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Key Outcomes of VAM Abatement Demo Project at Walter Energy's Mine in Alabama

U.S. Coal Mine Methane Conference
Pittsburgh| November 18, 2014

Agenda

- **Biothermica**
- **Challenges of VAM Application**
- **Vamox® Demo Project (JWR, Alabama, USA)**
  - Review
  - Key Outcomes including process simulator
- **Large Scale Vamox® Unit**
- **Moving Forward**

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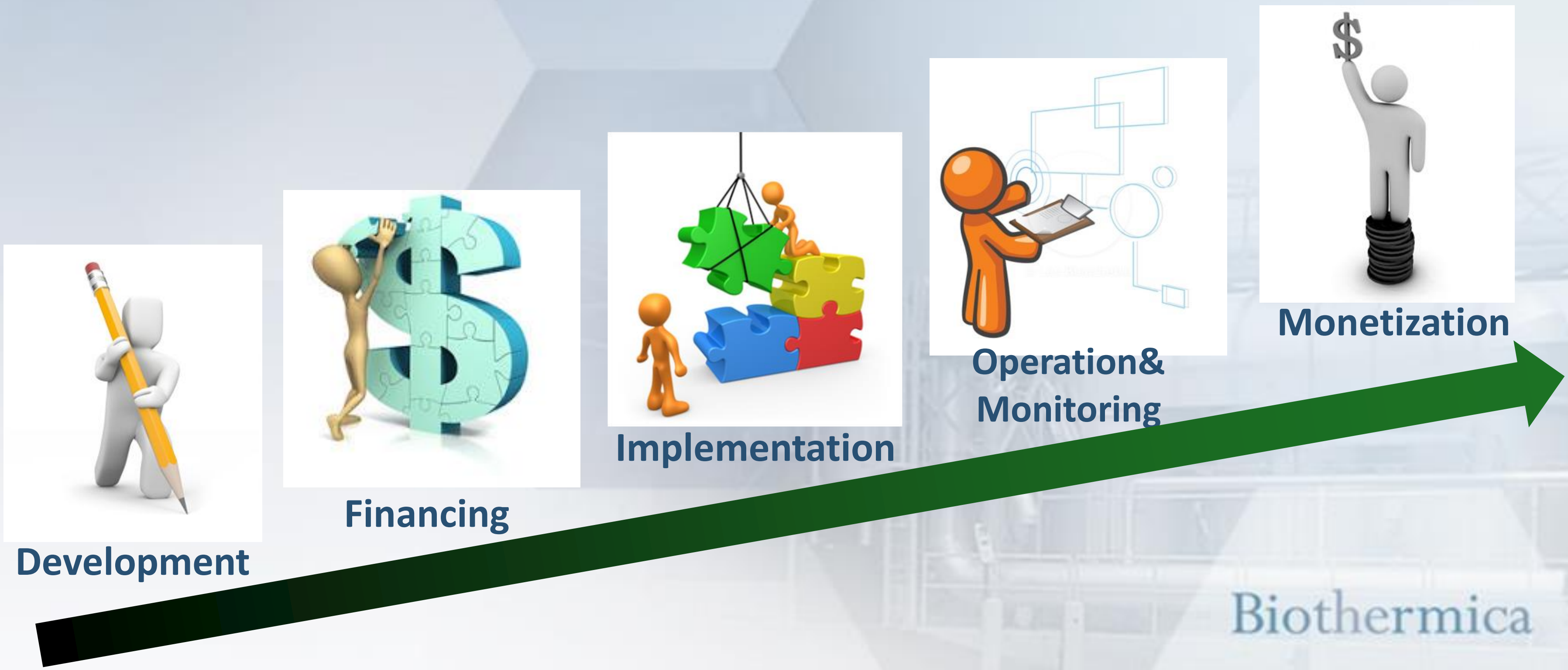
Who we are

- **Private Canadian group founded in 1987.**
- **Fully integrated carbon project developer.**
  - Managing all aspects of its carbon and energy projects.



Biothermica Achievements

- **Transactions exceeding $US 100 million in turn-key projects, including…**
  - $US **45 million** as equity sponsor.
    - Landfill gas collection and power generation systems.
  - $US **50 million** in carbon credit transactions.
    - Kyoto and voluntary carbon markets.

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Landfill Gas Projects

Gazmont 25 MW Power Plant
Montreal landfill (Canada)
2 billion kWh of electricity since 1996

El Salvador CDM Project
Nejapa landfill
215,000 carbon credits over 2006-2008
Major interest in project sold in 2008

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Industrial Emissions Control BIOTOX® Technology

- **Regenerative Thermal Oxidation (RTO).**
- **Expertise → Non-conventional emissions.**
  - Involving corrosive and/or Condensable Organic Compounds (COCs).
- **10 patents**

Food industry - COC emissions
Presque Isle, Maine, USA
100,000 cfm

Asphalt Shingles - COC emissions
Joliette, Quebec, USA
35,000 cfm

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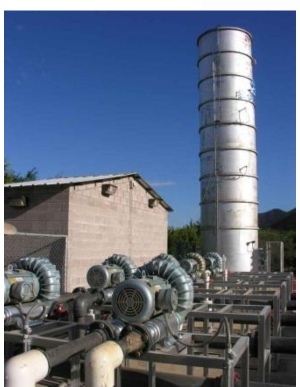
VAM Project Development Natural Evolution

RTO Technology



Landfill Methane
Carbon Project Experience

VAM
PROJECT

VAM Abatement:
More challenging than it looks!

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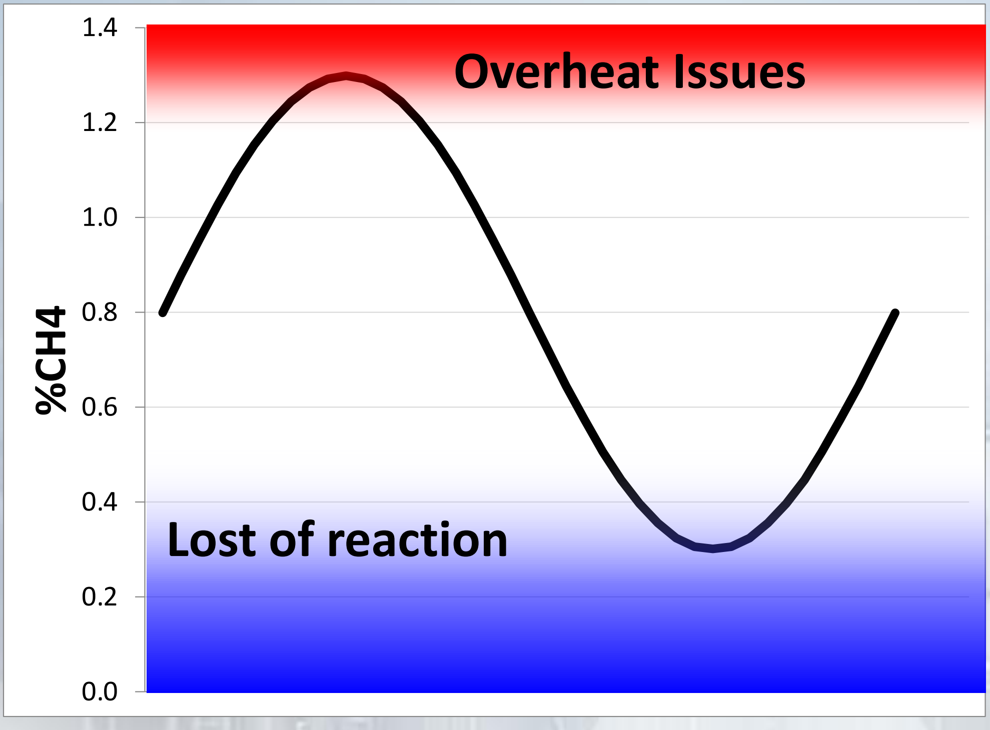
Highly Variable Methane Concentration

Challenges:

- ...at HIGH %CH4:
  - Prevent T° peak to compromise the integrity of the system.
- ...at LOW %CH4:
  - Maintain RTO in operation without supplemental energy input (e.g. propane).



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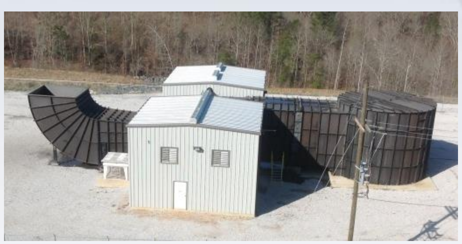
VAM Shaft → Short active life

- Bleeder shafts are typically operational 3-7 years.
- System must be easily **movable!**



Shaft #1 (3-7 years)

Shaft #2 (3-7 years)

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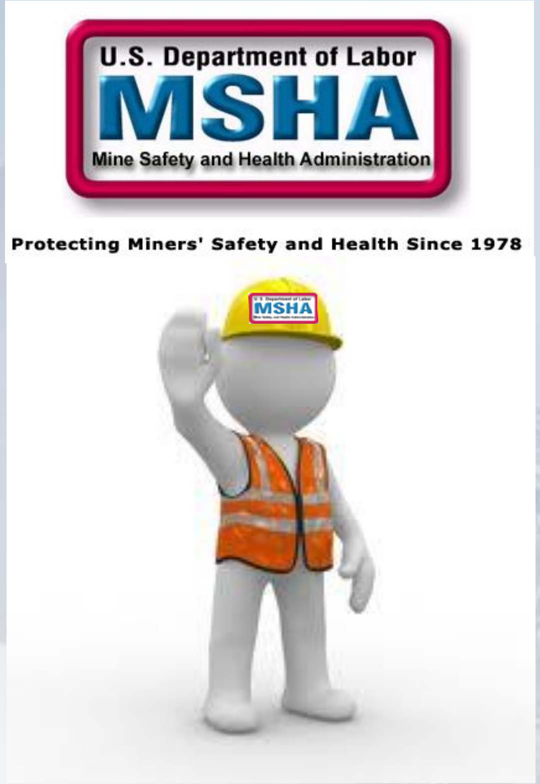
Stringent Safety Requirements

- **Each project must be approved by MSHA.**



Priority → Miners' Safety

- **Safety features are required to prevent a deflagration and flashback to the mine.**

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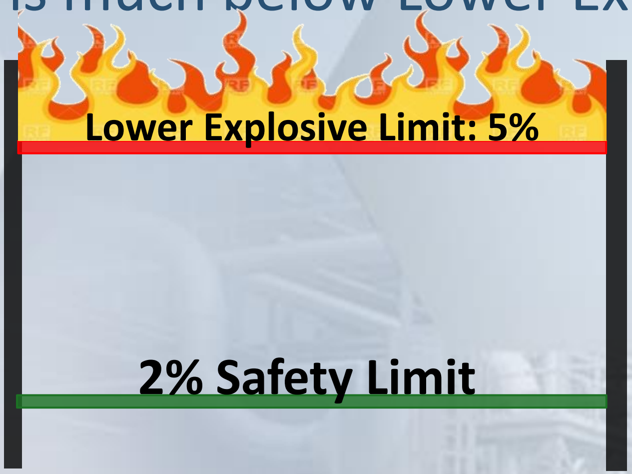
Features Required to Prevent Deflagation

- **System MUST be designed to prevent VAM exceeding 2% from reaching RTO.**
  - This safety limit is much below Lower Explosive Limit (LEL 5%).



- **Many preventative measures required, including:**
  - Fast CH4 Detectors
  - Fast Isolation Dampers
  - Safety Dilution Capacity

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Vamox® Technology

- **Biothermica has adapted its RTO technology (Biotox®) specifically for VAM abatement.**

1st Vamox® Demo Project

- Walter energy, No. 4 Mine (shaft 4-9), Brookwood, AL.
- 2009 to 2013.
- 1st VAM oxidation project at active U.S. Coal mine.
- Financed by Biothermica, 100% equity.
- Registered with the Climate Action Reserve (CAR).

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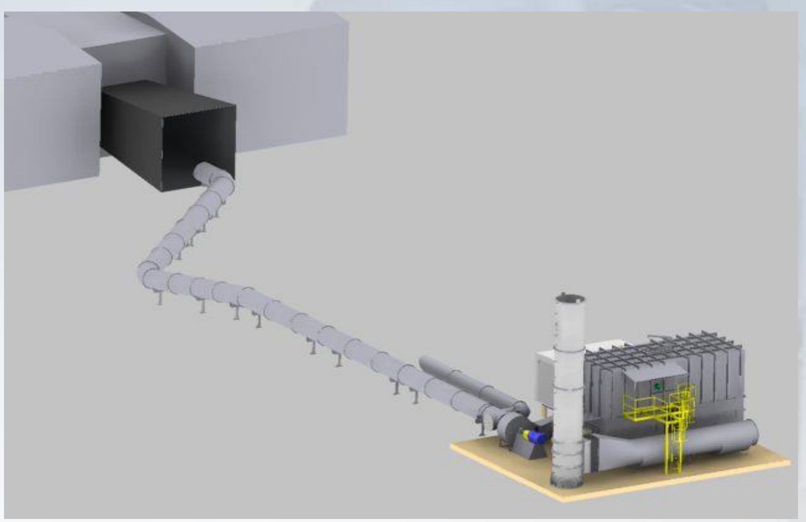
Demo Vamox® Specs

- **2 ceramic bed RTO.**
- **Nominal Capacity→ 30,000 cfm.**
  - Capture ~10% of VAM flow discharged by the ventilation shaft.
- **%CH4 Range→ 0.3% - 1.2%.**
  - Dilution with fresh air if required.
- **Footprint→ 1,400 ft^2 (40'X35')**




Demo Vamox®
Performance

tCO2e — 80,766 CRTs (Emission Reductions)

Hours — >27,000 hours of operation

Uptime — 92.7%* Availability Rate

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*Excluding external events such as CH4 concentration below min. threshold or electricity supply outages

Key Demo Project Outcome: Process Simulator

- **Simulator** is a reliable tool used to…

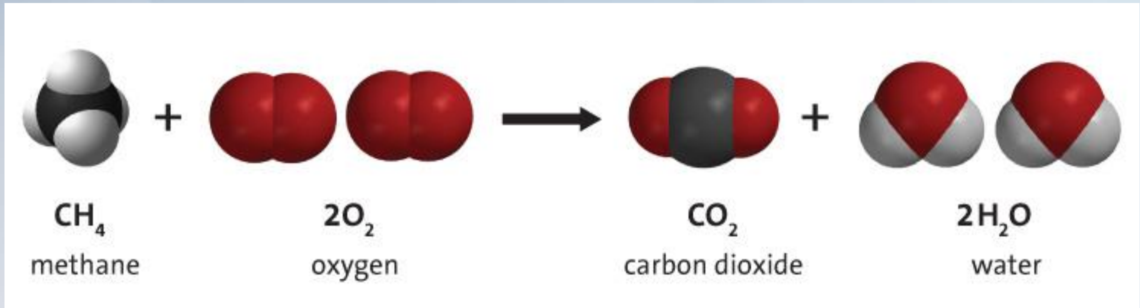
Guide large scale's design

Develop control strategies

Predict performance

Simulator Overview: Key Calculation

- **Methane oxidation reaction rate (k_r)**



- **Calculated based on Arrhenius Law**

$$k_r = A * exp\left(\frac{-E}{RT}\right)$$

Where

A **= experimental constant (s^{-1});**

E **= energy of activation (exp. constant) (cal/mol);**

R **= Gas constant (1.987 cal/mol/K)**

T **= absolute temperature (K).**

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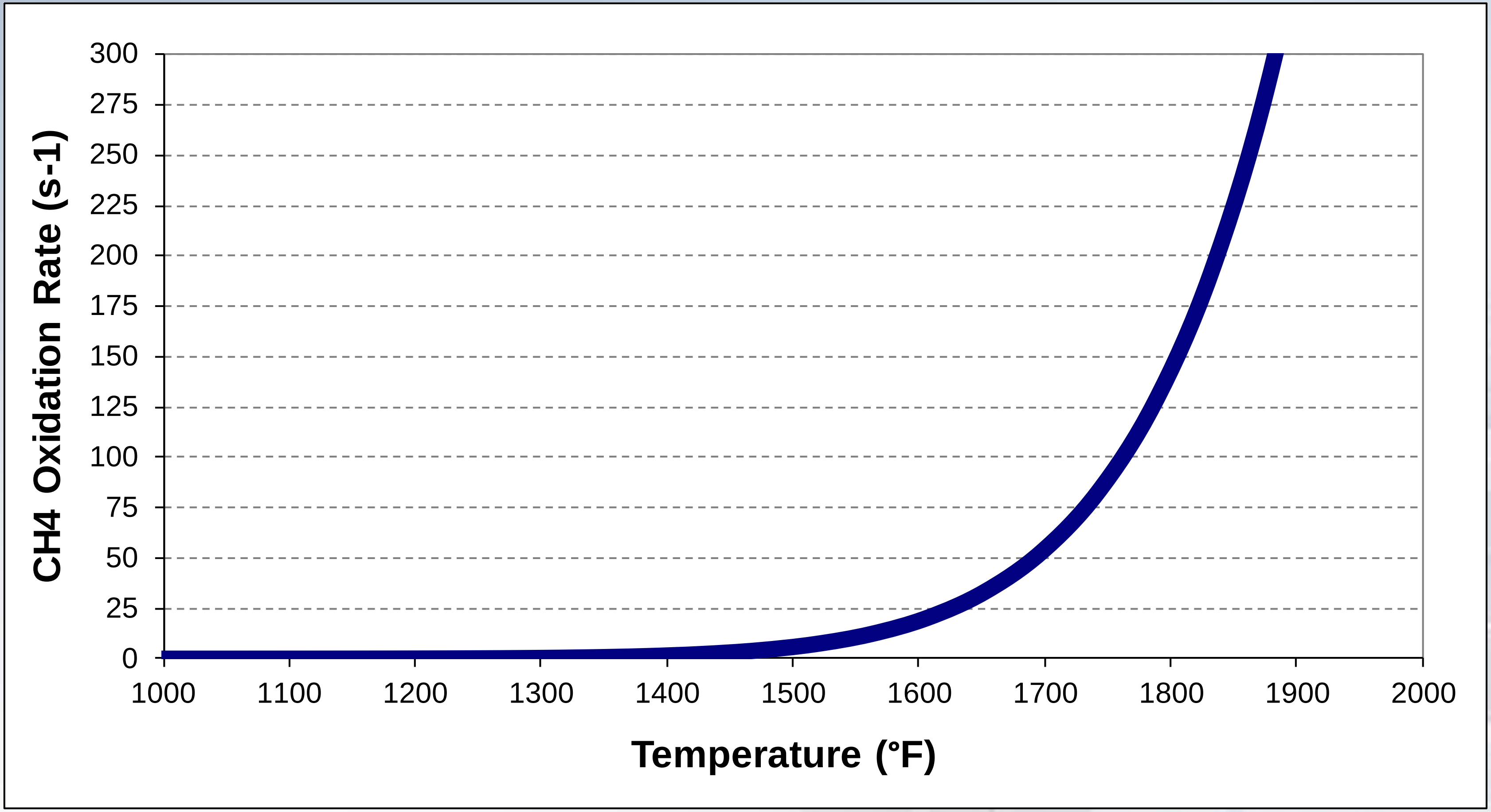
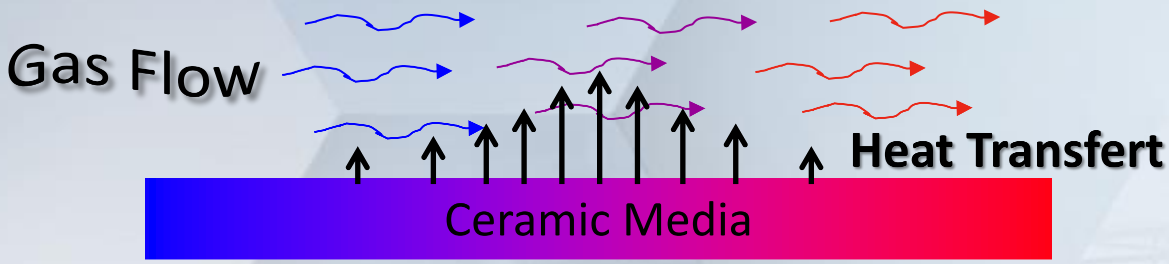
Simulator Overview: Key Calculation

Methane Oxidation Rate vs Temperature



Simulator Overview: Key Calculation

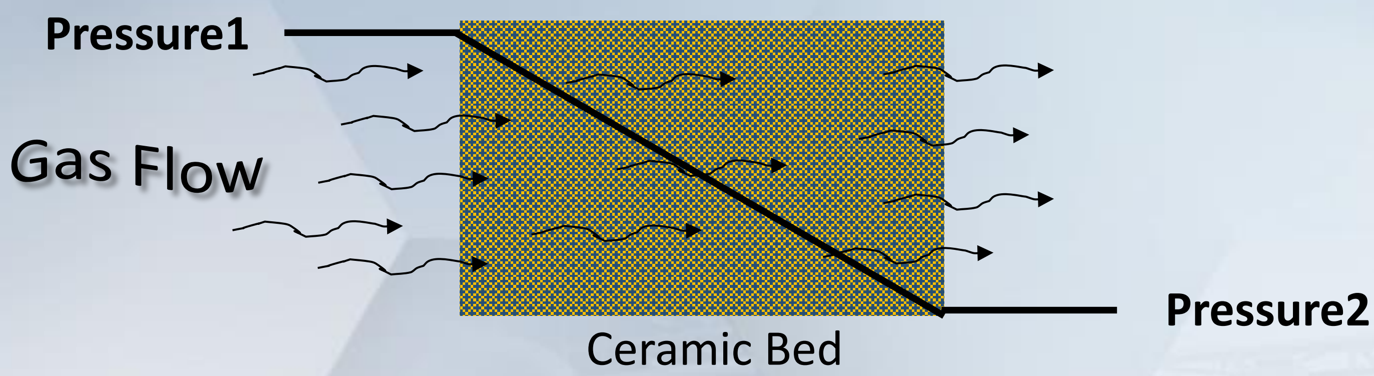
- **Heat Exchange Rate between gas and ceramic:**



- **Many inputs involved…**
  - Ceramic's characteristics (specific surface area, heat capacity, …).
  - Gas properties (heat capacity, density, …)
  - Gas velocity.
- **Retained model provides an excellent fit with process data over a wide range of conditions.**

Simulator Overview: Key Calculation

- **Pressure drop** through the system



- Many theoretical models tested (i.e. Ergun Equation)

$$\frac{\Delta P}{H_{layer}} = 150\left(\frac{\mu v_0}{D_p^2}\right)\frac{(1-\varepsilon)^2}{\varepsilon^3} + 1.75\left(\frac{\rho v_0^2}{D_p}\right)\frac{(1-\varepsilon)}{\varepsilon^3}$$

- Once again, **excellent fit** with process data over a wide range of conditions.

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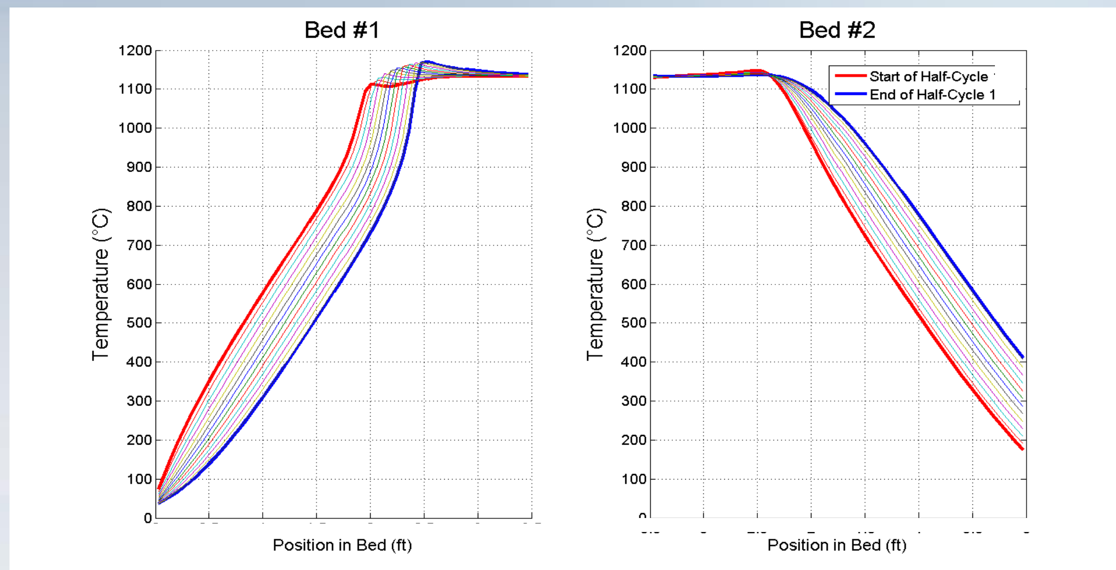
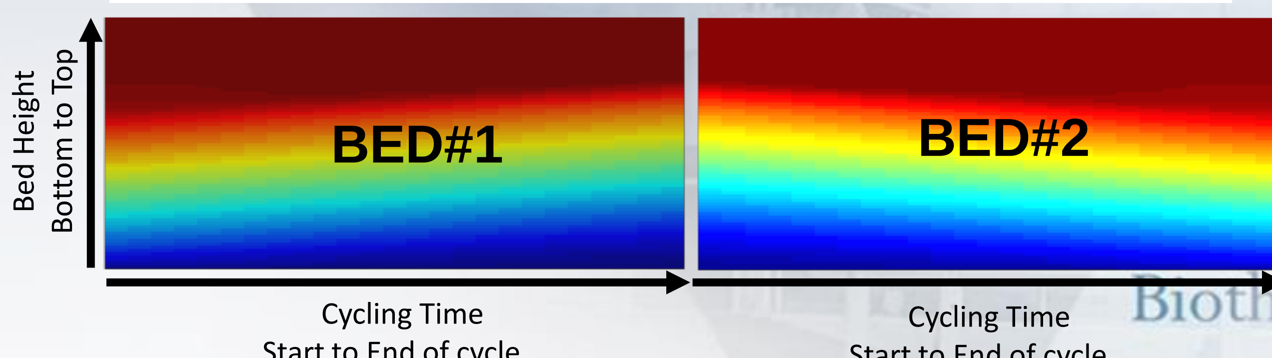
Simulator Overview: Key Results

- **Temperature profile in ceramic beds**





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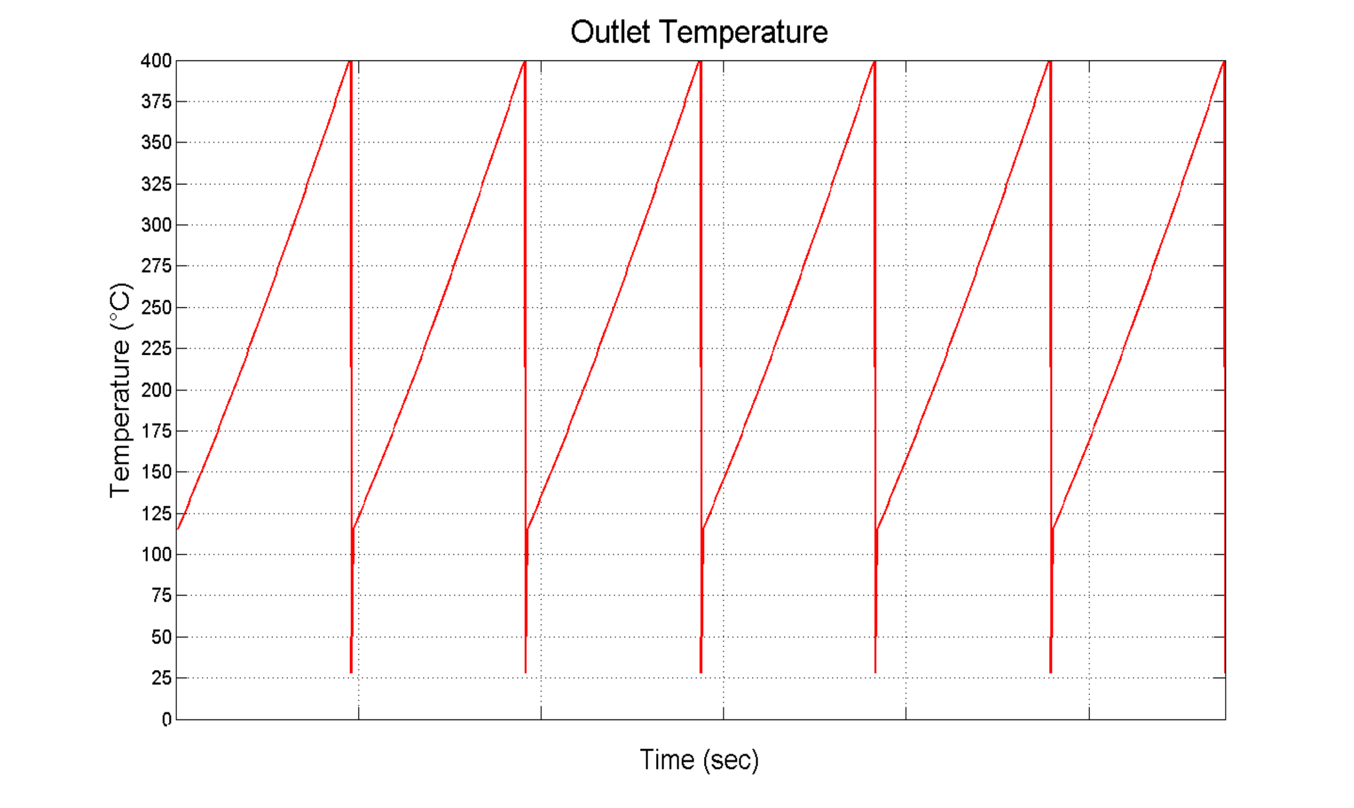
Simulator Overview: Key Results

- **Temperature profile** at stack



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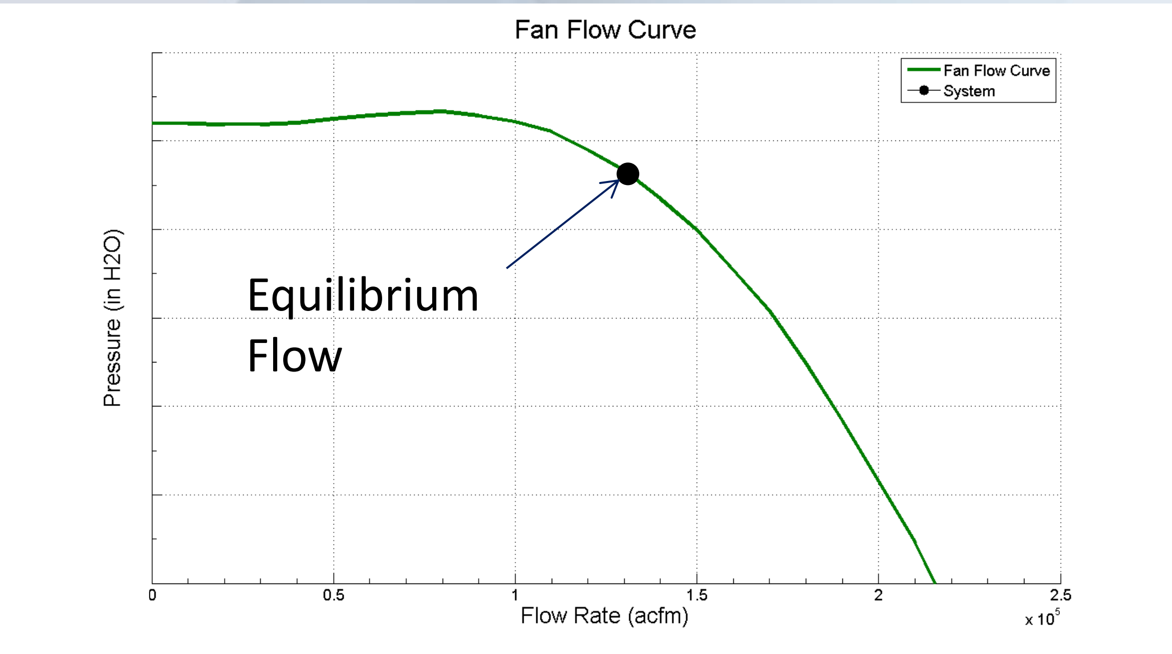
Simulator Overview: Key Results

- **Flow & Power Consumption (fan's performance)**
  - The fan flow curve provided by manufacturer is used by the simulator to determine the equilibrium flow.



Other Key Demo Project's Technical Outcomes

- **Identification of a ceramic media adapted for this stringent application.**
- **Optimization of control strategy.**
  - Auto-adjustment of operating conditions based on methane concentration to maximize performance.

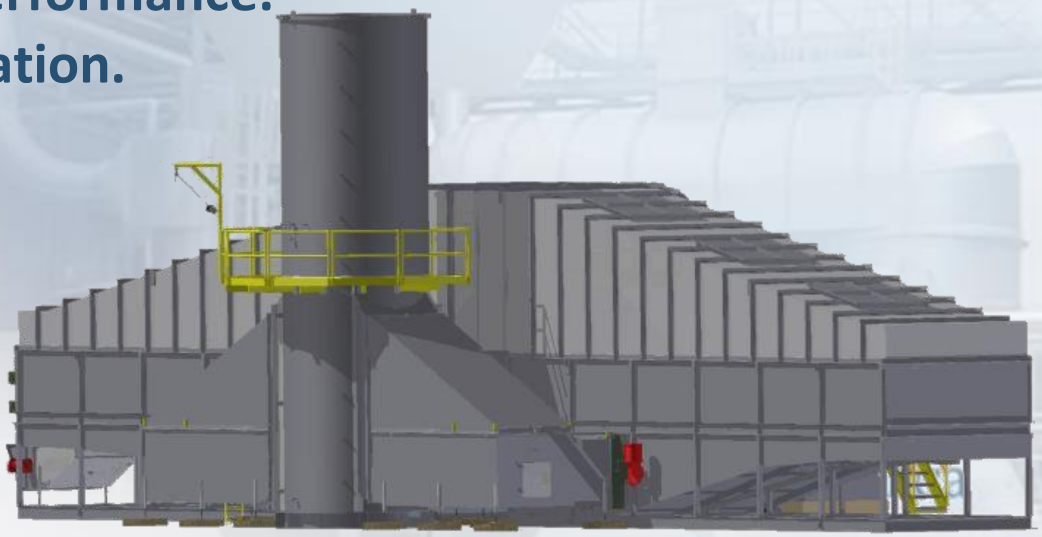
Large Scale's Design

- The experience gained from the Demo project has led to the design of a Large Scale Vamox® system.

Large Scale VAMOX® System

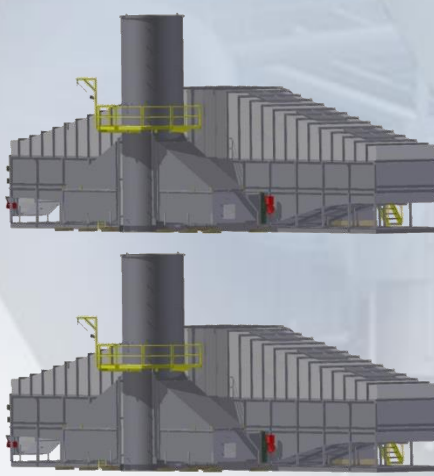
Specs - Large Scale Vamox®

- **2 ceramic beds.**
- **Nominal Capacity→ 140,000 cfm.**
- **%CH4 Range→ 0.3% - 1.2%**
  - Dilution with fresh air if required.
- **Footprint→ 5,000 ft² (~50'X~100').**
- **System fully instrumented for safety, process control and credit monitoring purposes.**
- **Self-Diagnostic of system's performance.**
- **Designed for facilitated relocation.**



Moving Forward

- Finalizing the planning of the next Vamox® project at Walter energy (Brookwood, AL) to connect **2 large scale units** on a bleeder shaft.
- Expected credits production : ~400,000 CCOs/year.
- Project to be registered under the new ARB's MMC Protocol.



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Thank You

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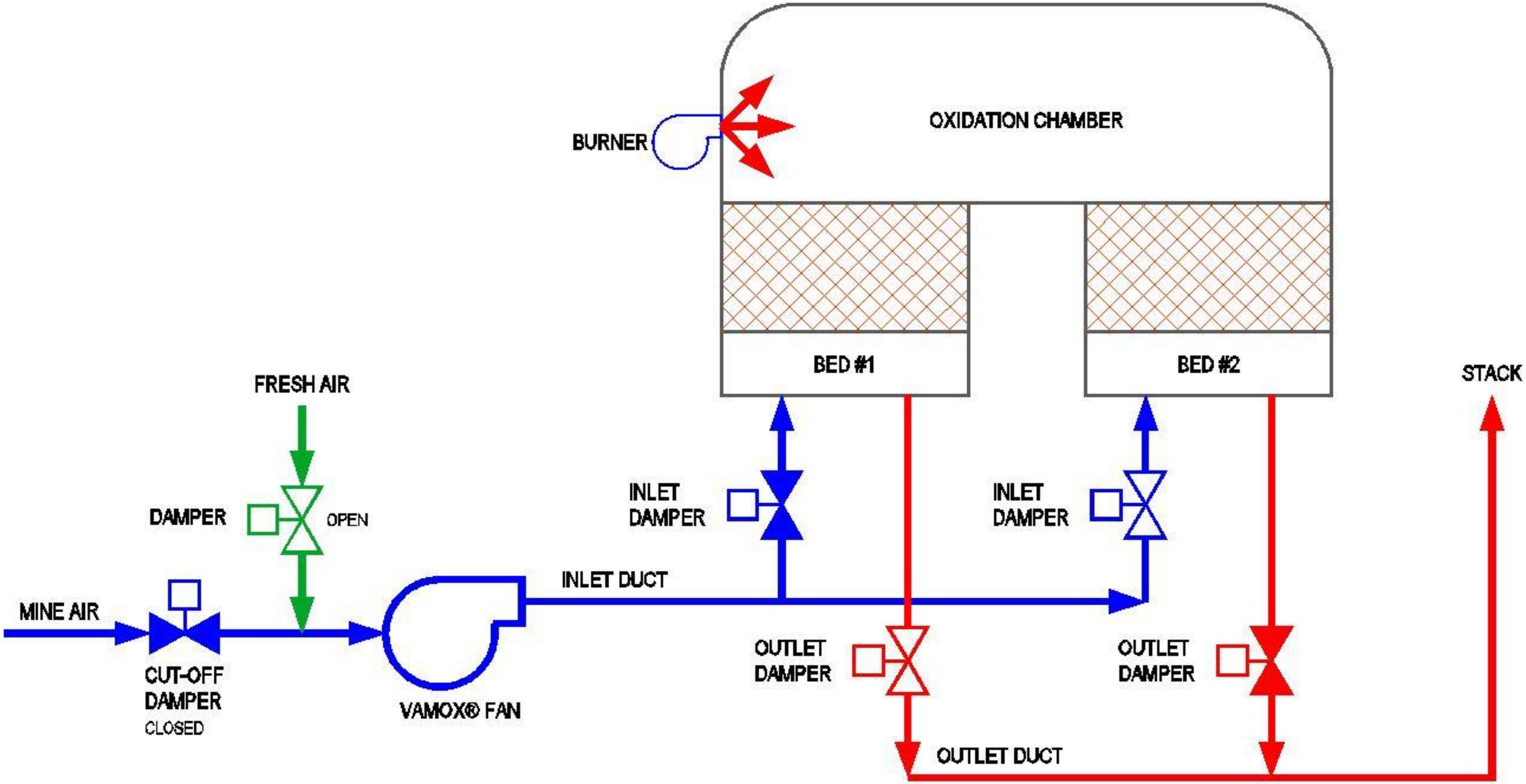
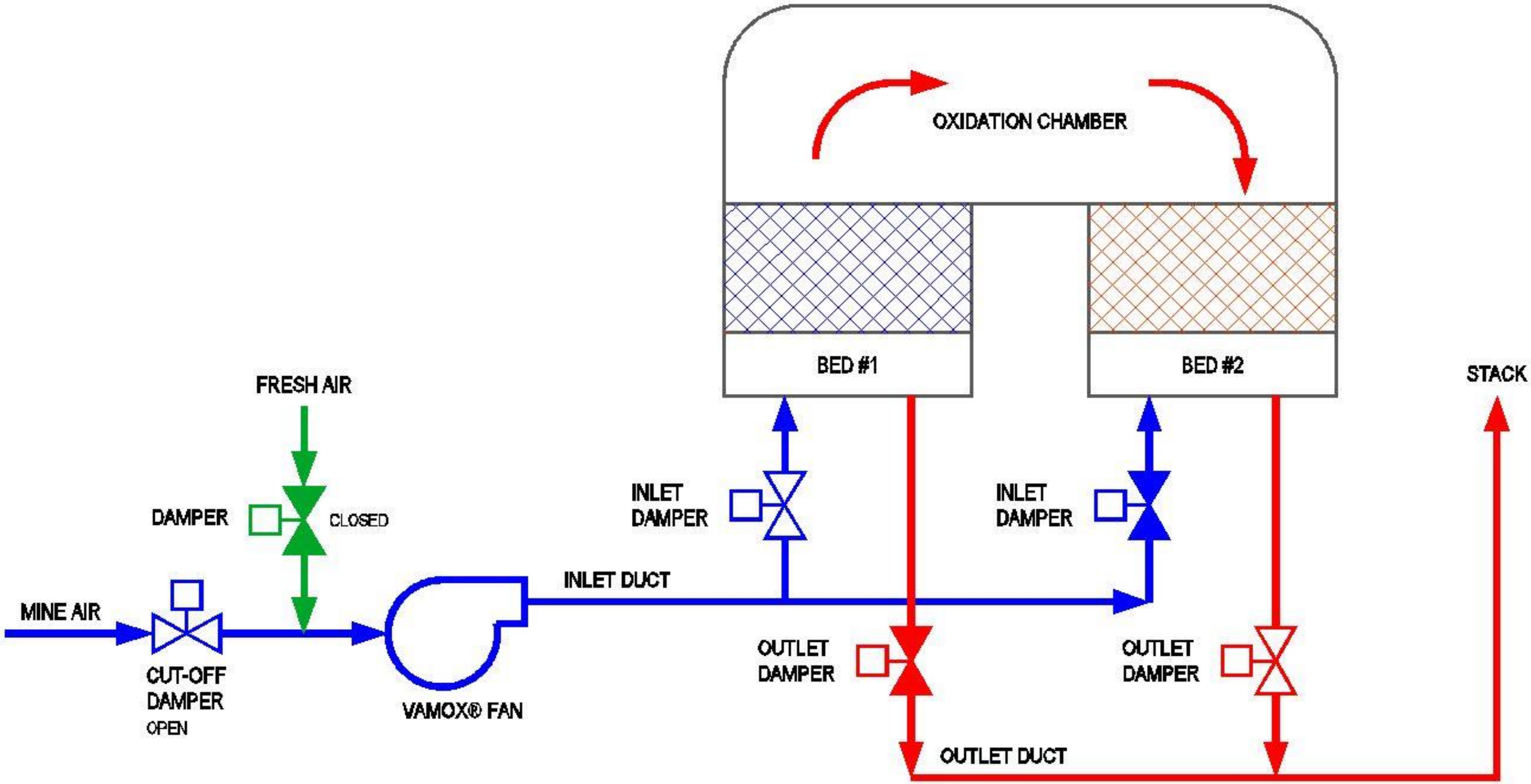
EXTRA SLIDES

Operating Principle
Start-up



Operating Principle
Cycle 1



Operating Principle
Cycle 2