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Sustainable Energy Technologies
(Session 6)

Biomass Energy Resources and Conversion Technologies

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2016

Definition
and
Terminology

Bioenergy

- The energy stored in biomass (organic matter) is called bioenergy. Bioenergy can be used to provide heat, make fuels, and generate electricity. Wood, which people have used to cook and keep warm for thousands of years, continues to be the largest biomass resource.
- Today there are also many other types of biomass we can use to produce energy. These biomass resources include residues from the agriculture and forest industries, landfill gas, aquatic plants, and wastes produced by cities and factories.

Wood and non-wood solid biomass fuel

- **Biomass** is the solid fuel material derived from forest or non forest based sources which can be used for producing the thermal energy through direct or indirect combustion which in tern can be used for other form of energy.
- **Biomass solid fuel** are produced from organic materials, either directly from plants or indirectly from industrial, commercial, domestic or agricultural wastes. They can be derived from a wide range of raw materials and produced in a variety of ways.
- **Biomass energy** is derived from any material of plant or animal origin such as woody biomass (stems, branches, twigs) non-woody biomass (stalks, leaves, grass), agricultural residues (rice husk, coconut shell), and animal and human faeces. The energy can be converted through a variety of processes to produce a solid, liquid or gaseous fuel. The biomass usually needs some form of processing stage prior to conversion, such as chopping, mixing, drying or densifying.*(RWEDP)*

Wood solid biomass fuel

Non-wood solid biomass fuel


Bagasse


Peat


Animal & Poultry Manure


MSW


Pulp Sludge

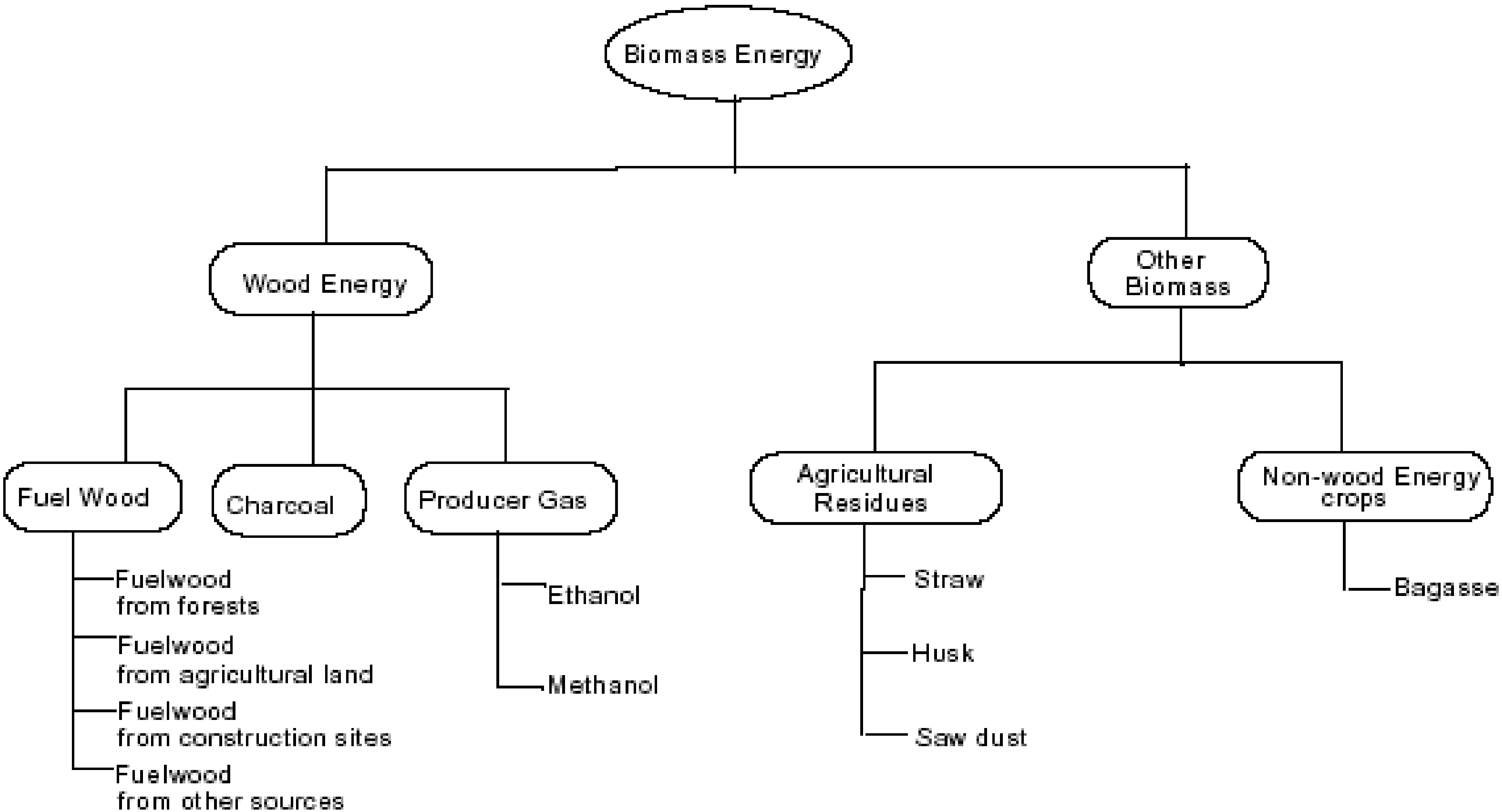

WWTP Sludge


Crop Residue


Wood Waste

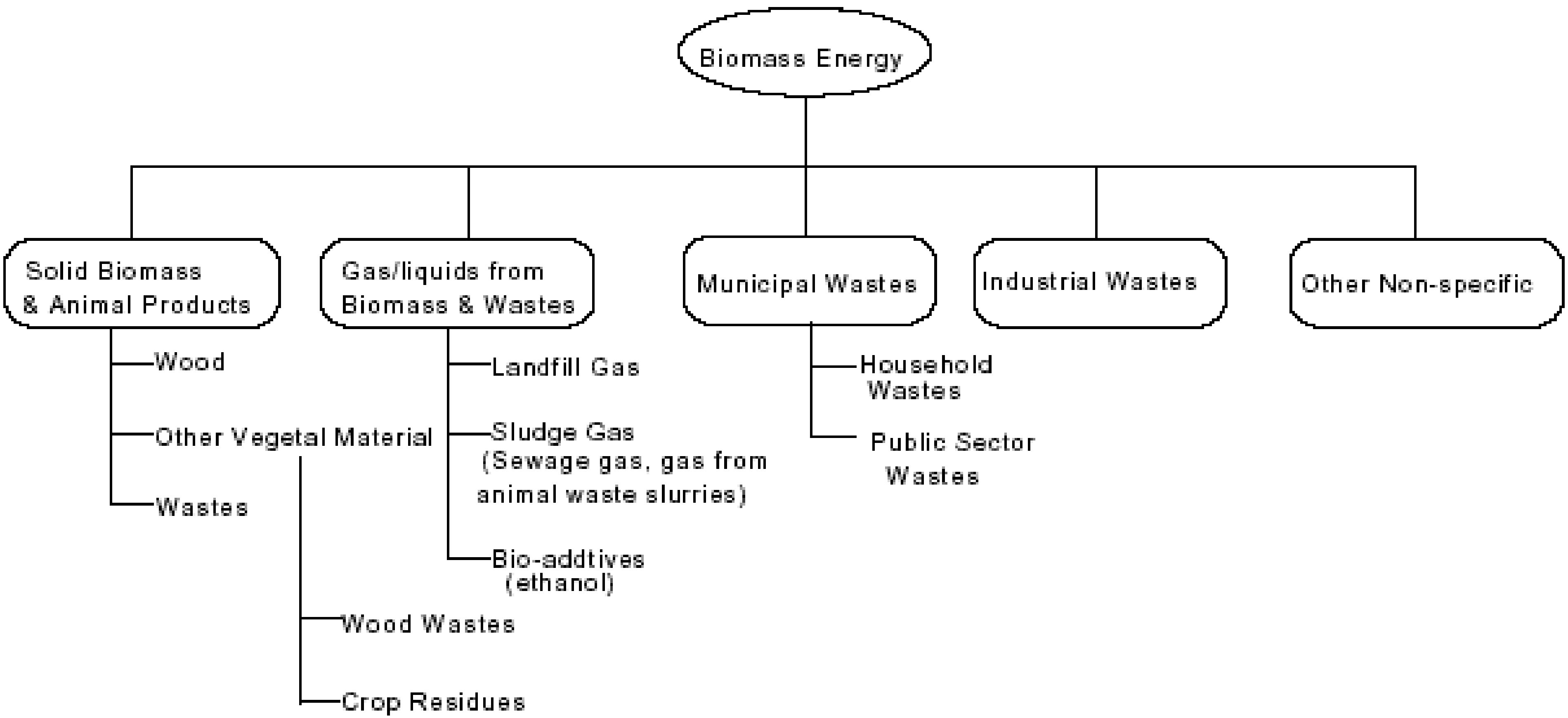
Terminology

RWEDP Classification



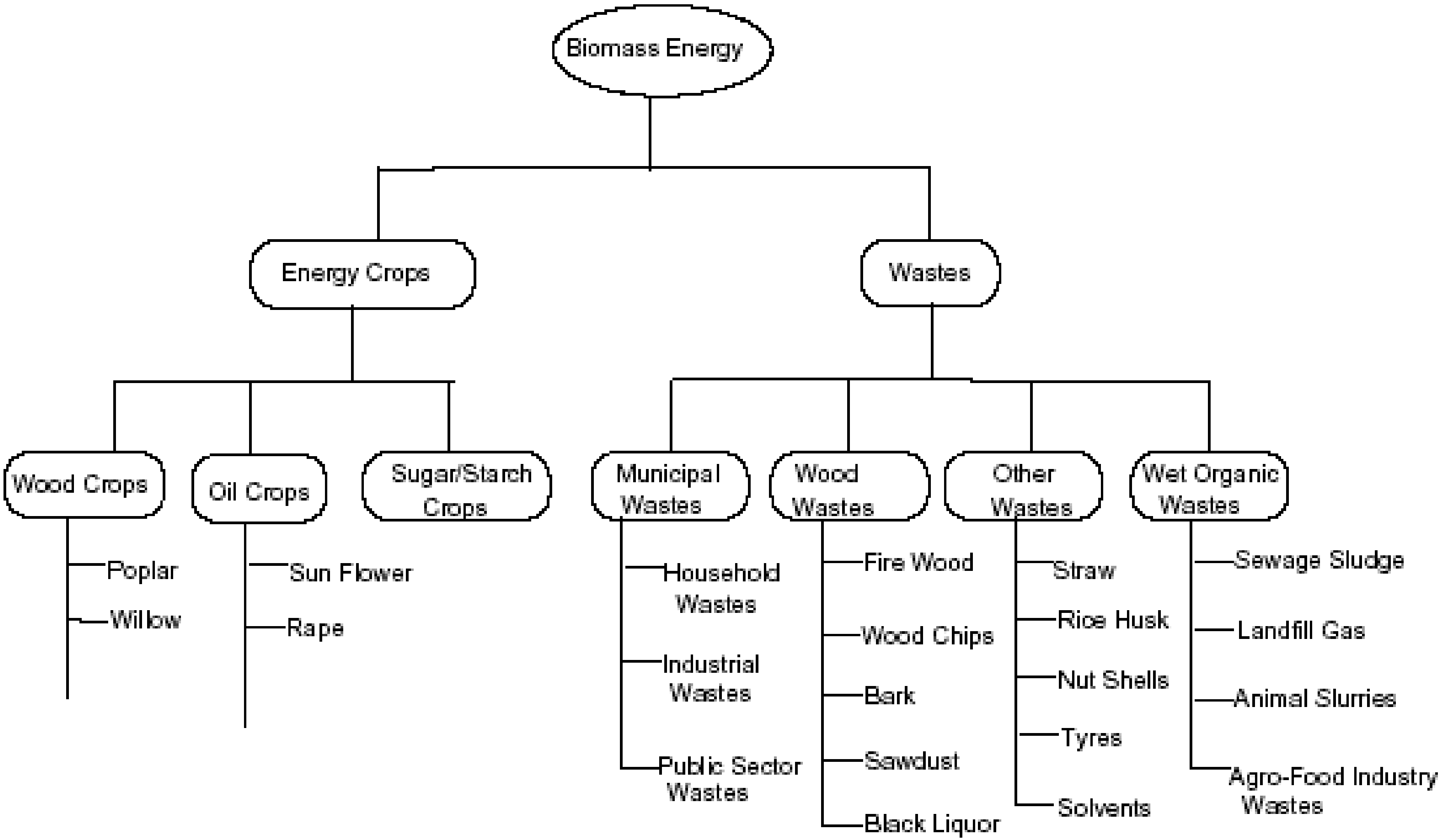
Terminology

IEA Classification



Terminology

EUROSTAT Classification



MSW – Heat of Combustion

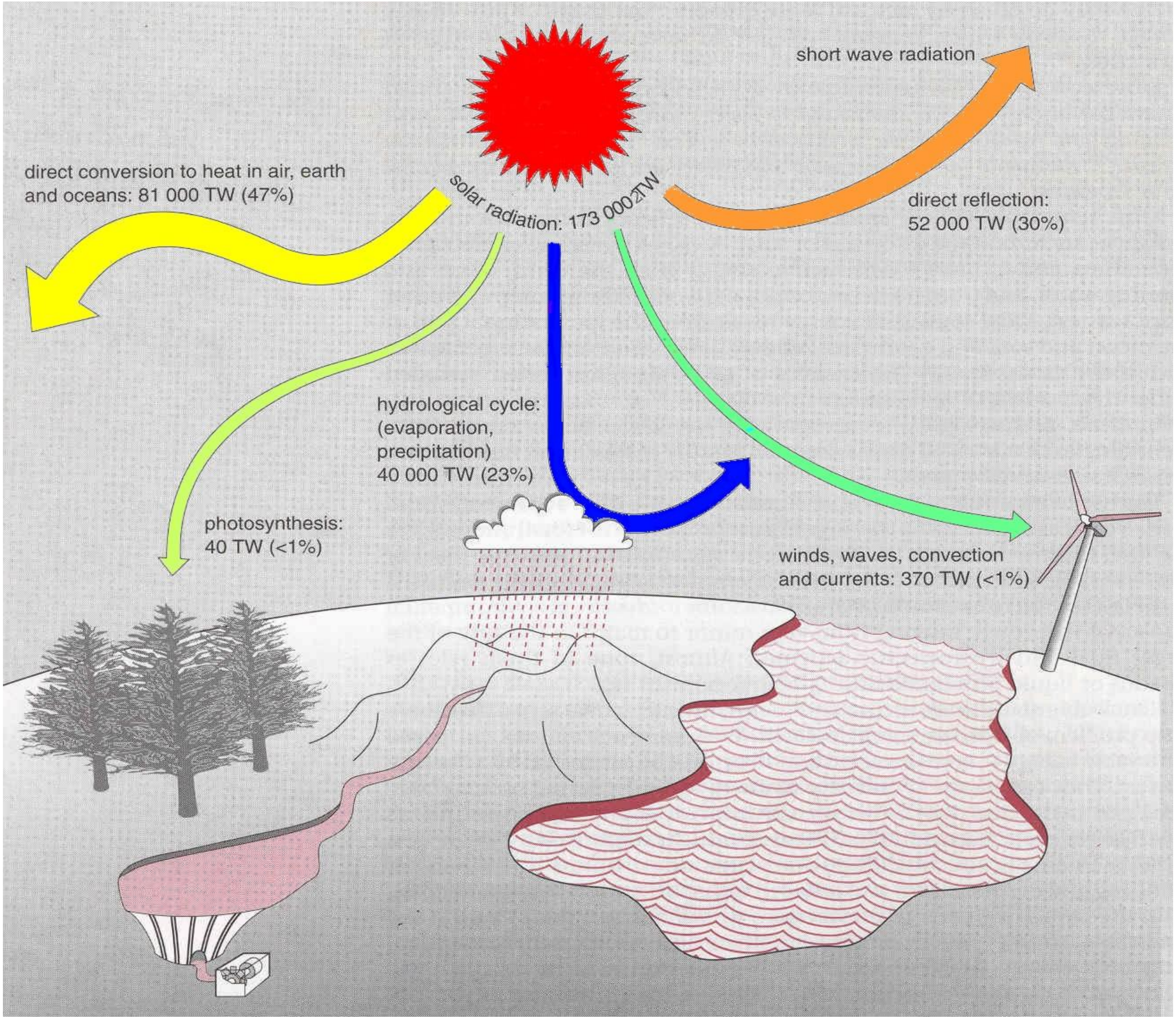
Component	Inerts (%)		Heat of combustion (kJ/g)	
	Range	Typical	Range	Typical
Yard wastes	2–5	4	2,000–19,0000	7,000
Wood	0.5–2	2	17,000–20,000	19,000
Food wastes	1–7	6	3,000–6,000	5,000
Paper	3–8	6	12,000–19,000	17,000
Cardboard	3–8	6	12,000–19,000	17,000
Plastics	5–20	10	30,000–37,000	33,000
Textiles	2–4	3	15,000–19,000	17,000
Rubber	5–20	10	20,000–28,000	23,000
Leather	8–20	10	15,000–20,000	17,000
Misc. organics	2–8	6	11,000–26,000	18,000
Glass	96–99	98	100–250	150
Tin cans	96–99	98	250–1,200	700
Nonferrous	90–99	96	—	—
Ferrous metals	94–99	98	250–1,200	700
Dirt, ashes, etc.	60–80	70	2,000–11,600	7,000

Fuel	Energy Content
Fuelwood	15 MJ/kg
Charcoal	25 MJ/kg
Crop residues	12.5 MJ/kg
Animal waste	8.4 MJ/kg
Electricity	3.6 MJ/kilowatt-hour
LPG	45 MJ/kg
Kerosene	43 MJ/kg

Table 6. Typical Energy Content of Fossil and Biomass Fuels

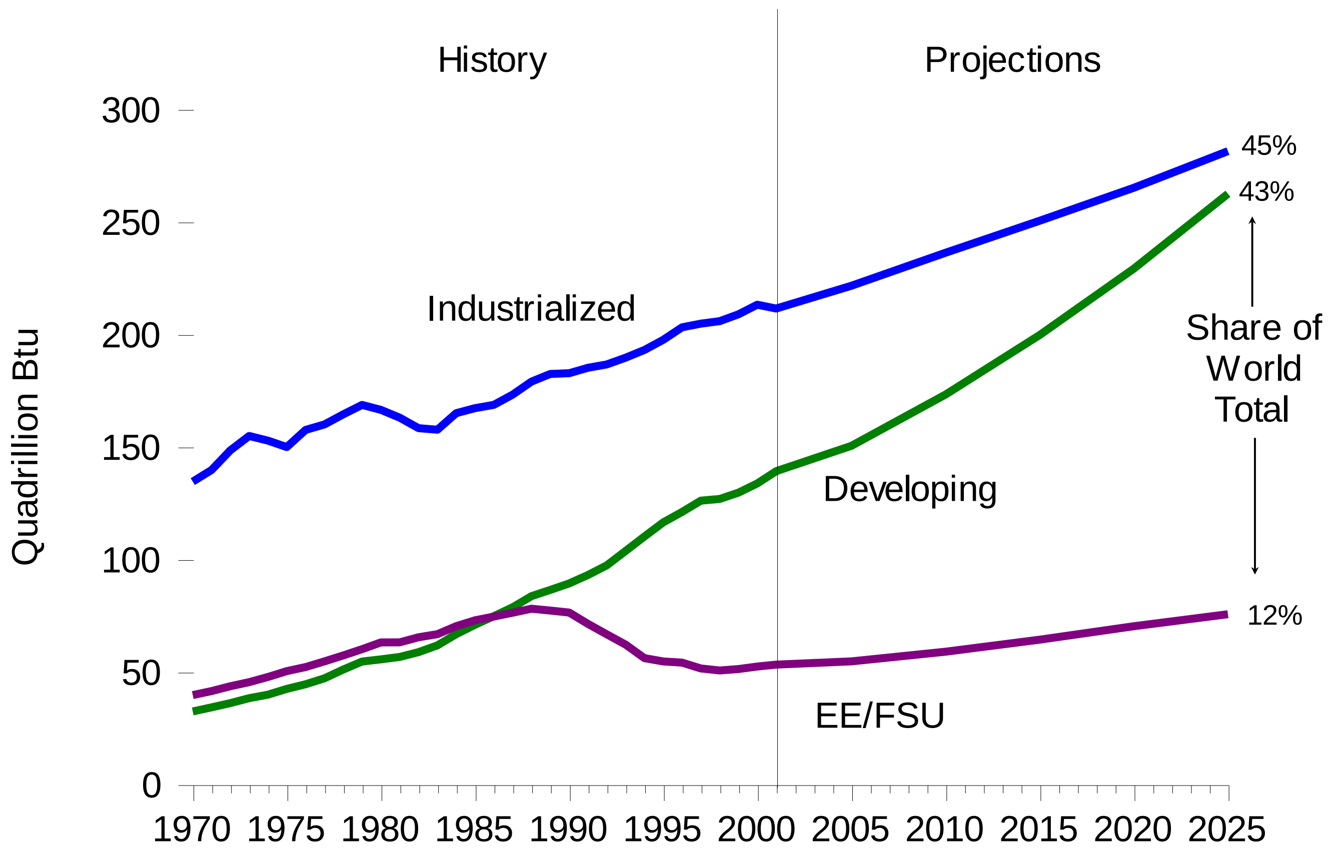
Solid Fuels	Moisture Content Wet Basis (% mcwb)	Typical Net Heating Values (NHVs) (MJ/kg)[a]
Biomass Fuels		
Wood (wet, freshly cut)	40	10.9
Wood (air-dry, humid zone)	20	15.5
Wood (air-dry, dry zone)	15	-
Wood (oven-dry)	0	20.0
Charcoal	5	29.0
Bagasse (wet)	50	8.2
Bagasse (air-dry)	13	16.2
Coffee husks	12	16.0
Ricehulls (air-dry)	9	14.4
Wheat straw	12	15.2
Maize (stalk)	12	14.7
Maize (cobs)	11	15.4
Cotton gin trash	24	11.9
Cotton stalk	12	16.4
Coconut husks	40	9.8
Coconut shells	13	17.9
Dung cakes (dried)	12	12.0
Fossil-Fuels		
Anthracite	5	31.4
Bituminous coal	5	29.3
Sub-bituminous coal	5	18.8
Lignite	-	31.4
Peat	-	29.3
Lignite briquettes	-	20.1
Coke briquettes	-	23.9
Peat briquettes	-	21.8
Coke	-	28.5
Petroleum coke	-	35.2

Trend of
Biomass Energy Consumption



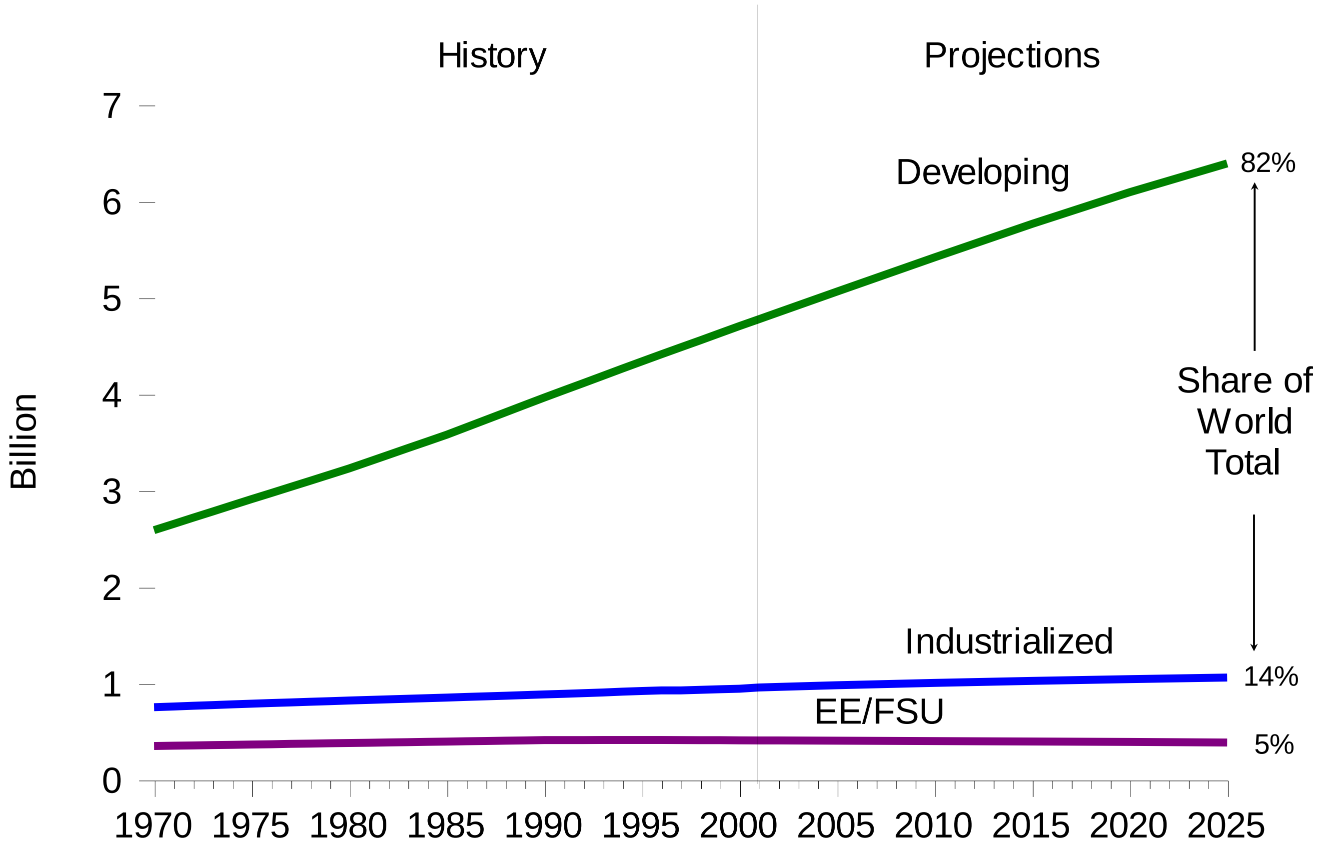
Source: Renewable Energy, Power for a Sustainable Future, Edited by Godfrey Boyle, 1996

World Marketed Energy Consumption by Region, 1970-2025



Source: EIA, *International Energy Outlook 2004*

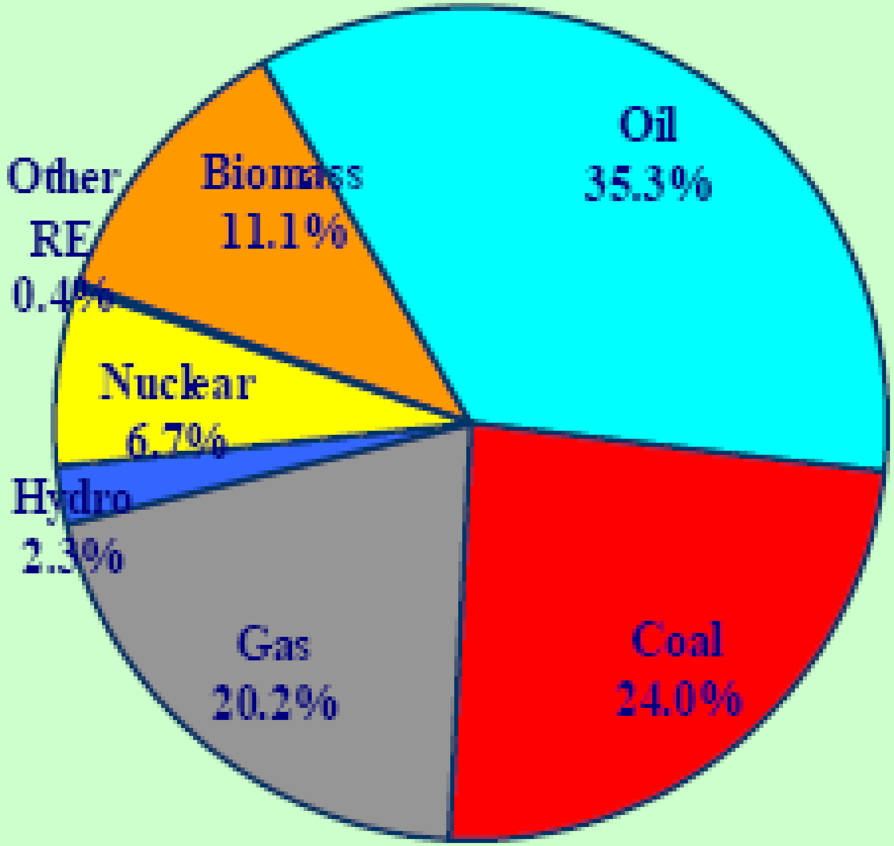
World Population by Region, 1970-2025



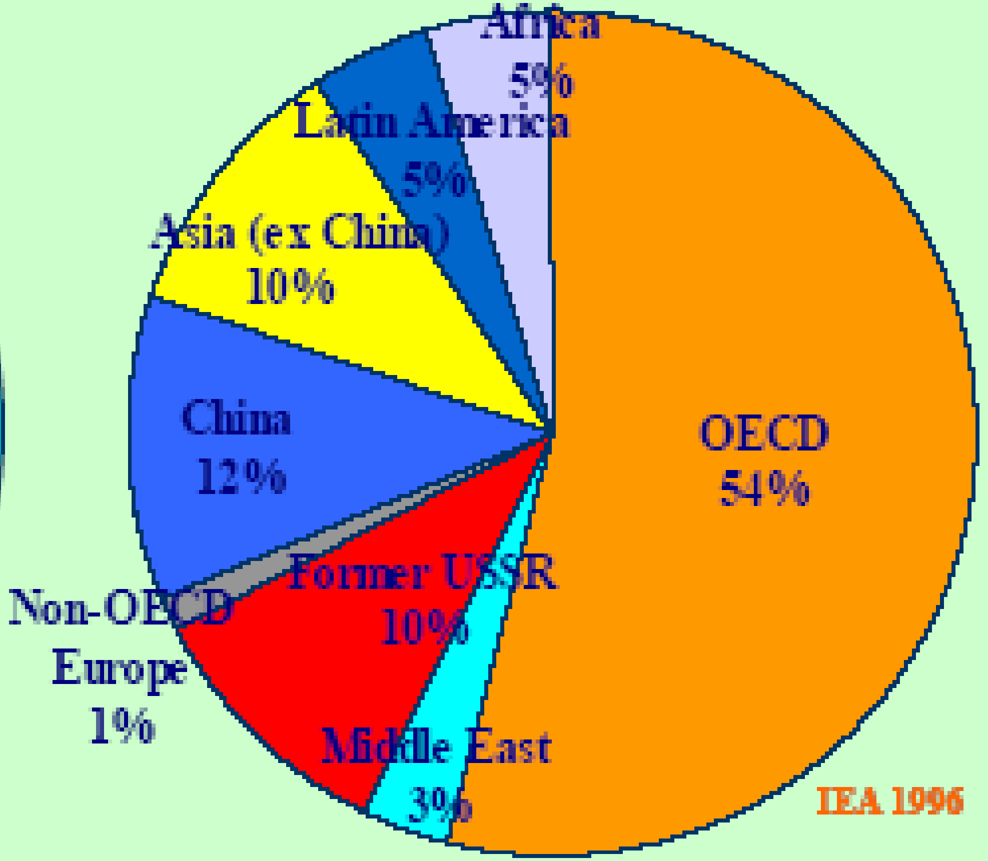
Source: United Nations, *World Population Prospects, The 2002 Revision.*

PRIMARY ENERGY SUPPLY
World Totals

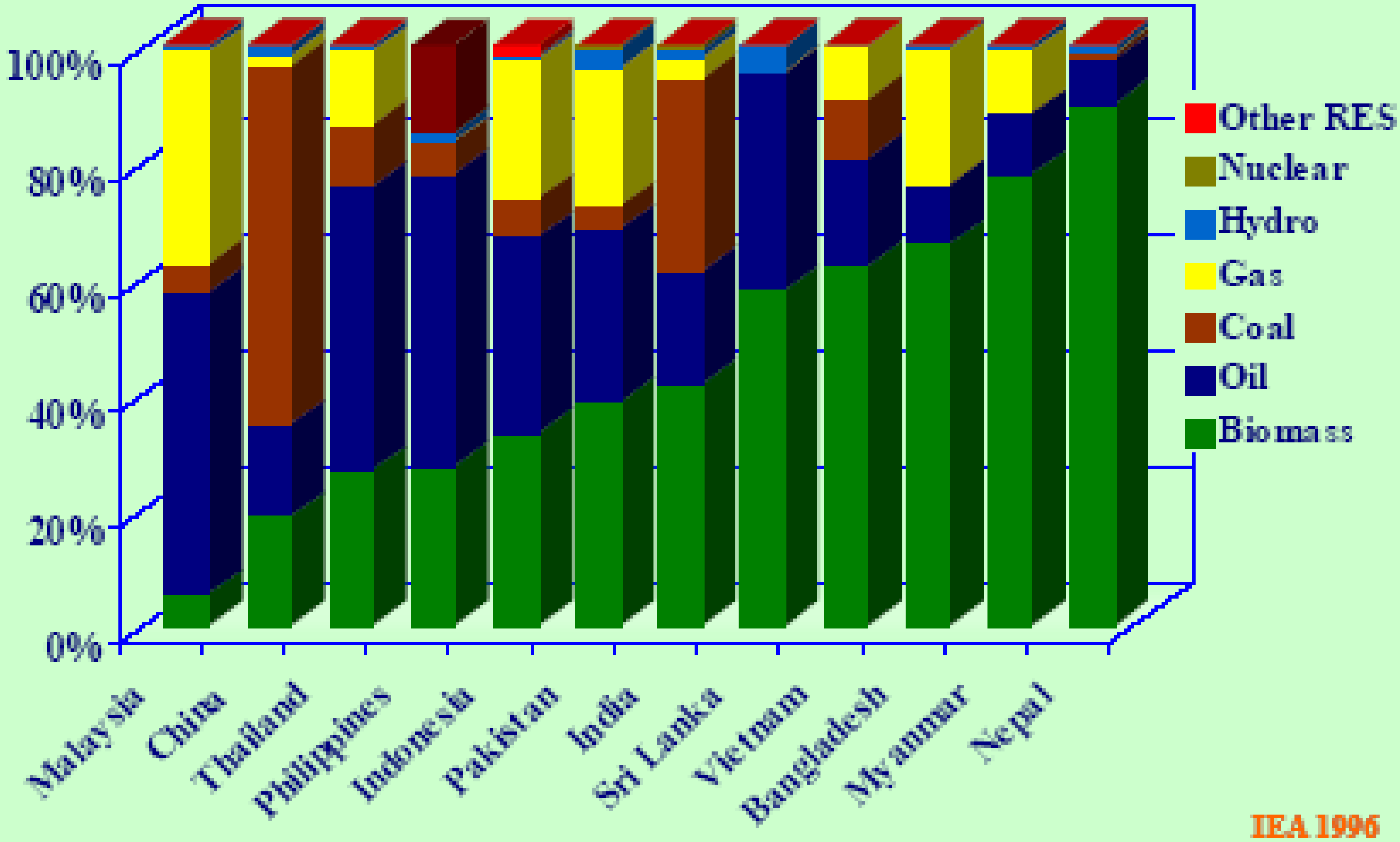
Energy Sources



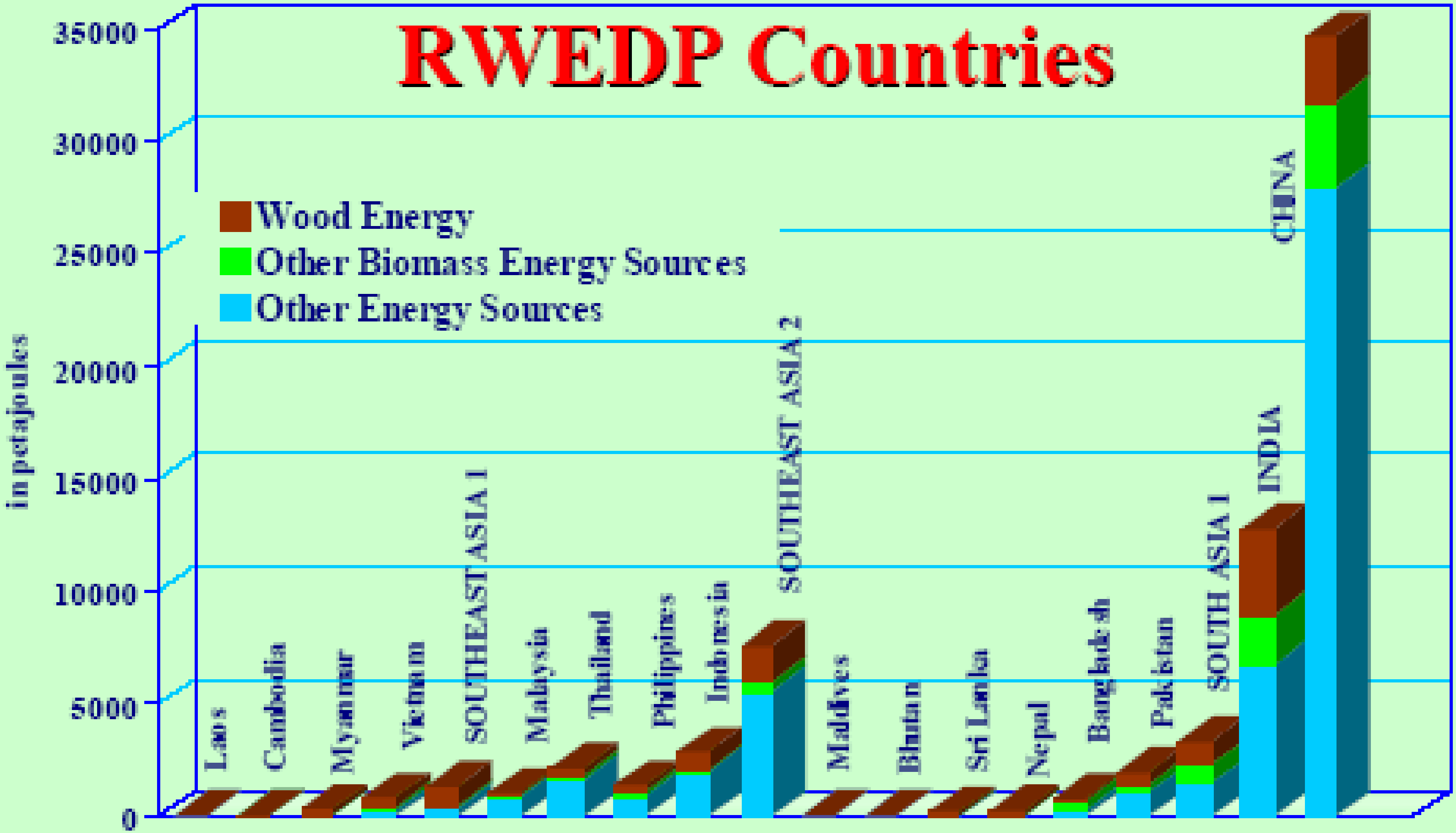
By Regions



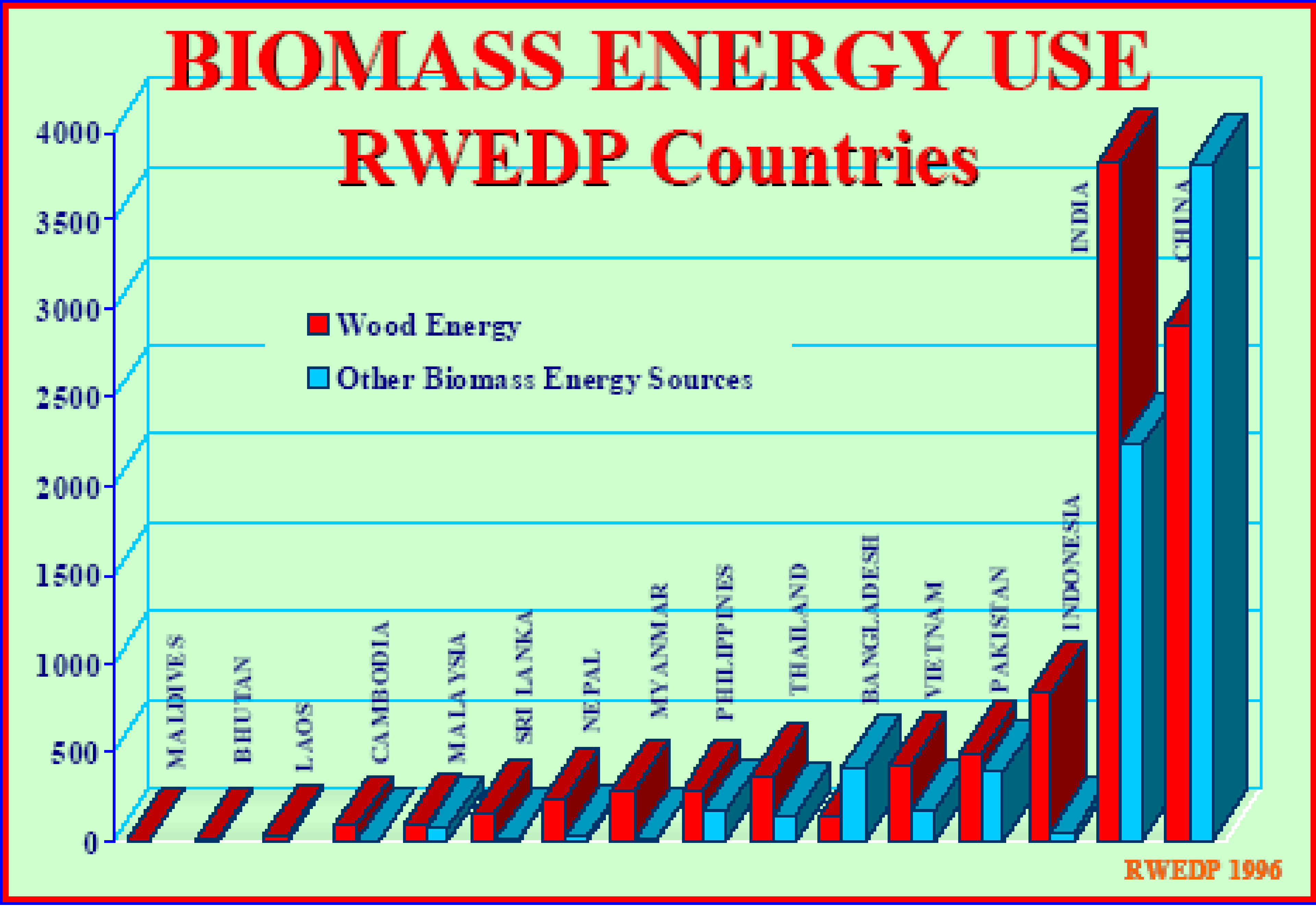
PRIMARY ENERGY SUPPLY RWEDP Countries



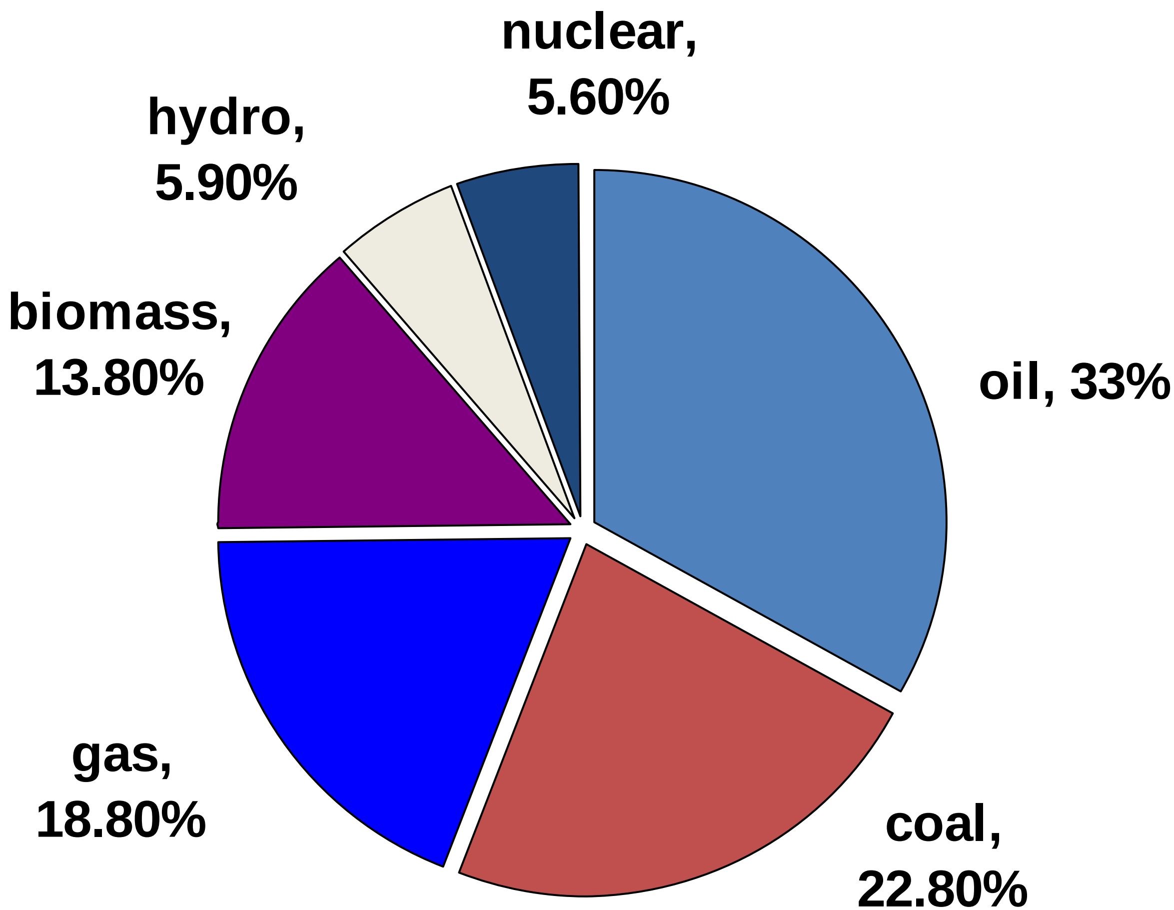
TOTAL ENERGY USE
RWEDP Countries



RWEDP 1996


BIOMASS ENERGY USE
RWEDP Countries
Wood Energy
Other Biomass Energy Sources
4000
3500
3000
2500
2000
1500
1000
500
0
MALDIVES
BHUTAN
LAOS
CAMBODIA
MALAYSIA
SRI LANKA
NEPAL
MYANMAR
PHILIPPINES
THAILAND
BANGLADESH
VIETNAM
PAKISTAN
INDONESIA
INDIA
CHINA
RWEDP 1996

Estimated Annual World Primary energy Consumption by source, 1992



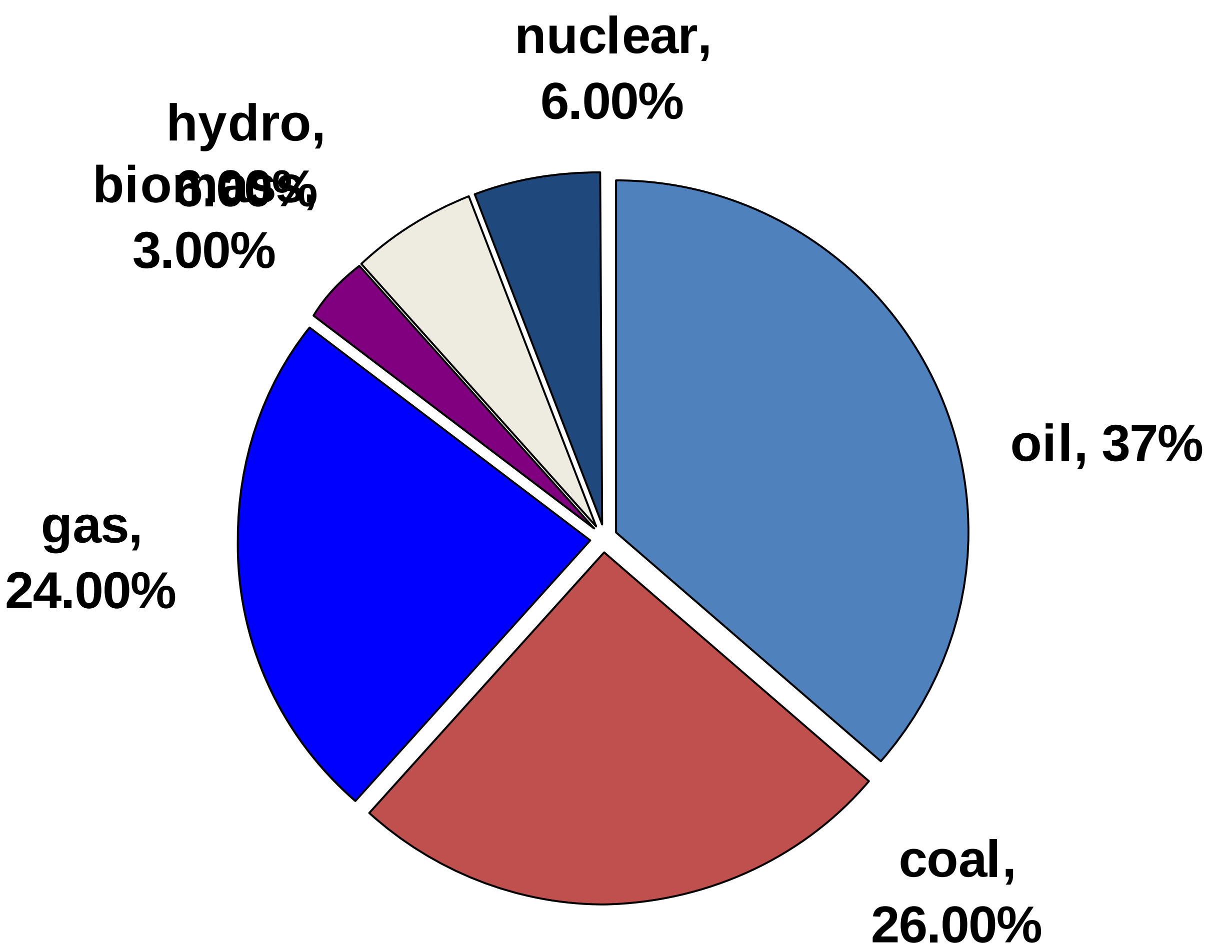
Total : 398 EJ (9476 mtoe)

EJ = exa joule

= 10^{18} J

Source: Renewable Energy, Power for Sustainable Future, Oxford University Press

Estimated Annual Primary energy Consumption by source of Industrialized countries, 1992



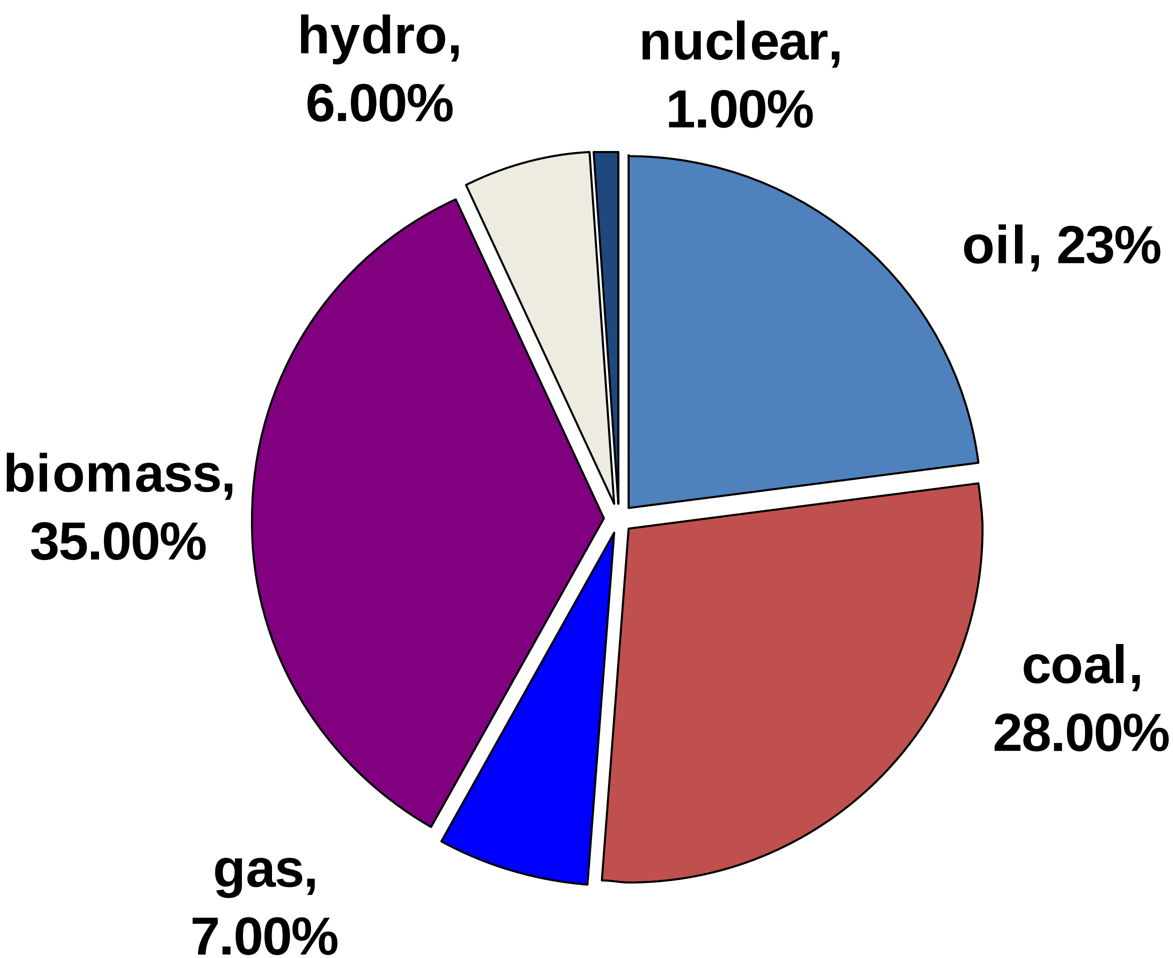
Total : 250 EJ

EJ = exa joule

= 10^{18} J

Source: Renewable Energy, Power for Sustainable Future, Oxford University Press

Estimated Annual Primary energy Consumption by source of Developing countries, 1992



Total : 150 EJ

EJ = exa joule

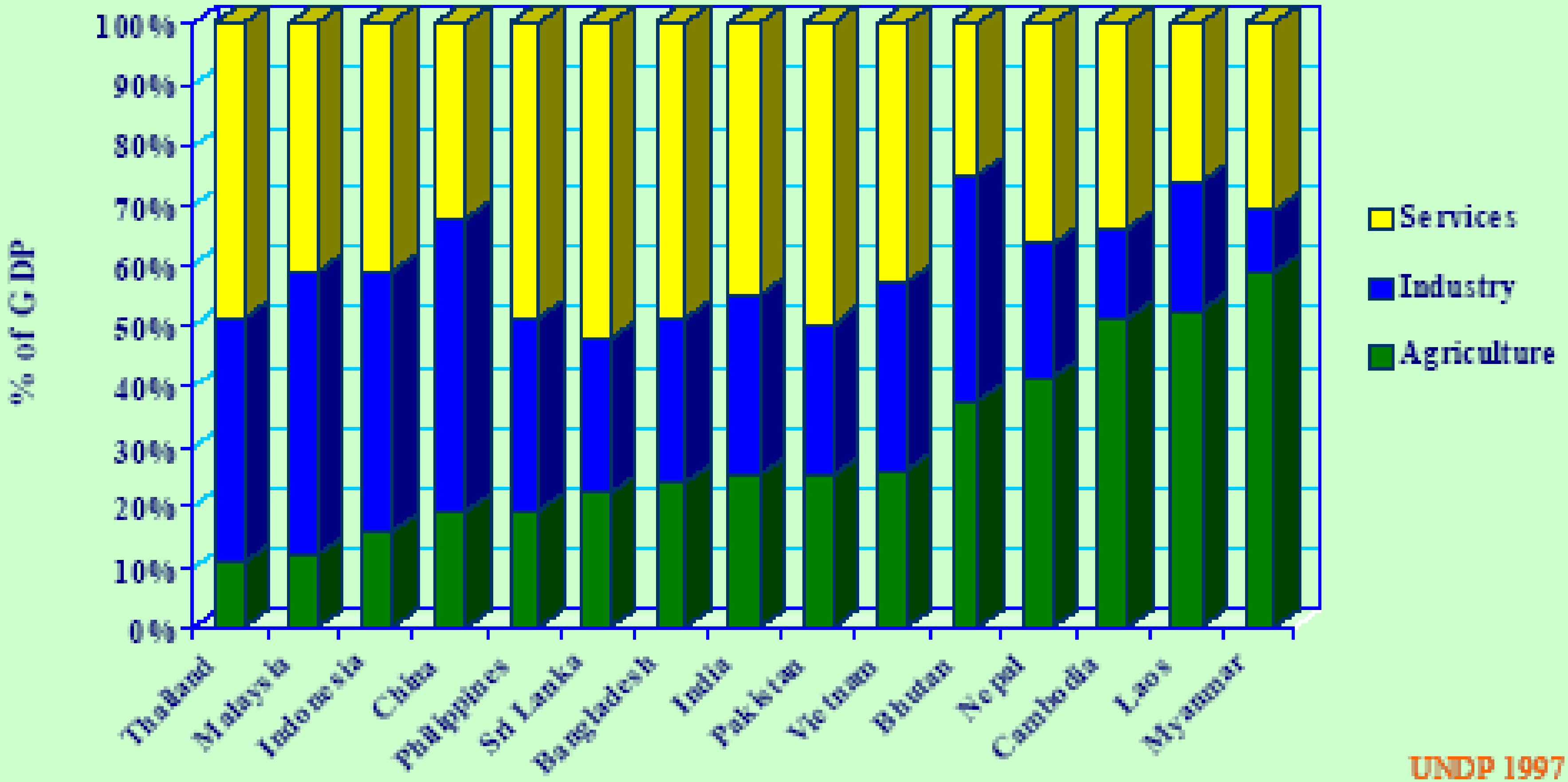
= 10^{18} J

Source: Renewable Energy, Power for Sustainable Future, Oxford University Press

ECONOMIC SECTORS

Percentages of GDP

RWEDP Countries



UNDP 1997

Biomass composition in the energy consumption pattern of some countries

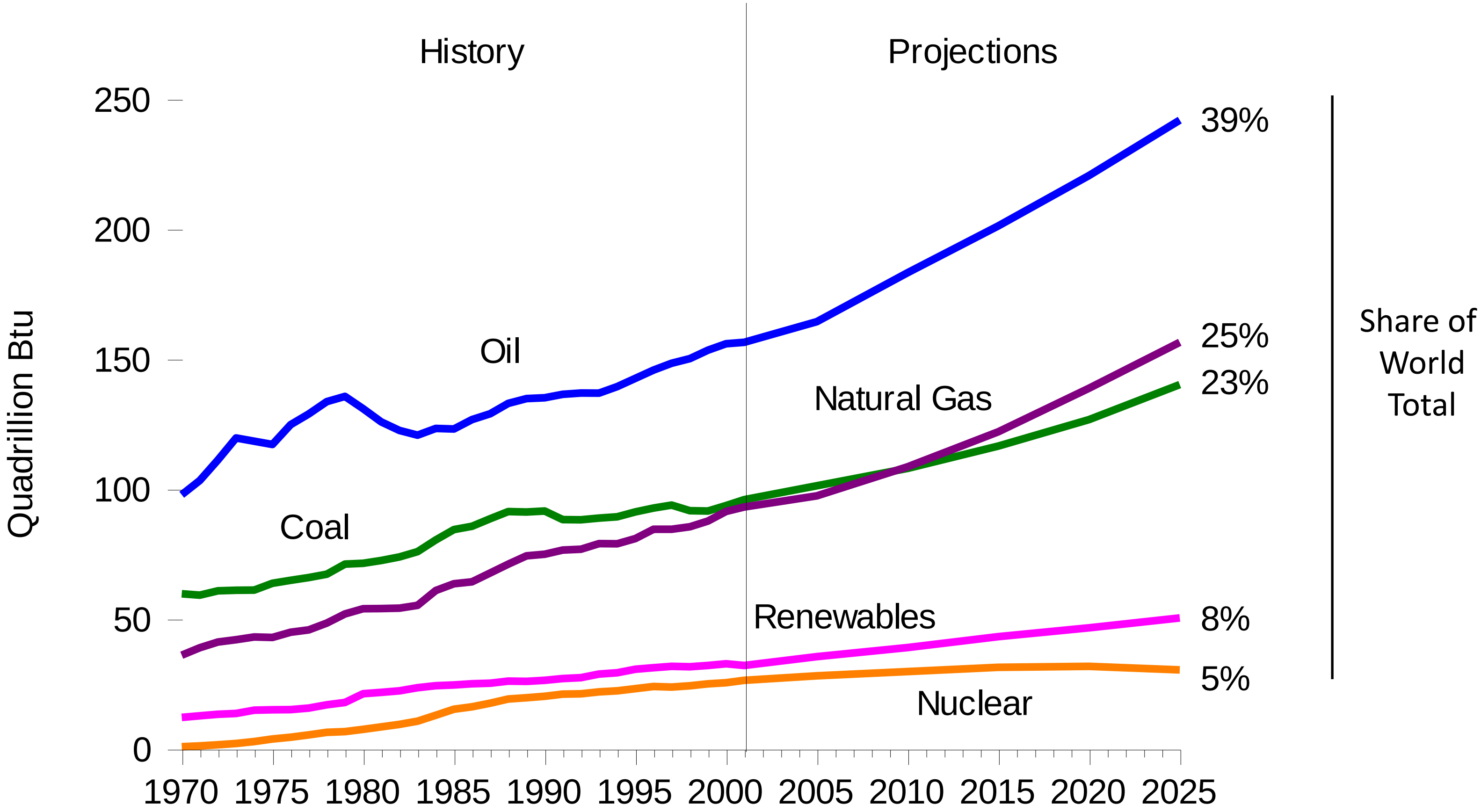
Third World countries	40%
Canada	14%
Sweden	8%
Brazil	25%
India	52%
Kenya	75%
Nepal	85%

Table 1.1 Wood and biomass energy consumption in RWEDP countries (1995/96)

Unit: TJ	Wood Energy	Biomass Energy	Total Energy	Share of Wood in Total Energy	Share of Biomass in Total Energy
Bangladesh	143,700	563,600	845,100	17%	67%
Bhutan	13,225	13,225	16,145	82%	82%
Cambodia	78,818	80,460	94,591	83%	85%
China	2,911,362	6,716,663	34,690,295	8%	19%
India	3,832,597	6,060,327	12,826,698	30%	47%
Indonesia	837,222	891,948	2,921,332	29%	31%
Laos	35,368	35,368	40,763	87%	87%
Malaysia	82,689	154,073	1,082,036	8%	14%
Maldives	1,355	1,355	4,133	33%	33%
Myanmar	286,380	289,275	335,237	85%	86%
Nepal	236,386	264,605	297,765	79%	89%
Pakistan	491,907	882,828	1,960,134	25%	45%
Philippines	287,160	451,080	1,397,340	21%	32%
Sri Lanka	159,279	164,332	250,013	64%	66%
Thailand	369,903	521,591	2,212,598	17%	24%
Vietnam	429,000	604,000	891,600	48%	68%

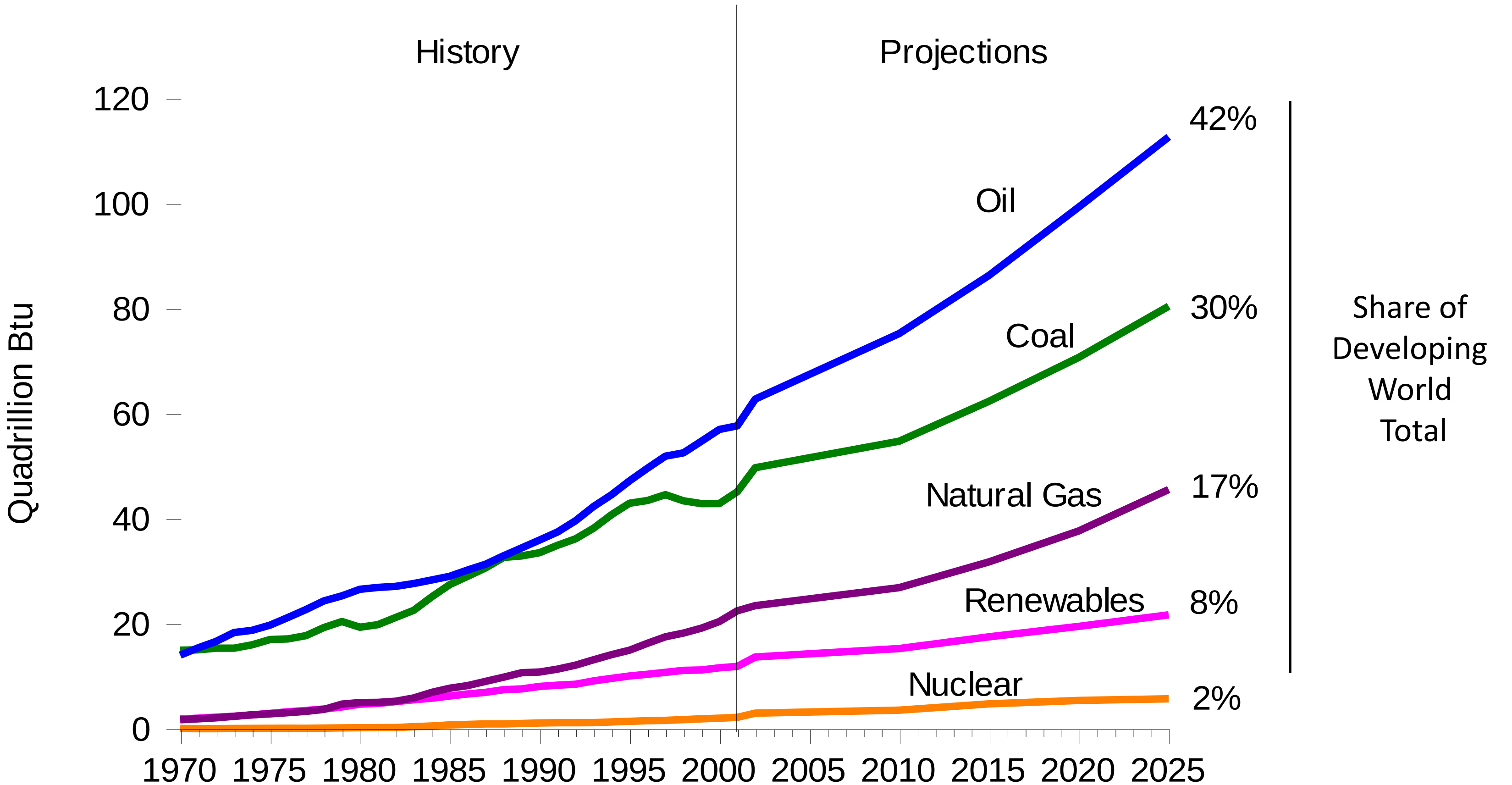
Source: RWEDP Wood Energy Database (http://www.RWEDP.org)

World Primary Commercial Energy Consumption by Fuel Type, 1970-2025



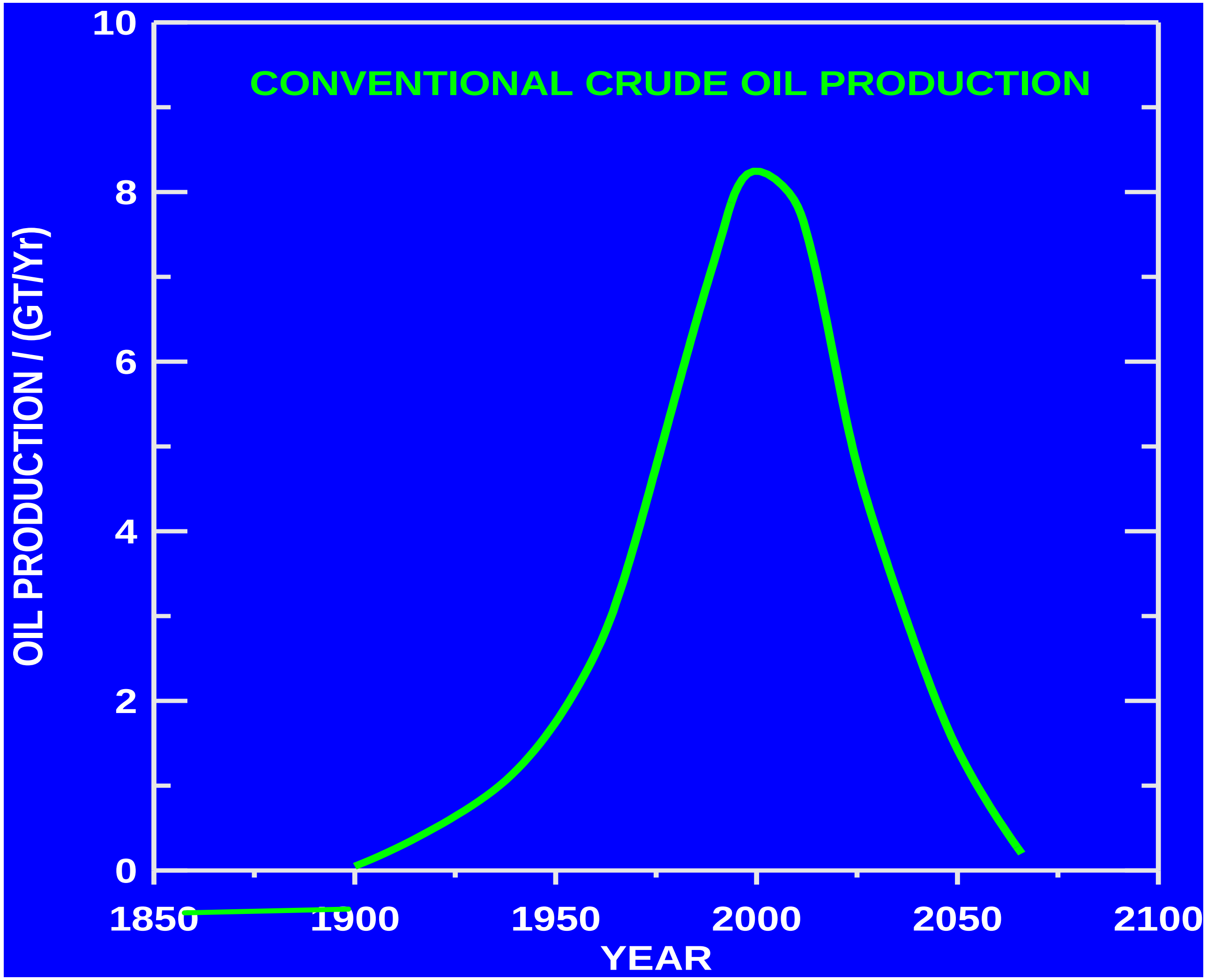
Source: EIA, *International Energy Outlook 2004*

Developing World Primary Commercial Energy Consumption by Fuel Type, 1970-2025

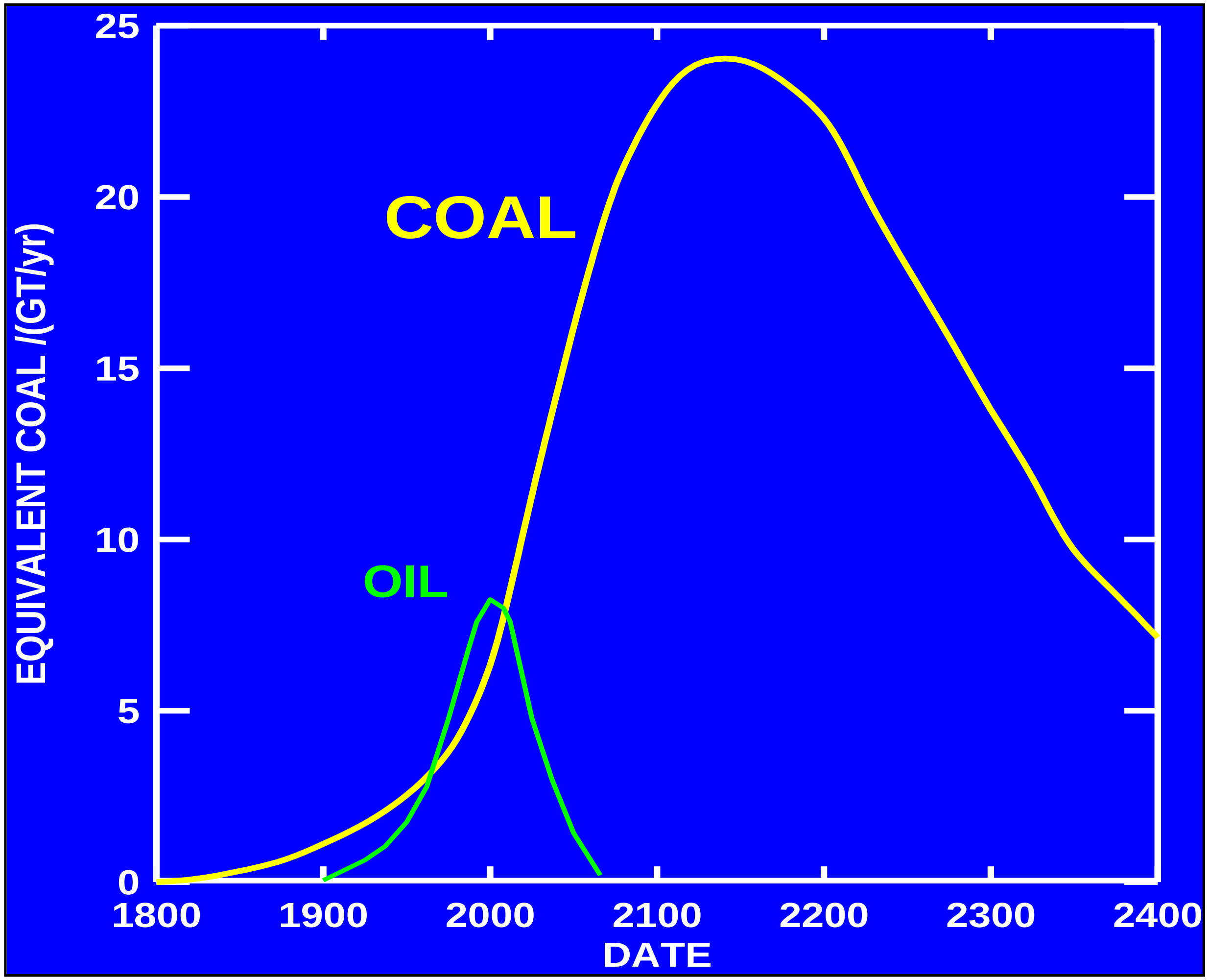


Source: EIA, *International Energy Outlook 2004*

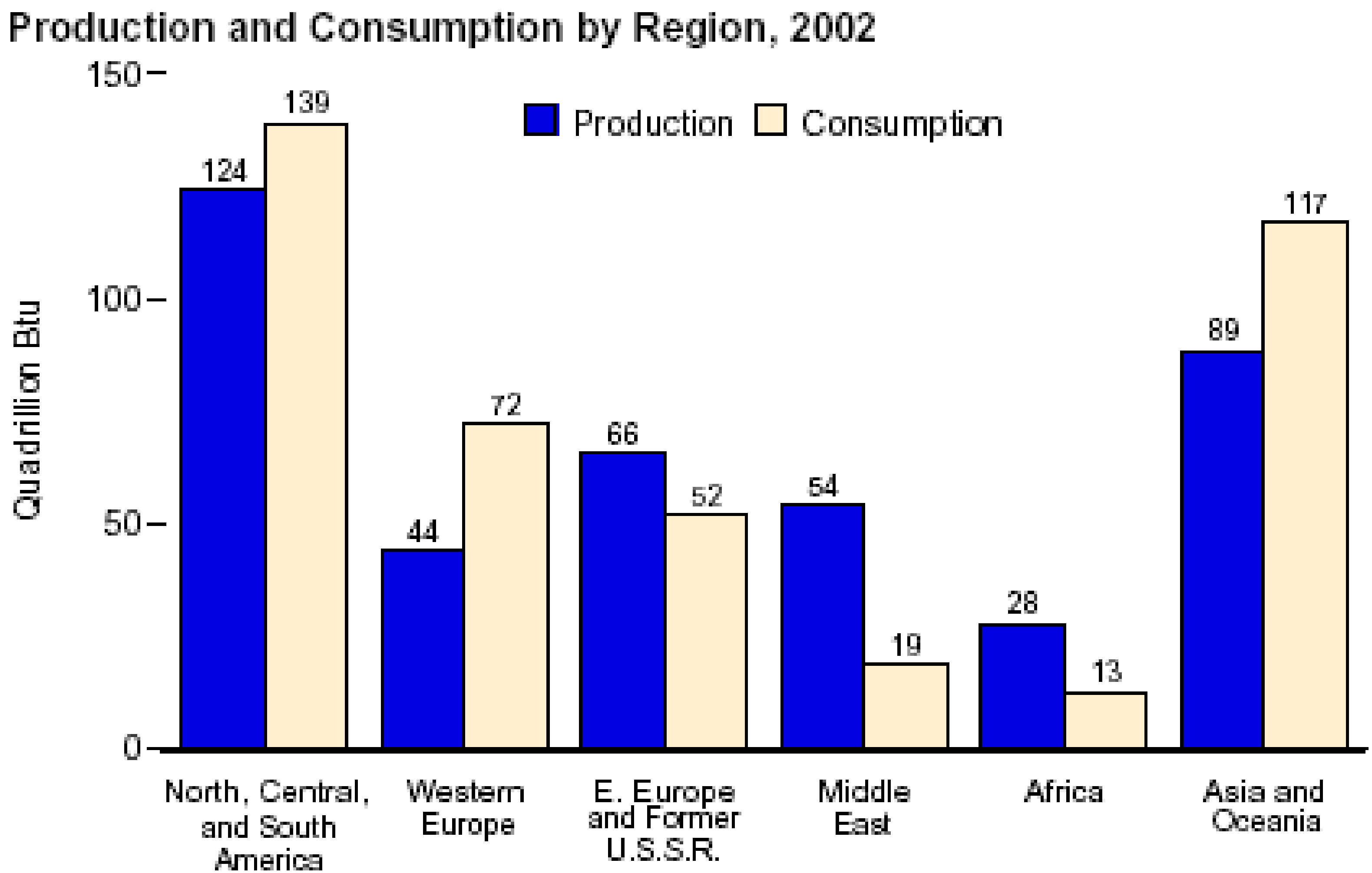
Are We Running Out of Petroleum ?



POTENTIAL COAL PRODUCTION

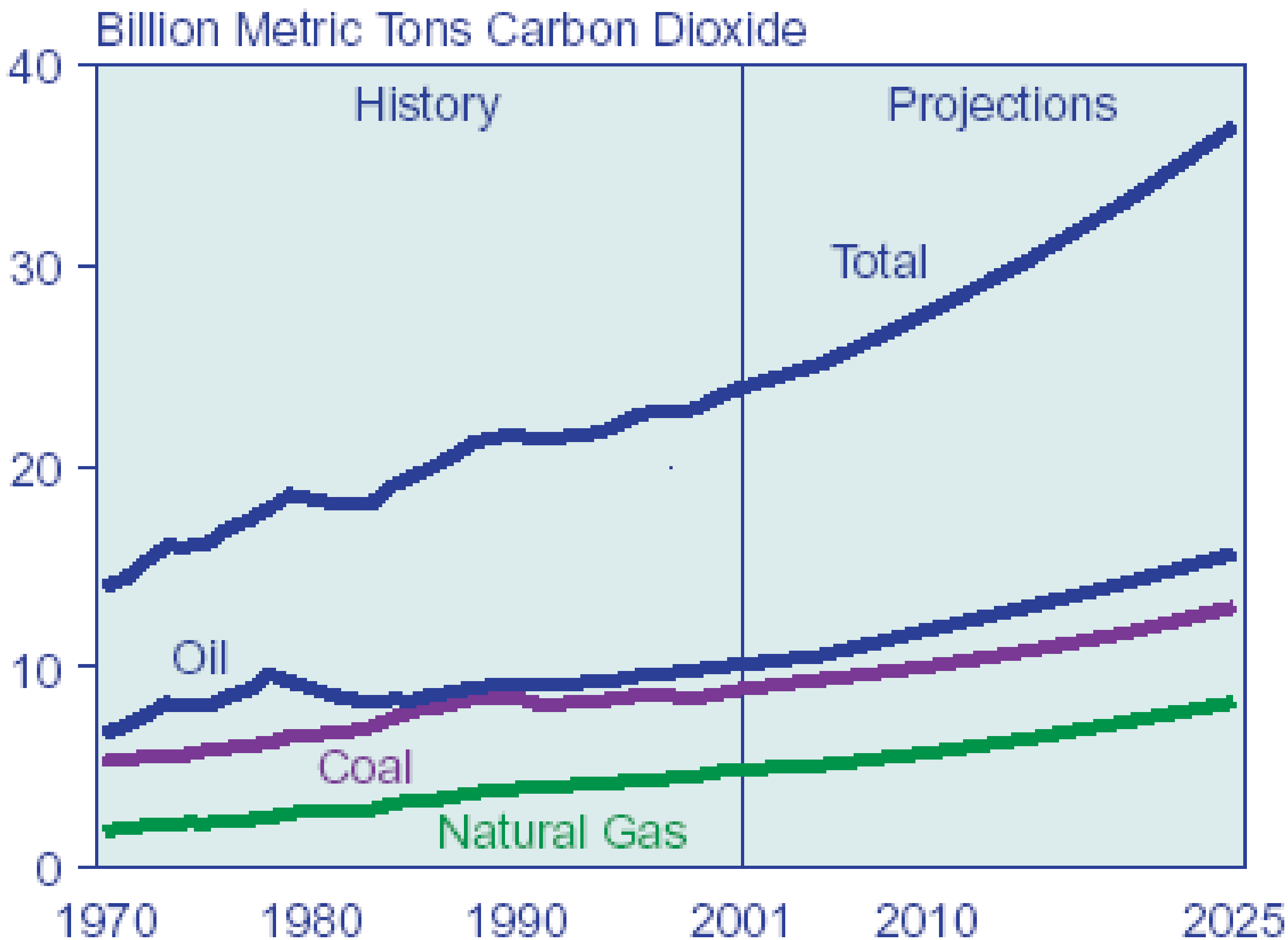


World Primary Energy Consumption



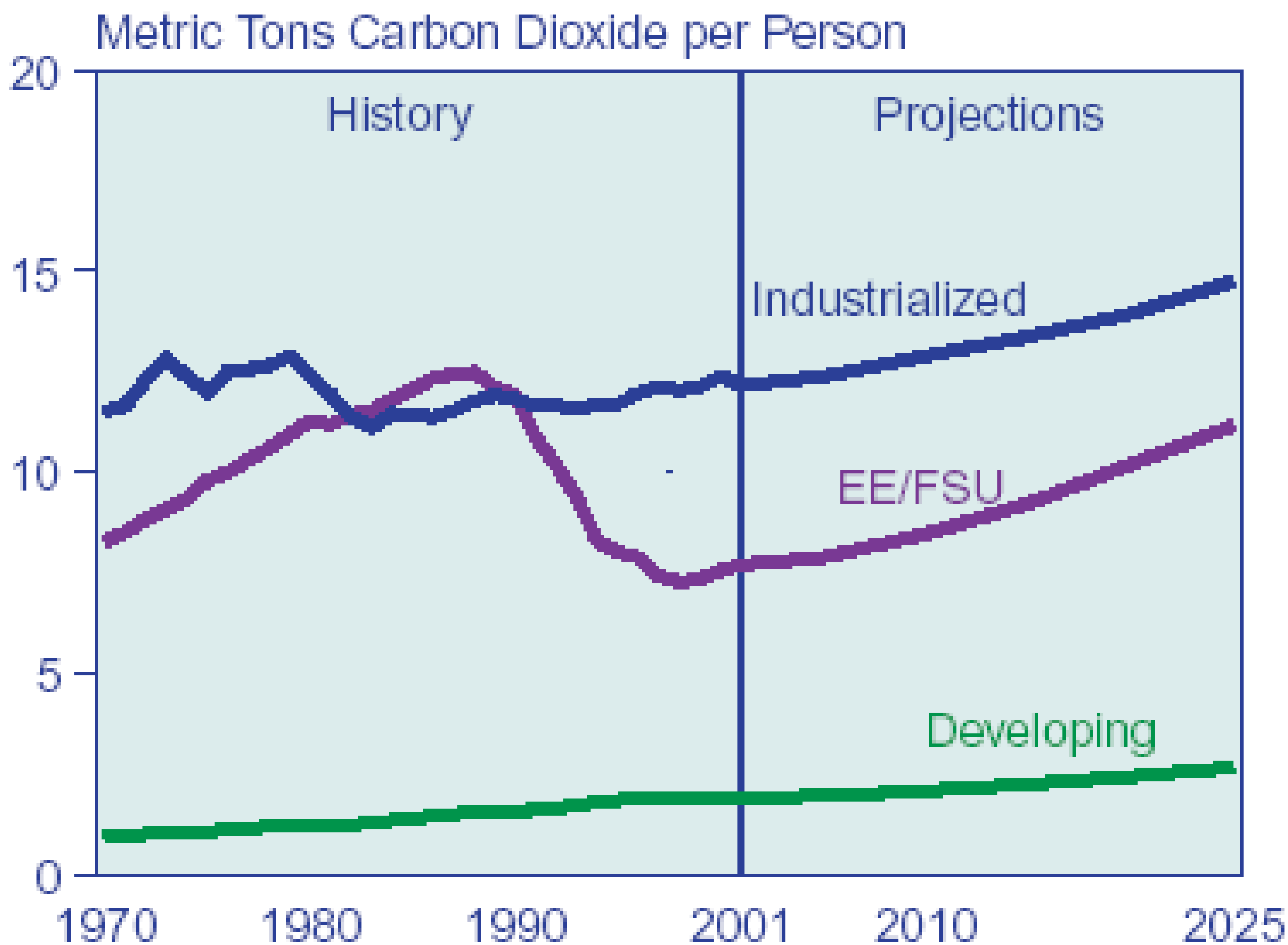
Source: Energy Information Administration/Annual Energy Review 2003

World Energy-related CO_2 Emissions by Fuel Type, 1970-2025



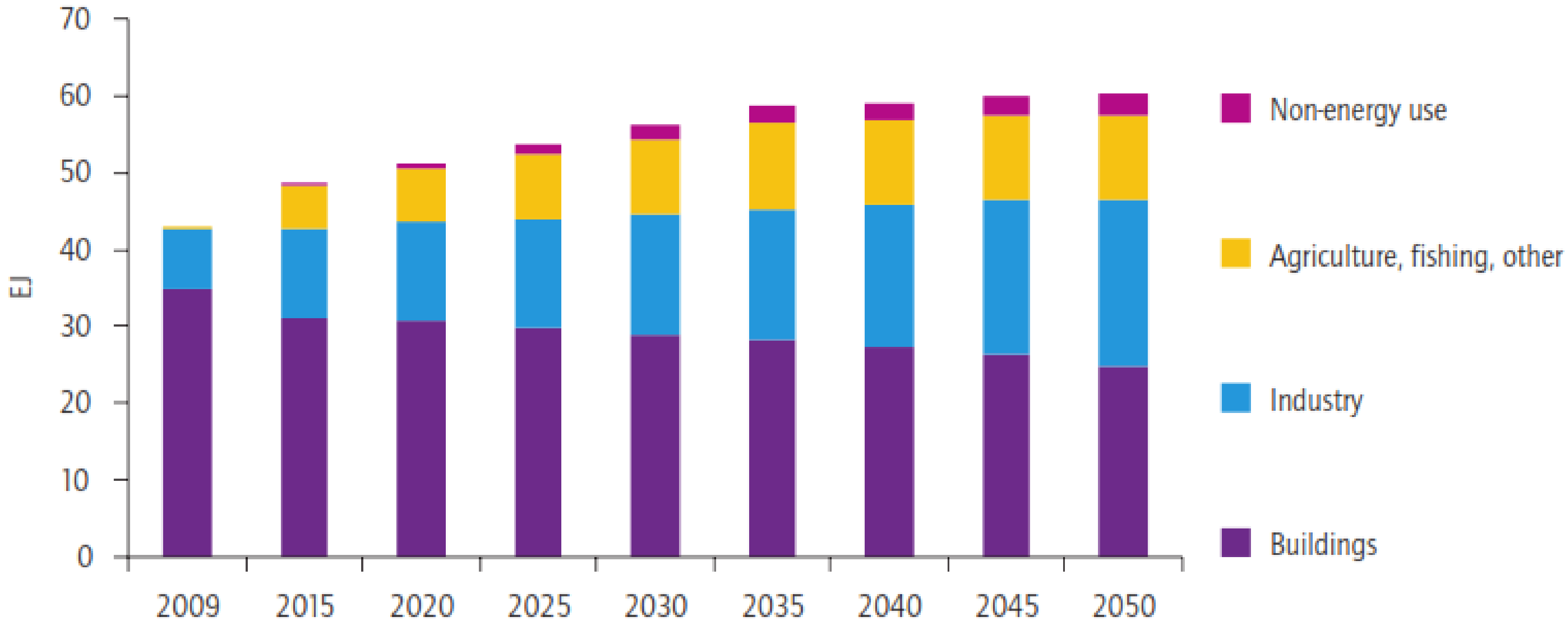
Source: History: EIA, *International Energy Annual 2001*.

Energy-related CO_2 Emissions per Capita by Region, 1970-2025



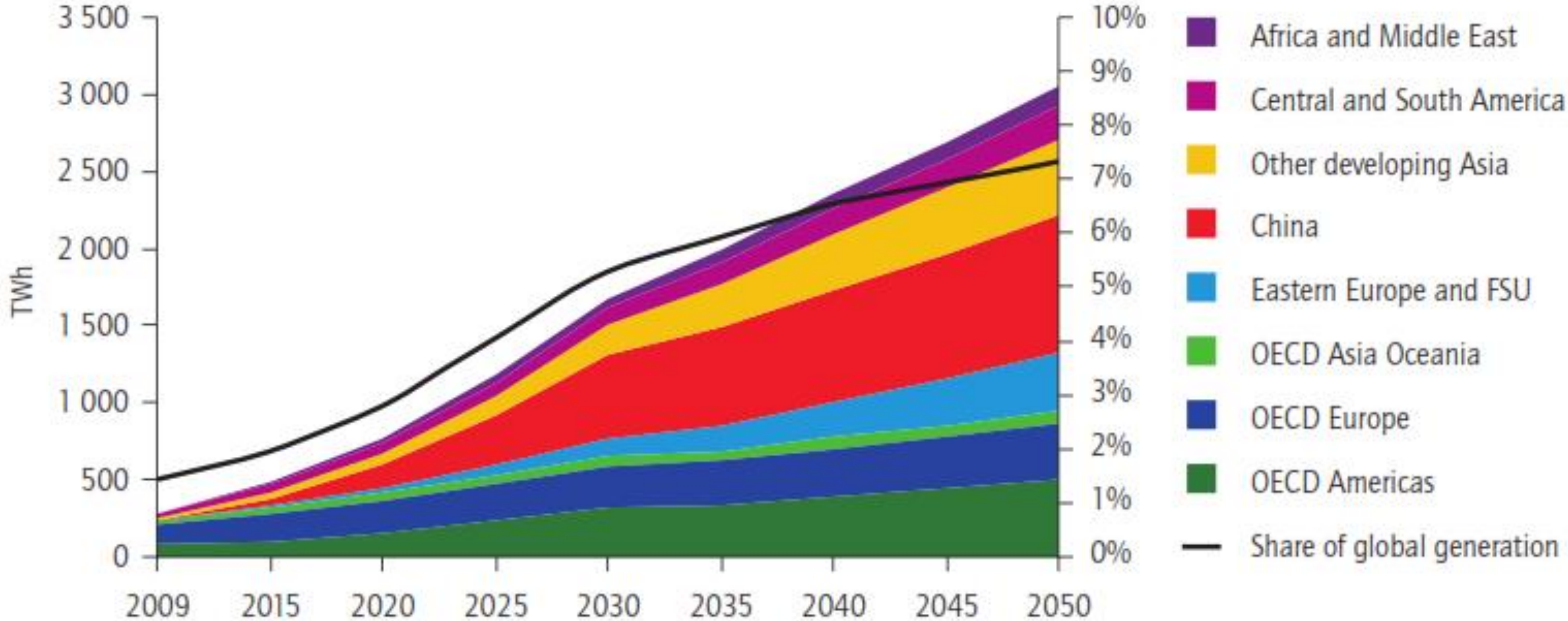
Source: History: EIA, *International Energy Annual 2001*.

Roadmap vision of world final bioenergy consumption in different sectors (IEA, 2012)



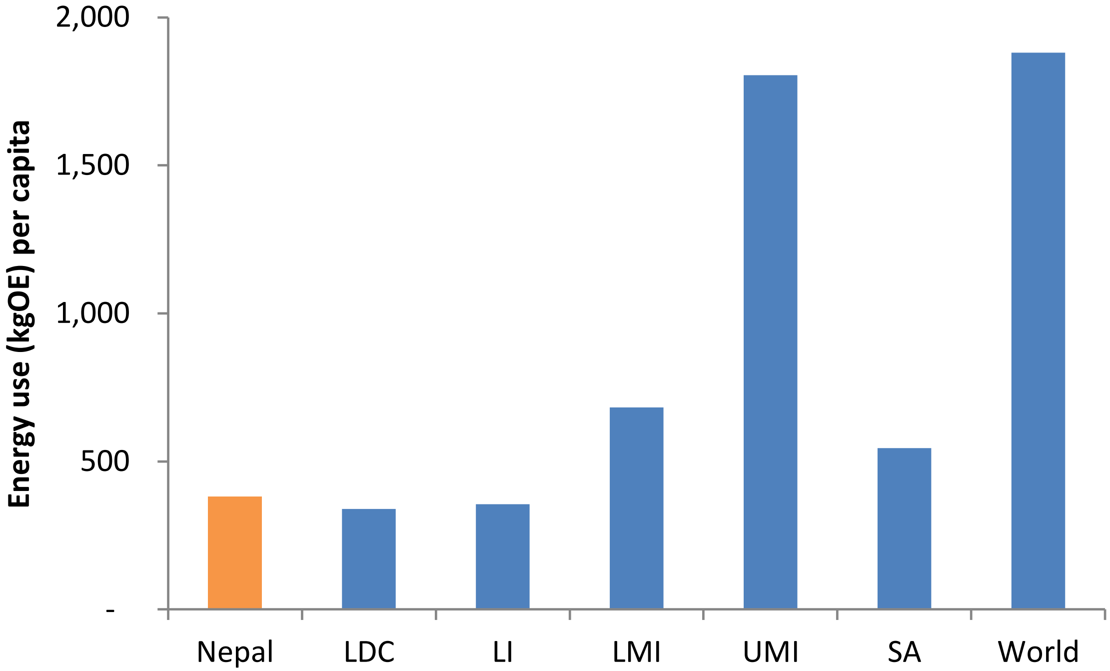
Note: Bioenergy use in the buildings sector is for both heating and cooking. Demand for transport fuels is not shown here since this has been discussed in a previous roadmap (IEA, 2011b).

Roadmap vision of bioenergy electricity generation by region (IEA, 2012)



Where R We?

Low energy use, security and access are Nepal's key challenges



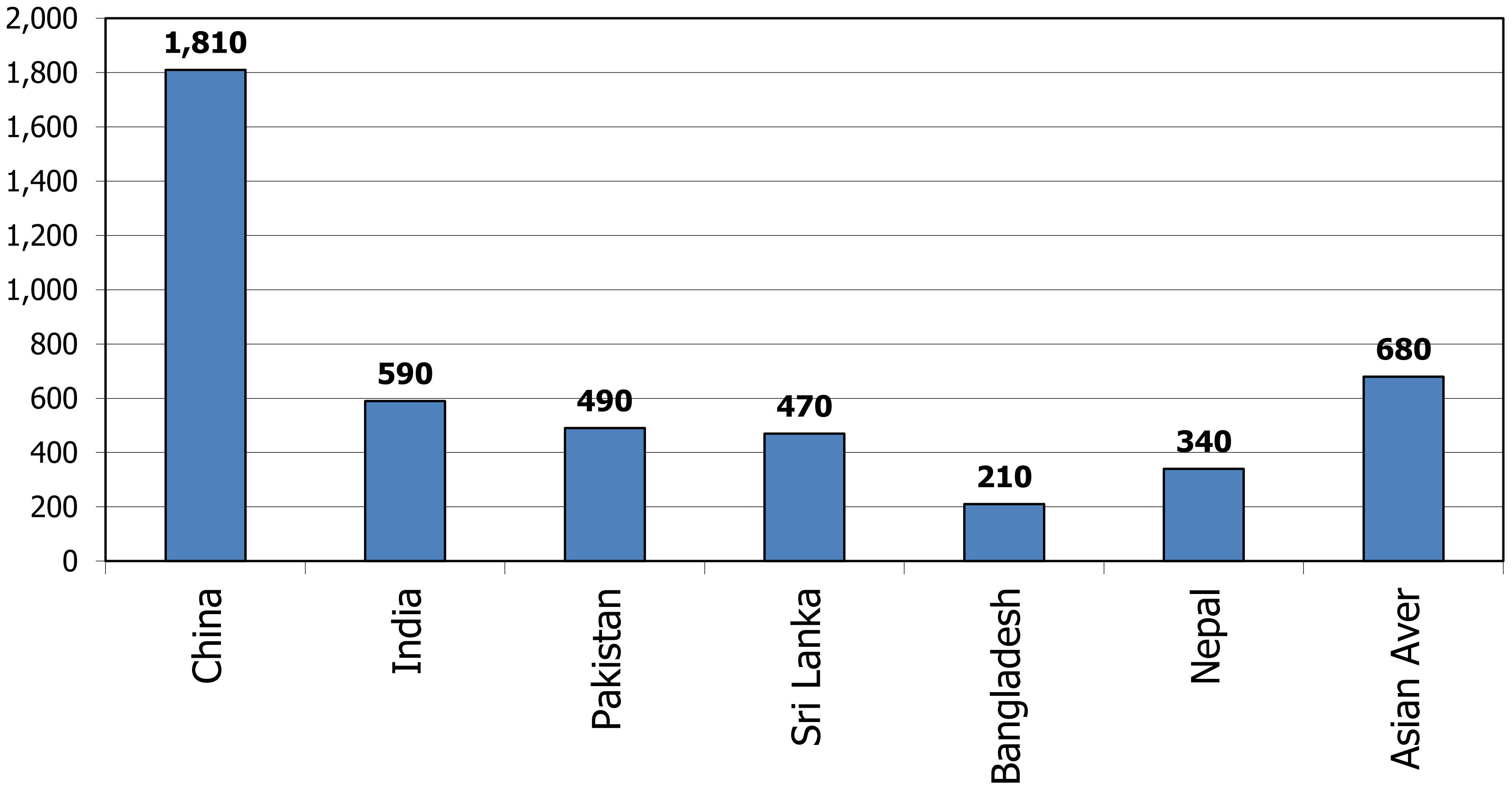
Very low per-capita energy use

- 55% of average of lower middle income countries
- 20% of world average

Source: World Development Indicators; data year – 2010; LDC – least developed countries; LI – low income countries; LMI – lower middle income; UMI – upper middle income; SA – South Asia; kgOE – kg Oil Equivalent

Source: Draft Energy Efficiency Strategy 2015, Courtesy of S.R.Shakya

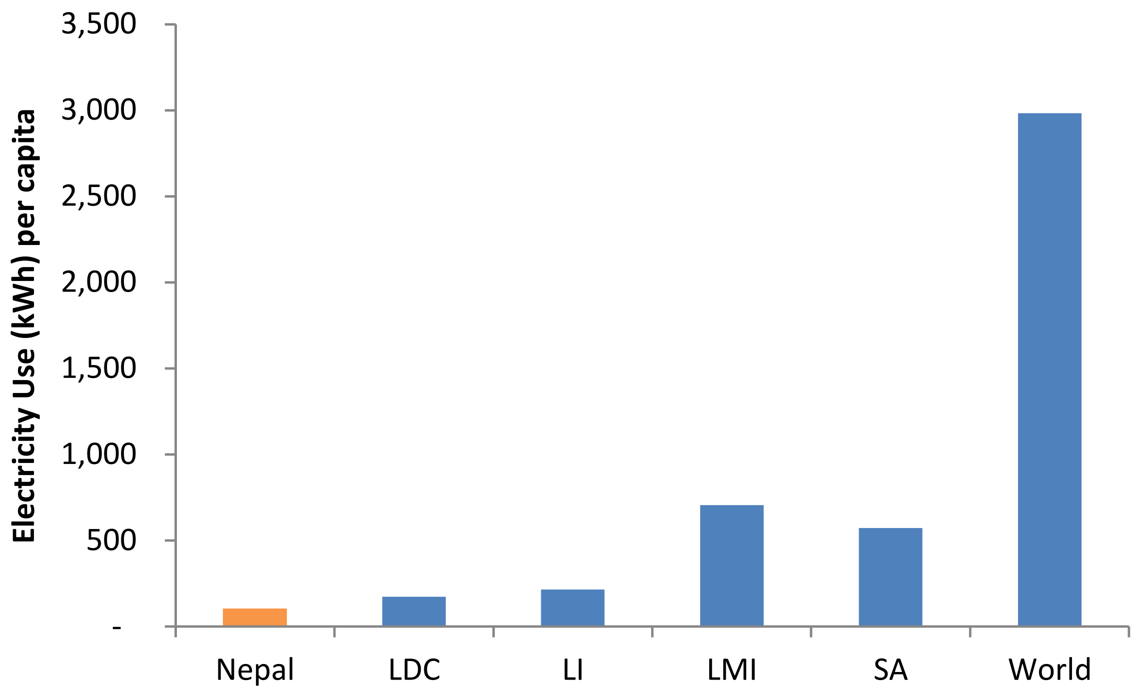
Per Capita Primary Energy Supply in 2010 (kgoe)



- **Low per capita primary energy supply**

Source: IEA (2012)

Low energy use, security and access are Nepal's key challenges



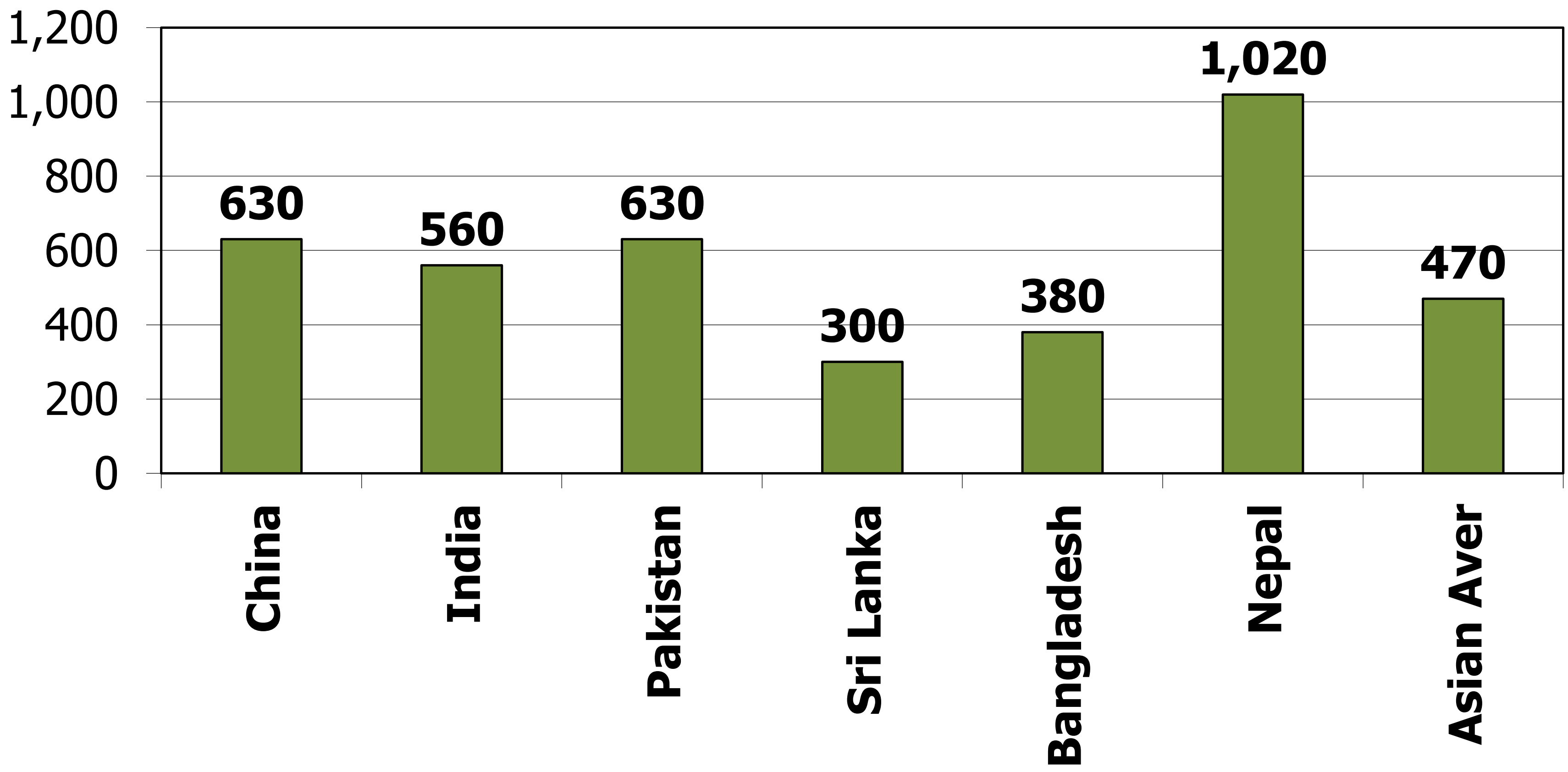
Very lower per-capita electricity consumption

- 59% of LDC average
- 47% of lower income countries average
- 18% of South Asia average

Source: World Development Indicators; data year – 2010; LDC – least developed countries; LI – low income countries; LMI – lower middle income; UMI – upper middle income; SA – South Asia; kgOE – kg Oil Equivalent

Source: Draft Energy Efficiency Strategy 2015, Courtesy of S.R.Shakya

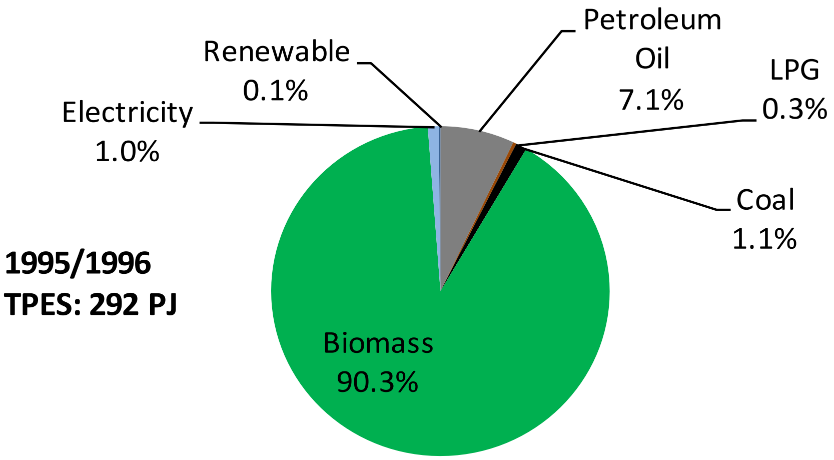
Primary Energy Supply/US$1,000 (GDP) in 2010 (kgoe) (Energy Intensity)

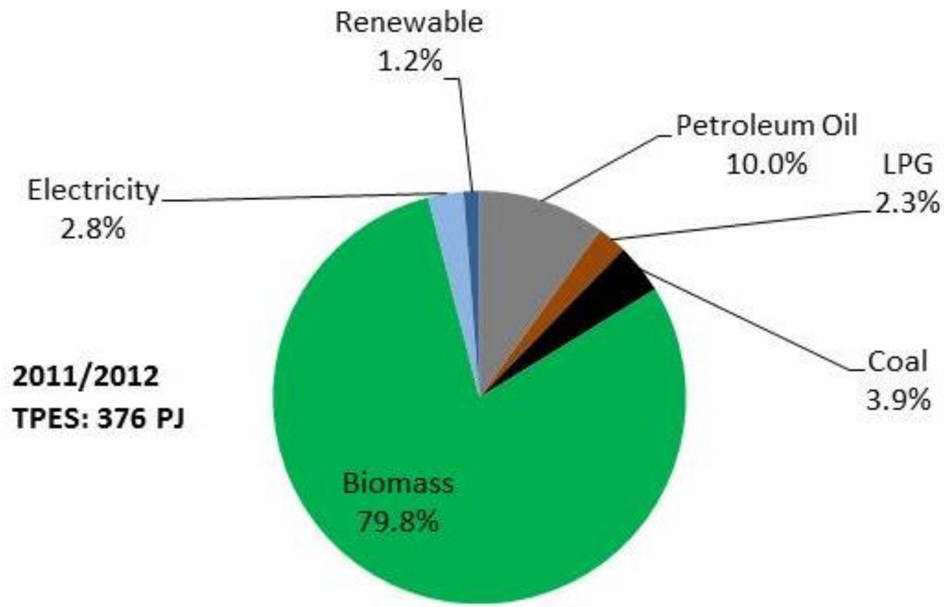


- **High energy intensity due to inefficient production sector**

Source: IEA (2012)

Energy Consumption Trend in Nepal during 1995/1996 to 2011/2012, PJ



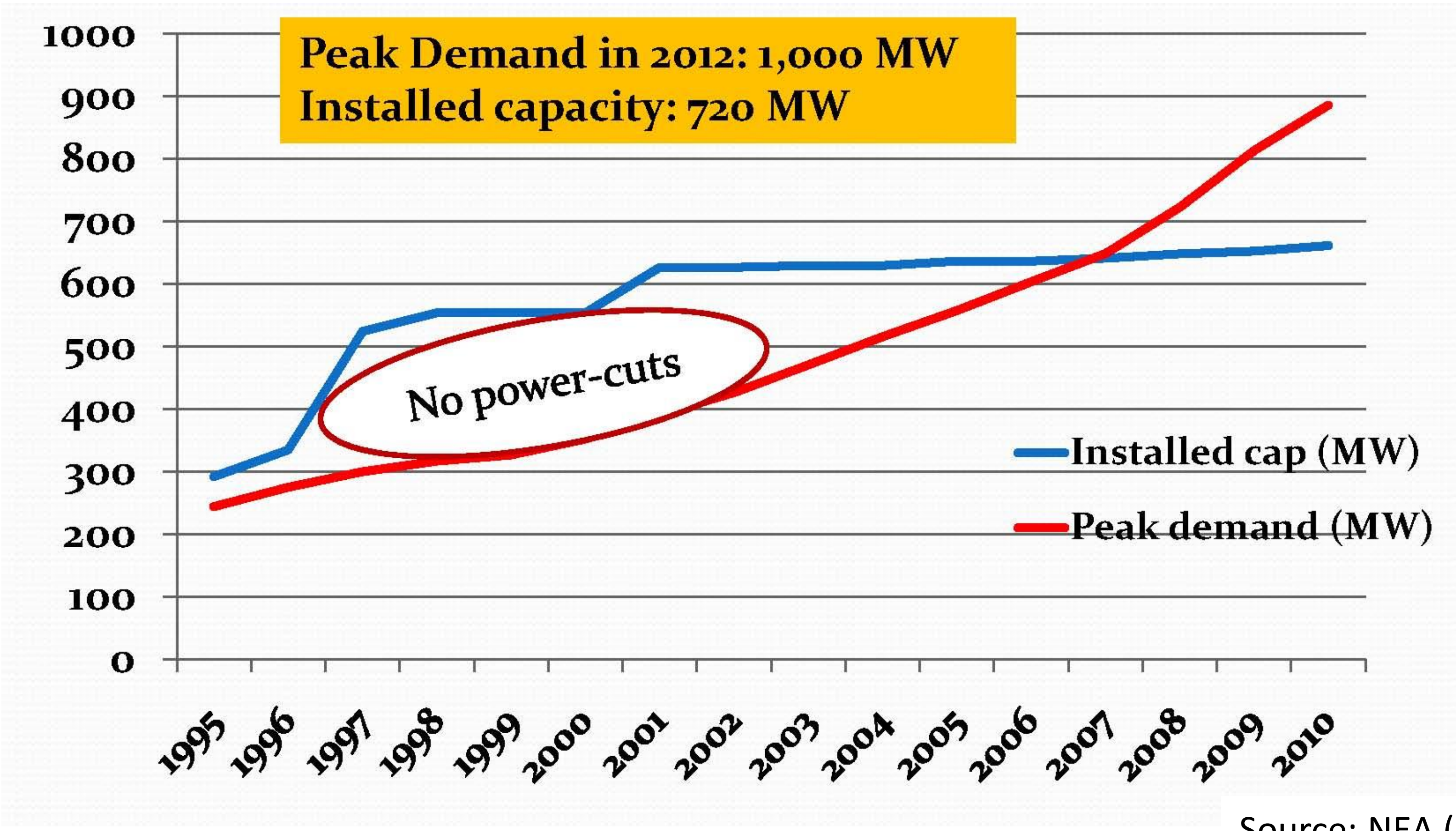


Source: WECS (1997, 2013)

- **Total energy consumption in the country was about 292 Peta Joule (PJ) in 1995/96. It increased by 29% at the annual growth rate of 1.6% (during 1995/96 to 2011/12)**
- **use of fossil fuels consisting of petroleum products, LPG and coal has increased at the growth rate of 5.8% mostly due to rapid increase in LPG and coal consumption => Energy Supply Security ?????**
- **electricity mostly from hydropower increase at growth rate of 8.0%**
- **Share of RETs increases from 0.1% in 1995/96 to 1.2% in 2011/12. It has got huge potential to replacing non-environment friendly imported fossil fuels and reduce unsustainable use of indigenous biomass resources.**

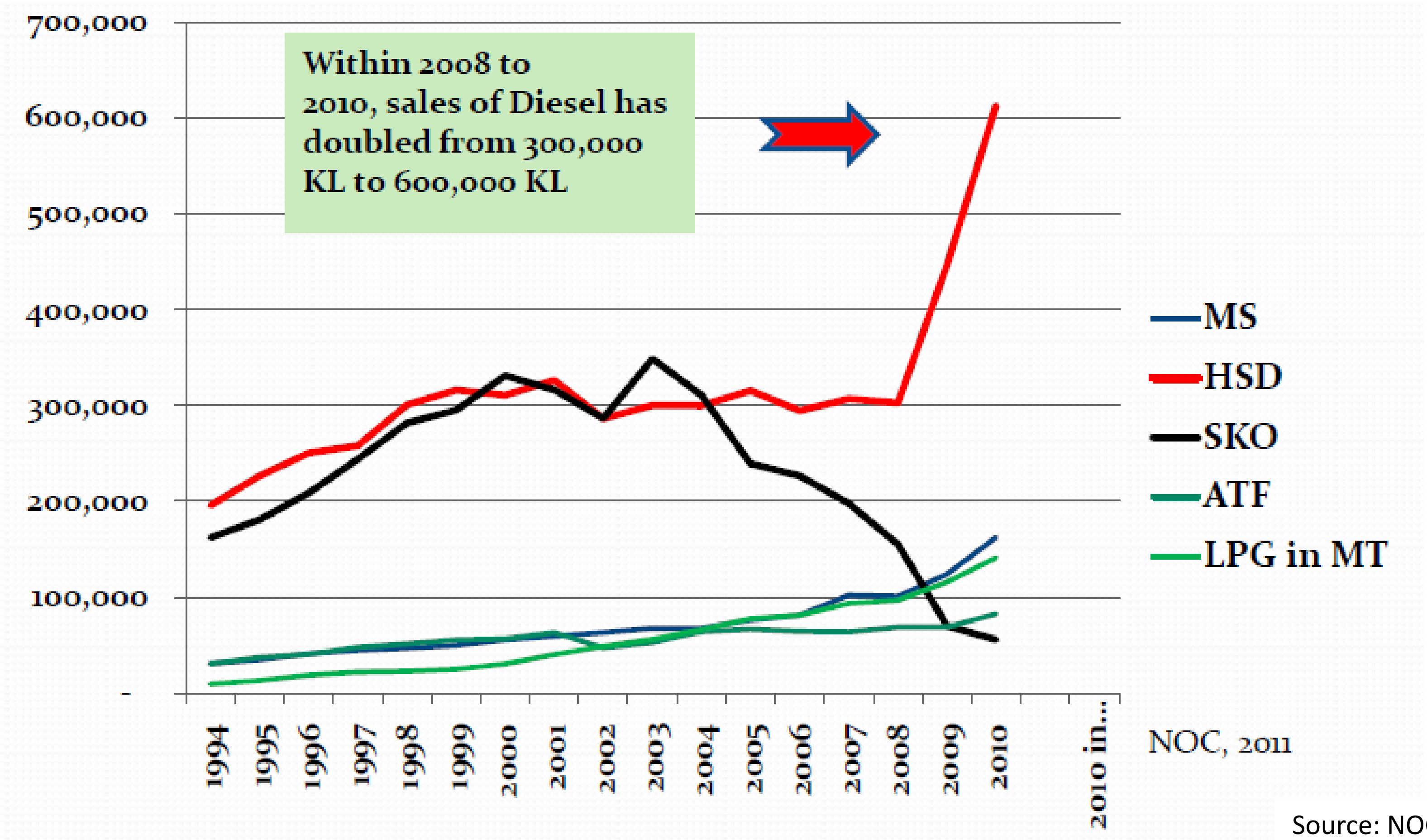
Power Capacity versus peak load

Power capacity development: historical trend



Source: NEA (2012)

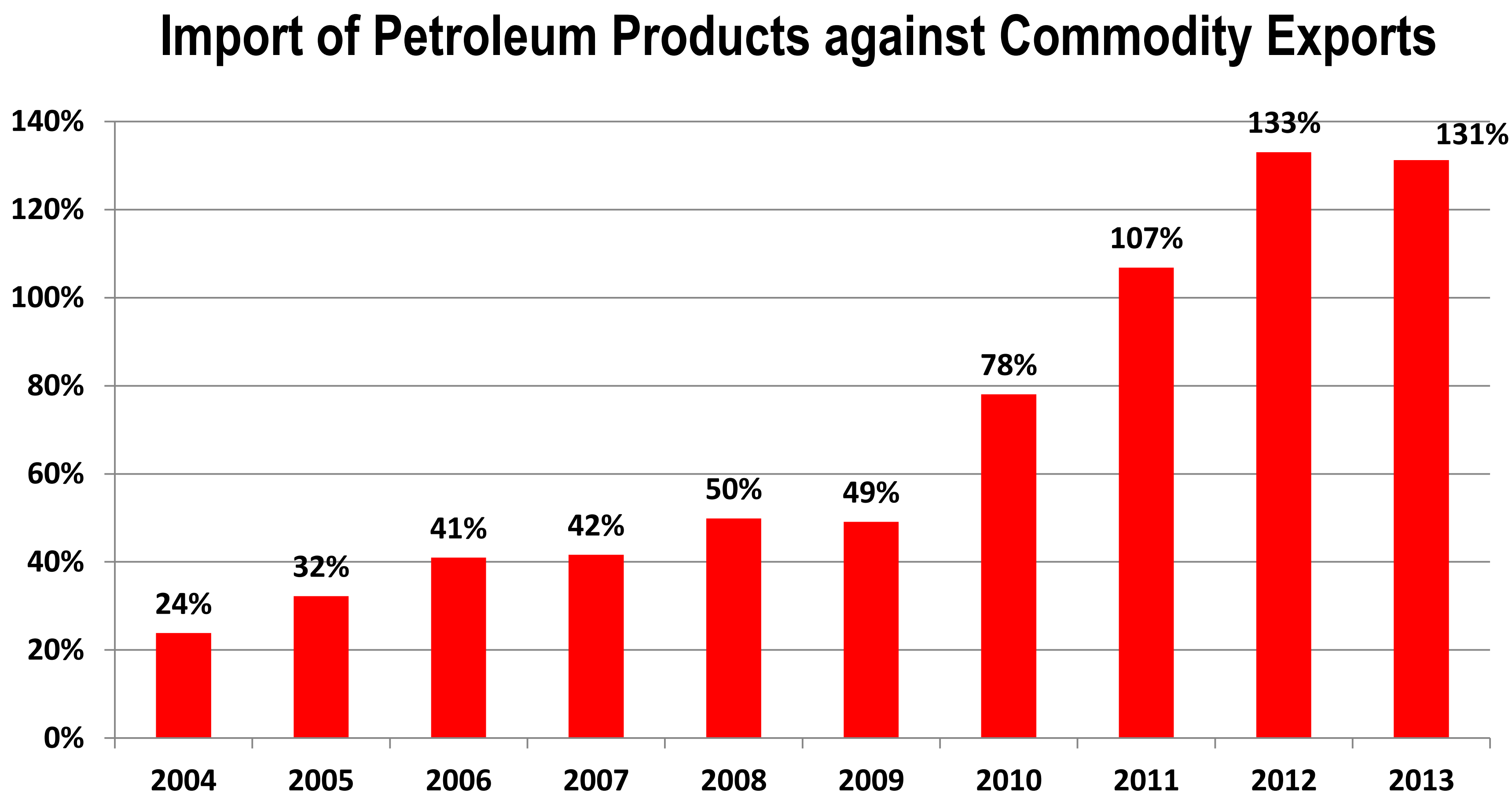
Sales of Petroleum Products from 1994 to 2010



Source: NOC (2011)

- **Unsustainable increase of diesel fuel (gen set) between 2008 – 2010 due to load shedding**
- **Energy Security of Supply ?**

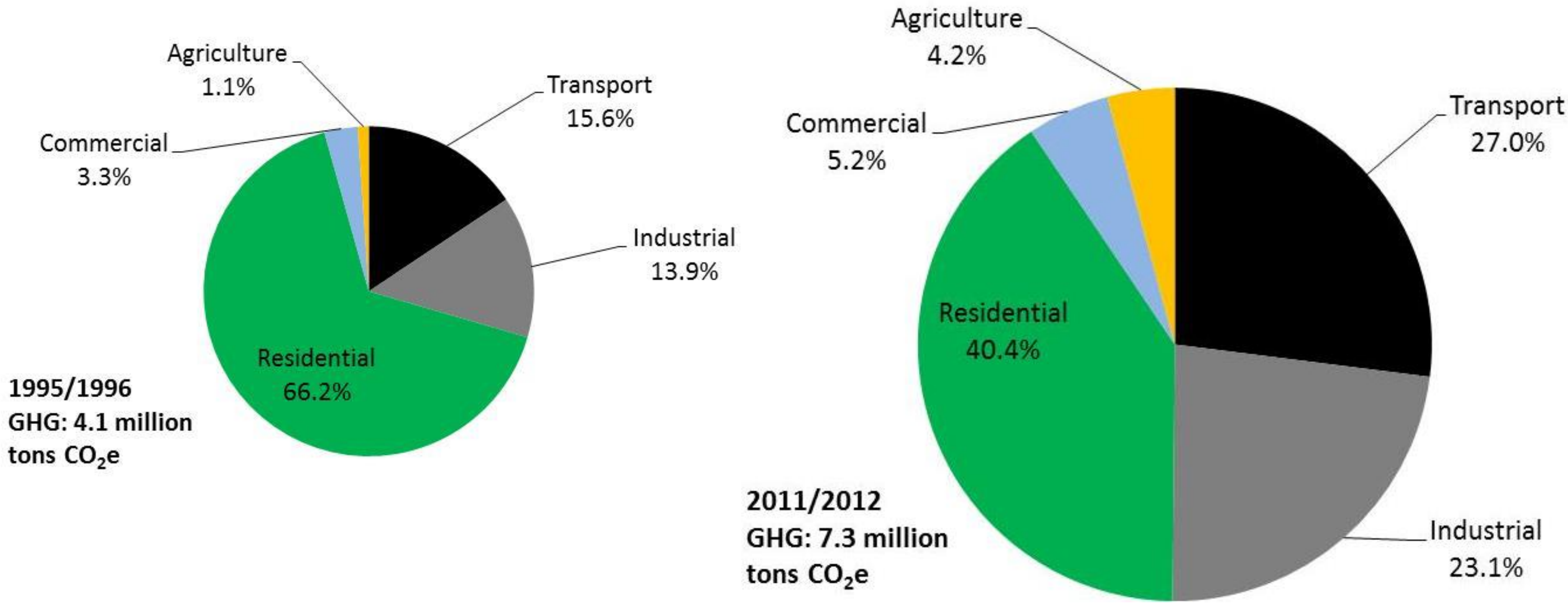
Economic burden from imported Fossil Fuels



- **Economic Vulnerability increasing**

(Source: MOF, 2013; NOC, 2014)

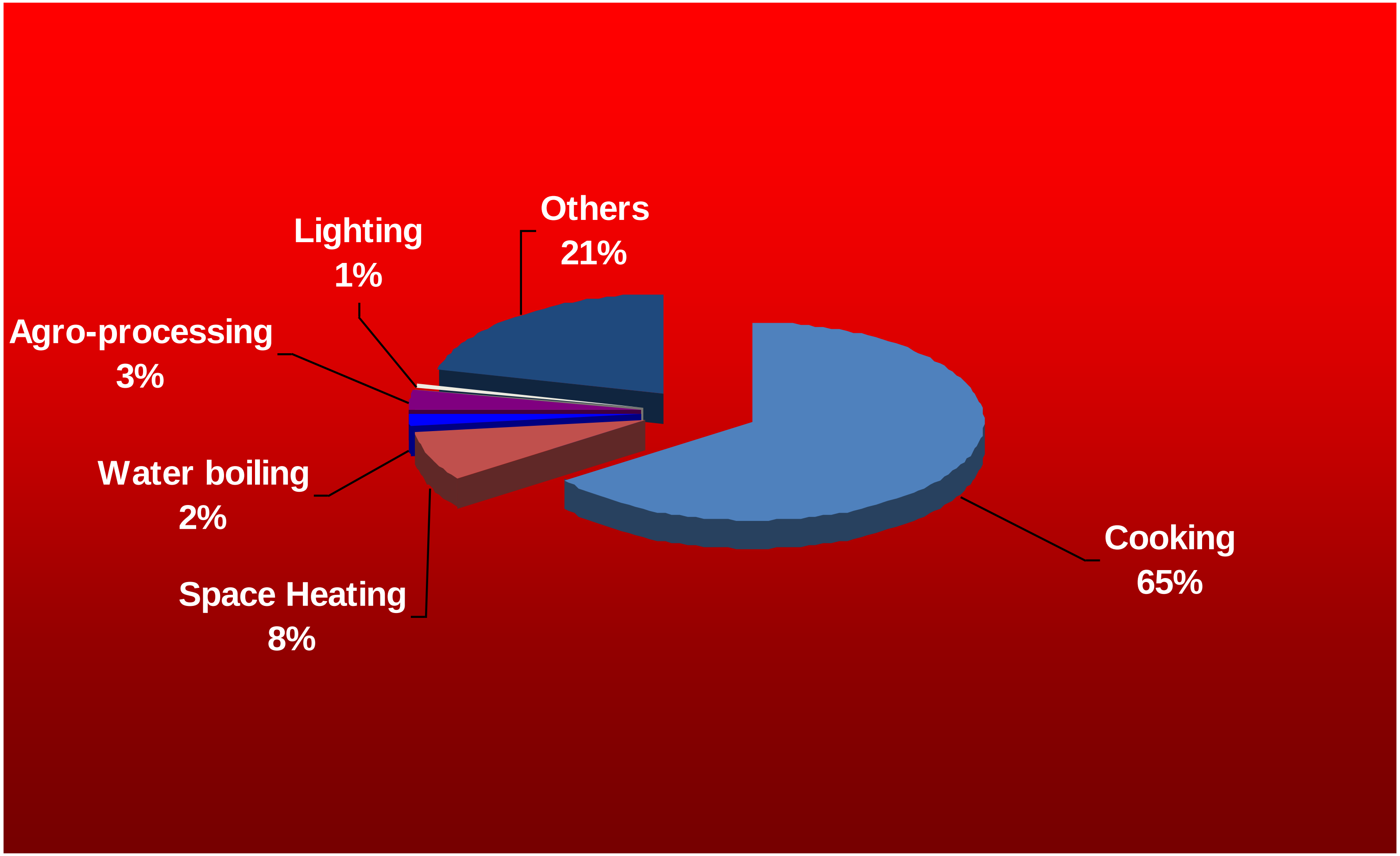
Trend of GHG Emissions during 1995/1996 to 2011/2012, million tons CO_2e



Source: WECS (1997, 2013), author estimation

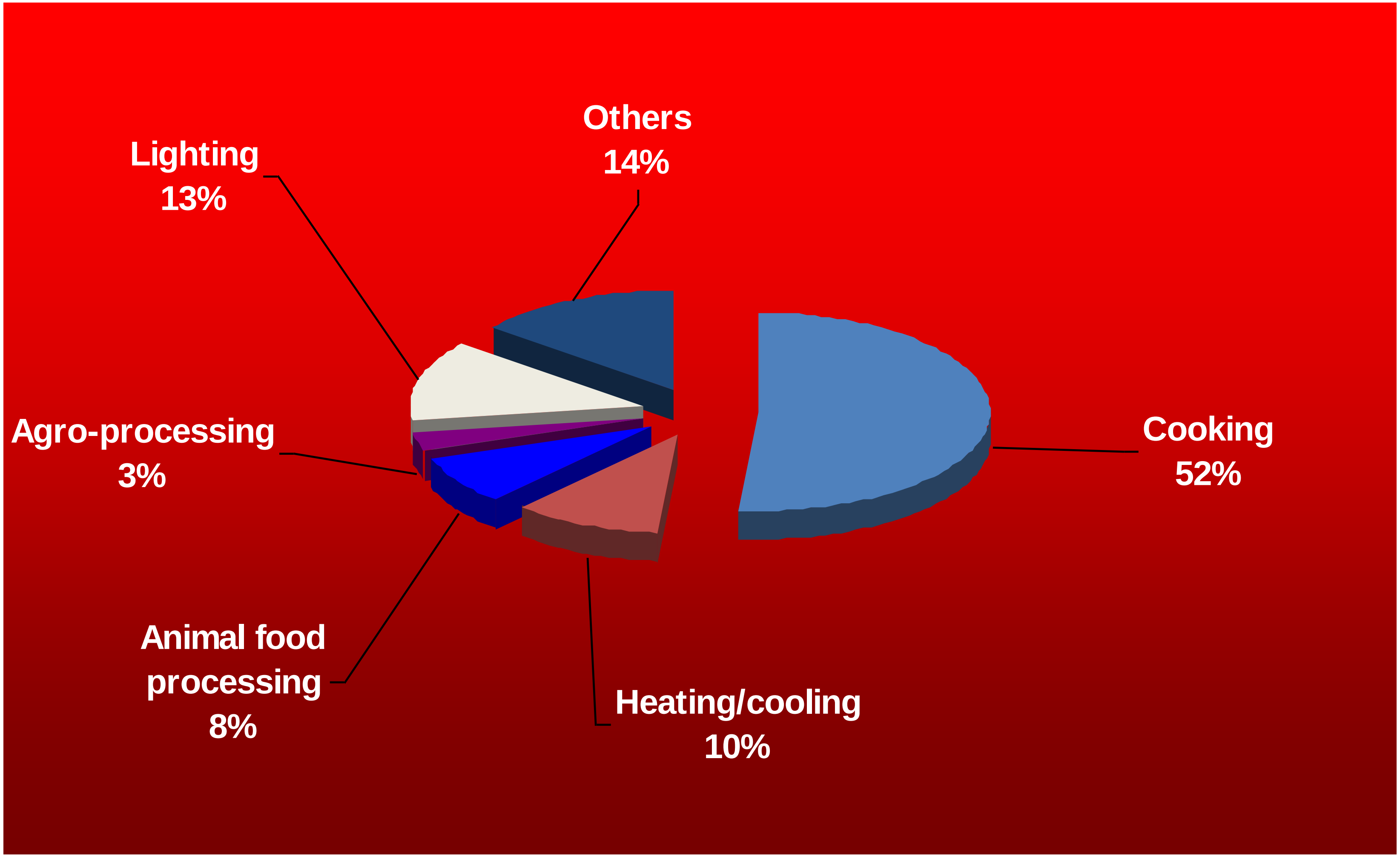
- **GHG emissions from energy use has increase by 76% from 4.1 million tons CO_2e in 1995/1996 to 7.3 million tons CO_2e in 2011/2012 (3.6% annual growth rate)**
- **The per capita GHG emission increases from 0.20 ton CO_2e/capita in 1995/1996 to 0.27 ton CO_2e/capita in 2011/2012**
- **Environmental Sustainability ???? Health ????**

Rural Household Energy End-Uses (1995)



WECS, 1995

Urban Household Energy End-Uses (2005)

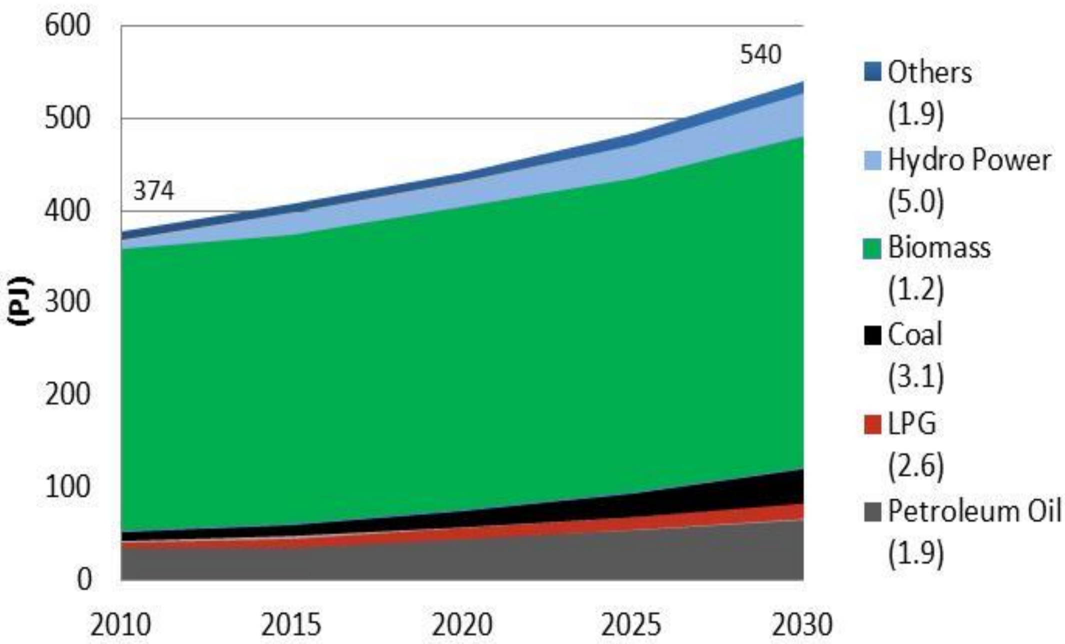


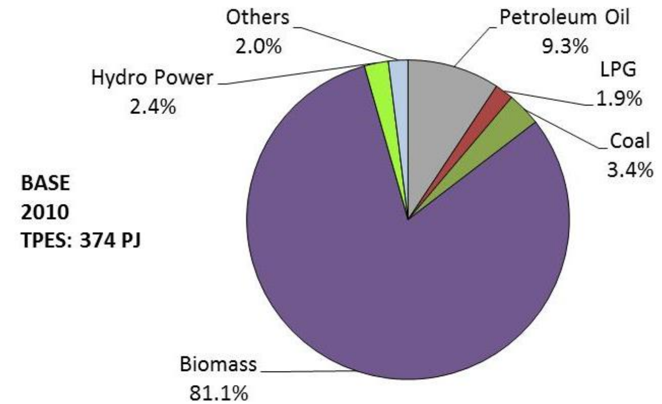
WECS, 2005

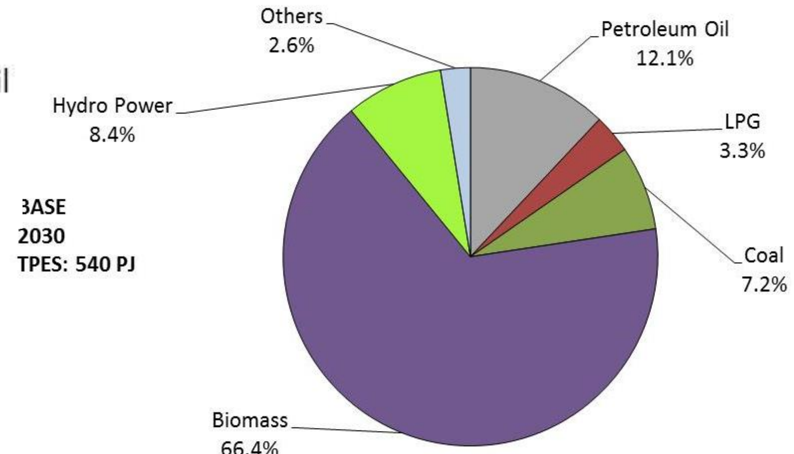
Relationship between HDI and Energy use pattern (UNDP,2006)

HDI	Country	Traditional fuel consumption (%)	Electricity consumption per capita (kWh)		C2 emission per capita (metric tons)	
		2003	1980	2003	1980	2003
1	Norway	6.1	22400	25295	8.2	9.9
7	Japan	1.2	4944	8212	7.9	9.7
8	USA	3.1	10336	14057	20.1	19.8
81	China	4.6	307	1440	1.5	3.2
126	India	19.8	173	594	0.5	1.2
137	Bangladesh	51.5	30	145	0.1	0.3
138	Nepal	93.2	17	91		0.1

Total Primary Energy Supply grows by 1.8% annually on average





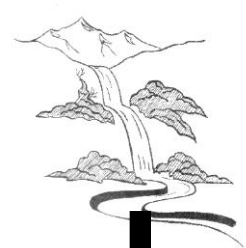


- Imported fossil fuel grows at **4.1%** annually
- Hydropower grows at 8.4% and biomass grows at 0.8%
- Share of imported fossil fuel => **12.7% to 19.3%**
- **Energy Security?** Economic Vulnerability ? Environmental Emission ?

Source: Draft Energy Efficiency Strategy 2015, Courtesy of S.R.Shakya

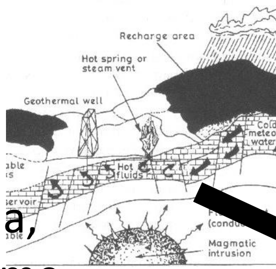
What R our Options?

Renewable Energy Resources

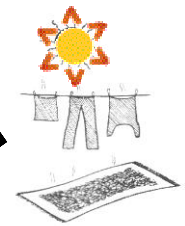


- 6,000 rivers (theoretical 83,000 MW and commercial 42,000 MW)
- about 556.8 MW (1.3 %)

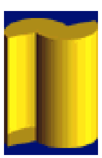
- 32 Geothermal sites
- Jomsom, Myagdi, Sankhuwasabha, Sindhupalchowk, Jumla, Kalikot, Humla, Mugu, Dailekh, Chilime etc)

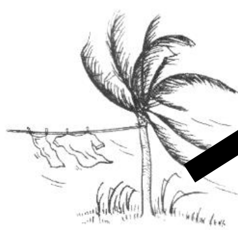


Energy

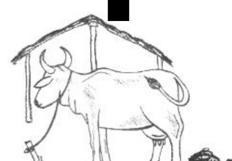


- 6.8 sunshine hours per day
- solar insolation 4.5 kWh/m2/day





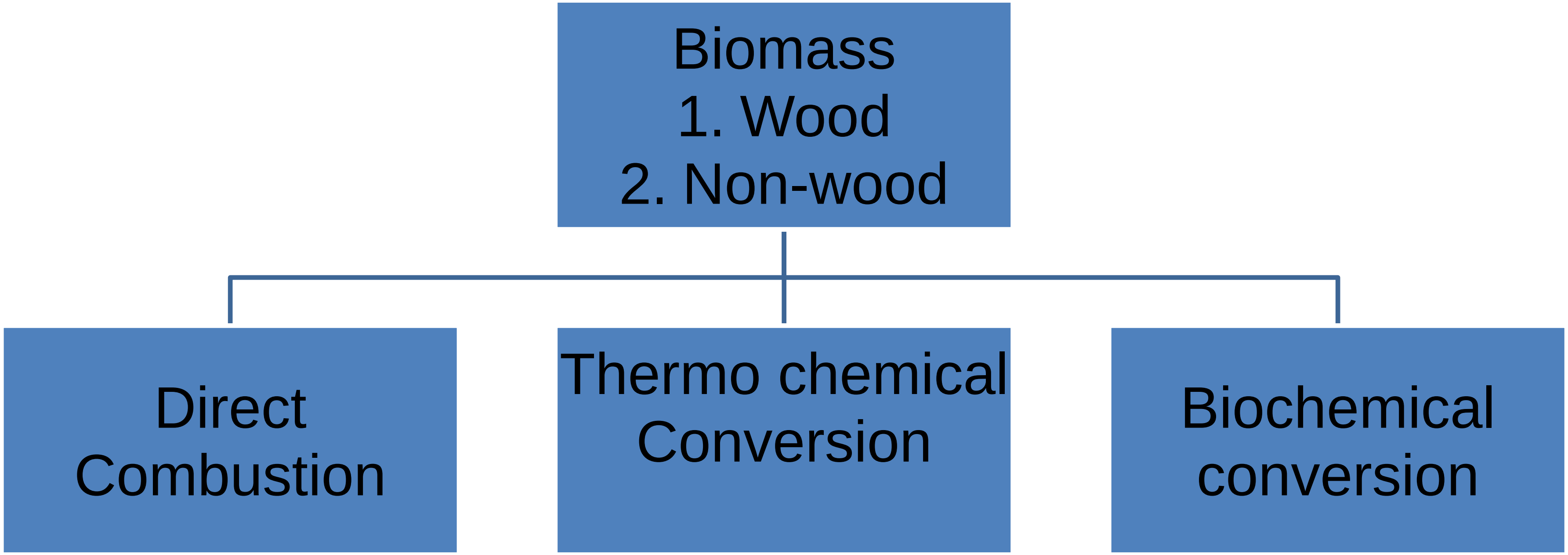
- various region (Mustang, Khumbu region, Palpa, Ramechhap, Karnali, Jumla)
- 200 MW from 12 km corridor from Kagbeni to Chusung



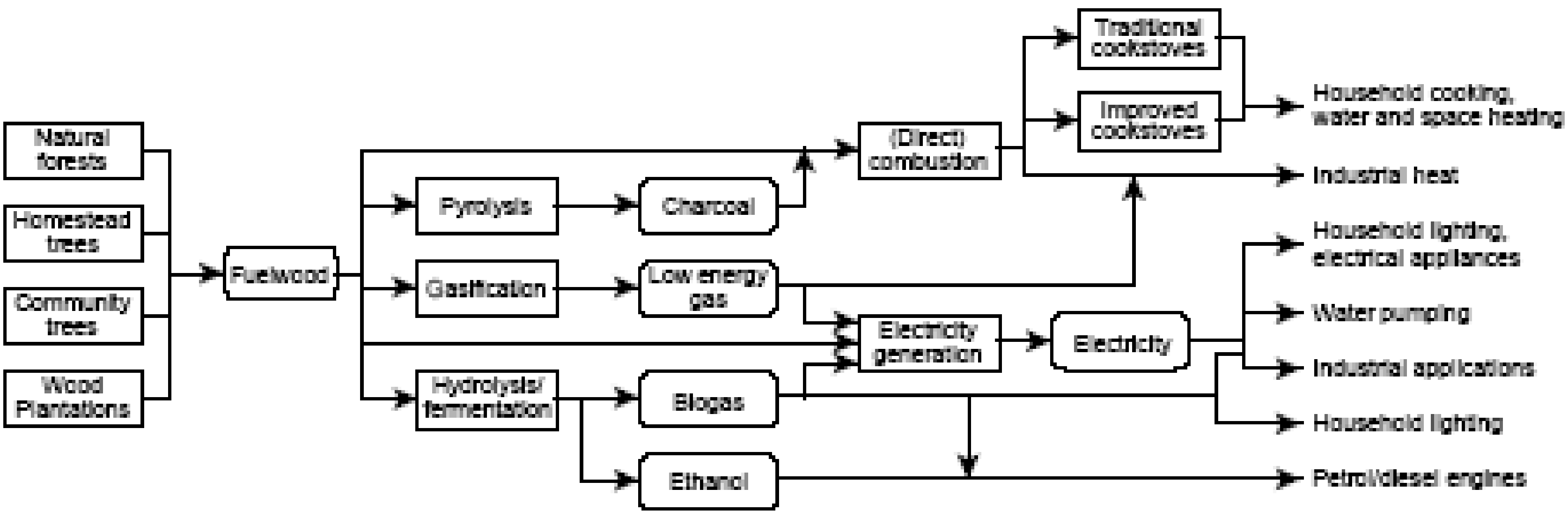
- agriculture residues and animal dung 9% of the energy demand

- Forest covers 37% of total area
- supplies 78 % of the total energy requirement

Biomass Energy Application


Biomass
1. Wood
2. Non-wood
Direct Combustion
Thermo chemical Conversion
Biochemical conversion

Energy chain for fuel wood (RWEDP)

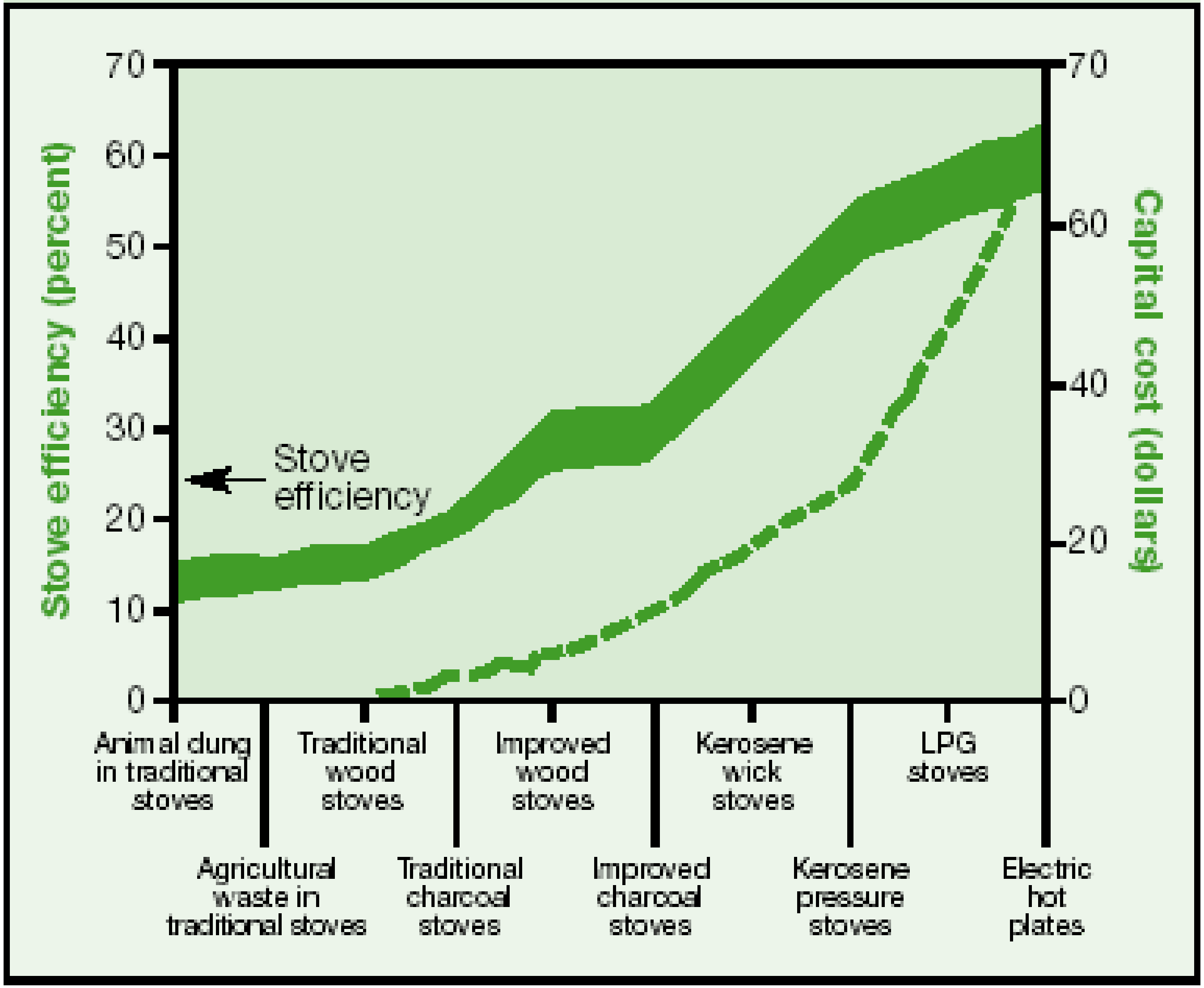


Application in Nepal

Improved Cooking Stove (ICS)

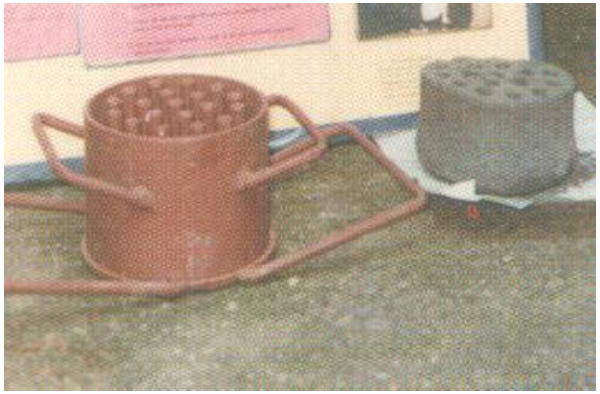
- More than 1,200,000 installed
- Cost from NRs. 300 to 500
- Each ICS saves annually about
  - 1 ton of Firewood
  - reduces about 1.6 ton of GHG CO2e (considering 27% efficiency increment)

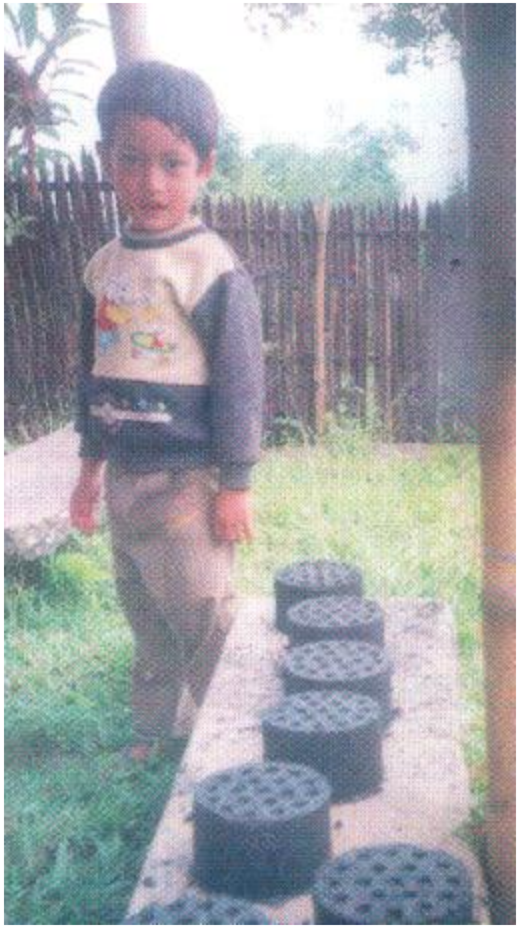
FIGURE 10.1. EFFICIENCY OF STOVES WITH COMMERCIAL AND NON-COMMERCIAL FUELS

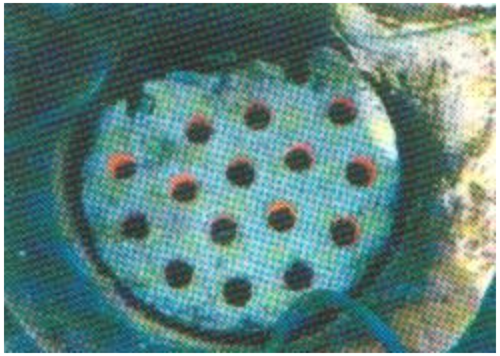


Source: Baldwin, 1987.

Other Biomass Technologies







Beehive Briquette

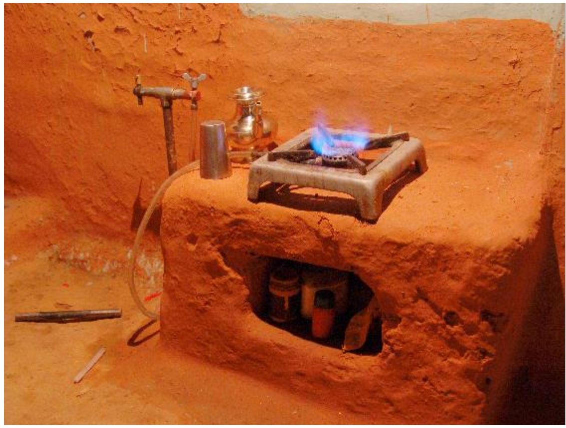
Other Biomass Technologies

Briquetting, Pelletising, Biomass gasifier

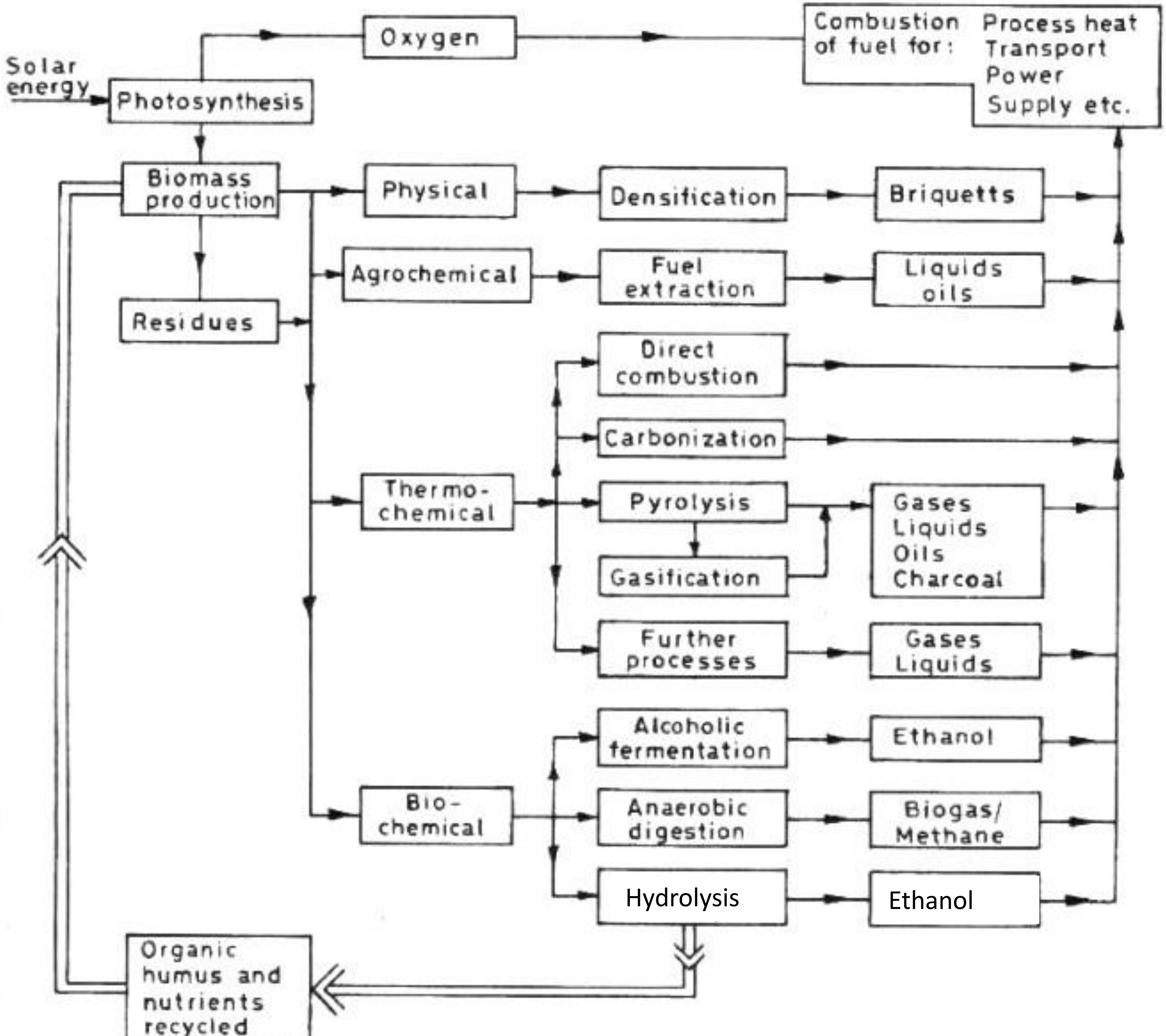
Biogas Plant

- Clean Source of Energy
- More than 300,000 installed in Nepal



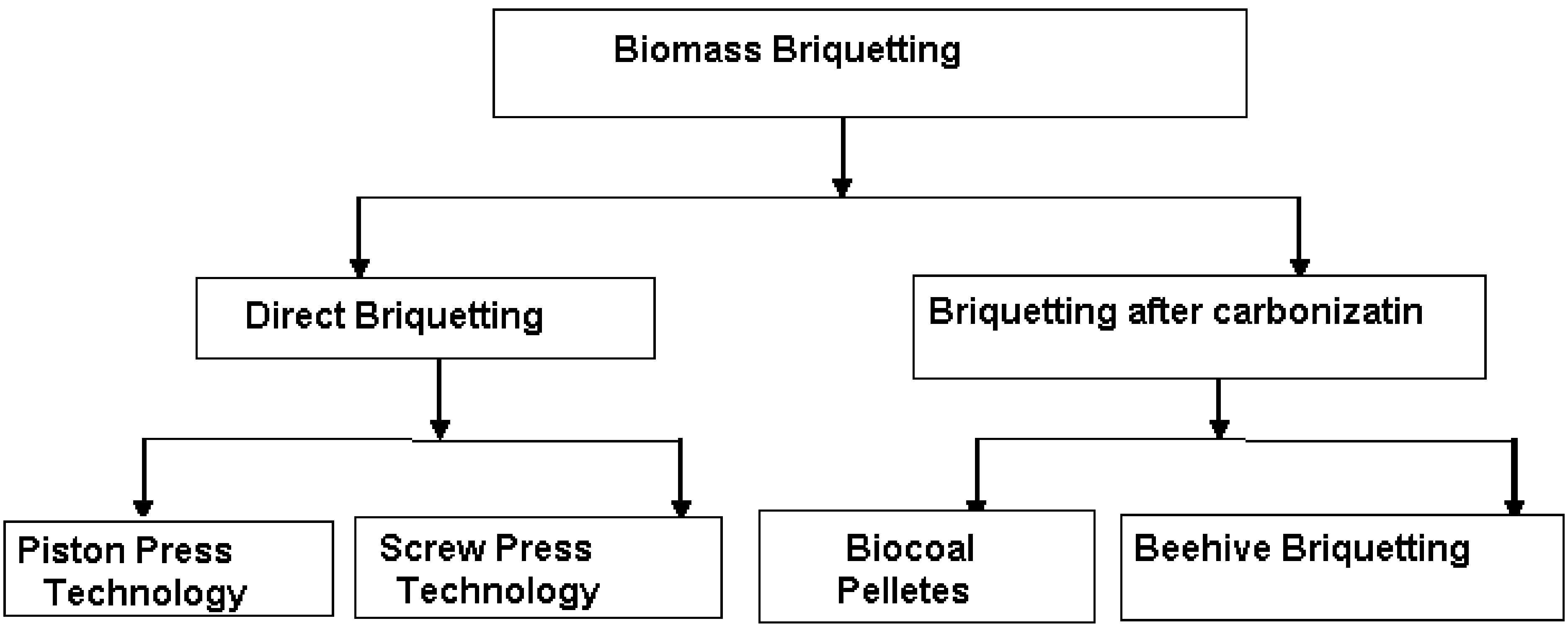



Biomass Energy Conversion Technologies

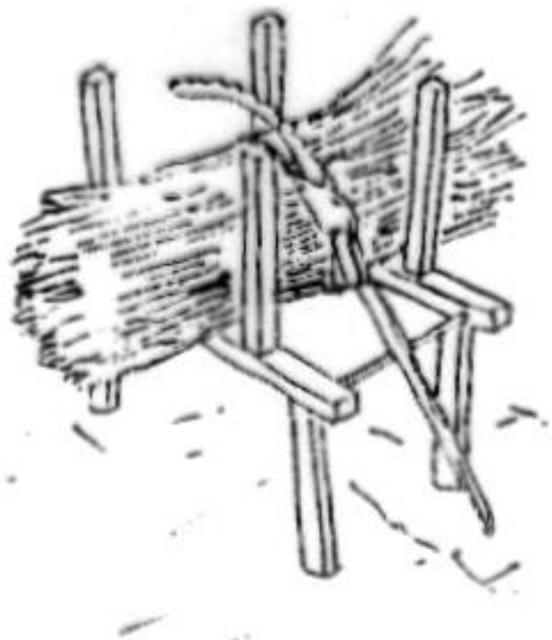

Solar energy
Photosynthesis
Oxygen
Combustion of fuel for:
Process heat
Transport
Power
Supply etc.
Biomass production
Residues
Physical
Densification
Briquetts
Agrochemical
Fuel extraction
Liquids oils
Thermo-chemical
Direct combustion
Carbonization
Pyrolysis
Gasification
Gases
Liquids
Oils
Charcoal
Further processes
Gases
Liquids
Bio-chemical
Alcoholic fermentation
Ethanol
Anaerobic digestion
Biogas/ Methane
Hydrolysis
Ethanol
Organic humus and nutrients recycled

Densification Technology

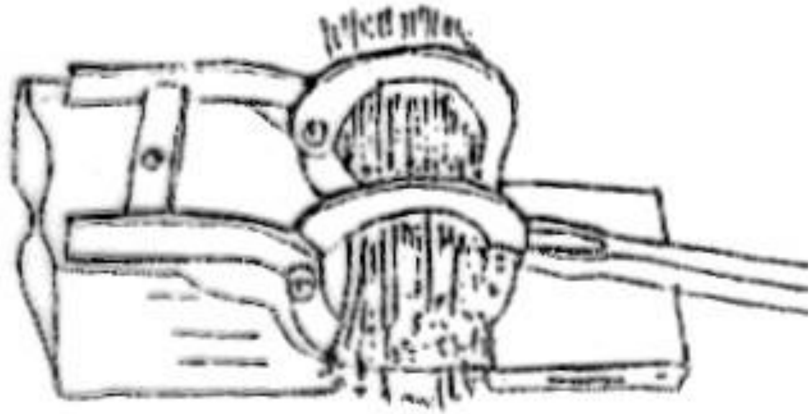
Process of compressing the bulk volume of the biomass to increase the calorific value, rigidity and ease in storage and mobility.



Traditional densification methods

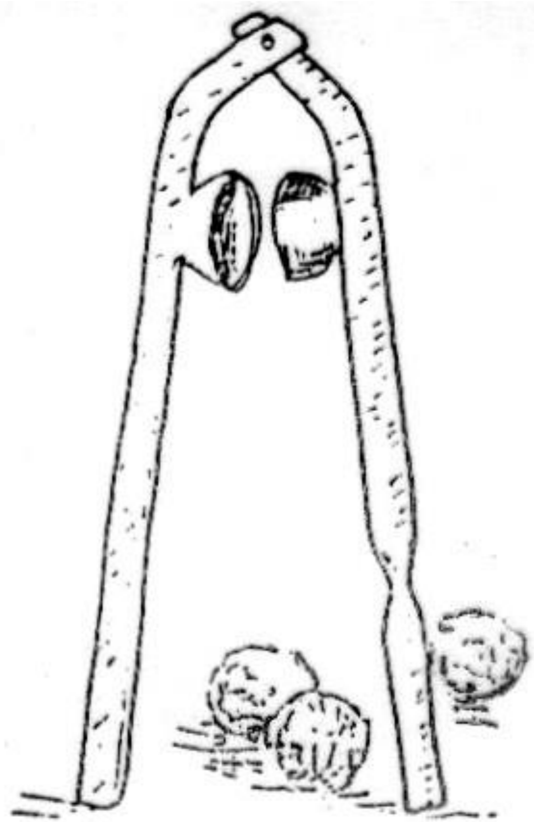


A "baker" press for larger bundles.

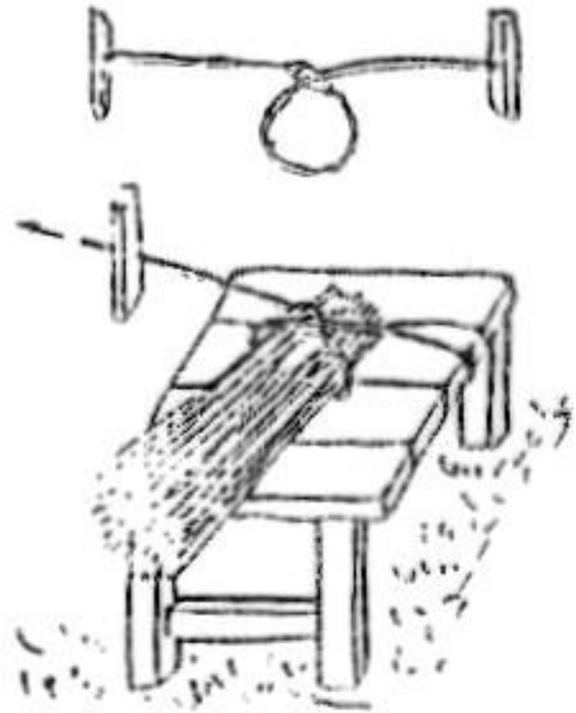


A small metal press.

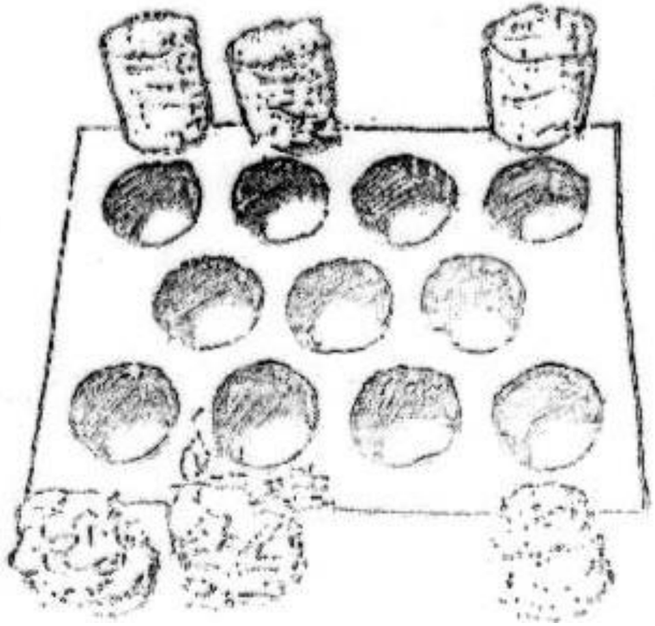
Traditional densification methods

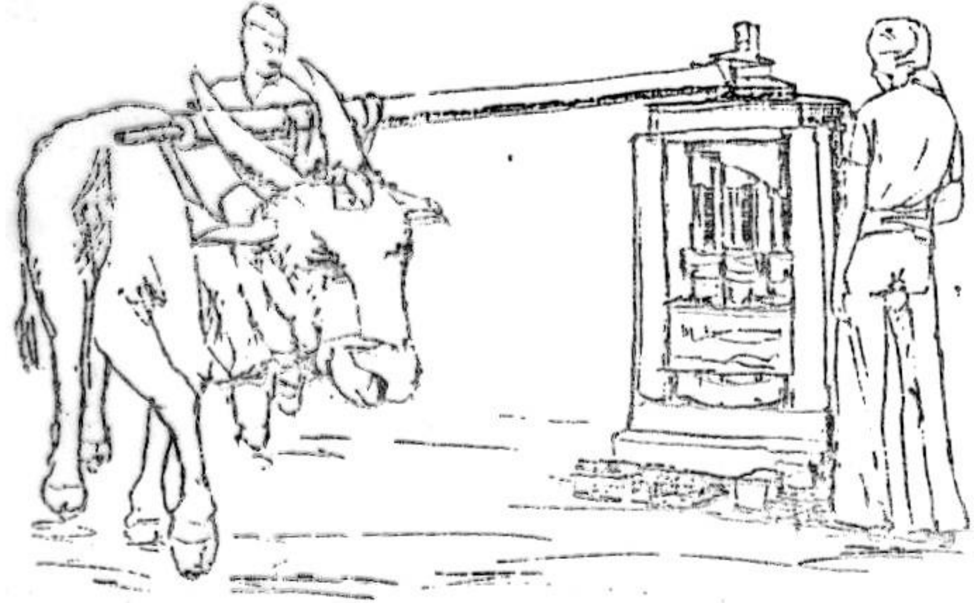


Simple hand operated briquetting press.



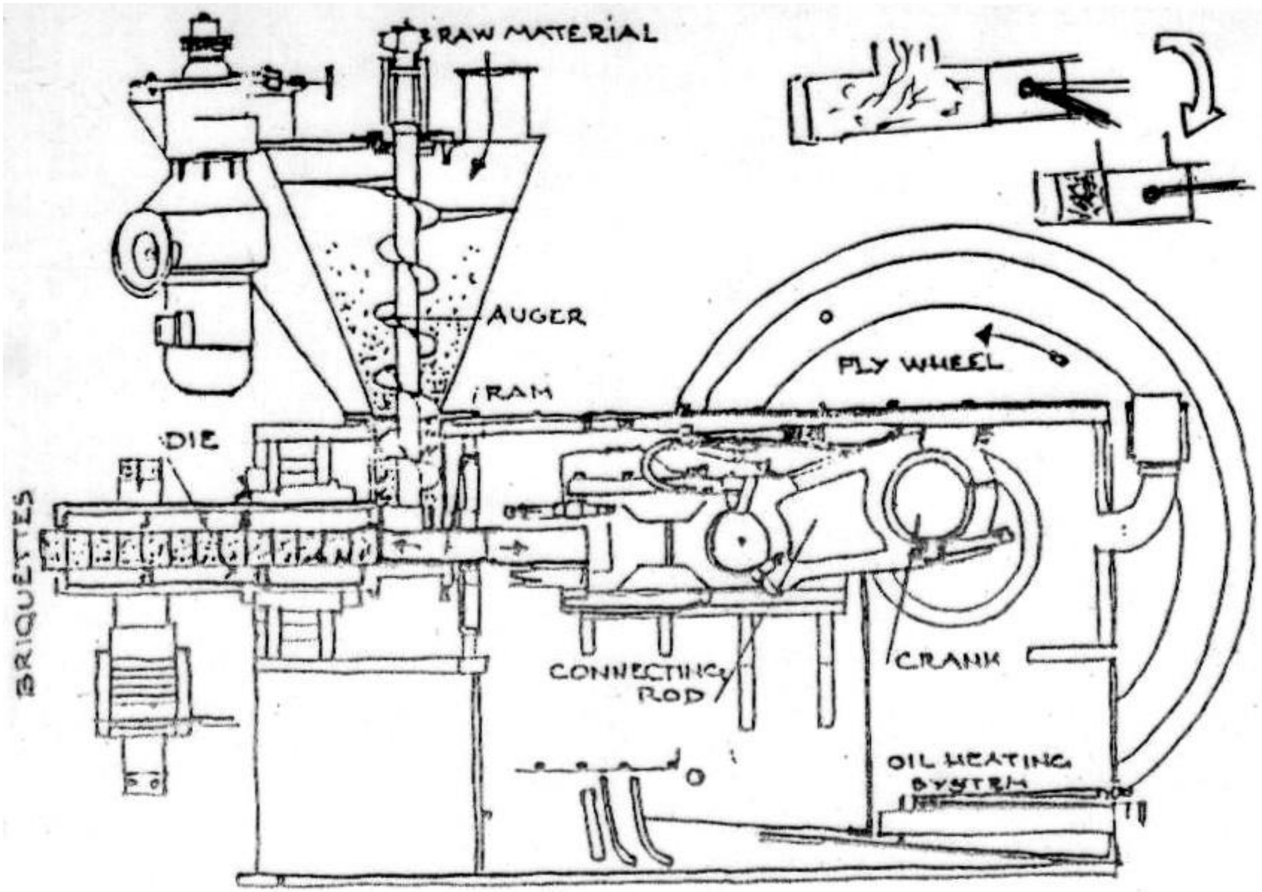
Tying the bundle.





Bullock operated compaction machine.

Piston press technology



Principle of piston extruder briquetting machine.

Piston press technology

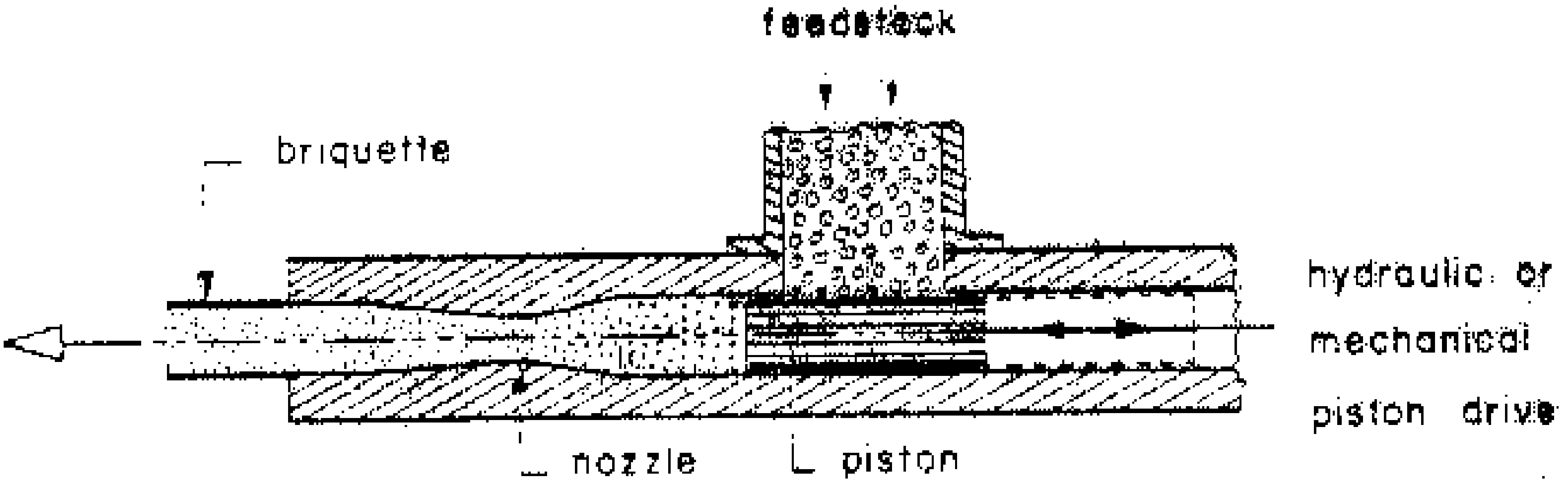


Figure 3.1 A Piston Press (reprinted by permission of Elsevier Applied Science Publishers Ltd.)

Screw press technology

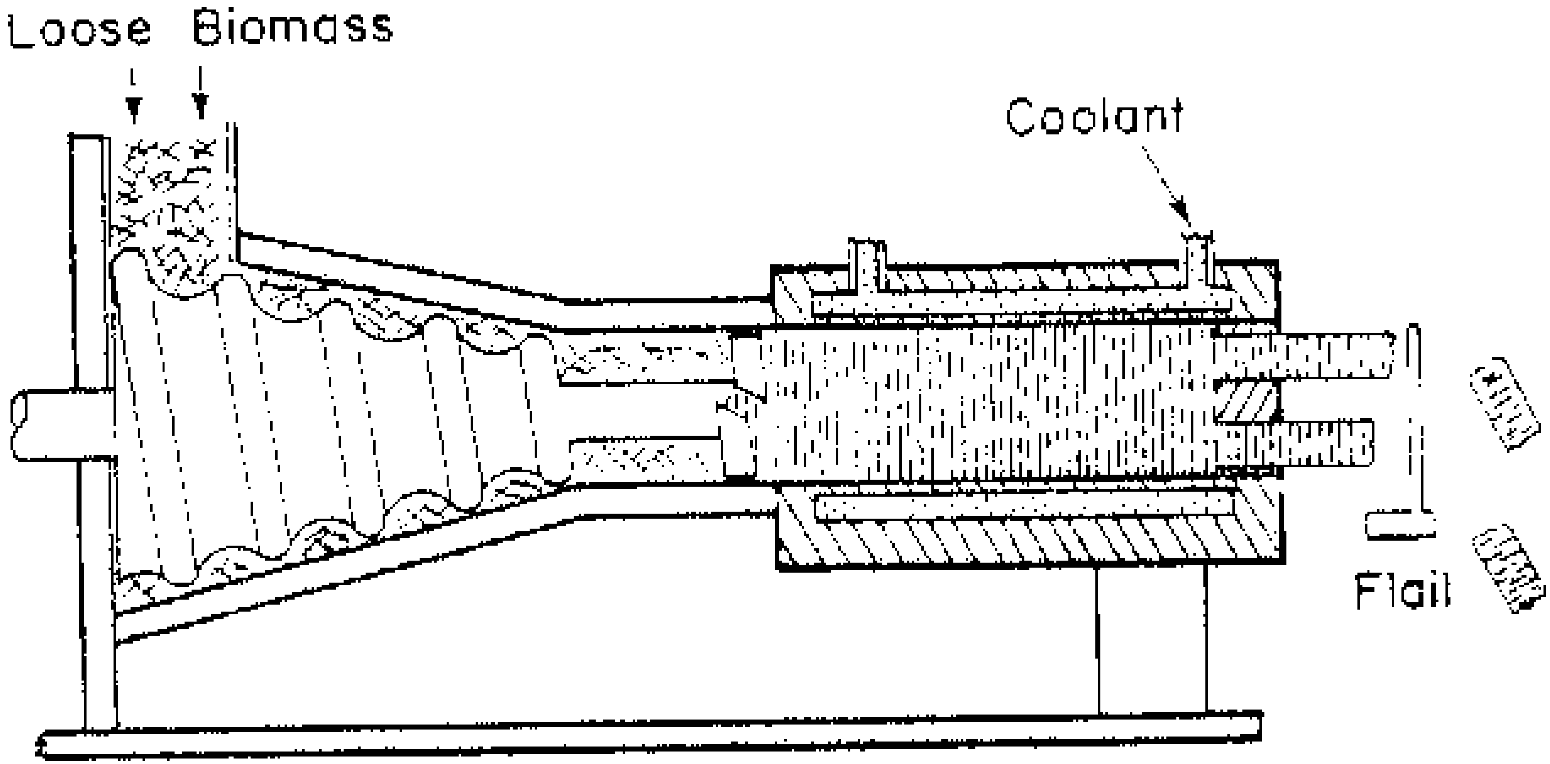


Figure 3.2 A Conical Screw

Screw press technology

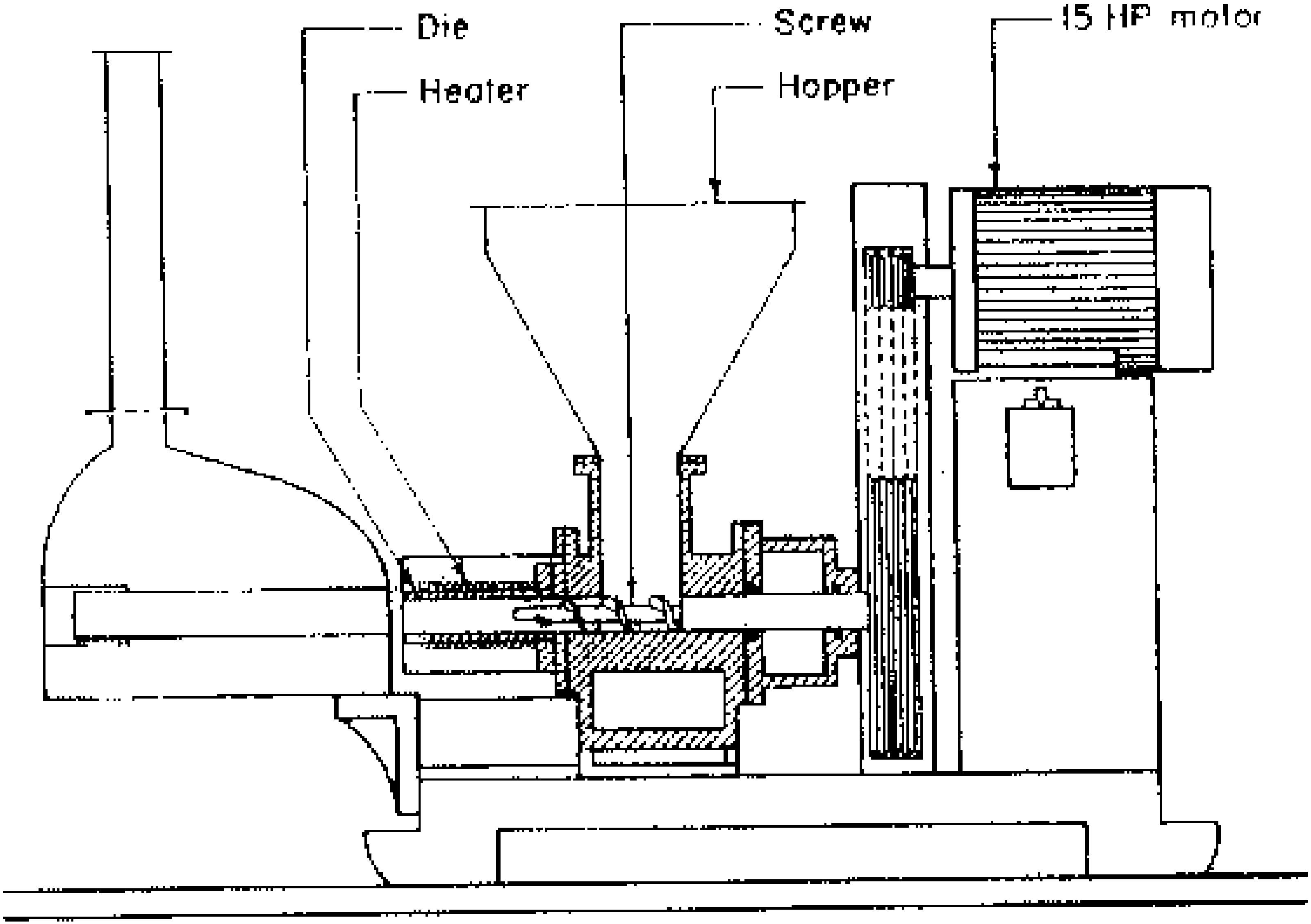
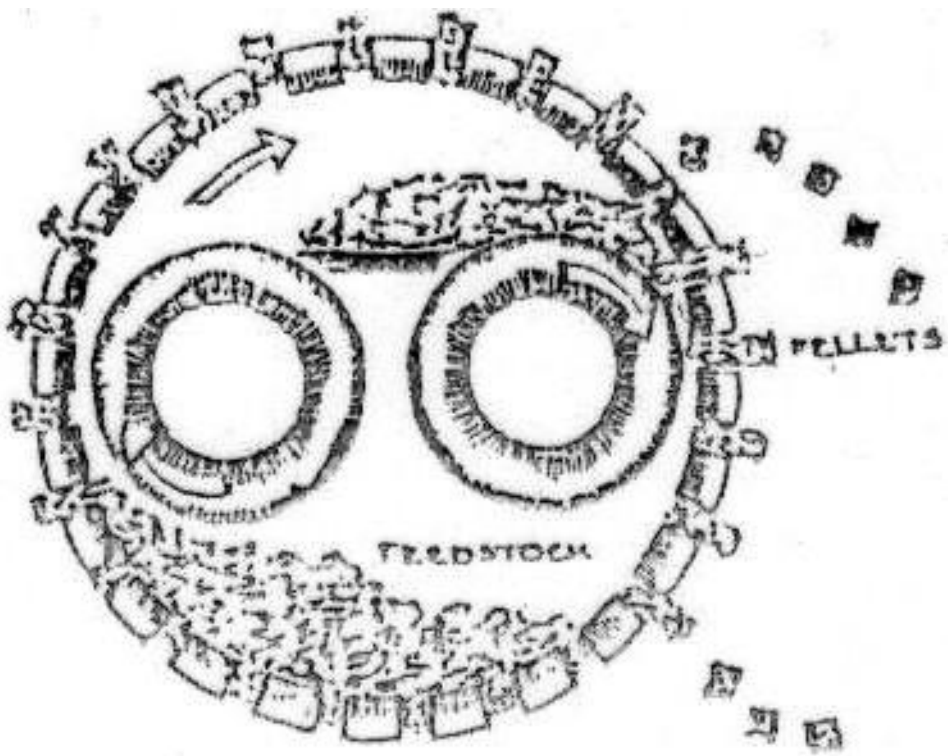


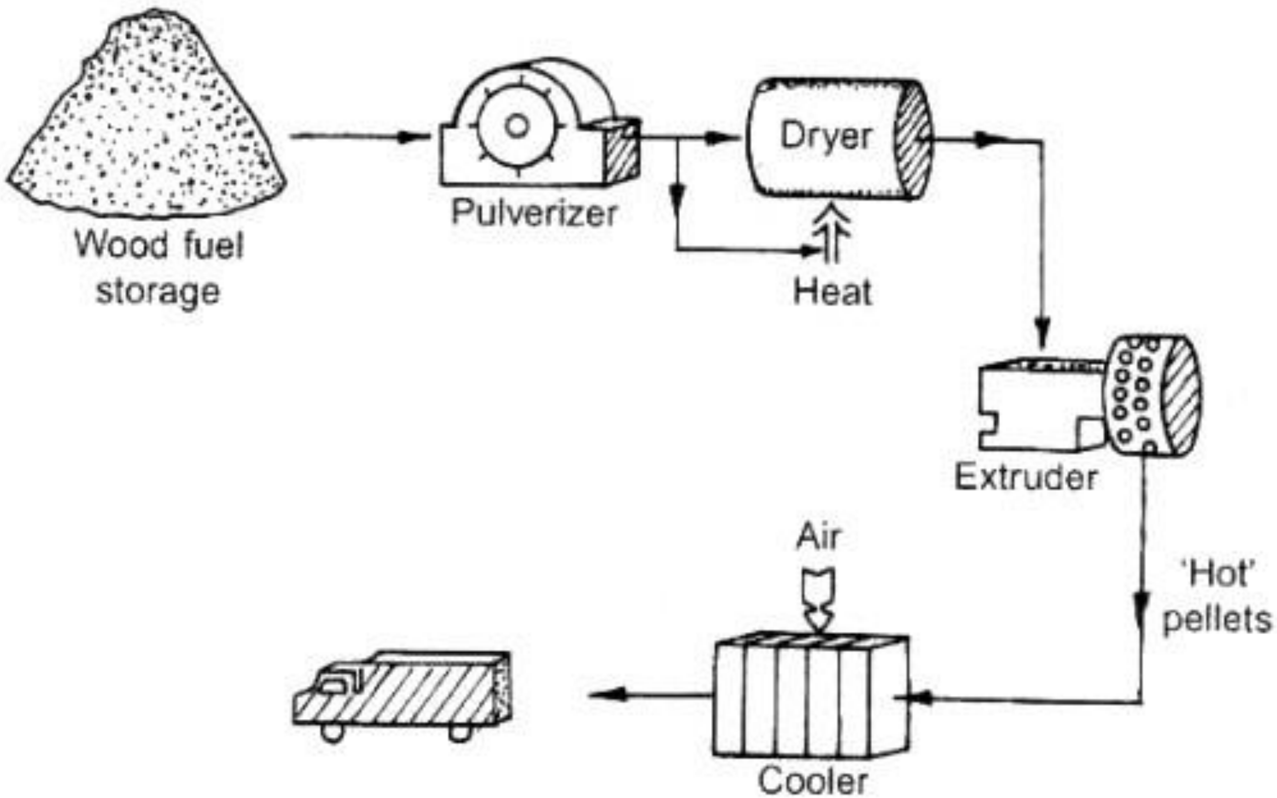
Figure 3.3b Sectional Elevation of a Heated Die Screw Press

Screw press technology

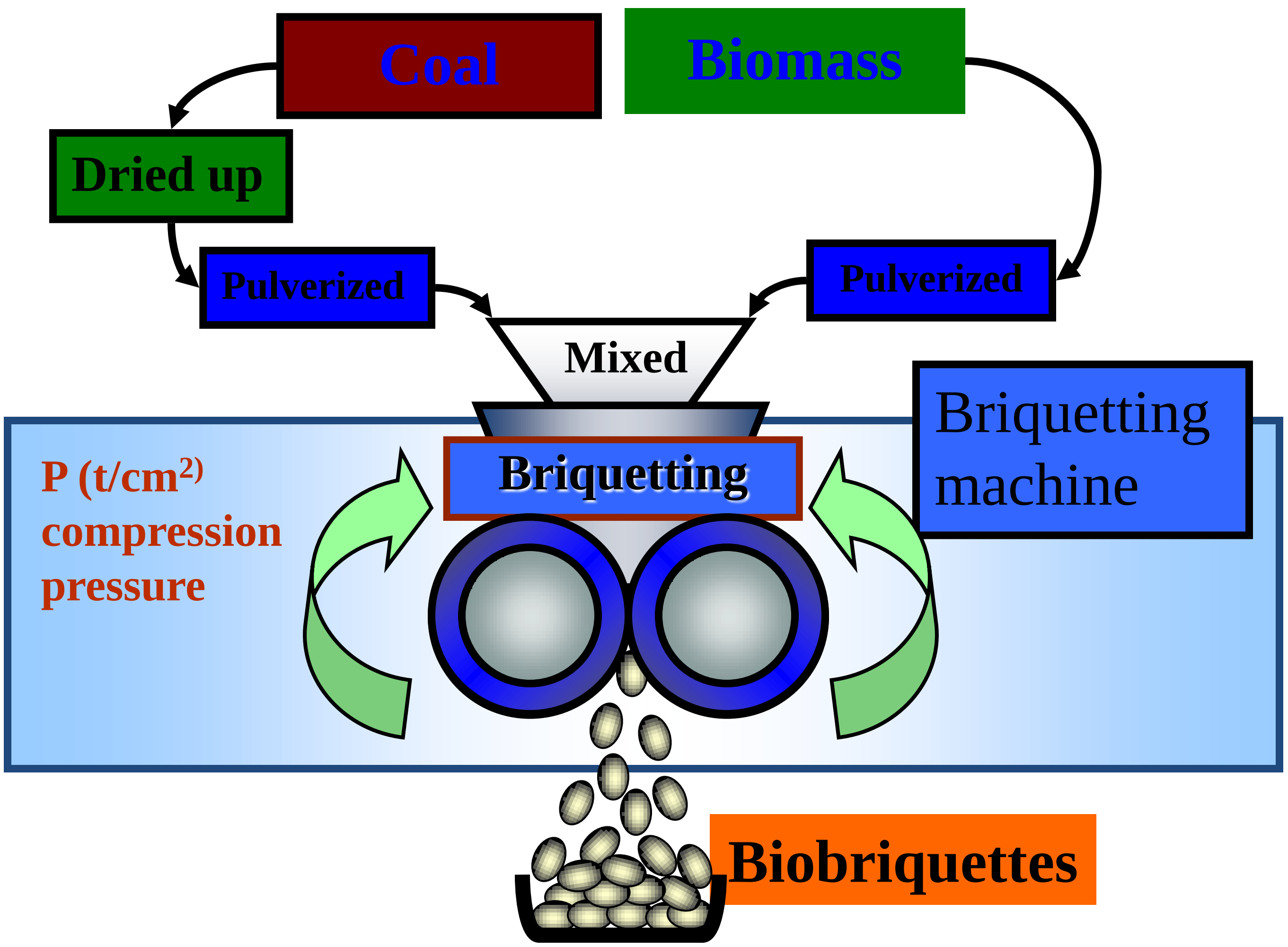
Wood Pelleting technology



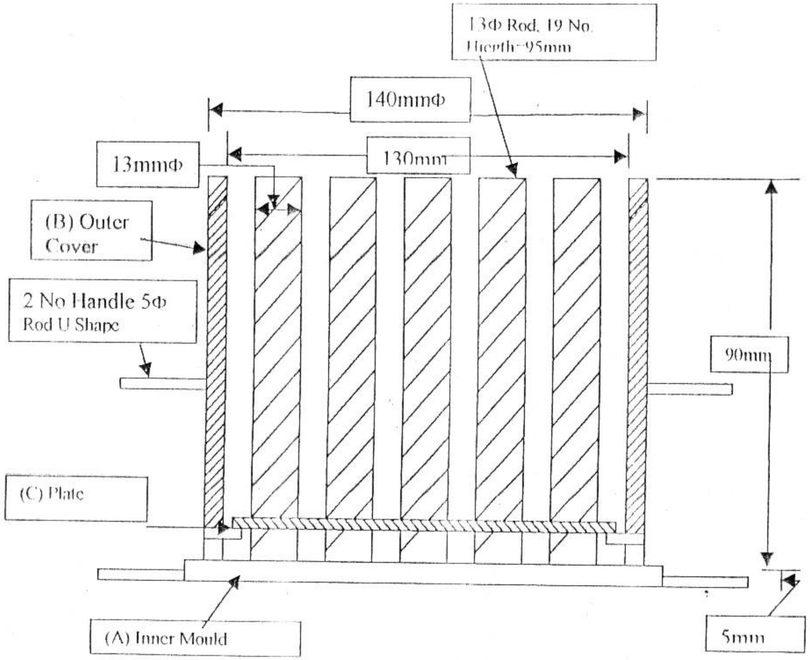
Wood Pelleting Plant



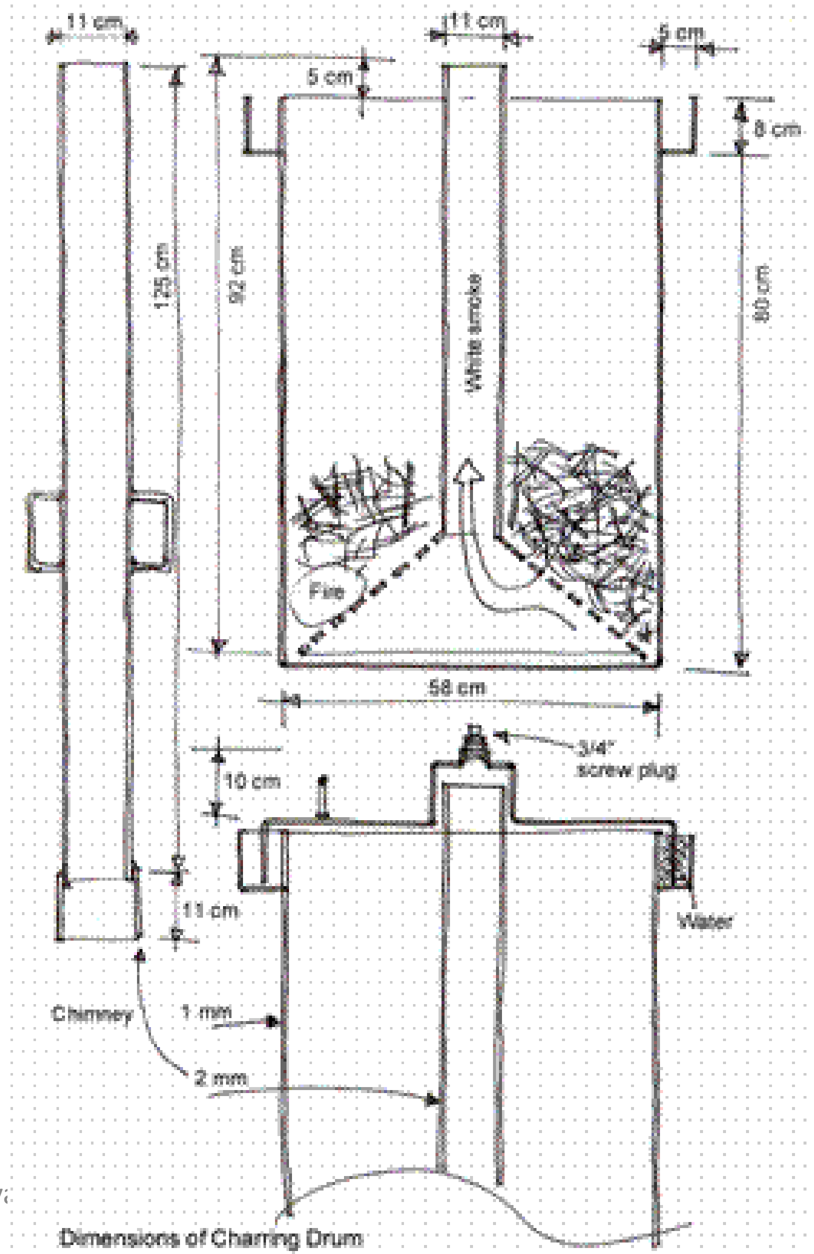
Bio-coal pelleting



Beehive Briquetting Technology



- 20-30% by weight of bentonite clay local potter clay + water (for binding + heat retainer)
- 26% thermal efficiency in stove burning
- Used for residential and commercial purposes.



Proximate Analyses and Heating values of Biomass Char and Beehive briquette

Proximate Analysis (%)					Heating Value
Material	Moisture Content	Volatile Matter	Fixed Carbon	Ash	Higher Heating Values (MJ/kg)
Biomass Char	8.86	17.97	69.72	12.31	26.04
Beehive Briquette	2.27	18.63	49.27	32.1	18.73

N.B. The Values of Volatile Matter, Fixed carbon and ash are given on dry basis.

Agrochemical fuel extraction

It is the process of the production of fuels from plants while the plant usually remains alive and unharmed.

(i) Seeds: Sunflower with 50% oil
(ii) Nuts: oil palm; coconut copra to 50% by mass of oil.
(iii) Fruits: olive
(iv) Leaves: eucalyptus with 25% oil
(v) Tapped exudates: rubber latex
(vi) Harvested plants: oils and solvents to 15% of the tree dry mass e.g. turpentine from pine trees; oil from Euphorbia.

Thermo chemical conversion

- Direct Combustion
- Carbonization
- Pyrolysis
- Gasification
- Liquefaction

Direct Combustion

- **Combustion may be defined as a chemical reaction of the fuel with the environment including heat and mass transfer.**
- **It involves a series of free radical reactions whereby carbon and hydrogen in the fuel react with oxygen to form carbon dioxide and water vapor respectively while liberating useful heat.**
- **Almost all of the biomass used for energy today is being used for electricity generation, process heat raising and co-generation.**

Fuel	Gross calorific value[a]		Remarks
	MJ kg^{-1}	MJ l^{-1}[b]	
Crops			
Wood			
Green	~ 8	~6	Varies more with moisture
Seasonal	~ 13	~ 10	content than species of wood
Oven dry	~ 16	~12	
Vegetation: dry	~15		Examples: grasses, hay
Crop residues			
Rice husk	12–15		For dry material.
Bagasse (sugarcane solids)	12–15		In practice residues may be
Cow dung	12–15		very wet
Peat	12–15		
Secondary biofuels			
Ethanol	30	25	C_2H_5OH: 789kg m^{-3}
Methanol	23	18	CH_3OH
Biogas	28	20×10^{-3}	50% methane + 50% CO_2
Producer gas	5–10	$(4 - 8) \times 10^{-3}$	Depends on composition
Charcoal			
Solid pieces	32	11	
Powder	32	20	
Coconut oil	39	36	
'Cocohol'	39	33	Ethyl esters of coconut oil
Fossil fuels			
Methane	55	38×10^{-3}	Natural gas
Petrol	47	34	Motor spirit, gasoline
Kerosene	46	37	
Diesoline	46	38	Automotive distillate, derv
Crude oil	44	35	
Coal	27		Black, coking grade

Cook Stove

- A cookstove is a device located in a specific location where fuel is burnt to cook food, heating the room, drying of certain items (agricultural products), agro-processing activities and also lighting purposes.
- In this activity, biomass (fuel wood, agri-residue and dung) energy is used.
- The traditional cook stoves consume fuel inefficiently, and lead to excessive levels of indoor air pollution.
- These traditional cook stoves create drudgery and are hazardous for the users.

Improved cook stove

- Improved cook stove is designed to overcome the drawback of the traditional cook stoves by taking into consideration of combustion of the biomass fuel and its physiochemical properties, quantity and mode of air supply, heat transfer, heat loss mechanism.

Stove Classification

a) Function

- **Mono-function stoves:** An ICS which performs primarily one function, such as cooking, or any other single special function such as fish smoking, baking, roasting, milk simmering, etc.
- **Multi-function stoves:** In many areas, apart from cooking, an ICS can also be used for other purposes or in combination, such as for water heating (back boiler attachment), room heating, animal feed cooking/ agro–processing, *rakshi* preparation, milk simmering, etc.

Stove Classification

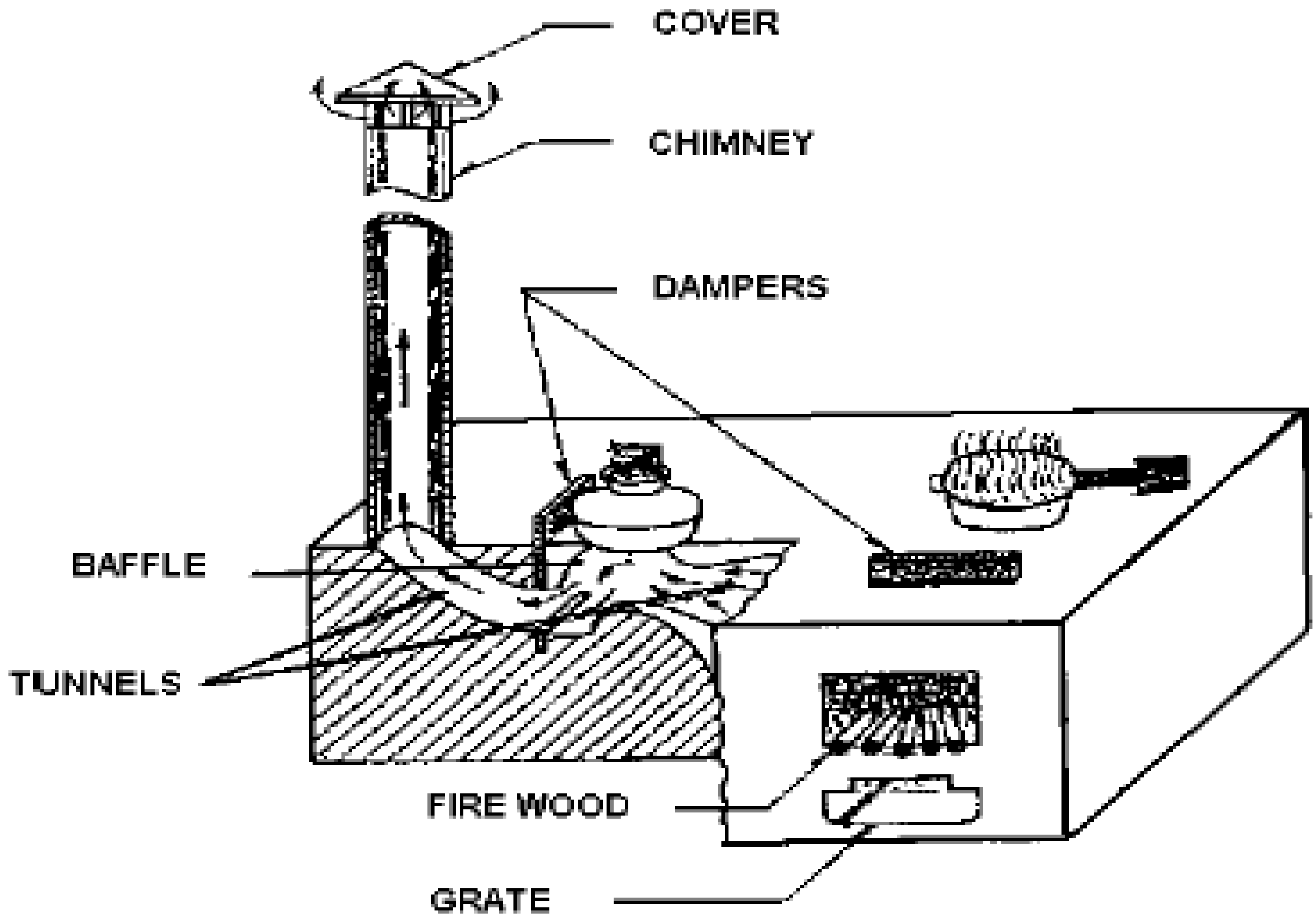
b) Construction Material: The materials may be clay, fired clay, metal, brick, cement, cast iron, or hybrids in which more than one material is used, etc.

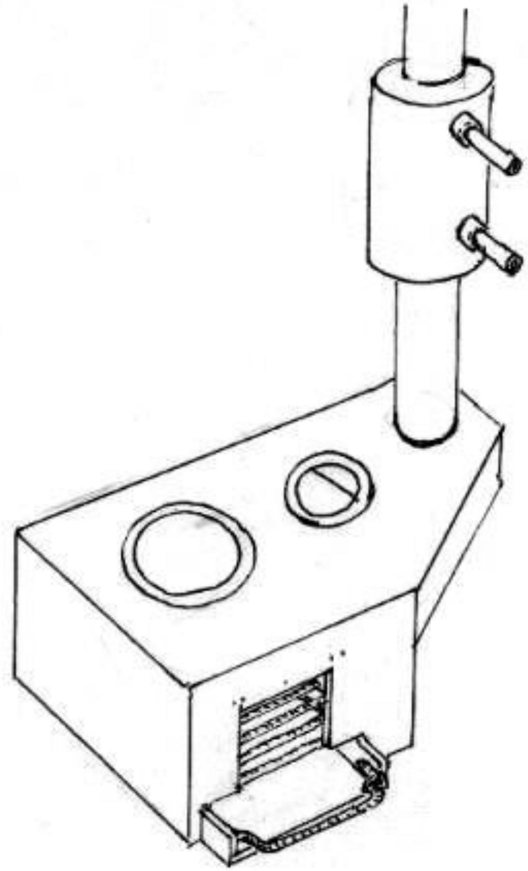
c) Portability: Metal and ceramic ICSs are normally portable in nature. Clay/brick/stone, mud are generally high mass and fixed type.

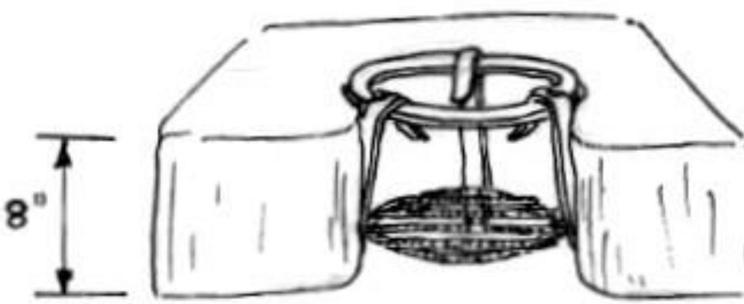
d) Design: In this category, ICSs can be one pot-hole to multi-pot-holes, single layer to double layers wall, various shapes and sizes, etc.

e) Fuel Type: The performance of ICSs also depends upon the fuel type. ICSs primarily designed for fuelwood would not perform well with loose residue fuel. Based on the fuel type, four stoves are encountered: charcoal stove, fuelwood/woody biomass stove, loose residue stove, and bio-briquette stove.

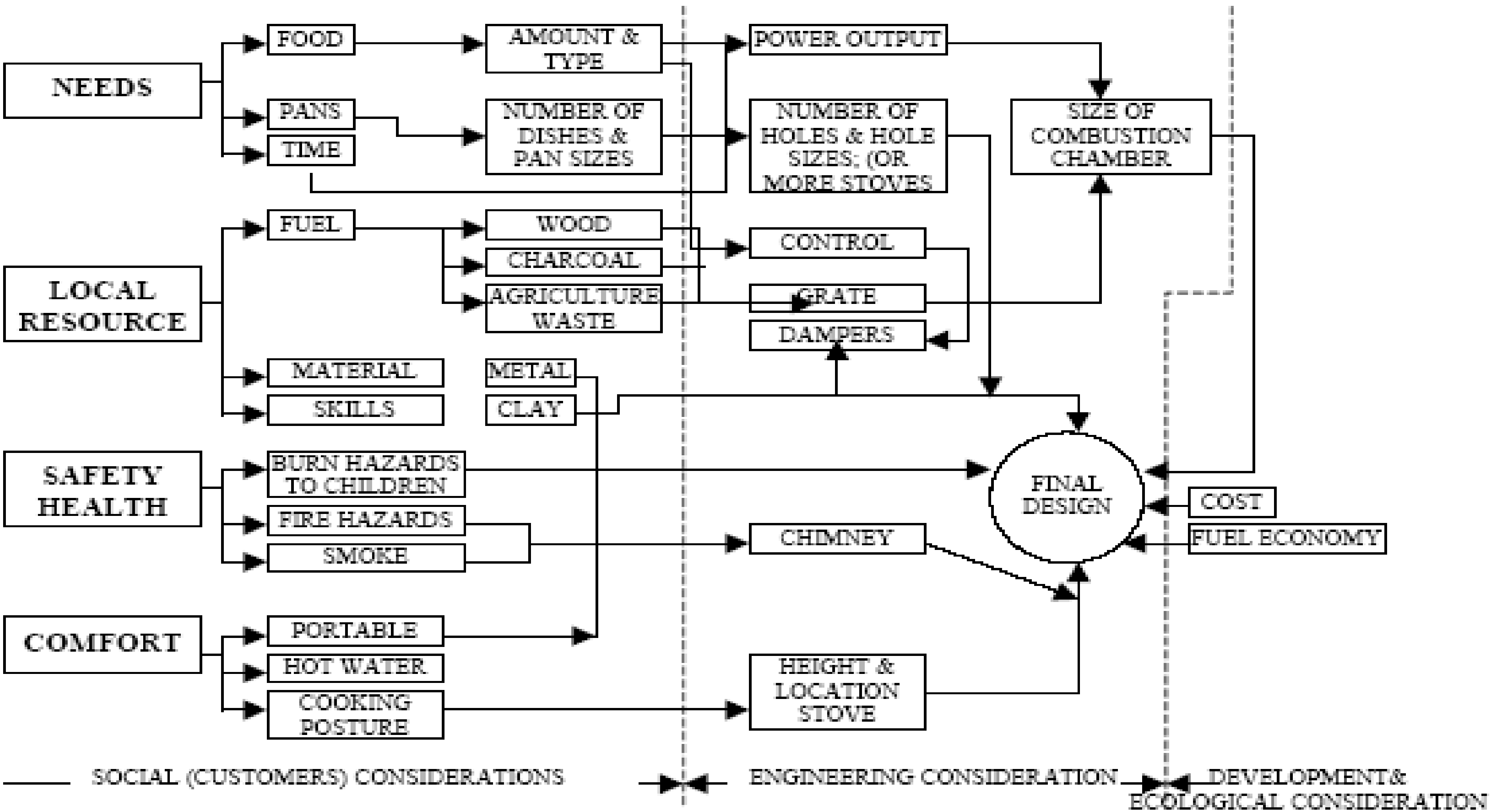
Components of Improved cook stoves



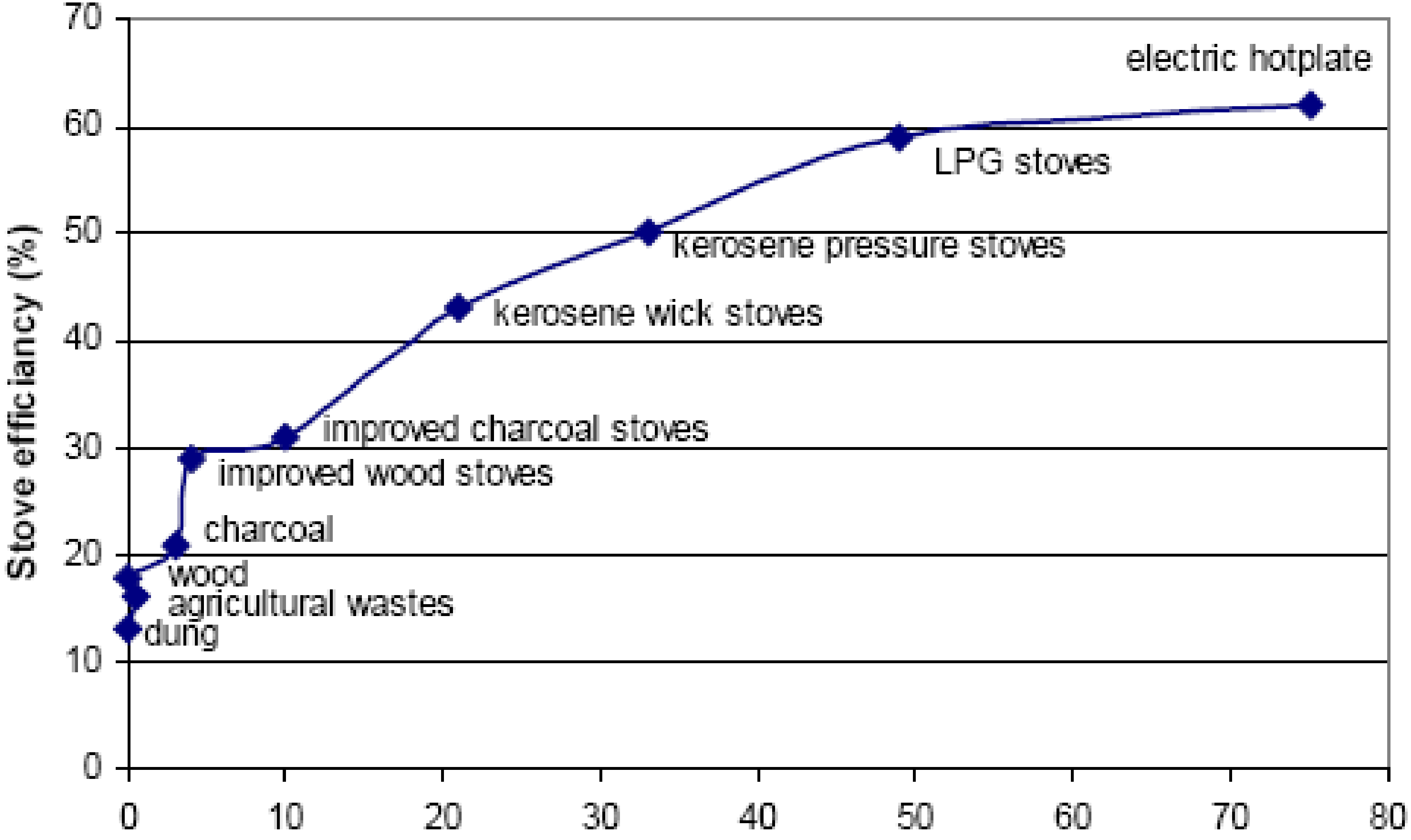



8"

Design Consideration for a Stove



Cost and efficiency of different types of stoves



Source: B. D. Saatkamp. et al.

Most polluting

Least polluting

Biomass:
- dung
- crop residues
- wood

Charcoal

Coal

Kerosene

Liquid Petroleum Gas (LPG)

Electricity

Emissions of Typical Household Stoves Used in the Region

Fuel	Combustion efficiency	Overall efficiency	Emission factors on energy basis (g/MJ)					GWC
			CO_2	CO	CH4	TNMOC	N_2O	
Biogas	99%	57%	81.5	0.11	0.06	0.03	0.0054	3.6
LPG	98%	54%	67.3	0.33	0.00	0.41	0.0032	74.6
Kerosene	98%	50%	70.2	0.41	0.01	0.35	0.0018	77.0
Fuelwood	90%	23%	90.7	4.34	0.26	0.53	0.0059	66.7
Crop residues	85%	14%	89.4	4.53	0.52	0.58	0.0034	45.6
Dung	85%	11%	87.3	4.25	0.51	1.60	0.0263	53.7

Source: Adapted from Smith, 1999, *Household stoves in India*

TNMOC: Total Non-Methane Organic Compounds (molecule weight 18/carbon atom)

GWC: Global Warming Commitment

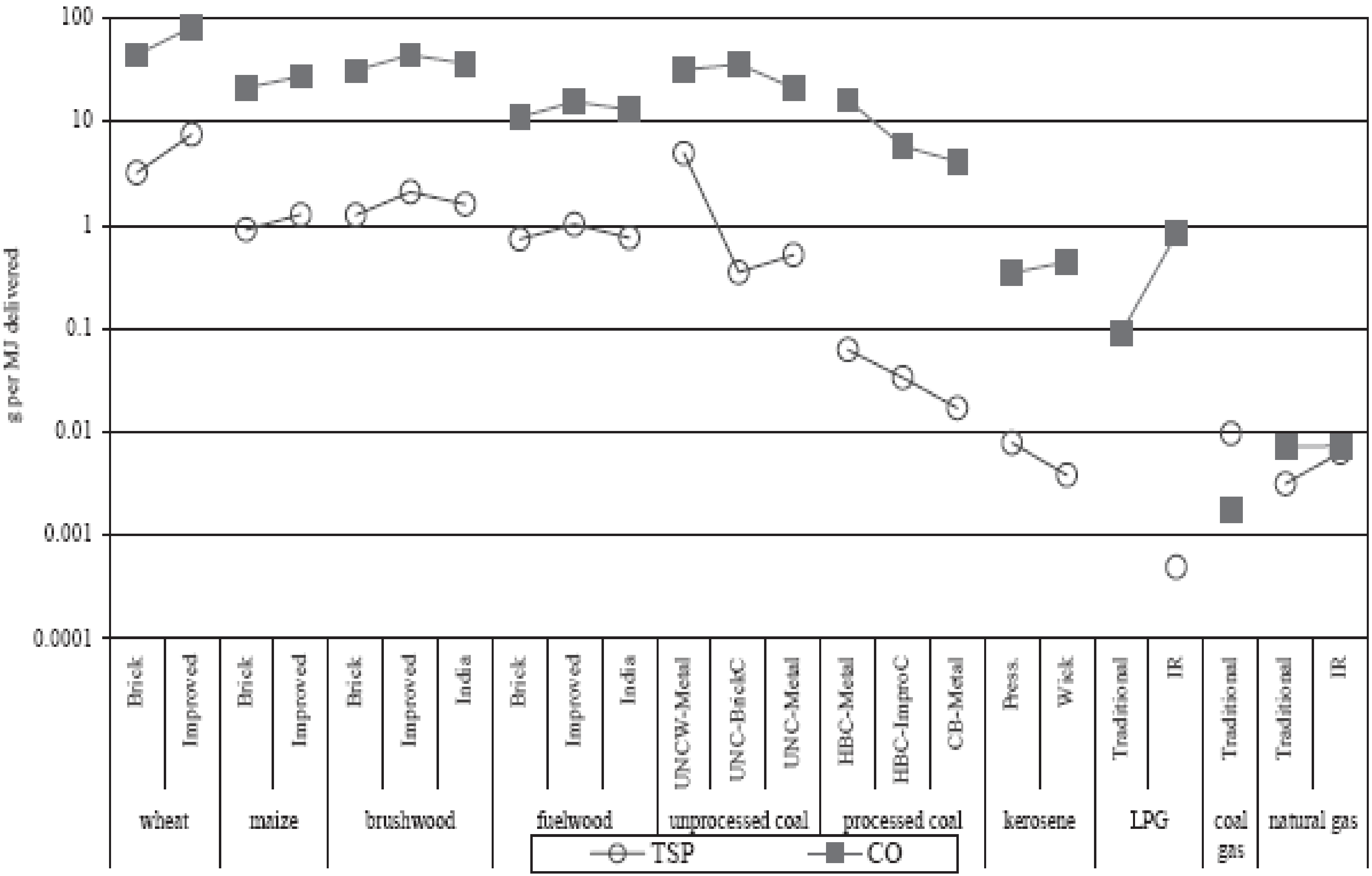
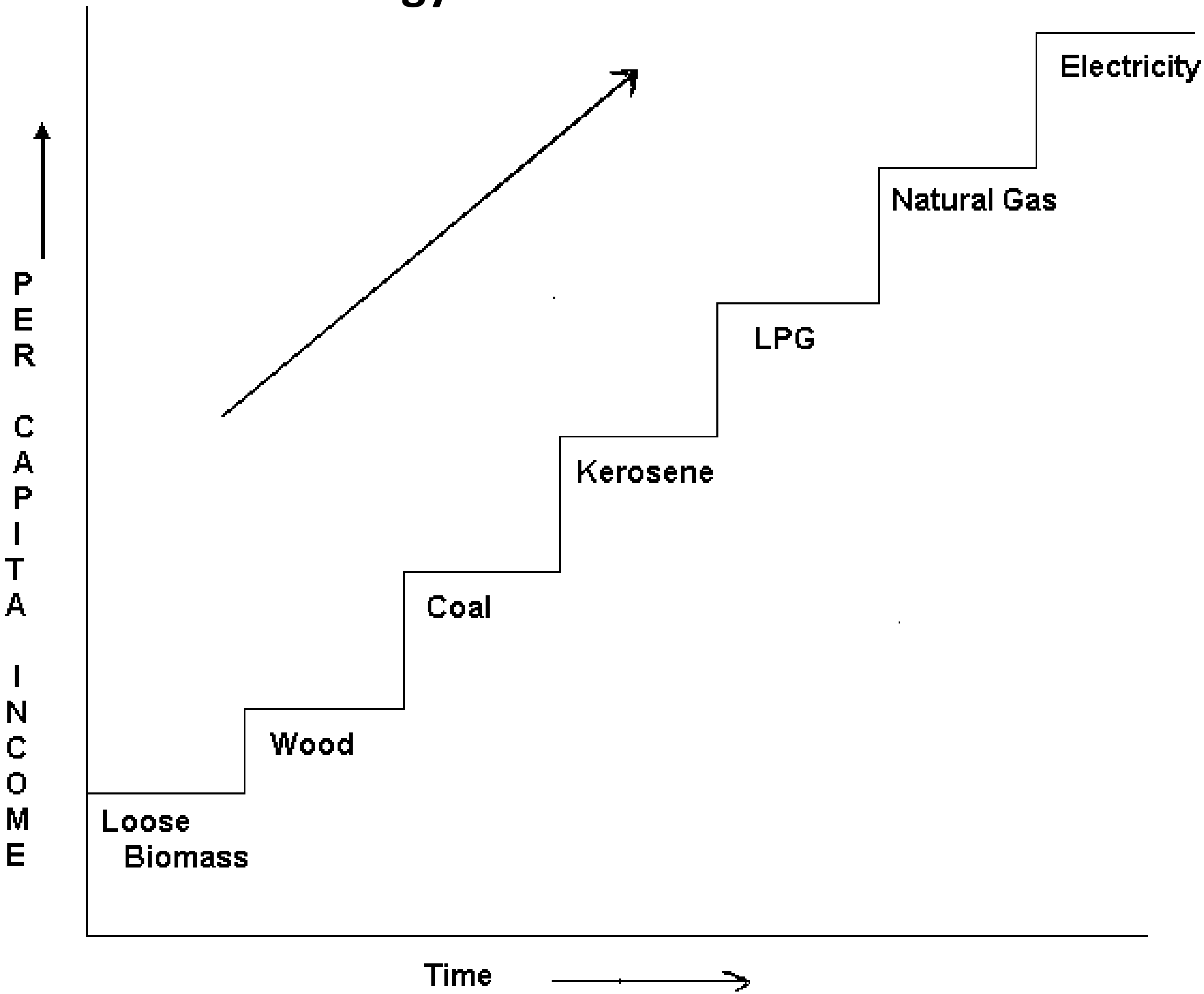


Fig. 3. Emissions of health damaging pollutants different stove/fuel combinations per MJ delivered.

Energy Ladder for Cook Stoves



TESTING THE EFFICIENCY OF COOKSTOVES

There are various ways of stove testing. The testing procedures should be simple, easy to perform in the laboratory and in the field.

Thus, three common stove testing methods are described. They are:

1. Water Boiling Test
2. Controlled Cooking Test
3. Kitchen Performance Test

Water Boiling Test

The Heat Utilization Efficiency is calculated by :

$$HU\% = \frac{[\, Sw \times Wm\,(Tf - Ti) + (L \times We)\,]}{[\,(Efm \times Wf) + (\,Ekm \times Wk)]} \times 100\%$$

Where,

Sw = Specific heat of water, 4.18 kj/kg.
Wm = Weight of water in pot at start of test, kg.
Tf = Temperature of water at boiling point, 0 C
Ti = Temperature of water at start of test, o C
L = Latent heat of water at boiling, 2256 kj/kg
We = Wt of water evaporated at end of each test, kg
Efm = heat value of fuel, kj/kg.
Wf = Weight of fuel used, kg.
Ekm = Heat value of kindling, kg.
Wk = Weight of kindling, kg.

a) High Power Phase b) Low Power Phase

The Power of the fire is calculated by :

$$P = \frac{(Efm \times Wf) + (Ekm \times Wk)}{t}$$

Where,

P = Power Input (Kw)

t = time taken to complete the task (sec)

The Burning Rate of the stove is calculated by :

$$BR = \frac{Efm + Ekm}{t} \times 1000$$

Where,

BR = Burning Rate (g per minute)

Efm = Weight of fuel used (equivalent dry weight)

Ekm = Wt of kindling used (equivalent dry weight)

t = time taken to complete the task (min)

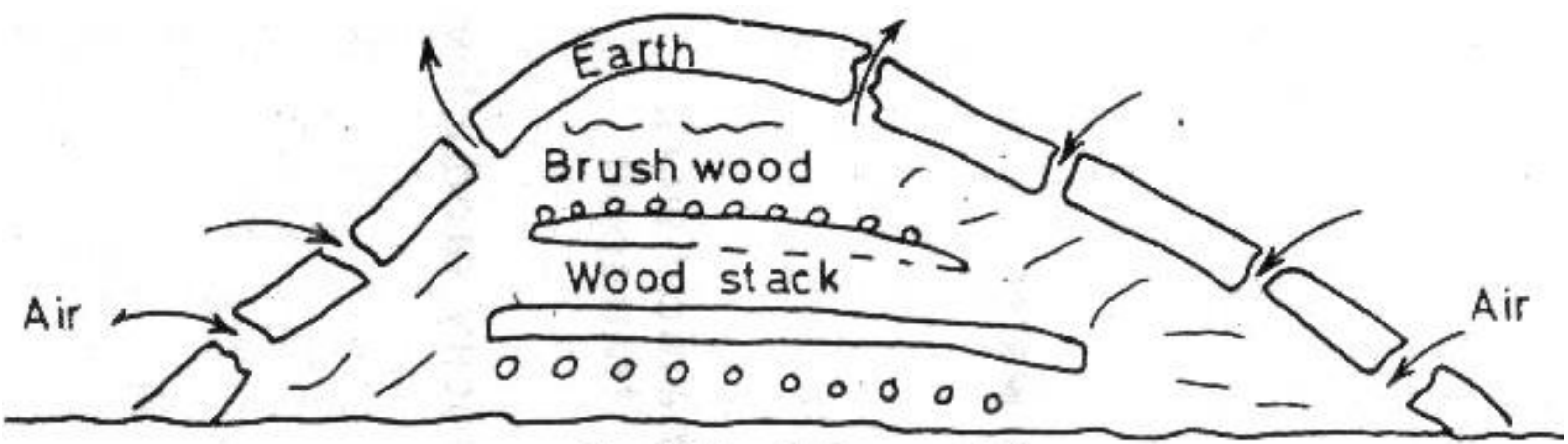
Carbonization

- **It is a process whereby wood is heated with restricted air flow to form a high carbon product (called charcoal) by removing volatile materials from it.**
- **Charcoal contains 20-25% volatiles and 75 – 80% fixed carbon on moisture free basis. It burns smokelessly and can be preserved for longer periods.**
- **Charcoal stove has higher efficiency than the wood burning stoves.**
- **Traditional method produce 10kg of charcoal from 80 kg of softwood. Modern method 25 – 40%**

Stages of carbonization process

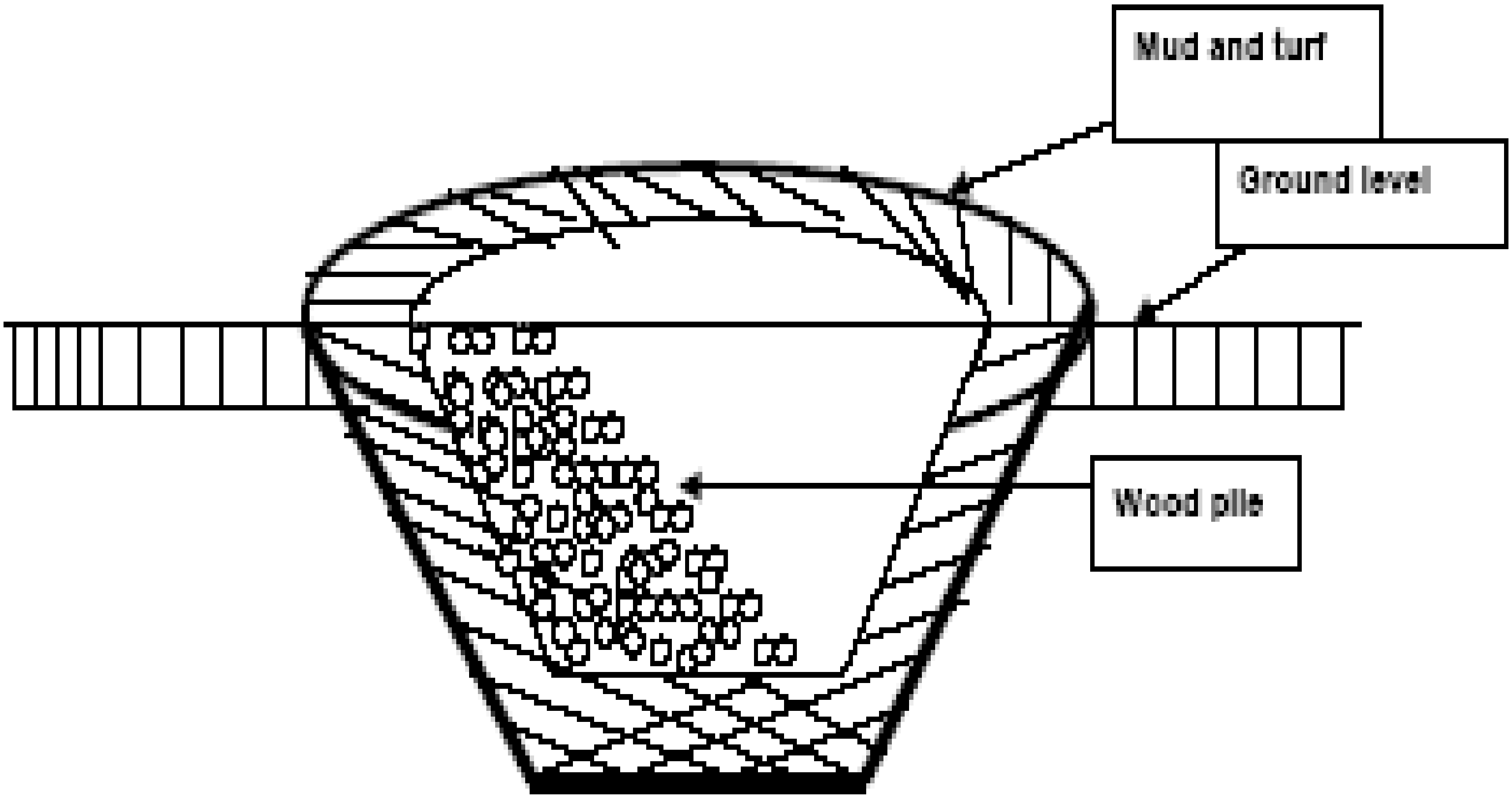
- **I Stage – initial drying , endothermic, temperature up to 200° C.**
- **II Stage – pre-carbonization stage, endothermic, 170 – 300° C, produces pyroligneous liquids and CO and CO_2.**
- **III Stage – carbonization stage, exothermic, 250 – 300° C, greater proportion of light tar and pyroligneous acids are released, form carbonized residue as charcoal.**
- **IV Stage – post carbonization stage, exothermic, over 300° C, remaining volatile components are driven off, increasing carbon content**
- **Cooling**

Carbonization (Charcoal making)

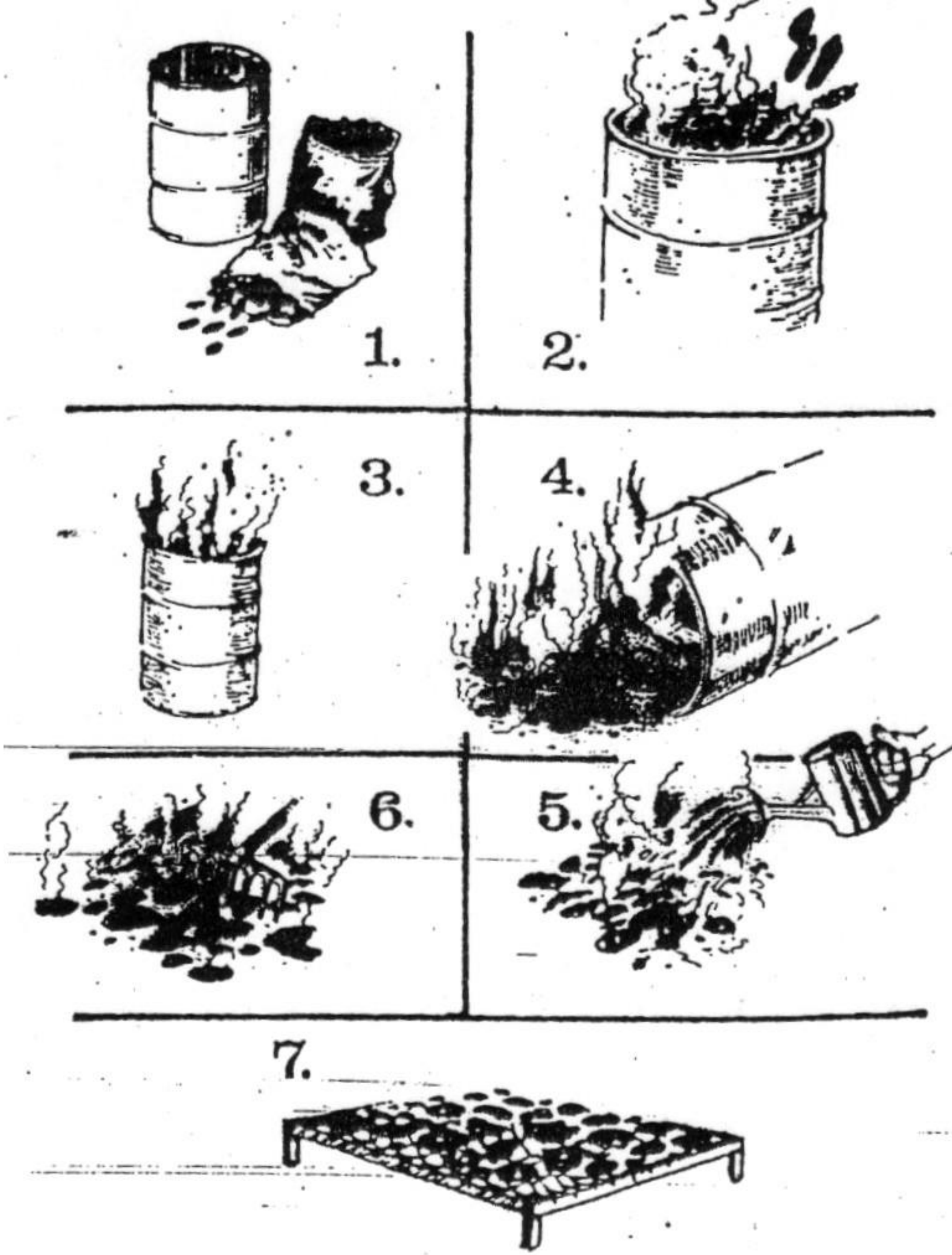


Traditional charcoal kiln.

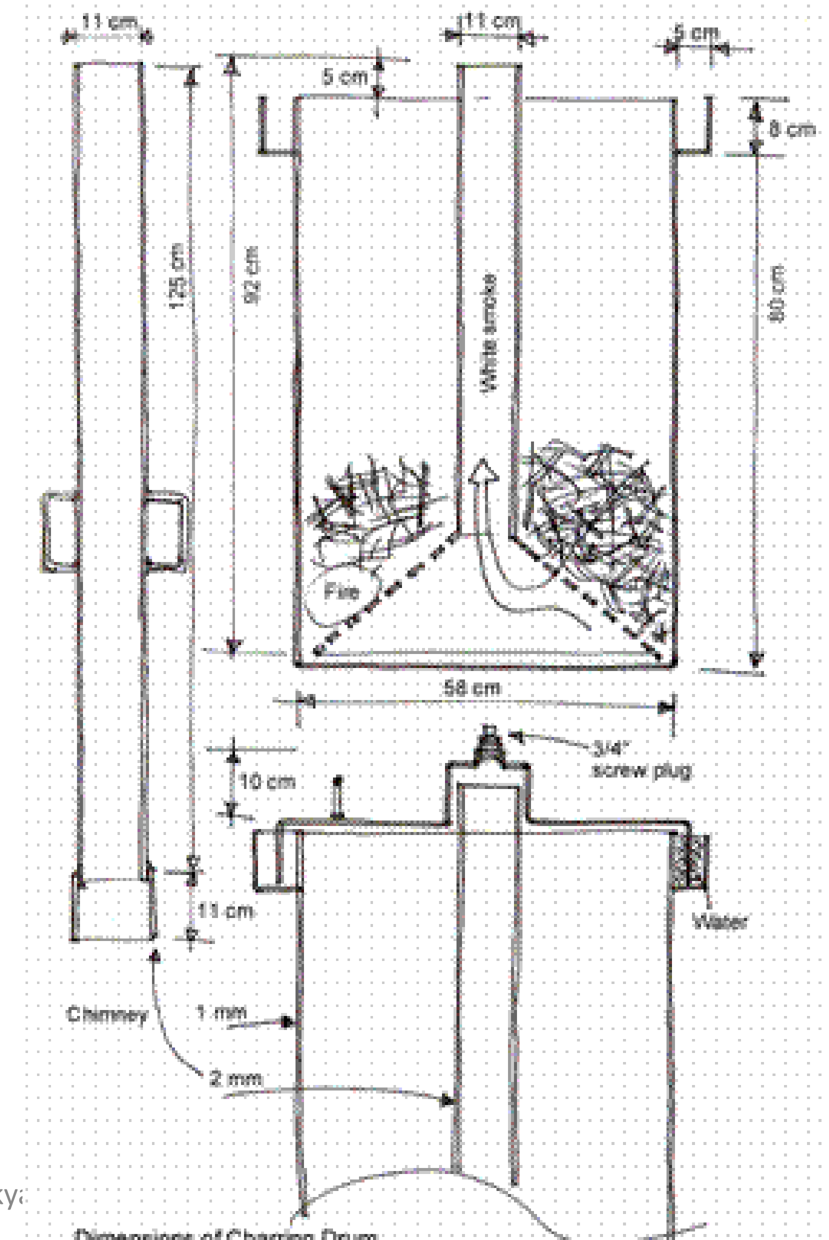
Carbonization (Charcoal making)



Carbonization (Charcoal making)



Carbonization (Charring drum)



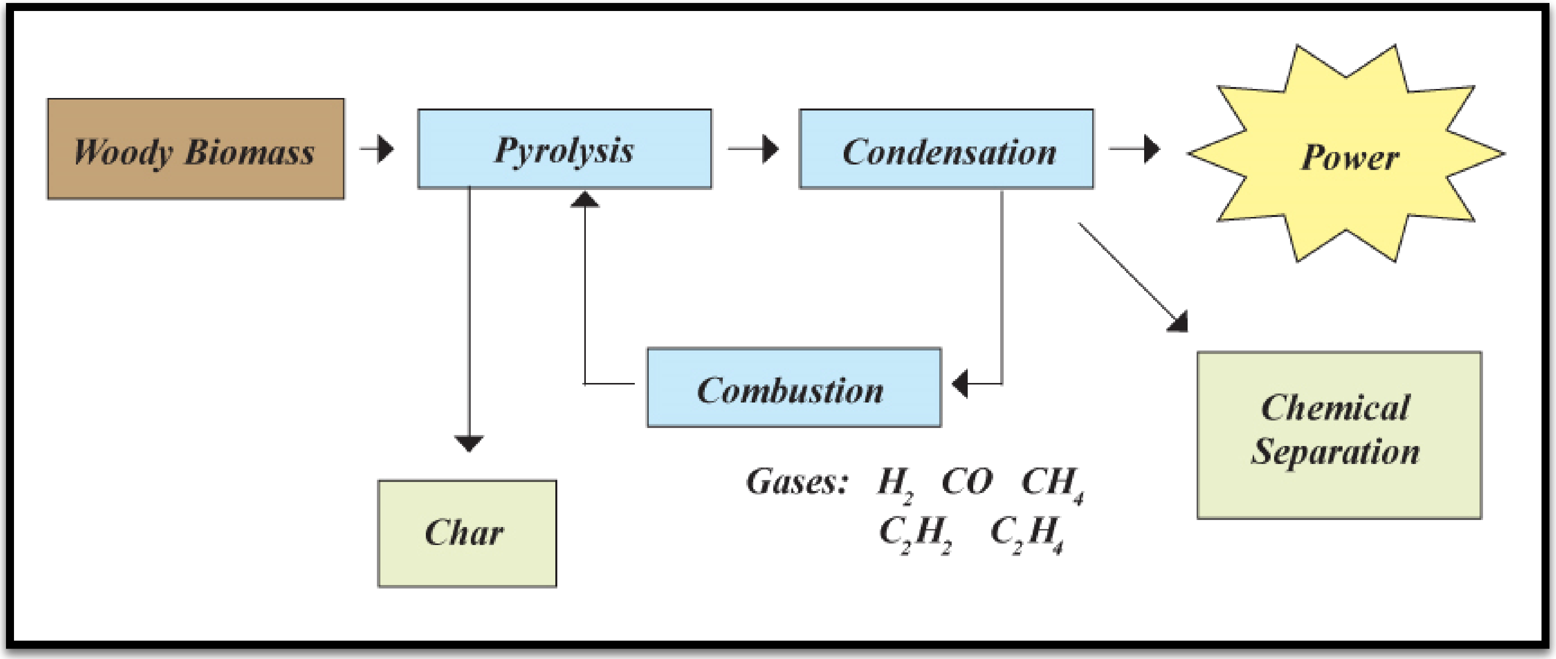
- Charred yield 25-35%

Pyrolysis technology

- **Pyrolysis refers to the thermal decomposition of organic matter in an inert atmosphere.**
- **In this process a mixture of gaseous products, tars, water soluble oils, and aqueous solutions of acetic acid, methanol and other organic compounds are evolved and a solid residue, char, is produced.**
- **The amounts of the various products generated are dependent upon the rate of heating and the final temperature to which the biomass is subjected.**
- **In general, the higher the heating rate and the higher the final temperature, the greater the fraction of the initial biomass that is converted into gaseous and liquid products.**

Pyrolysis

Pyrolysis is the thermal degradation of organic components in biomass in the absence of oxygen. Major products are oil, gas, and char.



Relative Proportion of Products at different Pyrolysis Temperatures

Pyrolysis temp (°C)	Char (wt %)	Liquid (wt %)	Gases (wt %)
400	42.14	35.85	22.01
500	32.02	39.56	28.42
600	29.81	29.53	40.66
700	25.46	20.47	54.07

Pyrolysis Process Parameters

Process	Residence time	Heating Rate (°C/min)	Temp. Range Max. (°C)	Product (max. wt %) G-L-S
Very slow (carbon-isation)	hr-days	<<1	(300–400) 400	Char
Slow	upto 30 min.	5–100	(400-600) 600	Char, bio-oil gas
Flash	0.5-5 sec	100	(450–600)650	Boi-oil chemicals, fuel gas
Ultra	<0.5sec	1000–10000	(700–900)1000	Chemicals, fuel gas

Note: G-Gas, L-Liquid, S-Solid Char.

Wood Pyrolysis Products (slow heating)

Products	Weight (%)
Char	32
C_6H_8O(Tar)	16
Water	27
CH_4	2
CO	7
CO_2	14
Paraffin	2
Total	100

Products of Pyrolysis and their uses

Pyrolysis

Char

1. Fuels
   - Domestic
   - industrial
   - Metallurgical
2. Feed Stock

   Calcium carbide
   Silicon Carbide
   Activated carbon

Liquids

1. Fuel for Combustion
2. Feed Stock

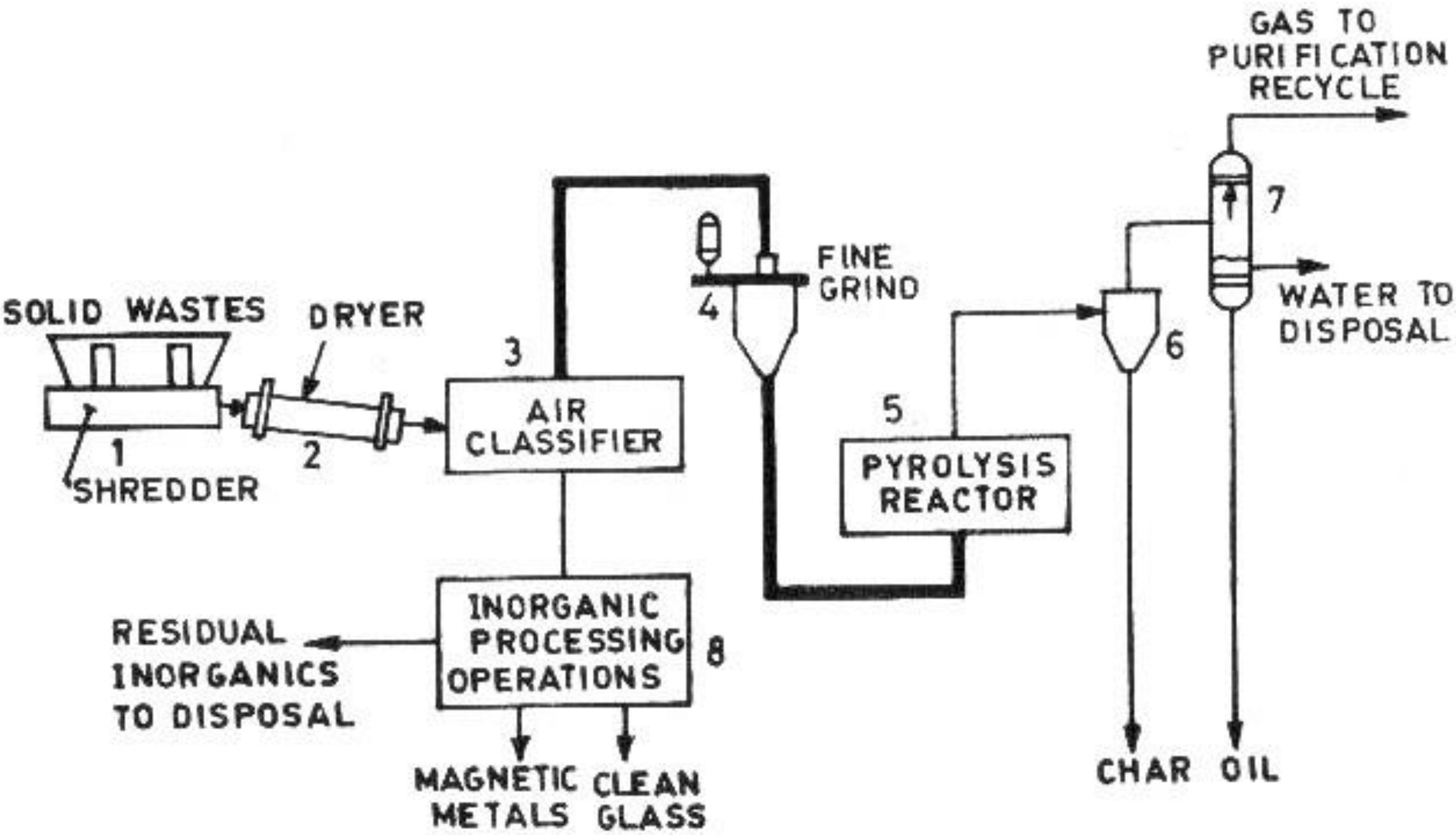
   * Phenolic compounds
   * Germicides
   * Black paint

Gases

1. Fuel

   * Industrial
   * I.C. Engines for mech & elec power
2. Synthetic liquid fuels

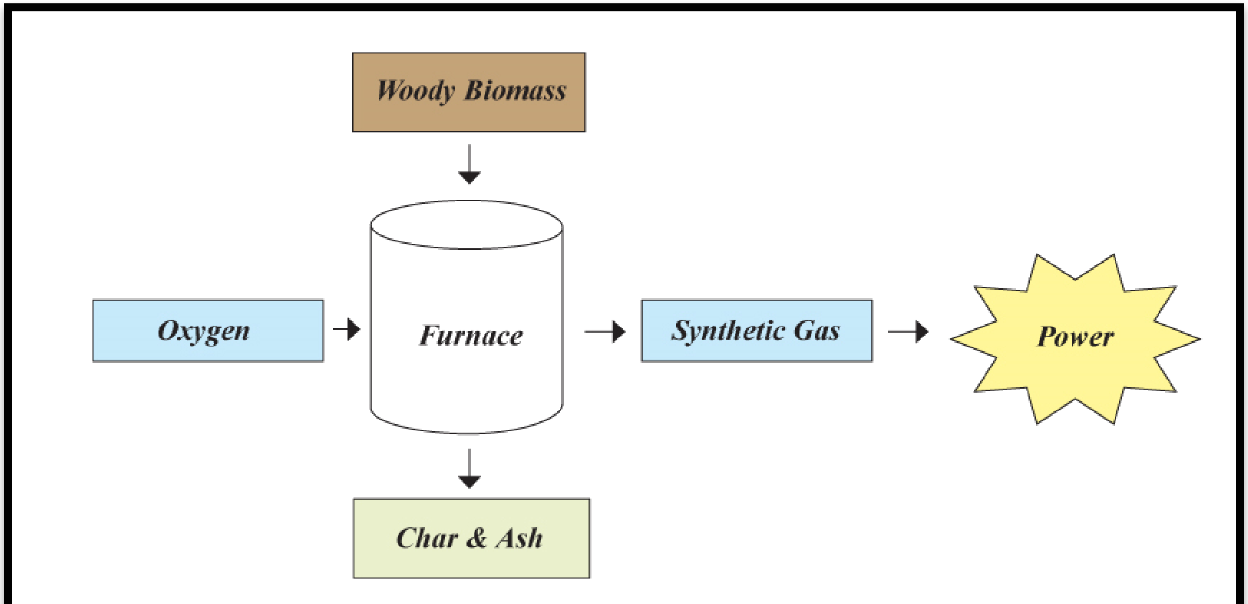
Pyrolysis Plant



Schematic of Pyrolysis

Gasification

Gasification is a thermochemical process in which biomass at high heat is turned directly from a solid into a gaseous fuel called syngas (a mixture of carbon monoxide, hydrogen and some methane).



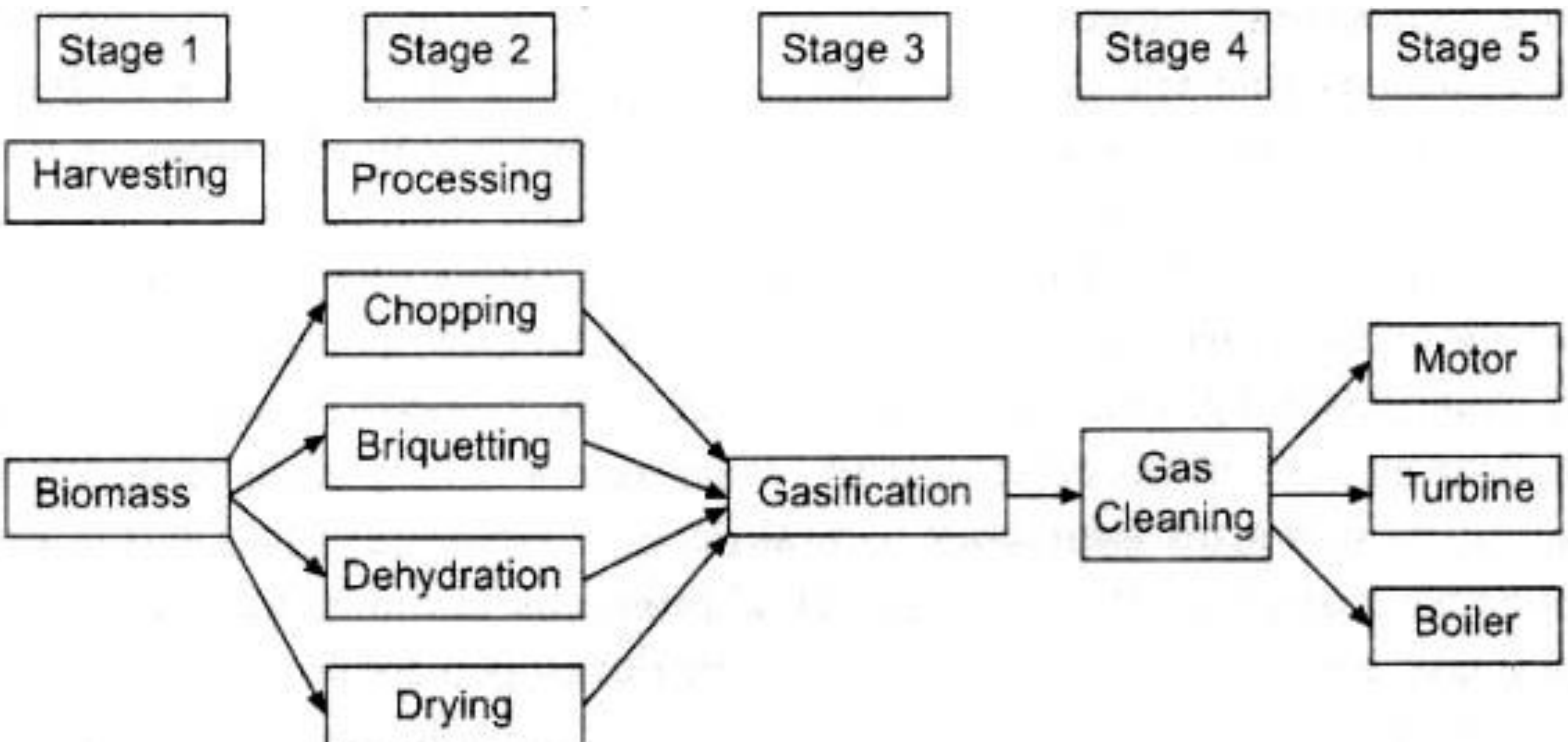
Gasification Technology

- **Gasification of biomass is the conversion of solid biomass (i.e. wood/ wood wastes, agro-residues and organic industrial wastes) into a combustible gas mixture.**
- **It is carried out in an enclosed reactor operating at about 900oC and part of the biomass is combusted by air to provide the heat. The resulting gas, known as producer gas, contains CO(15 - 29 %), CO2 (5 -15 %), H2 (5 -12 %), N2 (50 – 65 %) and small amounts of hydrocarbon gases.**
- **The calorific value of the gas ranges from 1200-1500 kcal/m3.**
- **The gases produced are applied mainly as a fuel gas for direct heating or for the operation of gas turbines or I.C. engines for generating power.**

Gasification Technology

- All types of gasifiers produce gases mixed with different quantities of vaporized tars depending upon the type and physical characteristics of biomass, its ash properties, reactor type and operating conditions.

Gasification Process



Gasification reactions

- Devolatilization — $C + heat \rightarrow CH_4 +$ condensible -hydrocarbons+char
- Steam-Carbon — $C + H_2O + heat \rightarrow CO + H_2$
- Reverse Boudouard — $C + CO_2 + heat \rightarrow 2\,CO$
- Oxidation — $C + O_2 \rightarrow CO_2 + heat$
- Hydrogasification — $C + 2\,H_2 \rightarrow CH_4 + heat$
- Water Gas shift — $H_2O + CO \rightarrow CO_2 + H_2 + heat$
- Methanation — $3\,H_2 + CO \rightarrow CH_4 + H_2O + heat$
  $4\,H_2 + CO_2 \rightarrow CH_2 + 2\,H_2O + heat$

Reaction

Oxidation reactions

$$C + O_2 = CO_2 + 393800 \text{ kJ/kg mol (Exothernic reaction)}$$

Hydrogen in the fuel reacts with oxygen in the air blast, producing steam

$$H_2 + \frac{1}{2}O_2 = H_2O + 2\,42000 \text{ kJ/kg mol (Exothermic reaction)}$$

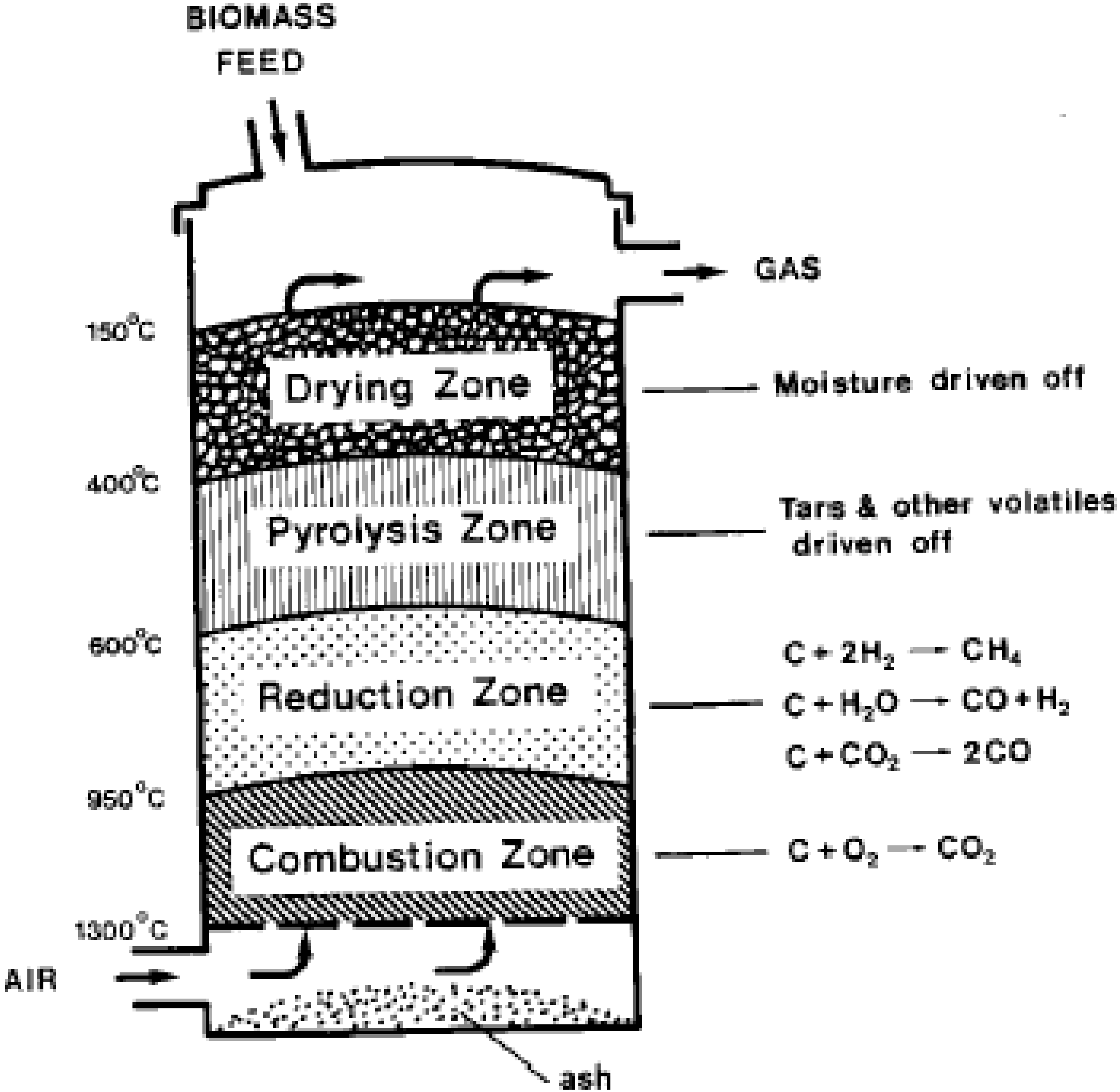
Reduction reactions

$$C + CO_2 = 2\,CO - 172600 \frac{\text{kJ}}{\text{kg mol}} \text{ (Boudouard reaction)}$$

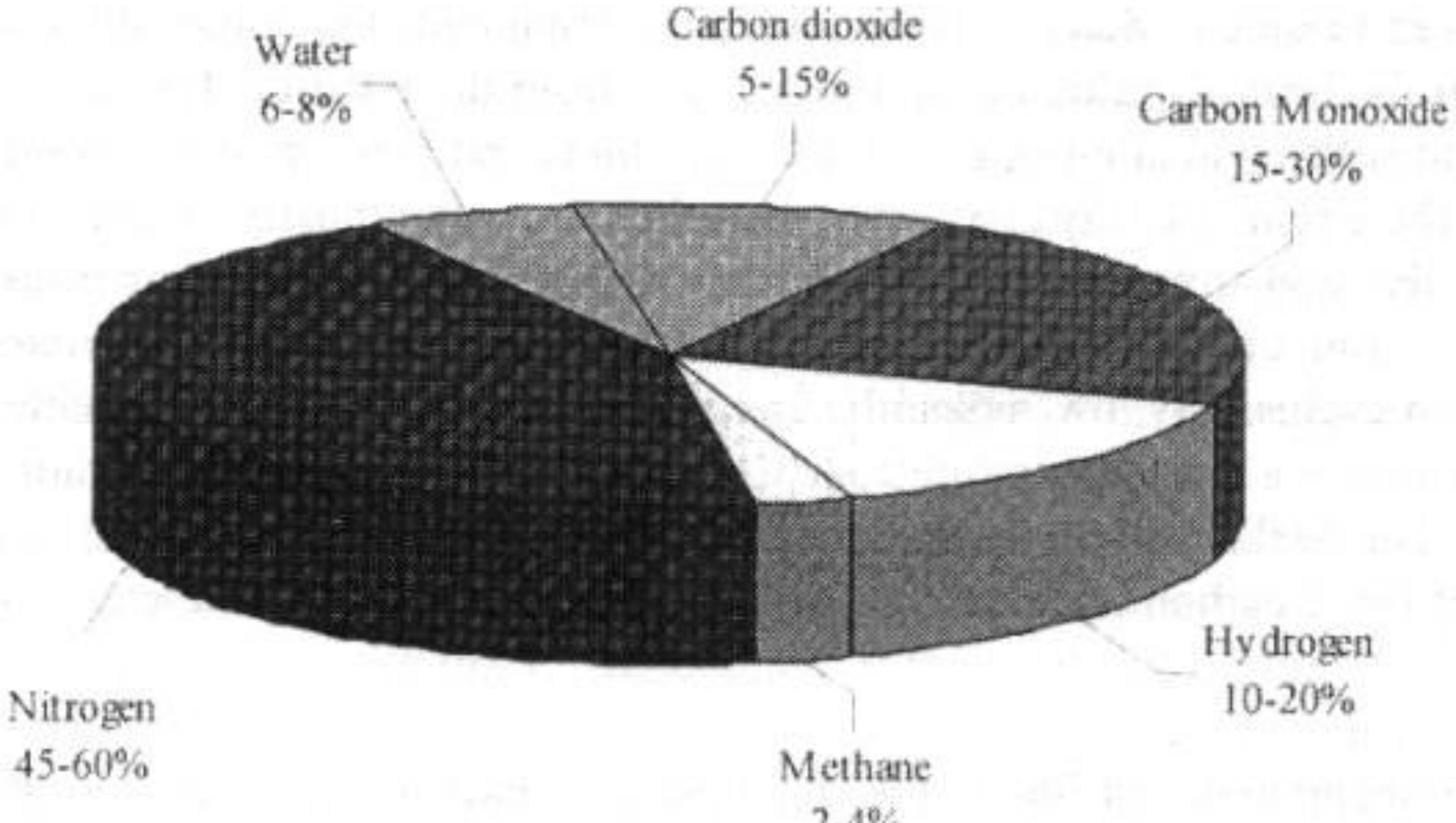
$$C + H_2O = H_2 + CO - 131000 \frac{\text{kJ}}{\text{kg mol}} \text{ (water gas reaction)}$$

$$CO + H_2O = CO_2 + H_2 + 42000 \frac{\text{kJ}}{\text{kg mol}} \text{ (water-shift-reaction)}$$

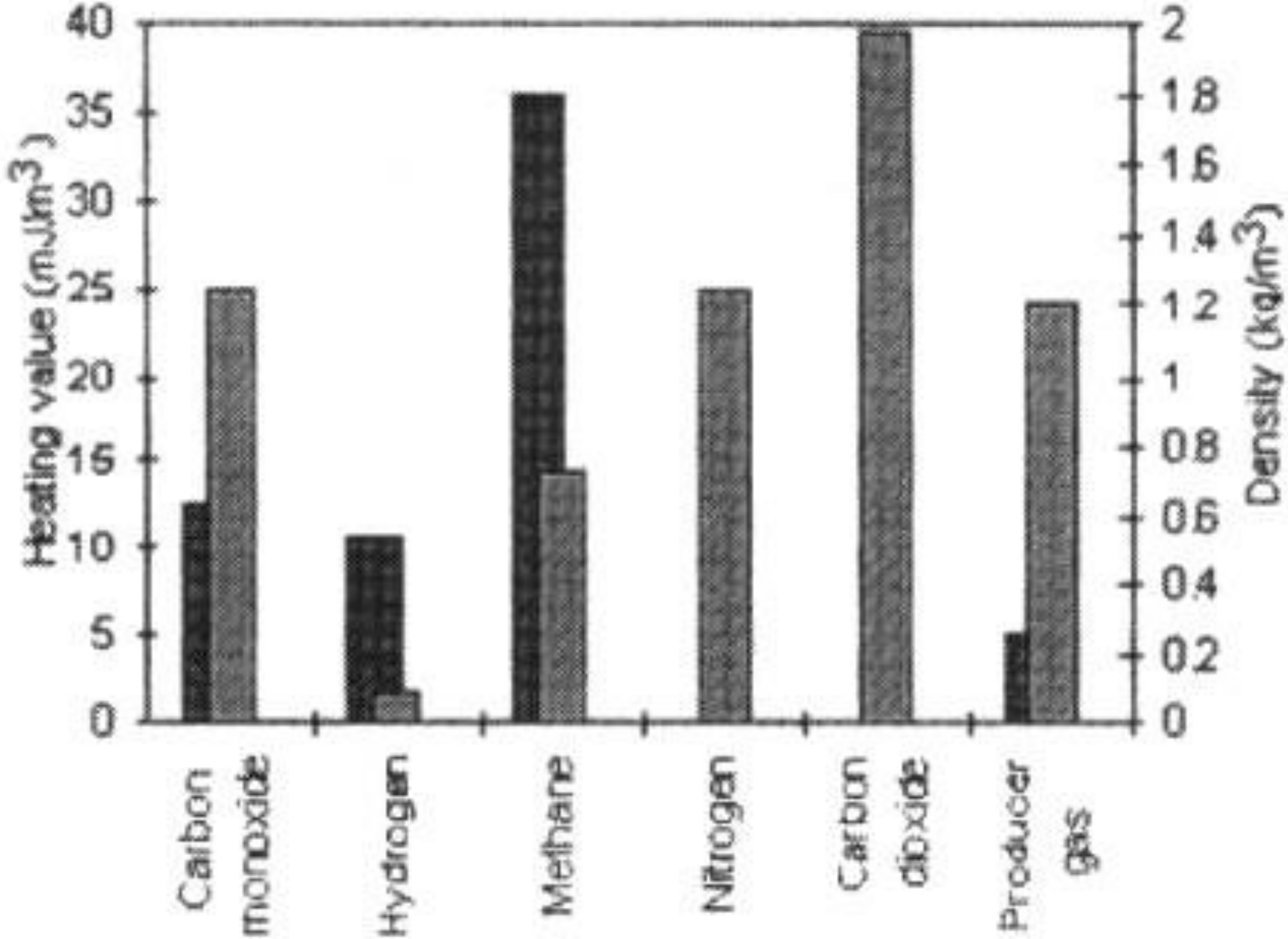
$$C + 2H_2 = CH_4 + 75000 \frac{\text{kJ}}{\text{kg mol}} \text{ (Hydrogeneration reaction)}$$


BIOMASS
FEED
GAS
150°C
Drying Zone
Moisture driven off
400°C
Pyrolysis Zone
Tars & other volatiles
driven off
600°C
C + 2H2 → CH4
Reduction Zone
C + H2O → CO + H2
C + CO2 → 2CO
950°C
Combustion Zone
C + O2 → CO2
1300°C
AIR
ash

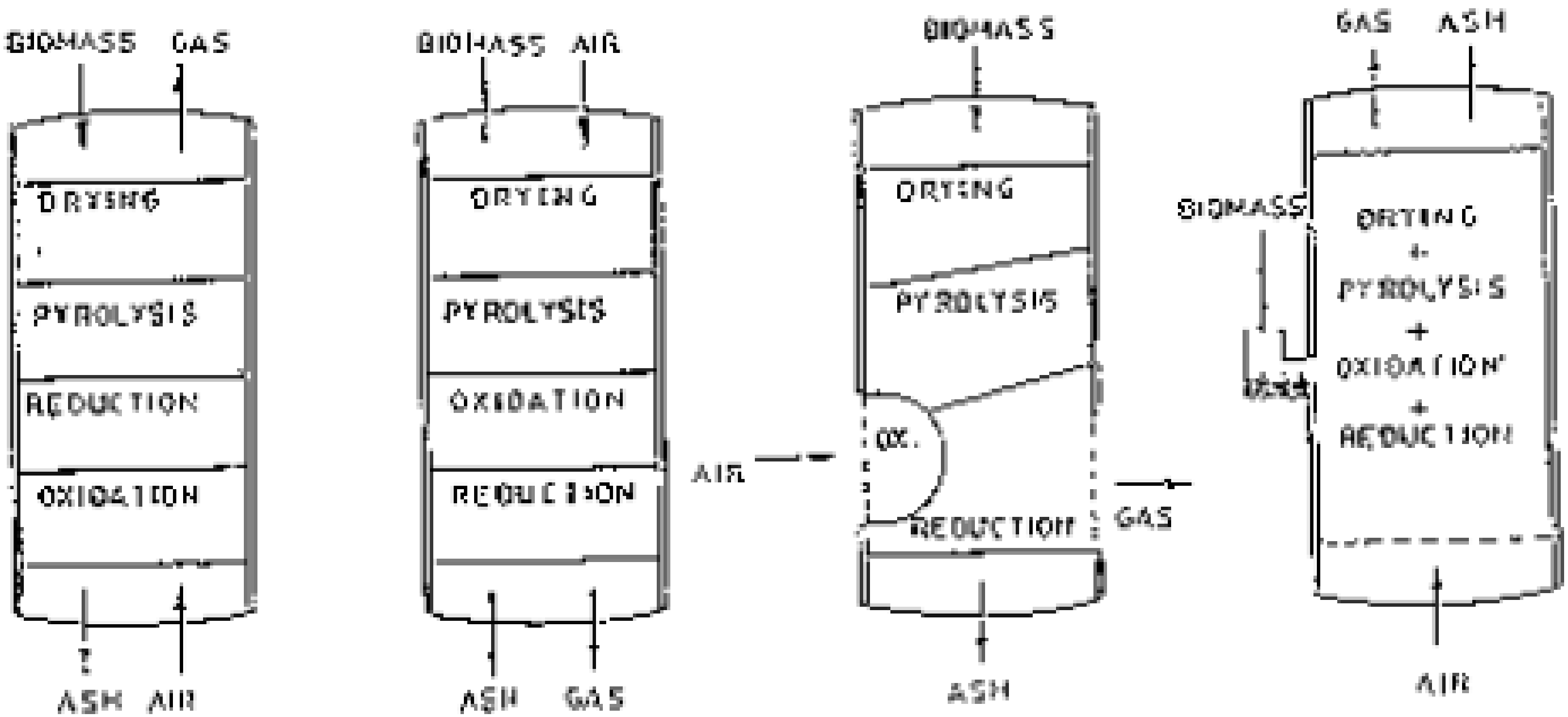
Gasifiers product composition



Heating value and Density of gasifiers products



Types of gasifiers



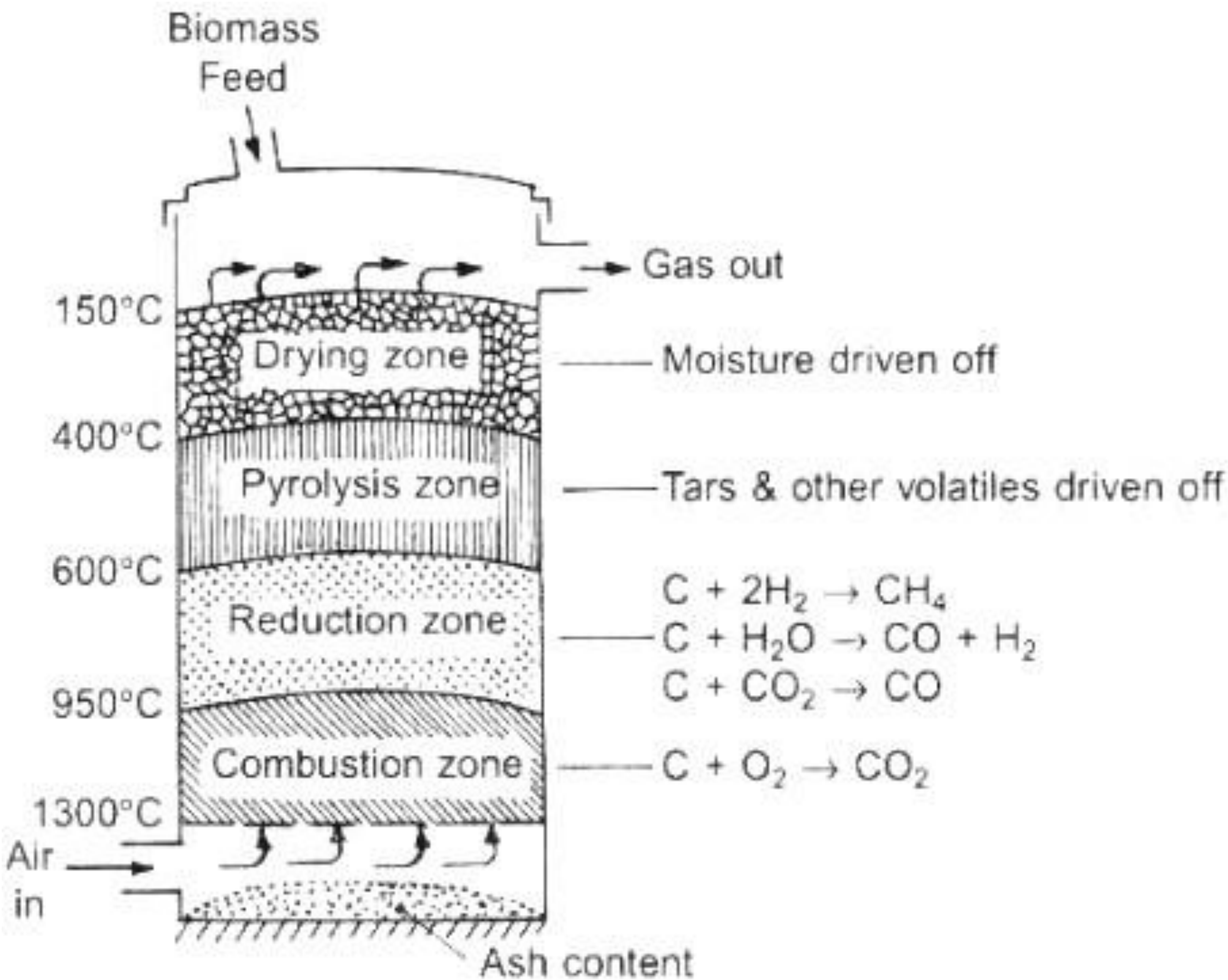
COUNTER CURRENT MOVING BED
(a)

CONCURRENT MOVING BED
(b)

CROSS CURRENT MOVING BED
(c)

FLUIDIZED BED
(d)

Updraft Gasifier



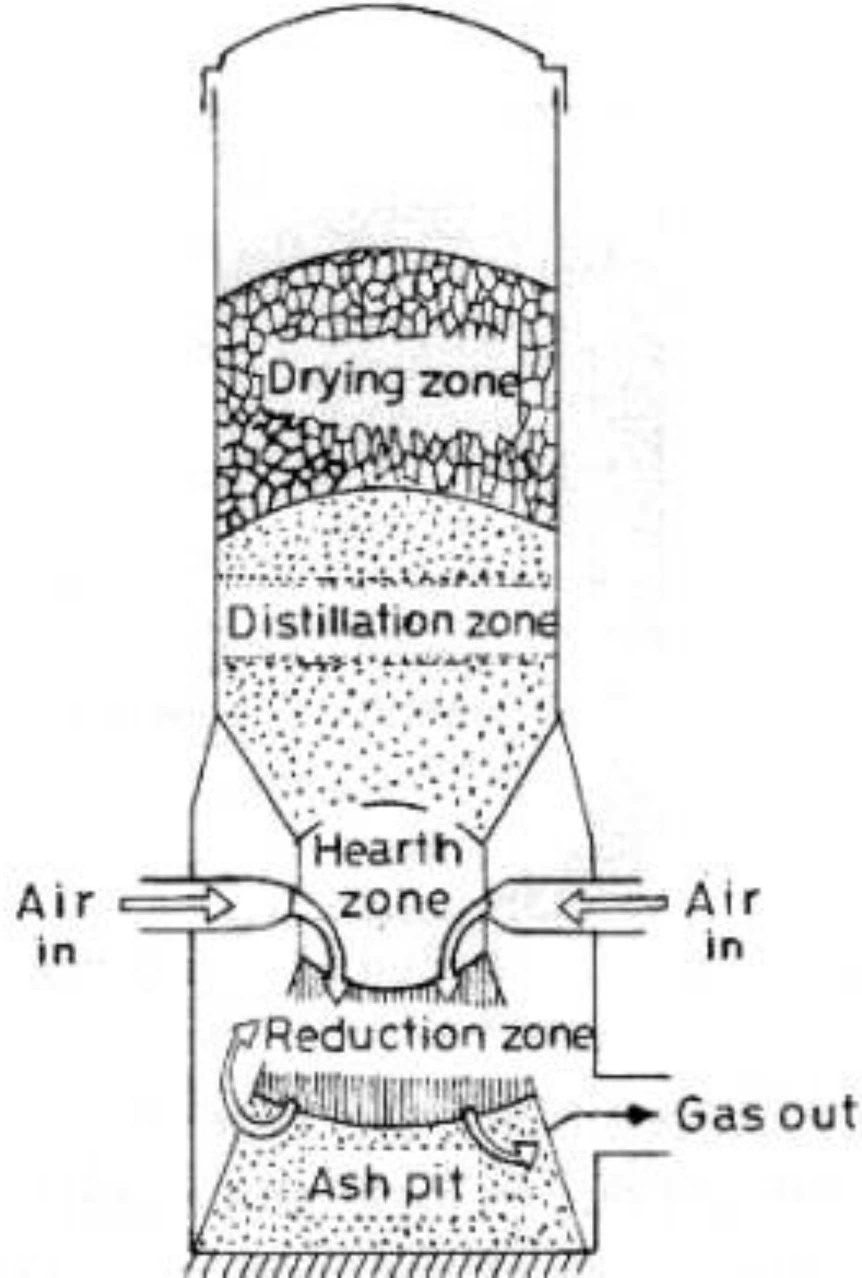
Updraft Gasifier

- In the countercurrent moving bed reactor (updraft gasifier), the air flow is upward.
- The gas produced in the reduction zone leaves the reactor together with the pyrolysis products and the steam from the drying zone.
- The resulting gas is rich in hydrocarbons (tars) and is suitable only for direct heating purposes in industrial furnaces.
- If it is to be used for electricity generation by I.C. Engines, it has to be cleaned thoroughly.

Characteristics of Updraft Gasifier

- It has **clearly defined zones** for various reactions.
- Its **efficiency** is **very high** because hot gases pass through the entire fuel bed and leave at lower temperatures. **Sensible heat is used for reduction, pyrolysis and drying**.
- **Products from pyrolysis and drying**, containing water vapor, tar and volatiles leave the gasifier **without passing through high temperature zones** and **are not cracked.** Hence the gasifier **needs elaborate gas cleaning operations**.
- **Unsuitable** for **high volatile fuels**.
- Sp. Gasification rate: Amount of fuel that can be gasified per m^2 grate area per hour
  - Range 100-300 kg/m2 hr
  - Slagging grates 300kg/m2 hr to keep high temp.
  - Fixed grate 100-200 kg/m2 hr

Downdraft Gasifier



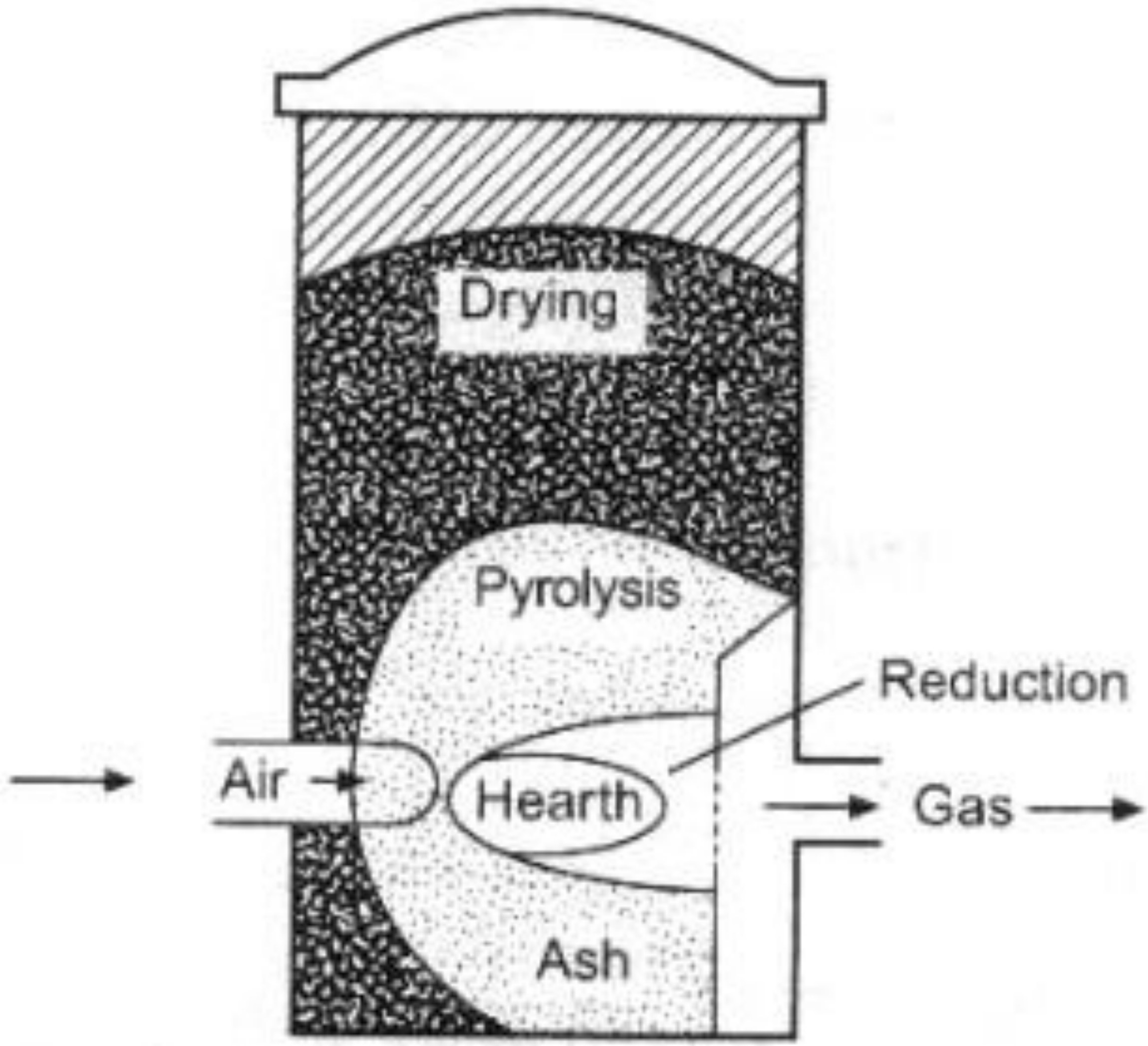
Downdraft Gasifier

- In the concurrent moving bed reactor (downdraft gasifier) the air flow is downward and all the decomposition products from the pyrolysis and drying zones pass through the oxidation zone.
- This leads to thermal cracking of the volatiles resulting in reduced tar content in the producer gas. For this reason it is very attractive to use this gas for engine applications.
- There is always a constriction at the level of the oxidation zone to force the pyrolysis products through a concentrated high temperature zone to achieve complete decomposition.
- This concentrated oxidation zone can cause sintering or slagging of ash resulting in clinker formation and consequent blocking of the constricted area and /or channel formation. Continuous rotating ash grates or other mechanical shaking may be required to avoid this problem.

Characteristics of Downdraft Gasifier

- The tar laden gases pass through the high temperature bed of coal in the oxidation zone and hence are cracked. Thus the **output gases are relatively clear** requiring **no elaborate cleaning system**.
- The **gas leaves at** relatively **high temperatures** of **400-500 °C**, hence the **gasifier efficiency** is **less than that of the updraft gasifier**.
- **Not suitable** for **high ash** fuels, **high moisture** and **low ash fusion temperature** fuels.
- S.P Gasification rate : 1 $Nm^3/hr\ cm^2$ throat area or 3000-4000 $kg/hr\ m^2$ dry fuel.

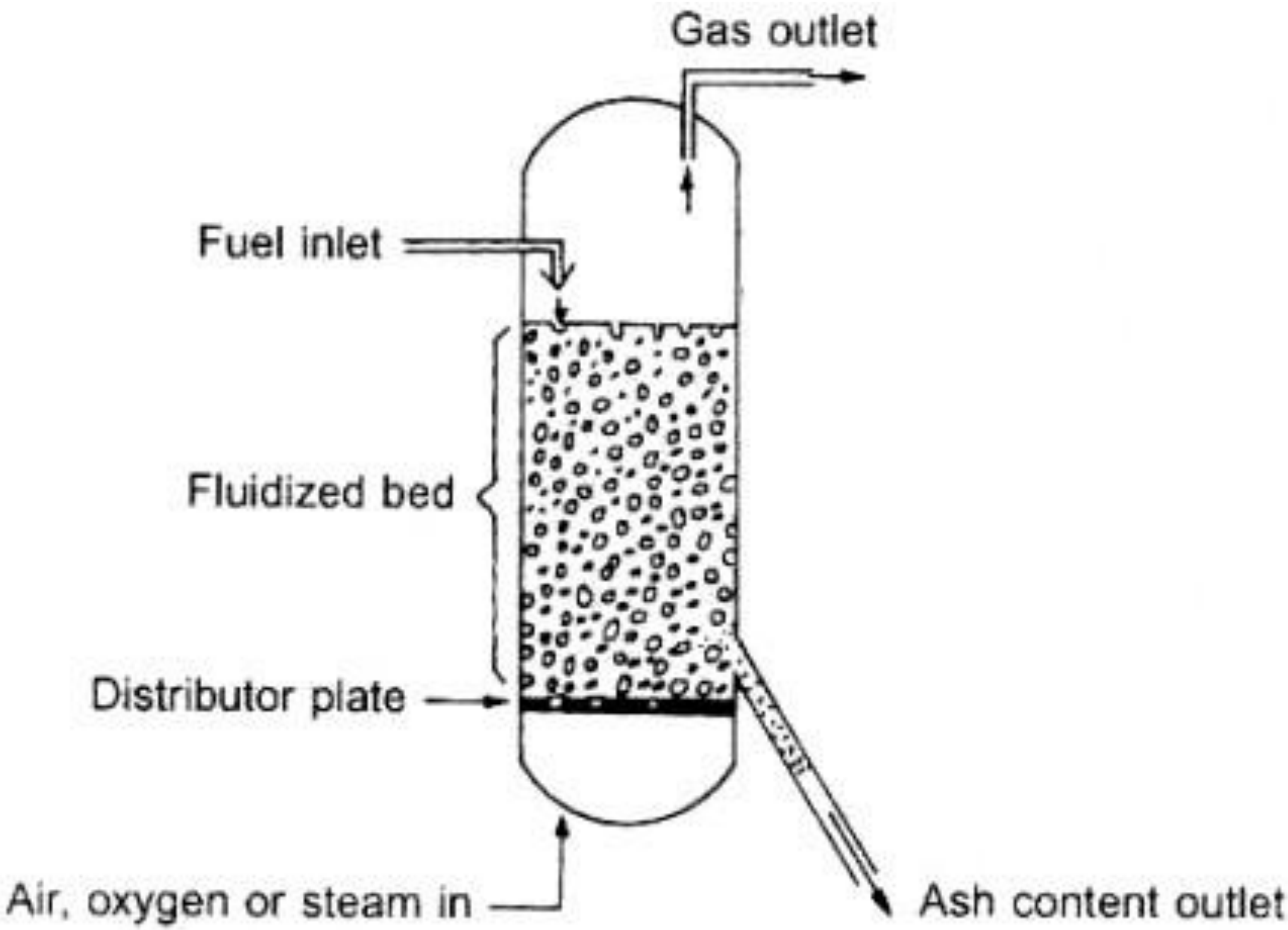
Cross draft Gasifier



Characteristics of Cross draft Gasifier

- Cross draft gasifiers have had very few applications and can hardly be credited with any advantage beyond good permeability of the bed.
- Grate not required.
- Single air tuyere.
- Ash formed due to high temperature falls to the bottom and does not hinder operation.
- The high exit temperatures of the gases and low CO_2 reduction results in poor quality of the gas and low efficiency.

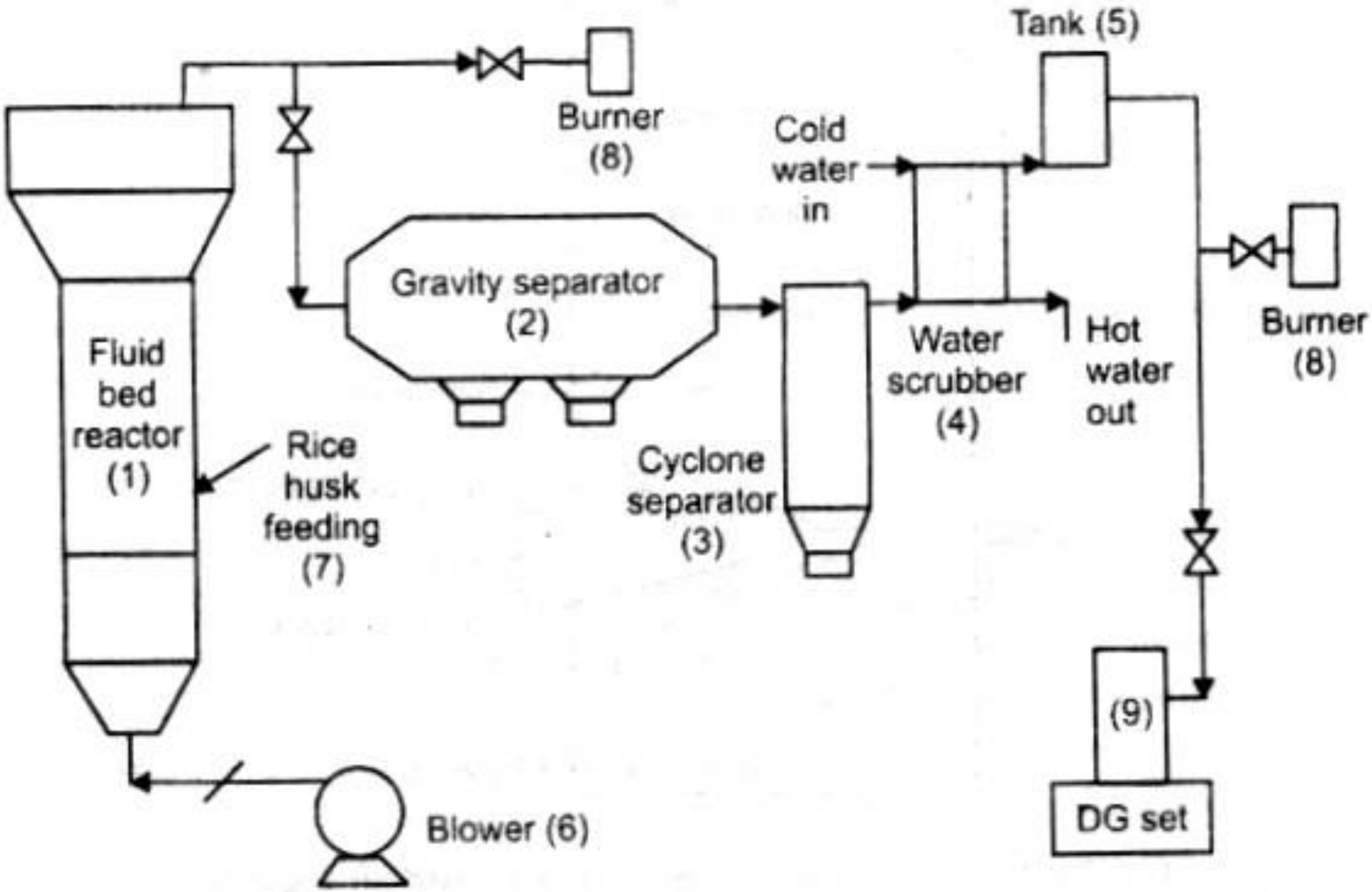
Fluidized bed Gasifier



Characteristics of Fluidized bed Gasifier

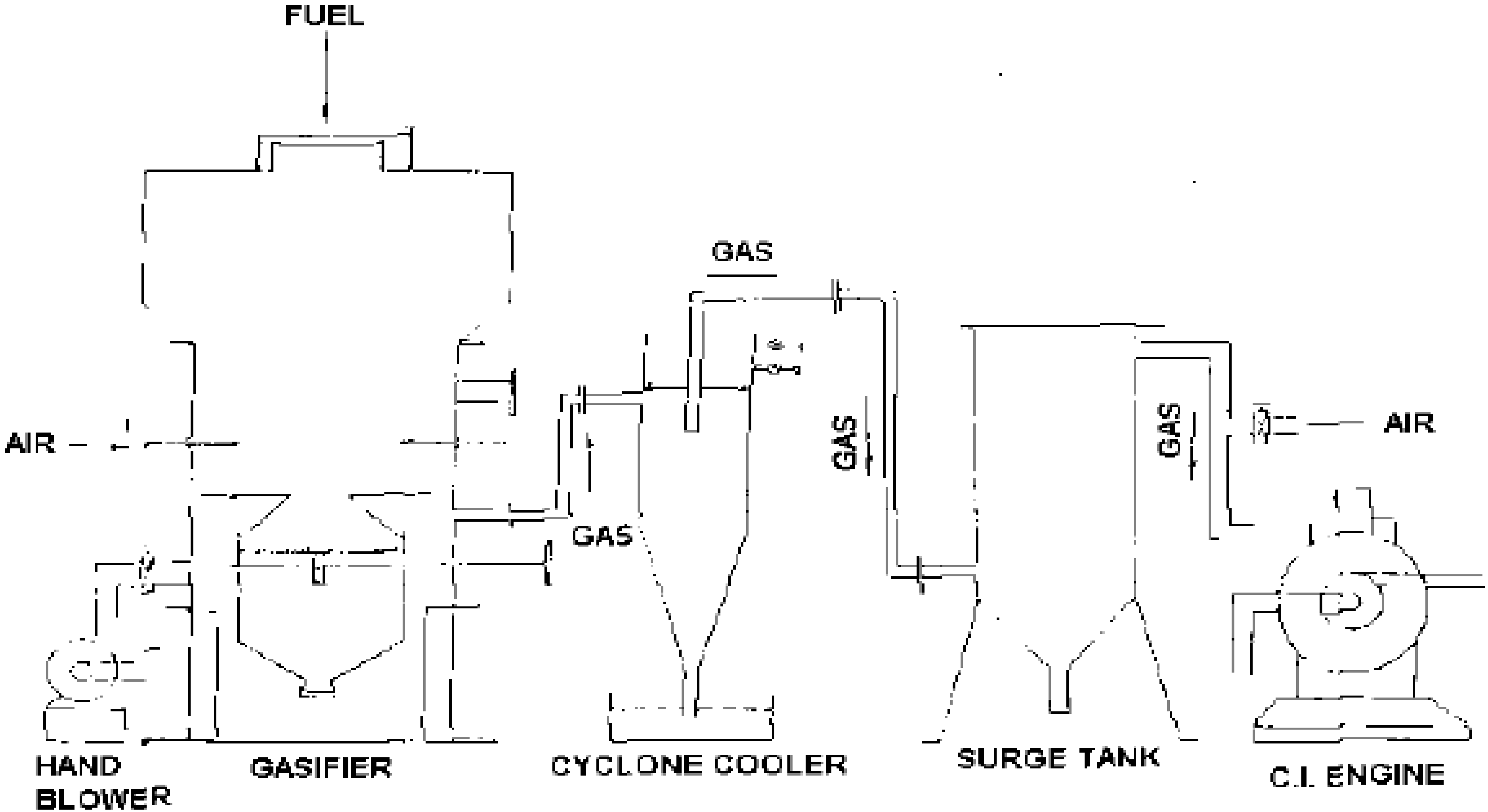
- The fluidized bed reactor/gasifier is essentially a hot bed of sand particles kept constantly under agitation by the gasifying agent, steam and inert gas.
- The fluidizing gas is distributed through the nozzle at the bottom.
- The product gas has the same high temperature (800-1000°C) as the temperature maintained in the bed and contains small quantities of tar and large quantities of ash particles.
- Although it has a somewhat higher throughput per unit of reactor volume than the moving bed, its main disadvantages are high outlet gas temperature, entrainment of charcoal fines and it requires a complex control system because of poor quality biomass held up in the bed.
- These systems are, however, most appropriate for biomass whose particle sizes ranges from 0.1 to 1 cm.

Fluidized bed Gasifier



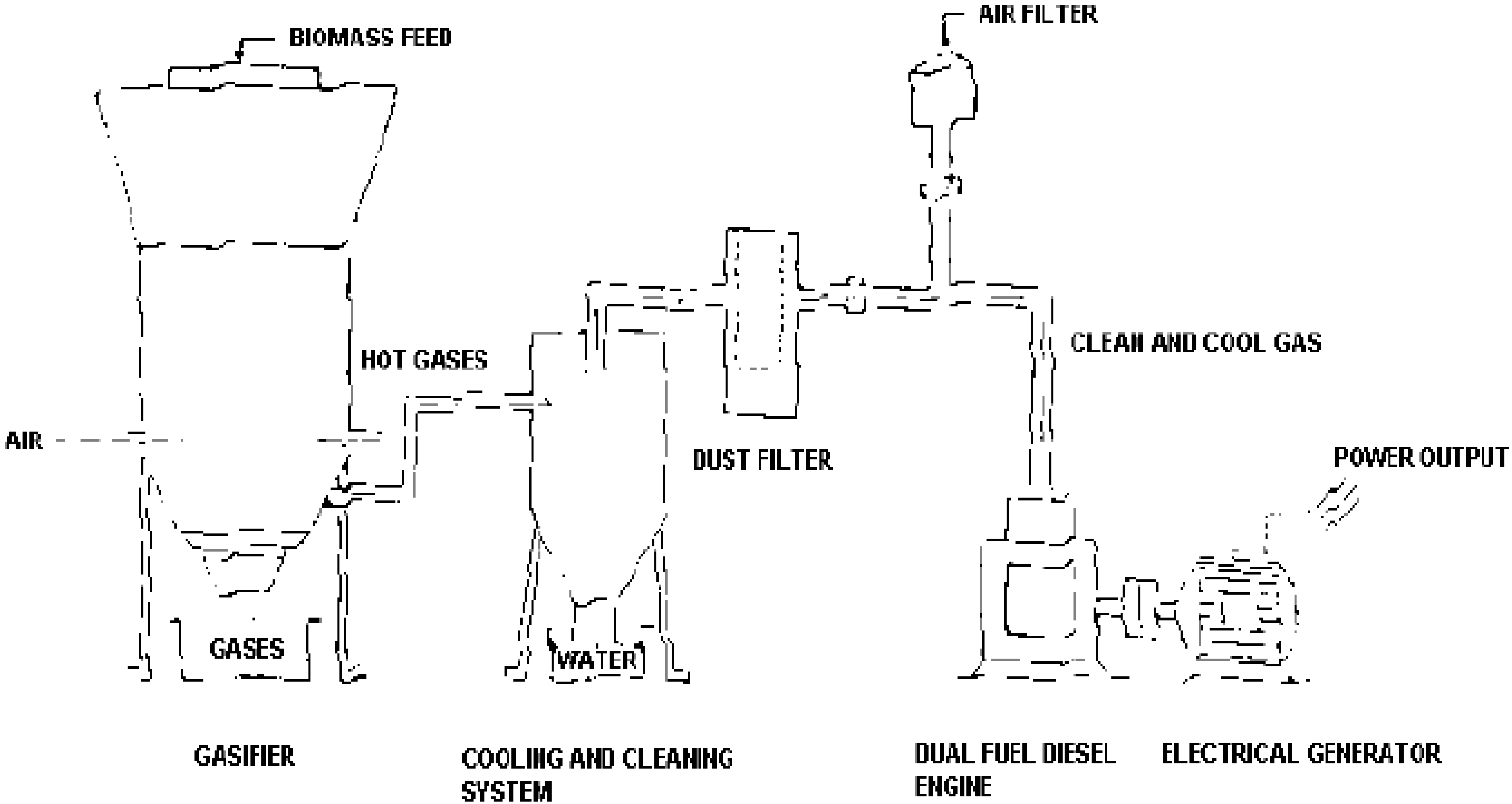
Schematic Diagram of Fluidised Bed Rice Husk Gasifier

Small scale gasifier system (IIT model)

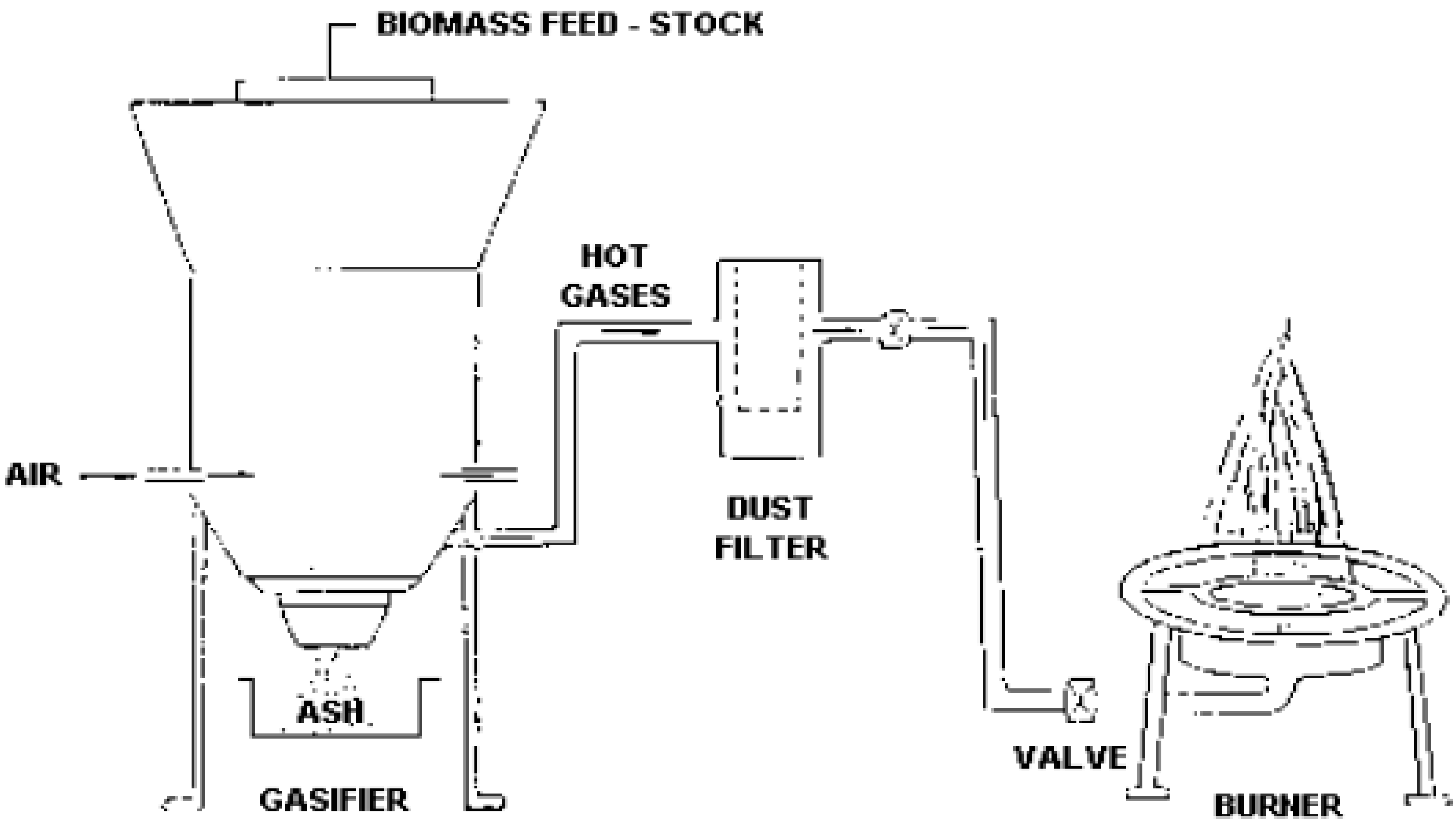


village level gasifier systems of 5, 10 and 20 HP based on partially pyrolysed and briquetted biomass fuels.

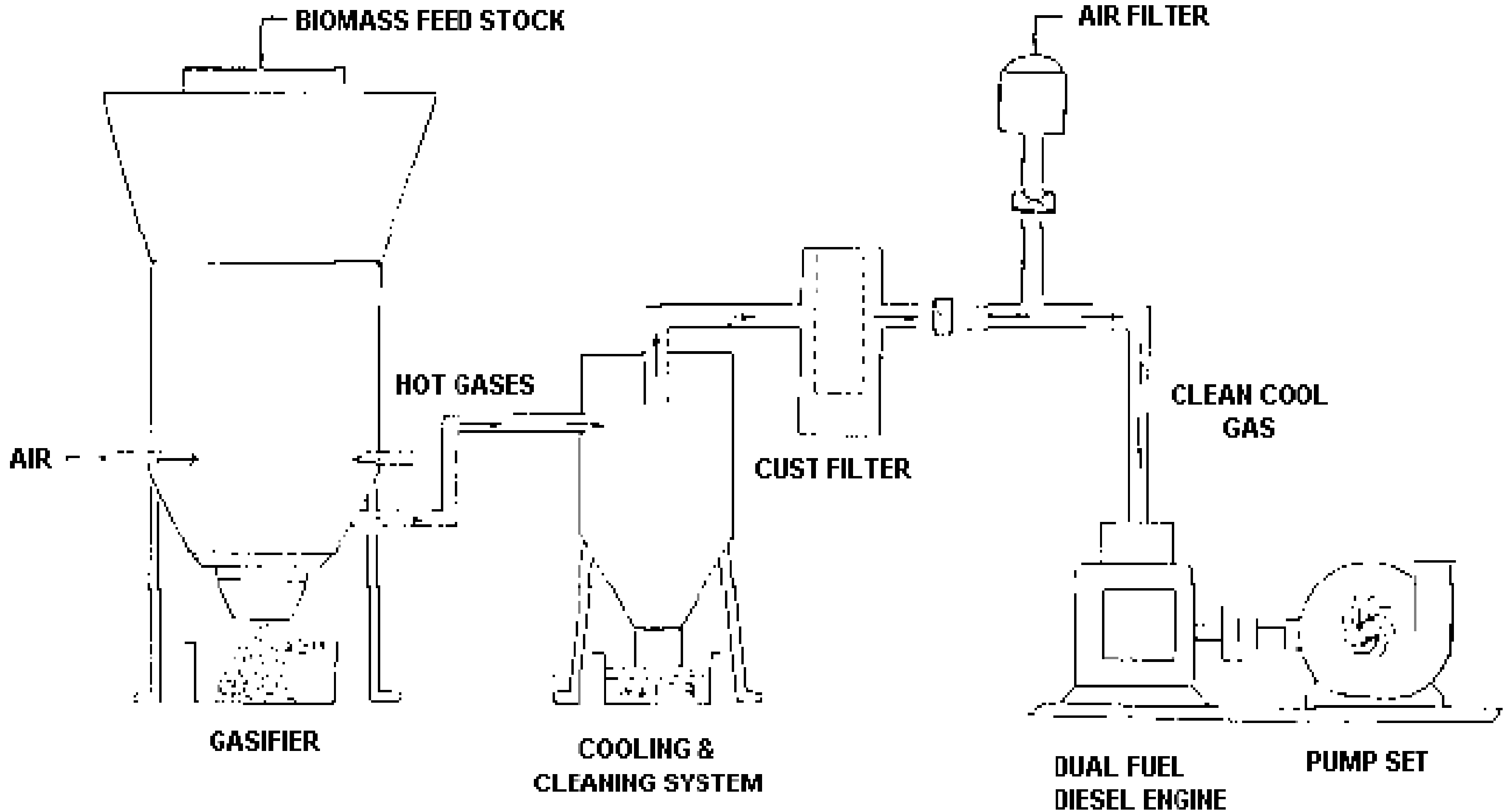
Biomass Gasifier Based Power Generation System



Biomass Gasifier Based Institutional Cooking System



Biomass Gasifier Based Water Pumping System



Overall Efficiency of Electricity Generation Gasifier System

$$\eta_{tot} = \frac{P_e}{m_s \, c_s} = \eta_g \cdot \eta_{en} \cdot \eta_e$$

Where

P_e = electric power generated,

m_s = mass flow rate of solid fuel,

c_s = calorific value of solid fuel,

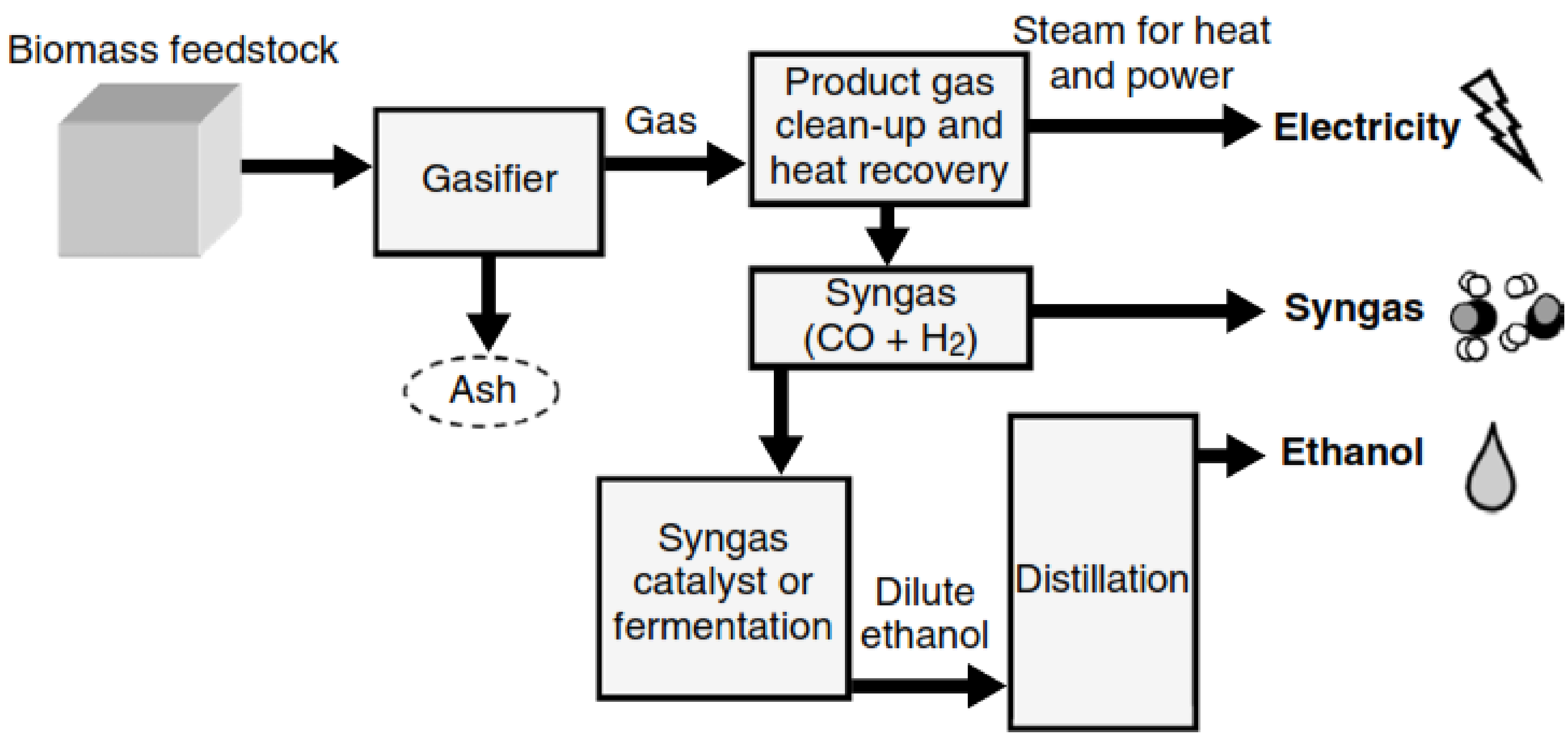
η_g = efficiency of the gasifier, 70 -75 %

η_{en} = efficiency of the engine, 25 - 30 %

η_e = efficiency of the electric generator, 90 %

η_{tot} = Total Efficiency, 16 - 20 %

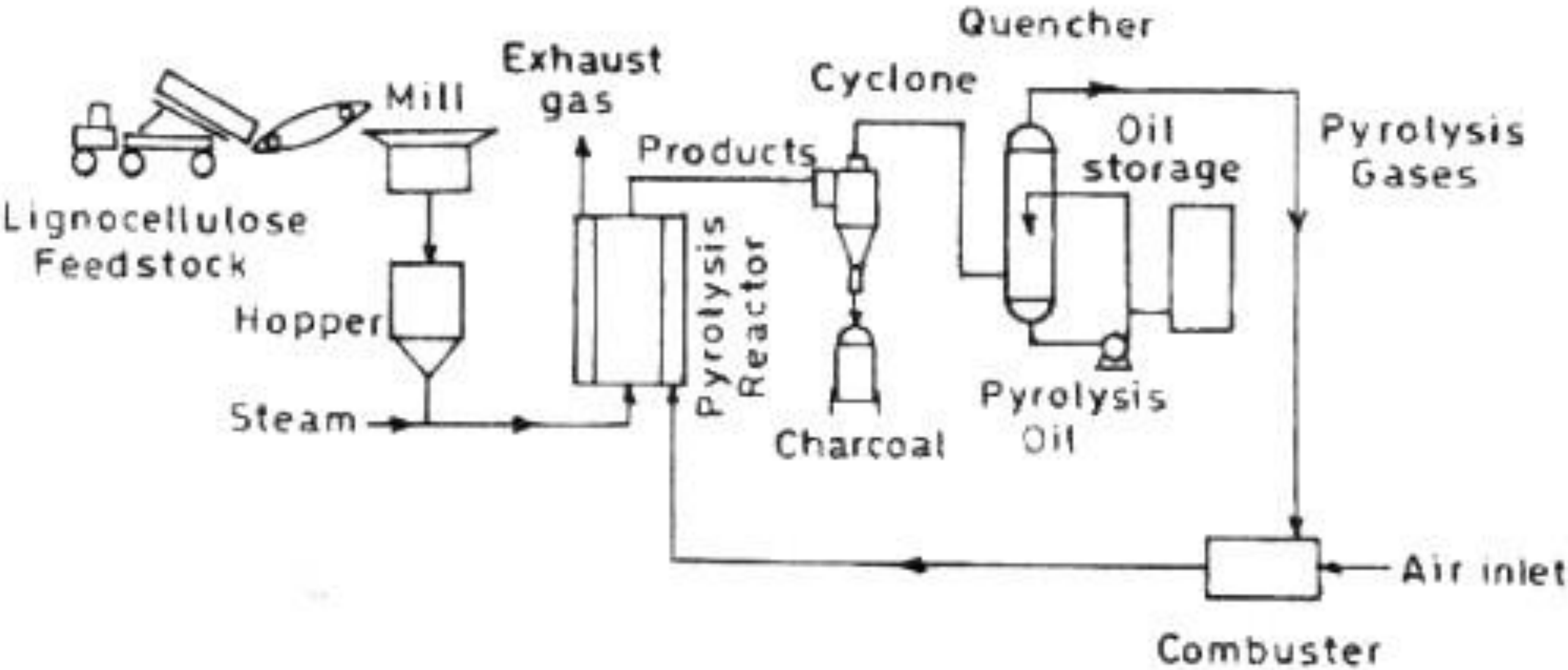
Thermochemical route for production of energy, gas, and ethanol.



Liquefaction

- Direct liquefaction is defined as any thermo-chemical conversion process that produces liquid products from biomass feed stock without going through a separate intermediate gas phase.
- In direct liquefaction, biomass slurries are heated to moderate temperatures at high pressures with a catalyst in a reducing atmosphere of carbon monoxide and hydrogen.
- The objective of the direct liquefaction is to produce liquid products which can be used as a substitute for fuel oils, and distillate fractions which can potentially be used as diesel fuels, octane enhancers and for other related uses.
- The liquefaction products have greater energy densities than the original biomass feed stock and can be readily transported.
- The potential use of such liquid products after some upgrading as fuel extenders or substitutes also provides a possible source of transportation fuels.

Liquefaction



Comparison of Four Major Thermochemical Conversion Processes

Process	Temperature (°C)	Pressure (MPa)	Catalyst	Drying
Liquefaction	250–330	5–20	Essential	Not required
Pyrolysis	380–530	0.1–0.5	Not required	Necessary
Combustion	700–1400	>0.1	Not required	Not essential, but may help
Gasification	500–1300	>0.1	Not essential	Necessary

Source: Adapted from Demirbas, 2009.

Bio Chemical Conversion Process

In biochemical conversion, biomass molecules are broken down into smaller molecules by bacteria or enzymes. This process is much slower than thermochemical conversion, but does not require much external energy.

The three principal routes for biochemical conversion are:

- Digestion (anaerobic and aerobic)
- Fermentation
- Enzymatic or acid hydrolysis

Bio Chemical Conversion Process

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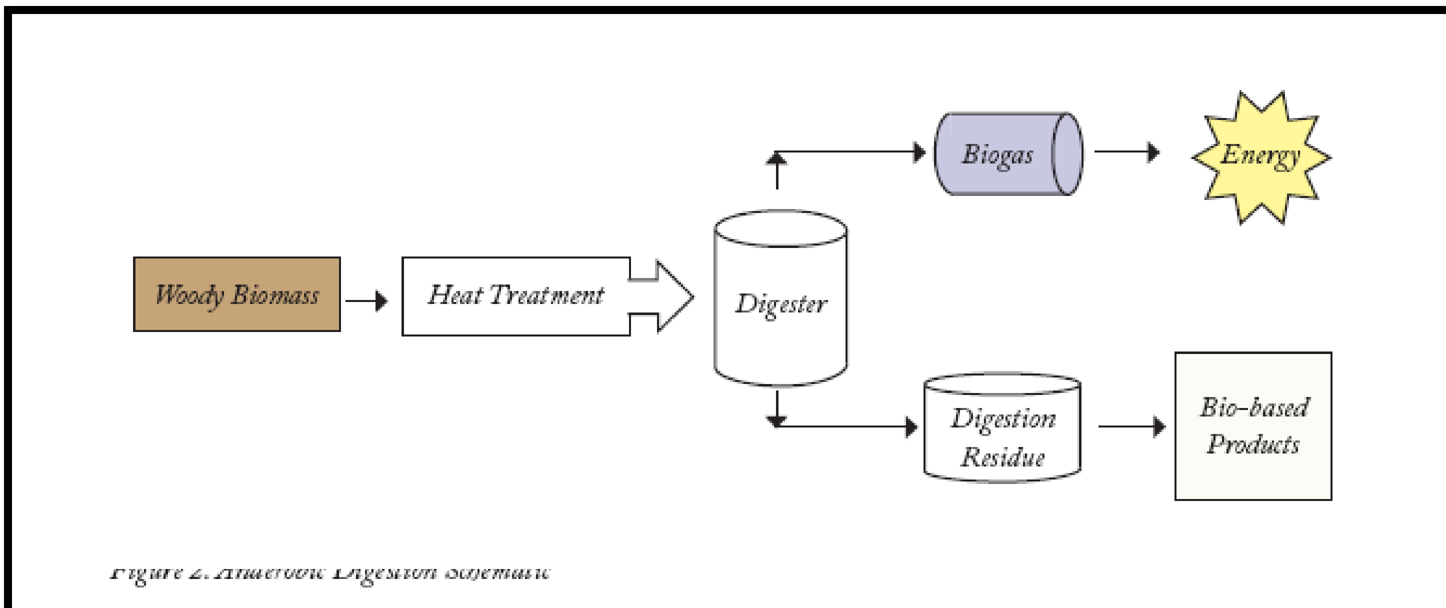
- Enzymatic or acid hydrolysis

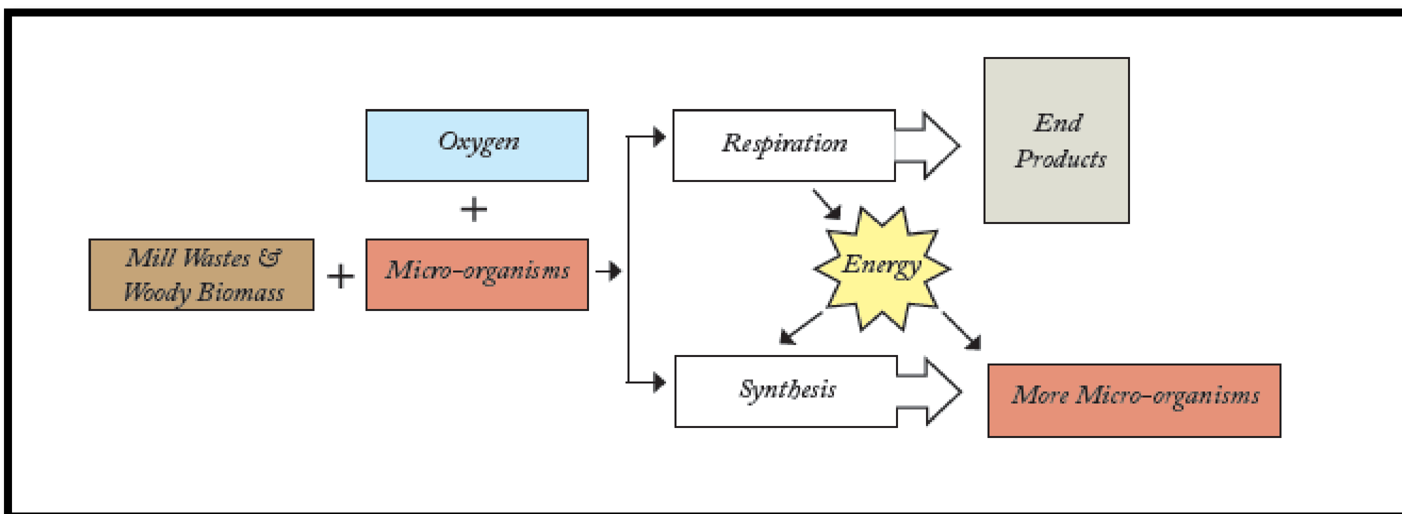
Anaerobic Digestion

The main products of anaerobic digestion are methane and carbon dioxide in addition to a solid residue. Bacteria access oxygen from the biomass itself instead of from ambient air.



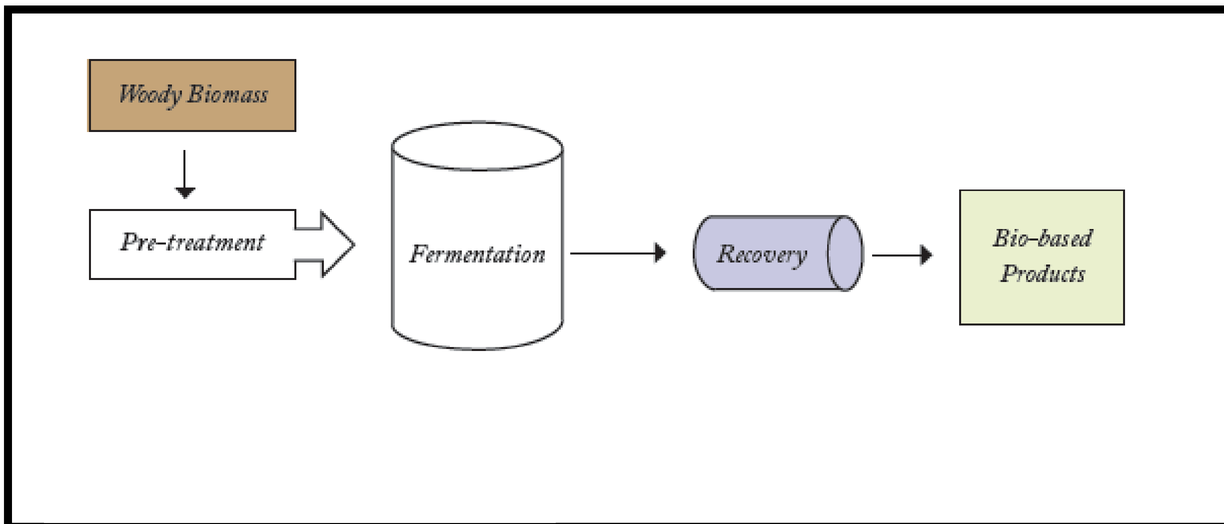
Aerobic Digestion

Aerobic digestion, or composting, is also a biochemical breakdown of biomass, except that it takes place in the presence of oxygen. It uses different types of microorganisms that access oxygen from the air, producing carbon dioxide, heat, and a solid digestate..



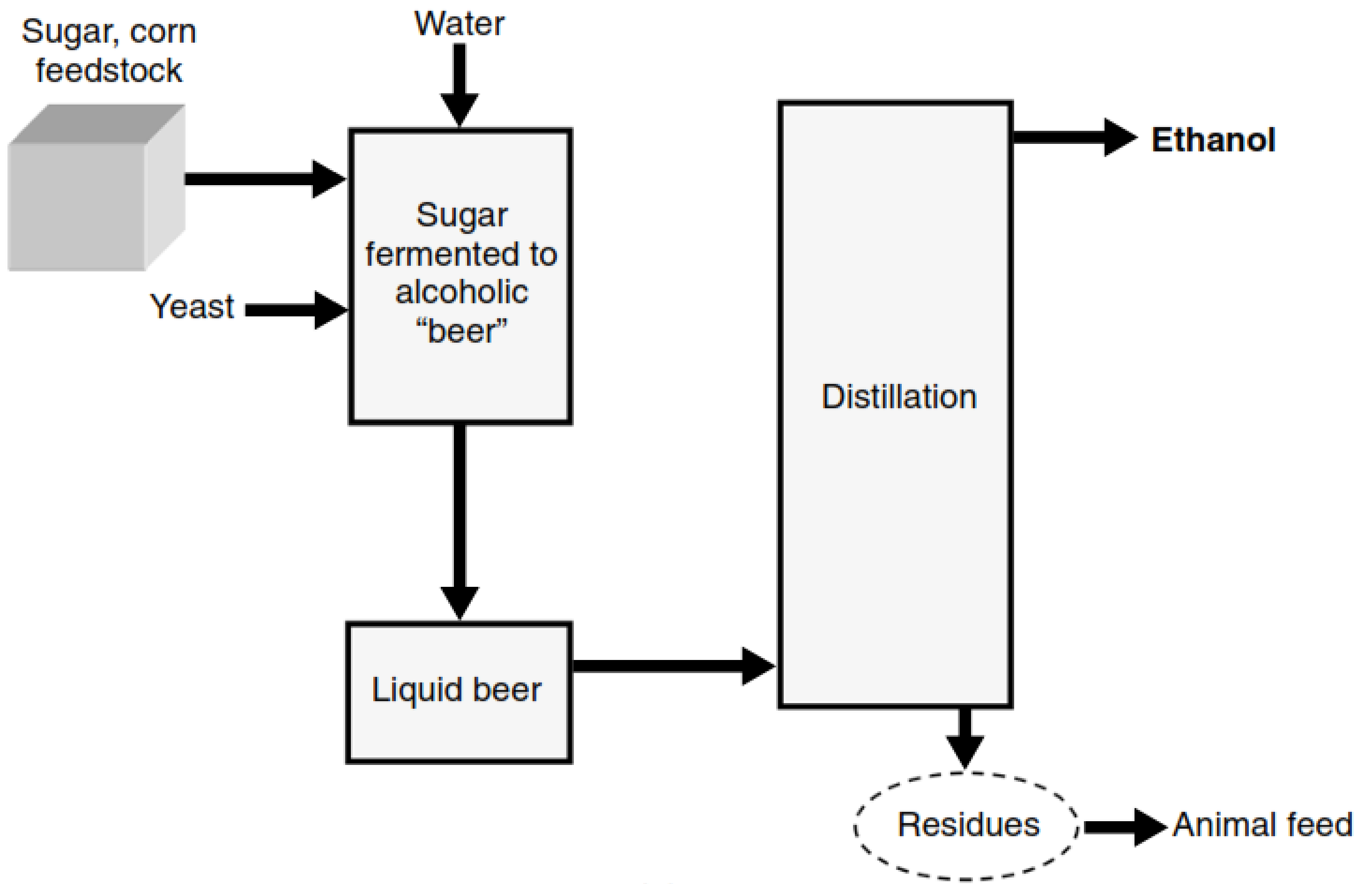
Fermentation

In fermentation, part of the biomass is converted into sugars using acid or enzymes. The sugar is then converted into ethanol or other chemicals with the help of yeasts. The lignin is not converted and is left either for combustion or for thermochemical conversion into chemicals. Unlike in anaerobic digestion, the product of fermentation is liquid.



Fermentation

Biochemical routes for production of ethanol from (noncellulosic) sugar

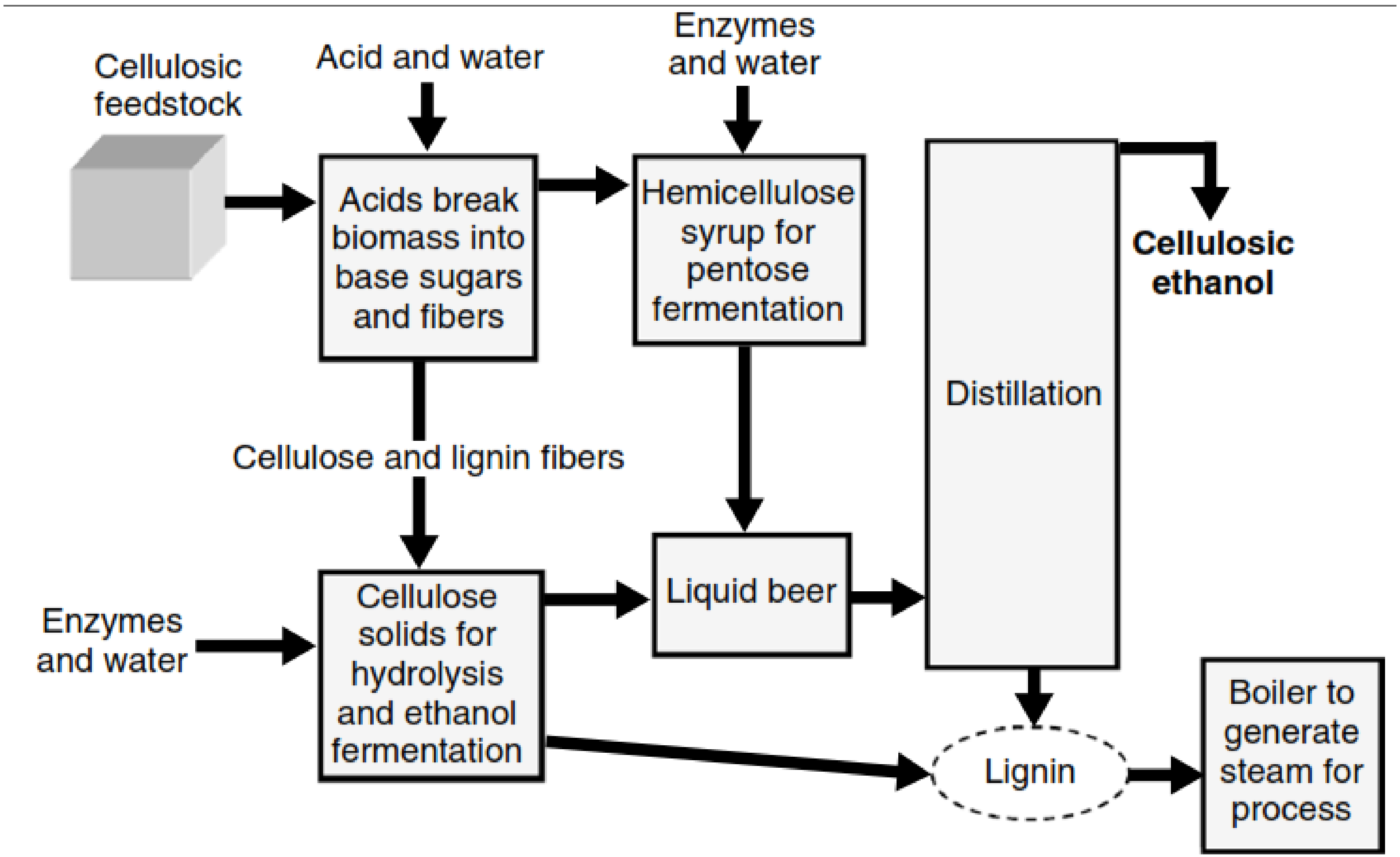


Enzymatic or acid hydrolysis

Fermentation of starch and sugar-based feedstock (i.e., corn and sugarcane) into ethanol is fully commercial, but this is not the case with cellulosic biomass because of the expense and difficulty in breaking down (hydrolyzing) the materials into fermentable sugars. Ligno-cellulosic feedstock, like wood, requires hydrolysis pretreatment (acid, enzymatic, or hydrothermal) to break down the cellulose and hemicellulose into simple sugars needed by the yeast and bacteria for the fermentation process. Acid hydrolysis technology is more mature than enzymatic hydrolysis technology, though the latter could have a significant cost advantage.

Enzymatic or acid hydrolysis

Biochemical routes for production of ethanol from and (cellulosic) biomass



Thank you !

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