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Garbage to Gold: The Alchemy of Wastefuel Utilization

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Outline

- **Opportunity streams**
  - Definition
  - Identification
- **Overview of oxygen enhanced combustion**
- **Commercial examples of oxygen enhanced combustion of "difficult-to-burn" streams**
  - Gases
  - Liquids (sludge)
  - Solids

Opportunity Streams

- **Characteristics of Opportunity Streams**
  - Difficult to burn with air
  - Poor flame stability with air
  - Low flame temperature with air
- **Gaseous fuels**
  - Byproduct streams with low heating value (high inert conc.)
  - Typically "sweetened" with high heating value (higher cost) fuels
- **Liquid fuels**
  - Difficult to atomize
  - Low heating value
  - Typically blended with higher heating value fuels
- **Solid fuels**
  - Low volatility solids
    - Pet coke
    - Anthracite coals
  - Typically blended with higher volatility (higher cost) fuels

Garbage or Gold?

- **Process Off Gas**
  - Medium heating value (> 300 Btu/scf)
  - Can be combusted with air
  - Provisions made to utilize these fuels
- **Process Tail Gas**
  - Low heating value (<300 Btu/scf)
  - Require “sweetening” with natural gas or higher value fuel to burn with air
  - Typically flared
    - Some streams require “sweetening” to allow flaring

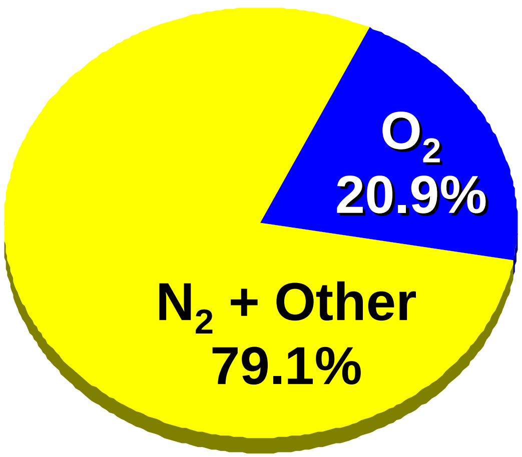
Convert flare streams into fuels

Example: Fuel vs. Flare Stream

- **Valuable Fuel**
  - Natural Gas (Methane – CH_4)
  - Higher Heating Value ~ 1000 Btu/scf
- **Low value stream**
  - 12% Methane
  - 88% Nitrogen
  - Higher Heating Value 123 Btu/scf
- **Traditional Conclusion**
  - Utilize as much as possible by blending with valuable fuel
  - Utilization depends on process temperature and flue gas capacity constraints (ID fan or natural draft)
  - Flare remaining quantity (requires supplemental BTUs)

Combustion Chemistry

Composition of Air



1 part O2

3.8 parts N2

Air = $(O_2 + 3.8N_2)$

- **Combustion Chemistry**
  - 2 volumes of oxygen required per volume of methane
  - $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
  - Inerts in fuel or oxidizer along for the ride
  - $CH_4 + 2(O_2 + 3.8N_2) \rightarrow CO_2 + 2H_2O + 7.6N_2$

Combustion Chemistry

- **Methane with air**

  $CH_4 + 2(O_2 + 3.8N_2) \rightarrow CO_2 + 2H_2O + 7.6N_2$

  – 7.6 volumes of N_2 associated with O_2 required

  – Pure fuel burning with diluted oxygen

- **Diluted methane with air**

  $(CH_4 + 7.6N_2) + 2(O_2 + 3.8N_2) \rightarrow CO_2 + 2H_2O + 15.2N_2$

  – 15.2 volumes of N_2 associated with fuel and O_2

  – Diluted fuel burning with diluted O_2

- **Diluted methane with O_2**

  – Remove N_2 from air

  $(CH_4 + 7.6N_2) + 2O_2 \rightarrow CO_2 + 2H_2O + 7.6N_2$

  – Diluted fuel burning with pure O_2

Economics of Waste Fuel Combustion

Property	Methane/Air	Waste Fuel/Air	Waste Fuel/O2
Adiabatic Flame Temp (F)	3,360	2,235	3,360
Waste Gas Flow (scf/MMBtu)	11,715	19,470	11,715
Fuel Cost ($/MMBtu)	5 - ?	0	0
Oxidizer Cost ($/MMBtu)	0	0	3.30 – 5.00
Total Energy Cost ($/MMBtu)	5 - ?	0	3.30 – 5.00

- **Waste Fuel:**
  - 12% CH_4/88% N_2
  - Higher heating value = 123 Btu/scf
- **Assumes oxygen cost of $40-60/ton**

Comparable combustion properties at reduced cost

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Increased Utilization Opportunities

- **Process requirements can limit utilization of waste fuels when combusted with air**
  - Process temperatures
  - Waste gas flow rate (ID fan or natural draft limitation)
- **Utilization of O_2 can overcome these limitations**
  - Process requirements
    - Process temperatures
    - Heat input (firing rate)
    - Waste gas flow (maintain or reduce)
  - Solution
    - Reduce air flow and add O_2
    - Air enrichment
    - O_2 lancing

Summary

- **Low heating value tail gas streams**
  - Result from high concentrations of inerts
  - Addition of O_2 to process lowers overall inert in oxidizer
- **Utilization of low heating value tail gas streams**
  - Can be upgraded to valuable fuels
  - Requires relaxing assumption that air is the only oxidizer for combustion

Oxygen is another tool that combustion engineers can utilize to optimize process economics

Examples of Waste Fuel Utilization with Oxygen

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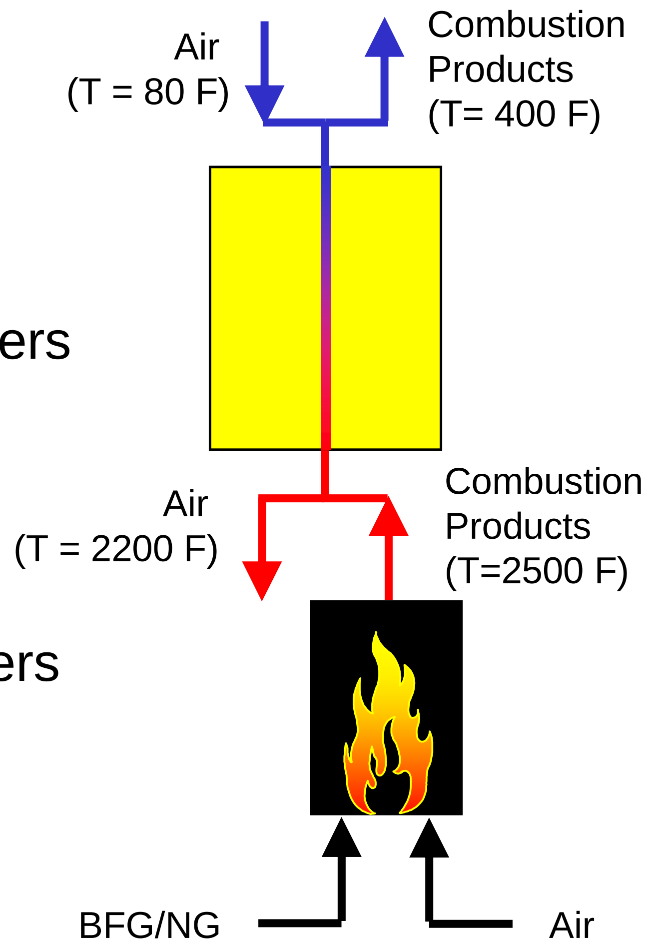
Blast Furnace Stoves

Blast Furnace Stoves

– Cyclic regenerative heat exchanger used to preheat air
  - Part 1: Combustion products heat checkers
  - Part 2: Hot checkers heat blast air
– Waste gas temperature
  - Typically 300-500 F
  - Similar to boilers and fired process heaters with waste heat recovery
– Target process temp ~ 2500 F



Blast Furnace Stoves

- **Blast furnace gas (BFG)**
  - Higher heating value ~ 85 - 100 Btu/scf
  - Adiabatic flame temp with air ~ 2300 F
  - Target process temp ~ 2500 F
  - Requires NG "sweetening" to achieve target temp
  - Excess BFG available, typically flared
- **Opportunity**
  - Increase utilization of excess BFG and reduce utilization of NG
  - Reduce overall operating cost of operation

Property	BFG
Composition (vol %)	
CO_2	20
CO	24
H_2	5
H_2O	5
N_2	46
HHV (Btu/scf)	91
Flame Temp. in air (F)	2,311
Flame Temp. in 100% O_2 (F)	3,252

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Oxygen Enriched Combustion

- **Blast furnace stove solution**
  - Maintain same furnace temperature
  - Modify combustion air
    - Enrich combustion air to ~ 25 - 28% O_2
  - Modify fuel composition and flowrate to
    - Increase usage of BFG
    - Eliminate usage of NG
    - Maintain same heat input (MMBtu/hr)
- **Effective cost of fuel ~ $3.40/MMBtu**
- **Typical net savings ~$2-6MM/yr**
- **Commercial sites**
  - 3 currently operating
  - 1 in engineering
  - 4 under evaluation

Examples of Other Waste Streams

Property	BFG	Stream A	Stream B
Composition (vol %)			
CH_4		1.3	0.2
C_2H_2			0.2
CO_2	20	0.6	3.7
CO	24	4.3	12.0
H_2	5	18.6	16.6
H_2O	5	1.4	8.0
N_2	46	73.6	59.2
O_2		0.2	
HHV (Btu/scf)	91	86	97
Flame Temp. in air (F)	2311	2187	2372
Flame Temp. in 100% O_2 (F)	3252	3222	3463

Oxygen addition can:

- Allow recovery of heating value if streams are not currently used
- Increase utilization of waste streams if limited by flame temperature
- Provide more cost effective method than supplemental NG

Combustion of Municipal Waste Biosolids

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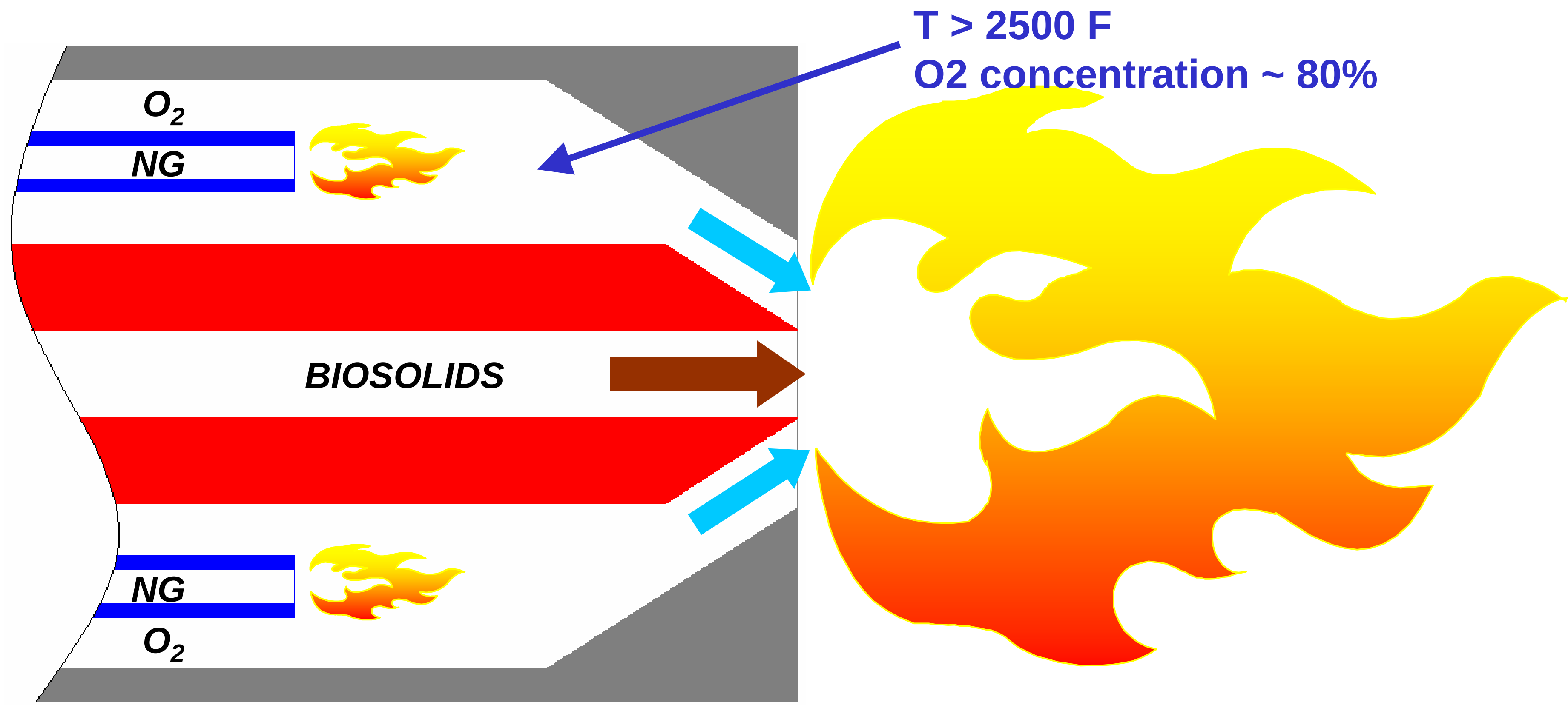
Combustion of Wastewater Biosolids

- **Opportunity**
  - Public dissatisfaction with land farming
  - Increasing costs for both land filling and incineration
  - Typically have low heating value and high moisture content
  - Flame stability and carbon burnout can be compromised if co-fired with MSW
  - Difficult to atomize
- **Solution**
  - Utilize Hot Oxygen Burner (HOB) to atomize and combust biosolids in waste-to-energy facility
  - Potential to recover value (energy) from former expense (landfill cost)

The Hot Oxygen Burner*



- **The effect of the partial combustion is to heat the oxygen to a high temperature - over 2500 ^{o}F**
- **Provides superior atomization and flame stability**

***US Patents 5,266,024 and 6,450,108 (others pending)**

HOB Tests conducted at Praxair Technology Center

- **Demonstration conducted at commercial scale**
  - 5 tph of wet sludge
  - 23% solids, 5300 Btu/lb HHV of dry sludge
- **Complete combustion achieved despite cool wall temperatures**

Fuel Flexibility in Solid Fuel Firing Systems

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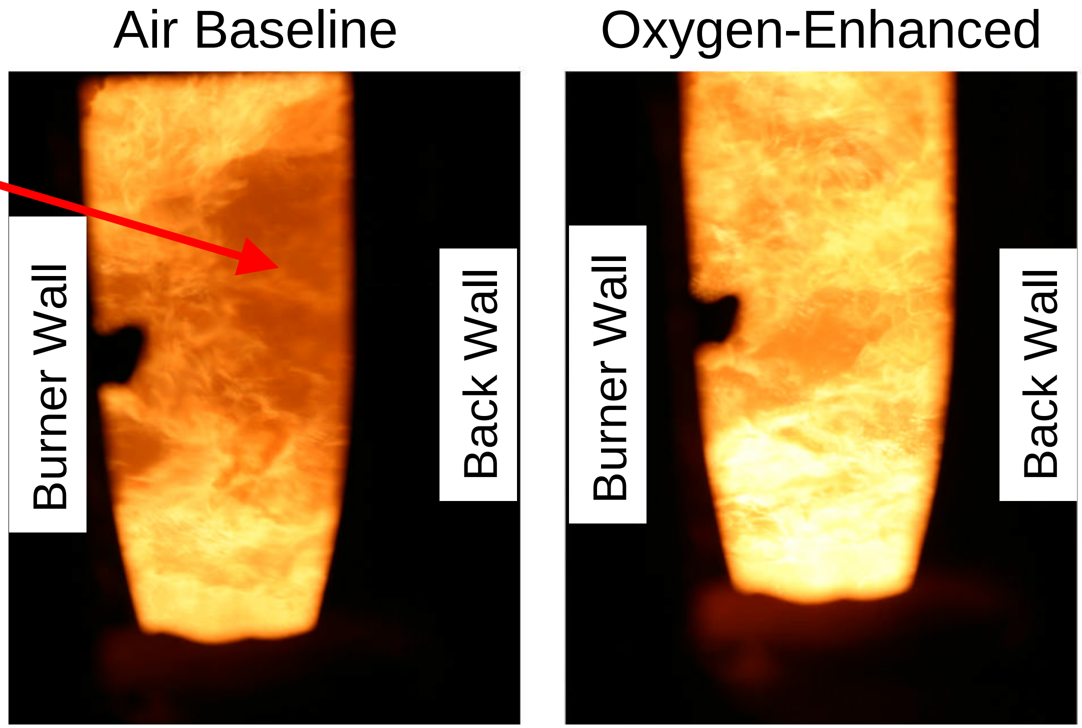
Oxygen Enhanced Solids Combustion

- **Stabilization of solid fuel flames**
  - Strongly dependent on volatile content of solids
  - Early release of volatiles is dominant mechanism
- **Low volatility solid fuels**
  - Combustion with air requires blending with higher volatility fuels
  - Strategic injection of O2 has demonstrated improved flame stability
- **Opportunity to burn low volatility fuels without addition of higher value fuels (and complexity of blending solids)**

Enhanced Flame Stability

Dark regions indicate areas of local extinction



- **Oxygen enhanced solid fuel combustion yields**
  – Faster release of volatiles
  – Higher local temperature in volatile combustion zone
- **Results in improved flame stability and lower NOx**
- **Allows utilization of lower volatility, lower cost fuels**

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Conclusion

- **Don't limit your combustion processes**
  - Industrial combustion is not limited to air
  - Oxygen allows combustion engineers to better utilize "difficult-to-burn" fuels
    - Utilize streams not thought of as "fuels" today
    - Increase utilization of streams currently supplemented with "better" fuels
  - Various levels of enrichment can be used to balance process/economic benefits
  - Various methods available to inject oxygen into system
- **Full utilization of combustibles in a plant will reduce overall energy consumption and CO_2 emissions**
- **While air is "free" it may limit your performance and result in higher operating cost!**