Feasibility Study:
FastOx® Gasification for Wood Waste to RNG
Study Execution

- **Motivation**
  - Production of RNG to help green the CA economy (SB 32, AB 3232, SB 100)
  - Assist with waste wood, forest and agricultural biomass residue conversion (decreasing fire risk and lowering overall criteria pollutant emissions)
  - Extend life of existing CoGen facilities, with associated local community economic benefits

- **Main Focus**
  - Generic California site, 1000 PSIG RNG injection pressure and meeting Rule 21 and Rule 30
  - Engagement with proven RNG Isle manufacturers, optimization of the combined FastOx-RNG plant
  - Evaluate LCOF vs various factors (pressure, LCFS credit, biomass fee/cost etc.)
  - Provide baseline study to progress into further project development

- **Main Documents Generated and Final Deliverables**
  - Feasibility-level Engineering Documents (for multiple plant configurations): Design Basis, Process Description, BFD, PFD (inc. Utility Summary), Major Equip. List, Site Plot Plan, CAPEX and OPEX
  - Final Report including LCOF Calculations and corresponding Optimal Plant Configuration selection.
FastOx Gasification

Waste Becomes:
- TIRES
- PETCOKE
- INDUSTRIAL
- C & D
- BATTERIES
- E-WASTE
- HAZARDOUS
- BIOMASS
- MSW
- MEDICAL

Syngas 90%

End Products:
- HYDROGEN
- ELECTRICITY
- FERTILIZER
- CLEAN WATER
- CHEMICALS
- FUELS
- CEMENT
- RARE METAL
- HEAT
- PROTEIN

Metal & Inert Stone 10%
FastOx Gasification
Study Execution – Additional Assumptions

• Major Assumptions
  • Site: Generic CA location
  • Feed Material
    • 40%wt. Forest Thinnings, 40%wt. C&D Wood Waste, 20% Ag. Residues
    • See below compositions. Assuming a conservative ~36%wt. moisture.
  • Utility Costs
    • Local Natural Gas: $3.00/MMBTU
      (2019 Forecasted Avg. Procurement Cost)
    • Local Electricity: $0.120/kWhe
      (2019 Forecasted Wholesale Cost)
Study Execution – Multiple Vendor Engagement

Detailed specification sheets. Preliminary Design Packages Received. Bid-Tab Analysis and Downselect
## Study Results – RNG Quality

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SYNGAS</th>
<th>SNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature [°C]</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Pressure [bar_g]</td>
<td>15</td>
<td>9.6</td>
</tr>
<tr>
<td>Molar Flow [kg/mole/h]</td>
<td>2997</td>
<td>640</td>
</tr>
<tr>
<td>Vol Flowrate [Nm³/h]</td>
<td>67184</td>
<td>14342</td>
</tr>
<tr>
<td>Mass Flow [kg/h]</td>
<td>59171</td>
<td>10564</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>41.49%</td>
<td>0.04%</td>
</tr>
<tr>
<td>CO</td>
<td>41.56%</td>
<td>0.00%</td>
</tr>
<tr>
<td>CO₂</td>
<td>16.05%</td>
<td>0.93%</td>
</tr>
<tr>
<td>H₂O</td>
<td>0.53%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Methane</td>
<td>0.00%</td>
<td>97.24%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.38%</td>
<td>1.78%</td>
</tr>
<tr>
<td>Ammonia</td>
<td>53 ppm</td>
<td>0</td>
</tr>
<tr>
<td>COS</td>
<td>9 ppm</td>
<td>0</td>
</tr>
<tr>
<td>H₂S</td>
<td>273 ppm</td>
<td>0</td>
</tr>
</tbody>
</table>

### Quality of Gas

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PG&amp;E (Rule 21)</th>
<th>Sempra (Rule 35)</th>
<th>Wood-TEP (VERTA) Product</th>
<th>Most Spec'</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>&lt;= 1.68 % vol.</td>
<td>&lt;= 3.00% vol.</td>
<td>0.93% vol.</td>
<td>Y</td>
</tr>
<tr>
<td>CO₂</td>
<td>&lt;= 1.68% vol.</td>
<td>&lt;= 2.00% vol.</td>
<td>0.00% vol.</td>
<td>Y</td>
</tr>
<tr>
<td>Inerts - Total (CO₂, N₂, O₂ etc.)</td>
<td>&lt;= 4.00% vol.</td>
<td>&lt;= 4.00% vol. And, zero H₂S-treatment served or by product</td>
<td>2.71% vol.</td>
<td>Y</td>
</tr>
<tr>
<td>S - H₂S</td>
<td>&lt;= 4 ppmV</td>
<td>&lt;= 4 ppmV</td>
<td>0 ppmV</td>
<td>Y</td>
</tr>
<tr>
<td>S - Mercaptan</td>
<td>&lt;= 8 ppmV</td>
<td>&lt;= 5 ppmV</td>
<td>0 ppmV</td>
<td>Y</td>
</tr>
<tr>
<td>S - Total</td>
<td>&lt;= 17 ppmV</td>
<td>&lt;= 12 ppmV</td>
<td>0 ppmV</td>
<td>Y</td>
</tr>
<tr>
<td>H₂O, P &lt;= 800 PSIG</td>
<td>&lt;= 7X/(120) x MMBtu/SCF @ 800PSIG</td>
<td>&lt;= 45 °F @ 800 PSIG</td>
<td>TBC</td>
<td>Y</td>
</tr>
<tr>
<td>Hydrocarbon Dewpoint, P &lt;= 800 PSIG</td>
<td>&lt;= 20 °F @ 800 PSIG</td>
<td>TBC</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Liquids</td>
<td>zero</td>
<td>zero</td>
<td>TBC</td>
<td>Y</td>
</tr>
<tr>
<td>Mercurability</td>
<td>zero dust, sand &amp; grit, gums, oils etc.</td>
<td>zero</td>
<td>TBC</td>
<td>Y</td>
</tr>
<tr>
<td>Temperature</td>
<td>60 °F &lt; T Injection &lt;= 130 °F</td>
<td>50 °F &lt; T Injection &lt;= 135 °F</td>
<td>90 °F</td>
<td>Y</td>
</tr>
<tr>
<td>Heating Valve - HVN</td>
<td>970 °F HHV; Btu/scf(day) &lt;= 1150</td>
<td>902.2 Btu/scf(day)</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Interchangeability</td>
<td>1279 °C Wobbe &lt;= 1385</td>
<td>902.2 Btu/scf(day)</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Biomechanic Max Allowable Constituents</td>
<td>Carcinogenic: n/a for this study - wouldn't be accurately modeled</td>
<td>Carcinogenic: n/a for this study - wouldn't be accurately modeled</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Non-Carcinogenic: n/a for this study - wouldn't be accurately modeled</td>
<td>Non-Carcinogenic: n/a for this study - wouldn't be accurately modeled</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Pipeline Integrity</td>
<td>Pipeline Integrity</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>NH₃</td>
<td>0.001% vol.</td>
<td>0 ppmV</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>H₂</td>
<td>0.15% vol.</td>
<td>0 ppmV</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Hg</td>
<td>0.88 mg/m³</td>
<td>0.04 % vol.</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Siloxanes</td>
<td>0.91 mg/(L)(mg)</td>
<td>0 ppmV</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

Note: 1 SCF (standard cubic foot) gas is measured at 1 atmosphere and 70°F.
Study Results – Plot Plan

Preliminary Site:
1050’ x 700’
= 735,000 SF
= 17 acres

Major Processing Units
(FastOx Gasification, RNG Isle, BOP)

Feed Dryers

Material Reception,
Pre-Processing,
Storage

O2 Plant (and CO2 Product Storage)
Study Results – CAPEX (LP scenario)

<table>
<thead>
<tr>
<th>Major Equipment / Isle</th>
<th>Modularized / Packaged Equip CAPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Pre-Processing Isle</td>
<td>$38,740,000</td>
</tr>
<tr>
<td>FastOx Gasification (GPRC) Isle</td>
<td>$35,600,000</td>
</tr>
<tr>
<td>Gas Cleaning Isles</td>
<td>$5,115,000</td>
</tr>
<tr>
<td>RNG Isle</td>
<td>$35,850,000</td>
</tr>
<tr>
<td>Oxygen Production</td>
<td>$51,000,000</td>
</tr>
<tr>
<td>Utilities Isles</td>
<td>$11,765,000</td>
</tr>
</tbody>
</table>

$178,070,000

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Modular Equipment and Isle Costs</td>
<td>$178,070,000</td>
</tr>
<tr>
<td>Additional Installation Costs</td>
<td>$60,000,000</td>
</tr>
<tr>
<td>Project Development Costs</td>
<td>$45,210,000</td>
</tr>
</tbody>
</table>

TICO (+/- 30%) $283,300,000

Note: Installation and Project Development Costs are highly-specific on site selected.
Study Results – LCA

- UCD LCA and Report
- Assumed smaller, 50MTPD system (less efficient), assumed 90% uptime (at 1,000MTPD would be 95%) and MSW (significantly higher CI compared to biomass/wood waste).
Study Results – Simple 10yr Breakeven Price

- HP more favorable over LP
- Syngas recycle (SR) more favorable over nat. gas (NG) procurement.
- Assumption: all CAPEX absorbed in Yr0, (no discounts or grants)

<table>
<thead>
<tr>
<th>Config</th>
<th>TICC</th>
<th>RNG Produced</th>
<th>LCFS Credit</th>
<th>Feed Mtl. Tip Fee</th>
<th>Annual Profit</th>
<th>SNG Sale Price Req.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[$MM]</td>
<td>[MMBtu/d]</td>
<td>[$/MMBtu]</td>
<td>[$/ton]</td>
<td>[$/yr]'</td>
<td>[$/MMBtu]</td>
</tr>
<tr>
<td>HP (150 PSIG), NG</td>
<td>$277.1</td>
<td>13,071</td>
<td>$15.85</td>
<td>$0.00</td>
<td>$27.7</td>
<td>$10.22</td>
</tr>
<tr>
<td>HP (150 PSIG), SR</td>
<td>$277.1</td>
<td>11,548</td>
<td>$15.47</td>
<td>$0.00</td>
<td>$27.7</td>
<td>$14.68</td>
</tr>
<tr>
<td>LP (&lt;15 PSIG), NG</td>
<td>$283.3</td>
<td>12,870</td>
<td>$15.85</td>
<td>$0.00</td>
<td>$28.3</td>
<td>$-5.98</td>
</tr>
<tr>
<td>LP (&lt;15 PSIG), SR</td>
<td>$283.3</td>
<td>11,433</td>
<td>$15.47</td>
<td>$0.00</td>
<td>$28.3</td>
<td>$-2.14</td>
</tr>
</tbody>
</table>
Study Results – LCOF and Sensitivity Analysis

### LCFS Credit ($20.00)
- $15.47
- $0.00 ($/MMBTU)

### Feed ($45)
- $30
- $30 ($/ton)

### CO2 ($0.200)
- $0.140
- $0.000 ($/100CF)

### CAPEX ($194MM)
- $277MM
- $380MM

### Elec ($0.040)
- $0.120
- $0.160 ($/KWh)

### Uptime (97.5%, 95%, 85%)

### NG ($2.000)
- $3.000
- $8.900 ($/MMBTU)

### LCOF ($/MMBTU)
- $-8.927

### Sensitivity Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Impact on LCOF (cents/MMBTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed</td>
<td>-10.937</td>
</tr>
<tr>
<td>CO2</td>
<td>-10.937</td>
</tr>
<tr>
<td>CAPEX</td>
<td>-11.148</td>
</tr>
<tr>
<td>Elec</td>
<td>-9.156</td>
</tr>
</tbody>
</table>

### Summary
- The sensitivity analysis shows that the feed and CO2 have the most significant impact on the LCOF, followed by CAPEX and elec.
- The LCOF is sensitive to changes in the input parameters, indicating the need for careful consideration in future projects.
Presentation Conclusions

- **FastOx-based projects** for the conversion of waste wood exhibit **strong project economics** that don’t require Carbon Credits to be feasible

- Sierra Energy supports the Standard Renewable Gas Interconnection Tariff, as it will lower project development costs and interconnection costs (on both sides), lowering the cost of RNG, increasing project and technology adoption.

- If the ‘Maximum allowable H₂’ in the injected RNG can be increased (above the existing 0.10%vol. limit), this **would have additional positive impact on the RNG yield, and CAPEX and OPEX**, lowering RNG costs and further increasing project and technology adoption.