton) by the calculation shown in Table 3.6.

Table 3.6 Production cost of white-leadtree pellet plant (case 2)

Item	Consumption		Consumption of pellet per kg	Unit cost (NT$)	Cost per year (NT$/year)	Cost of pellet per ton (NT$/ton)
Raw materials		3,771.4 kg/h	1.257 kg/kg	2,300/ton	45,799,882	2,891
Utility	water & chemicals	0 ton/h	0 kg/kg	10/ton	0	0
	wood fuel for heating	140.7 kg/h	4,030 kcal/kg	2,300/ton	1,708,904	108
	electricity	400.0 kw	0.133 kWh/kg	3.5/kwh	7,392,000	467
	waste water	0 kg/h	0 kg/kg	10/ton	0	0
	solid waste	0 kg/h	0 ton/kg	8,000/ton	0	0
Variable operating cost					54,900,785	
Labor	Table 3.3				3,220,000	203
Maintenance	2% of cost of facility, plant, pellet feeder/burner in Table 3.2				739,547	47
Insurance & tax	1.5% of cost of facility, plant, pellet feeder/burner in Table 3.2				554,660	35
Overhead	20% of labor cost				644,000	41
Fixed operating cost					5,158,207	
Total operating cost					60,058,993	3,792
Annual plant cost	Plant operation 20 years				1,760,826	111
Total investment					61,819,819	3,903

The purchase price of white-leadtree feedstock is 75.41US$ (2,300NT$/ton). As shown in Figure 3.7, the components of the total production cost and respective ratios are: bio-fuel feedstock 74.1%, electricity 12.0%, labor 5.2%, annual plant cost 2.8%, heating fuel 2.8%, maintenance 1.2%, overhead 1.0%, insurance and tax 0.9%. Of them, the cost of bio-pellet feedstock is still the largest component of the total cost.

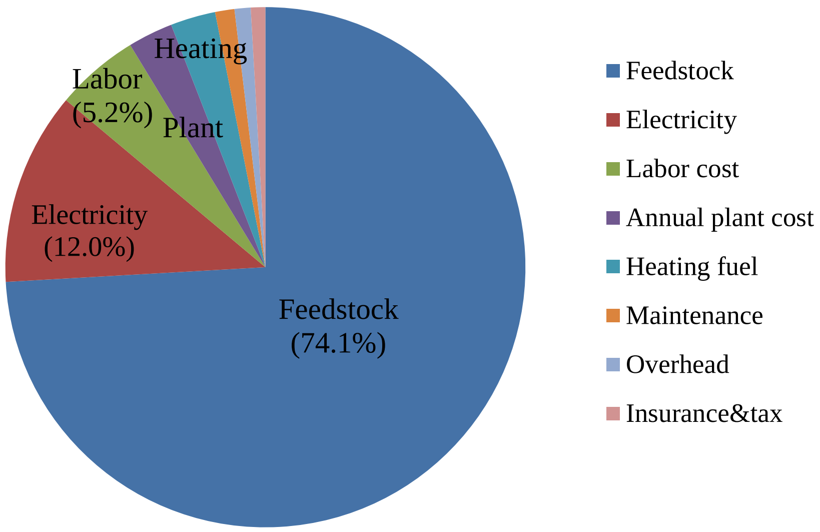


Figure 3.7 Production cost ratio of white-leadtree pellet (case 2)

The purchase price of white-leadtree feedstock is 75.41US$ (2,300NT$/ton). The plant is expected to operate for 20 years. The 10-year straight-line accelerated depreciation method is used to calculate the value of the plant. VAT is 17%. 60% of the total costs of facility, plant, pellet feeder/burner is paid with a loan from the bank. Based on the figures above and under the premise of IRR=15%, the selling price of white-leadtree pellet fuel is 145.8US$/ton (4,447NT$/ton) by calculation.

When the purchase price of white-leadtree feedstock is 75.41US$ (2,300NT$/ton), the selling price of white-leadtree pellet fuel is 145.8US$/ton (4,447NT$/ton), which is still lower than the EPP of 159.41US$/ton (4,862NT$/ton). Compared to the EPP, the selling price of white-leadtree pellet fuel is still competitive.

3.7 Case 3 (a win-win strategy)

Different purchase prices of white-leadtree feedstock are used for analysis in cases 1 and 2. In case 1, only the collection and transportation costs are included. The costs of cutting, collection and transportation are calculated in Case 2. The analysis results indicate that, under the premise of IRR=15% for the bio-pellet plant, the prices of white-leadtree pellet fuel in two cases are both lower than the EPP. That is, the manufacture and selling of white-leadtree pellet fuel in both cases are more competitive than selling the natural gas for packaged boiler end users of SMEs.

The competitiveness of operation of white-leadtree pellet plant is also analyzed in the above two cases. However, whether the boiler end users of SMEs can improve their competitiveness by using white-leadtree pellet fuel instead of natural gas in a packaged boiler remains to be further explored. In the next section, we will propose and analyze a win-win strategy for both white-leadtree pellet manufacturers and boiler end users of SMEs that use white-leadtree pellet fuel for packaged boilers.

Under the premise of EPP, we assume that the selling price of white-leadtree pellet fuel is only 90% of EPP, i.e., 90% of that of natural gas with equivalent heating value. In other words, boiler end users of SMEs can save 10% in the cost of fuel if they use white-leadtree pellet fuel instead of natural gas for a packaged boiler.

Further analysis is carried out on the profit that the white-leadtree pellet plant can make. When the purchase price of white-leadtree feedstock is 75.41US$ (2,300NT$/ton), the production cost of white leadtree pellet fuel is 127.97US$/ton (3,903 NT$/ton), as shown in Table 3.6 for case 2. Under the premise of EPP, it is assumed that the selling price of white-leadtree pellet fuel is 90% of EPP, which is 143.47US$/ton (4,376NT$/ton). Under the premise that the selling price of white-leadtree pellet fuel is 143.47US$/ton and based on the following assumptions: 20 years of operating period of the plant, 10-year straight-line accelerated depreciation of the plant, VAT of 17%, and a loan of 60% of the total cost of facility, plant and pellet feeder/burner, the IRR of running a white-leadtree pellet fuel production plant is 12.4% by calculation.

The analysis results presented above demonstrate that boiler end users of SMEs can save 10% in the cost of fuel and hence increase their competitiveness by using white-leadtree pellet fuel instead of natural gas for packaged boilers. On the other hand, although the white-leadtree pellet fuel manufacturers generate lower profits by selling the pellet fuel at the price of 90% of EPP, they still enjoy a decent 12.4% IRR. From the perspective of white-leadtree pellet fuel manufacturers, this is a win-win strategy thanks to higher sales volume and greater market share in return.

4. APEC Workshop on Bio-pellet Production, Handling and Energy Utilization

The world energy supply is facing a diverse and broad set of challenges. Owing to the development of industrial civilization and the rapid increase in population, the fossil fuel reserves on earth have been consumed rapidly. The over-reliance on the use of fossil fuels has led to environmental pollution and also global climate change. Concerns over climate change related to carbon emissions are not only affecting governmental policies and strategies but also being a great challenge for APEC, a region with 41 percent of the world's population. We believe that charting new pathways for utilization of clean and sustainable energy is the great aspiration for us.

Bio-pellets are sustainable bio-fuels which can be categorized into white pellet (pelletized from biomass) and black pellet (pelletized from torrefied biomass), both having the characteristics of being "carbon neutral" and clean combustion that they are effective alternatives to replace the fossil fuels in industrial combustion and power plant applications.

Based on the above concerns, an APEC Workshop on Bio-pellet Production, Handling and Energy Utilization was held in Tokyo, Japan on 24-25 October, 2017. More than 68 bio-pellet scientists and engineers from 11 APEC member economies (The United States; Chinese Taipei; Japan; Korea; China; Thailand; Russia; The Philippines; Malaysia; Indonesia; Viet Nam) and 1 non-APEC economy (The Netherlands), representing academia, industry, and government agencies, gathered in Tokyo to discuss the bio-pellet technologies and applications (Figure 4.1). The substantial interest in this workshop, evidenced by the diversity of participants, demonstrates the vital importance of this topic to APEC member economies.

Figure 4.1 APEC workshop on bio-pellet production, handling and energy utilization

The objective of the workshop is to articulate the suggested bio-pellets trade and the critical role that bio-pellets can substitute fossil fuels for energy applications, especially in the coal-fired power plants, to reduce the carbon dioxide emissions. The workshop agenda is attached in Appendix B. For readers who are interested in the presentation materials of the workshop, the presentation slides can be found at the website http://biopelletworkshop.itri.org.tw/index.html .

Several issues and comments concerning the bio-pellet technologies and applications over the presentations and panel discussions in the workshop had been raised up. The main issues and comments on bio-pellet technologies and applications are summarized as follows:

4.1 Demonstration and economic feasibility study of utilizing white-leadtree pellet instead of fossil fuel for boiler application

The use of an invasive species suggests that as an area is cleared, the project will have to reach increasing distances to get feedstock into the pellet plant. How will the pellet plant control feedstock costs over its lifetime?

- The white-leadtree plants are invasive species, they grow and mix with local high-value trees in the mountain. To harvest the local high-value trees, the white leadtree must be eradicated. The white leadtree is a “by-product” of harvesting the local high-value trees. So the values of these local high-value trees with high margin can compensate the increased cost of white leadtree because of increasing distances to get feedstock.
- The estimated costs of white-leadtree feedstock are in between 23US$/ton (includes collection and transportation) and 75.4US$/ton (includes cutting, collection and transportation). In average, the cost of white-leadtree feedstock is 49.2US$/ton. The estimated selling price of white-leadtree pellet is 115 US$/ton based on the averaged feedstock cost, which is much lower than the EPP (Equivalent Pellet Price) of 159.41US$/ton. This indicates that there are still a large cost margin to get feedstock in increasing distances.

The transport cost will increase as the area near the pellet plant is cleared and more distant sources must be procured. Is this potential for increasing delivered cost incorporated into the financial model?

- Yes, the delivered cost will increase. Same answer is replied in above question.

The chlorine levels in the analysis of white-leadtree pellets are 0.17%. The standard for most industrial or heating pellets is a maximum of 0.03%. What is the expected strategy for having white-leadtree pellets accepted and used?

- The wood-pellet applications can be divided into two aspects of household applications and industrial applications. The household usages on premium heating pellets require high-quality pellet due to no air pollution devices used in typical home usage. The bio-pellet made from white leadtree is not suitable for household application because of high ash content and chlorine level.
- However the white-leadtree pellets are applicable to industrial packaged boilers or power plants because most of the packaged boilers or power plants equipped with cyclones or scrubbers can lower the ash and chlorine emission. In this study, the test of white-leadtree pellet in a packaged boiler of SMEs indicates the emissions of white-leadtree pellet meet air pollution standard in Chinese Taipei.

What are the efficiency assumptions for the natural gas burner and the pellet burner?

- The typical efficiency of packaged boiler fired with natural gas is around 90~92%. We measured the packaged boiler fired with white-leadtree pellet, the boiler efficiency is 89.6% which is not bad for solid fuel.

Please discuss how policy can support this interesting strategy.

- In Chinese Taipei, the selling price of white-leadtree pellet is low as compared with other wood pellet. No policy subsidy is required to support application of white-leadtree pellet. However, the white leadtree is an invasive species and growing of white leadtree is not allowable. When all white-leadtree plants are eradicated, the bio-pellets made from local wood feedstocks may require governmental subsidy to enhance bio-pellet usage.

4.2 Biomass co-firing and black pellets applications

What are the assumed cost per gigajoule for the delivered black (torrefied) pellets? Compare that to white pellets?

- The production costs of black pellets per gigajoule are probably 10-15% higher in comparison with white wood pellets. The volumetric energy density of black pellets is roughly 30-40% higher than white wood pellets, which makes logistics and transport much more efficient.
- The EU SECTOR project demonstrated that when the torrefaction plant is large enough (more than 100,000 tons per year) and the transportation distance is more than 800 kilometers, black pellets will outperform white pellets financially at the power plant gate (on a per gigajoule basis). The benefits for the power plant owner were not yet accounted for in this calculation (using the existing coal handling and combustion infrastructure for black pellets versus the

investments needed for dedicated infrastructure to be able to co-fire white wood pellets in shares larger than 5%).

What government policies support co-firing in the Netherlands? What form is the monetary support for pellets versus coal?

- In the Netherlands a feed-in premium is used to support biomass co-firing in pulverized coal-fired power stations. These feed-in premiums are awarded in a competitive tender together with a multitude of other renewable energy technologies. The maximum support at the moment amounts approximately 7 eurocent per kWh for biomass co-firing, on top of the base load electricity price of roughly 4 eurocent per kWh.

What are the Dutch policies on assuring that the pellets are produced sustainably?

- Biomass used must lead to substantial reduction in GHG across value chain in comparison with fossil fuels (minimum reduction of 70%, maximum emission 56g CO_2eq/MJ).
- Furthermore, the soil quality must be maintained and where possible improved, the production of raw biomass may not result in destruction of carbon sinks, the use of biomass may not result in a long-term carbon debt or Indirect Land Use Change (ILUC), a Chain of Custody (CoC) must be in place that covers the entire value chain and several requirements are imposed on the certification systems.

4.3 Steam-based biomass gasification processes for syngas and hydrogen production

How are tar and particulate build-ups removed from the system and how frequently in blue-tower gasifier?

- In previous demo-plant test at initial stage, a tar content of 120mg/Nm^3 and a dust of 140mg/Nm^3 were measured. The tar generated depends upon the inner temperature in the vessel, and/or the ambient condition, especially the steam content.
- The blue-tower gasifier is consisted of a pre-heater, a reformer and a pyrolyzer. Each vessel is completely isolated and tar and/or particulates in decomposed syngas might not be difficult to move to the next vessel. Due to heat exchange, the alumina ball of heat carrier is circulated in each vessel. The heat carriers are likely to have a function of tar removal. Probably, a part of particulates in syngas can be removed in use of filter.

Given the composition of the impurities, how can they be disposed of and is there a cost estimate for that?

- In our study, HCl is expected to be removed as $CaCl_2$ which might be available for a snow melting agent. H_2S is a toxic gas and some kinds of techniques, e.g. processing of dissolution of H_2S in water would be necessary. Unfortunately, so far, no cost estimation has been conducted.

Is there a market for hydrogen or is it expected to be consumed on a co-located energy plant?

- The vehicle manufacturers focus on the FCV besides EV. They have a great concern of eco-benefit based on LCA. That is, from what resources can the hydrogen be produced? For instance, in EU countries, the electrolysis of water would be promising, if the power source from renewables, e.g. PV, wind etc. is available. Of course, biomass is promising because biomass is sustainable.
- In several fields besides FCV application, there are many potentials to promote FC batteries, e.g. in drones and mobile phones. These devices with Li-ion battery have a common problem of short duration time against increased functions. In our recent project of drone with FC battery, the reduction of battery weight in consideration of much capability of H2 is proposed. The increased pay load and long transportation of drone are expected.

Will this process be competitive with alternative energy sources? What changes in the external environment are needed to make this more competitive?

- The selling price of H_2 from H_2 station is approximate 110JPY/Nm3 in Japan. The necessary business model or countermeasure by which more beneficial value or environmental concern has to be considered. LCA defied by ISO 14040 and 14044 is extremely significant. For the sake, because of eco-burden the subsidy and/or the regulation would be effective. Or, a business model of hydrogen used in high-value added product would survive the hydrogen suppliers in the market.

4.4 Technical bottle-necks for SOFC operation in conjunction with biomass gasification

Given the negative impacts on the SOFC performance of the constituents of coal syngas, is it expected that biomass syngas would be better or worse?

- As possible expectations concerning the effects of trace contaminants in solid feedstocks (e.g. coal, biomass, wastes), the chemical impacts on SOFC anode performance in the case of coal syngas injection will be the worse and most complicated, much rather than the case of biomass-derived syngas (e.g. syngas derived from woody biomass).

- However, in the case of biomass gasification, as pointed out in the recent review paper (Renewable and Sustainable Energy Reviews (2016), 53, 1356-1376), the biomass-derived syngas could contain several trace compounds which are very much like the case of coal-derived syngas. Particularly, the systematic investigation about the impact of condensable hydrocarbons (tar) would be very crucial for SOFC operation fueled by biomass-derived syngas because tar is a major contaminant in the gas produced at relatively intermediate gasification temperatures and trace level aromatics can cause carbon deposition in SOFC anode, depending on the kind of feedstock, though. In any case, an advanced, cost-effective, environmentally-friendly gas conditioning process is very important subject to realize the SOFC-biomass gasification integrated system.

Please explain the net efficiency and expected ability to run continuously of the integrated gasification fuel cell power plant.

- One of the good information available for the public is on-line energy information provided by Kyushu-University at http://energy-info.kyushu-u.ac.jp/#/.
- The performance as well as durability of 250kW-SOFC-GT combined system, developed by Mitsubishi-Hitachi Power Systems Ltd., have been going on since 2014 in Fukuoka, Japan. They have achieved stable efficiency of 55% (from city gas to power, HHV) and have long-term operation in Kyushu University to ensure the operability and reliability. Thus, the RD&D of SOFC system is now in the first stage for the system reliability and applicability. Once proven, this sort of system will move to the next stage about the diversification of feedstock for SOFC.

4.5 Bio-pellet production, handling and energy utilization in China

Typically for straw pellets chlorine is high and for rice straw pellets silica is high. How are those issues expected to be dealt with for boilers using these as fuel?

- In China, straws are hardly used to produce pellets with diameters of 8-10mm. Some straw pellets with diameters of 25-32mm are used in small chain-grate boiler with capacity of 4 tons steam per hour. Straws with high chlorine and silica contents cannot be used in large-scale industrial boilers due to high ash content and low calorific value of straws, and furnace operation problems of slagging and corrosion.

Agricultural feedstocks are seasonal. How will this strategy deal with feedstock supply given that crops are harvested only periodically?

- The storage and transportation of biomass briquettes and pellets are convenient due to their high density, compact size, and low moisture content. On the other hand, a variety of raw materials is available for different seasons and can be used to produce briquettes and pellets. The factories can make a certain amount of briquettes and pellets for storage, and then gradually supply to end users. Due to these advantages, pellets can be produced and stored during summer and autumn times, then be used as a district heating fuel in cold winter.

The potential for the use of bio-pellets and briquettes in China is very big. Please explain how the current 5-year plan supports the growth of this market.

- During the 12th Five-Year Plan Period (2011-2015), Chinese government promoted the development of bio-pellet supply chain from bio-pellet productions to bio-pellet applications, such as applications on industrial boilers, hot air drying of foodstuffs and agricultural products, heating of plant greenhouse, which resulted in rapid growth of bio-pellet demands.
- In the current 13th Five-Year Plan Period (2016-2020), Chinese government focuses on controlling air pollutions and raises boiler emission standard. The bio-pellet-fired boilers have to meet the emission standard of natural-gas-fired boiler. With the technology developments and support from Chinese government, the bio-pellet market will increase rapidly: (1) Encourage renewable energy and conduct the financial subsidy policy on straw biofuel. (2) Promote integrated technologies on bio-pellet application, e.g. combined bio-pellet gasification and combustion to meet the air pollution standard. (3) Conduct transformation subsidy policy for boiler makers to meet air pollution standard.

4.6 Recommendations and action plan for bio-pellet production, handling and energy utilization

Several issues and comments concerning the bio-pellet applications over the presentations and discussions in the workshop had been raised up. The main recommendations on bio-pellet applications are summarized as follows:

- Government measures that would provide a more balanced fiscal environment for the promotion of bio-pellets and other sources of renewable energy versus traditional fossil fuels.
- The removal of subsidies for fossil fuels, especially subsidies for coal mining and crude oil production.
- Developing an inventory of feedstock availability and development, including forest products, agricultural residues and waste products. There was abundant feedstock but limited data on how much it costs to produce and collect.
- For inland trade, there needed to be the development of equipment and facilities adapted for small trucks that could operate in mountainous regions.
- Establishing baselines against which bio-pellet applications could demonstrate emission reductions eligible for carbon credit was a prerequisite for extending any carbon credit system to bio-pellets.
- Identifying likely potential products and product flows both within APEC and with non-APEC economies and also identifying and addressing potential barriers to trade, both behind the border and cross-border.
- Need strong government incentives and supports for bio-pellet trade in the APEC region.
- Participants thought APEC was a good forum for exchanging knowledge and technologies and for providing guidance on policy making as well as influencing investors and the general public. Collaboration through APEC would help to accelerate the promotion of bio-pellets applications and related trade.

After workshop discussions several action plans are suggested concerning the bio-pellet applications in the future. They are summarized as follows:

- The development of Life Cycle Analysis (LCA) as a means of determining emission reductions as a basis for obtaining carbon credits. This would also require standardization of LCA methodology.
- Land use impact assessments in each economy were vital to the development of baselines and to track emission reductions in the total system.
- An Emission Trading System would have to be established, including documentation/certification of the source of feedstock, the converting process, the blending process and a procedure of random product testing to police the system.
- A study of potential trade in bio-pellet products that would identify materials and likely product flows within and beyond APEC, including possible barriers and solutions.

- International trade development would need standardization and harmonization of product specifications among APEC economies and APEC economies would need to align their policies to allow opportunities for trade.
- International trade development depends on the establishment of standards. Since APEC is very much concerned with trade development, it was suggested that APEC's Trade and Liberalization Fund (TILF) could be used to fund a project for preparing bio-pellet product standards.

5. Conclusions

Bio-pellet technologies, applications, and their status have been discussed in the report above. Industrial Technology Research Institute (ITRI) have made the following conclusions based on the study and the presentations and discussions given at the APEC Workshop on Bio-pellet Production, Handling and Energy Utilization held at Tokyo, Japan, 24-25 October 2017.

Bio-pellets are sustainable bio-fuels which can be categorized into white pellet (pelletized from biomass) and black pellet (pelletized from torrefied biomass), both having the characteristics of being "carbon neutral" and clean combustion that they are effective alternatives to replace the fossil fuels in industrial combustion and power plant applications. Key findings in regards to the prospects of bio-pellets co-firing with coal-fired boilers indicate:

- There are two major markets for bio-pellets, the industrial pellets used as a substitute for coal in large utility power stations and the premium heating pellets used in pellet stoves and pellet fueled central heating systems. Global wood-pellet production increased from 19.5 million tons in 2012 up to 28.6 million tons in 2016, with average annual growth rate of about 10%.
- In 2016, industrial usages on bio-pellets and household usages on premium heating pellets have accounted for 50.4% and 49.6%, respectively. The demands of industrial pellets will grow rapidly in the future due to policy driven by each country for substituting some coal into bio-pellet for power plant applications.
- The United States and Canada are the world's leading producers of wood pellets with their nameplate production capacities of more than 13.7 million tons and 4 million tons respectively in 2016. Among them, approximately above two-thirds of their output is sold abroad, and one-thirds is kept for domestic use. Currently the United States and Canada dominate the trade in industrial wood pellets into Europe, the United Kingdom and Japan.
- The increase of wood pellet production and consumption within Canada is mainly driven by international demand as well as potentially new domestic policies. Coal power accounts for roughly 10% of Canada's total greenhouse gas emissions. In Canada cases where seven power plants of pulverized coal boilers are co-firing with bio-fuels, a total of four power plants have used wood pellets as co-firing fuel.
- The main drivers for wood pellet consumption in the U.S. have been regional price competitiveness with residential heating oil and propane as well as

replacements of fuelwood burners with respect to comfort and automatic feed-in.

- The EU has set up a new target for GHG emission reductions in 2014, which will reach 40% reduction by 2030 vs. 1990. It will promote the co-firing of biomass in the industrial sector, especially power plants. About two-thirds of the existing biomass co-firing cases are located in Europe, and are mostly commercial power plants. Among the co-firing biomass fuels, the most widely used are the wood-pellets.
- UK has gradually achieved the goal of bioenergy development plan by importing bio-pellets, establishing dedicated system for biomass fuels, having its existing coal-fired facilities utilize biomass fuels. Bio-pellets firing power plants contribute 5.6% of UK's electricity in 2017. Among them, the British Drax power plant is of the world's largest biomass fuel co-firing program that two 630 MW wood pellet fuel dedicated systems have been in operation, and the other four 630 MW systems for wood-pellet fuels are still under assessments.
- The FIT of ¥21/kWh for 20 years in Japan has led to 8 GW of renewable energy capacity being added since 2012. Co-firing wood pellets for large utility pulverized coal boilers have been increased from 80,000 tons in 2012 up to expected 500,000 tons in 2017.
- A RPS for Korea became effective in 2012 which mandates an increasing percentage of power generated from renewable sources increased to 10% in 2024. Wood pellet imports to Korea has almost tripled over the past three years, from 400,000 tons in 2013 to more than 1,400,000 tons in 2016. Korea is now the largest importer of wood pellets in Asia.

As discussed in the report above, supply chains of bio-pellets are of importance to the co-firing of bio-pellets with coal in power plant. Discussions of bio-pellets production, handling and energy utilization include:

- The biomass pelletizing process includes the serial steps of drying, grinding, mixing, pelletizing, cooling and packaging. The typical biomass dryer is the rotary kiln dryer, which is the most cost-effective option. The most commonly used grinder is the hammer mill due to their good mechanical durability. Pelletizers for biomass are of three types of screw extrusion press pelletizers, piston punch pelletizers and roller press pelletizers. Among them the roller press pelletizers are the most common used pelletizers and may further divide into flat-die pelletizers and ring-die pelletizers.
- Black pellets are biomass torrefied or steam exploded before pelletizing process. Torrefaction is a thermochemical treatment of biomass at 200 to 300°C of low

particle heating rates <50°C/min and under atmospheric conditions in the absence of oxygen. For steam exploded pellets, biomass is pre-dried and impregnated with steam at 10-35bar and 180-240°C, followed by explosive decompression to atmospheric pressure.

- Favorable properties of black pellets include high energy density, better water resistance, slower biodegradation, good grindability, good flowability, homogenized material properties and applicable to a wide range of lignocellulosic biomass feedstock.
- Indoor storage of bio-pellets requires a series of safety measures to overcome the problems of self-heating, self-ignition, dust generation and biomass off-gassing issues. Self-heating phenomenon could happen on bio-pellets due to oxidative reactions or microbial degradation, while the thermal developments caused by microbial degradation are highly correlated with moisture contents.
- In a closed storage environment, the poor heat transfer internally and the bio-pellets' insulation character, the internal heat is accumulated deep inside, and may result in the happening of self-ignition. Precautionary measures are taken to prevent bio-pellets self-heating and self-ignition from happening: avoid storing biomass fuels with moisture contents exceeding 15%, avoid mixing different types of biomass fuels in a storage tank, avoid mixing biomass fuels with different moisture contents, etc.
- Bio-pellet fuels have three types of coal co-firing applications on boilers, (a) direct co-firing: the bio-pellets are treated via the same or different grinding and feeder equipment, and then combined with coal into the same boiler for combustion, while the coal and bio-pellets may use the same burner or individual ones, (b) indirect co-firing: a bio-pellet gasifier is established, the bio-pellets are gasified into syngas firstly, and then conduct such syngas into the coal-firing boilers for burning, (c) parallel co-firing: this approach is to establish a separated bio-pellet fired boiler, and then the steam generated from bio-pellet boiler is fed into the coal-fired boiler steam system for use.
- Wood-pellet burner is a technically mature combustion device that can be categorized into three types of overfed burner, underfed burners, and horizontally fed burner. The existing small to medium-scale boilers are easy to be retrofitted by replacing the natural-gas/heavy-fuel-oil burners by bio-pellet burners and adding bio-pellet feeders without replacing the boiler main body for cost saving.

The white leadtree is one of the 100 worst invasive species and is a very common species in APEC economics. A win-win strategy is proposed that eradiation of white leadtree for bio-pellet production is not only good for land environment but also beneficial to climate environment by providing SMEs carbon-neutral bio-pellet for boiler application. Some findings of white-leadtree pellet production and combustion in a packaged boiler include:

- Most enterprises especially in the APEC's developing economics are SMEs, relying on firing fossil fuel with boilers to obtain heating required for the manufacturing process. It is difficult for SMEs to use modern green energy, especially the wind power and solar PV, due to the limited space available. A proposal is made to utilize white leadtree for the bio-pellet applications to SMEs packaged boiler.
- After white-leadtree plants are eradicated, local native trees are planted in the forest land areas for the sustainable supply of bio-pellets.
- The ash and chlorine contents of white-leadtree pellet are 1.83% and 0.17% respectively which are higher than the German DIN 51731 standard. The white-leadtree pellets are not qualified as premium heating pellets for household heating applications. The white-leadtree pellets may be suitable for the application of industrial packaged boilers equipped with air pollution control devices.
- A natural-gas-fired packaged boiler with steam capacity of 7.2ton/h is retrofitted into a bio-pellet-fired boiler. Test results of firing white-leadtree pellets indicate that NO_x and SO_x emissions are 76.6ppm(@6%O_2) and 6ppm(@6%O_2) respectively. The very low emissions of NO_x and SO_x meet the air pollution standard in Chinese Taipei. The boiler efficiency is calculated to be 89.6% based on the heat loss method.

Economic feasibility study of utilizing white-leadtree pellets instead of fossil fuel for boiler application is conducted. Key findings of this study indicate:

- It is assumed that 1 US$ can buy the same heating values whether it is natural gas or bio-pellet fuel. When the heating value of natural gas is 37.8MJ/m^3 and its selling price is 0.3725US$/$m^3$, then the calculated EPP (Equivalent Pellet Price) of white-leadtree pellet is 159.41US$/ton. Therefore, when the selling price of white-leadtree pellet is lower than the EPP, it indicates the white-leadtree pellet fuel can replace natural gas for packaged boiler applications because its price is competitive in the market.
- The discounted cash flow method is used to estimate the selling price of white-leadtree pellet in two cases. The calculation is based on the following conditions. The minimum bio-pellet production rate is 3tons/hr. IRR is 15%. 60% of the factory cost is paid with a loan (interest rate of 2%) from the bank. The plant is

expected to operate for 20 years. The 10-year straight-line accelerated depreciation method is used to calculate the value of the plant each year. VAT is 17%. Based on the assumption, the selling prices of white-leadtree pellet fuel in the two cases are 77.38US$/ton (case 1, feedstock 22.95US$/ton) and 145.8US$/ton (case 2, feedstock 75.41US$/ton). In both cases, white-leadtree pellet fuel can replace natural gas because its price is lower than EPP and is more competitive in the market.

- A win-win strategy for both bio-pellet fuel manufacturers and boiler end users of SMEs is proposed. SMEs can cut down the cost of fuel and hence increase their competitiveness when the white-leadtree pellet fuel is sold at 90% of EPP. Although bio-pellet fuel manufacturers generate lower profits, they still enjoy a decent 12.4% IRR and greater market share in return.

Several issues and comments concerning the bio-pellet technologies and applications over the presentations and roundtable discussions in the workshop had been raised up. The main issues and comments are summarized as follows:

- The white-leadtree plants are invasive species, they grow and mix with local high-value trees in the mountain. To harvest the local high-value trees, the white leadtree must be eradicated. The white leadtree is a “by-product” of harvesting the local high-value trees. So the values of these local high-value trees can compensate the increased cost of white leadtree when manufacturers have to reach increasing distances to get feedstock into the pellet plant.
- The production costs of black pellets per gigajoule are probably 10-15% higher in comparison with white wood pellets. The volumetric energy density of black pellets is roughly 30-40% higher than white wood pellets, which makes logistics and transport much more efficient.
- The vehicle manufacturers focus on the FCV besides EV in Japan. They have a great concern of eco-benefit based on LCA. That is, from what resources can the hydrogen be produced? For instance, in EU countries, the electrolysis of water would be promising if the power source from renewables, e.g. PV, wind etc., is available. Of course, biomass is promising for producing hydrogen for FCV because biomass is sustainable.
- As possible expectations concerning the effects of trace contaminants in solid feedstocks (e.g. coal, biomass, wastes), the chemical impacts on SOFC anode performance in the case of coal syngas injection will be the worse and most complicated, much rather than the case of biomass-derived syngas (e.g. syngas derived from woody biomass). However, in the case of biomass gasification, the impact of condensable hydrocarbons (tar) would be very crucial for SOFC

operation fueled by biomass-derived syngas because tar is a major contaminant in the gas produced at relatively intermediate gasification temperatures and trace level of aromatics can cause carbon deposition in SOFC anode, depending on the kind of feedstock, though.

- The storage and transportation of biomass briquettes and pellets are convenient due to their high density, compact size, and low moisture content. A variety of raw materials is available for different seasons in China and can be used to produce briquettes and pellets. The factories can make a certain amount of briquettes and pellets for storage, and then gradually supply to end users. Due to these advantages, pellets can be produced and stored during summer and autumn times, then be used as a district heating fuel in cold winter.

6. References

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Appendix

Appendix I Bio-pellet Workshop agenda

Asia-Pacific Economic Cooperation

APEC Workshop on Bio-pellet Production, Handling and Energy Utilization

SUPPORTED BY Bureau of Energy, Ministry of Economic Affairs

ORGANIZED BY ITRI Industrial Technology Research Institute

Agenda

October **24** / Tuesday

08:30	Registration
09:00	Opening Remarks
09:30	Keynote Speech - How substituting sustainably produced wood pellets for coal in utility power stations is a rational, pragmatic, and economical solution for reducing carbon emissions Dr. William Strauss President, Future Metrics, United States
10:10	Coffee Break
10:40	Progress and sharing of APEC project – 1. Bio-pellet technologies and demonstration of white-leadtree pellet fired in existing boilers for green energy application. 2. Economic feasibility study of utilizing white-leadtree pellet instead of fossil fuel for boiler application. Dr. Seng-Rung Wu Principal Researcher, Industrial Technology Research Institute, Chinese Taipei Ms. Sih-Ting Jhou Associate Researcher, Industrial Technology Research Institute, Chinese Taipei
11:20	Biomass co-firing experience in the Netherlands and black pellets status update Mr. Michiel Carbo Innovation Manager Biomass Upgrading, Energy Research Centre of Netherlands, The Netherlands
12:00	Steam based biomass gasification processes for syngas and hydrogen production Prof. Kiyoshi Dowaki Tokyo University of Science, Japan
12:40	Lunch
13:40	Technical bottle-necks for SOFC operation in conjunction with biomass gasification Dr. Koji Kuramoto Senior Researcher, Research Institute of Energy Frontier, National Institute of Advanced Industrial Science and Technology, Japan
14:20	Bio-pellet production, handling and energy utilization in China Prof. Kuichuan Sheng Zhejiang University, China
15:00	Coffee Break
15:30	Roundtable discussion on bio-pellet production, handling and energy utilization Host and speakers
17:10	Workshop evaluation survey Participants complete and turn in the evaluation survey
17:30	Workshop Close

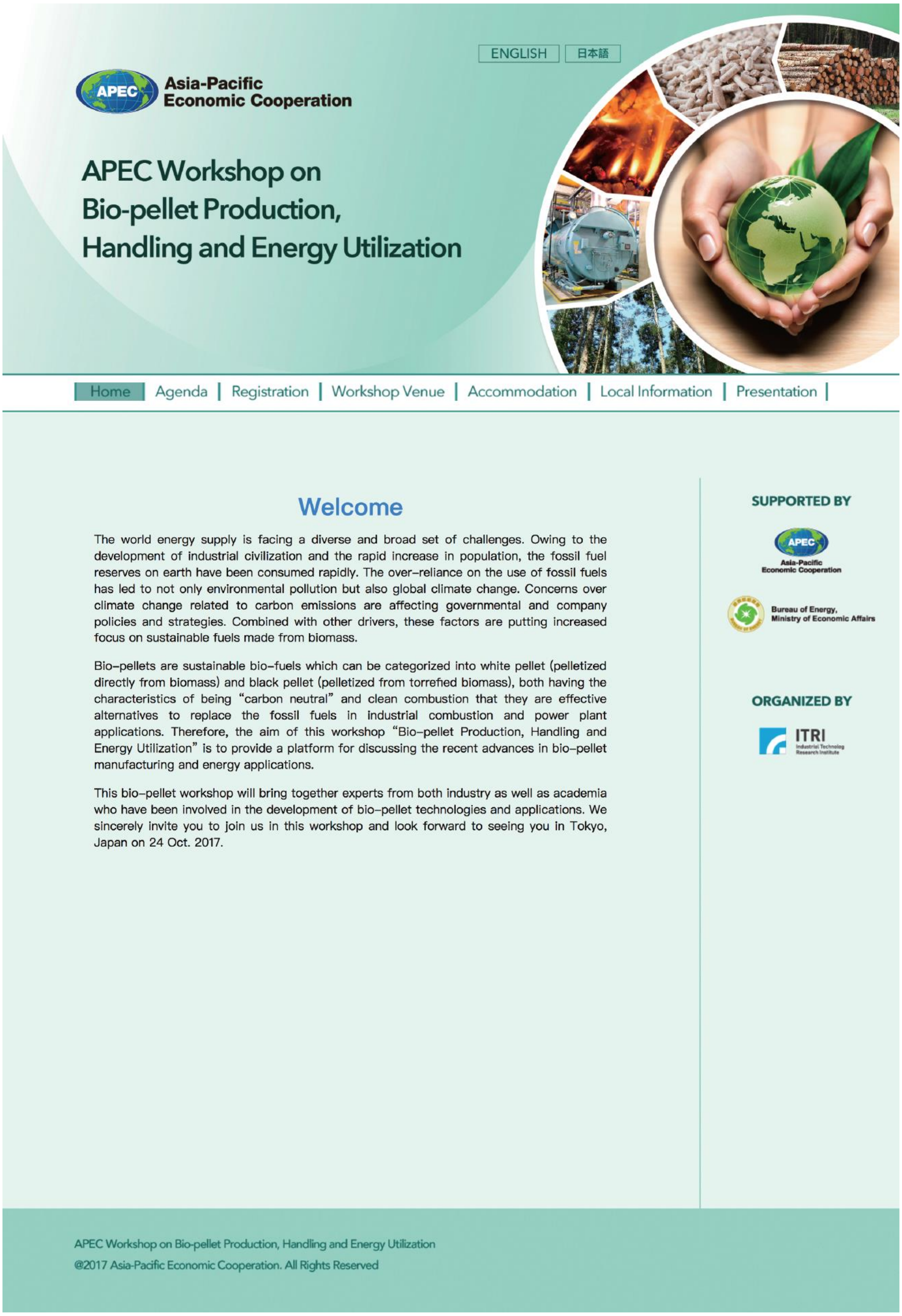
Appendix II Site visit agenda

Site Visit (by invitation) **October 25 (Wednesday)**

Japan Blue Energy Co., Ltd and Biomass Gasification Power Generation System, Minami Tama Water Reclamation Center, Bureau of Sewerage.

Time	Event	Venue
08:45	Gathering at Via Inn Lobby	Hotel Via Inn Higashi-Ginza
09:30	Bus arrive Le Port Kojimachi Hotel	
Biomass Gasification Power Generation System, Presented by Japan Blue Energy Co., Ltd. (JBEC)		
09:40	BLUE Project - A supply chain of biomass hydrogen from local production to local utilization ■ Mr. Naoki Dowaki, President of JBEC	Le Port Kojimachi Hotel
10:20	Break	Le Port Kojimachi Hotel
10:30	Environmental Challenge 2050 ■ Mr. 三谷合九，TOYOTA	Le Port Kojimachi Hotel
10:50	Q & A	Le Port Kojimachi Hotel
12:00	Lunch	Le Port Kojimachi Hotel
13:00	Bus leaves for destination	
Minami Tama Water Reclamation Center (MTWRC), Bureau of Sewerage		
14:00	Introduction of Gasification and PV facility in MTWRC ■ Mr. Sato, MTWRC	MTWRC
14:30	Tour Gasification and PV facility	MTWRC
15:30	Q & A	MTWRC
Hotel Via Inn Higashi-Ginza		
16:00	Bus leaves for destination	
17:00	Arrive Hotel Via Inn Higashi-Ginza	

Appendix III Bio-pellet website contents (http://biopelletworkshop.itri.org.tw/index.html)



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Asia-Pacific Economic Cooperation

APEC Workshop on Bio-pellet Production, Handling and Energy Utilization

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Welcome

The world energy supply is facing a diverse and broad set of challenges. Owing to the development of industrial civilization and the rapid increase in population, the fossil fuel reserves on earth have been consumed rapidly. The over–reliance on the use of fossil fuels has led to not only environmental pollution but also global climate change. Concerns over climate change related to carbon emissions are affecting governmental and company policies and strategies. Combined with other drivers, these factors are putting increased focus on sustainable fuels made from biomass.

Bio–pellets are sustainable bio–fuels which can be categorized into white pellet (pelletized directly from biomass) and black pellet (pelletized from torrefied biomass), both having the characteristics of being "carbon neutral" and clean combustion that they are effective alternatives to replace the fossil fuels in industrial combustion and power plant applications. Therefore, the aim of this workshop "Bio–pellet Production, Handling and Energy Utilization" is to provide a platform for discussing the recent advances in bio–pellet manufacturing and energy applications.

This bio–pellet workshop will bring together experts from both industry as well as academia who have been involved in the development of bio–pellet technologies and applications. We sincerely invite you to join us in this workshop and look forward to seeing you in Tokyo, Japan on 24 Oct. 2017.

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APEC Workshop on Bio-pellet Production, Handling and Energy Utilization

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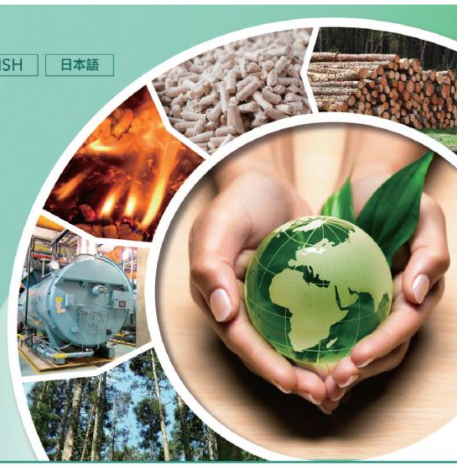
APEC Workshop on Bio-pellet Production, Handling and Energy Utilization



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APEC Workshop on Bio-pellet Production, Handling and Energy Utilization

Special thanks to

The Institute of Energy Economics, Japan (IEEJ)
Japan Woody Bioenergy Association (JWBA)
Biomass Power Association (BPA)
Japan Blue Energy Co., Ltd (JBEC)

Agenda

October **24** / Tuesday

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09:00	Opening Remarks
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11:20	**Biomass co-firing experience in the Netherlands and black pellets status update** Mr. Michiel Carbo Innovation Manager Biomass Upgrading, Energy Research Centre of Netherlands, The Netherlands

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12:00	**Steam based biomass gasification processes for syngas and hydrogen production** Prof. Kiyoshi Dowaki Tokyo University of Science, Japan
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15:30	**Roundtable discussion on bio-pellet production, handling and energy utilization** Host and speakers
17:10	**Workshop evaluation survey** Participants complete and turn in the evaluation survey
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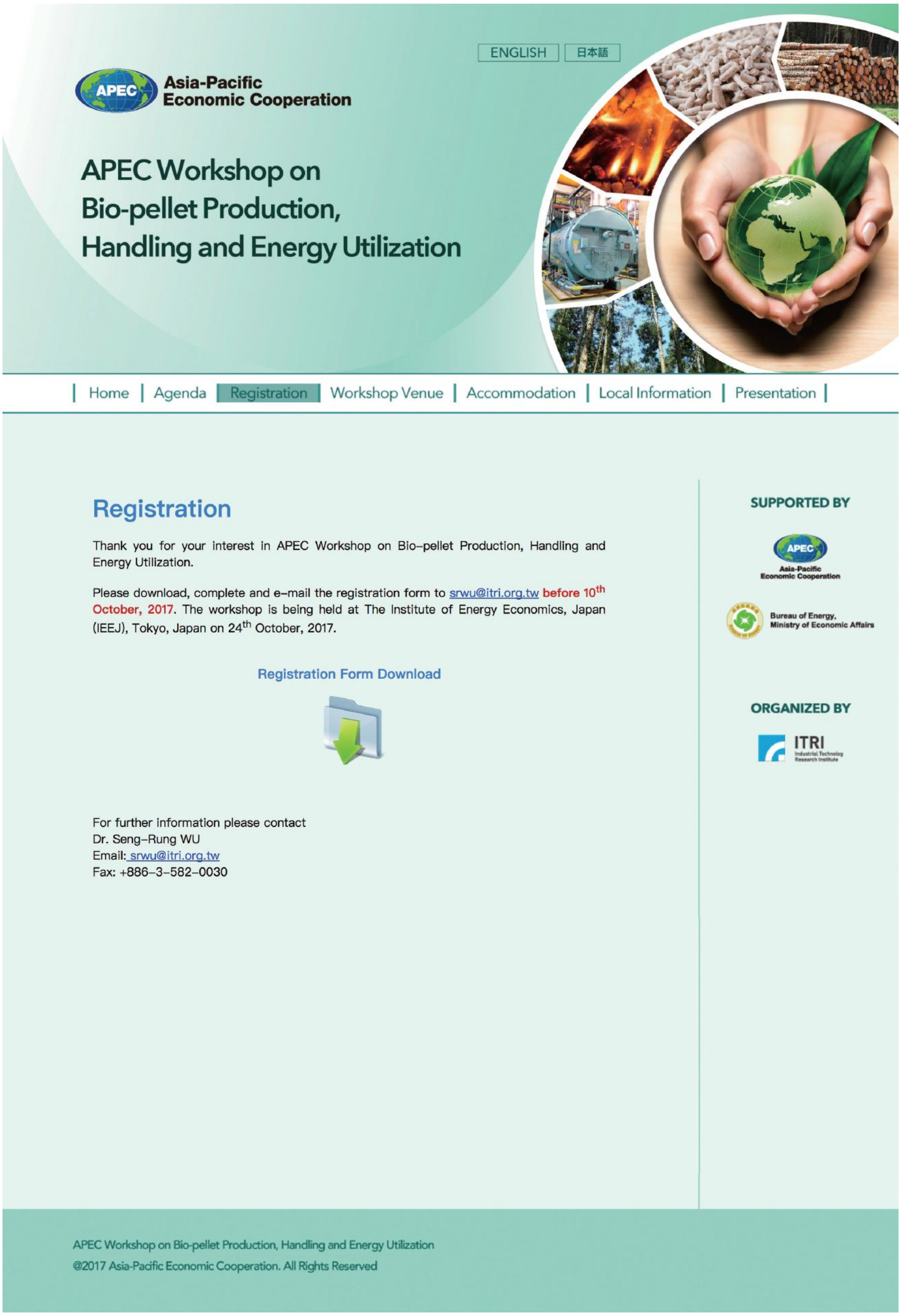
Site Visit (by invitation) October 25 / Wednesday

Japan Blue Energy Co., Ltd and Biomass Gasification Power Generation System, Kiyose Water Reclamation Center.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APEC Workshop on Bio-pellet Production, Handling and Energy Utilization

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Registration

Thank you for your interest in APEC Workshop on Bio-pellet Production, Handling and Energy Utilization.

Please download, complete and e-mail the registration form to srwu@itri.org.tw **before 10th October, 2017**. The workshop is being held at The Institute of Energy Economics, Japan (IEEJ), Tokyo, Japan on 24th October, 2017.

Registration Form Download

For further information please contact
Dr. Seng-Rung WU
Email: srwu@itri.org.tw
Fax: +886-3-582-0030

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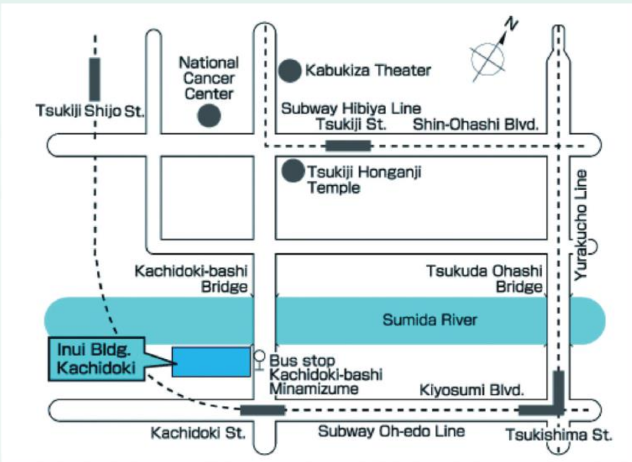
Workshop Venue

The Bio-pellet Workshop will be held at the Large Conference Room on 11th Floor in Inui Building Kachidoki, IEEJ Office, Tokyo, Japan.



The Institute of Energy Economics, Japan (IEEJ)

Venue:Large Conference Room on 11th Floor

Website : http://eneken.ieej.or.jp/en/about/

Address : Inui Bldg. Kachidoki, 11th Floor
13-1, Kachidoki 1-chome, Chuo-ku, Tokyo, Japan

Tel : +81-3-5547-0221

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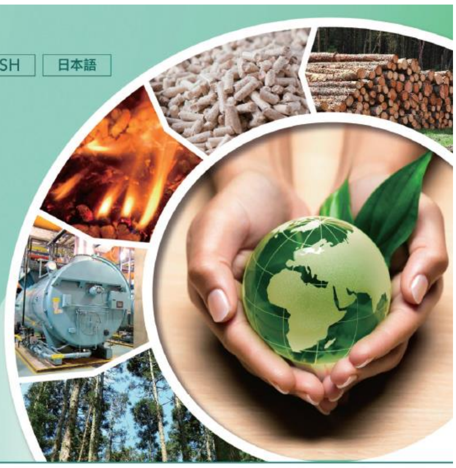

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Accommodation

Hotel Via Inn Higashi–Ginza

Hotel Via Inn Higashi–Ginza locates near Ginza in the walking distance and it takes 10 minutes from the workshop venue (IEEJ) to hotel on foot. A convenience store "Lawson" is located at the 1st floor of the hotel.

Please make reservations for accommodation through Hotel Official Website
http://www.viainn.com/en/higashiginza/

Hotel Room Information
http://www.viainn.com/en/higashiginza/#room

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Narita/Haneda Airport to Hotel Via Inn Higashi-Ginza

There are two international airports near Tokyo, which locate in Narita and Haneda. The Hotel Via Inn Higashi-Ginza can be accessed by many ways including using trains and subways (train transfers are necessary); however, it is expected heavily crowded inside the trains during morning (7-10am) and evening (5-6pm) rush hours. Using Airport Limousine buses from the international airports is recommended.
http://www.viainn.com/en/higashiginza/#access

By airport limousine bus

Following two ways of approaching by using limousine bus from the airports are recommended. You can make a reservation of returning bus ticket from website.

1. Via "Courtyard By Marriott Tokyo Ginza Hotel"

It takes 15 minutes from Courtyard By Marriott Tokyo Ginza Hotel to Hotel Via Inn Higashi-Ginza on foot.

Narita International Airport

There are 3 terminals in Narita international Airport. Please check in the following website where the bus ticket centers & bus stop numbers for in the terminal you arrive.

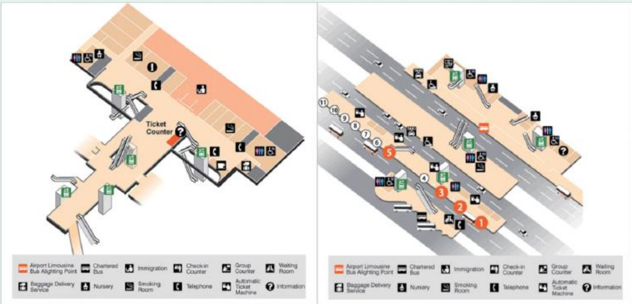
Time Table, Travel Time **from** Narita International Airport:
http://www.limousinebus.co.jp/en/platform_searches/index/1/69

Time Table, Travel Time **to** Narita International Airport:
http://www.limousinebus.co.jp/en/platform_searches/index/2/69

Fare from/to Narita International Airport :
One-way fare is JPY3,100. Please check discounted Round-trip ticket etc.
http://www.limousinebus.co.jp/en/information/visitor_tickets/

Haneda International Airport

Bus Ticket counter is on left hand side just after the customs gate on the 2F in the international terminal building. The bus stop to Ginza is No.3 on the 1F (Ground Floor).



http://www.limousinebus.co.jp/en/platform_searches/index/4/69#map

Time Table, Travel Time from Haneda International Airport:
http://www.limousinebus.co.jp/en/platform_searches/index/3/69

Time Table, Travel Time to Haneda International Airport:
http://www.limousinebus.co.jp/en/platform_searches/index/4/69

Fare from/to Haneda International Airport: One-way fare is JPY930.
http://www.limousinebus.co.jp/en/platform_searches/index/3/69#price

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2. Via "Tokyo City Air Terminal (TCAT)"

It takes 20 minutes from TCAT to Hotel Via Inn Higashi-Ginza by meter taxi. It costs about JPY1,500-JPY2,000. You can purchase returning bus ticket at TCAT.

■ **Narita International Airport**

There are 3 terminals in Narita international Airport. Please check in the following website where the bus ticket centers & bus stop numbers for in the terminal you arrive.

Time Table, Travel Time **from** Narita International Airport:
http://www.limousinebus.co.jp/en/platform_searches/index/1/10

Time Table, Travel Time **to** Narita International Airport:
http://www.limousinebus.co.jp/en/platform_searches/index/2/10

Fare from/to Narita International Airport: One-way fare is JPY2,800. Please check discounted Round-trip ticket etc.
http://www.limousinebus.co.jp/en/information/visitor_tickets/

■ **Haneda International Airport**

Bus Ticket counter is on left hand side just after the customs gate on the 2F in the international terminal building. The bus stop to Ginza is No.2 on the 1F (Ground Floor).

http://www.limousinebus.co.jp/en/platform_searches/index/4/69#map

Time Table, Travel Time **from** Haneda International Airport:
http://www.limousinebus.co.jp/en/platform_searches/index/3/10

Time Table, Travel Time **to** Haneda International Airport:
http://www.limousinebus.co.jp/en/platform_searches/index/4/10

Fare from/to Narita International Airport: One-way fare is JPY820.
http://www.limousinebus.co.jp/en/platform_searches/index/3/10#price

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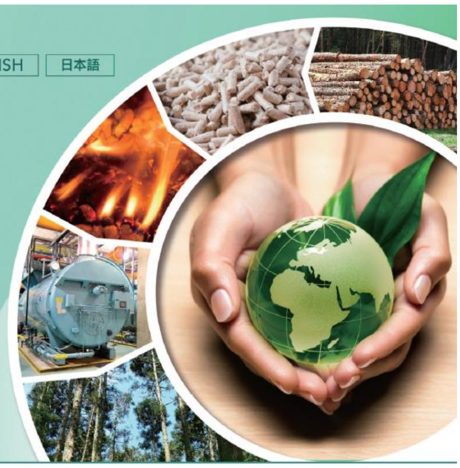
APEC Workshop on Bio-pellet Production, Handling and Energy Utilization



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Local Information

Local Time
Japan Standard Time is 9 hours ahead of GMT (GMT/UTC+9 hours).

The Weather
October is the present month in Tokyo with an average temperature of 18˚C(64˚F).
For further information please check

JAPAN WEATHER FORECAST FOR TRAVELERS

Electricity
The standard voltage in Tokyo is 100 volts (50 Hertz), and the receptacle outlet is two holes.

Getting around Tokyo
There are many places in/near Tokyo and many ways to visit there. The Via Inn Higashi-Ginza is just a few minutes away from “Higashi-Ginza” station and “Tsukiji” station. For further information please check the following website.
Tourism Site (Official Tokyo Travel Guide)

Official Tokyo Travel Guide GO TOKYO | 東京の観光公式サイト / Official Tokyo Travel Guide GO TOKYO

Subway and Trains
Tokyo Metro / Tokyo Toei / JR Site seeing Map

Tokyo Metro | TOEI TRANSPORTATION

Tokyo Sightseeing Map

Railway and Subway Route Map

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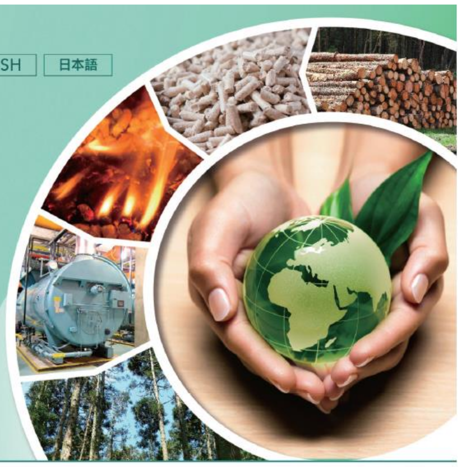

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Presentation

Presentation materials will be available after the workshop.

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APEC Workshop on Bio-pellet Production, Handling and Energy Utilization

APEC Project No. EWG 18/2016A

Produced by
Seng-Rung Wu, Ph.D., Principal Researcher
Green Energy and Environment Research Lab.
Industrial Technology Research Institute
Bldg. 64, 195, Sec. 4, Chung Hsing Rd.,
Chutung Hsinchu 31040, Chinese Taipei

ITRI
Industrial Technology
Research Institute

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace, Singapore 119616
Tel：(65) 68919 600
Fax：(65) 68919 690
Email：info@apec.org
Website：www.apec.org

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Produced by

Seng-Rung Wu, Principal Researcher
Green Energy and Environment Research Lab.
Industrial Technology Research Institute
Bldg. 64, 195, Sec. 4, Chung Hsing Rd.,
Chutung Hsinchu 31040, Chinese Taipei

For

Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace, Singapore 119616
Tel: (65) 68919 600
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