Rugged Fuel Cells: Clean power from dirty fuels
Team

Cleantech to Market Team

Jon Bachman  
PhD Chemical Engineering  
2018

Ben Bayat  
MBA  
2014

Sibel Leblebici  
PhD Materials Science  
2015

Mike Lebow (Team Lead)  
MBA  
2014

Ari van Schilfgaarde  
JD  
2015

James Tinker  
MDP  
2014

Point Source Power Team

Craig Jacobson  
Inventor, Co-Founder, CEO

Michael Tucker  
Electrochemical Technologies Group  
Lawrence Berkeley National Laboratory

Copyright © 2013

2
The off-grid natural gas market is growing.

North American shale plays
(as of May 2011)
The off-grid natural gas market is growing
The off-grid natural gas market is growing
The off-grid natural gas market is growing
The off-grid natural gas market is growing.
The off-grid natural gas market is growing
The off-grid natural gas market is growing

(VIDEO TOUR)
The off-grid natural gas market is growing

Off-grid natural gas wells require venting

Venting = $6B worldwide
Pneumatic venting results in harmful emissions

Cumulative Emissions Saved

US, MMTCO$_2$e, 2007-2011

- Switch to Natural Gas: 198
- Renewables: 116

Note: 1 car picture = 1M cars

Copyright © 2013
Pneumatic venting results in harmful emissions

Cumulative Emissions Saved

US, MMTCO$_2$e, 2007-2011

Switch to Natural Gas  |  Renewables

48                        |  116

Note: 1 car picture = 1M cars
Copyright © 2013
Pneumatic venting results in harmful emissions

Cumulative Emissions Saved

*US, MMTCO₂e, 2007-2011*

Switch to Natural Gas

Worldwide venting has the climate impact equivalent to 10M cars

Note: 1 car picture = 1M cars

Copyright © 2013
Double Bottom Line:

$6B annual savings 10M cars off the road per year
Clean power from dirty fuels

(TECHNOLOGY DEMONSTRATION)
PSP fuel cells use heat and fuel to generate electricity

\[ \text{H}_2, \text{CO}, \text{or CH}_4 \rightarrow \text{H}_2\text{O} + \text{CO}_2 \]

650 to 900°C

Source: Point Source Power, C2M Team analysis
Copyright © 2013
PSP fuel cells are ideal for conditions at the well pad

Source: Point Source Power, C2M Team analysis
Copyright © 2013
PSP fuel cells are ideal for conditions at the well pad

Flexible Fuel
Low Maintenance
Durable
Rapid Start-up
Inexpensive
Small Scale
20 Year Lifetime

Source: Point Source Power, C2M Team analysis
Copyright © 2013
PSP helps off-grid natural gas wells save money

Off-grid wells

Electronic valve control & data acquisition

Co-producing wells

Electronic valve control & data acquisition

Oil wells

Limited applications

Natural gas wells

Oil wells

Limited applications
PSP helps off-grid natural gas wells save money

- **Off-grid wells**
  - Natural gas wells
    - Electronic valve control & data acquisition
  - Co-producing wells
    - Electronic valve control & data acquisition
  - Oil wells
    - Limited applications

- **On-grid wells**
PSP fuel cells are applicable at off-grid wells
PSP fuel cells are applicable at off-grid wells
Valves are a major source of methane emissions at the well pad

Venting from pneumatic valves accounts for 52,560 scf/yr per device

($2,200)

per well

Source: EPA, Inventory of U.S. greenhouse gas emissions and sinks: 1990-2011; EPA 430-R-001
Copyright © 2013
Fuel cell power and electric controls provide significant advantages

Electric valves eliminates venting and only use 20% of previously lost gas

$1,700 per well

Source: EPA, Inventory of U.S. greenhouse gas emissions and sinks: 1990-2011; EPA 430-R-001
Copyright © 2013
Fuel cell power and electric controls provide significant advantages

Benefits of electric controls:

- Eliminate natural gas venting
- 27 month payback period
- Remote visibility and control
- Increased safety
- Regulatory compliance

Source: EPA, Inventory of U.S. greenhouse gas emissions and sinks: 1990-2011; EPA 430-R-001
Copyright © 2013
Current strategies to electrify wells are problematic

Natural Gas Generators

Solar

Diesel Generators

Source: C2M team interviews and analysis
Copyright © 2013
Current strategies to electrify wells are problematic

- **Natural Gas Generators**
  - Fuel too dirty

- **Solar**
  - Unreliable power

- **Diesel Generators**
  - Require fuel delivery

*Source: C2M team interviews and analysis*
PSP fuel cells have a cost advantage over competitors

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capital</th>
<th>Operational</th>
<th>Total Cost of Ownership (20 years)</th>
<th>Payback Period (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSP Fuel Cell</td>
<td>$2,250</td>
<td>$750</td>
<td>$17,250</td>
<td>27</td>
</tr>
<tr>
<td>Diesel Generator</td>
<td>$950</td>
<td>$2,200</td>
<td>$44,950</td>
<td>Never</td>
</tr>
<tr>
<td>Natural Gas Generator and Membrane</td>
<td>$2,900</td>
<td>$1,000</td>
<td>$22,900</td>
<td>47</td>
</tr>
<tr>
<td>Solar Panels and Batteries</td>
<td>$12,800</td>
<td>$2,160</td>
<td>$56,000</td>
<td>Never</td>
</tr>
</tbody>
</table>
PSP has a market opportunity of $880 million

The US is responsible for 20% of world production
EPA is tightening regulations to greenhouse gas emissions

**Confirmed regulations**

- **EPA publishes new emissions regulations for fracked gas wells**
- **Venting prohibited**
- **Low bleed pneumatic controllers** required upstream from processing plant.
- **Green completions** required – flaring prohibited

**Potential actions**

**Note:** A gas well is defined by how much gas is produced compared to oil, and varies state by state.

**Source:** EPA New Source Performance Standards (40 CFR Part 60 Subpart OOOO) (Oct. 15, 2012), President’s Climate Action Plan

Copyright © 2013
PSP has three possible go-to-market channels

1. Exploration & Production
   - Benefits: Strong influence & need
   - Drawbacks: Fragmented market

2. Contract Drilling
   - Benefits: A few big players
   - Drawbacks: Limited motivation

3. Electric Valve Manufacturing
   - Benefits: Compelling value proposition
   - Drawbacks: Limited influence

Maintain strategic flexibility while establishing a beachhead
PSP needs $5M to deploy a product in 3 years

Key Activities
- Design 500 W prototype
- Test and refine in the field
- Deploy full-scale products to beachhead

Funding Needed
- 2014: $1.5M
- 2015: $1.5M
- 2016: $2M

Time Required
- 2014: 12 months
- 2015: 9 months
- 2016: Determined by market adoption rates

Milestone to Achieve
- Deploy 500 W prototype in field
- Start pilot manufacturing
- Start manufacturing at scale
Deploying PSP fuel cells at off-grid well sites delivers a double bottom line.

Need

Alignment

Timing

10 million cars

Market opportunity

$880 M
Questions

Clean power from dirty fuels
Clean power from dirty fuels
Vented Gas Calculations

- 210.3 Bcf vented in US production sector annually\(^1\)
- 20% of this is from pneumatic valves\(^1\)
- The US accounts for 19.2% of world production\(^2\)
- Price of NG at wellhead is $2.66 /1000 scf\(^3\)

\[
210,000,000,000 \text{ scf} \times \frac{0.2 \text{ from pneumatics}}{0.192 \text{ from US}} \times \frac{0.00266 \text{ scf}}{\text{scf}} = 5.83B
\]


Market Size Calculations

- $1,500 to produce fuel cell and all other components
- 33,411 new pneumatics in the US per year\(^1\)
- 19.2% of natural gas is produced in the US\(^2\)
- 1 fuel cell per new pneumatic

\[
Serviceable\ Accessible\ Market = \frac{33,411\ new\ wells\ in\ US}{1\ well\ in\ World} \times \frac{1}{0.192\ Wells\ in\ US} \times $1,500 \times Fraction\ of\ Market \times (1 + margin)
\]


Cost Competitor Calculations

Capital Costs:
• At 50% margin, fuel sell cost to consumer = $2,250
• 1 kW Diesel Generator = $950\(^1\)
• 1 kW Gas Generator = $1,000\(^2\)
• Membrane for CO\(_2\)/CH\(_4\) separation = $1,900\(^3\)
• 1 kW Solar Panels = $2,000\(^4\)
• 72 kWh of batteries = $10,800\(^5\)

Operational Costs:
• Fuel cell replacements = 1/3 capital cost = $750/year
• 0.28 L fuel burned per kWh in diesel generator\(^6\) * $1.05/L * 8760 h/yr = $2,575/yr in fuel cost
• $1,000/yr in membrane maintainance\(^3\)
• Battery lifetime is 5 years\(^5\)

Payback Period:
• $2,168/well vented, 20% consumed in FC

\(^1\)Honda Generators: Portable Generator Power for Home, Work, and Play. Honda.com
\(^2\)Inverter Generator with CMD Triple-Fuel System. Honda.com
\(^3\)Hybrid Membranes with Metal-Organic Frameworks for Carbon Dioxide Removal from Natural Gas, 2013 NSF SBIR 007
\(^4\)Amazon.com
\(^5\)Tesla.com
\(^6\)Cummins Power Generation: Model DGDB. Cumminspower.com
Car equivalent to pneumatic venting

- Annual CO2 emissions from one vehicle: 5.1 metric tons CO2
  - Source: “Greenhouse Gas Emissions from a Typical Passenger Vehicle” EPA

- Table 3-36: CH₄ Emissions from Petroleum Systems (Tg CO₂ Eq.)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Field Operations</td>
<td>34.7</td>
<td>28.7</td>
<td>29.3</td>
<td>29.5</td>
<td>30.1</td>
<td>30.3</td>
<td>31.0</td>
</tr>
<tr>
<td>Pneumatic device venting</td>
<td>10.3</td>
<td>8.4</td>
<td>8.4</td>
<td>8.7</td>
<td>8.8</td>
<td>8.7</td>
<td>9.0</td>
</tr>
<tr>
<td>Tank venting</td>
<td>5.3</td>
<td>3.9</td>
<td>4.1</td>
<td>3.9</td>
<td>4.2</td>
<td>4.4</td>
<td>4.7</td>
</tr>
<tr>
<td>Combustion &amp; process upsets</td>
<td>1.9</td>
<td>1.5</td>
<td>1.5</td>
<td>1.6</td>
<td>2.0</td>
<td>2.0</td>
<td>2.1</td>
</tr>
<tr>
<td>Misc. venting &amp; fugitives</td>
<td>16.8</td>
<td>14.5</td>
<td>15.0</td>
<td>14.8</td>
<td>14.6</td>
<td>14.7</td>
<td>14.7</td>
</tr>
<tr>
<td>Wellhead fugitives</td>
<td>0.6</td>
<td>0.4</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Crude Oil Transportation</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Refining</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Total</td>
<td>35.2</td>
<td>29.2</td>
<td>29.8</td>
<td>30.0</td>
<td>30.5</td>
<td>30.8</td>
<td>31.5</td>
</tr>
</tbody>
</table>

Note: Totals may not sum due to independent rounding.


\[
\frac{(8.4 + 8.7 + 8.8 + 8.7 + 9.0)}{5 \text{ yrs}} \times \frac{10^6 \text{ tons}}{\text{Tg}} \times \frac{\text{car \cdot yr}}{5.1 \text{ tons}} = 1.7 \text{ million cars} \sim 2 \text{ million cars in US}
\]
Reduced carbon intensity

“The carbon intensity of the electricity produced fell by 13 percent from 2007 to 2012. Emissions would have been about 314 MMTCO2 higher if the carbon intensity of the electricity supply had not declined and this accounts for most of the reduction in the carbon intensity of the total energy supply.

- Of this reduction about 198 MMTCO2 is due mainly to the shift from coal to natural gas.
- The remainder (116 MMTCO2) is largely the result of a 9-percent increase in non-carbon generation (renewable and nuclear).”

• Source: http://www.eia.gov/environment/emissions/carbon/
Natural gas can reduce US climate forcing emissions if venting can be reduced.

Source: Climactic Change, EIA
Copyright © 2013
But leaks and accidental emissions are far larger than originally expected.

### Estimated Emissions Reductions from Pneumatics Controllers by Sector

<table>
<thead>
<tr>
<th>Tons per Year</th>
<th>639,341</th>
<th>520,507</th>
<th>165,333</th>
<th>310,678</th>
</tr>
</thead>
</table>

**Total Emissions**

**Methane Savings**

“Studies Find Methane Emissions in California and U.S. 1.5 Times Greater Than Expected”

Unless leakage rates for new methane can be kept below 2%, substituting gas for coal is not an effective means for reducing the magnitude of future climate change.


NOAA aerial monitoring of Denver-Julesberg andUintah Basins indicates fugitive emissions equivalent to 4-9% of production.


Electric and pneumatic controllers

½ in ID electronic valve, $126\textsuperscript{1}  
½ in ID pneumatic valve, $112\textsuperscript{2}

\textsuperscript{1}Solenoid Valve, ½ in. NC, 120V, Brass. Granger.com
\textsuperscript{2}Honeywell ½ in. NPT Two-Way Unitary Valve (1.6 Cv) Item# 32544 Model# VP531C1000. Honeywell.com
Market Assessment

Time to Market (years)
There are a variety of possible applications for rugged fuel cells

Camping

Wood Stoves

Agriculture Waste

Landfills

Emergency preparedness

Research stations

Oil Wells

Communication towers

Source: Copyright © 2013
Rugged fuel cells are ideal for co-producing oil wells

Size (W)

1. Camping
   - Emergency preparedness
   - Wood Stoves
   - Research stations
   - Agriculture Waste
   - Landfills

2. Oil Wells
   - Communication towers

Source: Copyright © 2013
PSP’s customers are well services engineers