Denbury Resources Inc.
IOGCC Meeting – CO_2 Dispersion Model

Defining Denbury

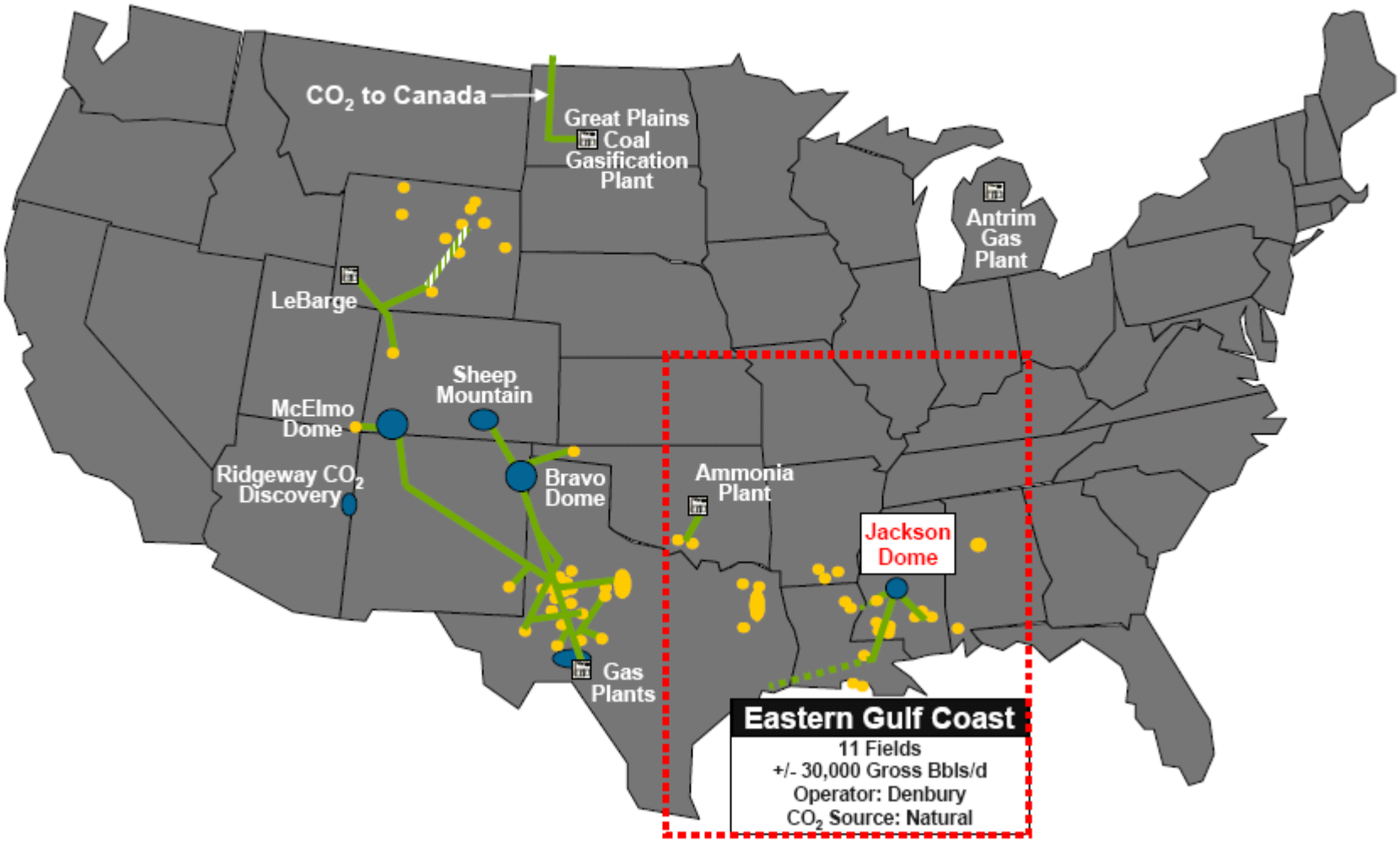
Introduction

- **Denbury is a growing, independent, publically owned oil and gas company based out of Plano, TX.**
- **Denbury is the largest oil producer in the State of Mississippi and owns the largest reserves of CO_2 (Carbon Dioxide) used for Enhanced Oil Recovery (EOR) east of the Mississippi River.**
- **Denbury uses CO_2 to recover oil from depleted oil reservoirs that would otherwise remain stranded.**
- **From a global perspective, EOR allows Denbury and the country to produce domestic oil making us less dependent on global oil production.**

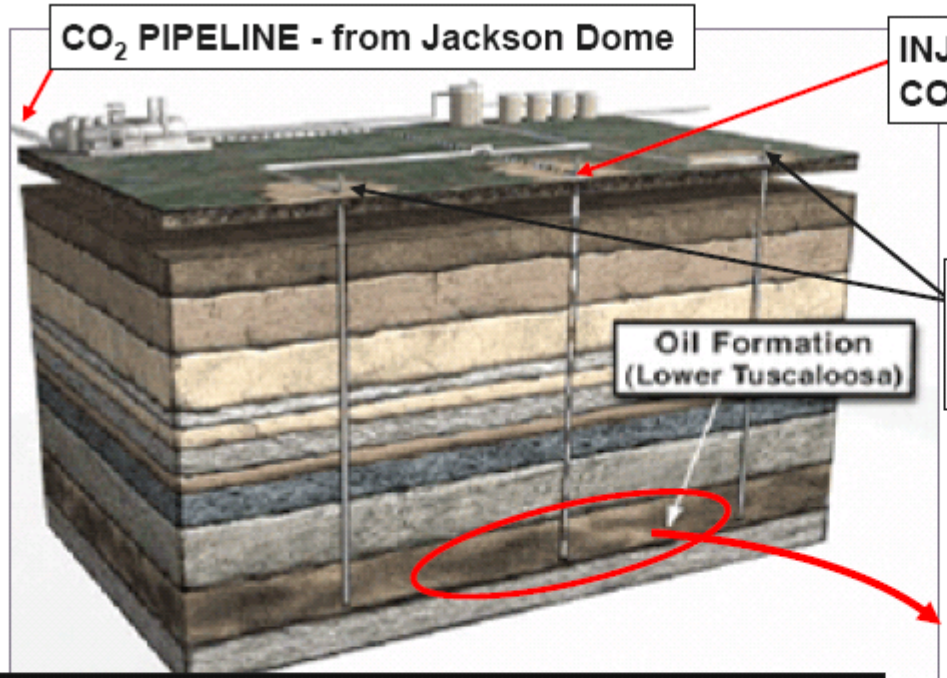
Denbury's Operations

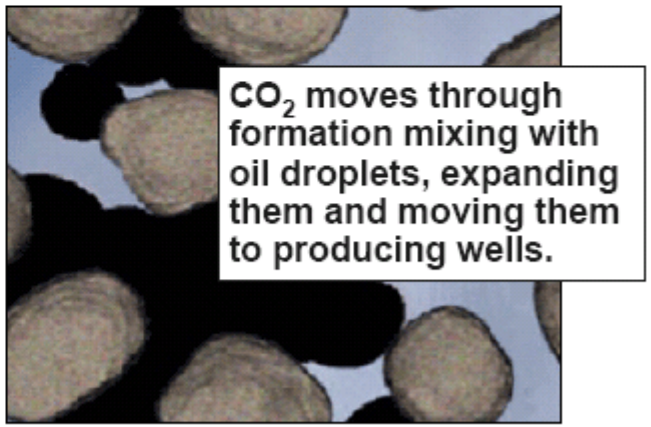
Denbury's Operations

Current CO_2 Sources & Pipelines



Denbury's Operations





Model for Oil Recovery Using CO_2 is +/- 17% of Original Oil in Place (Based on Little Creek)

Primary recovery = +/- 20%

Secondary recovery (waterfloods) = +/- 18%

Tertiary (CO_2) = +/- 17%

What is CO_2?

- **CO_2 is an inert gas**
- **Can exist as a gas, liquid, super-critical fluid, or solid state in certain conditions.**
- **CO_2 will form a dense, white cloud when released and has no smell unless accompanied by a foreign contaminant (hydrocarbons, H2S, etc.)**
- **CO_2 is heavier than air (specific gravity of 1.53 @60 degF) and may accumulate in low areas if released in very high concentrations.**
- **Potential Hazards**
  - **Frostbite**
  - **Release of pressure**
  - **Asphyxiation at high concentrations**

What Happened at Lake Nyos?

- August 1986 event killed 1700 people presumably by asphyxiation
- Stratified volcanic lake contained large amounts of CO_2 at depth (682' deep)
- Some event triggered deep water to rise releasing vast amounts of CO_2 to the surface
- Dense CO_2 cloud spilled over crater rim and "flowed" down hill to village
- All living things within ~15 miles around the crater were killed

Gas Estimates[1]	CO_2 (km^3)	CO_2 (mmcf)
Possible CO_2 storage	1.45	51,206
Amount of CO_2 stored in May 1987	0.38	13,420
Estimated CO_2 released in 1986	0.68 (up to 1.0)	24,014 (35,315)

1. Kling, 1989

Pipeline Transport	0.05	1,200

Occupational Guidelines

Exposure Guideline	CO_2 (ppm)	CO_2 (%)
OSHA PEL – TWA[1]	5,000	0.5
ACGIH TLV – STEL[2]	30,000	3.0
O_2 Limiting[3]	70,000	7.0

ACGIH = American Conference of Governmental Industrial Hygienists
OSHA = Occupational Safety and Health Administration

1. OSHA PEL-TWA = Permissible Exposure Limit – Time Weighted Average (PEL-TLV). Permissible concentration in air of a substance that shall not be exceeded in any 8 hour work shift of a 40 hour week.

2. ACGIH TLV-STEL = Threshold Limit Value – Short Term Exposure Limit, (TLV-STEL). A 15 minute TWA exposure that should not be exceeded tat any time during a workday.

3. The level at which O_2 levels are estimated to fall below the breathable range enforced by OSHA (19.5%).

Dispersion Model Exercise

- **Why did we conduct a dispersion model?**
  - **Denbury's Operations involves transportation and handling of CO_2 in everyday operations**
  - **Facility Construction – Useful in design and construction planning**
  - **Pipelines – Useful for regulatory (DOT) High-Consequence Area ER planning**
  - **Operations – Useful in ER planning and employee safety (relief vent placement)**

- **Why now?**
  - **Opportunity existed during a controlled environment while testing a new CO_2 producer (well)**
  - **Denbury's future in CO_2**
  - **Government and public interest in CO_2 safety**

Dispersion Model Exercise – Partners

- **Center for Toxicology & Environmental Health, LLC (CTEH)**
- **Mississippi Department of Environmental Quality (MDEQ)**
- **Madison County Emergency Management Agency (EMA)**
- **University of Texas, Bureau of Economic Geology (BEG)**

Objectives

- **Conduct real time monitoring for several “real-world” release scenarios**
- **Run model on same scenarios**
- **Compare model results to real time data to understand model reliability and predictability**
- **Compare day and night conditions**
- **Compare relative release velocities**
- **Evaluate OSHA and ACGIH thresholds in each scenario**

Scenarios

Scenario	Flow Direction	Flow Rate (mmcfd)	Pipe Diameter	Exit Height
1	Horizontal	~35	6”	0’
2	Vertical	~35	20”	20’
3	Vertical	~35	10”	10’
4	Vertical	~35 → ~5 (10 min steps)	20”	20’

- **Began project on Wed evening and ran through Fri evening**
- **Used fixed, mobile, and handheld monitors for O_2, CO_2, and H_2S**
- **Measured meteorological conditions**
- **Each scenario was run under “unstable” (day) and “stable” (night) atmospheric conditions**

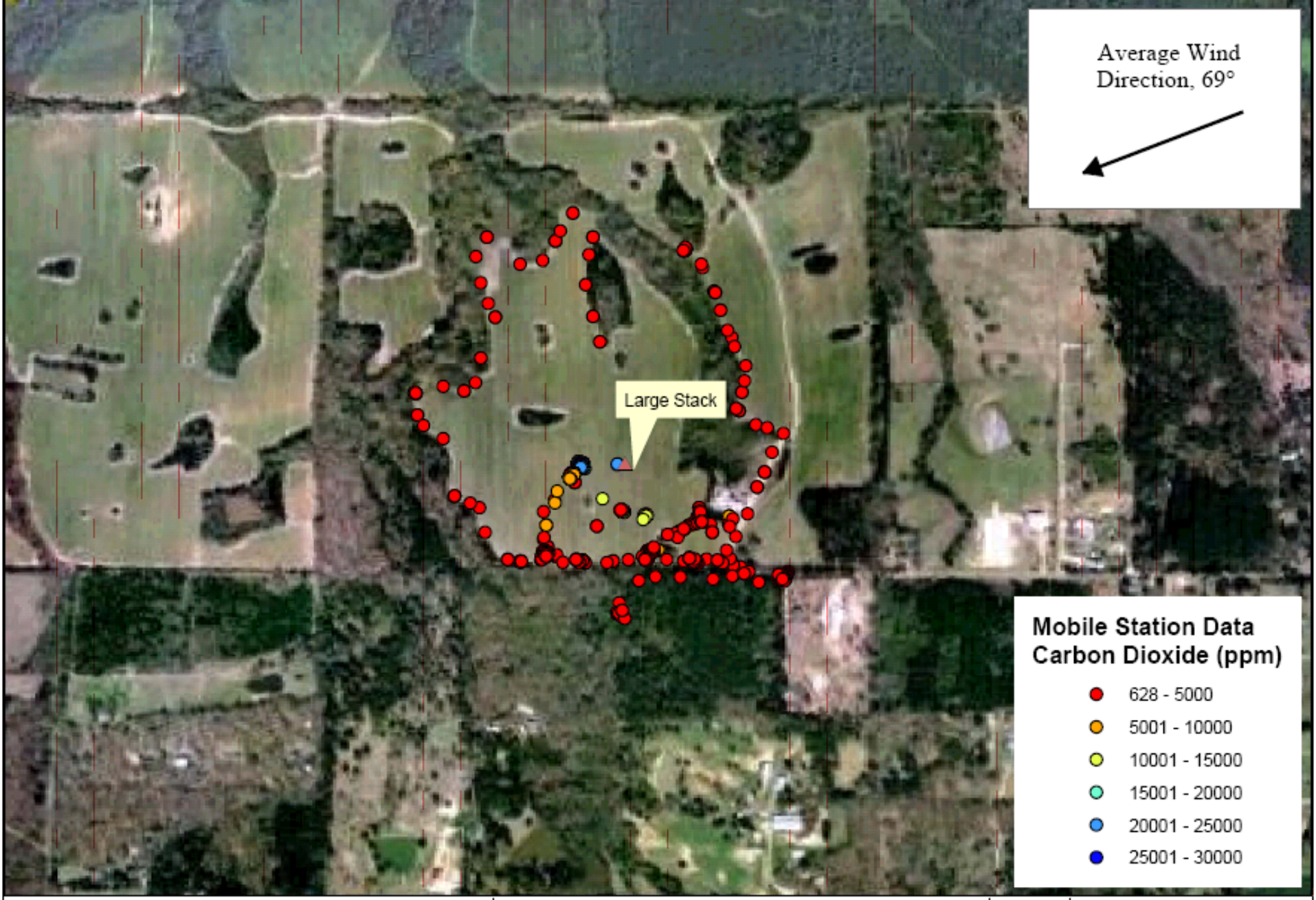
Denbury Onshore, LLC
CTEH
High Flow Stack
Low Flow Stack
Horizontal Release
Well Head
Water Pit
AR1
AR2
AR3
AR4
AR5
AR6
AR7
AR8
AR10
AR11
AR12
Monitoring station location
Water Pit
High Flow Stack
Low Flow Stack
Horizontal Stack
CO_2 Well Vent Operation
08/12/2009 - 08/14/2009
Denbury Onshore
Madison, MS
Fayette County
Date Created: 07/24/2009
4867

View of Stacks and Mobile Unit

Date: 8/12/09	Location: 32.49686, -90.05450
Photo ID: 0358	Well Head: LH Kuriger Well 35-16 #1 Madison County, Mississippi
Description: View of horizontal pipe release high flow (background), mobile station 9 (foreground)	

Scenario 2 – Vertical – Large Stack

Date: 8/13/09	Location: Station 4
Photo ID: 0375	Well Head: LH Kuriger Well 35-16 #1 Madison County, Mississippi
Description: View of vertical pipe release from front gate during large stack high flow	



Mobile Station 9
Scenario 2: Large Stack
August 12-13, 2009 22:00-15:00

0 0.05 0.1 0.2 Miles

CTEH	Denbury Onshore
	L.H. Kuriger CO2 Well
Project No. 4857	Madison County
	August 12-13, 2009

Diurnal Variation

Day

Night

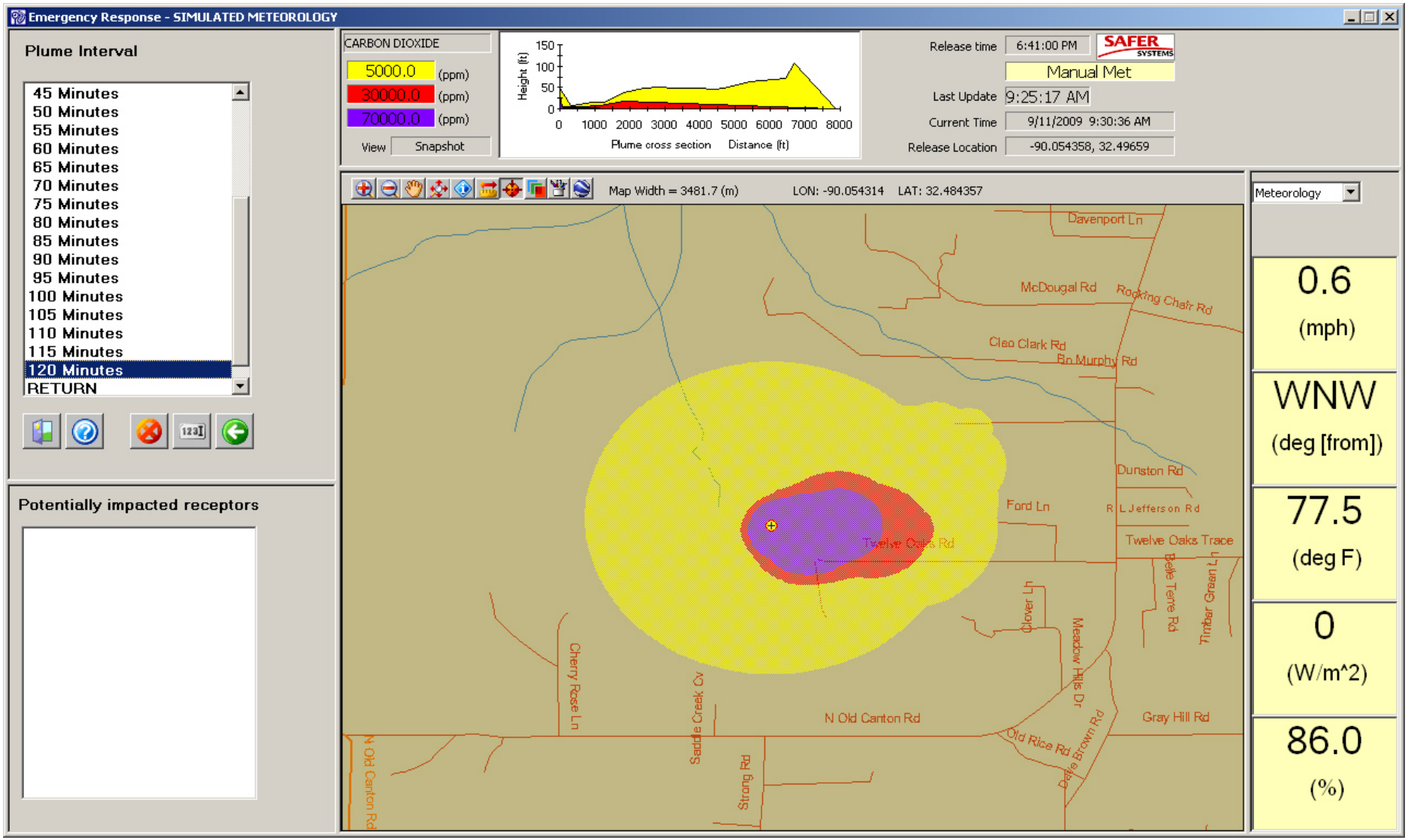
Scenario 2 – Vertical – Large Stack

- **Results**
  - **Day**
    - **Most fixed station readings generally around 5,000 ppm.**
    - **Nearest fixed station read as high as 15,000 ppm.**
  - **Night**
    - **Fixed station readings ranged from 10,000 to 15,000 ppm.**
    - **Vertical momentum carried cloud about 50' above the stack.**
    - **During periods of low wind, the cloud settled to the ground in nearly a 360° pattern.**
    - **Mobile unit parked at the base of the stack saw readings up to 30,000 ppm.**
    - **Station 11 - nearest fixed station read O_2 levels of 19.7% indicating 50,000 ppm CO_2.**
  - **Temperatures**
    - **Ambient ~90°F**
    - **Outside of stack was 32°F**
    - **Gas at top of stack was 0°F**
    - **Increased density of cold gas resulted in visual slumping of gas and condensing atmospheric water vapor (cloud)**

Model Info

- **SAFER STAR™ dispersion modeling software (SAFER) was used.**
- **Meteorological data was measured and fed directly into the SAFER model.**
- **The model includes algorithms for addressing atmospheric dispersion, thermal radiation, and blast over pressuring modeling.**
- **The model incorporates terrain information in addition to meteorological conditions.**
- **Primary modeling results were produced from the data collected on-site for comparison with the monitoring data.**
- **The levels to which modeling results are reported are as follows:**
  - **5,000 ppm (the OSHA – PEL, 8-hour TWA)**
  - **30,000 ppm (ACGIH – STEL)**
  - **70,000 ppm (O_2 limiting)**
- **The model outputs all depict ground-level concentrations. Ground-level results are not expected to vary greatly from the breathing-zone concentrations.**

Model – Scenario 2



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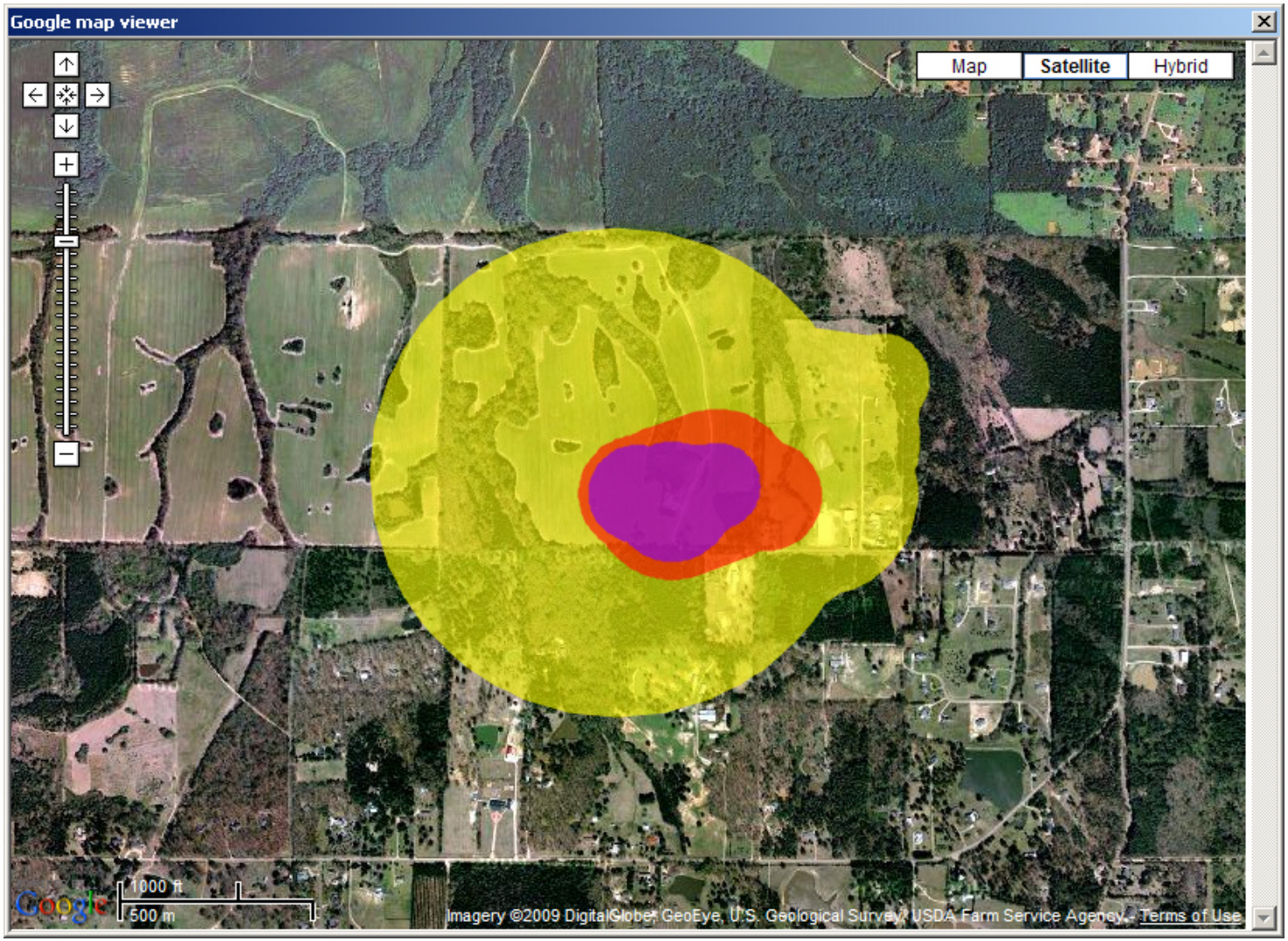

Summary (Model vs. Monitoring)

CO_2	Expected O_2	Day (max distance)	Night (max distance)
5,000 ppm	20.9 %	80’	4200’
30,000 ppm	20.3 %	30’	2100’
70,000 ppm	19.5 %	20’	1300’
Monitoring	• lowest O_2 reading was 19.7% at adjacent to source	• Most stations <=5,000 ppm • Station 1 (nearest source) <=(15,000 ppm)	• Most stations 10,000-15,000 ppm • 15,000-30,000 ppm in work area (250-300’) • ~50,000 ppm at immediate vicinity of stack

Conclusions

- **Results from the air monitoring indicate that a horizontal release under stable atmospheric conditions, concentrations of CO_2 up to 10,000 ppm may be present up to 750-1000 feet from the release location.**

- **During the times of concentrations >10,000 ppm, the corresponding levels of O_2 were well within the breathable range. This is consistent with what might be expected based upon fundamental principles – a 10,000 ppm (1%) increase in carbon dioxide concentration leads to a 0.2% drop in oxygen concentration from 20.9% to 20.7%.**

- **Given the worst-case conditions tested during this project, levels of CO_2 in an outdoor release are not expected to yield oxygen-deficient environments (<19.5%), even in low-lying areas or ditches, except within the immediate vicinity of the release (<50 feet).**

- **Results from the air dispersion modeling indicate that the models most frequently <u>over-predict</u> the air concentrations of carbon dioxide in the area by a factor of 5 to 10.**

- **For nighttime conditions and high-momentum vertical jets, the model appears to <u>over-predict</u> the resulting air concentrations of CO_2, possibly due to an incomplete analysis of the momentum of the jet and its propensity to cause the released gas to exit the turbulent boundary layer.**

QUESTIONS?

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