A Total Cost of Ownership Model for Design and Manufacturing Optimization of Fuel Cells in Stationary and Emerging Market Applications

Department of Energy Annual Merit Review for Fuel Cell Research
Arlington, Virginia
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Lawrence Berkeley National Laboratory

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Overview

Timeline

- Project start date: Oct 2011
- Project end date: Sept 2016
- Percent complete: 30%

Budget

- Total project funding
  - DOE share: $1.9M
  - Contractor share: n.a.
- Funding received in FY11: $100K
- Funding received in FY12: $500K
- Planned Funding for FY13: $560K

Barriers Addressed

- Fuel-cell cost: expansion of cost envelope to total cost of ownership including full life cycle costs and externalities (MYPP 3.4.5B)
- Lack of High-Volume Membrane Electrode Assembly Processes (MYPP 3.5.5A)
- Lack of High-Speed Bipolar Plate Manufacturing Processes (MYPP 3.5.5B)

Partners

- University of California Berkeley
  - Department of Mechanical Engineering Laboratory for Manufacturing and Sustainability
  - Transportation Sustainability Research Center
- Ballard Power Systems
- Strategic Analysis
- Other Industry Advisor (Altergy)

DOE Cost Targets

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>2015 Target</th>
<th>2020 Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>10kW CHP System</td>
<td>$1900/kW</td>
<td>$1700/kW</td>
</tr>
<tr>
<td>100kW CHP System</td>
<td>$2300/kW</td>
<td>$1000/kW</td>
</tr>
</tbody>
</table>
Total-cost-of-ownership (TCO) modeling tool for design and manufacturing of fuel cells in stationary and materials-handling systems in emerging markets

Expanded framework to include life-cycle analysis (LCA) and possible ancillary financial benefits, including:
• carbon credits, health/environmental externalities, end-of-life recycling, reduced costs for building operation

Identify system designs that meet lowest manufacturing cost and TCO goals as a function of application requirements, power capacity, and production volume

Provide capability for sensitivity analysis to key cost assumptions

BARRIERS
• High capital and installation costs.
• Potential policy and incentive programs may not value fuel cell (FC) total benefits.
Overview: Chemistries and Applications

- **Fuel cell types to be considered:**
  - Conventional, low-temp (~80°C) PEM fuel cell (LTPEM)
  - High-temp (~180°C) PEM fuel cell (HTPEM)
  - Solid oxide fuel cell (SOFC)

- **Application Space:**

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>SIZE [KW]</th>
<th>PRODUCTION VOLUME (UNITS/YEAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td>STATIONARY POWER / COMBINED HEAT AND POWER (C)</td>
<td>100</td>
<td>10,000</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10,000</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>50,000</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>50,000</td>
</tr>
<tr>
<td>BACKUP POWER (B)</td>
<td>100</td>
<td>50,000</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>50,000</td>
</tr>
</tbody>
</table>
Research and Modeling Approach: Task Flow

BOM: Bill of Materials
DFMA: Design for Manufacturing and Assembly
TCO: Total Cost of Ownership
Research and Modeling Approach: Inputs and Tools

- Literature and Patent Sources
- DER-CAM (CHP Apps)
- Vendor Quotes
- Industry Advisors

Exposure /Impact Models and Tools e.g. Tom McKone Model

1. Assess markets
   - Functional specs
   - BOP requirements

2. Derive design specifications
   - Materials
   - Components
   - Configuration

3. Design BOM/architecture
   - Unit processes
   - Make vs. buy

4. Facility cost modeling

5. TCO modeling
   - Operations & end of Life
   - Life cycle impacts and externalities
   - Incentives/benefits

6. DFMA optimization

7. Integrated user model
   - Sensitivity analysis
   - Scenario analysis
   - Risk and uncertainty analysis
   - Data quality assessment

Boothroyd Dewhurst DFMA® Software

LCA database tools, Integrated Model in Analytica
## Milestones - AOP 2012 / 2013

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 8.2</td>
<td>Meetings with project Advisory Partner groups</td>
<td>Done</td>
</tr>
<tr>
<td>(6/12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 8.2</td>
<td>Develop technical and performance specifications for LTPEM fuel cells and initial applications (Stationary, CHP, and Backup Power)</td>
<td>Done</td>
</tr>
<tr>
<td>(6/12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 8.3</td>
<td>Detailed LTPEM design plans and BOMs; including cell stack and balance of plant components plus materials and component requirements and cost estimates.</td>
<td>Done</td>
</tr>
<tr>
<td>(9/12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/13</td>
<td>Manufacturing cost model completed for LTPEM CHP and BU-Power systems.</td>
<td>Done</td>
</tr>
<tr>
<td>6/13</td>
<td>Literature search and functional specs defined for HTPEM CHP and BU-Power systems.</td>
<td>In Progress</td>
</tr>
<tr>
<td>9/13</td>
<td>DFMA and Total cost of ownership model completed for LTPEM CHP and BU-Power systems</td>
<td>In Progress</td>
</tr>
</tbody>
</table>
• LT-PEM CHP and BU-Power initial focus
  ▪ Manufacturing Cost Model (PEM CHP, BU-Power) - March 2013
  ▪ Total Cost Model (PEM CHP, BU-Power) - Sept 2013
  ▪ HTPEM, SOFC to follow
TCO Model Structure and Key Outputs

Total Cost of Ownership (TCO) Model

Assumptions:
- Application/ Size
- Mfg Volume/Yr
- Location (mfg, op)
- Prices
- Policies
- Fuel input
- Outages/Lifetimes

Manufacturing Cost Model
- Direct mfg costs
- Indirect mfg costs

Lifecycle Cost Model
- Capital/installation
- Fuel and operations
- Maintenance
- Stack replacements
- End of life

LCIA Model
- Monetized health and GHG impacts

Key Outputs:
1) System mfg costs and “factory gate” prices
2) TCO Metrics: Levelized costs ($/kWh), Total costs/yr
3) TCO including broader social costs
**Costing Approach**

- **Direct Manufacturing Costs**
  - Capital costs
  - Labor costs
  - Materials costs
  - Consumables
  - Scrap / yield losses
  - Factory costs

- **Global Assumptions**
  - Discount rate, inflation rate
  - Tool lifetimes
  - Costs of energy, etc.

- **Other Costs:**
  - R&D costs, G&A, sales, marketing
  - Product warranty costs

Source: Altergy Systems
Technical Accomplishments

CHP System Designs and Specs

• Functional specifications completed for 1, 10, 50, 100, 250kW H₂ fuel systems

SYSTEM DESIGN

<table>
<thead>
<tr>
<th>100 kW Size</th>
<th>Unique Properties</th>
<th>Best. Ests.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>Gross system power</td>
<td>115 kW</td>
<td>kW</td>
</tr>
<tr>
<td></td>
<td>Net system power</td>
<td>100 kW</td>
<td>kW</td>
</tr>
<tr>
<td>Physical size</td>
<td>2.9x4.8x5 meter x meter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical weight</td>
<td>~8,000 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical output</td>
<td>480V AC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak ramp rate</td>
<td>12 kW/sec - size dep</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste heat recovery</td>
<td>188400 BTU/hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste heat grade</td>
<td>65 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel utilization</td>
<td>0.98 SLPM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>also see fn- &gt; Avg. electrical efficiency</td>
<td>38 % LHV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal efficiency</td>
<td>30 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total efficiency</td>
<td>68 Elect.+thermal (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stack</td>
<td>stack power</td>
<td>8.85 kW</td>
<td>kW</td>
</tr>
<tr>
<td></td>
<td>total plate area</td>
<td>360 cm²</td>
<td>cm²</td>
</tr>
<tr>
<td></td>
<td>CCM coated area</td>
<td>232 cm²</td>
<td>cm²</td>
</tr>
<tr>
<td></td>
<td>single cell active area</td>
<td>198 cm²</td>
<td>cm²</td>
</tr>
<tr>
<td></td>
<td>gross cell inactive area</td>
<td>45</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>cell amps</td>
<td>126 A</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>current density</td>
<td>0.64 A/cm²</td>
<td>A/cm²</td>
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<tr>
<td></td>
<td>reference voltage</td>
<td>0.7 V</td>
<td>V</td>
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<td></td>
<td>power density</td>
<td>0.446 W/cm²</td>
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<td></td>
<td>single cell power</td>
<td>88 W</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td>cells per stack</td>
<td>100 cells</td>
<td></td>
</tr>
<tr>
<td></td>
<td>percent active cells</td>
<td>100 %</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>stacks per system</td>
<td>13 stacks</td>
<td></td>
</tr>
<tr>
<td>Parasites</td>
<td>Compressor/blower</td>
<td>4 kW</td>
<td>kW</td>
</tr>
<tr>
<td></td>
<td>Other paras. loads</td>
<td>11 kW</td>
<td>kW</td>
</tr>
<tr>
<td></td>
<td>Parasitic loss</td>
<td>15 %</td>
<td>%</td>
</tr>
</tbody>
</table>
**Technical Accomplishments**

**CHP System Designs and Specs**

- **Functional specifications** completed for 1, 10, 50, 100, 250kW reformate fuel systems

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**SYSTEM DESIGN**

---

**FUNCTION. SPECS – 100kW**

<table>
<thead>
<tr>
<th>Component</th>
<th>100 kW Size</th>
<th>Unique Properties</th>
<th>Best. Ects.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td></td>
<td>Gross system power</td>
<td>116</td>
<td>kW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Net system power</td>
<td>100</td>
<td>kW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical size</td>
<td>2.9x4.8x9</td>
<td>metre x metre x metre</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical weight</td>
<td>~3,000</td>
<td>kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrical output</td>
<td>480V AC</td>
<td>Volts AC or DC</td>
</tr>
<tr>
<td></td>
<td>Peak ramp rate</td>
<td></td>
<td>12</td>
<td>kW/sec - size dep</td>
</tr>
<tr>
<td></td>
<td>Waste heat recovery</td>
<td></td>
<td>188,400</td>
<td>BTU/hr</td>
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<tr>
<td></td>
<td>Waste heat grade</td>
<td></td>
<td>65</td>
<td>Temp. °C</td>
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<tr>
<td></td>
<td>Fuel utilization</td>
<td></td>
<td>9.08</td>
<td>SLM</td>
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<tr>
<td></td>
<td>also see fn-&gt; Avg. electrical efficiency</td>
<td></td>
<td>38</td>
<td>% LHV</td>
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<tr>
<td></td>
<td>Thermal efficiency</td>
<td></td>
<td>30</td>
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</tr>
<tr>
<td></td>
<td>Total efficiency</td>
<td></td>
<td>68</td>
<td>Elect. + thermal (%)</td>
</tr>
<tr>
<td>Stack</td>
<td></td>
<td>stack power</td>
<td>8.92</td>
<td>kW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>total plate area</td>
<td>360</td>
<td>cm^2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CCM coated area</td>
<td>232.2</td>
<td>cm^2</td>
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<td>single cell active area</td>
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<tr>
<td></td>
<td></td>
<td>cell amps</td>
<td>116</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>current density</td>
<td>0.58</td>
<td>A/cm^2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>reference voltage</td>
<td>0.7</td>
<td>V</td>
</tr>
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<td></td>
<td></td>
<td>power density</td>
<td>0.409</td>
<td>W/cm^2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>single cell power</td>
<td>81</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cells per stack</td>
<td>110</td>
<td>cells</td>
</tr>
<tr>
<td></td>
<td></td>
<td>percent active cells</td>
<td>100</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>stacks per system</td>
<td>13</td>
<td>stacks</td>
</tr>
<tr>
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<td></td>
<td>4</td>
<td>kW</td>
</tr>
<tr>
<td></td>
<td>Other paras. loads</td>
<td></td>
<td>12</td>
<td>kW</td>
</tr>
<tr>
<td></td>
<td>Parasitic loss</td>
<td></td>
<td>16</td>
<td>%</td>
</tr>
</tbody>
</table>
Technical Accomplishments

100 kW PEM Stationary (CHP) – Reformate Fuel

- **NG Supply**
- **Pre-treat**
- **Reformer + WGS**
- **Clean-up**
- **Inverter/Conditioning**
- **H2O Makeup**
- **H2O Pump**
- **Air Humidif.**
- **Reactant Air Supply**
- **Air Filter**
- **Blower**
- **Vent Air Supply**
- **Exhaust Air**
- **Exhaust H2O**
- **Coolant Pumps**
- **Controls/Meters**
- **Thermal Host**
- **Anode**
- **Electrolyte**
- **Cathode**
- **Gross stack power 116 kW**
- **4 kW Gross stack power**
- **65 °C**

**Subsystems**
- Subsystem A
- Subsystem B
- Subsystem C
- Subsystem D
- Subsystem E
- Subsystem F
- Subsystem G
- Subsystem H

**Components**
- **Burner**
- **Blower**
- **Clean syn-gas**
- **Clean-up**
- **Vent Air Supply**
- **Exhaust H2O Blower**
- **T. Lipman - DOE FC TCO Project**
Technical Accomplishments

Manufacturing Cost Model - Plates

Process Flow

Key Materials

- **Binder (polymer):** Polypropylene
- **Filler (carbon):** Graphite + Carbon Black
- **Composition:**
  30wt% PP, 66.5wt% Graphite, 3.5wt% Carbon Black
- **Composite density:**
  1.585 g/cm³
- **Composite cost:** $10.259/kg

L = 360mm, W = 100mm, \( T_{\text{max}} = 3\text{mm} \)

Cost Plot - 100kW system
**Technical Accomplishments**

**Manufacturing Cost Model – CHP H2**

### 100kW CHP System (H2)

#### BOP vs Stack

- **Stack Assembly**: 1%
- **Plate**: 18%
- **MEA**: 11%
- **CCM**: 52%
- **GDL**: 18%

1000 systems/yr

#### Table: Stack Cost

<table>
<thead>
<tr>
<th>Stack Size (kW)</th>
<th>100</th>
<th>1,000</th>
<th>10,000</th>
<th>50,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Volume (Systems/yr)</td>
<td>100</td>
<td>1,000</td>
<td>10,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Stack Cost ($/kWnet)</td>
<td>$426</td>
<td>$274</td>
<td>$248</td>
<td>$256</td>
</tr>
<tr>
<td>BOP ($/kWnet)</td>
<td>$357</td>
<td>$349</td>
<td>$343</td>
<td>$358</td>
</tr>
<tr>
<td>Total ($/kWnet)</td>
<td>$782</td>
<td>$622</td>
<td>$581</td>
<td>$574</td>
</tr>
</tbody>
</table>

Note: Cost refers to direct manuf. cost and excludes profit, R&D costs, and other corporate costs (sales and marketing, general/admin., warranty, etc.).
Technical Accomplishments

Manufacturing Cost Model – CHP reformate

100kW CHP System (Reformate)

Stack

- CCM 52%
- Plate 18%
- MEA 11%
- GDL 18%

1000 systems/yr

BOP/ Fuel Processor

- Fuel Processor 52%
- Controls Subsystem 6%
- Power Subsystem 5%
- Coolant Subsystem 14%
- Air Subsystem 10%

1000 systems/yr

Stack Assembly 1%

Note: Cost refers to direct manuf. cost and excludes profit, R&D costs, and other corporate costs (sales and marketing, general/admin., warranty, etc.).
Technical Accomplishments
Manufacturing Cost Model – Backup Power

10kW BU-Power System (H2)

Stack

BOP

Stack Size (kW)  10
Production Volume (Systems/yr)  100  1,000  10,000  50,000
Stack Cost ($/kWnet)  $1,549  $433  $290  $273
BOP ($/kWnet)  $647  $641  $636  $631
Total ($/kW$_{net}$)  $2,196  $1,074  $926  $903

Note: Cost refers to direct manuf. cost and excludes profit, R&D costs, and other corporate costs (sales and marketing, general/admin., warranty, etc.).
Technical Accomplishments

Manufacturing Cost Model – Sensitivity ($/kW)

Note: Yield is limited to 100% for “+20% case”

Yield of MEA/Frame, CCM, BPP and Pt price are key factors
DER-CAM Tool for Realistic FC Duty Cycles in CHP Mode:

- LBNL Distributed Energy Resources Customer Adoption Model (DER-CAM) optimization of distributed generation (DG) resource economics in micro-grid context

- Incorporates building load shapes for electricity and heating for given climate zone

- Includes utility tariff structures, demand charges, and electricity marginal carbon intensity

- Allows comparison of fuel cell CHP case vs. conventional “no DG” reference case

- Includes: Capital amortization, natural gas fuel costs, O&M costs, stack replacement costs, avoided utility costs
Technical Accomplishments
Life Cycle Cost Example

Climate Zone05 MED-LODGING
(San Francisco)

- 100kW Fuel Cell System
- Annual costs
  - Cap amort $16.8K
  - O&M $22.2K
  - Fuel $48.6K
- Annual Savings vs No DG Case
  - 34% CO2 Emissions
  - 37% Energy Costs

Climate Zone13 MED-LODGING
(San Diego)

- 100kW Fuel Cell System
- Annual costs
  - Cap amort $16.8K
  - O&M $26.2K
  - Fuel $48.8K
- Annual Savings vs No DG Case
  - 23% CO2 Emissions
  - 20% Energy Costs
  - 59% lower demand charges
Technical Accomplishments
San Diego, Medium Lodging Building

2) electric consumption, January, week - FCZ15 - MLODG

JANUARY

Fuel Cell Power

1) electric consumption, July, week - FCZ15 - MLODG

JULY

Fuel Cell Power

- electricity generation from DG
- utility electricity consumption
- electricity provided by battery

4) heat consumption, January, week - FCZ13 - MLODG

JANUARY

Fuel Cell Heat

3) heat consumption, July, week - FCZ13 - MLODG

JULY

Fuel Cell Heat

- heat collected from DG
- heat collected from NG
- heat taken from storage
- heat collected from solar thermal
Technical Accomplishments

High Temp-PEM Membrane Lit./Patent Review

- Patent search conducted for HT-PEM membrane
- PBI Membrane manufacturing review completed

Relevant Patents:


- Proton Conductive Polymer Electrolyte and Fuel Cell Including the Same (US Patent 8,017,659 B2 (2011))

- Polymer Electrolyte Membrane for Fuel Cell, Method of Manufacturing the Same, and Fuel Cell Employing the Same (US Patent 8,039,166 B2 (2011))

<table>
<thead>
<tr>
<th>Processing Step</th>
<th>Primary Process Input</th>
<th>Primary Process Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Casting</td>
<td>Dimethylacetamide solution, and equilibrated with 11M H3PO4</td>
<td>Cast films</td>
</tr>
<tr>
<td>2. Solvent Evaporation</td>
<td>At 60C- 140C</td>
<td>Polymerized cast film</td>
</tr>
<tr>
<td>2. Boiling</td>
<td>Water, cast films</td>
<td>Films</td>
</tr>
<tr>
<td>3. Doping</td>
<td>Film, phosphoric acid</td>
<td>Acid doped PBI membrane</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Processing Step</th>
<th>Primary Process Input</th>
<th>Primary Process Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Knife-edge or slot die dep. on sacrificial carrier</td>
<td>PBI powder and DMAc on glass plate</td>
<td>Film formation</td>
</tr>
<tr>
<td>2. IR heating 140C</td>
<td>Deposited film</td>
<td>PBI membrane; Multiple passes of 1, 2.</td>
</tr>
<tr>
<td>3. Doping</td>
<td>Film, phosphoric acid</td>
<td>Acid doped PBI membrane</td>
</tr>
</tbody>
</table>
Collaborations

• Partners

  University of California Berkeley
  Laboratory for Manufacturing and Sustainability, Dept. of Mechanical Engineering:
  — Manufacturing process analysis, DFMA analysis

  Transportation Sustainability Research Center and DOE Pacific Region Clean Energy Application Center:
  — System and BOP design, funct. specs, BOM definition, parametric relationships
  — CHP applications and functional requirements

  Ballard Power Systems
  — Consultation on fuel cell system design and manufacturing processes

  Strategic Analysis:
  — Fuel processor systems and DFMA costing

• Other Collaborators

  — Altergy: Consultation on backup power system
Future Work

FY13-14 Specific Plans :

• LT-PEM CHP, BUP applications: Total Cost of Ownership Model -- Sept 2013
  o Manufacturing cost model enhancements (CCM, metal plates, fuel processor)
  o Life cycle cost profiles for buildings in different geographies
  o End-of-life Pt recovery
  o Environmental/health impact valuation

• HT-PEM CHP, BUP applications: Manufacturing Cost model -- March 2014
  o Literature review
  o Functional and stack specifications
  o System design
  o Process flows
  o Component costing / DFMA
Building Modeling – Other U.S. Regions

• Extension of DER-CAM model to other climate zone in U.S.
  — 16 climates zones
  — 16 building types x 3 vintages
  — Comprehend utility tariff structure

• Northwest/Midwest U.S. Simulation of FCS adoption
  — Output: displaced grid electricity and displaced utility fossil fuel (natural gas, heating oil) + CO2 reduction
  — DER-CAM Output + Criteria pollutant impact ➔ Input to Lifecycle Impact Assessment Model (LCIA)
Quantifying human health damages

Emissions

Ambient concentration

Exposure

Effect

Damage

Define geographic boundary of interest

Fuel cell cost & technology parameters

Baseline scenario

Fuel cell scenario

Map changes at power plant and building levels

Net emissions = avoided emissions from power plants & building heating + fuel cell system emissions

Pollutant Emissions Modification

Air quality modeling

Intake fraction

Dose-response

Monetized damages
Example: monetized health damage from fossil fuel electric power plants

Ref: APEEP website, Nicholas Muller
Project Summary

Relevance: Provide more comprehensive cost analysis for stationary and materials handling fuel cell systems in emerging markets including ancillary financial benefits.

Approach: Design for manufacturing and assembly (DFMA) analysis cost model and integrated lifecycle cost analysis (LCA) impacts including life cycle costs, carbon credits, and health and environmental benefits.

Technical Accomplishments and Progress: System designs, functional specs, and manufacturing cost models for LT-PEM CHP and BU-Power systems. Demonstration of LCC cost modeling with DER-CAM.

Collaboration: Partnerships with UC-Berkeley manufacturing analysis and transportation sustainability research groups and Ballard Power Systems. Collaboration with Altergy and ClearEdge Power, and planned with SA.

Proposed Next-Year Research: Total cost of ownership model for LT-PEM systems and Manufacturing Cost model for HT-PEM system.

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TEMcKone@lbl.gov
Backup technical slides
Balance of Plant Components

- Direct costing example, CHP with H2 fuel system

<table>
<thead>
<tr>
<th>Balance of Plant - Stationary PEMFC</th>
<th>Plant Capacity [in kW]</th>
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<tbody>
<tr>
<td></td>
<td>250</td>
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<tr>
<td><strong>Subsystems</strong></td>
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<tr>
<td>Subsystem 1: Fuel</td>
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<tr>
<td>Hydrogen Tank</td>
<td>$1,280.00</td>
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<tr>
<td>Hydrogen Purifier</td>
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<td>Hydrogen Pump</td>
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<td>Hydrogen Pump Motor</td>
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<td>Hydrogen Piping</td>
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<td>$9,114.00</td>
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<td>Subsystem 2: Air</td>
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<td>Air Humidifier Tank</td>
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<tr>
<td>Humidification Pump</td>
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<td>Air Pump Motor</td>
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<td>Radiator</td>
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<td>Humidification Pump Motor</td>
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<td>Subsystem 3: Coolant</td>
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<tr>
<td>Power Inverter</td>
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<td>Braking Transistors</td>
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<td>$4,029.75</td>
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<td>Subsystem 5: Controls/Meters</td>
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<td>Variable Frequency Drive</td>
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<td>Coriolis Flow Meter* ** (optional)</td>
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<td><strong>Total Cost</strong></td>
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<td>S/kW</td>
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• **LBNL DER-CAM Model** (Distributed Energy Resources Customer Adoption Model)

• **CEUS database** of Commercial building electrical and thermal demand profiles in California: 90% of total commercial floor space is in buildings with a peak load < 1MW.

<table>
<thead>
<tr>
<th>Peak Load of Building</th>
<th>Number of Types</th>
<th>Total number in SDG&amp;E</th>
<th>%</th>
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<tbody>
<tr>
<td>100 – 250 kW</td>
<td>4</td>
<td>620</td>
<td>35%</td>
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<tr>
<td>250 – 500 kW</td>
<td>3</td>
<td>574</td>
<td>32%</td>
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<tr>
<td>above 500 kW (***</td>
<td>9</td>
<td>589</td>
<td>33%</td>
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Air Pollution Emissions Experiments and Policy Analysis Model (APEEP)

- Emissions
- Air Quality Model
- National Ambient Concentrations
- Dose-Response: Human Health, Agriculture, Timber, Visibility, Recreation, Materials
- National Exposures
- Economic Valuation

Nicholas Muller
• Air quality model predictions calibrated to Community Multi-scale Air Quality model (Byun, Schere, 2006).
  – CMAQ: USEPA CAIR RIA.
• Focus on ambient concentrations of PM$_{2.5}$ and O$_3$ (dominant health and environmental externalities)
• Limitations of source-receptor matrix approach.
  – Pollution episodes, atmospheric inversions.
  – Spatial resolution: heterogeneity within county receptors.
  – Atmospheric chemistry.
• Advantages of source-receptor matrix approach.
  – Computational efficiency.
    • Model domain & resolution.
APEEP: Baseline PM2.5 (2002)

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<th>(ug/m^3)</th>
<th>Color</th>
<th>Range</th>
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<td>Green</td>
<td>0 - 2.5</td>
</tr>
<tr>
<td>2.5 - 5.0</td>
<td>Yellow</td>
<td>2.5 - 5.0</td>
</tr>
<tr>
<td>5.0 - 7.5</td>
<td>Orange</td>
<td>5.0 - 7.5</td>
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<tr>
<td>7.5 - 10.0</td>
<td>Brown</td>
<td>7.5 - 10.0</td>
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<td>10.0 - 15.0</td>
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<td>10.0 - 15.0</td>
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<tr>
<td>15.0 - 20.0</td>
<td>Yellow</td>
<td>15.0 - 20.0</td>
</tr>
<tr>
<td>20.0 - 40.0</td>
<td>Red</td>
<td>20.0 - 40.0</td>
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