Thermochemical Power Group

Master Degree in InnovativeTechnologies in Energy Efficient Buildings for Russian & Armenian Universities and Stakeholders

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MARUEEB

Biomass boilers

Advantages of Energy from Biomass

- Environmental benefits such as mitigation of greenhouse gas emissions, reduction of acid rain, and soil improvement;
- Political benefits - e.g. reduced dependency on imported fossil fuels; rural development; energy diversification;
- Employment creation - biomass fuels create up to 20 times more employment than fossil fuels.
- Biomass fuel prices have been stable historically and are not directly linked to national or global energy markets. Biomass pricing is not subject to monopolistic control.

Energy Conversion Technologies Options

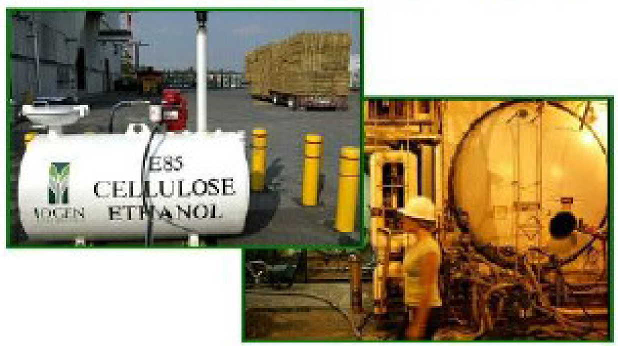
Combustion - Heat

Combustion - CHP

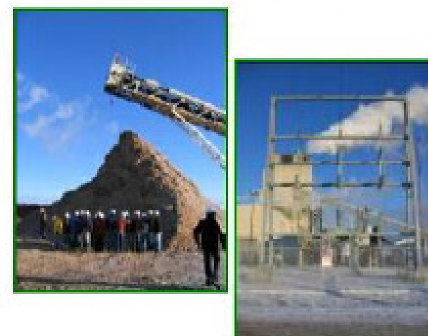
Gasification - Heat

Pyrolysis – Bio-Oil

Enzymatic Fermentation – Ethanol



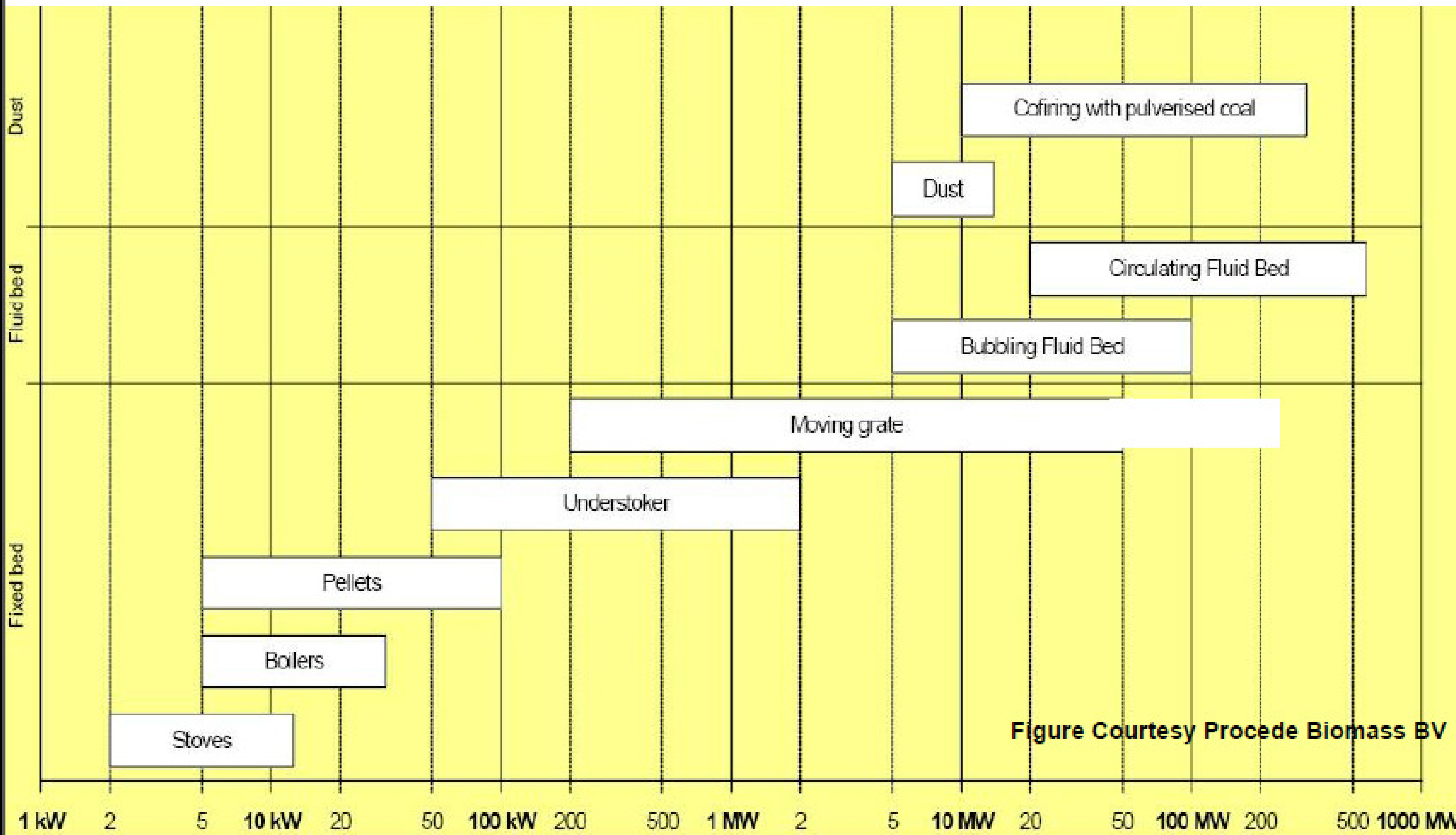
Gasification - Power



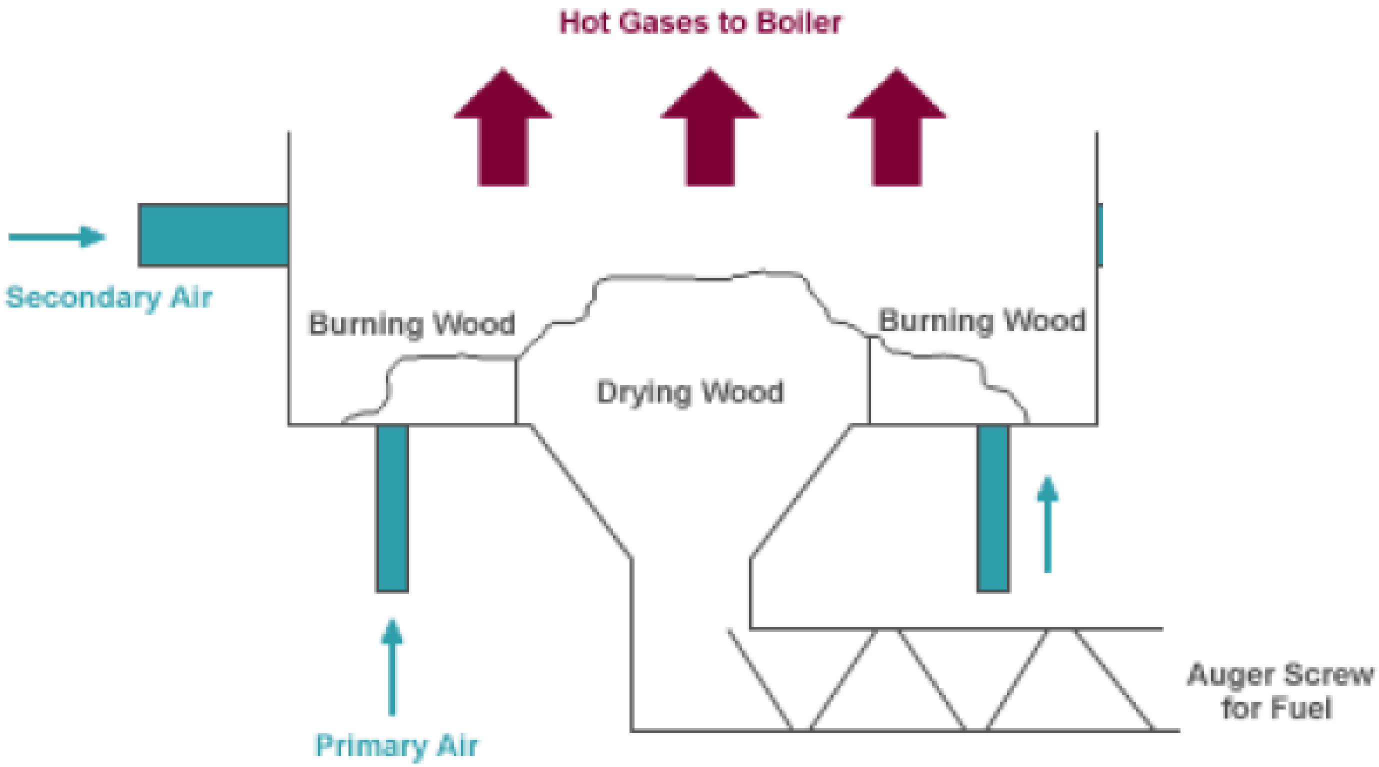
Combustion systems are the only commercially available bioenergy technologies!

They are available in sizes from 2 kW to 500 MW

Combustion Equipment Size Ranges



Underbed Stokers



Underbed Stokers

ADVANTAGES

- Low Cost.
- Small fuel inventory makes for very rapid response to load changes

DISADVANTAGES:

- The fuel must be fairly dry: preferably <30%, not more than 35%.
- The fuel particle size and moisture must be consistent: the small, intense fire is easily disrupted.
- Because they were designed for coal, some units have no separate provision for primary and secondary air supply, limiting the opportunity for fine tuning to the needs of varying fuel – especially significant for agricultural residues

Grate Furnaces

- **Grate Type**
  - Pre-Combustors (aka Two-Stage)
  - Vibrating grate
  - Reciprocating/stepping grate
  - Travelling grate/chain
  - Fixed bed
    - pin-hole grate
    - sloping grate

Generally as you go up the list:

Better control

Lower emissions

Lower quality fuels

Higher thermal efficiency

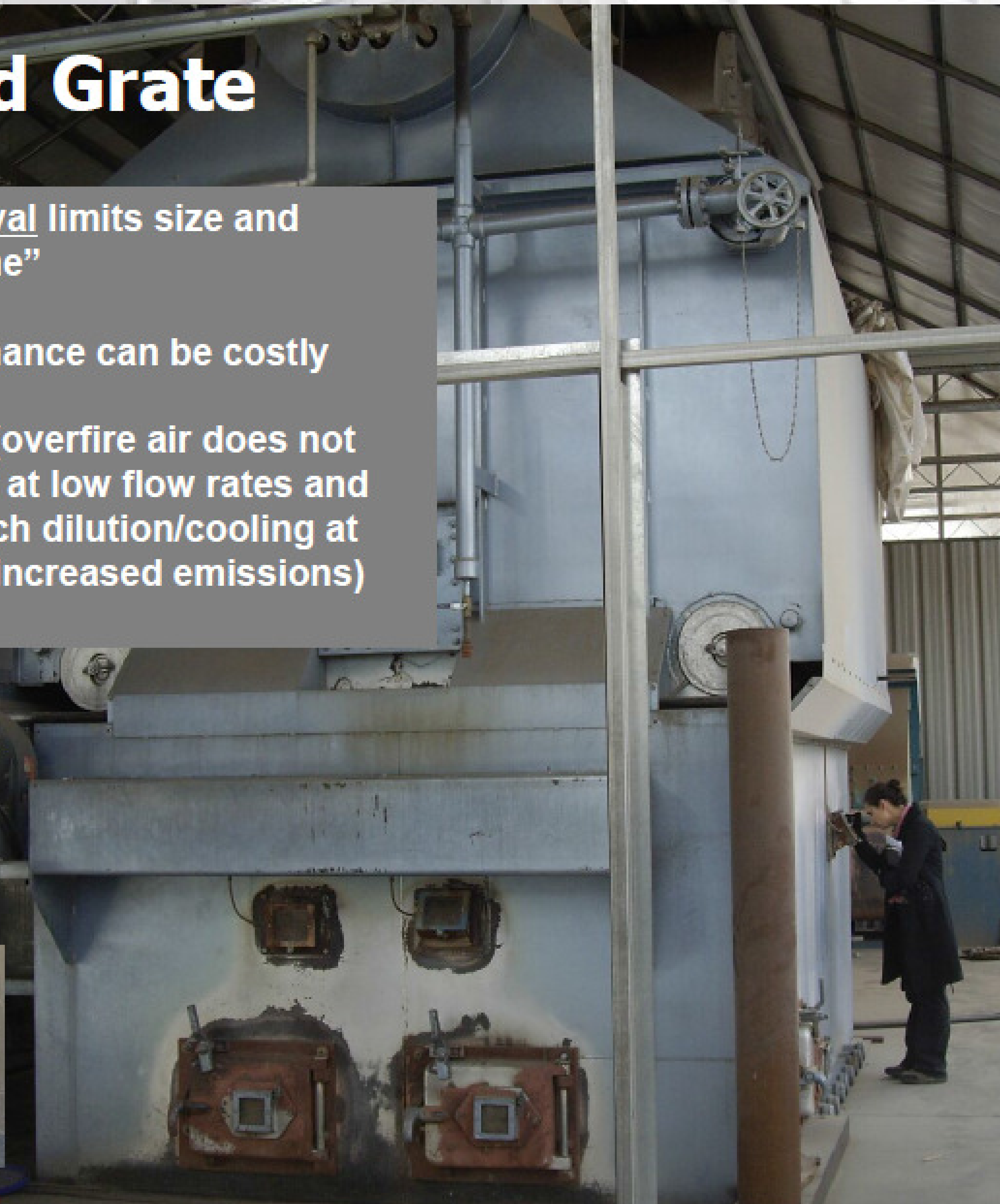
Higher Cost

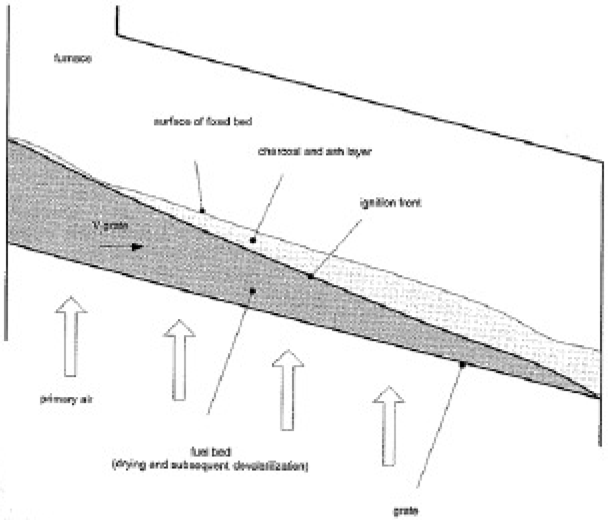
Fixed Bed Grate

<u>Manual Ash Removal</u> limits size and requires "down time"

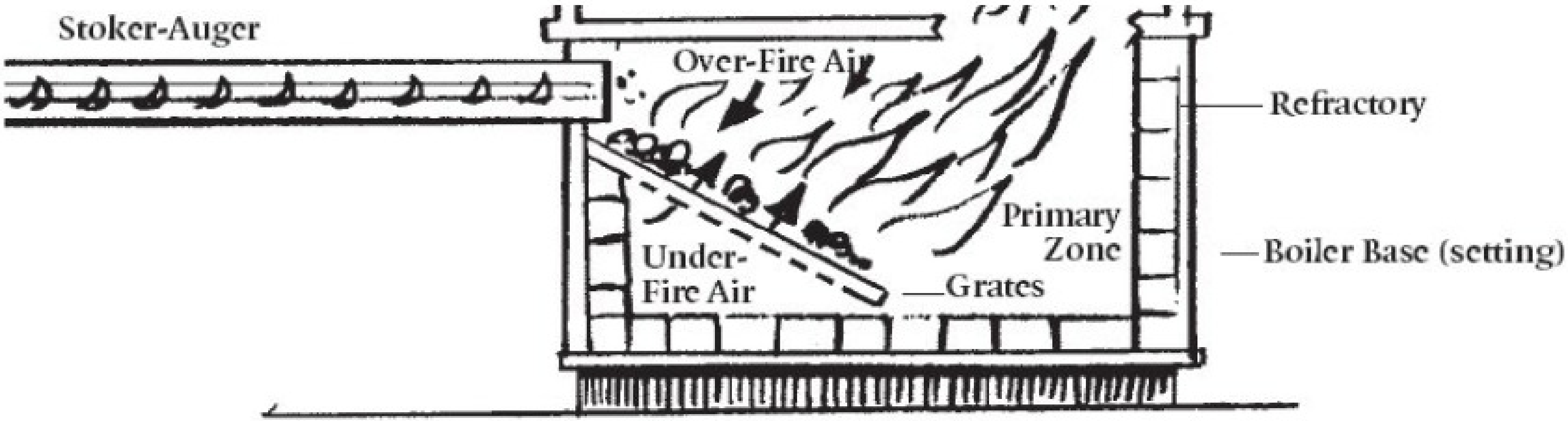
Refractory maintenance can be costly

Low air flow rates (overfire air does not penetrate chamber at low flow rates and may cause too much dilution/cooling at low fire leading to increased emissions)




furnace
surface of fixed bed
charcoal and ash layer
ignition front
V grate
primary air
fuel bed
(drying and subsequent devolatilization)
grate

Inclined Grates



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Inclined Grates

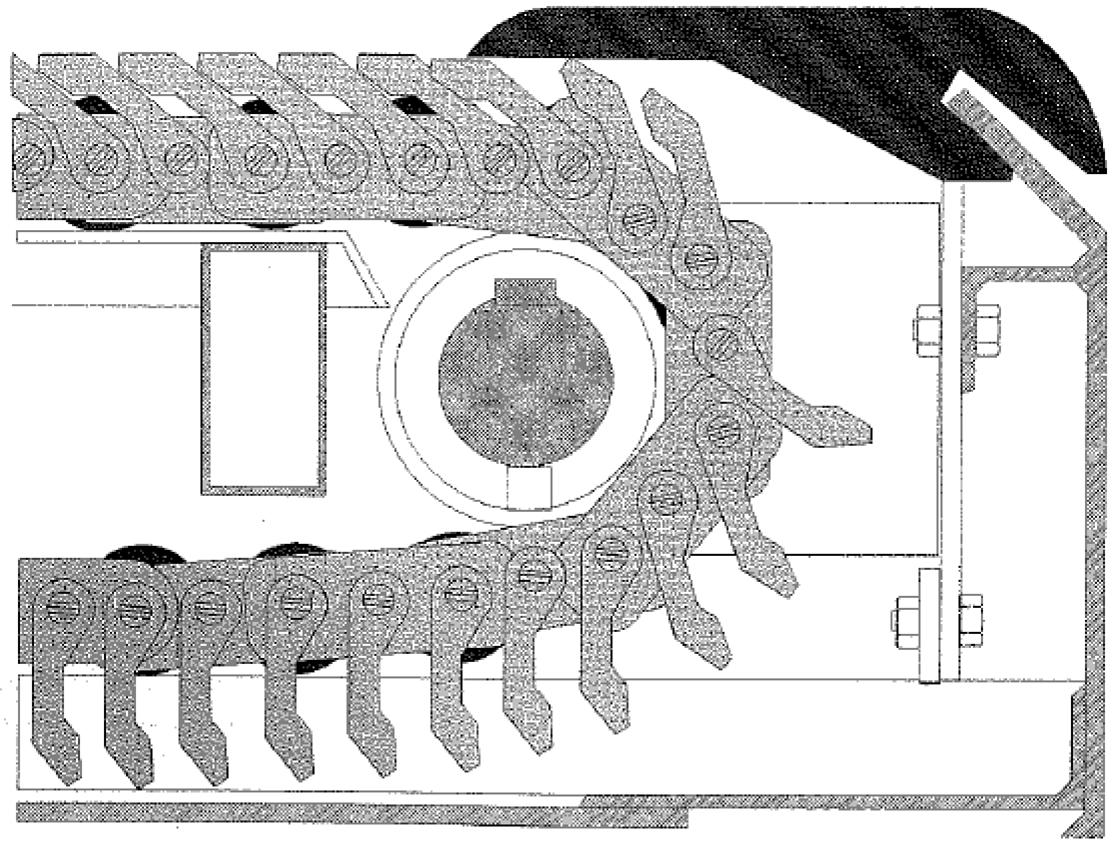
ADVANTAGES:

- Some tolerance of fuel type, moisture and particle size
- Positive movement of fuel down grate reduces blockages
- Well controlled air distribution leads to high efficiency

DISADVANTAGES:

- Large fuel inventory slows response to load changes
- Poor mixing especially when co-firing different fuels
- Problems with high moisture fuels (>45% moisture)
- Moving elements have problems with rocks and metal
- Increased emissions at low loads

Moving Grate



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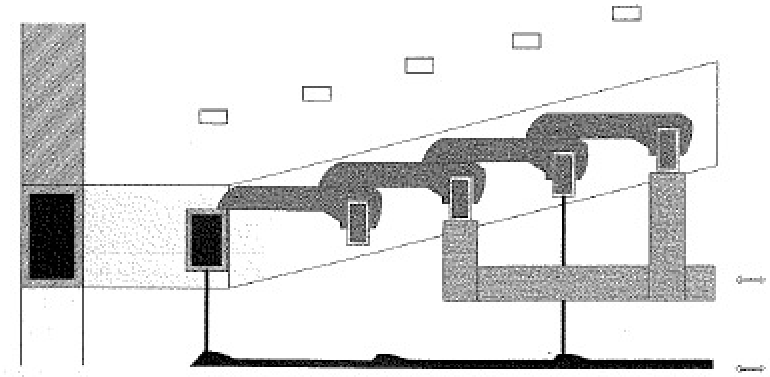
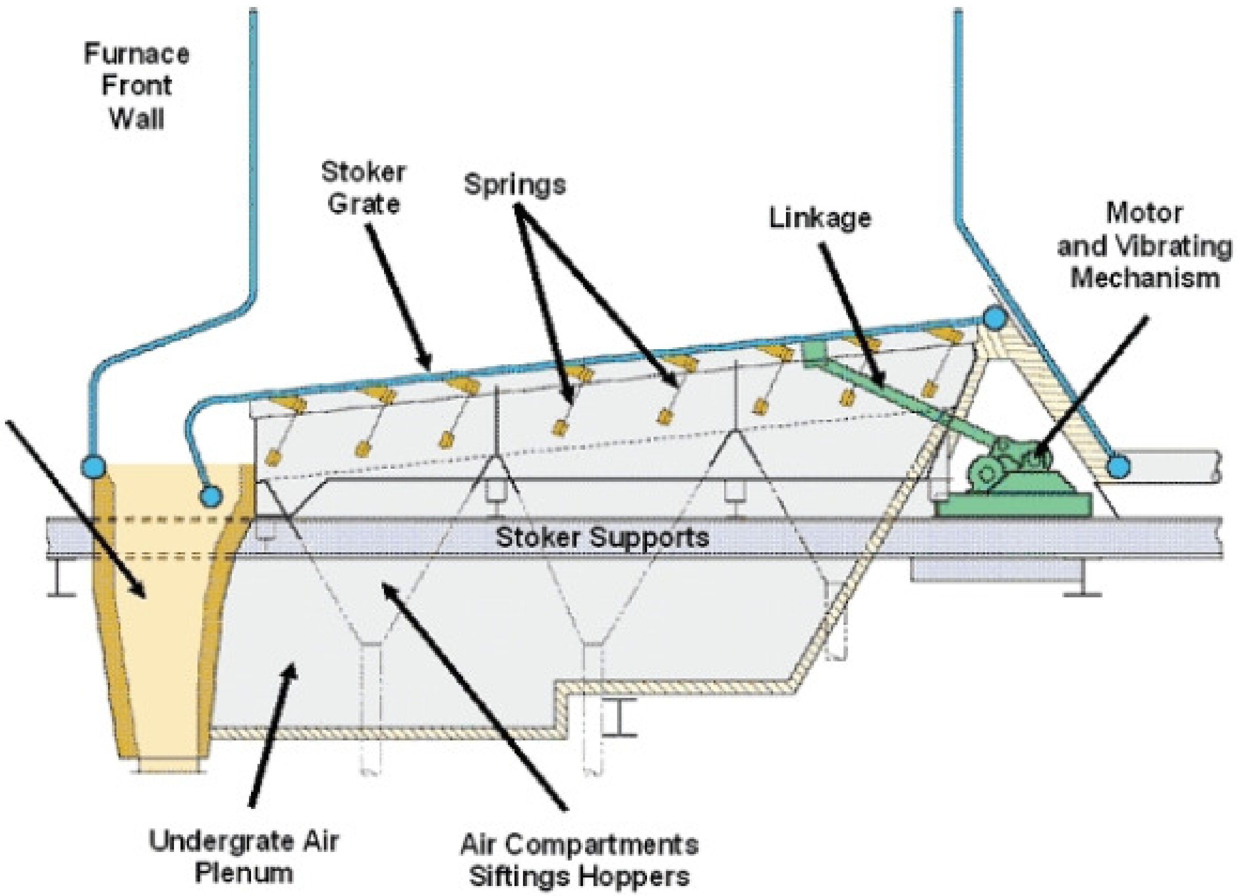


Vibrating Inclined



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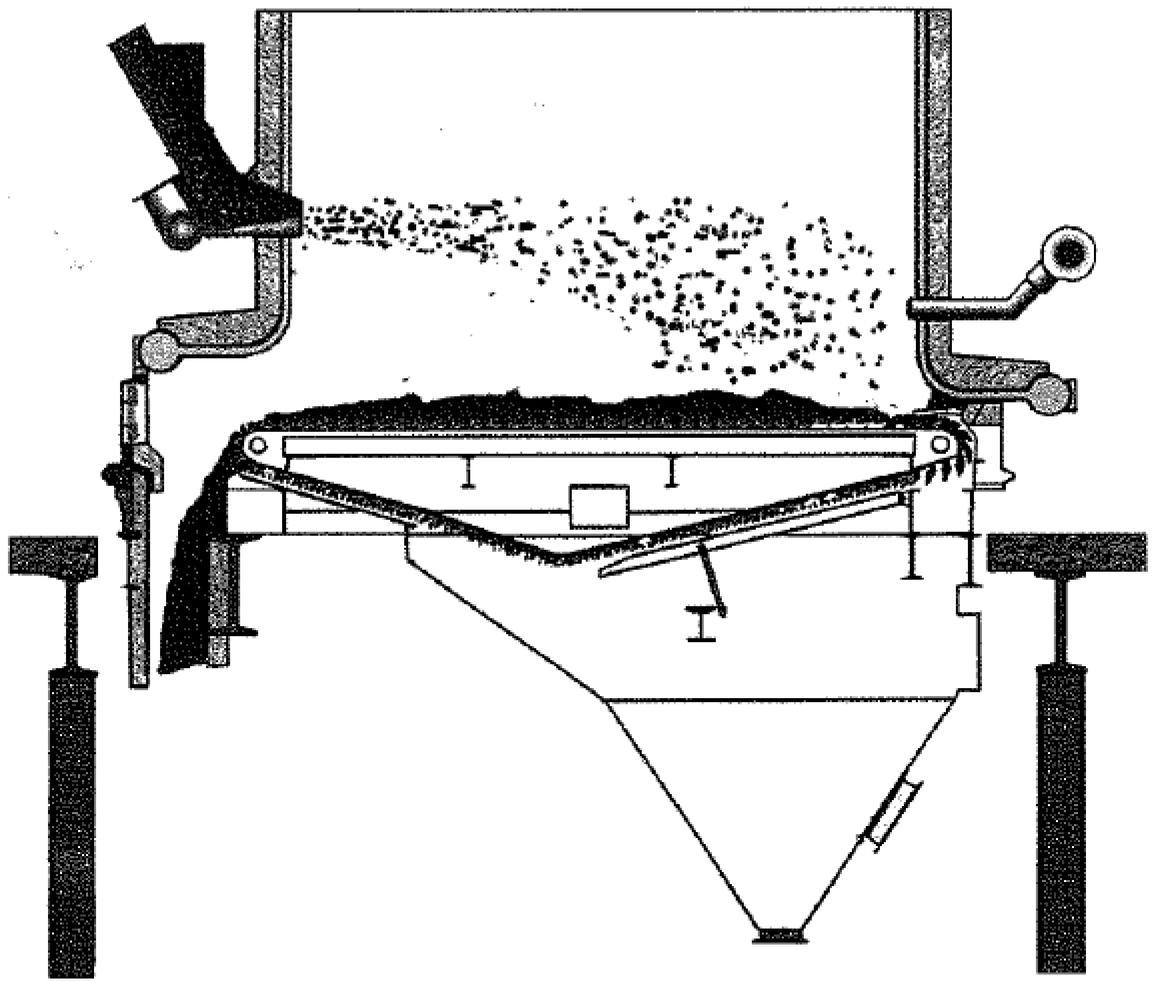
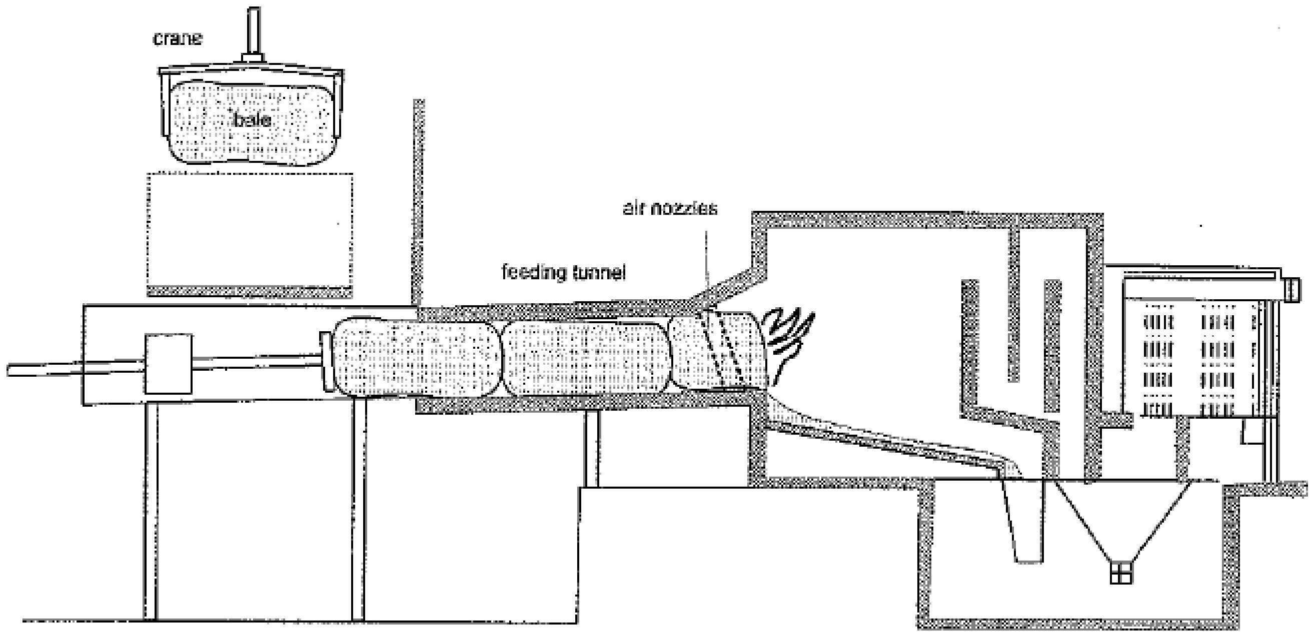
Spreader stroker



Cigar burner



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Innovation for Fuel Variations

- **Preheat primary air**
  - Handles higher moisture fuels
  - Preheating primary air air (125 – 350°C) helps to dry and combust fuel but higher temperatures are only possible with water-cooled grates
- **Flue gas recirculation**
  - Varies O2 in combustion air to handle different fuel compositions

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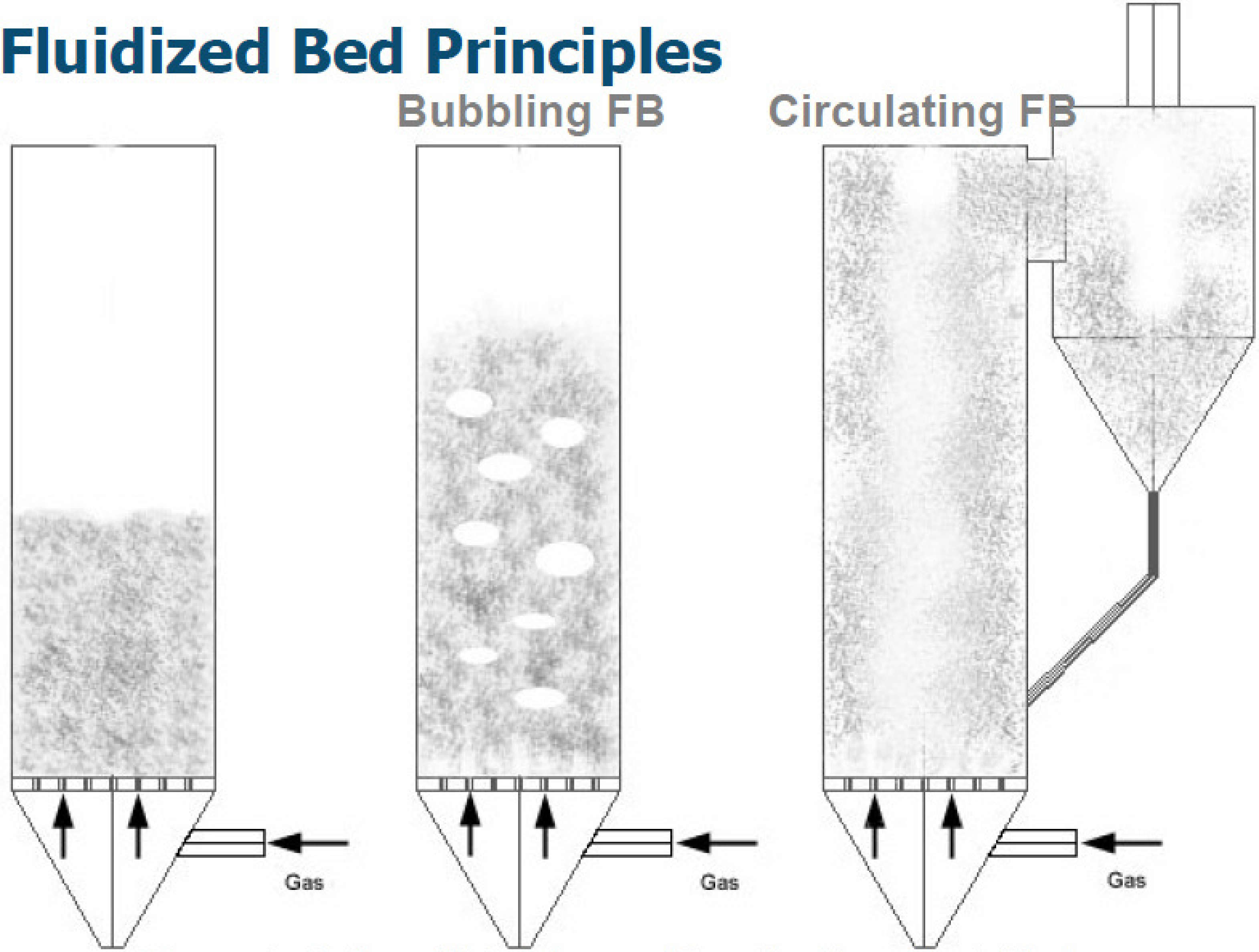
Fluidized Bed Principles



Characteristics: High Thermal Inertia, Excellent Mixing

Bubbling FB

- 10 MW(th) - 200 MW(th)
- low excess air means high efficiency
- good NOx reduction
- very good fuel flexibility
- very good mixing
- high thermal efficiency
- High Costs

Circulating FB

- > 100 MW(th)
- high heat and mass transfer rates
- high efficiency
- good NOx reduction
- good fuel flexibility
- high thermal efficiency
- Very High Costs
- Some sizing of fuel required

- Sensitive to ash slagging so maximum temperature is limited to below 1000 C and extra care must be taken with high ash fuels (e.g. agricultural residues)

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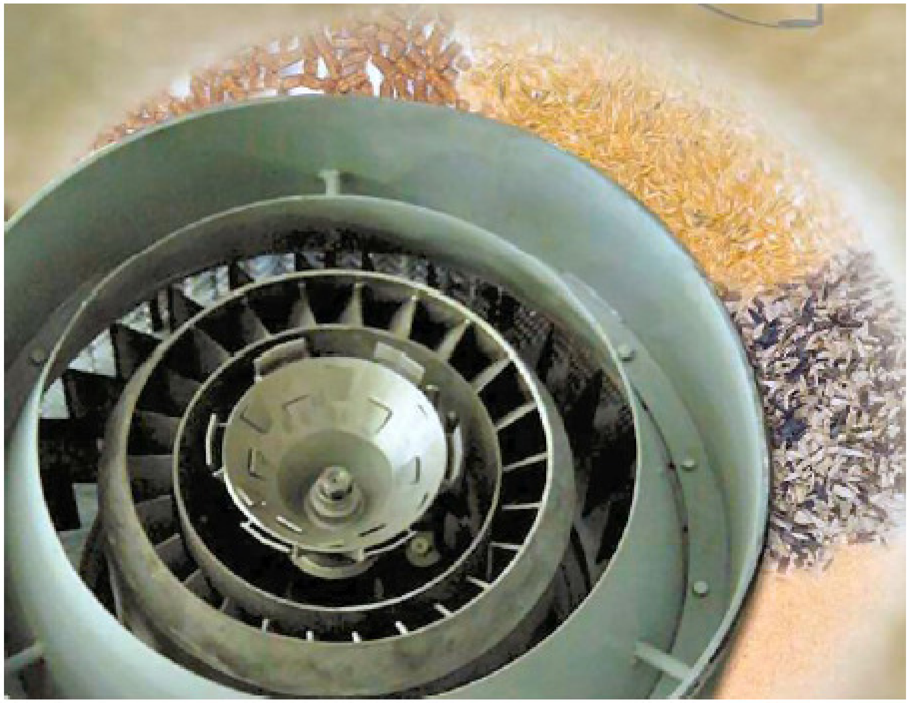
Suspension or Dust Burners

Dry (<15% moisture) finely pulverized fuel burner. Fuel drying and size reduction is required to minimize emissions and unburnt particulate carryover. Effect of high ash fuels not well demonstrated.



Challenges

For Suppliers:

- Regional Emissions Standards
- Lack of Fuel Standards
- Lack of Trained Personnel
- Combustion Equipment is Available But There Are Currently No Commercial Technologies for Small Scale Power

For Users:

- Moisture
- Energy Density and Form Factor (Fuel Handling)
- Fuel Composition (High ash, alkali and halogens)
- Emissions and Fouling
- Furnace Design and Operation (Furnace MUST be designed for the specific fuel)

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Biomass Burn Characteristics

Table 2. .Ultimate analysis for a variety of biomass fuels in Ontario (**All Values Reported on a Dry Matter Basis**).

Biomass Type	MJ/kg	BTU/lb	Ash %	Carbon %	Hydrogen %	Nitrogen %	Sulphur %	Oxygen % (by difference)	Total Chlorine (ug/g)
OFF-SPEC (non-food) GRAINS						*Typical	Values*		
Beans	19	7,996	4.7	45.7	6.3	4.3	0.7	38.8	193
Corn	17	7,350	1.5	42.1	6.5	1.2	0.1	48.9	472
Canola	28	12,220	4.5	60.8	8.3	4.5	0.5	21.4	163
Dried Distillers Grain	22	9,450	4.9	50.4	6.7	4.7	0.7	32.6	1,367
GRASS/ FORAGES									
Big Blue Stem	19	8,020	6.1	44.4	6.1	0.8	0.1	42.6	1,880
Miscanthus	19	8,250	2.7	47.9	5.8	0.5	0.1	43.0	1,048
Sorghum	17	7,240	6.6	45.8	5.3	1.0	0.1	42.3	760
Switchgrass	18	7,929	5.7	45.5	6.1	0.9	0.1	41.7	1,980
STRAW/ RESIDUE									
Alfalfa	17	7,435	9.1	45.9	5.2	2.5	0.2	39.5	3,129
Barley Straw	17	7,480	5.9	46.9	5.3	0.7	0.1	41.0	1,040
Corn Cobs	18	7,927	1.5	48.1	6.0	0.4	0.1	44.0	2,907
Corn Stover	19	7,960	5.1	43.7	6.1	0.5	0.1	44.6	1,380
Flax Straw	18	7,810	3.7	48.2	5.6	0.9	0.1	41.6	2,594
Wheat Straw	18	7,710	7.7	43.4	6.0	0.8	0.1	44.5	525
Processing By-Product									
Oat Hulls	19	7,960	5.1	46.7	6.1	0.9	0.1	41.1	1,065
Soybean Hulls	18	7,720	4.3	43.2	6.2	1.8	0.2	44.3	266
Sunflower Hu lls	20	8,530	4.0	47.5	6.2	1.0	0.2	41.2	3,034
WOOD									
Bark	19	8,432	1.5	47.8	5.9	0.4	0.1	45.4	257
Willow	19	8,550	2.1	50.1	5.8	0.5	0.1	41.4	134
Harwdood	19	8,300	0.4	48.3	6.0	0.2	0.0	45.1	472
COAL									
PRB (Low Su lphur SubBit Coal)	25	10,520	6.0	55.0	3.7	0.9	0.4	11.5	35
Lignite	22	9,350	22.0	58.8	4.2	0.9	0.5	13.6	25

Data compiled from the following sources: AURI, 2005; BIOBB 1992; Preto, 2010.

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Furnace Designs

Furnace	Type	Chamber Vol. m3/MWth	Secondary Air %
A	Stoker	0.5	No
B	Moving C.	0.7	<20 %
C	Stepping G.	2.1	up to100%

Furnace A: Underfed Stoker

Furnace B: Moving Chain Grate

Furnace C: Stepping Grate

Comparison

Some Findings

Furnace	Chamber Vol.	Secondary Air	O2	CO	NOx	TPM	VOC
	m3/MWth	%	%	ppm	ppm	mg/m3	ug/m3
A	0.5	No	13.4	49	201	424	>7000
B	0.7	<20 %	14.0	68	188	384	5639
C	2.1	up to100%	9.8	46	260	450	30

For agricultural residues, the key factors in obtaining efficient combustion proved to be chamber volume (test units ranged from 0.5 to 2.1 m3/MWth), geometry and also the capability to run with very low primary to secondary air ratios. In most cases, low CO emissions (< 100 ppm) could be achieved only with stoichiometric ratios above 1.75. In some cases, uncontrolled total particulate emissions were found to be in the same range as wood (~200 mg/m3) however for most unpelletized residues, particulate emissions were found to be ~350–450 mg/m3. Volatile Organic Compound (VOC) emissions were found to depend heavily on furnace geometry and ranged from <50 µg/m3 for units with large combustion chambers to >7000 µg/m3 for the smallest units.

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OBSERVATIONS

- On a mass basis agricultural residues have similar energy content to wood and other biomass fuels, but low energy density requires special handling equipment and/or densification for combustion in conventional furnaces/boilers;
- High ash (and alkali) content requires adaptation of furnace design and or operating conditions to minimize ash fouling.
- Harvest timing can reduce “problem causing” elements.
- As with other biomass fuels, these fuels have high volatile/low fixed carbon content and thus require appropriately sized combustion chambers to achieve complete combustion (and low emissions).
- Corn Cobs and Stover are not recommended due to high chlorine content (High VOC’s also found for Corn Cobs).