CONTENTS

• NSU Sustainable Intelligent Infrastructure
  – Platform Development
  – AD Control

• Anaerobic Digestion Dynamic Model
  – The model
  – Calibration
  – Results

• Conclusions and next steps
ANAEROBIC DIGESTION CONTROL

Optimized power production and feedstock revenue – Estimated 500% increase in biogas production with optimized codigestion with FOG
ANAEROBIC DIGESTION OPTIMUM FEEDING SCHEDULING

**FEEDSTOCK CHARACTERISTICS**
- Type of feedstock
- Feed flowrate
- Total Solids, Volatile Solids, Biodegradability, TKN, COD, TOC

**DYNAMIC MODEL**

**DIGESTER “HEALTH” VARIABLES**
- pH
- Alkalinity
- Volatile Fatty Acids (VFA)

**DIGESTER PERFORMANCE VARIABLES**
- Total Biogas Production
- % Methane
- % Carbon Dioxide

**FEEDSTOCK-SPECIFIC COEFFICIENTS BASED ON CHARACTERISTICS**
- Yield coefficients for VFA, NH3, CO2
- Maximum Bacterial Growth Rate
- Half Saturation Constants

**DIGESTER FEEDING DECISION BASED ON MODEL OUTPUT FOR SPECIFIC FEEDING REGIME**
SET OF 14 DIFFERENTIAL EQUATIONS SOLVED SIMULTANEOUSLY

- Biodegradable volatile suspended solids for each feedstock
- pH, Volatile Fatty Acids, Ammonia, Alkalinity in digester
- Concentration of Acetogenic and Methanogenic Bacteria
- Total Biogas Production Rate
- Methane Concentration in Gas Phase
- Carbon Dioxide Concentration in Gas Phase
CALIBRATION OF MODEL FOR STEADY-STATE (RIDGECWOOD)

BIOGAS FLOWRATE AND FOG ADDITION IN RIDGECOOD FOR OCTOBER 2013

VARIATION IN DIGESTER pH AND ALKALINITY (2013)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Calibrated Model (Steady state)</th>
<th>Ridgewood Plant Data</th>
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<tbody>
<tr>
<td>pH (standard units)</td>
<td>7.12</td>
<td>7.16</td>
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<tr>
<td>VFA (mg/L)</td>
<td>172</td>
<td>170</td>
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<tr>
<td>Alkalinity (mg/L CaCO₃)</td>
<td>2,200</td>
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<td>Biogas Production (cuft/d)</td>
<td>61,700</td>
<td>62,500</td>
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<tr>
<td>%CH₄ (v/v)</td>
<td>64%</td>
<td>67%</td>
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<td>%CO₂ (v/v)</td>
<td>36%</td>
<td>33%</td>
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MODEL APPLIED TO RIDGEWOOD DIGESTER FEEDING REGIME

Variation of Digester Constituents - RIDGEWOOD - PLANT DATA OCT 2013

- BVSS Feedstock, g/L
- WW Sludge Feed
- FOG Feed

Variation of Digester Constituents - RIDGEWOOD - PLANT DATA OCT 2013

- VFA, g/L
- VFA/ALKALINITY
- ALKALINITY, g/L as CaCO3
- NH3, g/L

DATE (MONTH/DAY)

10/16 10/17 10/18 10/19 10/20 10/21 10/22 10/23 10/24 10/25 10/26
MODEL APPLIED TO RIDGEWOOD DIGESTER FEEDING REGIME

VARIATION IN pH

Gas Production and Composition

- Gas Production, Total
- % CO₂
- % CH₄
MODEL PREDICTION COMPARED TO RIDGEWOOD ACTUAL DATA

Gas Production and Composition - RIDGEWOOD - PLANT DATA OCT 2013

BIOGAS PRODUCTION, %CH4 AND %CO2 IN RIDGEWOOD FOR OCTOBER 2013

NATURAL SYSTEMS UTILITIES
**USER INTERFACE – DECISION TOOL**

**DYNAMIC MODEL OF ANAEROBIC DIGESTION**

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<td>END DATE</td>
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### DIGESTER FEEDING SCHEDULE

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<th>START TIME</th>
<th>STOP TIME</th>
<th>% SOLIDS</th>
<th>% VOLATI</th>
<th>GAL/D</th>
<th>PRIM/ D</th>
<th>ALK, mg/L</th>
<th>NH3, mg/L</th>
<th>% SOLIDS</th>
<th>% VOL</th>
<th>ALK</th>
<th>NH3</th>
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**WW PRIMARY - LEAVE BLANK IF ENTER IN COMBINED WW SLUDGE**

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<th>% VOLATI</th>
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<th>ALK, mg/L</th>
<th>NH3, mg/L</th>
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<th>% VOL</th>
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**WW WAS - LEAVE BLANK IF ENTER IN COMBINED WW SLUDGE**

<table>
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<th>STOP TIME</th>
<th>% SOLIDS</th>
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<th>GAL/D</th>
<th>ALK, mg/L</th>
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DYNAMIC MODELING – INPUT/OUTPUT

FEEDSTOCK LOADING RATE

Variation of Digester Constituents

VFA, g/L and VFA/ALKALINITY

ALKALINITY, g/L as CaCO3, NH3, g/L

DATE (MONTH/DAY)

10/16 10/17 10/18 10/19 10/20 10/21 10/22 10/23 10/24 10/25 10/26
DEATH OF A DIGESTER I

RIDGEWOOD CASE - EFFECT OF QUANTITY OF FOG FED ON TOTAL GAS PRODUCTION

RIDGEWOOD CASE - EFFECT OF QUANTITY OF FOG FED ON % CH4 AND % CO2 IN BIOGAS
DEATH OF A DIGESTER II

RIDGEWOOD CASE - EFFECT OF QUANTITY OF FOG FED ON DIGESTER pH

RIDGEWOOD CASE - EFFECT OF QUANTITY OF FOG FED ON DIGESTER VFA/ALKALINITY RATIO
DYNAMIC MODELING – VARYING FEEDSTOCK

FEEDSTOCK LOADING RATE

DATE (MONTH/DAY)

6/30 7/1 7/2 7/3 7/4 7/5 7/6 7/7 7/8 7/9 7/10

FEEDSTOCK, GALLONS/D

0 10,000 20,000 30,000

COMBINED WW SLUDGE
SSO
FOG
COW MANURE

GAS PRODUCTION AND COMPOSITION

TOTAL BIOGAS, CUFT/D 35°C

6/30 7/1 7/2 7/3 7/4 7/5 7/6 7/7 7/8 7/9 7/10

Gas Production, Total
% CH4
% CO2
% CH4 and % CO2
DYNAMIC MODELING – VARYING FEEDSTOCK

VARIATION IN DIGESTER CONSTITUENTS

VFA, g/L AND VFA/ALKALINITY

DATE (MONTH/DAY)

ALKALINITY, g/L as CaCO3, NH3, g/L

VFA
vfal/alk
ALKALINITY
NH3

VARIATION IN pH

DATE (MONTH/DAY)
pH
DYNAMIC MODEL OF ANAEROBIC DIGESTION – PROGRESS TO DATE

- Feedstocks Modeled
  - Municipal Primary Sludge
  - Waste-Activated Sludge
  - FOG
  - Source-separated organics (SSO’s)
  - Cow Manure
  - Fruit and Vegetable waste
  - Poultry litter
  - Crop residues

- Dynamic Model calibrated and feeding regimes evaluated for one case (Ridgewood)
CONCLUSIONS

- Dynamic model of anaerobic digestion is a state-of-the-art interactive operations tool

- Optimal scheduling of codigestion provides a means of maximizing tipping fees and biogas revenues which is tailored to available feedstocks

- User interface provides operator with an immediate output by which to make a decision on the feeding schedule of available feedstocks

- Model can be easily expanded for new feedstocks based on waste characteristics
NEXT STEPS

- Optimization of hourly feeding schedules to produce a desired biogas production rate in order to minimize biogas storage and optimize power production.

- Incorporate hydrogen sulfide modeling to optimize digester management by pH control and sulfide precipitation which optimizes cost of chemical addition and SOx emissions.
CONTACT INFORMATION

Our thanks to NEBRA and NEWEA Residuals Committee for allowing us to present our work here. It has been a pleasure to participate.

For additional information please contact:
Eugenio Giraldo, PhD, Chief Technology Officer
Natural Systems Utilities
giraldo@naturalsystemsutilities.com