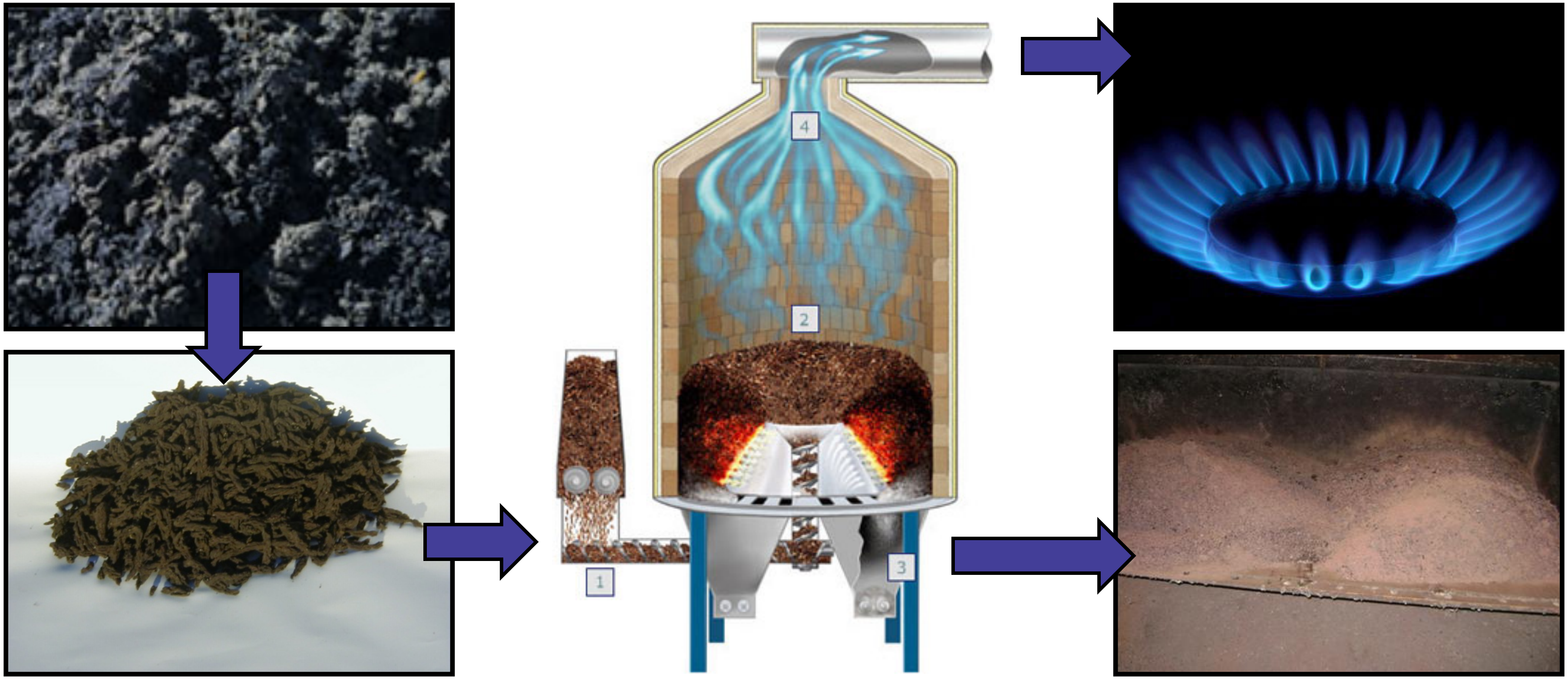
PNCWA 2012

Boise, ID

Gasification of Sludge and Biosolids – A Review of Technology Fundamentals and the Current Commercial Status

October 24 | 2012

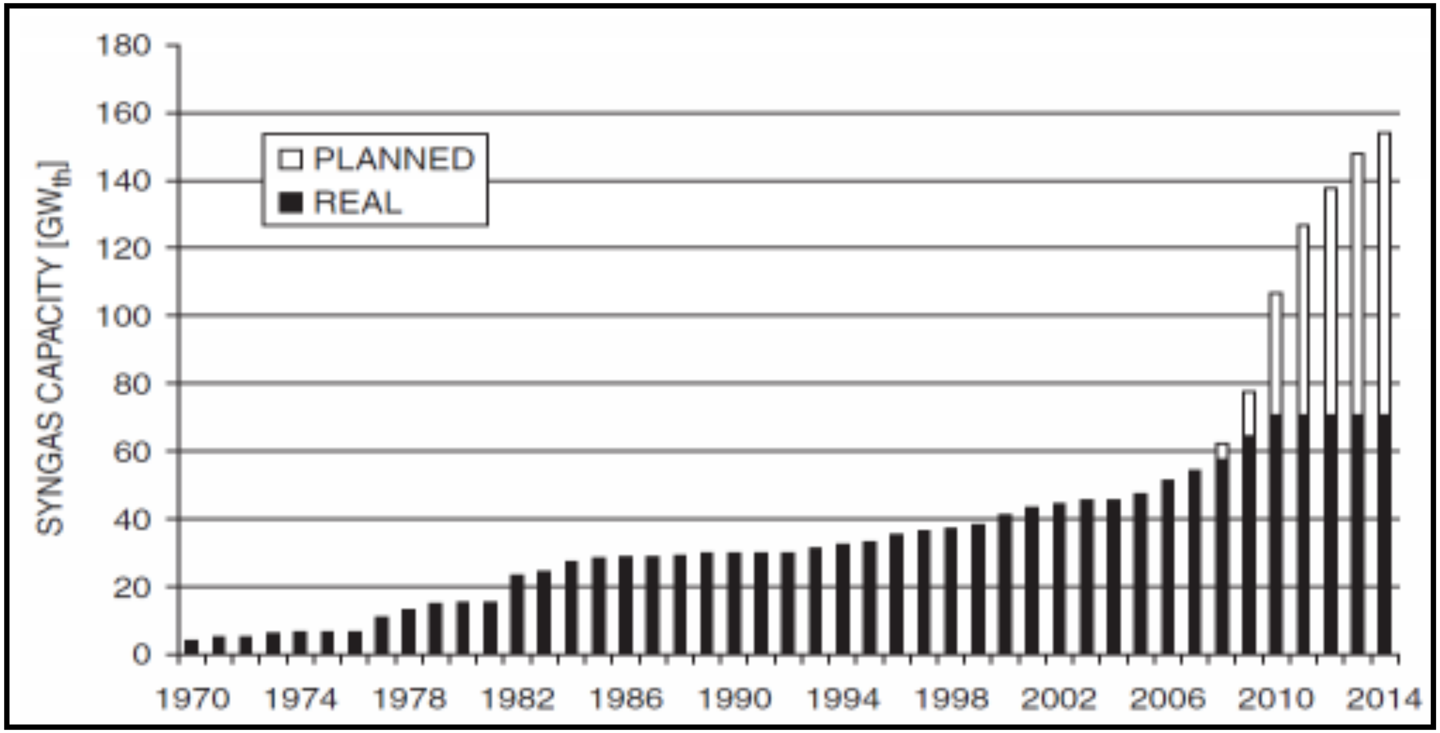


Agenda

- Background
- Process Fundamentals
- Types of Gasifiers
- Commercial Status
- Energy Balances
- Gasification Relative to Today’s Issues
- Summary

Background – History of Gasification

- Charcoal formation (pyrolysis)
  - Several thousand years old
- Gasification
  - Large scale use on coal in the 1800's; wood in 1900's
  - New focus → alternative feedstocks



EPA, U.S. (2012). Technology Assessment Report: Aqueous Sludge Gasification Technologies.

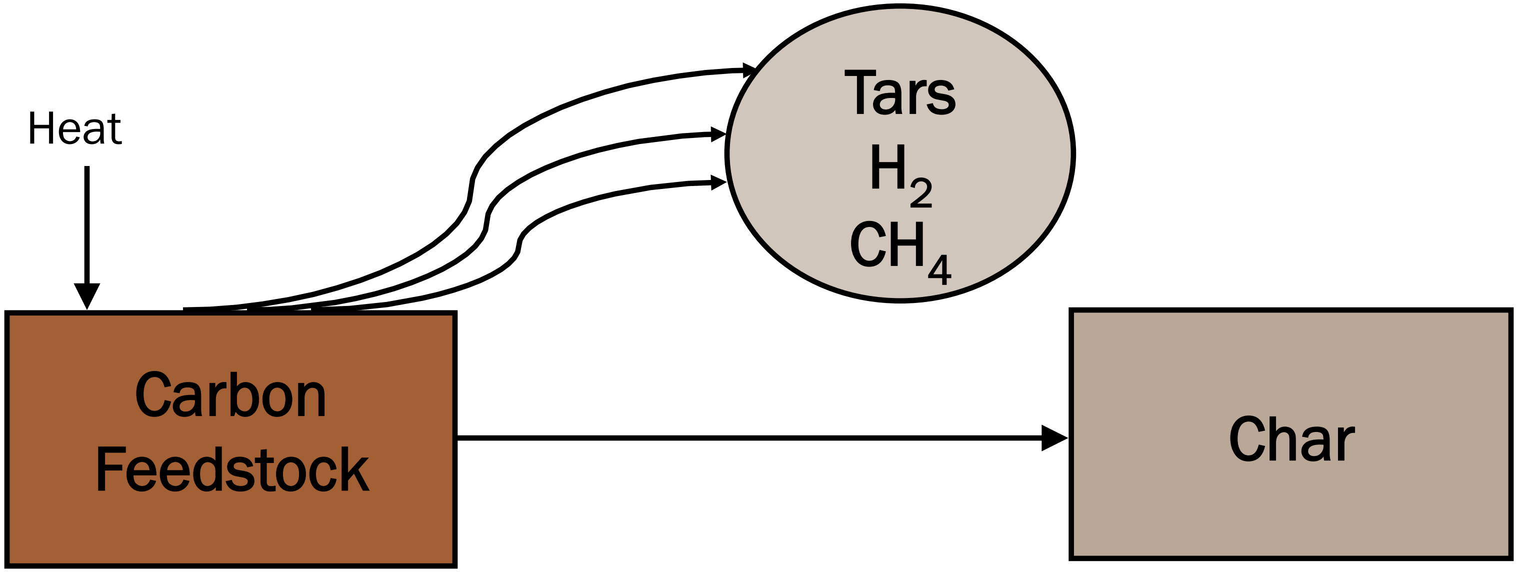
Process Fundamentals

General Steps

1. Drying
2. Pyrolysis (volatilization)
3. Combustion (oxidation)
4. Gasification (reduction)

Main Types of Gasifiers

- Fixed bed
- Fluidized bed



Pyrolysis Reactions

Reaction Pathways

Combustion (Oxidation) Reactions

$C + \frac{1}{2}O_2 \rightarrow CO$ ΔH = -111 MJ/kmol

$CO + \frac{1}{2}O_2 \rightarrow CO_2$ ΔH = -283 MJ/kmol

$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ ΔH = -242 MJ/kmol

Gasification (Reduction) Reactions

$C + CO_2 \leftrightarrow 2CO$ ΔH = +172 MJ/kmol

$C + H_2O \leftrightarrow CO + H_2$ ΔH = +131 MJ/kmol

$C + 2H_2 \leftrightarrow CH_4$ ΔH = -75 MJ/kmol

$CO + H_2O \leftrightarrow CO_2 + H_2$ ΔH = -41 MJ/kmol

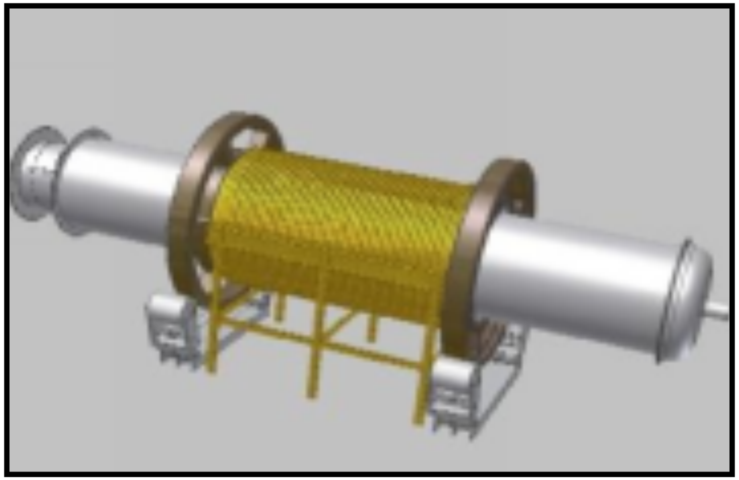
$CH_4 + H_2O \leftrightarrow CO + 3H_2$ ΔH = +206 MJ/kmol

Heating Methods

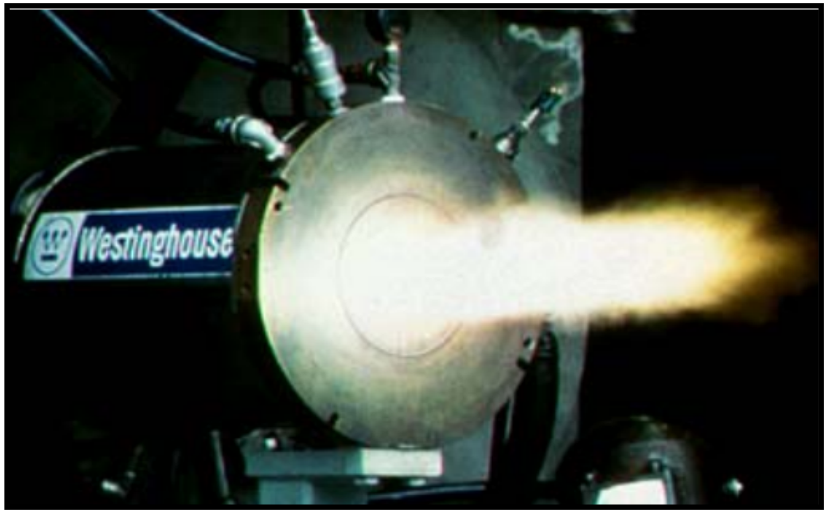
Feedstock Combustion:

$$\text{Char} + \text{Limited } O_2 \rightarrow CO_2 + CO + H_2O + \textbf{Heat}$$

External Heat Sources:



Induction Heater (Pyromex)

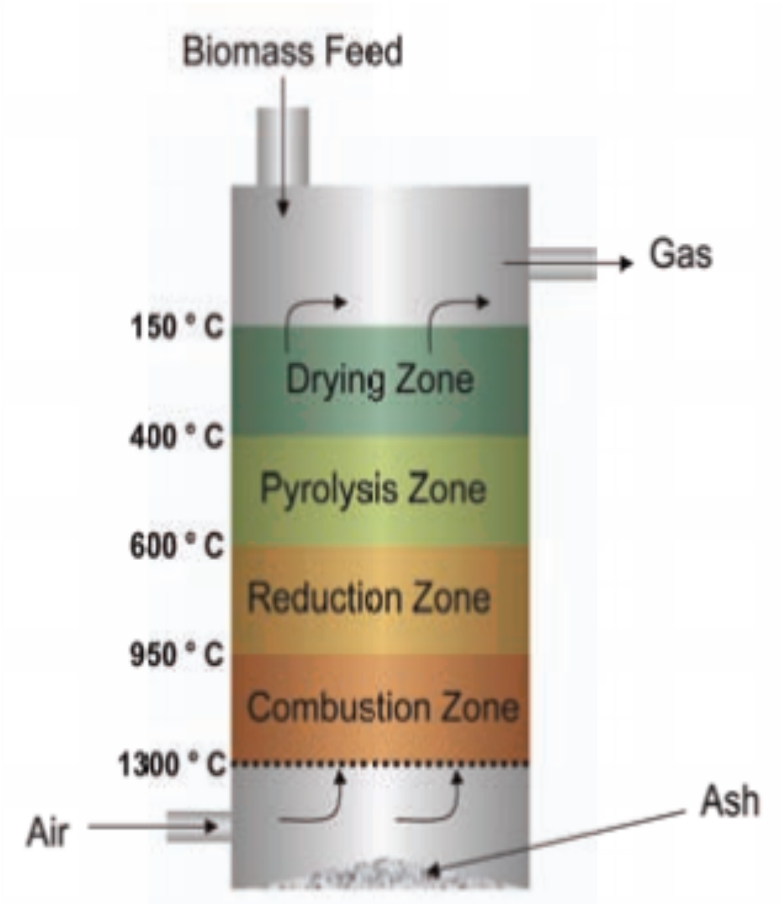


Plasma Torch (Westinghouse)

Technologies – Fixed Bed Gasifiers

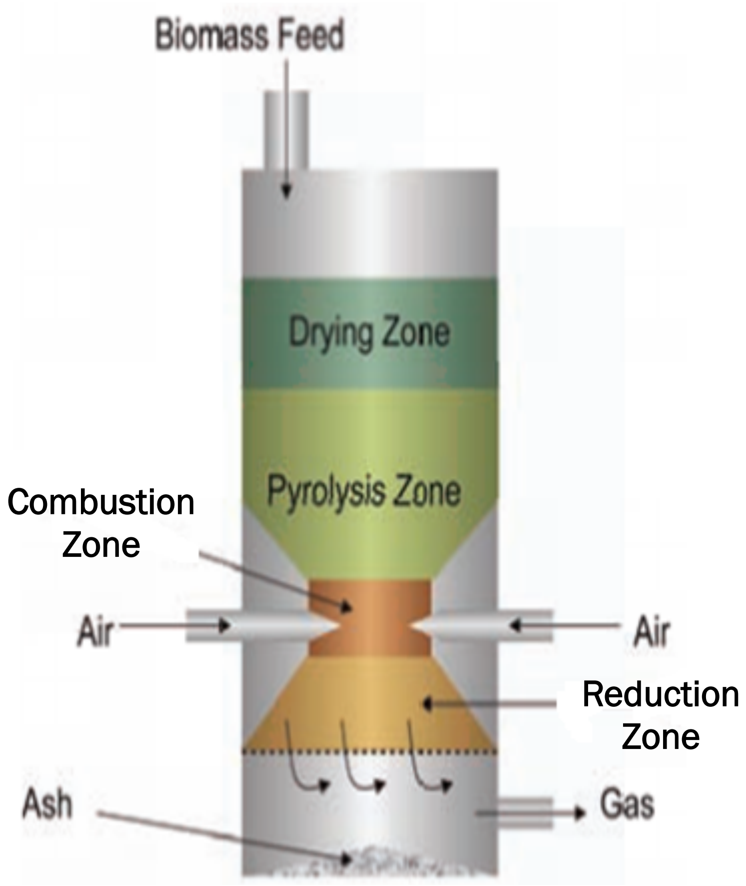
Updraft Gasifier

- Feed: 45-50% DS possible



Downdraft Gasifier

- Feed: >80% DS

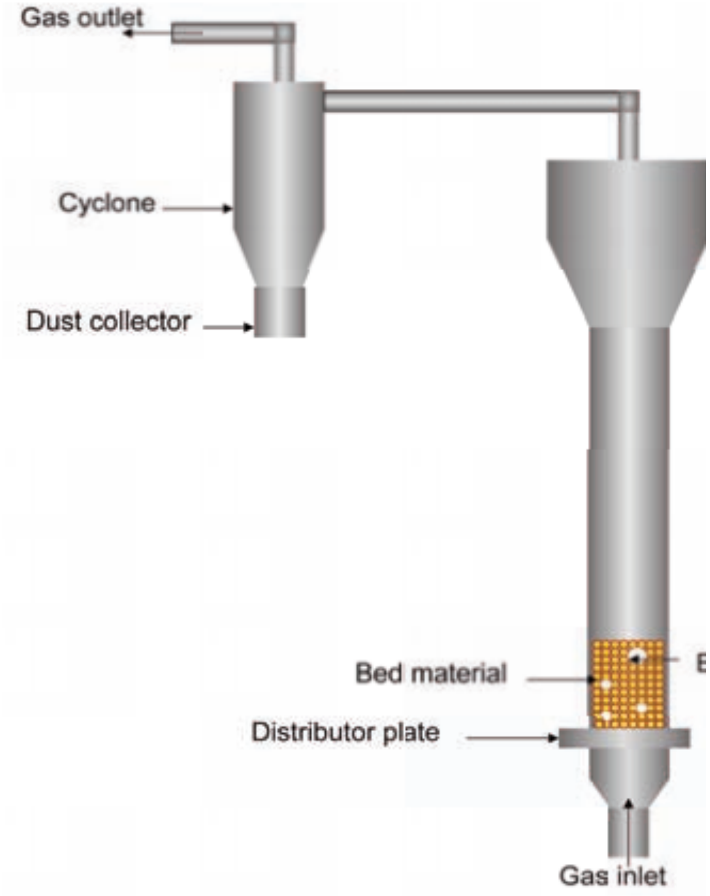


http://www.uaex.edu/Other_Areas/publications/publications_list.asp

Technologies – Fluidized Bed Gasifiers

Bubbling Fluidized Bed

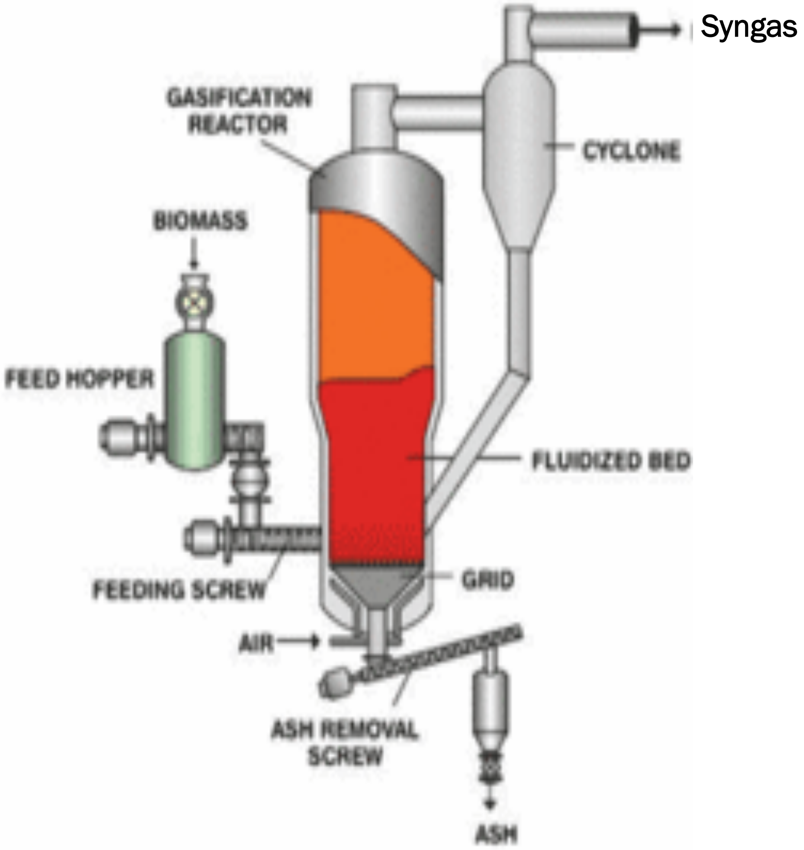
- Feed: >85% DS



http://www.uaex.edu/Other_Areas/publications/publications_list.asp

Circulating Fluidized Bed

- Feed: >85% DS



http://www.cospp.com/articles/print/volume-10/issue-1/features/danish-biomass-gasification.html

Feedstock Properties

- Prefer undigested sludge
- Higher volatile content and less ash preferred

Proximate Analysis of Various Biosolids Feedstocks

Parameter	"Typical" Undigested Sludge [1]	"Typical" Digested Sludge [1]	"Fresh Solids" [2]
Ash, %	25-30	40-50	5.5-8.5
Volatile, %	65-70	40-50	86.3
Fixed C, %	5-10	5-10	7.9
HHV, Btu/lb	6,500-8,500	3,000-5,500	7,500-8,000

Sources: 1. Stamford Waste to Energy Draft Report; 2. Gikas et al., 2011

Syngas Properties

- Low energy content
  - 100-130 Btu/ft^3 typical (air-blown)
  - Biogas ~550 Btu/ft^3
  - Natural gas ~950 Btu/ft^3
- Primarily CO and H_2
- Usually highly diluted with N_2
- Syngas conditioning required for use in a gas engine
- Thermal oxidation of syngas avoids gas cleaning

Example Syngas Composition (v/v)

Hydrogen = 9%
Carbon monoxide = 14%
Carbon dioxide = 20%
Methane = 7%
Nitrogen = 50%

Gasification vs. Incineration

Gasification	Incineration
Drying required as pretreatment step	Drying not required as pretreatment step
Designed to maximize feedstock conversion to CO and H_2	Designed to maximize feedstock conversion to CO_2 and H_20
Reducing environment	Highly oxidizing environment
Limited oxygen	Excess air

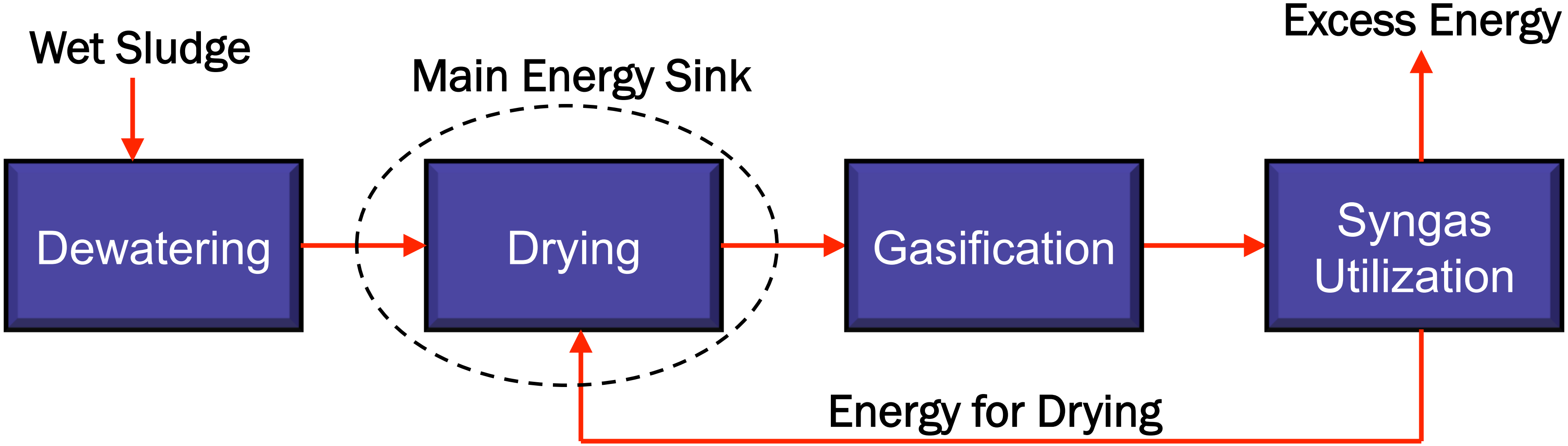
Biosolids Gasification Configurations

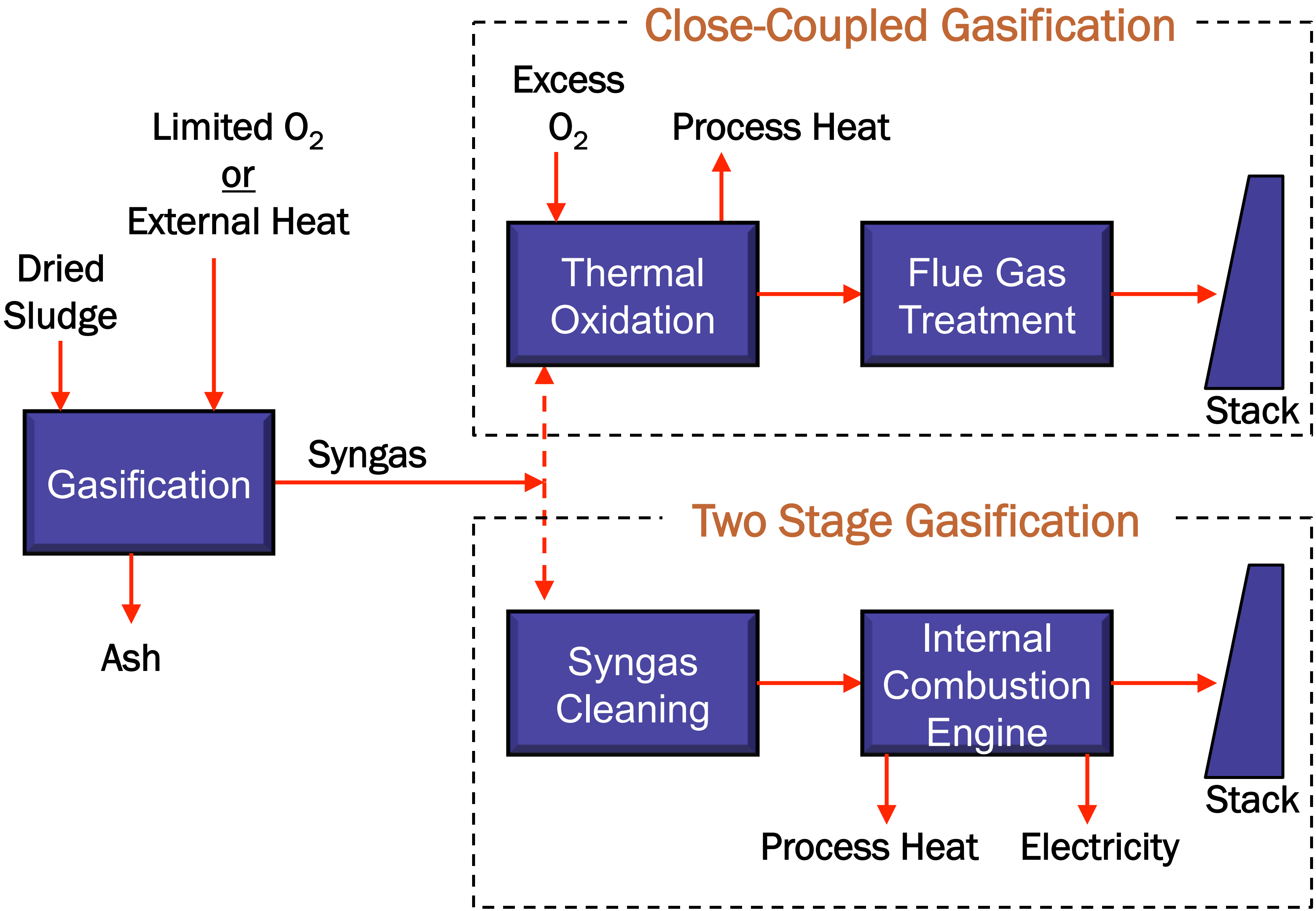
Two Stage Gasification

- Syngas cleaning
- Internal combustion engine
- Produce electricity and recoverable heat

Close-Coupled Gasification

- No syngas cleaning
- Syngas thermally oxidized
- Heat recovery and/or power generation from flue gas





Dried Sludge

Limited O_2
or
External Heat

Gasification

Ash

Syngas

Close-Coupled Gasification

Excess O_2

Process Heat

Thermal Oxidation

Flue Gas Treatment

Stack

Two Stage Gasification

Syngas Cleaning

Internal Combustion Engine

Stack

Process Heat

Electricity

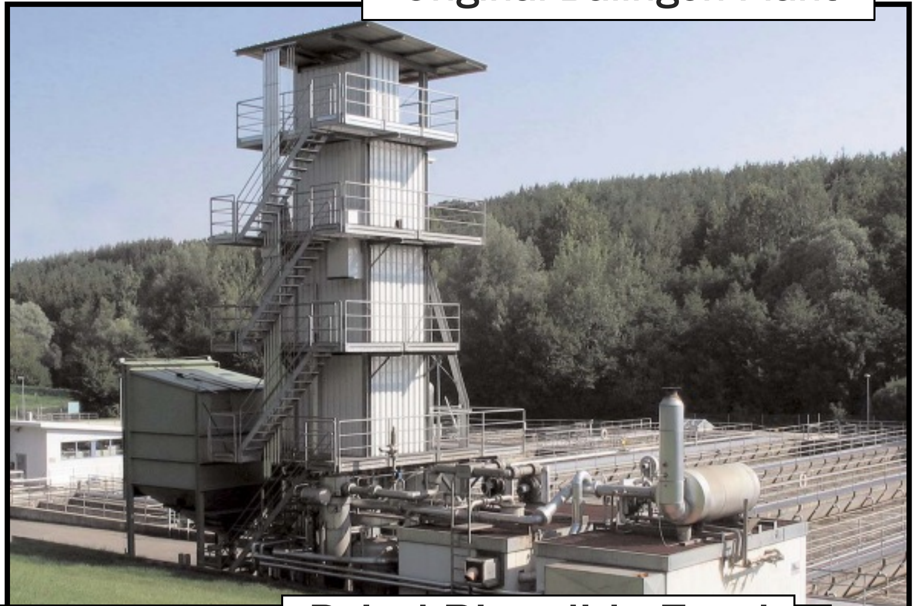
Commercial Status

- Biosolids gasification still in embryonic stages
- **Pilot-scale and demonstration facilities:**
  - M2R/Pyromex – Emmerich, Germany (trials in 2010)
  - Nexterra – Kamloops, BC (trials in 2009)
  - Primenergy – Tulsa, Oklahoma (trials in 2008)
  - Tokyo Bureau of Sewerage – Kiyose, Japan (2005-2006)
  - Stamford Biogas – Stamford, CT (2008)
- **Full-scale installations:**
  - Kopf – Balingen, Germany (2002-present)
  - Kopf – Mannheim, Germany (in commissioning phase)
  - MaxWest – Sanford, FL (September 2009-present)
  - Tokyo Bureau of Sewerage – Kiyose, Japan (July 2010-present)

Kopf Full-Scale Installations

- Capacity:
  - Balingen: 5.4 tpd
  - Mannheim: 13.7 tpd

Original Balingen Plant

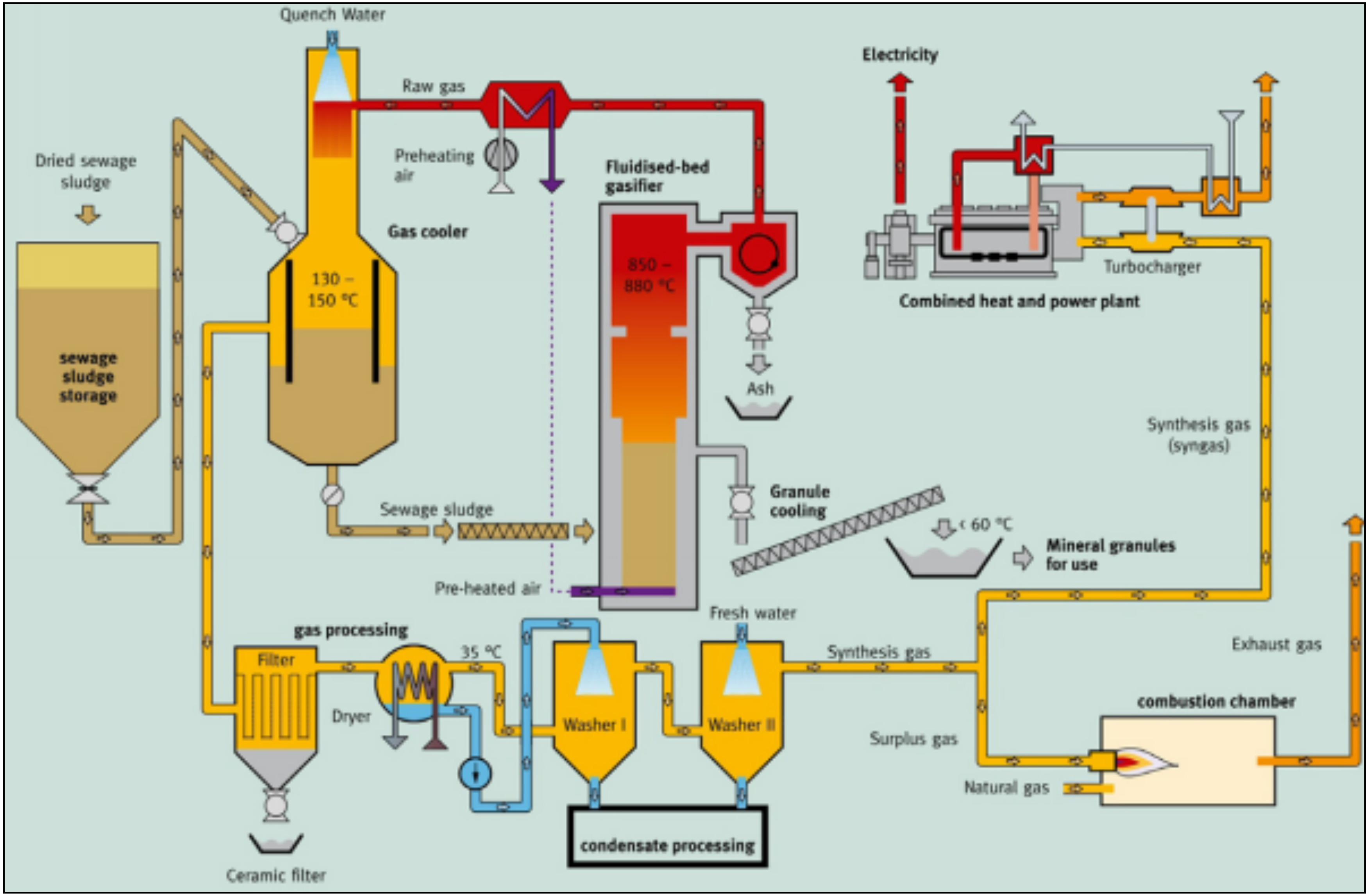


Rebuilt Balingen Plant

Dried Biosolids Feed

Photos courtesy of Kopf

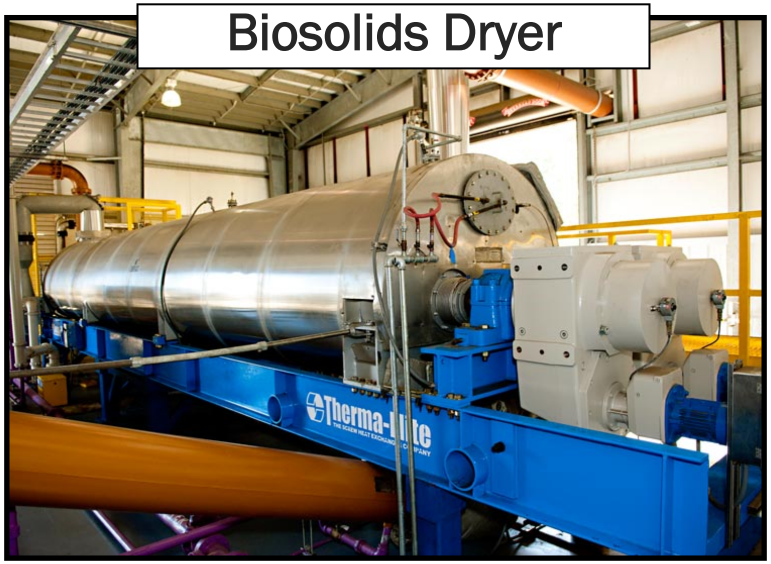
Process Diagram for Kopf Gasification Plant



MaxWest Full-Scale Installation

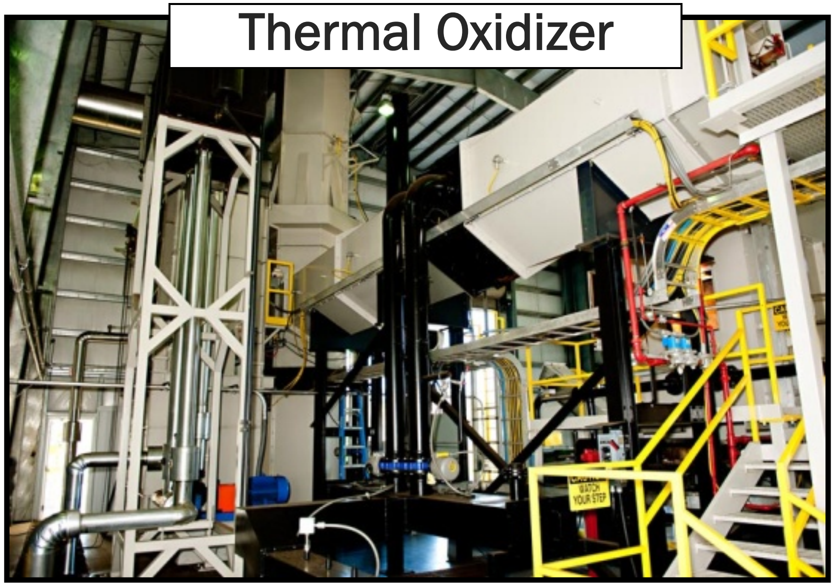
- Capacity: 80 tpd (wet)
- Owned and operated by MaxWest
- Dryer requires some supplemental natural gas

Biosolids Dryer



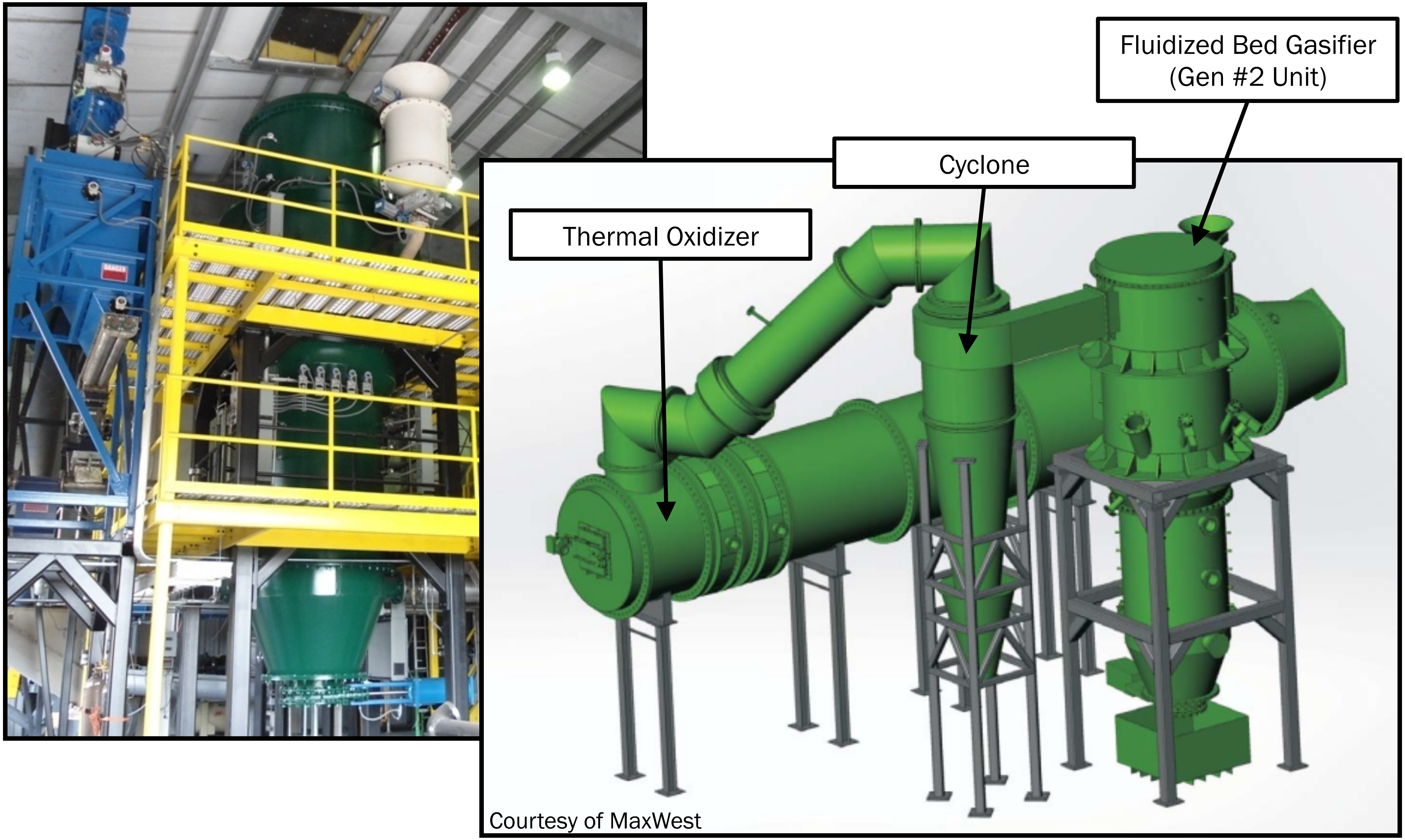
Updraft Gasifier (Gen #1 Unit)

Thermal Oxidizer



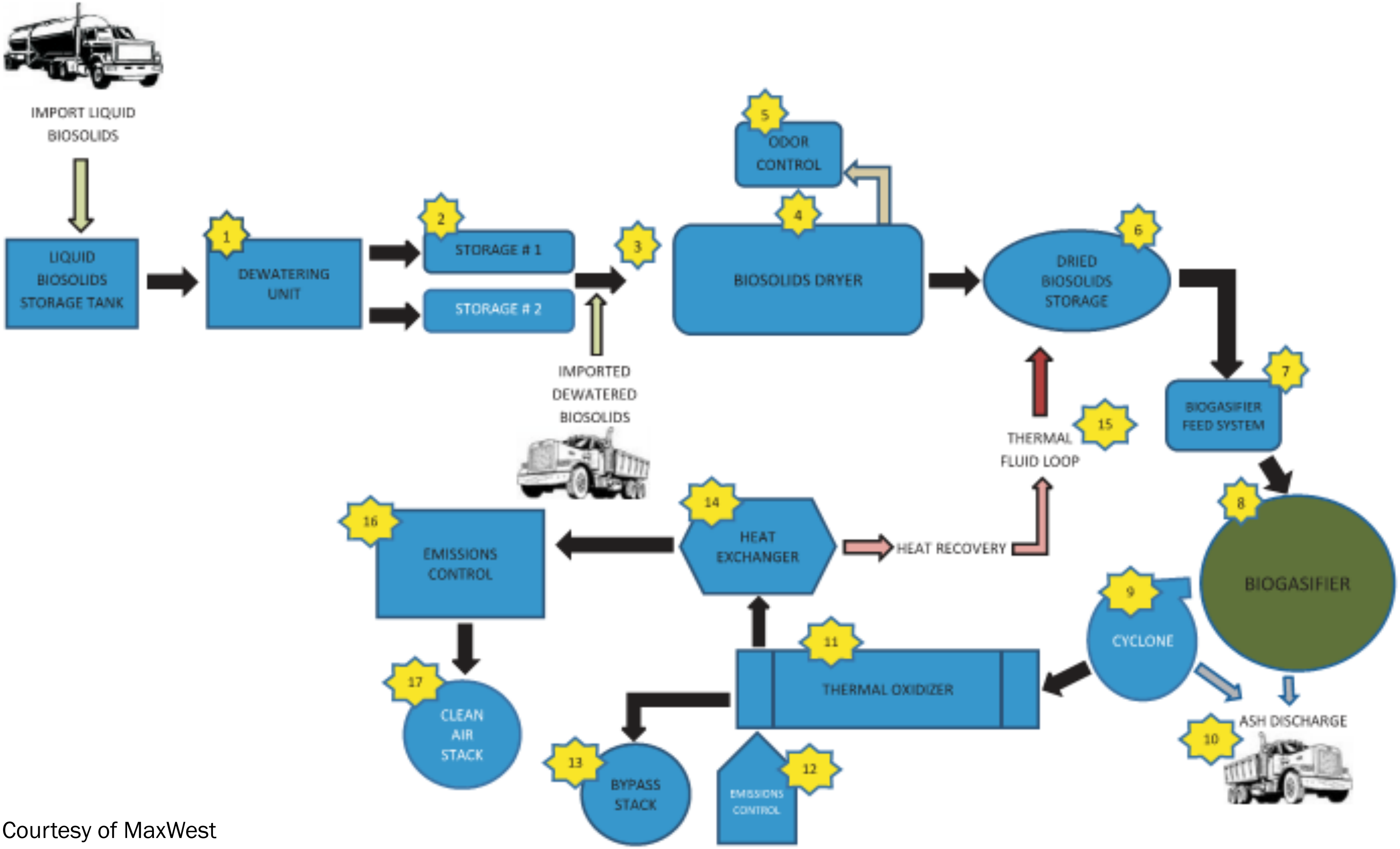
Photos Courtesy of MaxWest

Photos and Schematics of MaxWest System



Courtesy of MaxWest

Sanford Facility Process Flow Diagram



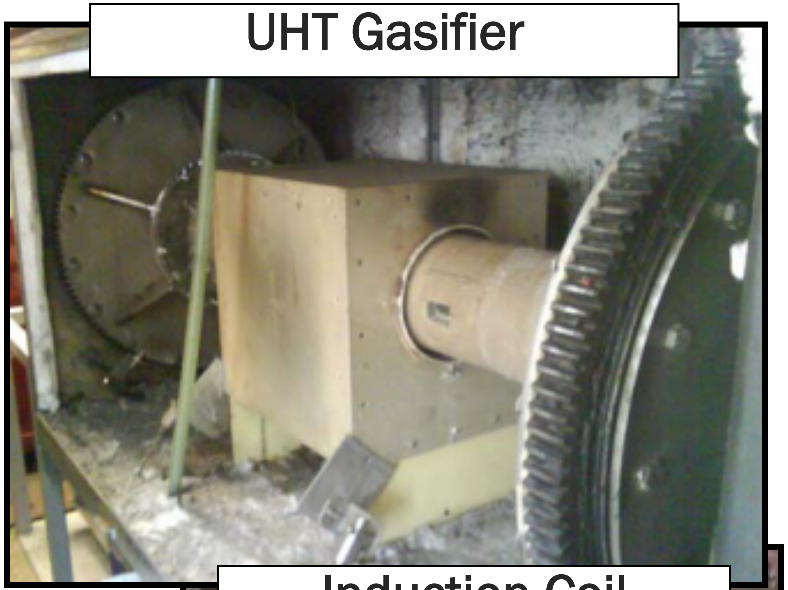
Courtesy of MaxWest

Staffing Requirements

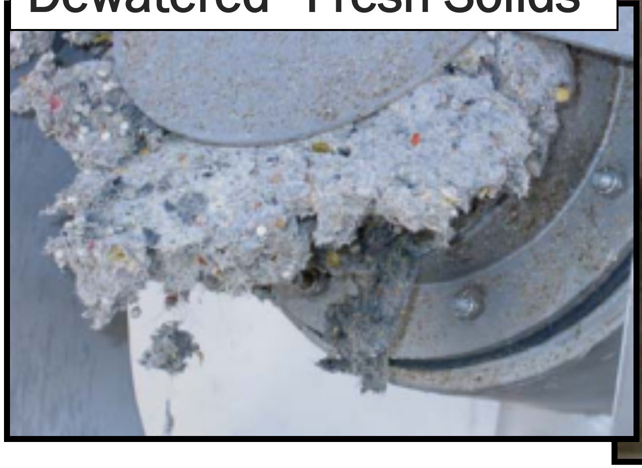
- Sanford facility staffing requirements
  - 6 full-time operators
  - Plant manager and administrator
  - Owned and operated by MaxWest
- Now offering gasification equipment as capital sale
- Typical installed cost in the range of $7-10M

M2R/Pyromex Demonstration Unit

- 1 tpd demonstration unit
- Solids from raw wastewater screening (after headworks screens)
  - "Fresh solids" from 200-350 µm fabric screen filter
- "Ultra-high temperature gasification"
  - ~1150°C
  - No oxygen


UHT Gasifier


Induction Coil


Dewatered "Fresh Solids"

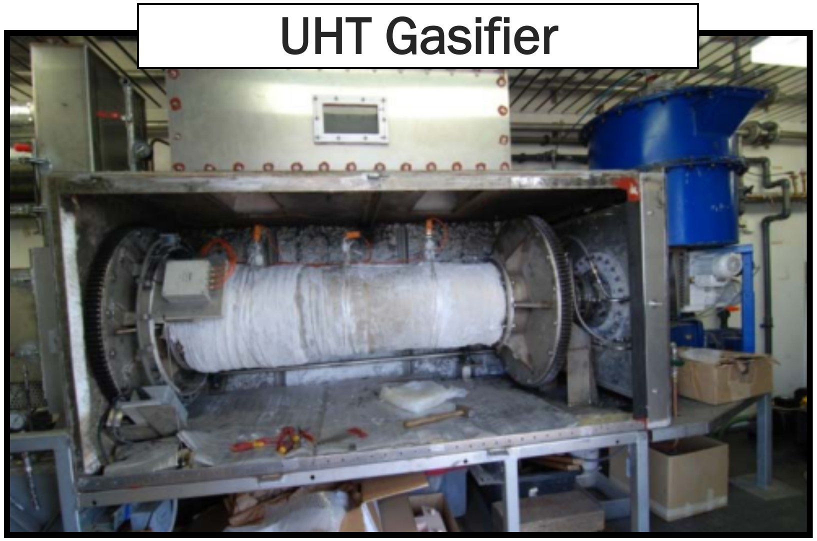
Gikas et al., 2011

Syngas from "Fresh Solids"

- Trials with solids from Adelanto, CA WWTP
- January and June of 2010
- Syngas properties
  - $CO = 31.5\%$
  - $H_2 = 49.2\%$
  - $CH_4 = 7.73\%$
  - $CO_2 = 3.20\%$
  - 8.83% "unidentified gases"

Rotary Fabric Fine Screen

UHT Gasifier



Gikas et al., 2011

Stamford, CT Waste to Energy Project

- High electricity costs
  - $0.18/kwh
  - City identified need for up to 15 MW additional power
- Proposed gasification system to generate electricity
  - 25 tpd (dry) facility
  - Produce 1-3 MW of electricity from syngas
- 2007 - Thermal drying facility constructed
- Pilot gasification facility
  - Trailer mounted fixed-bed updraft gasifier (0.53 tpd)
- 2008 to 2009 - Full-scale trials with three vendors
  - Primenergy, Nexterra, Kopf

Stamford Pilot Gasifier

- Gasification pilot donated to UCONN for research in March 2012…

Trailer Mounted Gasification Pilot

Fixed-bed Updraft Reactor

www.stamfordbiogas.com/Kappe%20Gasification%20for%20SF.pdfSimilar

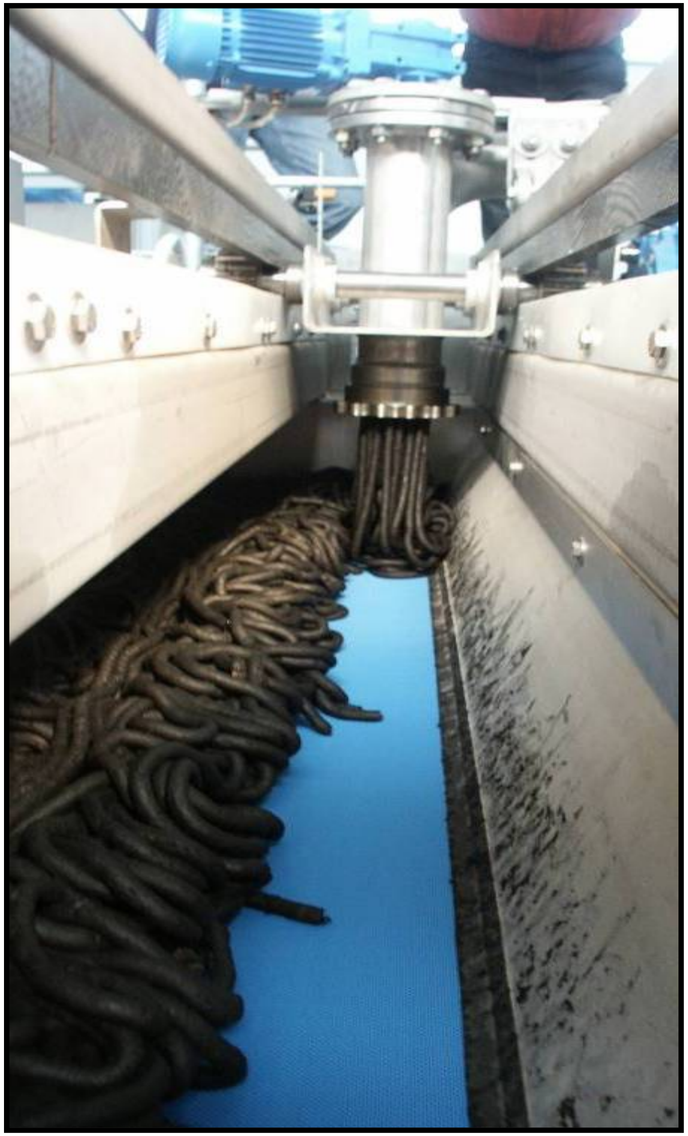
Stamford/Nexterra Current Status

- “The public balked at the project's $40 million price tag, and the WPCA board voted to kill the venture in early 2010 after losing faith in its technical and economic feasibility.”

  Read more: http://www.stamfordadvocate.com/news/article/Waste-to-energy-remnant-donated-to-UConn-3431002.php#ixzz2AAK4RDIv

Energy Balance Considerations

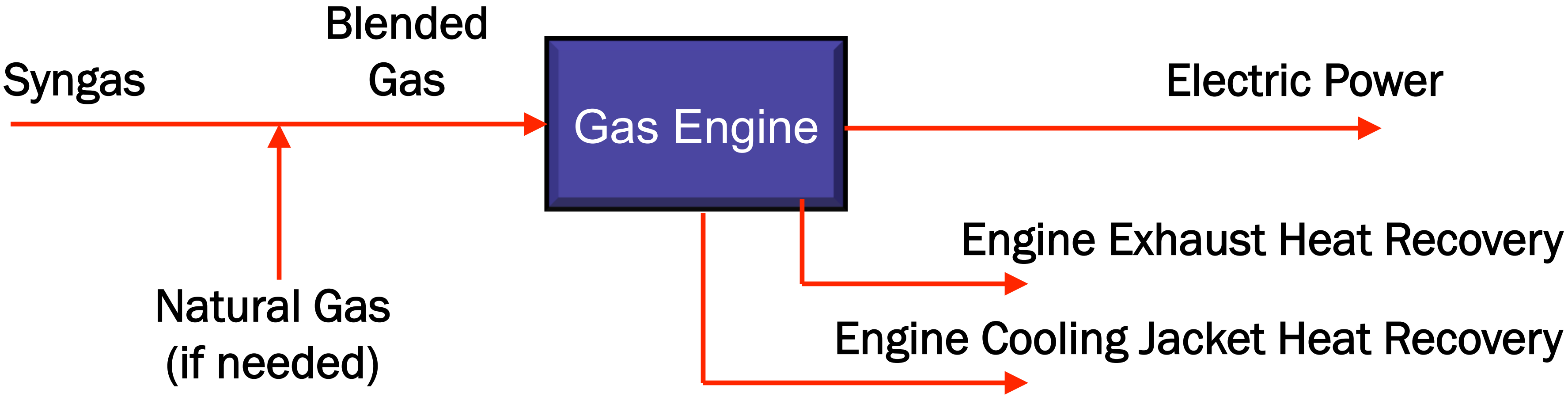
- Net Energy = Energy Outputs – Energy Inputs
- Main energy outputs
  - Electric power
  - Heat
- Main energy inputs (parasitic loads)
  - Dryer
  - Blowers
  - Gasifier startup
  - Gasifier external energy needs
    - Induction heater, plasma torch, etc.
  - Syngas cleanup



Courtesy of Huber

Power Generation Options

- Fuel cells – not currently used with syngas
- Gas turbines – require minimum heating value of 450 Btu/ft^3 and pressurization of syngas
- Internal combustion engines – possible
  - Requires minimum heating value of ~140 Btu/ft^3
  - Still may need to blend with natural gas



Energy Required for Drying

- Thermodynamics
  - Typically 1,400-1,700 Btu/lb of water evaporated
- Heat sources:
  - Natural gas, methane, propane, electric power
  - Recovered heat, waste heat
  - Solar

25 dtpd gasification + thermal oxidation system could yield approx. 8-10 MMBtu/hr

For a 25 dtpd drying facility:

Scenario	Energy Required (MMBtu/hr)	Natural Gas Cost ($/yr)	Power Cost ($/yr)
15% Solids Feed	17.4	$1,181,000	$2,006,000
20% Solids Feed	12.2	$827,000	$1,404,000
25% Solids Feed	9.0	$614,000	$1,043,000

Assumes 1,500 Btu/lb water evaporated, 90% dry solids product, natural gas = 1,030 Btu/cf, natural gas =$8/1000-cf, power = $0.045/kWh

Energy Balances Presented in Literature

- 5 tpd two-stage gasification system (~4-6 mgd WWTP)
- Energy balances **NOT** from actual full-scale operation

Air-Blown Gasifier [1]

- Net output = 165 kW
- Assumptions:
  - Syngas HHV = 190 Btu/ft^3
  - System parasitic load = 75 kW
  - Biosolids dried to 90% solids

M2R/Pyromex Gasifier [2]

- Net output = 295 kW
- Assumptions:
  - Syngas HHV = 338 Btu/ft^3
  - System parasitic load = 116 kW
  - Biosolids dried to 78% solids

- M2R also presented energy balances in recent paper for a hypothetical 20 mgd WWTP (Noll, 2012)
  - Claimed net electrical energy output of nearly 2:1 vs. anaerobic digestion

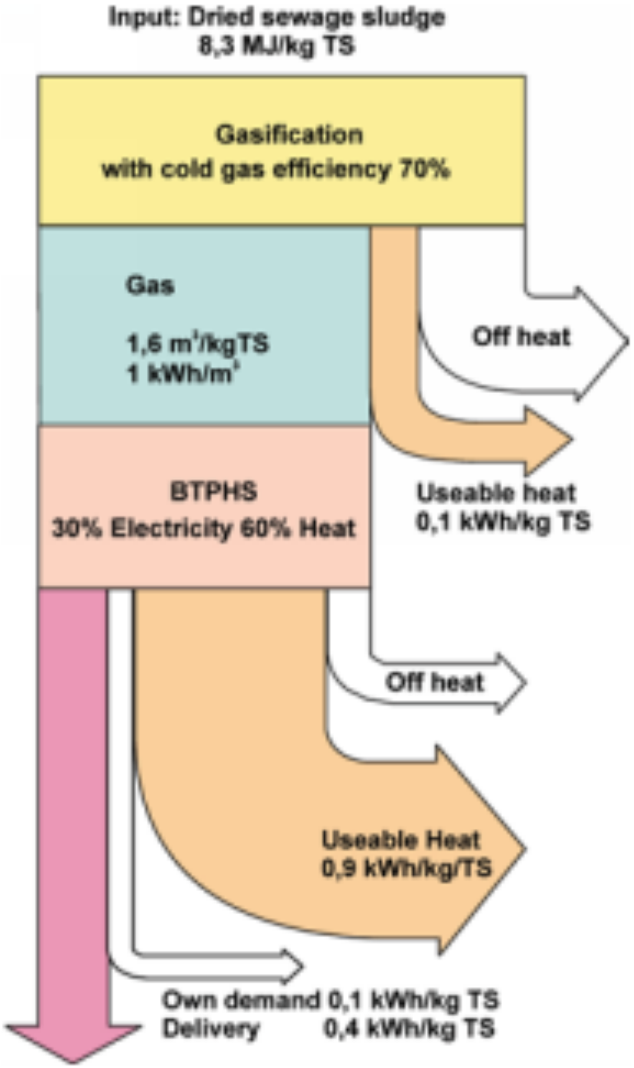
1. Source: US EPA, 2012; 2. Source: M2R Thermal Energy Conversion Brochure

Energy Balances Presented in Literature

- From Stamford Waste to Energy project report:
  - Biosolids feed rate = 3,695 lb/hr
  - Syngas production rate = 2,595 scfm
  - Syngas LHV = 117 Btu/scf
  - Quantity of syngas = 84,287 scf/ton-biosolids
  - Cold gas efficiency = 69.4%
  - Gross electric power production = 1,869 kW
  - Net electric power production = 1,623 kW
- Proposed facility footprint of 140’x100’
- Project killed due to cost and technical feasibility

Energy Balances from Operating Facilities

- Kopf – Balingen plant
  - Digested sludge
  - Equivalent to approx. 7.2 mgd
  - Original plant used solar drying
    - Produced ~70 kW of electric power
      - 15 kW needed for parasitic loads
      - ~55 kW net
    - Produced ~140 kW of thermal energy
      - Used to heat digesters at the WWTP
  - Rebuilt in 2006 – added belt dryer
    - Most of the gas now used for heating the belt dryer



Courtesy of Kopf

Energy Balances from Operating Facilities

- MaxWest facility in Sanford, FL
- Main goal is an energy-neutral system
  - Current input to dryer is 16% solids
  - Needs to be dried to 90% solids
  - Current system requires natural gas supplement for dryer
- According to MaxWest, achieving energy-neutral requires:
  - 23-25% solids feed depending on ratio of primary/secondary sludge

Economics of Two-Stage Sludge Gasification

- Economics largely dependent on electricity cost
  - Renewable energy tariff

Case	National Average Wholesale Electricity Rate	New England Average Industrial Electricity Rate + RE Tariff ($0.0435/kWh)
Electricity Cost, $/kWh	$0.042	$0.093
Tipping Fee, $/DT	$70	$70
Annual Operating Revenue, $	$41,624	$61,742
Annual Operating Cost, $	($36,995)	($41,551)
Capital Costs, $	($269,815)	($269,815)
CAPEX per kW, $/kW	$4,652	$4,652
Payback Years	21	7

Costs presented in USD per dry ton per day operating capacity; source: US EPA, 2012

Air Emissions Regulatory Requirements

- Currently no specific EPA regulations
  - Case by case basis
  - May be classified as incinerators
- Criteria air pollutants
  - Sulfur oxides (SOx)
  - Carbon monoxide (CO)
  - Nitrogen oxides (NOx)
  - Particulate Matter (PM)
- Hazardous air pollutants
  - Hydrogen chloride (HCl)
  - Dioxins and furans (chlorinated organics)

Air Emissions Data

Emission Limits in 40 CFR Part 60 – Final Rule for SSIs

Pollutant	Units	Existing FB SSIs	New FB SSIs	MaxWest Gen #1 [1]	MaxWest Gen #2 [2]
Cadmium (Cd)	mg/dscm	0.0016	0.0011	0.0000723	-
Carbon Monoxide (CO)	ppmvd	64	27	7.87	16.1
Hydrogen Chloride (HCl)	ppmvd	0.51	0.24	1.8	0.321
Mercury (Hg)	mg/dscm	0.037	0.0010	0.00798	-
Oxides of Nitrogen (NO_x)	ppmvd	150	30	432.17	15.4
Lead (Pb)	mg/dscm	0.0074	0.00062	0.000819	-
Dioxins/Furans	ng/dscm	0.10	0.0044	0.0285	-
Particulate Matter (PM)	mg/dscm	18	9.6	9.6	8.23
Sulfur Dioxide (SO_2)	ppmvd	15	5.3	4.17	0.0

1. Source: US EPA, 2012
2. Source: data provided by MaxWest

Gasification Relative to Today's Issues

Energy

? Potential for energy generation (depends on syngas quality)

- Drying required as a pretreatment step

- Heat recovery mostly used for drying

Emissions

+ Reduced relative to incineration

+ Lower air requirements

+ Reducing environment

Regrowth/Reactivation

+ Pathogens destroyed

+ No biosolids to dispose of

Resource Recovery

+ POTENTIAL P recovery from ash

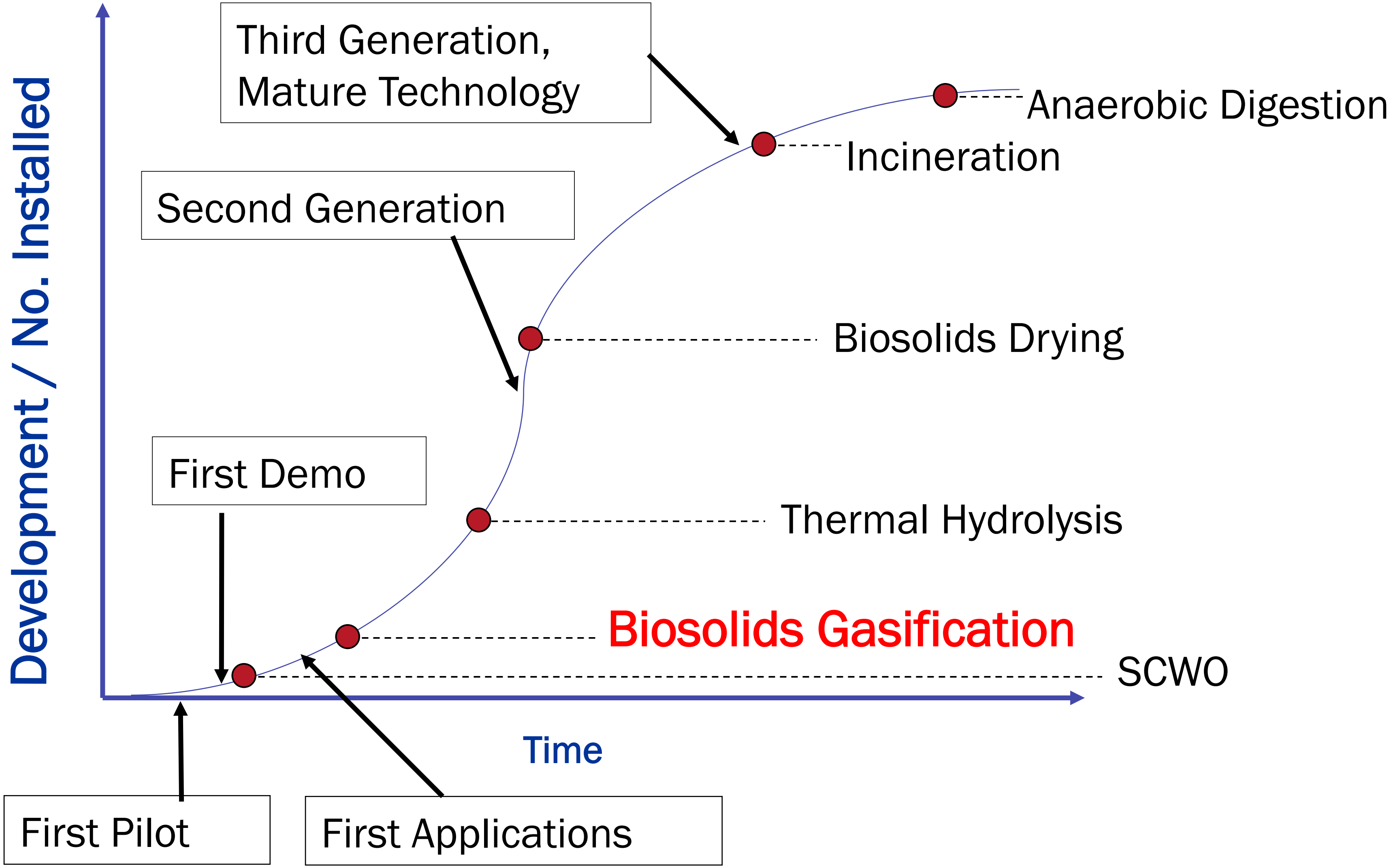
- No N recovery

Process Reliability

- Four full-scale installations worldwide

- One full-scale installation in North America

Be Aware of the Process Cycle History…



Questions?

Thank You!

Courtesy of Nexterra

Courtesy of Kopf

References

1. Judex, J., Gaiffi, M., Burgbacher, H. (2012). Gasification of dried sewage sludge: Status of the demonstration and the pilot plant. Waste Management, 32 (4), 719-723.
2. Gikas, P., Noll, S., Stedman, K. “Gasification of Primary Fine-Screened Solids for Energy Production,” Eurasia Waste Management Symposium, Halic Congress Center, Istanbul, Turkey, November 14-16, 2011.
3. Mountouris, A., Voutsas, E., Tassios, D. (2008). Plasma gasification of sewage sludge: Process development and energy optimization. Energy Conversion and Management , 49 (8), 2264-2271.
4. EPA, U.S. (2012). Technology Assessment Report: Aqueous Sludge Gasification Technologies. U.S. Environmental Protection Agency.
5. Noll, S. (2012). A Net Energy Comparison of Anaerobic Digestion vs. Ultra-High Temperature Gasification to Achieve Zero Energy, WEF Residuals and Biosolids 2012.
6. Li-ping, X., Tao, L., Jian-dong, G., Xue-ning, F., Xia, W., Yuan-guang, J. (2010). Effect of moisture content in sewage sludge on air gasification. J Fuel Chem Technol , 38 (5), 615-620.