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

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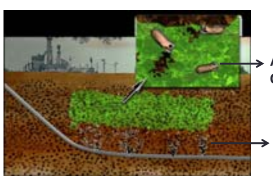
Background

- 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



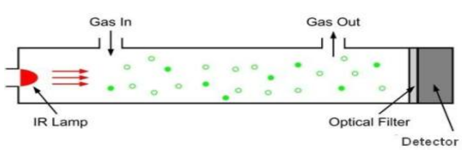
Affected Microbial Community

Oil Pipe Leakage

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

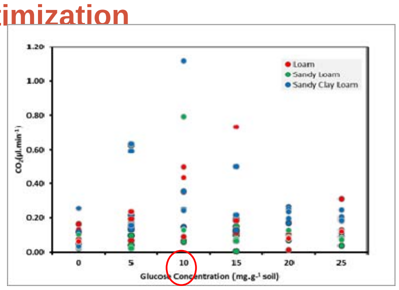
Experimentation

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).

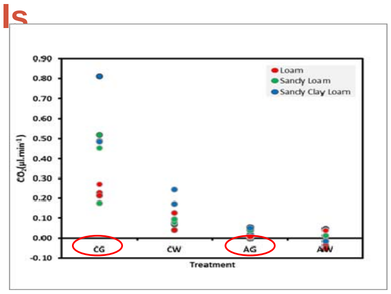
Experiment 3:
To evaluate the applicability of sensor to determine petroleum hydrocarbon contamination in soil. Five diesel treatments (0, 5, 20, 60 and 150 mg/g of soil) were applied to all three soils.

Results: Exp. 1. Substrate Optimization



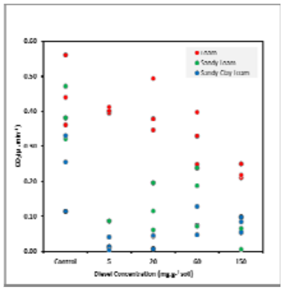
Emission of CO_2 from three soils on adding aq. glucose at different concentrations. Data represents 20 g of soil samples and five replicates.

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

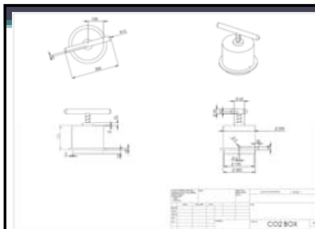
RCSA

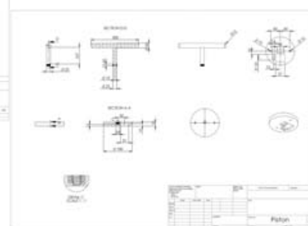
Logistics - No site preparation

Labor - Single person job,

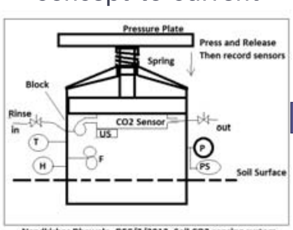
Time - No need for lab analysis

Mechanical Design

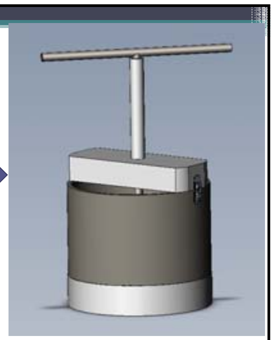




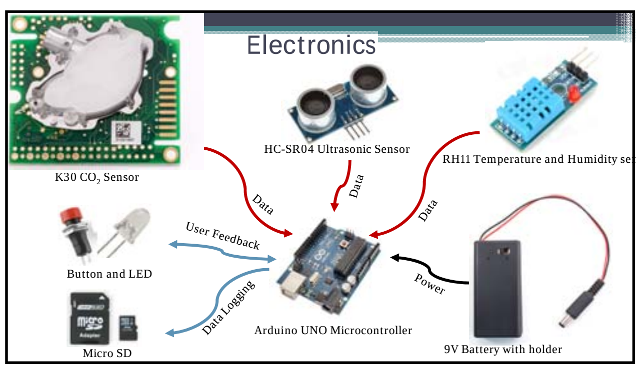
Concept to Current



Nandkishor Dhawale- DEC/3/2013- Soil CO2 sensing system



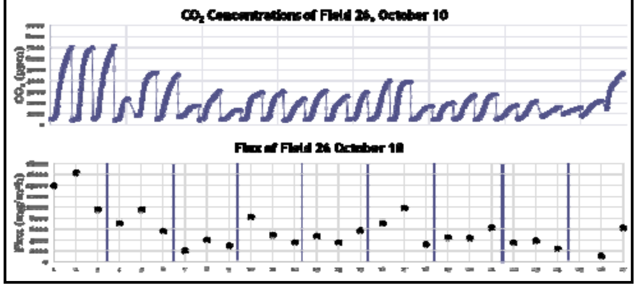
Electronics



Gas Sampling Procedure

1. **Choose location**
2. **Insert RCSA in soil**
3. **Push button** -> Data recording starts
4. **Wait 20 seconds** -> Ambient logged
5. **Wait 2min** -> Data recording stops
6. **Pull handle slowly** -> Gas is sucked in
7. **Wait 1–2 min** -> Sensor normalizes
8. **Repeat**

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 Tested according 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) Linear Conversion Range: 0 to 4 V = 0 to 2000 ppm Electrical Characteristics: R_{OUT} < 100 Ω, R_{LOAD} > 5 kΩ
OUT 2	D/A Resolution: 5 mV (10 bit) Linear Conversion Range: 1 to 5V = 0 to 2000 ppm 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

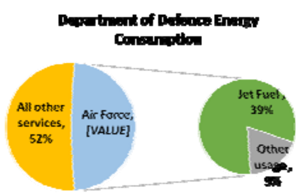
Mohamed Leila, Ph.D. Candidate (Renewable Resources)

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

Content

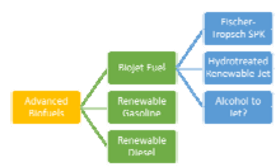
Introduction(1/4)

- 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



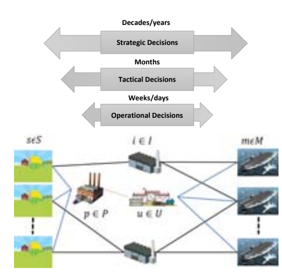
Introduction (3/4)

- 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)

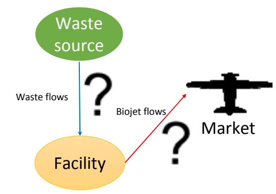
- Supply Chain (SC) optimization is a sub field of Operations Research
- Strategic SC decisions: Facilities locations, maximum capacities, technologies
- Tactical decisions : material flow, operating capacities



Content

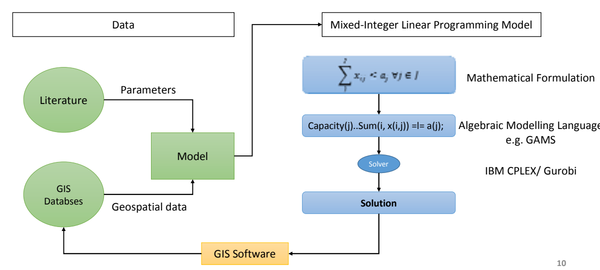
Research Question

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



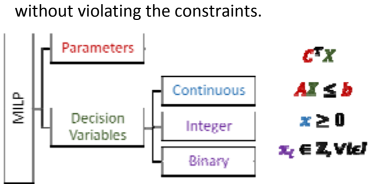
Content

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.



$c^T x$ Objective function

$Ax \leq b$ Set of constraints

$x \geq 0$ Non-negativity constraint

$x_i \in \mathbb{Z}, \forall i \in I$ Integrality constraint

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)

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Mathematical Formulation: Objective Function

$$Profit = \sum_j R_j - \left(c_{waste}\sum_i^I\sum_j^J d_{ij}\,waste_{ij} + c_{bio}\sum_j^J\sum_m^M f_{jm}\,biofuel_{jm}\right) - \left(fc \cdot \sum_j y_j\right) - \left(pw \cdot \sum_i\sum_j waste_{ij} + \sum_j opcost \cdot capacity_j\right)$$

Revenues | Transportation Costs | Investment Costs | Operating Costs

Mathematical Formulation: Constraints

Supply constraint $\sum_j^J waste_{ij} \le w_i \quad \forall i \in I$

Mass balance $\sum_m^M biofuel_{jm} \le a \cdot \sum_i^I waste_{ij} \quad \forall j \in J$

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

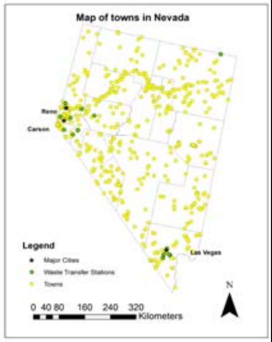
Boolean decision $\frac{biofuel_{jm}}{dm_m} \le y_j \quad \forall j \in J, \forall m \in M$

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

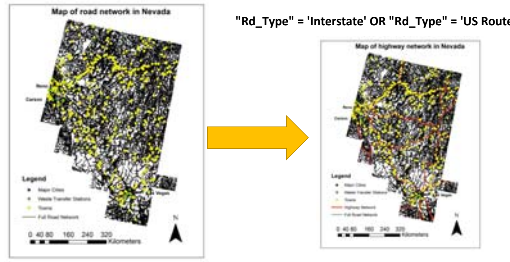
Content

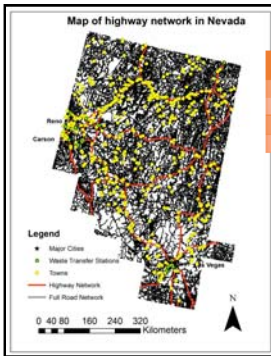
Methods: GIS Screening

516 towns = 516 candidate facilities locations

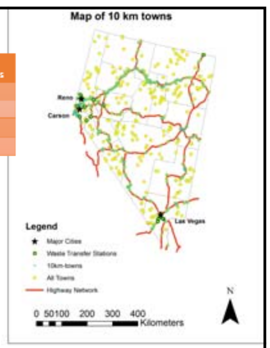


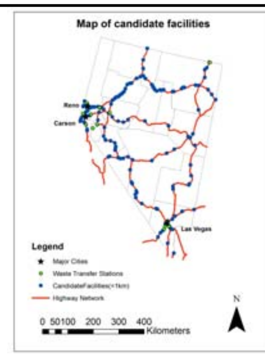
Methods: GIS Screening





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

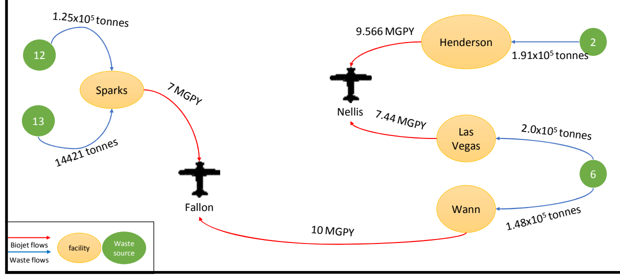
Model
- Number of continuous variables: 3778
- Number of binary variables: 167
- Number of constraints: 1663

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

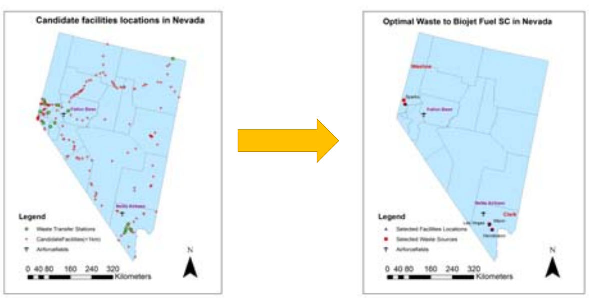
Hardware
- The model was solved using the Network Enabled Optimization System (NEOS) offered by University of Wisconsin

Content

Results: Network Configuration



Appendix A: Nevada Case Study Results



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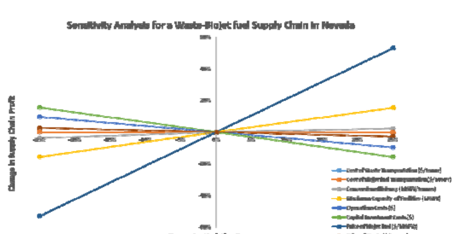
Appendix A: Nevada Case Study Sensitivity Analysis



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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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