2024 NORTH AMERICAN
BIOCHAR CONFERENCE
USBI
CALIFORNIA, USA

Large-Scale Biomass Gasification and the Co-Production of Biochar and Bioenergy

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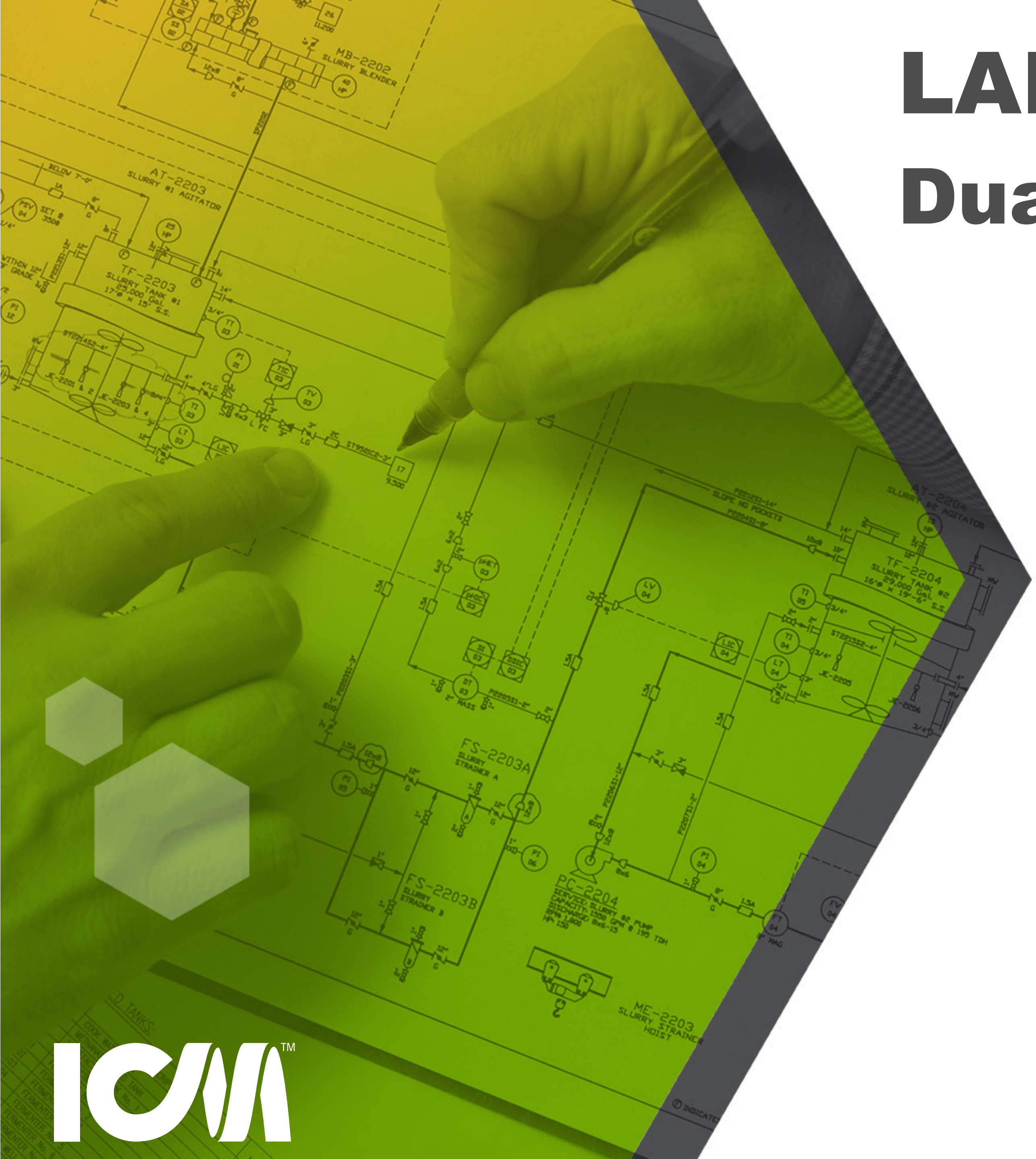
2024 North American Biochar Conference

CLIMATE SOLUTIONS

Need to Include Viable, Large-Scale Systems

One Potential Pathway: Biochar and CHP Systems

- **Co-Production of High Volumes of Biochar**
- **Maximize Co-Production of Carbon-Neutral Combined Heat and Power**
  - Offset fossil fuel carbon by …
    - Co-production of electrical power
    - Utilization of low-grade waste heat



LARGE-SCALE: ICM's Dual M-300 Configuration

Co-Production BioChar:

100+ mt/day

36,000+ mt/yr

BioEnergy:

up to 60 $MW_{thermal}$

up to 18 MW_{el}

Where To Locate?

- Upgrade Existing or Decommissioned Biomass Power Plants
- … or Industrial Forest Products Processing Facilities
- Locate near Medium-Large Municipalities
- Reduce Carbon Intensity of Cement Plants, Biorefineries, etc.

BIOCHAR AND CHP SYSTEMS

Gasification

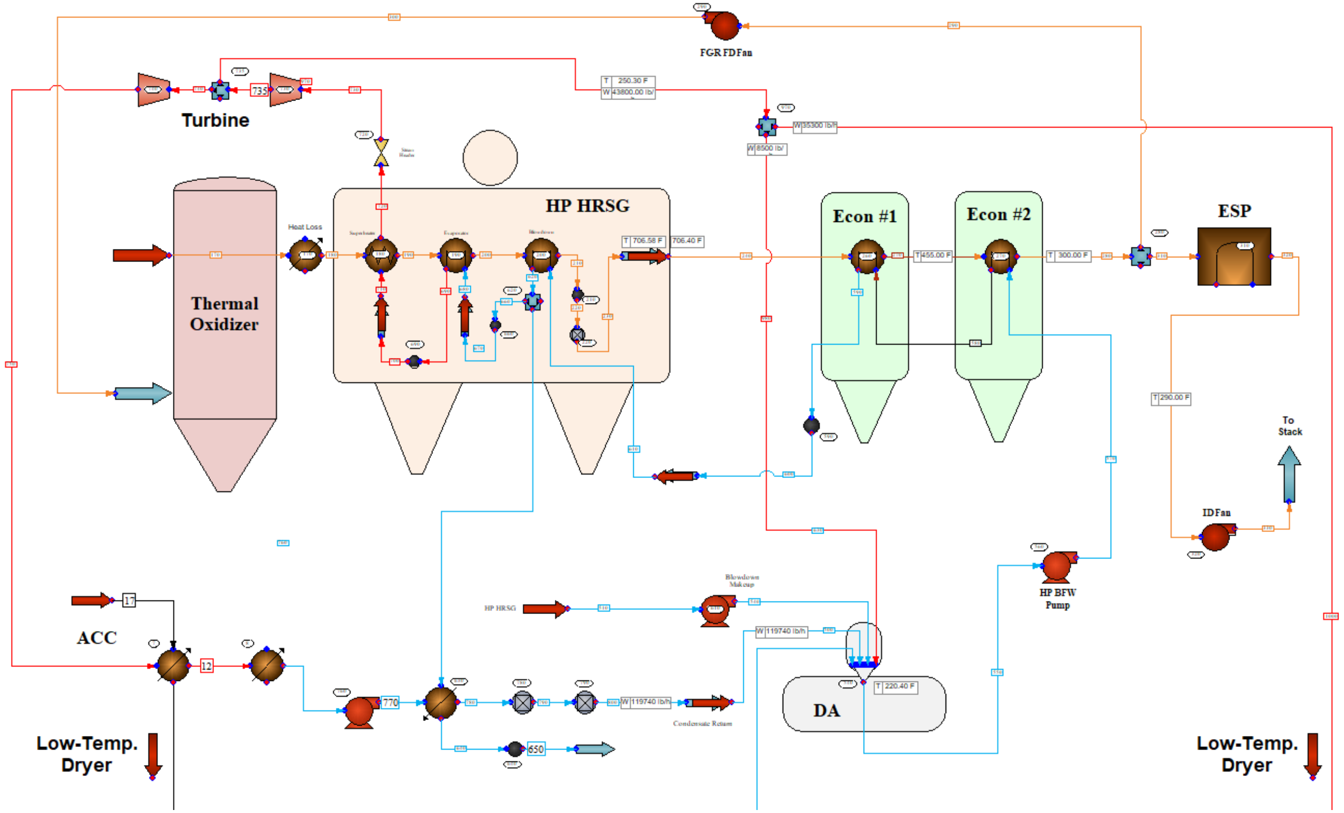
vs

Pyrolysis

Which Process Can Yield the Largest Climate Impact?

Comparison Using Same CHP Process Assumptions

- Using Very Powerful Process and Combustion Simulation Software (ChemCAD)



- Major CHP Components Include
  - Low Temperature Feedstock Dryer
  - Gasifiers or Pyrolizers
  - Heat Recovery Steam Generator (HRSG)
  - Steam Turbine




Feedstock Inputs, Biochar Yields and Low-Grade Heat Recovery

- **Identical Feedstock Input Assumptions**
- **Biochar Yield Assumptions (dry matter basis)**
  - Pyrolysis: 27.7% DM, with 100% recalcitrant C to biochar
  - Gasification: 21.7% DM, with 92% recalcitrant C to biochar
  - Maximum Recalcitrant C yields based on Fixed-C content
    - Derived from Feedstock's Proximate Analysis
- **Single Day Comparison with Ambient Air = - 6.7°C**
  - Feedstock dried from 50% to 15% mc
- **Greenhouse Heating using Low-Grade Heat**

CHP Results - Gasification can have a Greater Impact

Regarding Electrical Power Generation and Greenhouse Heating

Gasification:

Net Electrical Power
15.9 MWel

Low-Temp Dryer
23.7 MWth

Greenhouse Heating
14.5 MWth
80% waste heat recovery

Drying …
1000 mt/d @ 50%mc
to
590 mt/d @ 15% mc

5.4 ha greenhouse
vs
1.6 ha greenhouse

Ambient Air at - 6.7°C

Pyrolysis:

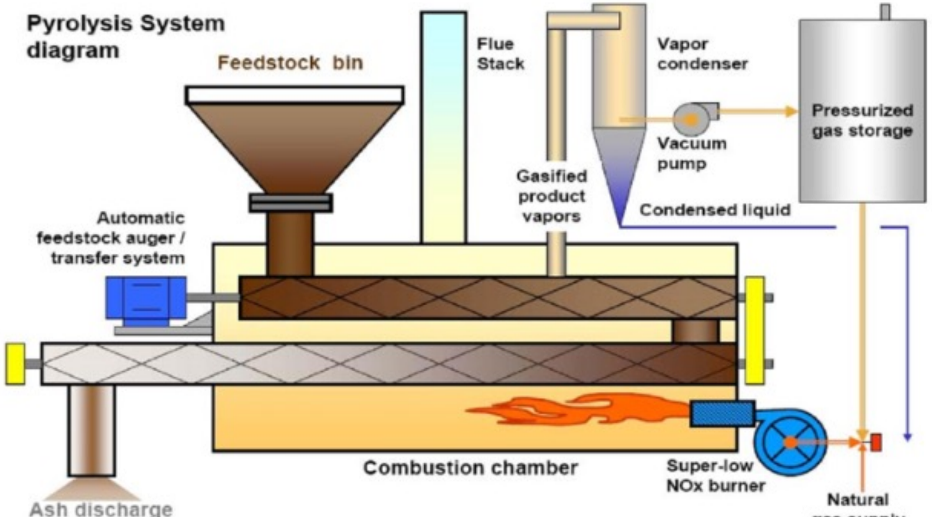
Net Electrical Power
8.6 MWel

Low-Temp Dryer
23.7 MWth

Greenhouse Heating
4.5 MWth
80% waste heat recovery

Direct Gasification has a Greater CHP Capacity Than Indirectly Heated Pyrolysis Systems

- **Direct, Autothermic Gasification Processes**
  - The exothermic process is self-sustaining
  - The Hot Producer Gas is then combusted, and
  - ALL that heat is available to the downstream CHP Systems



- **Indirectly Heated Pyrolysis Reactors**
  - When using its Syngas to drive pyrolysis, less heat is available for downstream CHP systems
  - Advantage Pyrolysis: at smaller scales when heat recovery becomes much more expensive
    - especially electrical power generation

Results – Pyrolysis has Greater Overall Biochar Yields

When Compared to Typical Low-Volatile Matter Gasification Derived Biochars

Overall Biochar Production

- Pyrolysis: 45,800 mt/y (138.9 mt/d)
- Gasification: 36,000 mt/y (107.9 mt/d)

Recalcitrant Carbon Content

- Pyrolysis: 33,000 mt/y (100.1 mt/d)
- Gasification: 31,700 mt/y (92.1 mt/d)

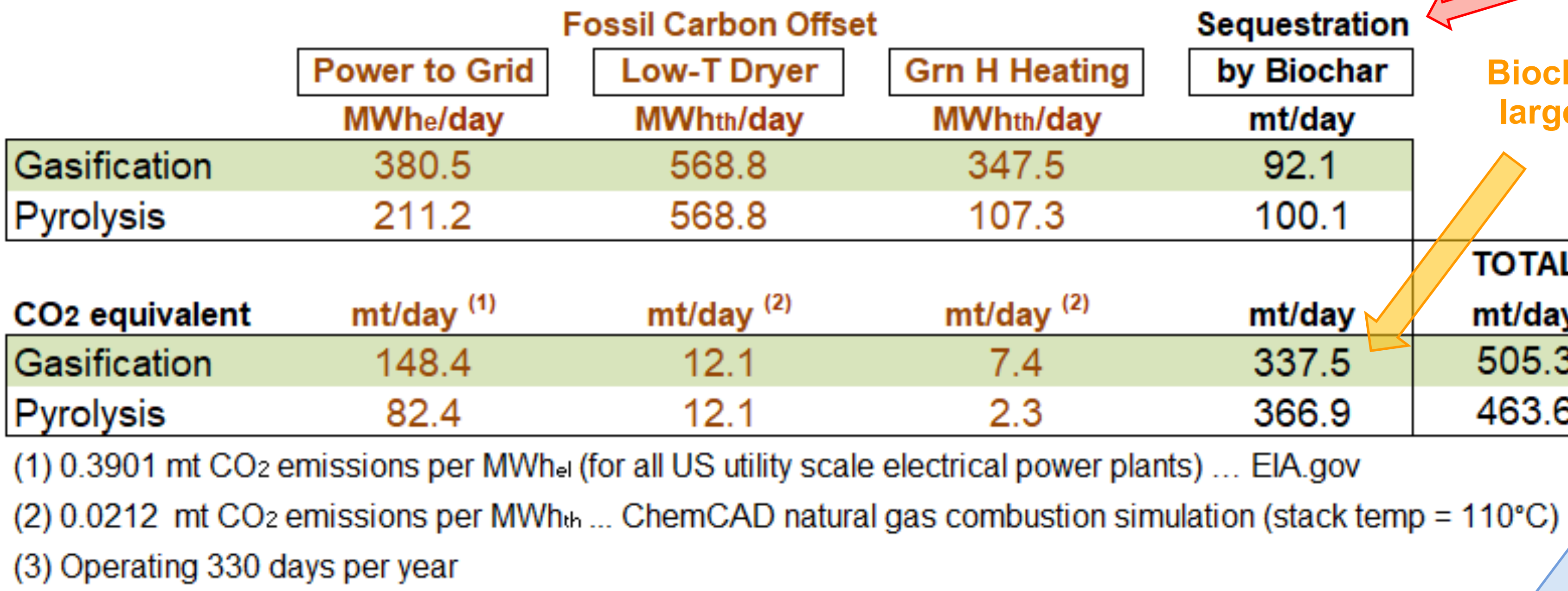
CLIMATE SOLUTION POTENTIALS

CO_{2e} Removal

Fossil-C Offset

Results - Gasification can have a Greater Impact on CDR and Fossil Carbon Offsets

Using Long-Term Storage of Biochar in Soils



	Fossil Carbon Offset			Sequestration		
	Power to Grid	Low-T Dryer	Grn H Heating	by Biochar		
	MWh$_e$/day	MWh$_{th}$/day	MWh$_{th}$/day	mt/day		
Gasification	380.5	568.8	347.5	92.1		
Pyrolysis	211.2	568.8	107.3	100.1		
					TOTAL	excluding GHH
CO$_2$ equivalent	mt/day (1)	mt/day (2)	mt/day (2)	mt/day	mt/day	mt/y(3)
Gasification	148.4	12.1	7.4	337.5	505.3	164,333
Pyrolysis	82.4	12.1	2.3	366.9	463.6	152,233

(1) 0.3901 mt CO$_2$ emissions per MWh$_{el}$ (for all US utility scale electrical power plants) … EIA.gov

(2) 0.0212 mt CO$_2$ emissions per MWh$_{th}$ ... ChemCAD natural gas combustion simulation (stack temp = 110°C)

(3) Operating 330 days per year

via Recalcitrant Carbon Only

Biochar has the largest impact

Gasification removes/offsets 12,100 mt CO$_{2e}$ per year more than an equivalent pyrolysis-based CHP system

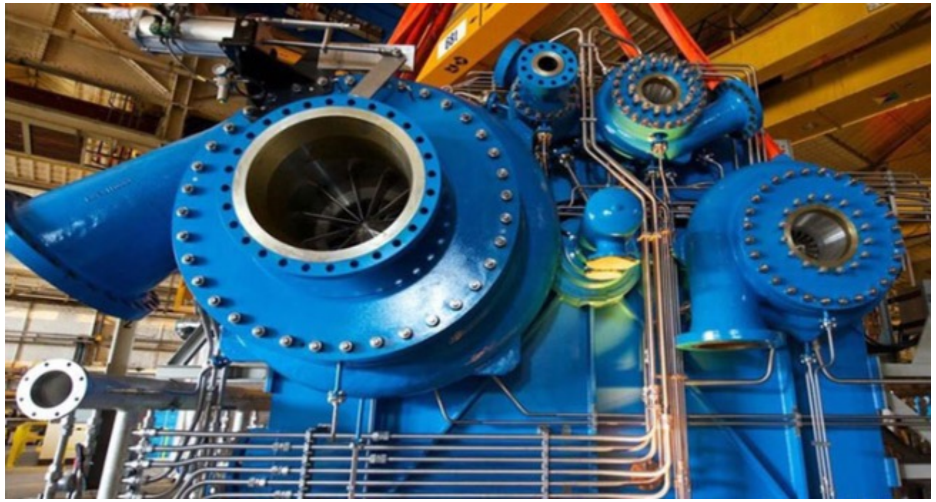
Permanent Storage of High-Volatile Matter Biochars can have an Even Greater Climate Impact

- **Example: pumping a biochar slurry**
  - into deep wells or
  - abandoned underground salt mines

More on Permanent Storage

- **Pumping Biochar Slurries**
  - Low Capital Costs
  - Low Power Requirements
- **Many Locations**
  - Appropriate for permanent storage of high VM biochars
- **Negligible Risk of Leaking CO_2**

- **CO_2 Compression ~ 2400 psi**
  - High Capital Costs
  - Very High Power Requirements
- **Limited Geological Formations**
  - Appropriate for permanent storage of compressed CO_2

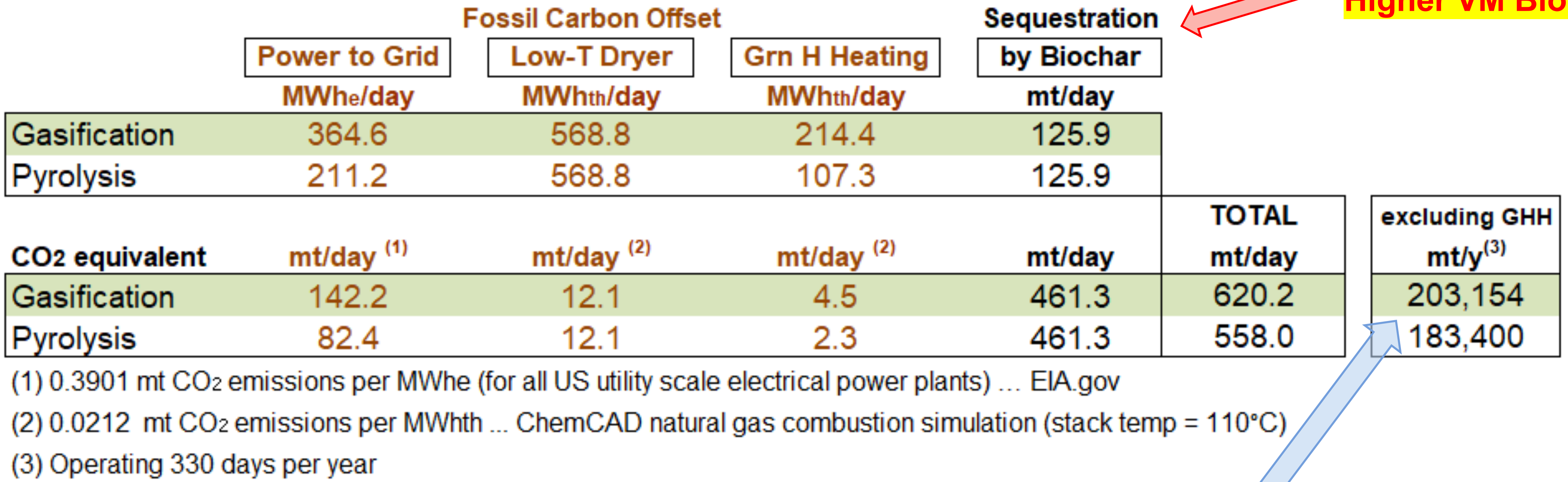


Even Greater Climate Impacts are Possible using Permanent Storage of High VM Biochars

ICM Gasifiers can also High VM Biochars

- Producing a mixture of biochar and torrefied biomass
- via high precision control of air inputs and distribution

Permanent Storage of Higher VM Biochars



	Fossil Carbon Offset			Sequestration
	Power to Grid	Low-T Dryer	Grn H Heating	by Biochar
	MWhe/day	MWhth/day	MWhth/day	mt/day
Gasification	364.6	568.8	214.4	125.9
Pyrolysis	211.2	568.8	107.3	125.9

CO2 equivalent	mt/day (1)	mt/day (2)	mt/day (2)	mt/day	TOTAL mt/day	excluding GHH mt/y(3)
Gasification	142.2	12.1	4.5	461.3	620.2	203,154
Pyrolysis	82.4	12.1	2.3	461.3	558.0	183,400

(1) 0.3901 mt CO_2 emissions per MWhe (for all US utility scale electrical power plants) … EIA.gov

(2) 0.0212 mt CO_2 emissions per MWhth ... ChemCAD natural gas combustion simulation (stack temp = 110°C)

(3) Operating 330 days per year

Gasification removes/offsets 19,750 mt CO_{2e} per year more than an equivalent pyrolysis-based CHP system

What is the Impact of Feedstock Transportation?

CO_{2e} Emissions for Feedstock Transport*

- 50 trucks/day
- 100 miles/day/truck
- 5000 miles/day
- 6 miles/gal diesel
- 833 gal diesel/day
- 10.19 kg CO_{2e}/gal (EIA)
- 8.49 mt/day CO_{2e}

* Assumes ONLY waste feedstock collection from Forest Product Facilities

Better with EVs

<< CO_{2e}

CDR + Fossil C Offsets

500 mt/d CO_{2e}

vs

Diesel Fuel

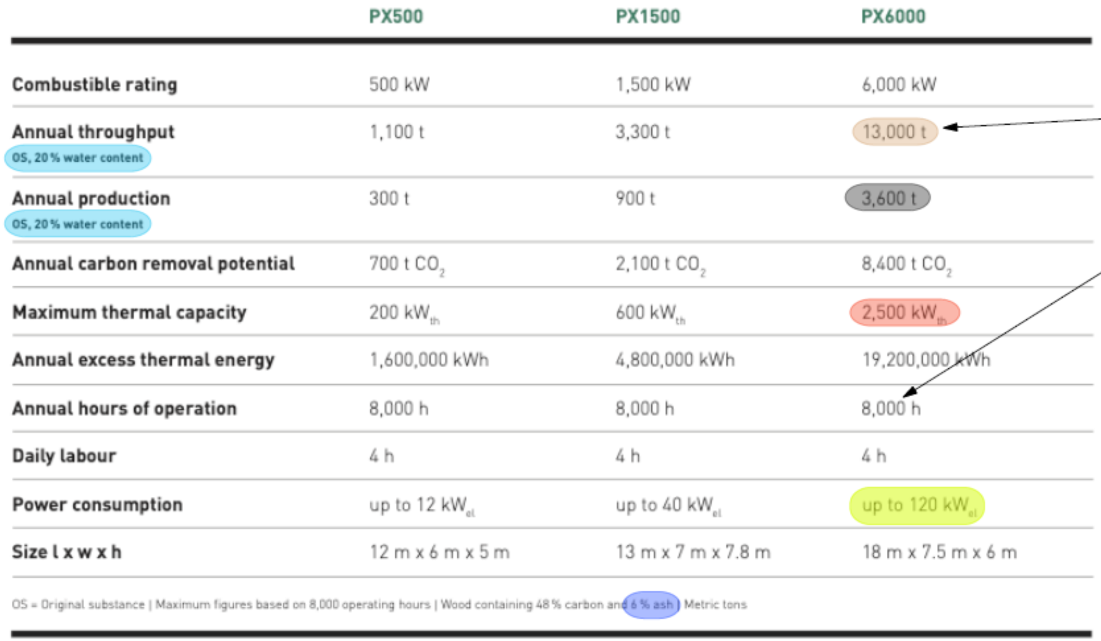
9 mt/d CO_{2e}

MORE DETAILS

Process Flows and Mass and Energy Balances

Pyrolysis System Performance Estimates

Source Information (pyreg.com/downloads):
Data Sheet "230908_flyer_datenblaetter_biomass_EN_DRUCKDATEN"



	PX500	PX1500	PX6000
Combustible rating	500 kW	1,500 kW	6,000 kW
Annual throughput OS, 20 % water content	1,100 t	3,300 t	13,000 t
Annual production OS, 20 % water content	300 t	900 t	3,600 t
Annual carbon removal potential	700 t CO_2	2,100 t CO_2	8,400 t CO_2
Maximum thermal capacity	200 kW_{th}	600 kW_{th}	2,500 kW_{th}
Annual excess thermal energy	1,600,000 kWh	4,800,000 kWh	19,200,000 kWh
Annual hours of operation	8,000 h	8,000 h	8,000 h
Daily labour	4 h	4 h	4 h
Power consumption	up to 12 kW_{el}	up to 40 kW_{el}	up to 120 kW_{el}
Size l x w x h	12 m x 6 m x 5 m	13 m x 7 m x 7.8 m	18 m x 7.5 m x 6 m

OS = Original substance | Maximum figures based on 8,000 operating hours | Wood containing 48 % carbon and 6 % ash | Metric tons

Feedstock "As Received"
at 20% mc & 6% ash dry basis

$$\frac{13{,}000\text{ mt}}{8{,}000\text{ h}} = 1.625\text{ mt/h}$$

Feedstock "Dry Matter"

$$\frac{1.625\text{ mt}}{\text{h}} * (1 - 0.2) = 1.3\text{ mt/h (db)}$$

Feedstock "Dry Ash-Free"

$$\frac{1.3\text{ mt}}{\text{h}} * (1 - 0.06) = 1.222\text{ mt/h (dAF)}$$

Biochar "Dry Matter"

$$\frac{3{,}600\text{ mt}}{8{,}000\text{ h}} * (1 - 0.2) = 0.36\text{ mt/h (db)}$$

Maximum Excess Thermal Energy

$$\frac{2{,}500\text{ kW}_{th} * 1\text{ h}}{1.222\text{ mt}} = 2{,}045.8\text{ kWh}_{th}\text{/mt}$$

~ 2,050 kWhth/mt

(dry ash-free basis)

Biochar Yield "% Dry Matter"

$$\frac{0.36\text{ mt/h}}{1.30\text{ mt/h}} = 0.277$$

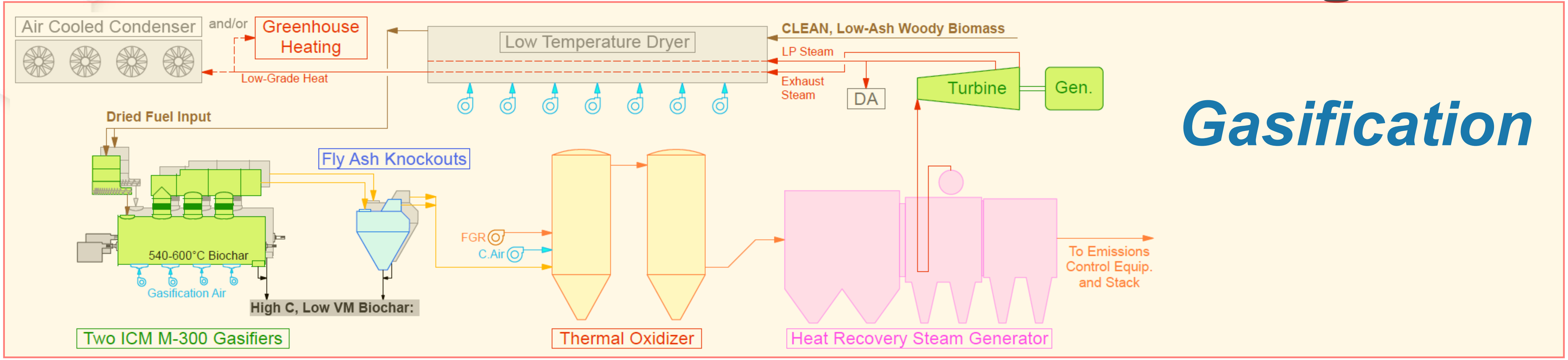
27.7% DM

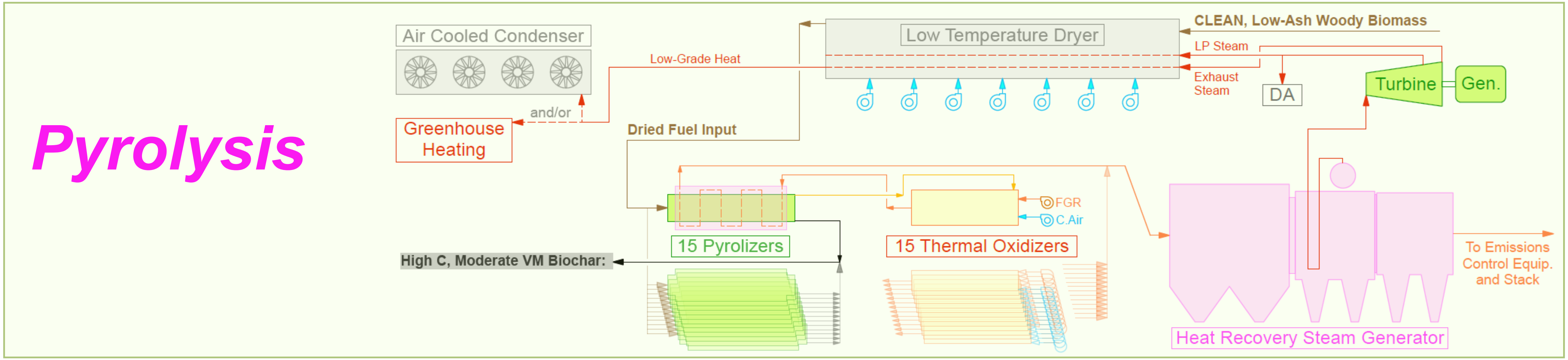
Power Consumption

Maximum 120 kWel
per one (1) PX6000

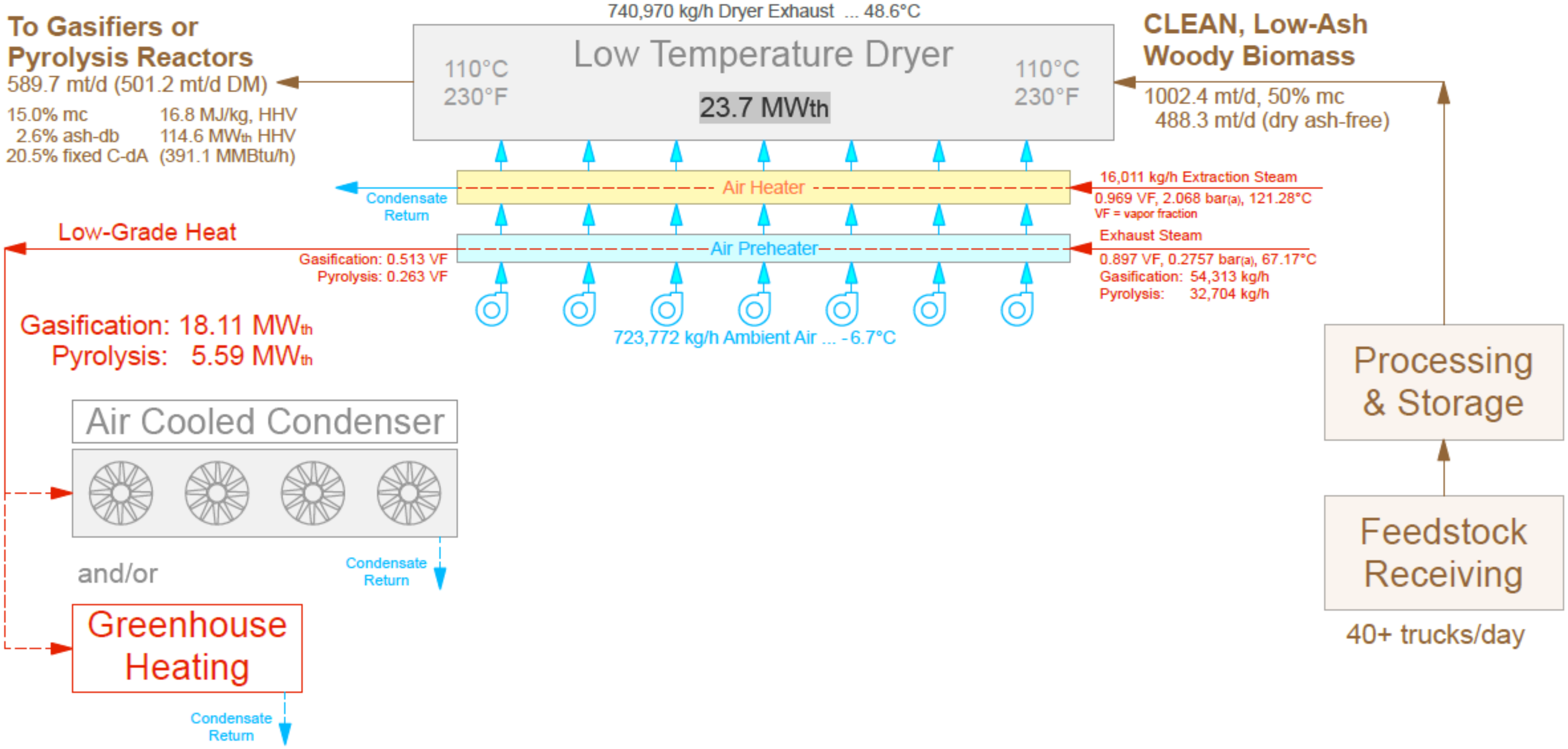
Assume 60% of max.
72 kWel per (1) PX6000

Biochar and CHP - Process Flow Diagrams





Feedstock Drying and Low-Grade Heat Utilization
- Mass & Energy Balance -



740,970 kg/h Dryer Exhaust ... 48.6°C

To Gasifiers or
Pyrolysis Reactors
589.7 mt/d (501.2 mt/d DM)

15.0% mc	16.8 MJ/kg, HHV
2.6% ash-db	114.6 MW$_{th}$ HHV
20.5% fixed C-dA	(391.1 MMBtu/h)

Low Temperature Dryer

110°C
230°F

23.7 MWth

110°C
230°F

CLEAN, Low-Ash
Woody Biomass
1002.4 mt/d, 50% mc
488.3 mt/d (dry ash-free)

Air Heater

Condensate Return

16,011 kg/h Extraction Steam
0.969 VF, 2.068 bar$_{(a)}$, 121.28°C
VF = vapor fraction

Low-Grade Heat

Air Preheater

Gasification: 0.513 VF
Pyrolysis: 0.263 VF

Exhaust Steam
0.897 VF, 0.2757 bar$_{(a)}$, 67.17°C
Gasification: 54,313 kg/h
Pyrolysis: 32,704 kg/h

723,772 kg/h Ambient Air ... -6.7°C

Gasification: 18.11 MW$_{th}$
Pyrolysis: 5.59 MW$_{th}$

Air Cooled Condenser

Condensate Return

and/or

Greenhouse Heating

Condensate Return

Processing & Storage

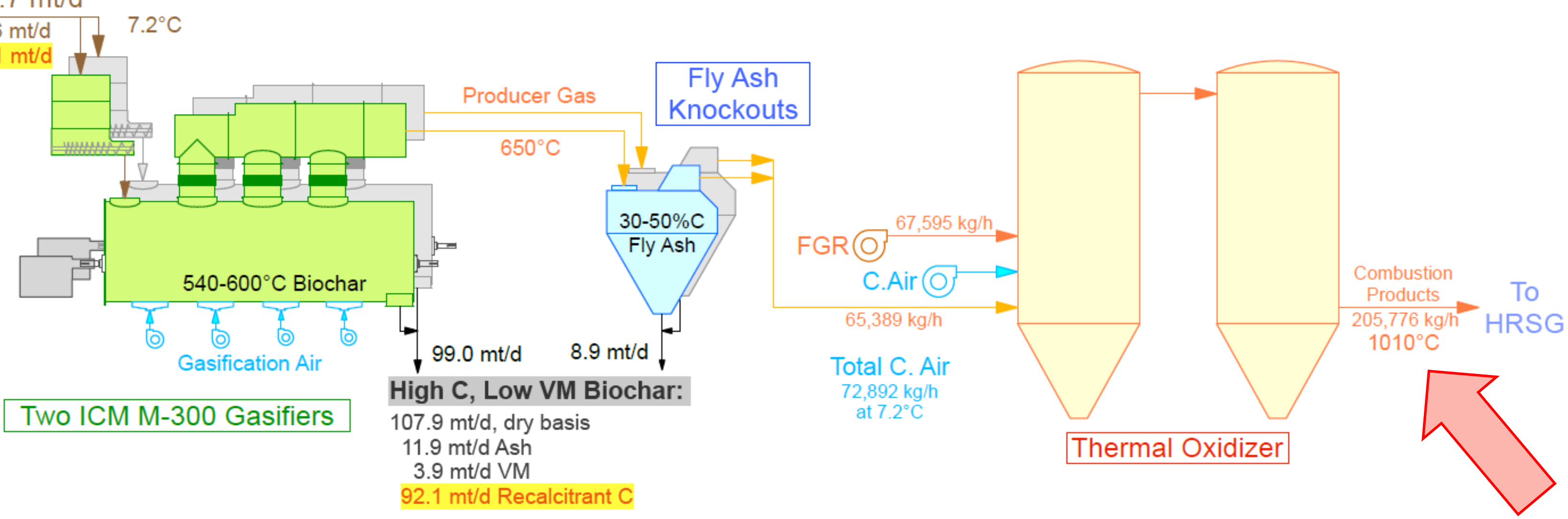
Feedstock Receiving

40+ trucks/day

Gasifiers and Pyrolysis Reactors – M&EB

Two Gasifiers and One Thermal Oxidizer

Fuel Input: 589.7 mt/d
Total Carbon: 274.6 mt/d
Recalcitrant C: 100.1 mt/d



7.2°C

Producer Gas

650°C

Fly Ash Knockouts

30-50%C Fly Ash

540-600°C Biochar

Gasification Air

Two ICM M-300 Gasifiers

99.0 mt/d

8.9 mt/d

High C, Low VM Biochar:
107.9 mt/d, dry basis
11.9 mt/d Ash
3.9 mt/d VM
92.1 mt/d Recalcitrant C

FGR 67,595 kg/h

C.Air

65,389 kg/h

Total C. Air
72,892 kg/h
at 7.2°C

Thermal Oxidizer

Combustion Products
205,776 kg/h
1010°C

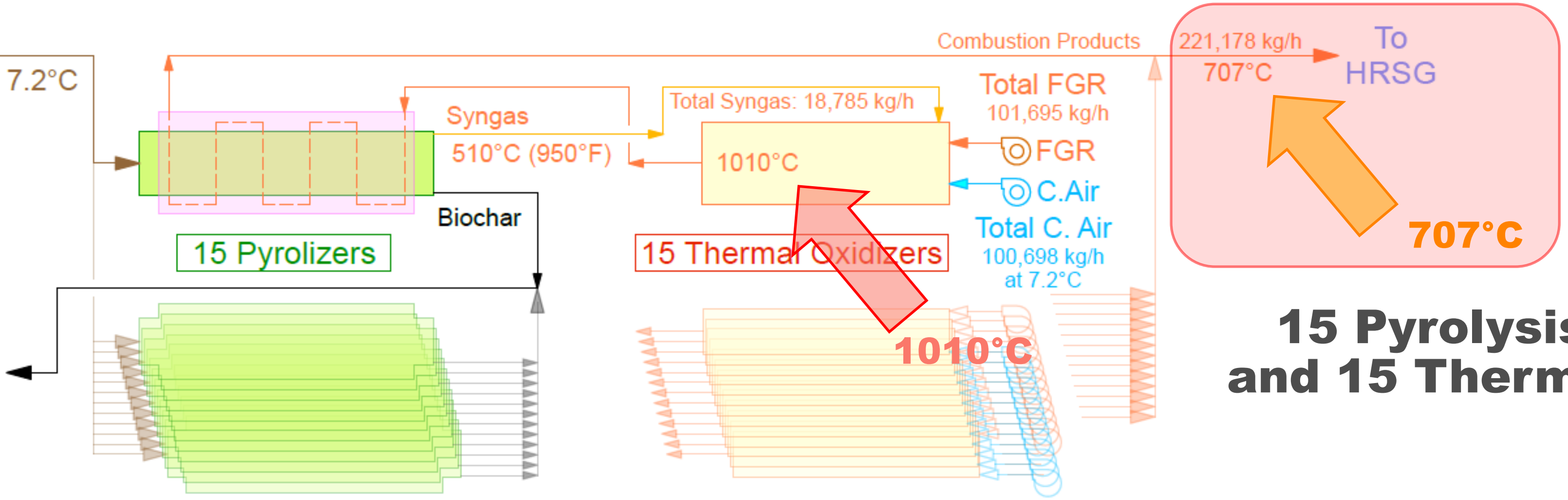
To HRSG

1010°C

Fuel Input: 589.7 mt/d
Total Carbon: 274.6 mt/d
Recalcitrant C: 100.1 mt/d

ASSUMPTION:
~2050 kWhth/mt * (dryAF basis)
as exportable high-grade
thermal energy

* derived from PYREG's pyrolysis
reactor data sheet



7.2°C

Combustion Products
221,178 kg/h
707°C

To HRSG

Syngas
510°C (950°F)

Total Syngas: 18,785 kg/h

1010°C

Total FGR
101,695 kg/h

FGR

C.Air

Total C. Air
100,698 kg/h
at 7.2°C

Biochar

15 Pyrolyzers

15 Thermal Oxidizers

1010°C

707°C

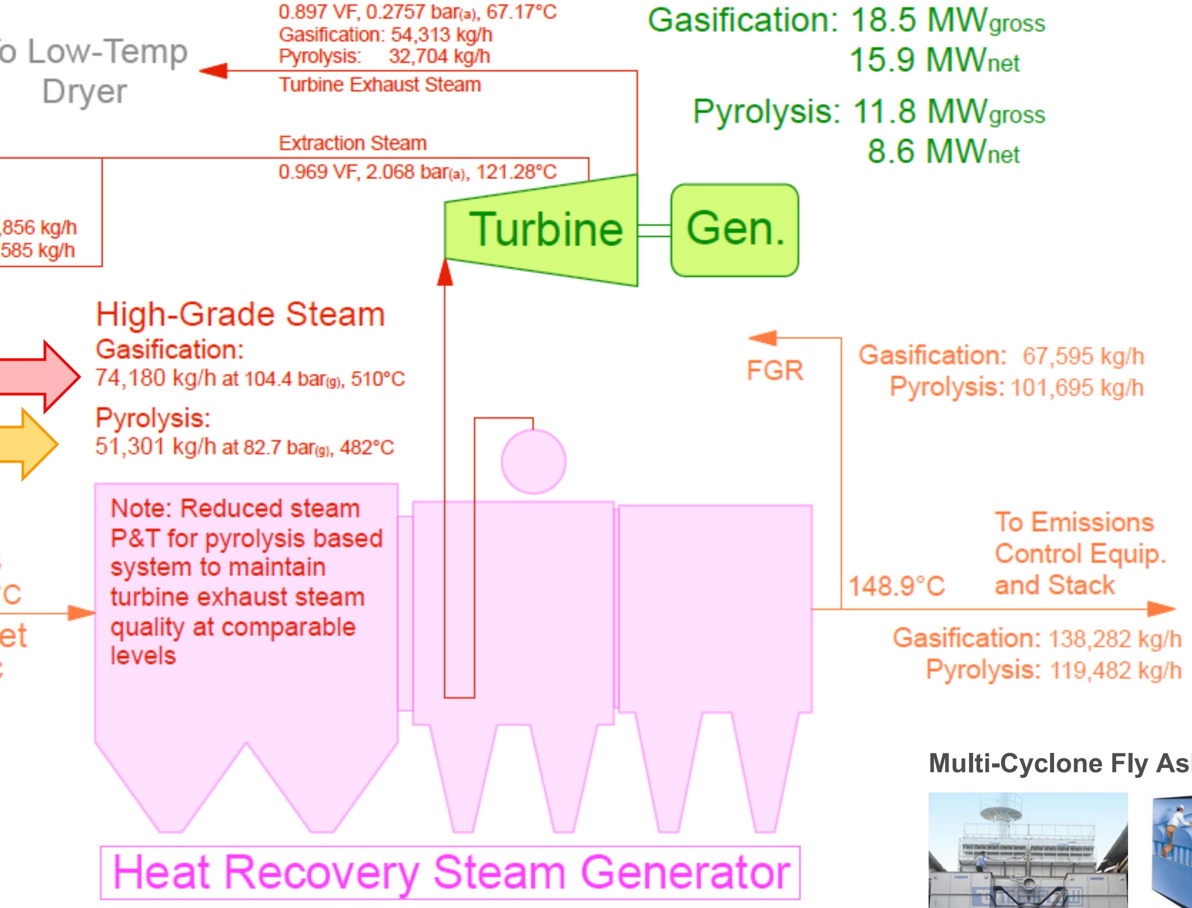
High C, Moderate VM Biochar:
138.8 mt/d, dry basis
11.9 mt/d Ash
26.9 mt/d Volatile Matter
100.1 mt/d Recalcitrant C

15 Pyrolysis Reactors and 15 Thermal Oxidizers

HRSG and Steam Turbine – Mass & Energy Balance


Deaerator

BFW Pumps


To Low-Temp Dryer

0.897 VF, 0.2757 bar$_{(a)}$, 67.17°C
Gasification: 54,313 kg/h
Pyrolysis: 32,704 kg/h
Turbine Exhaust Steam

To Air Preheater

16,012 kg/h

Extraction Steam
0.969 VF, 2.068 bar$_{(a)}$, 121.28°C

Deaerator

Gasification: 3,856 kg/h
Pyrolysis: 2,585 kg/h

Turbine

Gen.

Gasification: 18.5 MW$_{gross}$
15.9 MW$_{net}$

Pyrolysis: 11.8 MW$_{gross}$
8.6 MW$_{net}$

Greater mass flow & higher P&T

High-Grade Steam
Gasification:
74,180 kg/h at 104.4 bar$_{(g)}$, 510°C
Pyrolysis:
51,301 kg/h at 82.7 bar$_{(g)}$, 482°C

FGR

Gasification: 67,595 kg/h
Pyrolysis: 101,695 kg/h

T.O. Combustion Products
Gasification: 205,776 kg/h, 1010°C

Pyrolysis Reacter FG Outlet
Pyrolysis: 221,178 kg/h, 707°C

Note: Reduced steam P&T for pyrolysis based system to maintain turbine exhaust steam quality at comparable levels

148.9°C

To Emissions Control Equip. and Stack

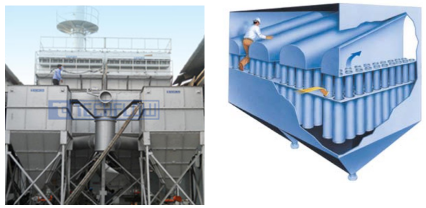
Gasification: 138,282 kg/h
Pyrolysis: 119,482 kg/h

Heat Recovery Steam Generator


Steam Turbine & Generator

Electrostatic Precipitator

Multi-Cyclone Fly Ash Collectors



HRSG

More Details - Mass and Energy Balance

Feedstock Characteristics

At Dryer Outlet

Proximate Analysis	dry AF	kg/h	mt/d
Fixed Carbon	20.505%	4,171.8	100.1
Volatile Matter	79.495%	16,174.0	388.2
Biomass, dry ash-free		20,345.8	488.3
HHV, kJ/kg		16,782.8	
MWth (HHV)		114.5	
LHV, kJ/kg		15,357.9	

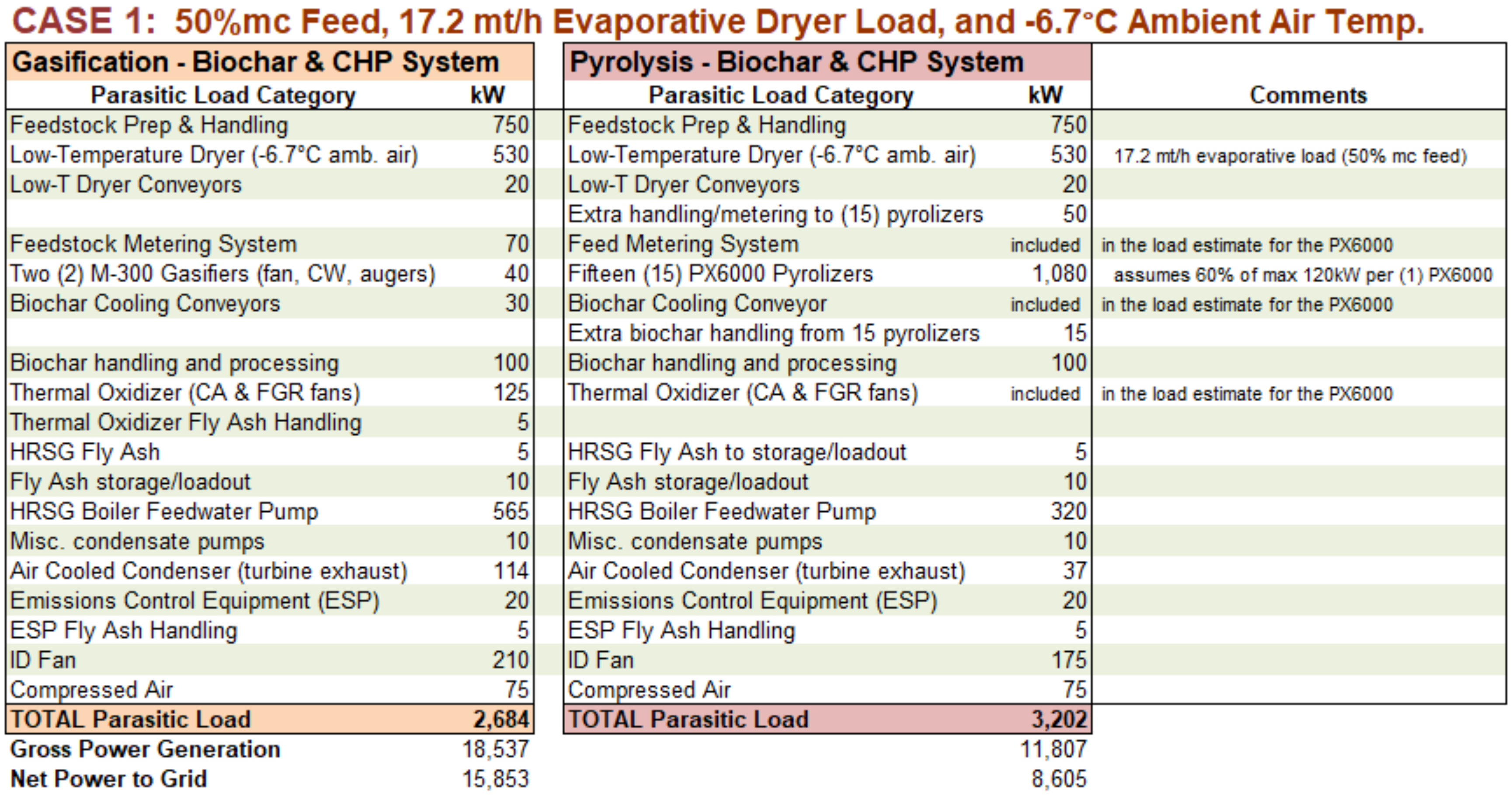
Ultimate Analysis	% wt	kg/h	mt/d
Carbon	46.57%	11,441.4	274.6
Hydrogen	4.85%	1,192.7	28.6
Nitrogen	0.16%	38.4	0.9
Oxygen	31.21%	7,667.8	184.0
Sulfur	0.01%	2.2	0.1
Chlorine	0.01%	3.3	0.1
Ash	2.19%	538.3	12.9
Water (l)	15.00%	3,685.5	88.5
Total Biomass (15% mc)	100.00%	24,569.6	589.7

Assumption: The feedstock's Proximate Analysis value for fixed carbon content is the source and maximum LIMIT for the Biochar's recalcitrant carbon content

ICM™

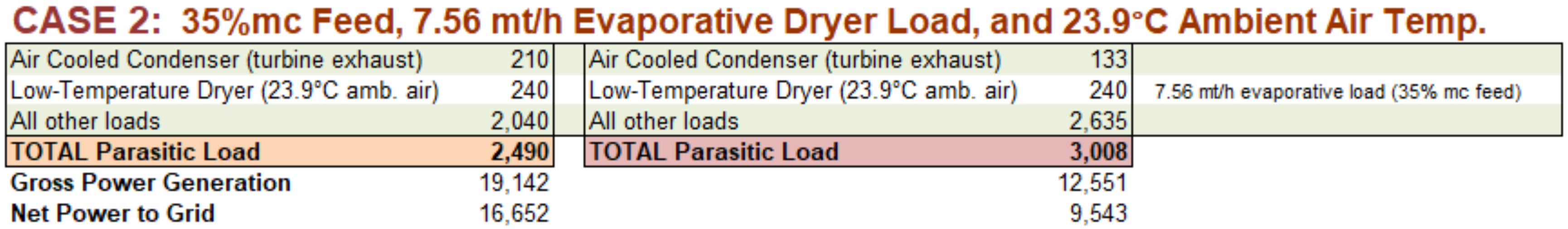
Parasitic Load Estimates

Gross and Net Power Generation Estimates



CASE 1: 50%mc Feed, 17.2 mt/h Evaporative Dryer Load, and -6.7°C Ambient Air Temp.

Gasification - Biochar & CHP System		**Pyrolysis - Biochar & CHP System**		
Parasitic Load Category	**kW**	**Parasitic Load Category**	**kW**	**Comments**
Feedstock Prep & Handling	750	Feedstock Prep & Handling	750	
Low-Temperature Dryer (-6.7°C amb. air)	530	Low-Temperature Dryer (-6.7°C amb. air)	530	17.2 mt/h evaporative load (50% mc feed)
Low-T Dryer Conveyors	20	Low-T Dryer Conveyors	20	
		Extra handling/metering to (15) pyrolizers	50	
Feedstock Metering System	70	Feed Metering System	included	in the load estimate for the PX6000
Two (2) M-300 Gasifiers (fan, CW, augers)	40	Fifteen (15) PX6000 Pyrolizers	1,080	assumes 60% of max 120kW per (1) PX6000
Biochar Cooling Conveyors	30	Biochar Cooling Conveyor	included	in the load estimate for the PX6000
		Extra biochar handling from 15 pyrolizers	15	
Biochar handling and processing	100	Biochar handling and processing	100	
Thermal Oxidizer (CA & FGR fans)	125	Thermal Oxidizer (CA & FGR fans)	included	in the load estimate for the PX6000
Thermal Oxidizer Fly Ash Handling	5			
HRSG Fly Ash	5	HRSG Fly Ash to storage/loadout	5	
Fly Ash storage/loadout	10	Fly Ash storage/loadout	10	
HRSG Boiler Feedwater Pump	565	HRSG Boiler Feedwater Pump	320	
Misc. condensate pumps	10	Misc. condensate pumps	10	
Air Cooled Condenser (turbine exhaust)	114	Air Cooled Condenser (turbine exhaust)	37	
Emissions Control Equipment (ESP)	20	Emissions Control Equipment (ESP)	20	
ESP Fly Ash Handling	5	ESP Fly Ash Handling	5	
ID Fan	210	ID Fan	175	
Compressed Air	75	Compressed Air	75	
TOTAL Parasitic Load	**2,684**	**TOTAL Parasitic Load**	**3,202**	
Gross Power Generation	18,537		11,807	
Net Power to Grid	15,853		8,605	



CASE 2: 35%mc Feed, 7.56 mt/h Evaporative Dryer Load, and 23.9°C Ambient Air Temp.

Air Cooled Condenser (turbine exhaust)	210	Air Cooled Condenser (turbine exhaust)	133	
Low-Temperature Dryer (23.9°C amb. air)	240	Low-Temperature Dryer (23.9°C amb. air)	240	7.56 mt/h evaporative load (35% mc feed)
All other loads	2,040	All other loads	2,635	
TOTAL Parasitic Load	**2,490**	**TOTAL Parasitic Load**	**3,008**	
Gross Power Generation	19,142		12,551	
Net Power to Grid	16,652		9,543	

COMBINED HEAT AND POWER

Large Scale Proven Systems

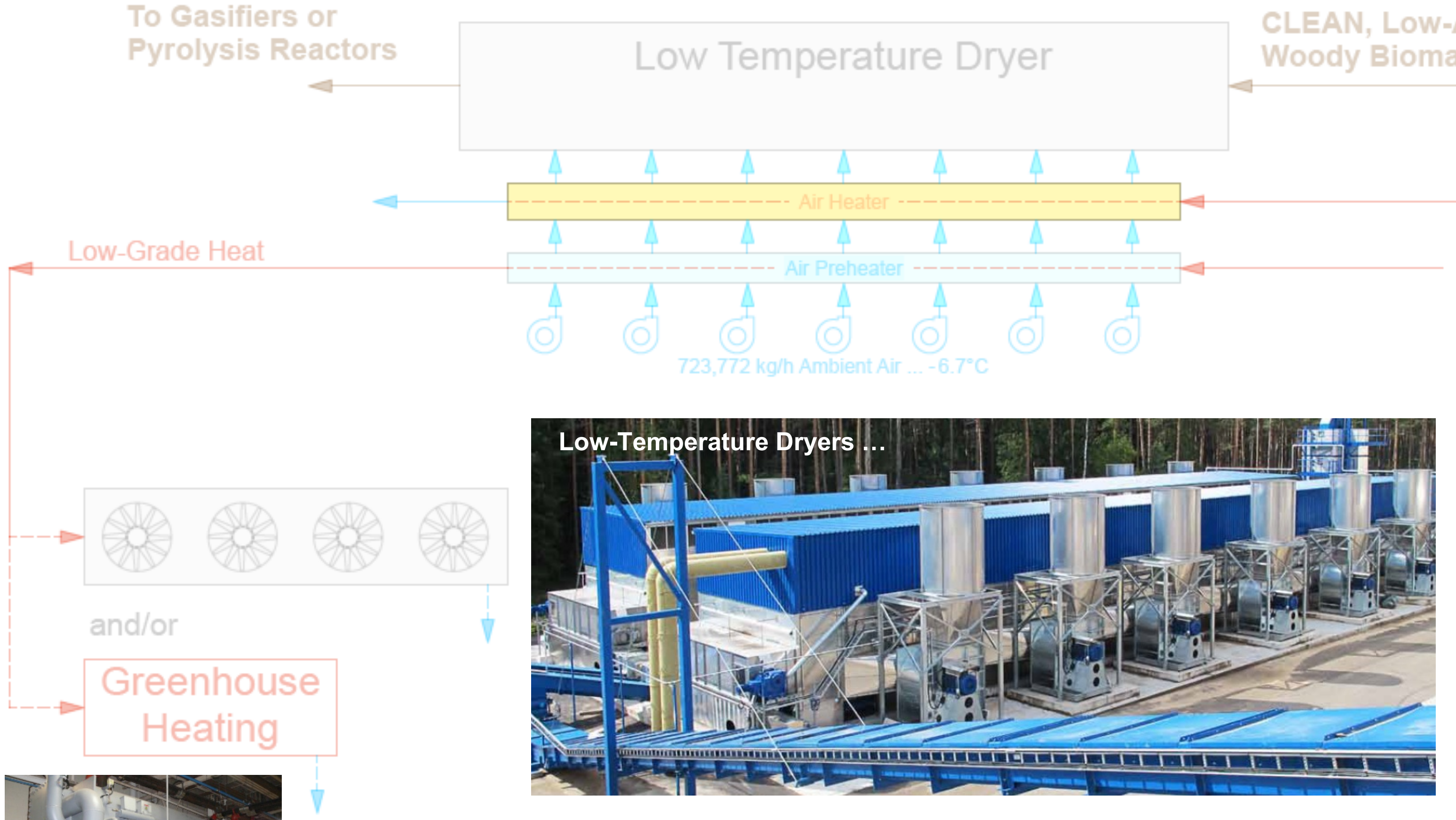
Well Developed Technologies

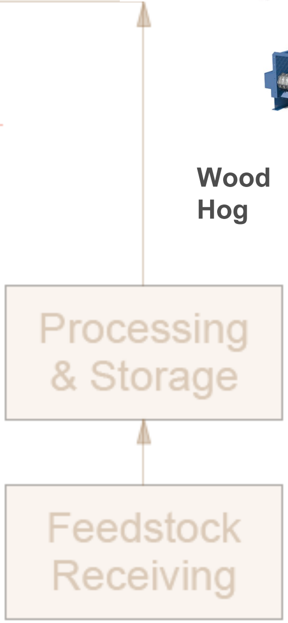
Large Scales using Well Developed, Mature Technologies

Dried Feedstock Storage

Air Cooled Condenser

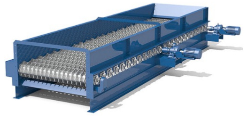
Greenhouse Cooling using Absorption Chillers





Magnets

Screener



Wood Hog

Receiver

Truck Dumper

Advantages - Steam Turbines, Air Cooled Condensers and Low Temperature Dryers

Steam Turbine and Generator

Economies of Scale

- 5 MW, $2,000,000 USD*
- 20 MW, $4,000,000 USD*
- 40 MW, $6,000,000 USD*

* Excludes installation, etc.

Low-Temperature Dryer

- Advantage - can use low-grade waste heat
- Advantage - low-temp = reduced emissions
- Disadvantage - More $$

Air Cooled Condenser

Why Air-Cooled Condensers instead of Cooling Towers?

- Integration with low-temp dryers
- Eliminates water consumption
- Disadvantage - More $$

Cooling Tower

ICM'S PATENTED GASIFICATION TECHNOLOGY

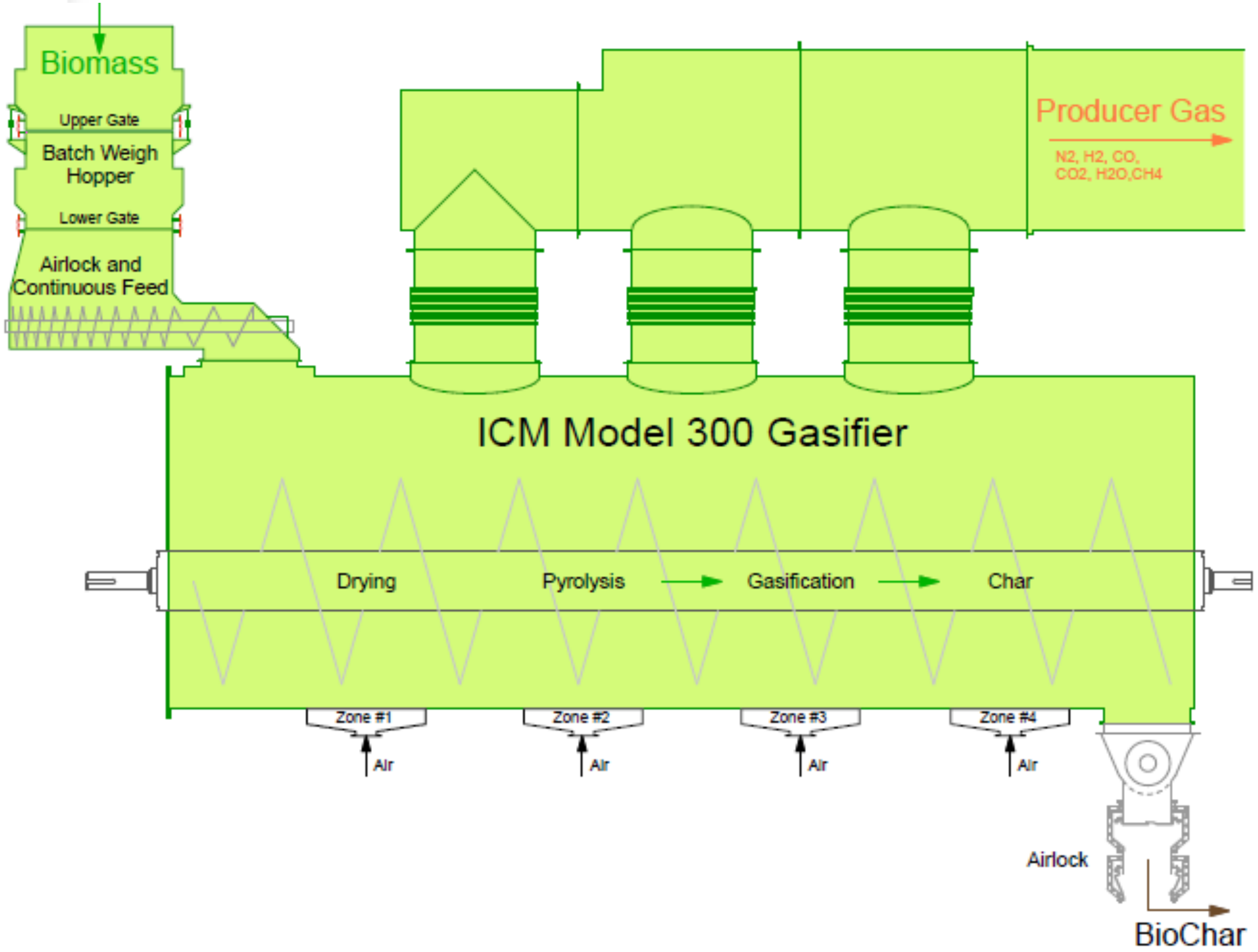
Development Started
In Early 1970s

16+ years of Development, Refining and Demonstrating ICM's Gasification Platform

- **Two Demonstration Facilities 2007 to 2016**
  - 135 and 15 mt/d nominal throughput
- **Numerous feedstocks tested**
  - 9000 tons demonstrated
  - 400 tons biochar to Research Institutions

Tested Feedstocks			
Wood	4,600 tons	Auto shredder res	50 tons
Corn stover	1,000 tons	MSW (RDF)	800 tons
Wheat straw	400 tons	MSW (RDF) + Tires	400 tons
Sorghum stalks	400 tons	Min. processed MSW	120 tons
C & D	200 tons	Chicken litter	220 tons
Paper pulp + plastics	100 tons	Dairy manure	50 tons
Switchgrass	50 tons	Manure + wood chips	50 tons
Corn bran + syrup	50 tons	Tires + Wood chips	50 tons

Unique Robust Design: One Moving Internal Part



- ○ **Horizontal, "Cross-Flow" Gasifier**
- ○ **Air Blown – Autothermic**
- ○ **Very Low Power Draw**
  - < 70kW per 300mt/d
  - Near-Atmospheric Pressure
- ○ **Better Scalability**
  - vs Indirectly Heated Pyrolysis
  - vs Updraft or Downdraft Gasifiers
- ○ **Feedstock Flexibility**

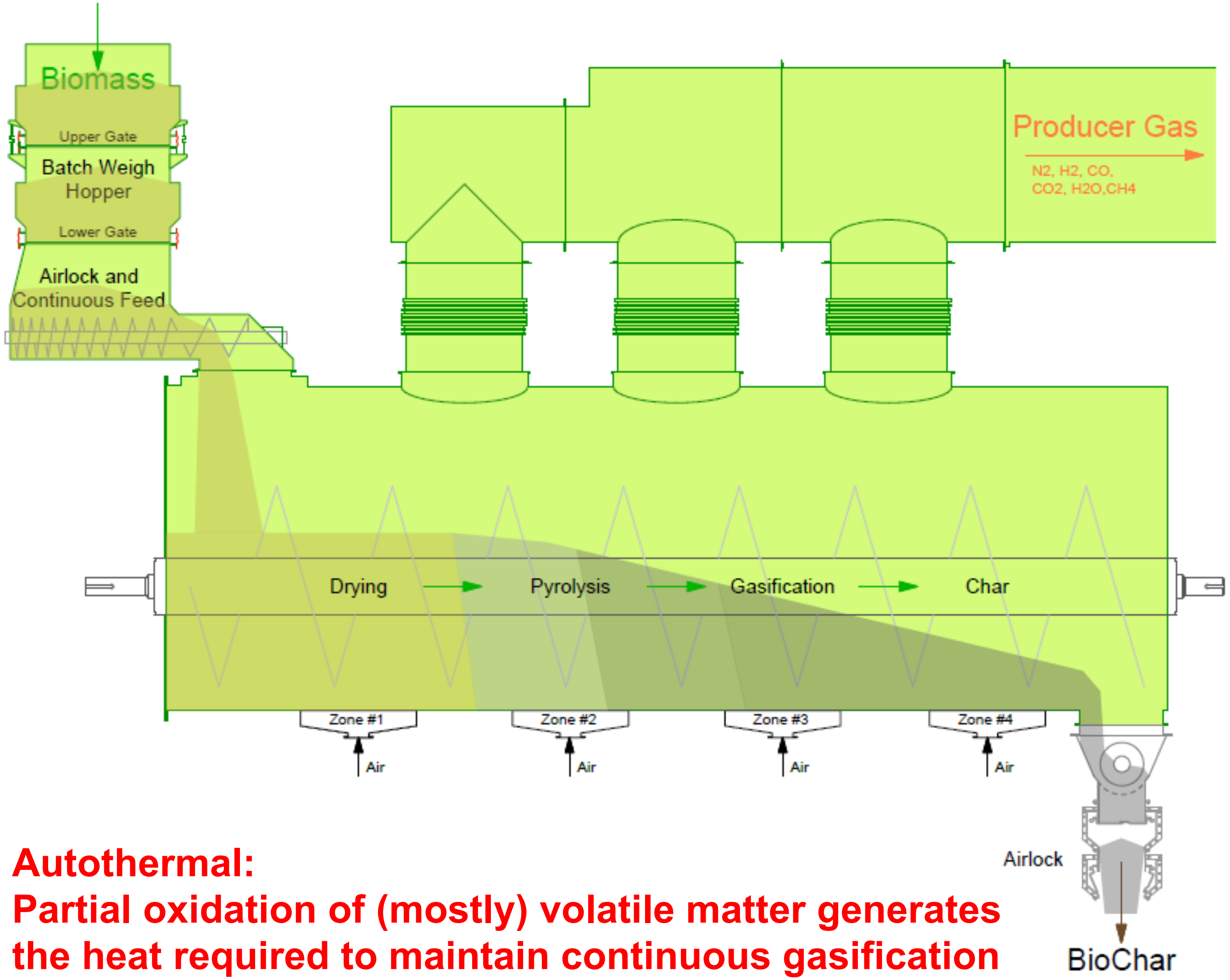
ICM Gasifiers and Better Control

Better Control

- Mass input, adjustable bed depth
- Variable-speed, Low rpm auger
- Adjustable retention time
- Zoned air to maximize biochar yield
- Wide turndown range
- 10 - 35+ % moisture content

Lower Power Required to Operate

- Autothermal: no indirect heating
  - Benefit: Scalability & Efficiency
- Low Power: < 70 kW for Model-300 gasifier operating at 300 mt/day
  - Infeed & takeaway conveyors
  - Feedstock metering
  - Main internal auger drive (just 5 kW)
  - Gasification air supply fans
- **After start, no external fuel required**



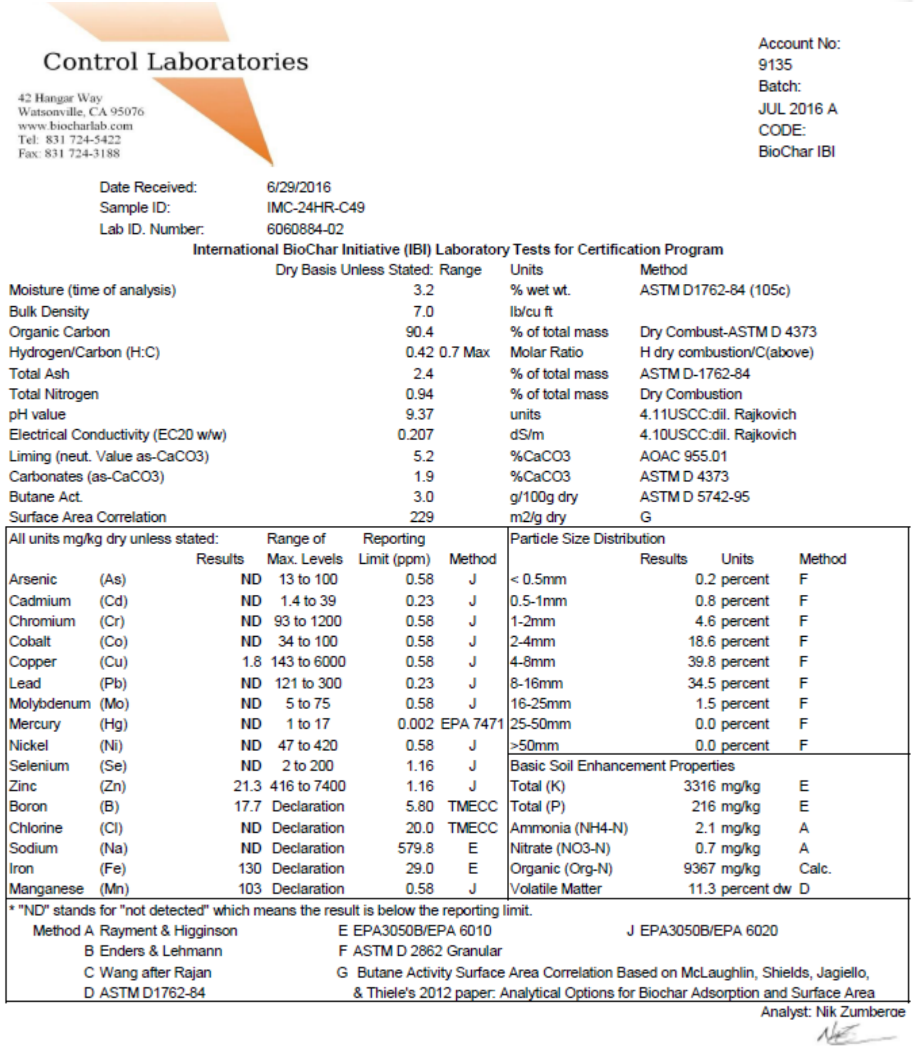
Autothermal:
Partial oxidation of (mostly) volatile matter generates the heat required to maintain continuous gasification

Typical Gasification Based Biochars

Five Samples from 2016 Biochar Yield Demonstration Study*	
Organic Carbon	89.3 to 91.7
H:C Mole Ratio	0.24 to 0.42
Total Ash	2.4 to 4.0
Total N	0.78 to 0.94
pH	9.37 to 10.12
Liming	5.2 to 7.0
S. Area Correlation	194 to 231
Germination	100%

** At ICM's Newton, Kansas R&D Gasification Facility … June 2016*

IBI Biochar Certification Program



Control Laboratories

42 Hangar Way
Watsonville, CA 95076
www.biocharlab.com
Tel: 831 724-5422
Fax: 831 724-3188

Account No:
9135
Batch:
JUL 2016 A
CODE:
BioChar IBI

Date Received: 6/29/2016
Sample ID: IMC-24HR-C49
Lab ID. Number: 6060884-02

International BioChar Initiative (IBI) Laboratory Tests for Certification Program

Dry Basis Unless Stated:		Range	Units	Method
Moisture (time of analysis)	3.2		% wet wt.	ASTM D1762-84 (105c)
Bulk Density	7.0		lb/cu ft	
Organic Carbon	90.4		% of total mass	Dry Combust-ASTM D 4373
Hydrogen/Carbon (H:C)	0.42	0.7 Max	Molar Ratio	H dry combustion/C(above)
Total Ash	2.4		% of total mass	ASTM D-1762-84
Total Nitrogen	0.94		% of total mass	Dry Combustion
pH value	9.37		units	4.11USCC:dil. Rajkovich
Electrical Conductivity (EC20 w/w)	0.207		dS/m	4.10USCC:dil. Rajkovich
Liming (neut. Value as-CaCO3)	5.2		%CaCO3	AOAC 955.01
Carbonates (as-CaCO3)	1.9		%CaCO3	ASTM D 4373
Butane Act.	3.0		g/100g dry	ASTM D 5742-95
Surface Area Correlation	229		m2/g dry	G

All units mg/kg dry unless stated:		Results	Range of Max. Levels	Reporting Limit (ppm)	Method
Arsenic	(As)	ND	13 to 100	0.58	J
Cadmium	(Cd)	ND	1.4 to 39	0.23	J
Chromium	(Cr)	ND	93 to 1200	0.58	J
Cobalt	(Co)	ND	34 to 100	0.58	J
Copper	(Cu)	1.8	143 to 6000	0.58	J
Lead	(Pb)	ND	121 to 300	0.23	J
Molybdenum	(Mo)	ND	5 to 75	0.58	J
Mercury	(Hg)	ND	1 to 17	0.002	EPA 7471
Nickel	(Ni)	ND	47 to 420	0.58	J
Selenium	(Se)	ND	2 to 200	1.16	J
Zinc	(Zn)	21.3	416 to 7400	1.16	J
Boron	(B)	17.7	Declaration	5.80	TMECC
Chlorine	(Cl)	ND	Declaration	20.0	TMECC
Sodium	(Na)	ND	Declaration	579.8	E
Iron	(Fe)	130	Declaration	29.0	E
Manganese	(Mn)	103	Declaration	0.58	J

Particle Size Distribution	Results	Units	Method
< 0.5mm	0.2	percent	F
0.5-1mm	0.8	percent	F
1-2mm	4.6	percent	F
2-4mm	18.6	percent	F
4-8mm	39.8	percent	F
8-16mm	34.5	percent	F
16-25mm	1.5	percent	F
25-50mm	0.0	percent	F
>50mm	0.0	percent	F
Basic Soil Enhancement Properties			
Total (K)	3316	mg/kg	E
Total (P)	216	mg/kg	E
Ammonia (NH4-N)	2.1	mg/kg	A
Nitrate (NO3-N)	0.7	mg/kg	A
Organic (Org-N)	9367	mg/kg	Calc.
Volatile Matter	11.3	percent dw	D

* "ND" stands for "not detected" which means the result is below the reporting limit.

Method A Rayment & Higginson
B Enders & Lehmann
C Wang after Rajan
D ASTM D1762-84
E EPA3050B/EPA 6010
F ASTM D 2862 Granular
G Butane Activity Surface Area Correlation Based on McLaughlin, Shields, Jagiello, & Thiele's 2012 paper: Analytical Options for Biochar Adsorption and Surface Area
J EPA3050B/EPA 6020

Analyst: Nik Zumberge

Gasification, Thermal Oxidizers and HRSGs

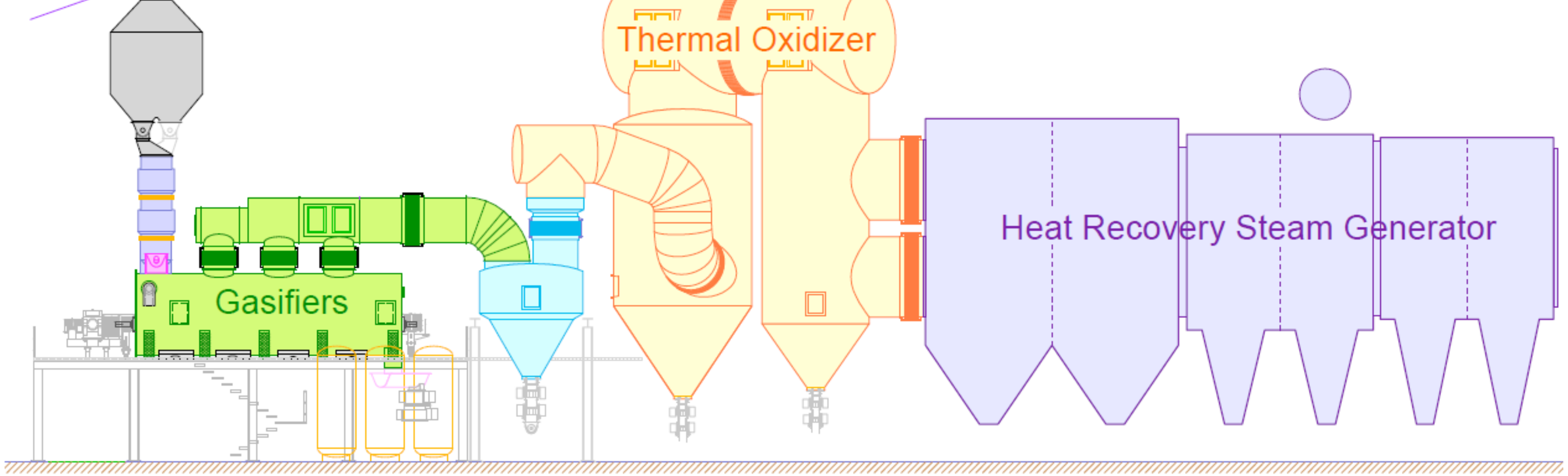
VS

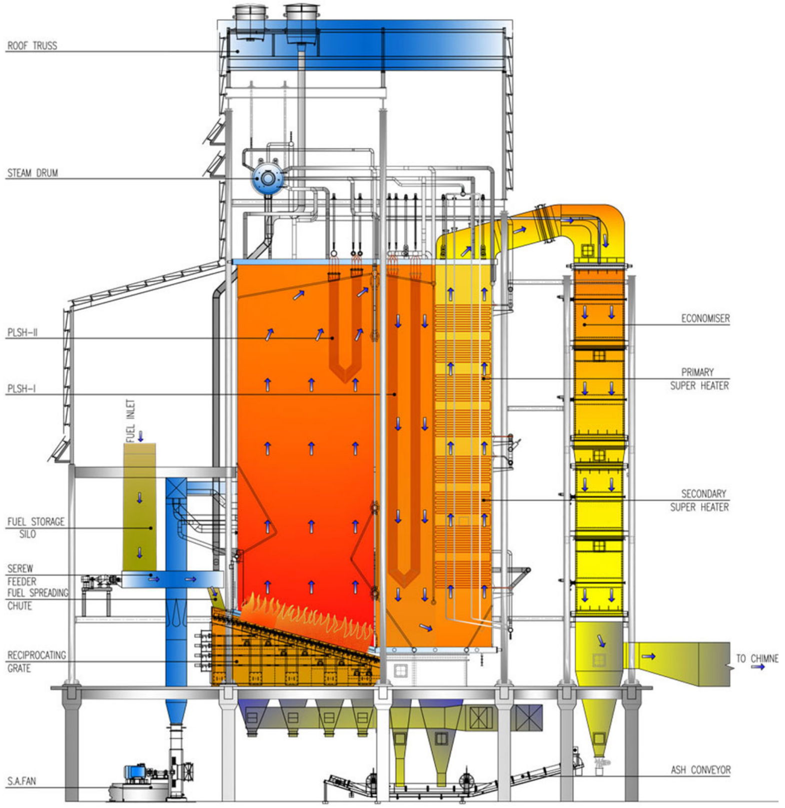
Traditional Biomass Boilers

Competitive Costs

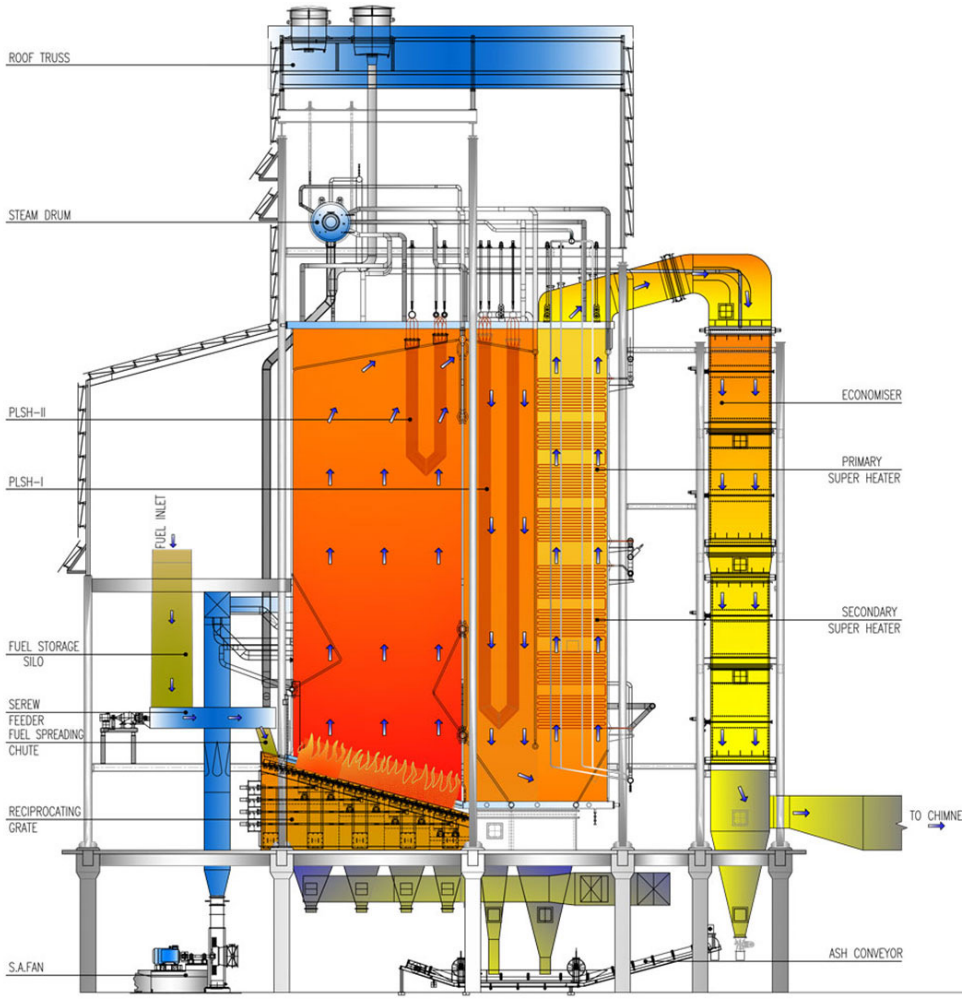
- Large BBs require more field labor to install and have higher install $
- Gasifiers with TOs can use lower cost shop fabricated TO components and modular HRSG components

- Gasifiers cost more than Biomass Boiler grates



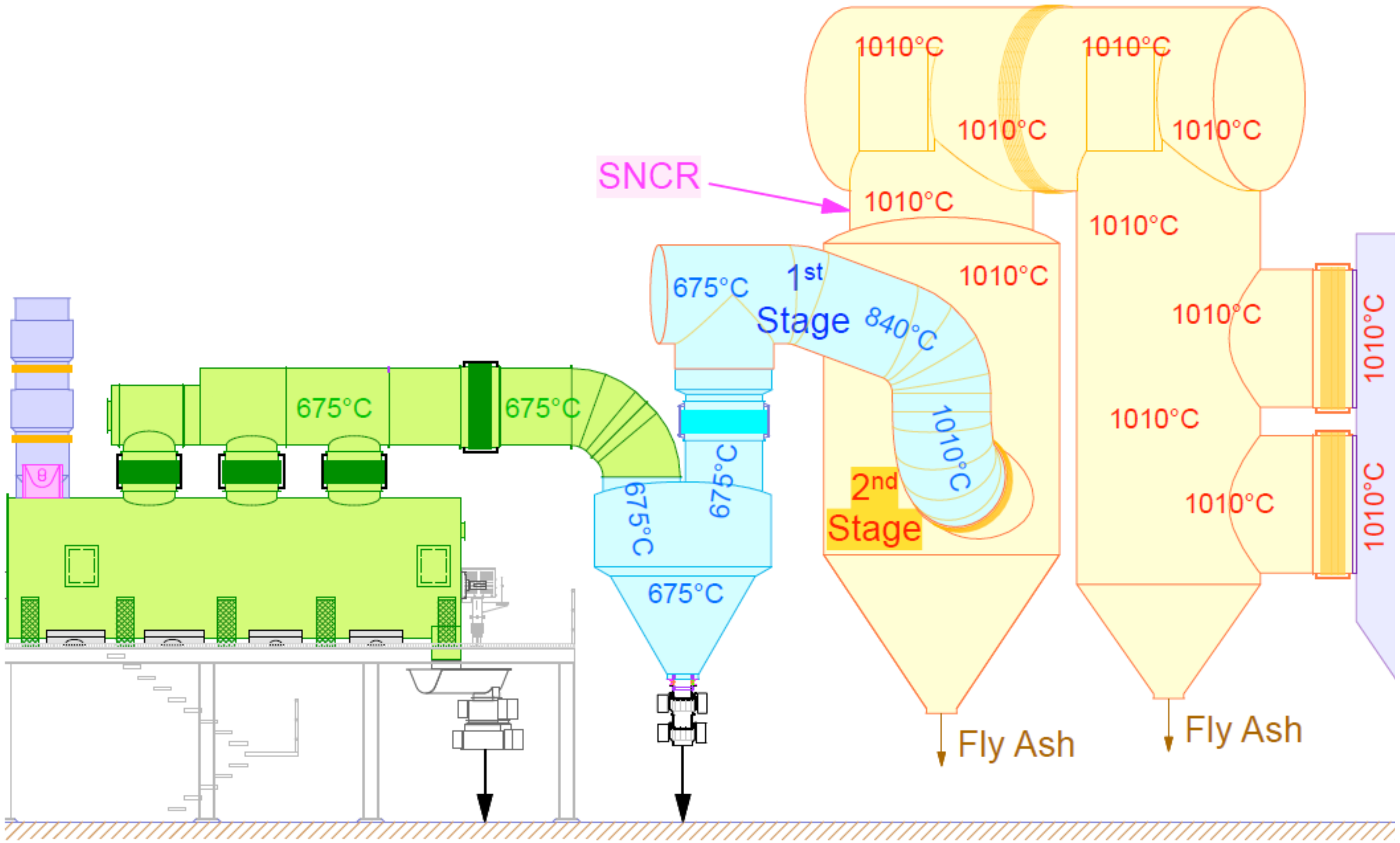


Large Scale Biomass Boilers - Advantages



- **High Efficiency Conversion: of feedstocks to combustion products**
  - High conversion is NOT an advantage when maximizing biochar
    - If that’s the goal, gasifiers & TOs can also be designed for high conversion efficiencies
- **BBs can combust very high moisture feedstocks**
  - But that’s NOT an advantage when maximizing biochar
    - More fixed-C is combusted to vaporize excess H_2O

ICM Gasifiers Collect All Biochars before the Thermal Oxidizer

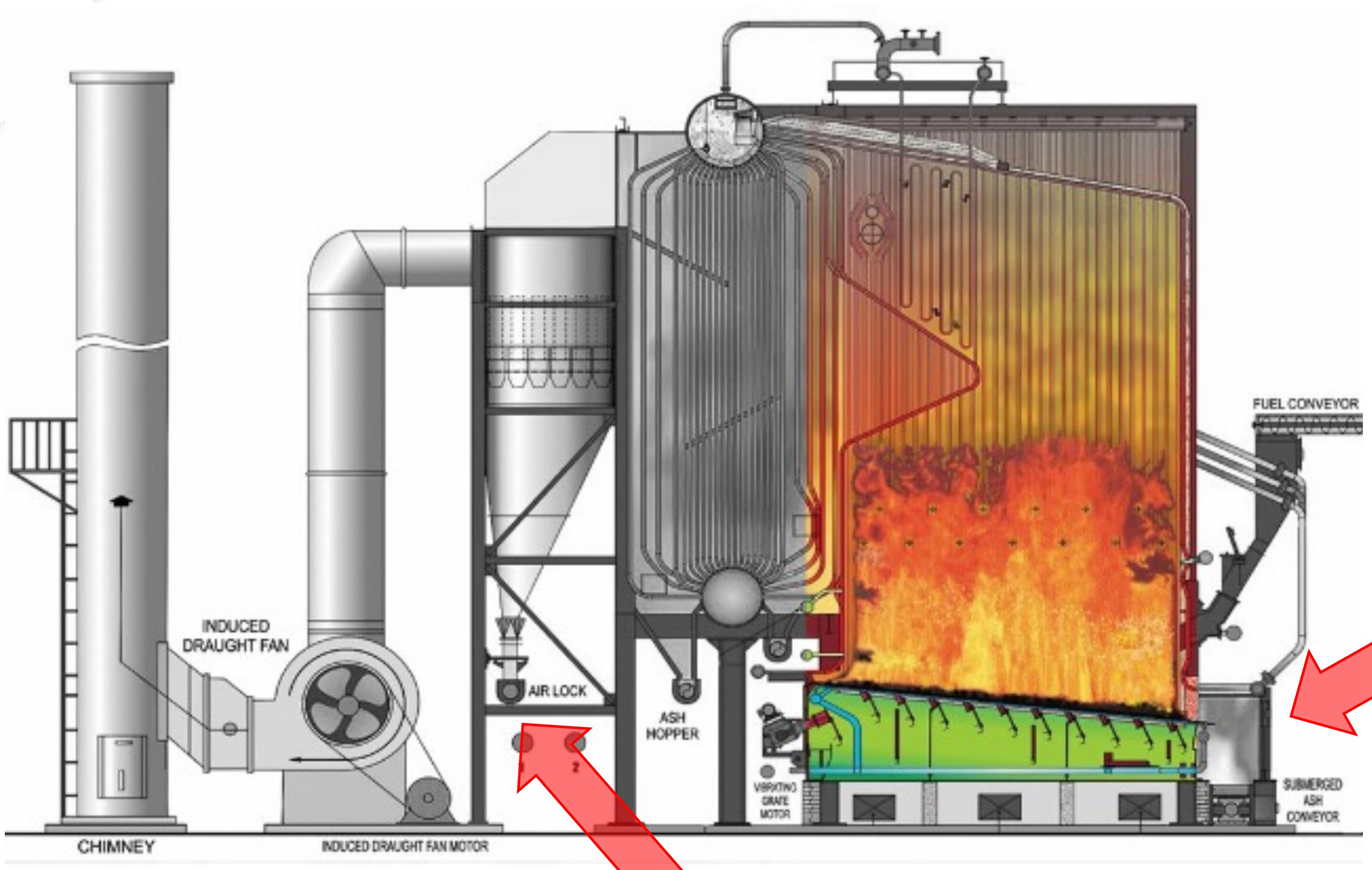


High-C, Low-Ash (580°C Biochar)

Low-C, High-Ash (675°C Biochar)

- **High-C, Low-Ash, Low-VM Biochar at Gasifier Outlet**
  - ~ 90% of total biochar production
- **Low-C, Higher-Ash Biochar at Fly Ash Knockout**
- **ICM's Biochars are NOT exposed to high temps**
  - that are typically found inside the Biomass Boiler's furnace

Most Biomass Boilers Collect Biochar at their Outlet



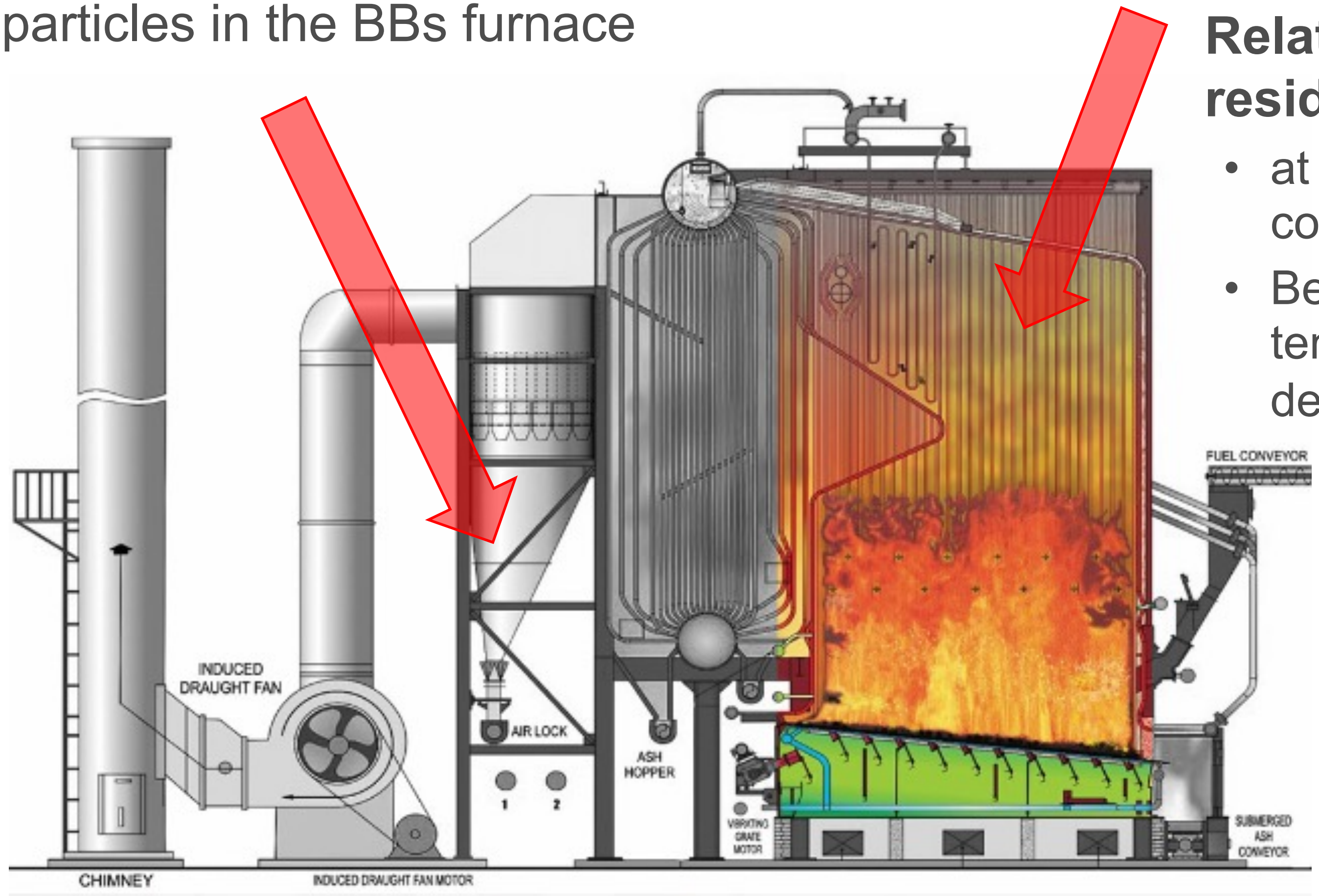
BBs can be designed to operate their grate in "gasification" mode and increase biochar yields

Low-C, High-Ash Biochar at Boiler Outlet

Biomass Boilers Have Higher Emissions!

Biochar yield at BB's outlet =
incomplete combustion of carbon & char particles in the BBs furnace

Why higher emissions?



Relatively short residence times

- at optimum temps for complete combustion
- Because furnace temps quickly decrease

Shorter residence times at appropriate oxidation temps will adversely impact emissions for:

NOx, VOCs, CO, CH_4 and other C_xH_y

Thermal Oxidation with Long Residence Times

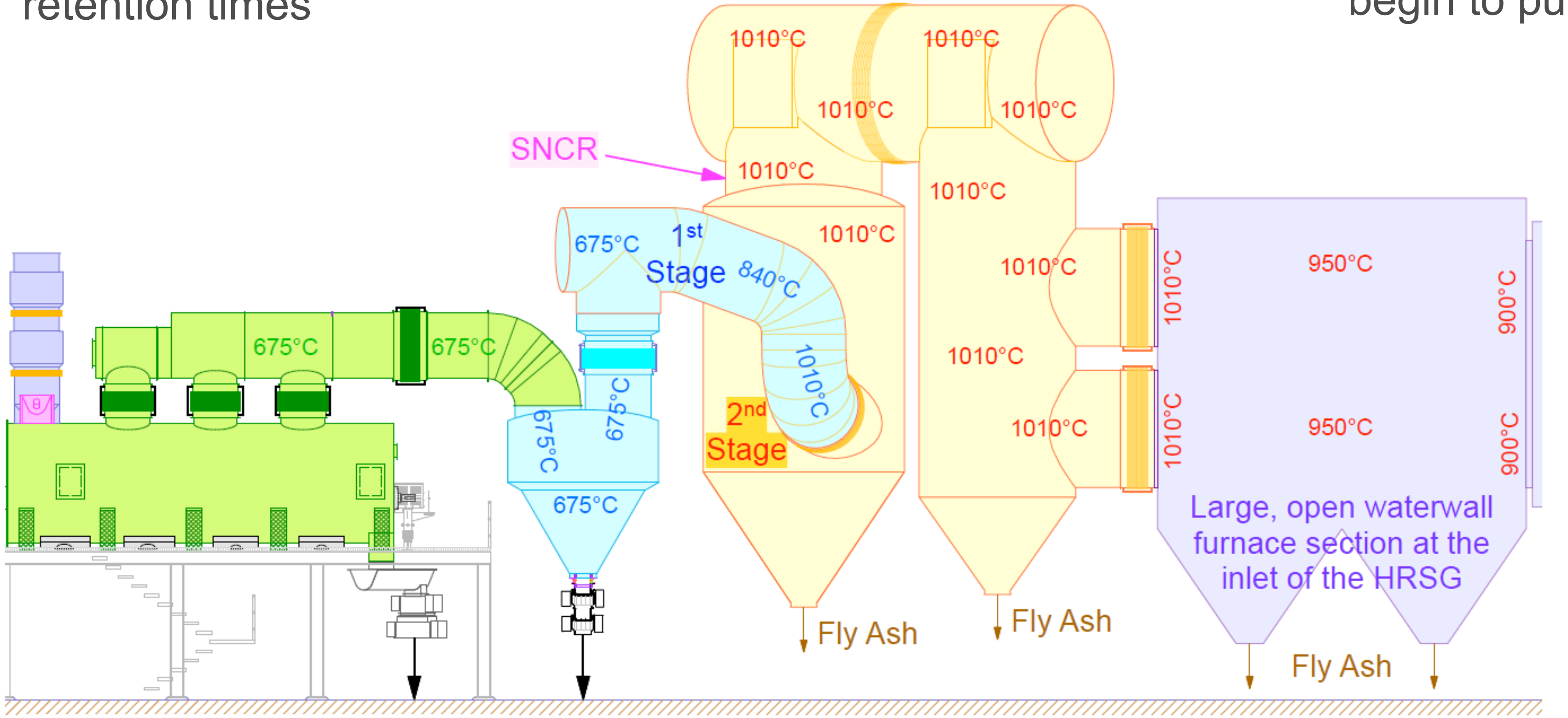
ICM’s Dual M-300 Thermal Oxidizer:

10x or more residence time than BBs

- It’s very easy to design for even longer retention times

At Constant High Temperatures

- Optimum for thermal oxidation
- In contrast, Biomass Boilers immediately begin to pull heat & drop temps

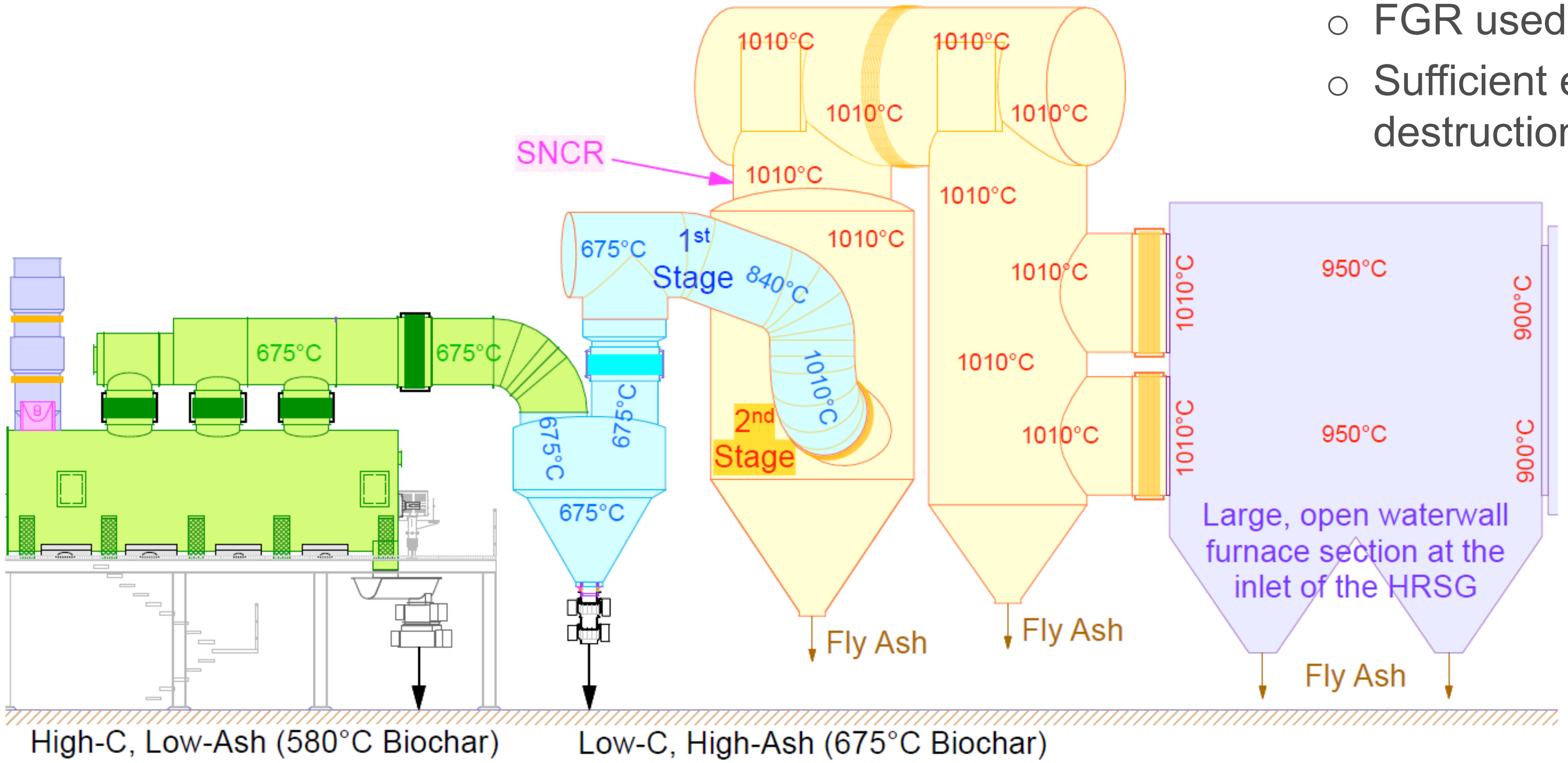


With Turbulent Flow

- For better mixing of combustion reactants

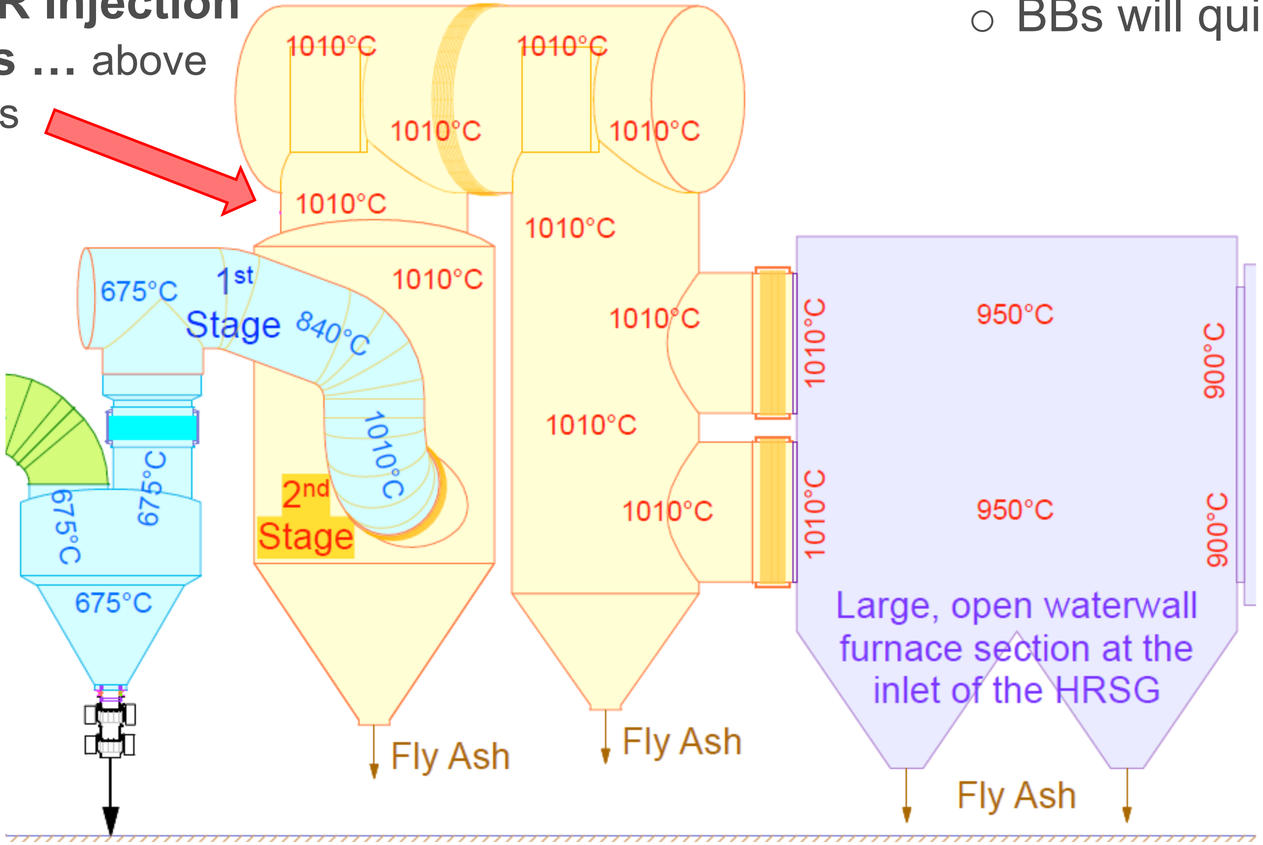
Staged Combustion – To Maximize Thermal Oxidation and Minimize Thermal NOx Formation

- **ICM: Staged Combustion with Flue Gas Recirc.**
  - **1st Stage Combustion**
    - Starts high temp destruction of soot, VOCs, etc.
  - **2nd Stage Combustion**
    - Long, turbulent residence time at ~1000°C
    - FGR used to minimize thermal NOx
    - Sufficient excess air to maximize destruction of VOCs, CO, CH_4, etc



Up to 20x Longer Residence Time at Optimum SNCR Temperatures for NOx Control

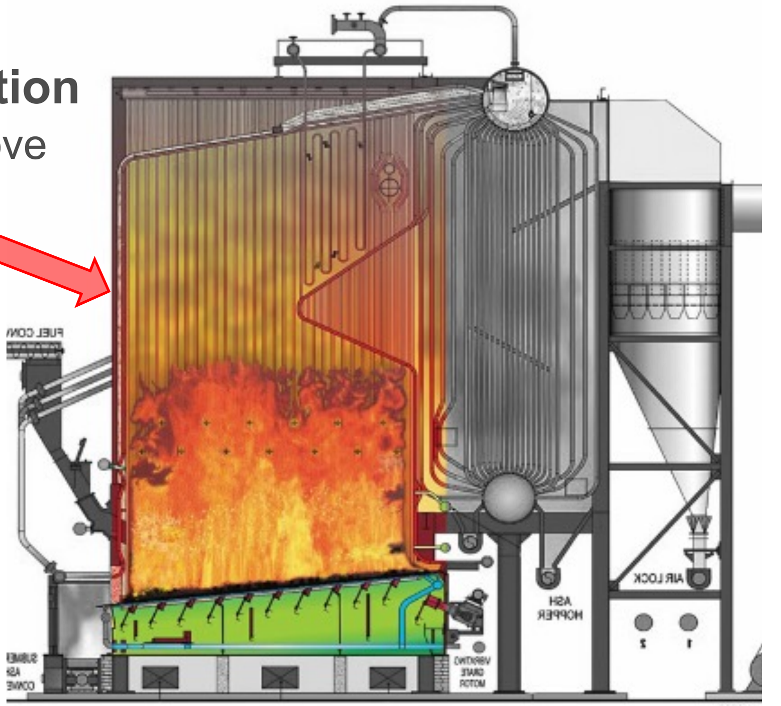
SNCR Injection Ports … above flames



Optimum SNCR Temps = 850°C to 1050°C

- BBs will quickly drop below 850°C

SNCR Injection Ports … above flames



ICM's Dual M-300 Gasification System

Applications for Biochar and CHP Systems

ICM’s 1st Dual M-300 and CHP System

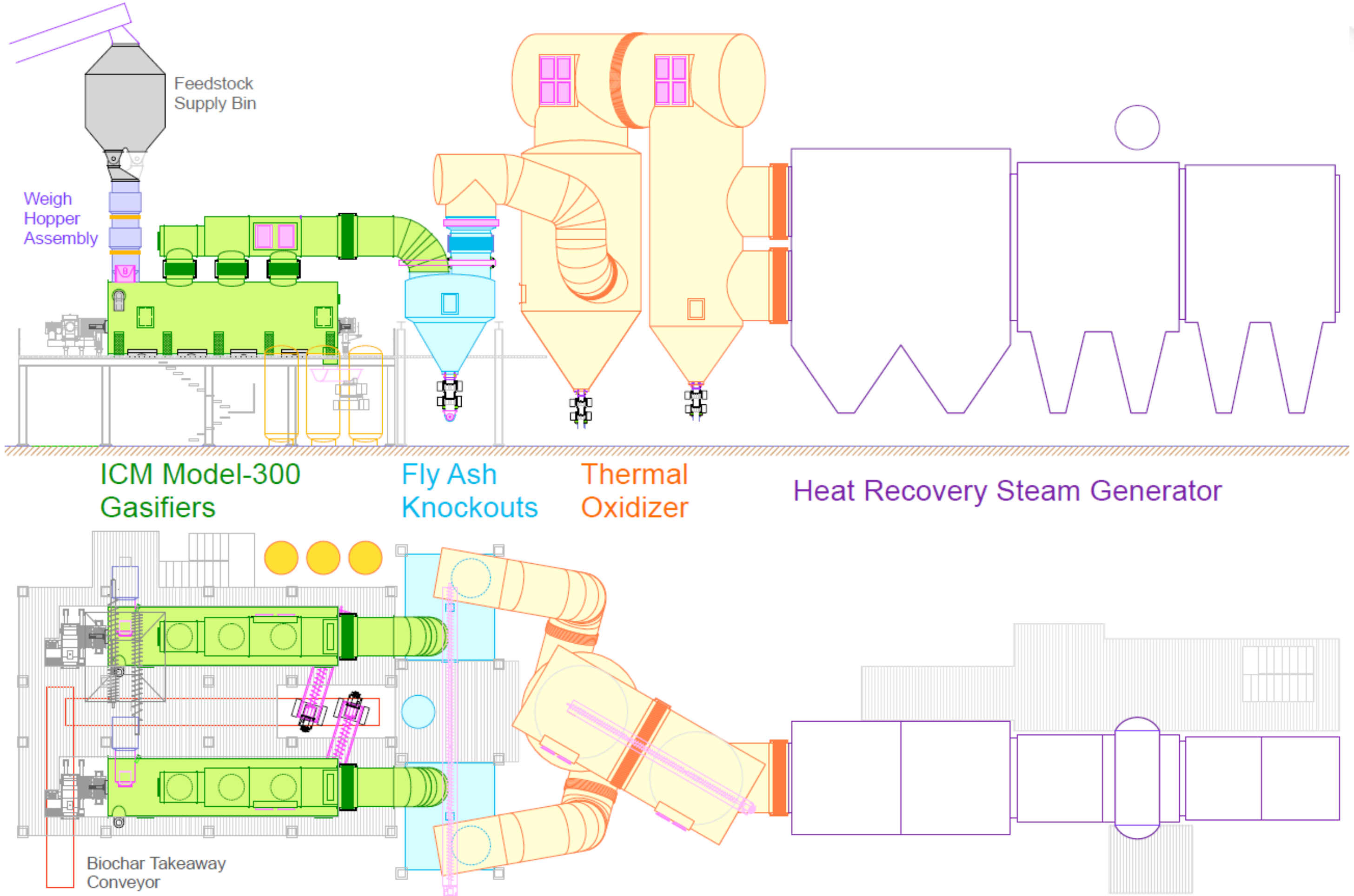
- Bio-refinery located in Colwich, KS
- Up to 70% natural gas offset in the HRSG
- Biomass gasification design capacity up to 350 mt/day
- Co-generation of power: 7 MW$_{el}$
- 61,200+ kg/h of MP steam to plant
- Commissioned in 2020

ICM's 2nd Dual M-300 Project in Progress

BIOCHAR and CHP

- Location: Pacific NW
- 590 mt/d Throughput of Woody Biomass
- 110 mt/d Biochar Production
- Co-Production of 18 MW_{el}

- Preliminary Engineering Contract Completed
- Detailed Engineering Starting Soon

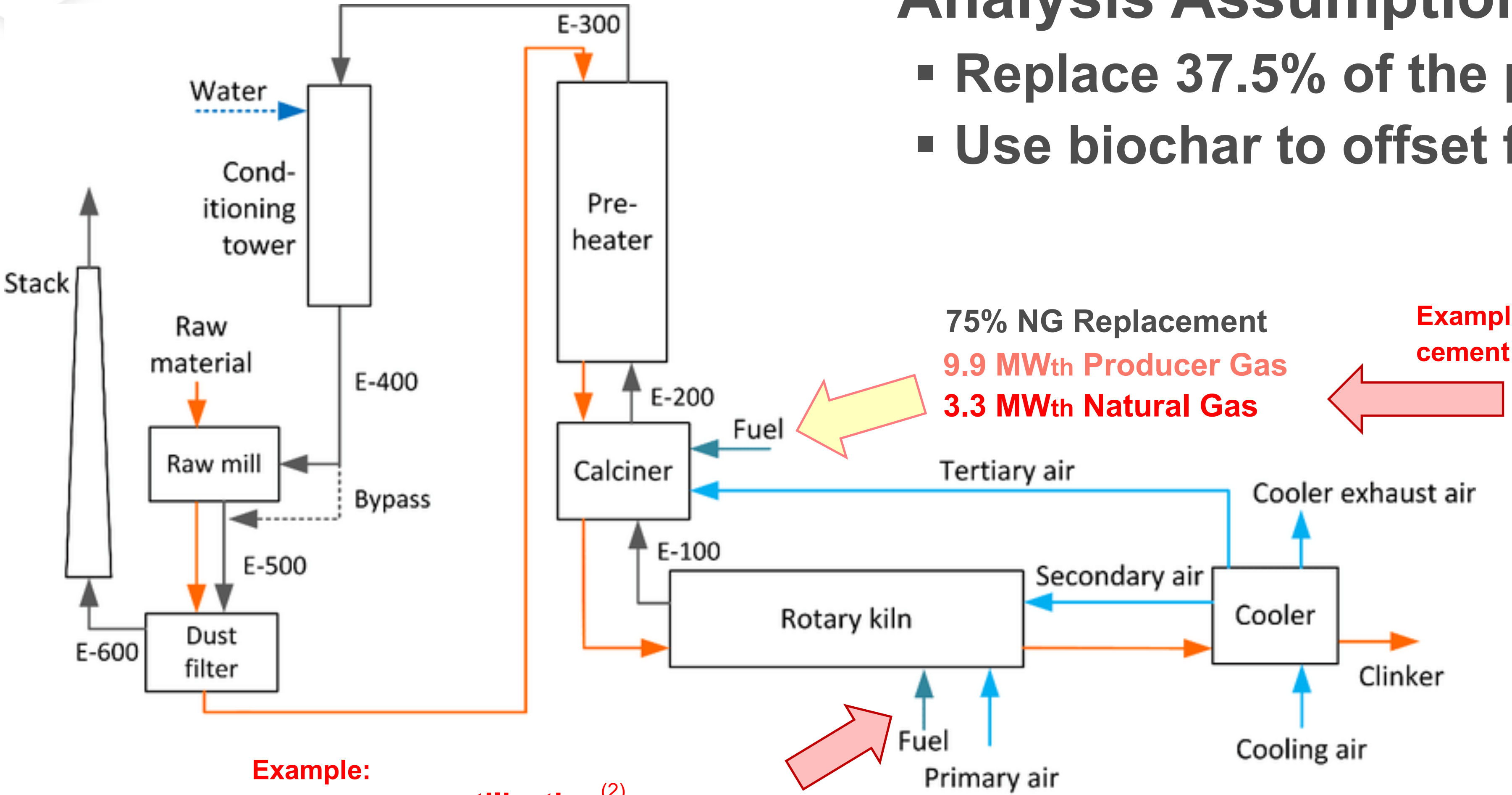


OTHER POTENTIAL APPLICATIONS

- Cement Plants
- Municipal Wastes
- Biochar, CHP and Renewable Chemicals

Offset Fossil Fuel Carbon at Cement Plants

Cement Plant Block Diagram (1)



Analysis Assumptions:

- Replace 37.5% of the plant's NG Usage
- Use biochar to offset fossil fuel carbon

75% NG Replacement

9.9 MWth Producer Gas

3.3 MWth Natural Gas

Example:
cement calciner NG utilization(2) = 13.2 MWth

Example:
cement kiln NG utilization(2) = 13.2 MWth

(1) Anantharaman et.al., 2015. CEMCAP Framework for Comparative Techno-Economic Analysis of CO_2 Capture from Cement Plants

(2) Personal Communications with a Senior Process Engineer working in the Cement Industry

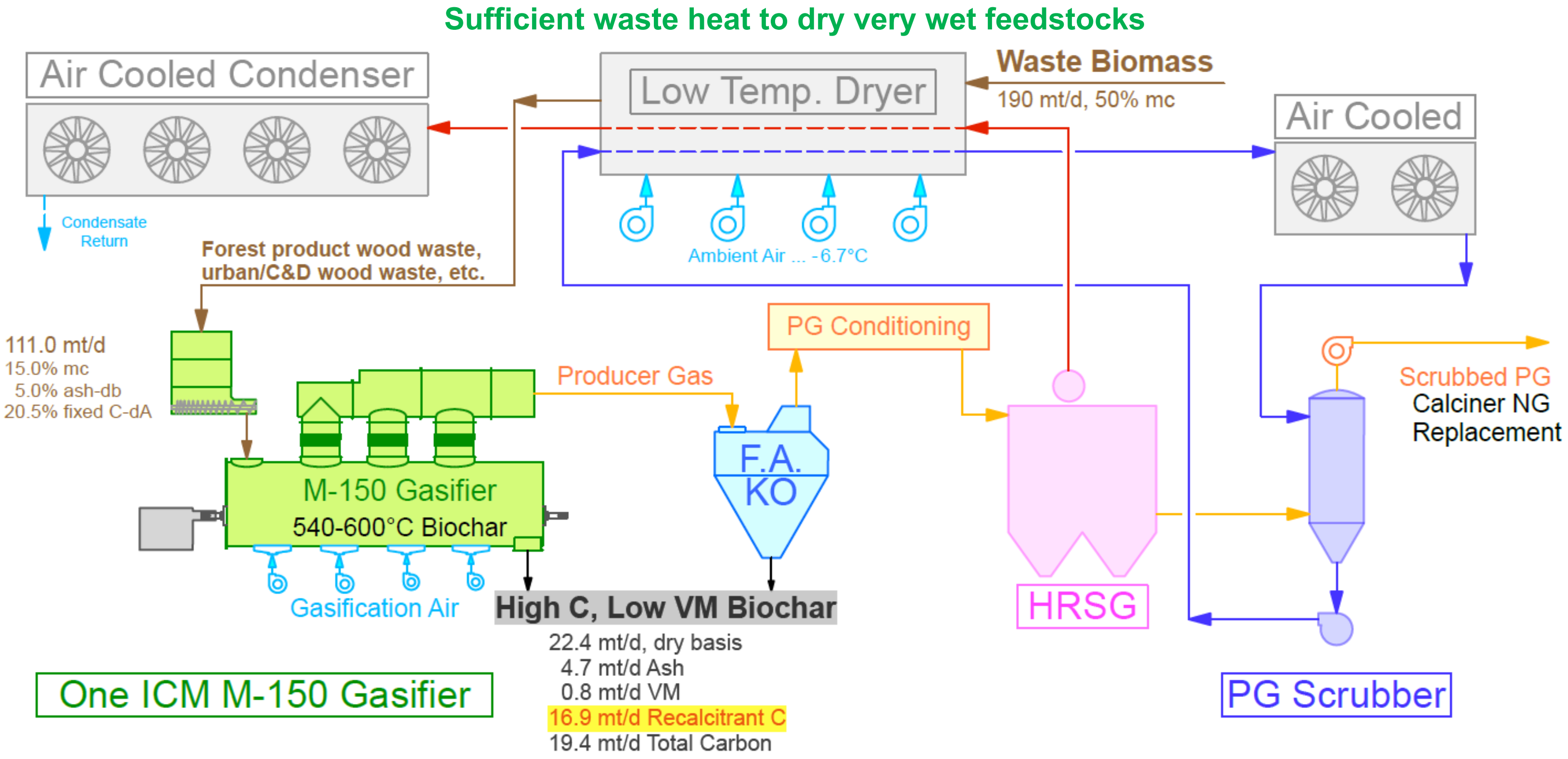
Offset Fossil Fuel Carbon at Cement Plants

RESULTS … Replace 37.5% of the plant's NG Usage

- 16.5 MW_{th} of natural gas (HHV basis) = 71.6 mt CO_2/d
- Offset with 16.9 mt/d recalcitrant carbon = 62.0 mt CO_{2e}/d

~87% Fossil-C Offset

(rotary kiln and calciner fuel use only)



Greater Offsets are Possible!

- Produce and place high VM biochars in permanent storage

Municipal Wastes to Char and CHP

Urban Waste Biomass + Refused Derived Fuel (from MSW) + Biosolids

Urban Waste Biomass

- **200 mt/d** (dry matter)
- **98 mt/d biogenic carbon**
- Woody biomass from C&D, waste pallets, palm fronds etc.

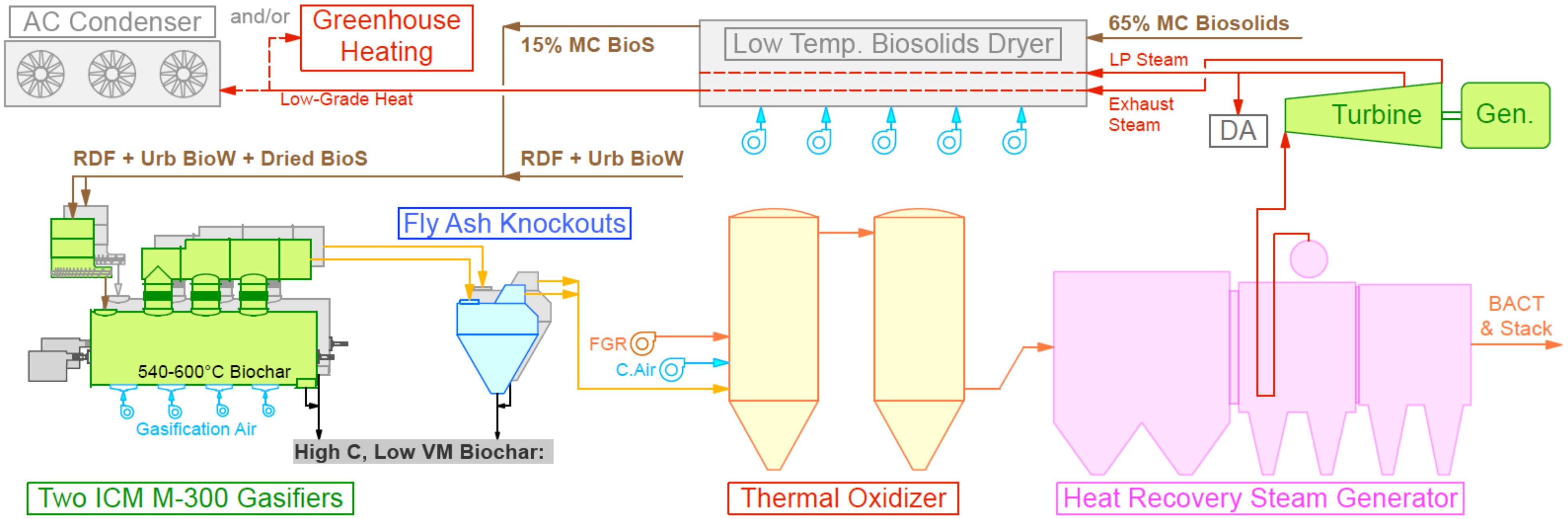
Refused Derived Fuel (from MSW)

- **200 mt/d** (dry matter)
- **39 mt/d biogenic carbon**
- **60 mt/d fossil carbon**

Biosolids

- **39 mt/d** (dry matter)
- **13 mt/d biogenic C**

Gasification-CHP from 544 mt/d of Urban Waste



Municipal Wastes to Char and CHP

Urban Waste Biomass + Refused Derived Fuel (from MSW) + Biosolids

Biochar Offsets the non-biogenic carbon in the RDF

BioChar Production

- 105.4 mt/d, dry
- 60.0 mt/d, R-C
- 42.9 mt/d, Ash
- 2.5 mt/d, VM

Carbon Neutral RDF Fuel Utilization

- 60.0 mt/d, R-C

offsets

- 60.0 mt/d, fossil-C

Renewable Electrical Power Generation Offsets Fossil Fuel Carbon

Electrical Power Generation

Net to Grid

13.7 MW_{el}

Annual* Fossil Fuel Carbon Offset

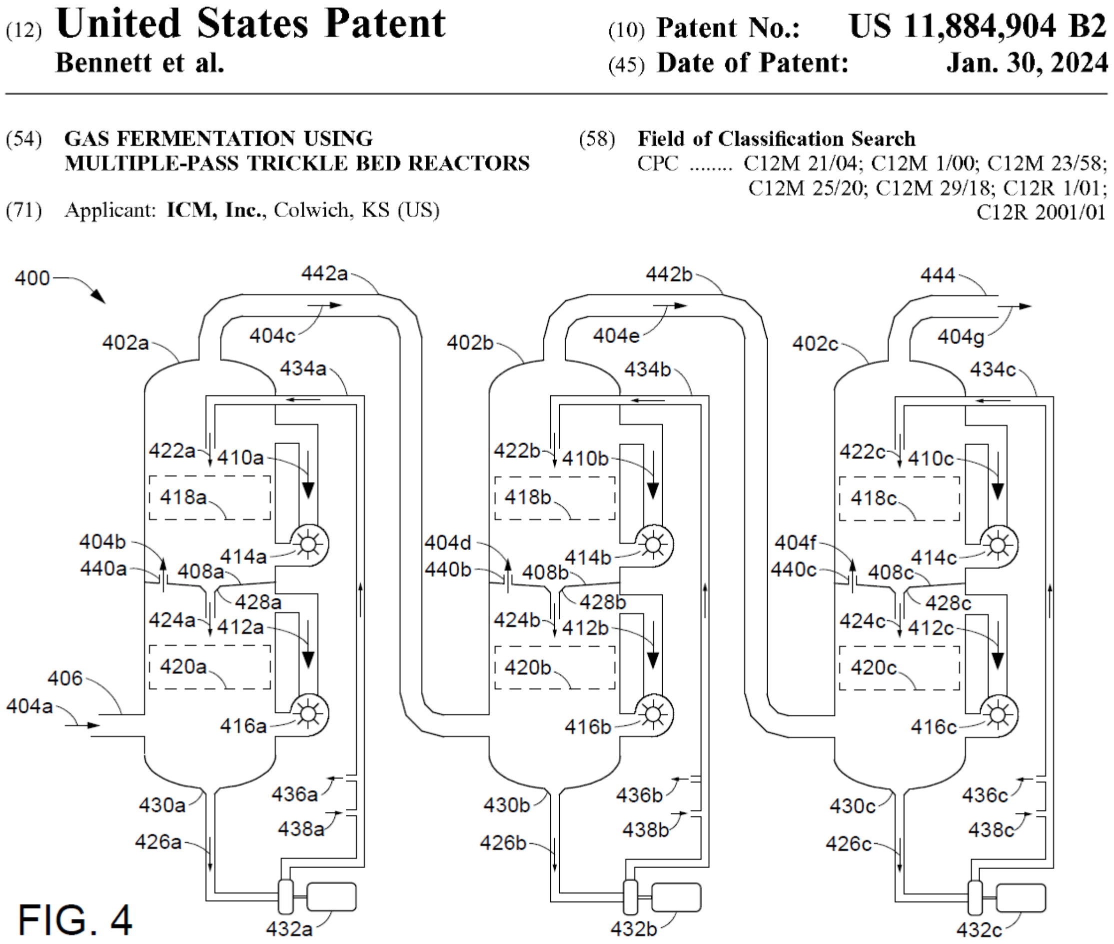
Natural Gas	47,740 mt $CO_{2}e$
Petroleum	117,740 mt $CO_{2}e$
Coal	113,200 mt $CO_{2}e$

* 330 days operation per year

Another Benefit - Landfill Methane reduction by keeping urban biomass & RDF out of landfills

BioChar, BioEnergy and Renewable Chemicals

Still in R&D Phase and Not Ready For Commercial Deployment



(12) **United States Patent**
Bennett et al.

(10) **Patent No.: US 11,884,904 B2**
(45) **Date of Patent: Jan. 30, 2024**

(54) **GAS FERMENTATION USING MULTIPLE-PASS TRICKLE BED REACTORS**

(71) Applicant: **ICM, Inc.**, Colwich, KS (US)

(58) **Field of Classification Search**
CPC C12M 21/04; C12M 1/00; C12M 23/58; C12M 25/20; C12M 29/18; C12R 1/01; C12R 2001/01

FIG. 4

- ○ **Fermentation and Renewable Chemicals**
  - Microbes are amazing, and highly adaptive
- ○ **MP-TBRs Operate at ATM and Low temps**
  - Ideal for use with air-blown gasification
  - With very large operational energy savings
- ○ **Integration into Gasification based Biochar and CHP facilities**
  - Share existing facility infrastructure and significant CAPEX savings

Conclusions

- **Proven, Large Scale Gasification and Biochar Productions Technologies are Commercially Available**
- **Large Scales BOP Systems are Well Developed and Mature Technologies**
  - Feedstock Handling, Processing and Storage Systems
  - Combined Heat and Power Systems
  - Industrial Scale Emissions Control Systems
    - And far lower emissions compared to 1000s of small unregulated biochar production systems

- **Large Scale = Very Large Capital Investments**
- **Challenging ROIs due to Low-Cost Energy in US**
- **1.5 to 2+ years to develop, plus lots of engineering, permitting, etc.**
- **Municipal Systems further challenged by community concerns over emissions, odors, etc.**
  - The good news is Gasification with Long-Residence Thermal Oxidation is NOT incineration!

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THANK YOU

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Patented AGT - Advanced Gasification Technology

Patented Multiple-Pass Trickle Bed Reactors for Gas-to-Liquid Fermentation Processes

Patented Large-Scale, Rotating Drum Torrefaction Reactors

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