Flex Fuel Polygeneration: Optimizing Cost, Sustainability, and Resiliency

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Analyzing New Energy Investment Portfolios

- **Program Objective**
  - Analyze new energy and transportation investment portfolios
  - Become more sustainable

- **Resilient energy production facilities**
  - Capacity of the system to function while incurring contingencies

- **Flexibility**
  - Location
  - Energy sources
  - Energy carriers
Initial Analysis of FFPG Systems

- Design power plants that are resilient to environmental and economic shocks
- Utilize multiple inputs, create multiple outputs
- Design a system to perform high level techno-economic analysis (TEA)
- Determine economic feasibility of each plant
Level of Uncertainty of this Project

- **Study Estimate**
  - Intended to serve as a cost indicator at an early stage of the project
  - Utilize detailed process models and data available in literature
  - Level of accuracy $\pm 30\%$

<table>
<thead>
<tr>
<th>Estimation Type</th>
<th>Accuracy Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detailed</td>
<td>-5% to +10%</td>
</tr>
<tr>
<td>Definitive</td>
<td>-1% to +20%</td>
</tr>
<tr>
<td>Preliminary</td>
<td>-20% to +25%</td>
</tr>
<tr>
<td><strong>Study</strong></td>
<td>-25% to +30%</td>
</tr>
<tr>
<td>Order of Magnitude</td>
<td>-30 to +50%</td>
</tr>
</tbody>
</table>

(Couper 2003)
Conventional Approaches to Energy Conversion

Energy Source → Energy Carrier

(Coal, Biomass, Wind, Natural Gas, Photons) → (Fuel, Chemicals, Electricity, Biochar, Heat)

Energy Source → Energy Carrier → Energy Carrier
The Effect of Extreme Events on Energy Production

Both renewable and fossil fuel feedstock are vulnerable to contingencies

- Availability
  - Water supply and temperature, wind patterns and intensity, solar radiation
- Transportation
  - Pipelines, railways, highways
- Market demand
  - Fluctuations in the electricity and fuel sectors
Recent Effects of Drought on Ethanol Production

U.S. Crop Report May-August 2012 (percent of total crop by condition)

U.S. Production of Fuel Ethanol (thousand barrels per day)

(EIA 2012)
Possible Effects of Hurricanes on Fuel Production

Hurricane Isaac

Hurricane Sandy

(EIA 2012)
Proposed Flex Fuel Polygeneration

Energy Source → Energy Carrier
Energy Source → Energy Carrier

(Coal, Biomass, Wind, Natural Gas, Photons) → (Fuel, Chemicals, Electricity, Biochar, Heat)
Challenges Faced when Considering FFPG

- Technology Down Selection
  - Development of technology, profitability, costs involved, outlook

- Feedstock Cost/Availability
  - Location, size of plant, transportation

- Market Demand
  - Products compatible with infrastructure, demands

- GHG Emissions

<table>
<thead>
<tr>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
</tr>
<tr>
<td>Gasification</td>
</tr>
<tr>
<td>Pyrolysis</td>
</tr>
<tr>
<td>Fuel cell</td>
</tr>
<tr>
<td>Solar photovoltaic</td>
</tr>
<tr>
<td>Solar thermal</td>
</tr>
<tr>
<td>Geothermal</td>
</tr>
<tr>
<td>Wind power</td>
</tr>
<tr>
<td>Tidal power</td>
</tr>
<tr>
<td>NG or coal CC</td>
</tr>
<tr>
<td>Hydroelectric</td>
</tr>
</tbody>
</table>
Advantages of Flex Fuel Polygeneration

- A study by He et al. has shown that multiple input multiple output systems can save costs and energy
  - Higher energy utilization
  - Capital savings by joint usage
  - Waste emissions savings

  (He 2012)

- FFPG can also...
  - take advantage of market changes in primary energy costs
  - take advantage of market changes in price of energy carriers
  - improve environmental performance of power plants
    - (including carbon negative energy)
Reasons for Focusing on Chosen Systems

• Abundance and price of natural gas
• Lower capital costs associated with natural gas energy production
• NG distribution infrastructure is developed
• Fischer Tropsch (FT) synthesis has been proven at commercial scale for a long time (Espinoza 1999)

<table>
<thead>
<tr>
<th>Potential Technologies</th>
<th>Electricity Generation Capital Costs ($/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onshore Wind</td>
<td>$2090</td>
</tr>
<tr>
<td>Power from Biomass</td>
<td>$2620</td>
</tr>
<tr>
<td>Fuel Cell</td>
<td>$5800</td>
</tr>
<tr>
<td>Natural Gas CC</td>
<td>$920</td>
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<tr>
<td>Nuclear</td>
<td>$3040</td>
</tr>
<tr>
<td>Solar Photovoltaic</td>
<td>$5200</td>
</tr>
<tr>
<td>Hydropower</td>
<td>$2040</td>
</tr>
<tr>
<td>Coal</td>
<td>$1920</td>
</tr>
</tbody>
</table>

(U.S. DOE 2012)
Schematics of Methane Refinery

Adapted from (Swanson 2010) and (Brown 2003)
Methane Refinery Sensitivity Analysis

- Fuels Selling Price: 2.77:3.25:3.82 ($/gal)
- Grassroots Capital Cost: 130:100:70 (%)
- Natural Gas Purchase Cost: 6.60:5.05:3.50 ($/GJ)
- MSW Methane Production: 0.15:0.21:0.27 (m³/kg)
- Income Tax Rate: 30:35:39 (%)
- MSW Tipping Fee: 64.15:49.15:34.15 ($/ton)
- Balance of Plant: 16:12:8 (% of TPEC)
- Electricity Selling Price: 4.0:6.1:8.0 (₵/kWh)

IRR (%)
Baseline 5.51%

IRR (%)
Schematics of Methane/Wind Refinery

Adapted from (Swanson 2010) and (Brown 2003)
Methane/Wind Refinery Sensitivity Analysis

Methane/Wind Refinery IRR (%)

-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8
IRR (%)

0.38% baseline

-3.58 -2.00 -2.71 -0.42 -0.12 -0.12 -0.08 0.04 -0.14

Fuels Selling Price 2.77:3.25:3.82 ($/gal)
Grassroots Capital Cost 130:100:70 (%)
Natural Gas Cost 6.60:5.05:3.50 ($/GJ)
Income Tax Rate 30:35:39 (%)
Electrolyzer Capacity Factor 36:52:68 (%)
WT Annual Production 600:858:1115 (GWh)
Hydrogen Selling Price 0.9:1.26:1.6 ($/kg)
Balance of Plant 16:12:8 (% of TPEC)
Electricity Selling Price 4.0:6.1:8.0 (₵/kWh)
The Role of Feedstock Costs in Plant Economics

FFPG Plant Cost Distributions

Percent of Total Costs

- Initial Methane Refinery Costs
- Initial Methane/Wind Refinery Costs
- Methane Refinery Costs Yr 20
- Methane/Wind Refinery Costs Yr 20

Legend:
- Green: Feedstock
- Red: O & M
- Blue: Equipment
Concluding Remarks

- Feedstock prices play a large role in plant economics
- Price and availability of feedstock are vulnerable to contingencies
- FFPG plants have the ability to adjust to feedstock prices, product prices, and can improve plant efficiency
• National Science Foundation for sponsorship of this study

• CSET Staff – Ryan Smith

• Collaboration with Professors Guiping Hu, Mark Wright, and James McCalley

• Fellow graduate students a CSET
References


• EIA (2012) Drought has significant effect on corn crop condition. Washington, DC, Energy Information Administration.

