# Development of an NDIR $CO_2$ sensor-based system for assessing soil toxicity using substrate-induced respiration

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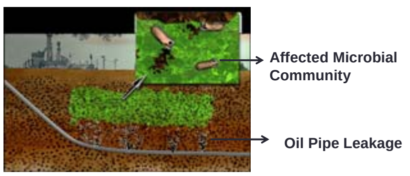
## Background

- Petroleum hydrocarbon pollution results from accidental discharge during transportation, leakage from storage tanks and pipeline ruptures.
- Common approaches to determine petroleum hydrocarbons in soil
  - Gas chromatography techniques
  - Eco-toxicological tests (due to **bioavailability**)




## Hypothesis

- Petroleum hydrocarbons have a significant impact on microbial community abundance, composition and diversity
- Thus, the soil microbial activity in a hydrocarbon-contaminated soil can be used as an indicator of hydrocarbon contamination present in the soil



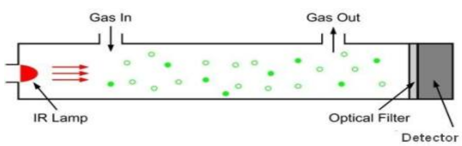



## Soil Respiration

- Soil micro-organisms can be quantified by measuring the soil $CO_2$ production or $O_2$ consumption
- Basal respiration (BR)
- Substrate-induced respiration (SIR)
- Presently, evolved $CO_2$ is determined by a **colorimetric reaction** in gas absorbent alkali



## NDIR-based $CO_2$ Sensors




- $CO_2$ absorption at 4.3 µm
- IR light source passed through narrow band optical filter



## Objectives of the Study

- To develop and evaluate an NDIR $CO_2$ sensor based system to measure substrate-induced soil $CO_2$ emission
- To investigate applicability of the system to distinguish between control soil samples and the samples contaminated with different concentrations of diesel

# Material and Methods

SenseAir's $CO_2$ Engine® K30 $CO_2$ Sensor



# Sensor System




# Soil Sampling

| Sample No. | Soil Type | % sand | % silt | % clay | pH | %OM |
|---|---|---|---|---|---|---|
| 1 | Loam | 36.50 | 40.16 | 23.34 | 6.90 | 63.27 |
| 2 | Sandy Loam | 62.38 | 24.60 | 13.03 | 5.85 | 7.76 |
| 3 | Sandy Clay Loam | 46.45 | 27.95 | 25.60 | 7.35 | 7.49 |



# Experimentation

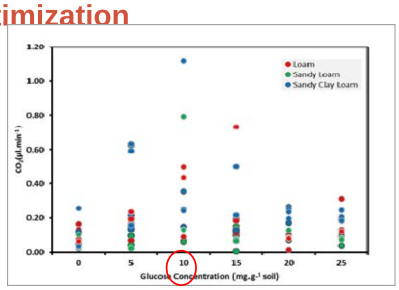
**Experiment 1:**
Substrate Optimization: 20 g air-dry (a. d.) soil samples were amended with a series of glucose concentrations (0-25 mg/g soil) in aq. solution and $CO_2$ emission was measured for 5 minutes

**Experiment 2:**
Performed to check the applicability of the designed system to distinguish between the soils with (control soils) and without microbial activity (autoclaved, sterile soils).

**Experiment 3:**
To evaluate the applicability of sensor to determine petroleum hydrocarbon contamination in soil. Five diesel treatments (0, 5, 20, 60 and 150 mg/g of soil) were applied to all three soils.



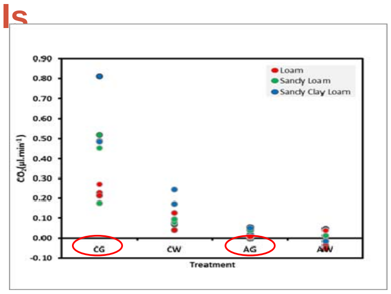
# Results: Exp. 1. Substrate Optimization




Emission of $CO_2$ from three soils on adding aq. glucose at different concentrations. Data represents 20 g of soil samples and five replicates.

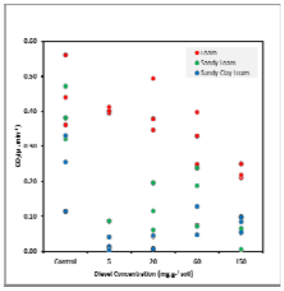


# Exp. 2. Untreated and Sterile Soils




GC: glucose-control, DC: distilled water-control, GS: glucose-sterile and DS: distilled water-sterile.

# Exp. 3. Diesel Treated Soils



- The diesel treatment at different rates indicated different $CO_2$ emission patterns, in terms of the level of SOM:
- High SOM=> the hydrophobic compounds get **partitioned** into the organic fraction of soil=>Low bioavailability
- Low SOM=> diesel hydrocarbon was **adsorbed** on the soil solid=> High bioavailability



# Conclusions

The results lie in favor of application of proposed $CO_2$ sensor based system for measurement of substrate induced respiration and toxicity evaluation.

# RSCA- Rapid Soil $CO_2$ Analyzer

Florian Reumont
Dr. Viacheslav Adamchuk

## Current Method

**Logistics** – Chamber installed in field after planting and removed before harvest

**Labor** – Multiple people needed for multiple hours to collect gas samples

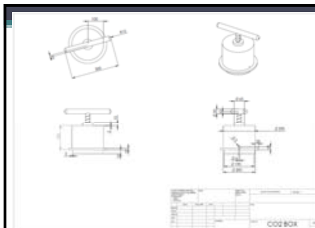
**Time**– Gas samples sent to lab for analysis

## RCSA

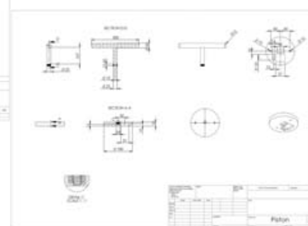
**Logistics** - No site preparation

**Labor** - Single person job,

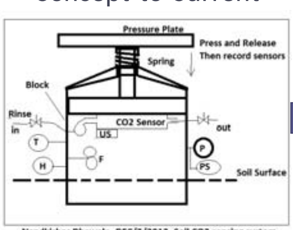
**Time** - No need for lab analysis

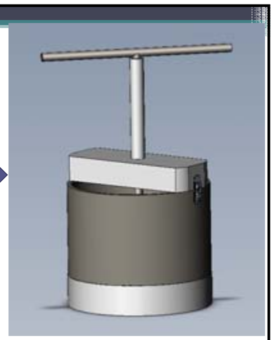



## Mechanical Design

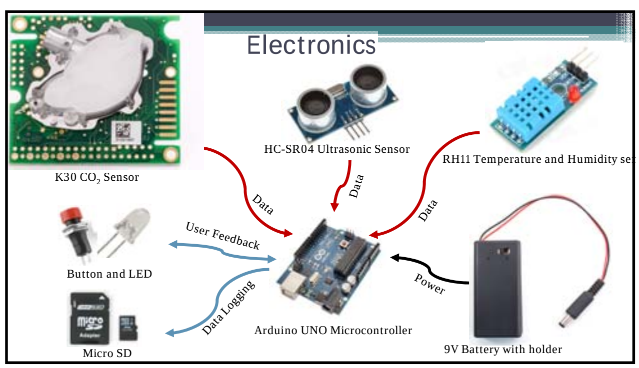



## Concept to Current

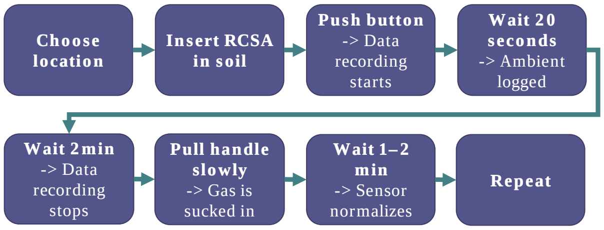


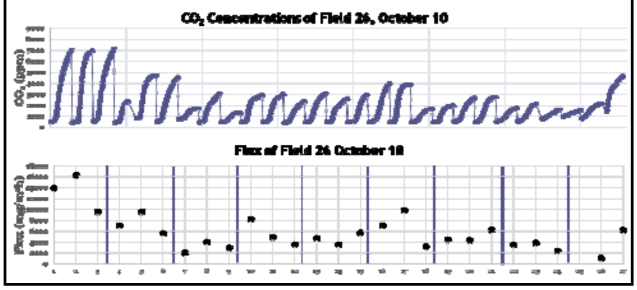
## Electronics



## Gas Sampling Procedure




## Raw and Processed Data




## Improvements

- **Mechanical:** locking connectors, additional O ring seal, improved cutting disk, etc.
- **Electronic:** GPS module, real time clock
- **Feedback:** additional LEDs, LCD screen, adjustable logging time.
- **Sensors:** 1+Hz $CO_2$ Sensor, pressure meter and valve, mixing fan

# Questions?

## K30 Spec Sheet

| Item | $CO_2$ Engine® K30* Art. no. 030-8-0006 |
|---|---|
| Target gas | Carbon dioxide ($CO_2$) |
| Operating Principle | Non-dispersive infrared (NDIR) |
| Measurement range | 0 to 5000 $ppm_{vol}$ |
| Accuracy | ±30 ppm ±3% of reading[1] |
| Response time ($T_{1/e}$) | 20 sec diffusion time |
| Rate of Measurement | 0.5 Hz |
| Operating temperature | 0 to +50 °C |
| Operating humidity | 0 to 95% RH non condensed |
| Storage temperature | -30 to +70 °C |
| Dimensions (mm) | 51 x 57 x 14 mm (Length x Width x approximate Height) |
| Power supply | 4.5 to 14.0 VDC maximum rating (without reverse polarity protection) stabilized to +-5% over load and line changes. Ripple voltage less than 100mV.[2] |
| Warm Up time to spec precision | 1 min |
| Life expectancy | >15 years |
| Compliance with | RoHS directive 2011/65/EU<br>Tested according<br>Immunity: EN 61000-6-3:2007, Emission: EN 61000-6-2:2007 |
| Serial communication | UART, Modbus protocol. Direction control pin for direct connection to RS485 receiver integrated circuit. |
| OUT 1 | D/A Resolution: 10 mV (10 bit)<br>Linear Conversion Range: 0 to 4 V = 0 to 2000 ppm<br>Electrical Characteristics: $R_{OUT}$ < 100 Ω, $R_{LOAD}$ > 5 kΩ |
| OUT 2 | D/A Resolution: 5 mV (10 bit)<br>Linear Conversion Range: 1 to 5V = 0 to 2000 ppm<br>Electrical Characteristics: $R_{OUT}$ < 100 Ω, $R_{LOAD}$ > 5 kΩ |
| OUT 3 | Digital (High/Low) output, 700/800 ppm |
| OUT 4 | Digital (High/Low) output, 900/1000 ppm |
| Maintenance | Maintenance-free when using SenseAir ABC algorithm (Automatic Baseline Correction) |

# Optimization of A Military Waste-to-Jet Fuel Supply Chain in Nevada

**Mohamed Leila, Ph.D. Candidate (Renewable Resources)**

Department of Natural Resources Sciences
Supervisor: Professor Joann Whalen
Co-Supervisor: Professor Jeffrey Bergthorson

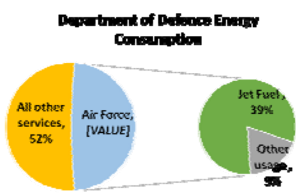
## Content





## Introduction(1/4)

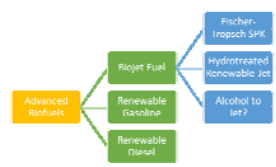
- General Problem: Oil dependency
- Special Problem: The United States imports 50% of its Jet Fuel requirements
- Why Jet fuel? special significance to the DoD
- Solution? Produce more jet fuel locally






## Introduction (2/4)

- Increasing conventional oil production is not a sustainable solution
- Biojet fuels, a class of advanced biofuels, are being considered to supplement JP-8/A-1
- Energy Security and Independence Act set targets for advanced biofuels production in the US






## Introduction (3/4)

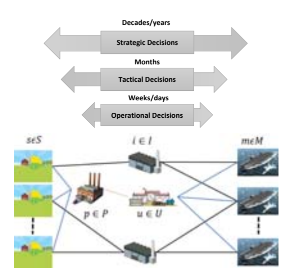
- Air Force Mandate: 50% of jet fuel consumption from renewable sources by 2016
- Navy Mandate: 50% of all fuel requirements from renewable resources by 2020

| EISA compatible | Available locally | Cost competitive | Renewable | Drop-in |
|---|---|---|---|---|
| Life cycle green house gases should be <50% of oil based fuels | Feedstock should be produced in US or Canada | Price per gallon should be <$4 | Feedstock should be renewable | Fuel should be identical to JP-8 |



## Introduction (3/4)

- Supply Chain (SC) optimization is a sub field of Operations Research
- Strategic SC decisions: Facilities locations, maximum capacities, technologies
- Tactical decisions : material flow, operating capacities



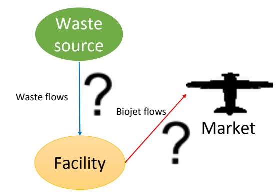
## Content





## Research Question

What is the optimal SC design (network configuration) that maximizes the profits of waste-to-jet fuel enterprises in Nevada?



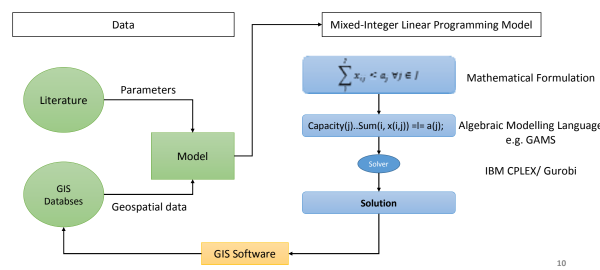



## Content





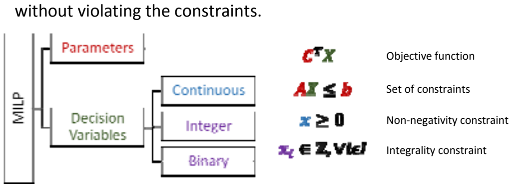
## Methods: Overview






## Methods: Overview

- Constrained optimization problem with linear objective function and constraints
- Finds values for decision variables that optimizes the objective function without violating the constraints.






## Content

## Parameters

Waste availability

- Per capita generation in Nevada
- Multiply by population in county
- Divide by number of transfer stations

Facility parameters

- Modelled after Fulcrum Bioenergy

Demand

- Estimates of jet fuel consumption per military installation

### Assumptions

1.Facility maximizes jet fuel production
2.Waste is purchased at $10/tonne

## Nomenclature

| Sets | Description |
|---|---|
| $i \in I$ | Waste Transfer Stations |
| $j \in J$ | Facility locations |
| $m \in M$ | Markets |
| **Continuous Decision Variables** | |
| $R_j$ | Revenue of facility j ($) |
| $R_{total}$ | Total Revenues of the SC ($) |
| Totalcost | Total costs of the SC ($) |
| Tcost | Transportation costs ($) |
| FC | Fixed costs ($) |
| $oc_j$ | Operating costs of facility j ($) |
| Totoc | Total operating costs ($) |
| $waste_{ij}$ | Amount of waste shipped from transfer station i to facility j (Tonnes) |
| $biofuel_{jm}$ | Amount of biofuel shipped from facility j to market m (MGPY) |
| $Capacity_j$ | Amount of biofuels produced in facility j (MGPY) |

| Parameter | Description |
|---|---|
| $\alpha$ | conversion factor (MGPY per tonne) |
| $wa_i$ | Waste availability on station i |
| cmax | maximum capacity of any facility MGPY |
| cmin | minimum capacity of any facility MGPY |
| ctbio | cost of transporting 1 MGPY per meter |
| ctwaste | cost of transporting 1 tonne of waste per meter |
| fc | cost of constructing one facility per year (assuming 20 years lifetime) |
| pb | price of biofuel in dollars per MGPY |
| pw | price of waste in dollars per tonne |
| opcost | operating costs in dollars per Million gallon |
| $\alpha$ | conversion factor (MGPY per tonne) |
| cmax | maximum capacity of any facility MGPY |
| cmin | minimum capacity of any facility MGPY |
| ctbio | cost of transporting 1 MGPY per meter |
| ctwaste | cost of transporting 1 tonne of waste per meter |
| $d_{ij}$ | Distance from transfer i to facility j |
| $f_{jm}$ | Distance from facility location j to market m |
| **Binary Decision Variable** | |
| $y_j$ | build facility at location j or not |



## Content





## Mathematical Formulation: Objective Function

$$Profit = \sum_{j}^{J} R_j - \left(c_{waste}\sum_{ij}^{IJ} d_{ij}\, waste_{ij} + c_{bio}\sum_{jm}^{JM} f_{jm}\, biofuel_{jm}\right) - \left(fc \cdot \sum_{j}^{J} y_j\right) - \left(pw \cdot \sum_{j}^{J}\sum_{i}^{I} waste_{ij} + \sum_{j}^{J} opcost \cdot capacity_j\right)$$

Revenues | Transportation Costs | Investment Costs | Operating Costs

## Mathematical Formulation: Constraints

Supply constraint $\sum_{j}^{J} waste_{ij} \le wa_i \quad \forall i \in I$

Demand constraint $\sum_{j}^{J} biofuel_{jm} = dm_m \quad \forall m \in M$

Capacity constraint $c_{min} y_j \le \alpha \cdot \sum_{i}^{I} waste_{ij} \le c_{max} y_j \quad \forall j \in J$

Mass balance $\sum_{m}^{M} biofuel_{jm} \le \alpha \cdot \sum_{i}^{I} waste_{ij} \quad \forall j \in J$

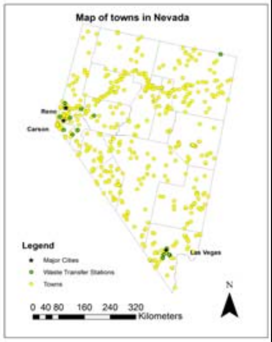
Boolean decision $\frac{biofuel_{jm}}{dm_m} \le y_j \quad \forall j \in J, \forall m \in M$



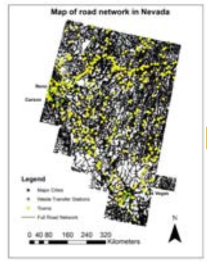
## Content

## Methods: GIS Screening

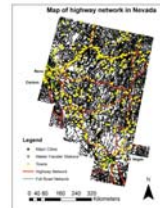
516 towns = 516 candidate facilities locations

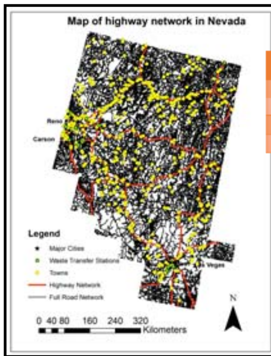



## Methods: GIS Screening

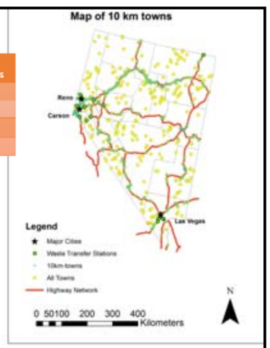



"Rd_Type" = 'Interstate' OR "Rd_Type" = 'US Route'

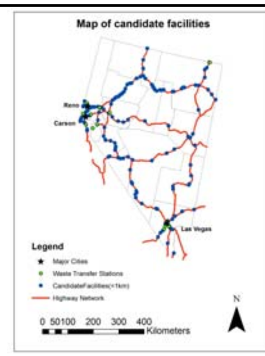



| Highway proximity | # of locations |
|---|---|
| All towns | 516 |
| <10 km | 294 |
| <5 km | 247 |
| <1km | 164 |








## Content





## Methods: Implementation

**Algebraic Modelling Language**
- The model was coded in the Generalized Algebraic Modelling Language GAMS

**Model**
- Number of continuous variables: 3778
- Number of binary variables: 167
- Number of constraints: 1663

**Solver**
- The model was solved using Gurobi solver, offered by the NEOS-Server

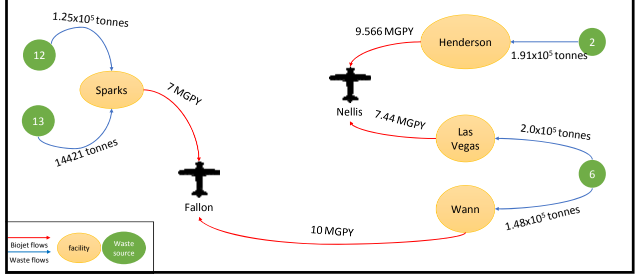
**Hardware**
- The model was solved using the Network Enabled Optimization System (NEOS) offered by University of Wisconsin

## Content

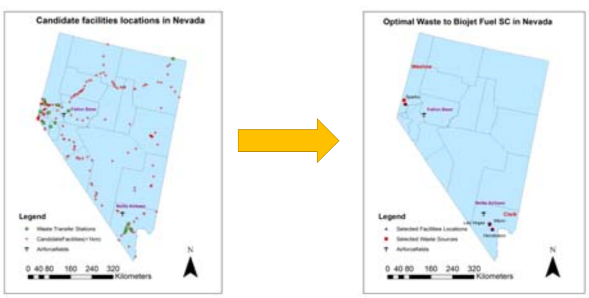




## Results: Network Configuration




## Appendix A: Nevada Case Study Results

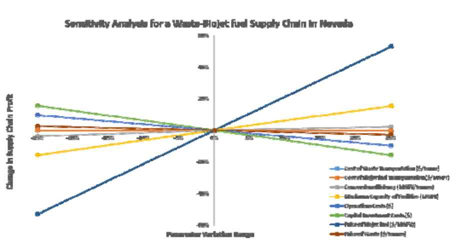



## Content





## Appendix A: Nevada Case Study Sensitivity Analysis




## Content

## Conclusions

Methodological:

- Prescreening of data in GIS environment significantly reduces the data points input to the optimization model, reducing computational burdens

Thematic:

- Four waste-to-jet fuel facilities are needed to meet the military demand in Nevada
- Biojet fuel selling price is the most influential parameter on waste-to-jet fuel supply chains in Nevada

# Thank You
# Questions?

**Contact Information**

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