FC Backup Power Case Study Norway

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Kjeller, Norway

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Contents

• Introduction to IFE

• Fuel Cell Backup Power Case Study
Annual turnover: 1 BNOK

Annual scientific publications: 280

1948: IFA
1980: IFE

No. of employees: 650
Nationalities: 37
Researchers: 218
PhDs: 105

14000 Visitors a year

Advanced Laboratories: 24

National Centres for Environment-friendly Energy Research 2

International projects: > 120
Digital Systems
- Control Room and Operations Centres
- Virtual and Augmented Reality
- Intelligent Systems
- Automation and User Monitoring
- Risk, Safety and Security
- Human and Organizational Factors

Material and Process Technology
- Solar Energy
- Battery Technology
- Renewable Energy Systems
- Neutron Material Characterization
- Material Processes
- Sustainable Industry

Flow Technology and Environmental Analysis
- Flow Technology
- Wind Technology
- Corrosion
- Tracer Technology
- Environmental Analysis
Li-ion Battery Value Chain

Raw materials → Adapted materials → Batteries → Modules → Applications

- Raw materials
- Adapted materials
- Batteries
- Modules
- Applications

Flags: Norway, Japan, China
Li-on Battery Life Time Testing

- **Accelerated Testing** using
  - Fireproof storage
  - Temperature controlled cells
  - 104 test channels (0-5V, 0-50A)

- **Characterization of Degradation** with:
  - High precision Coulombic efficiency measurements
  - Differential capacity (dQ/dV) cycling measurements
  - Entropy spectroscopy (thermal characterization)
  - Electrochemical impedance

- **Battery Lifetime Modeling**

- **Key Projects:**
  - SafeLiLife → BattMarine
Hydrogen Systems

Focus Areas

• Fuel Cell Systems
  • Hybrid PEMFC / Li-ion Battery Systems
• Water Electrolysis
  • Small-scale PEM (high pressure)
  • Large scale Alkaline
• System Modelling: Matlab Simulink, EES
• System Testing: IFE Hynor

Key Projects

• FME MoZEES
• Norwegian FCH Centre
• Contract Research

Research Infrastructure

Clients & Partners

• Energy & Power Companies
• System Integrators
• Technology Companies
Research Center on Zero Emission Mobility

1 of 8 National Research Centers

Heavy Duty Transport
– New Areas for Innovation & Value Creation

Battery & Hydrogen – Technology Value Chains

Illustration: NFR (2016)

Materials | Components | Batteries & Fuel Cells | Modules | Systems
---|---|---|---|---

Foto: NFR (2016)

ASKO

Road | Sea | Rail

Brødrene Aa

Alstom

The Research Council of Norway

Mobility Zero Emission Energy Systems
New Research Infrastructure (2016 – )
• Fuel Cell / Battery Laboratory System
• Water Electrolyzer Laboratory System

New Key Projects (2017 – )

EMPIR MetroHyVe-project
Contents

• Introduction to IFE

• Fuel Cell Backup Power Case Study

Source: DoE, USA
Telecom Backup Power Market in Norway

• Technology Options
  • Lead-acid Batteries – most commonly used (largest market share)
  • Diesel Generators – relatively few installations (small market share)
  • Hydrogen Fuel Cells – a few demonstration systems installed

• System Specifications
  • Most common power requirements today: ca. 5 kW
  • Future power requirement with 5G: ca. 10 -15 kW
  • Stand-alone power (legislatve) requirement today: 2-4 hours
  • Stand-alone power requirement at some specific sites: 72 hours

Sources: Nkom, Telia, Telenor
Case Study – Assumptions

• System Design Parameters*
  • Batteries – 5 kWh/h +70% extra capacity → 17 kWh battery per 2 hours
  • Fuel Cell Systems – 2 hydrogen bottles per 2 hour

• Economic Parameters
  • Cost data from literature (reports), suppliers, users, and IFE (data base)
  • Sensitivity analysis wrt. specific costs, lifetime, etc.

• Method
  • Net Present Value (NPV) calculations; $i = 3\%$, $n = 10$ and 15 years
  • Excel Spreadsheets

*Sources: Battery, Hydrogen, and Fuel Cell Technology suppliers
# Hydrogen Fuel Cell System – Parameters

<table>
<thead>
<tr>
<th>System category</th>
<th>FC Rated Power (kW)</th>
<th>System 1 5 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2 4 24 48 72</td>
</tr>
<tr>
<td>Hours of back-up</td>
<td></td>
<td>2 4 24 48 72</td>
</tr>
<tr>
<td># of H2 bottles necessary</td>
<td>2 3 8 14 21</td>
<td>1 1 + 5 bot</td>
</tr>
<tr>
<td>Bundles if necessary (16 bottles)</td>
<td>1</td>
<td>1 + 5 bot</td>
</tr>
</tbody>
</table>

## CAPEX

<table>
<thead>
<tr>
<th></th>
<th>NOK/kW or % of FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cell stack (10000-30000)</td>
<td>20,000</td>
</tr>
<tr>
<td>Power electronics + cables + rack</td>
<td>50%</td>
</tr>
<tr>
<td>Supercap</td>
<td>50%</td>
</tr>
<tr>
<td>H2 bottles</td>
<td>0</td>
</tr>
<tr>
<td>H2 storage cabinet and other equipment</td>
<td>10,000</td>
</tr>
</tbody>
</table>

**Sum CAPEX**: NOK

## OPEX

<table>
<thead>
<tr>
<th></th>
<th>NOK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standby power (NOK/kW)</td>
<td>286</td>
</tr>
<tr>
<td>Hydrogen (rent + test usage) (NOK/bottle) +50%</td>
<td>1000</td>
</tr>
<tr>
<td>Service every 5th year (NOK)</td>
<td>5000</td>
</tr>
</tbody>
</table>

**Sum yearly OPEX**: NOK

**Sum year 5 OPEX**: NOK
# Battery System – Parameters

<table>
<thead>
<tr>
<th>System category</th>
<th>System 1 5 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Battery Rated Power (kW)</strong></td>
<td>2</td>
</tr>
<tr>
<td>Hours of back-up</td>
<td></td>
</tr>
<tr>
<td>Capacity needed (kWh)</td>
<td></td>
</tr>
<tr>
<td># of batteries (battery capacity = 1.8 kWh)</td>
<td></td>
</tr>
<tr>
<td># of strings (4 batteries in each string)</td>
<td></td>
</tr>
<tr>
<td># of battery racks needed</td>
<td></td>
</tr>
</tbody>
</table>

**CAPEX**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (NOK/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery (1000-4000)</td>
<td>2,000</td>
</tr>
<tr>
<td>Battery racks (max 4 strings)</td>
<td>7,000</td>
</tr>
<tr>
<td>Rectifier module</td>
<td>3,000</td>
</tr>
<tr>
<td>Rectifier controller + casing + rack</td>
<td>50%</td>
</tr>
<tr>
<td>Cables (per string)</td>
<td>1,000</td>
</tr>
<tr>
<td>Installation</td>
<td>30%</td>
</tr>
<tr>
<td><strong>Sum CAPEX</strong></td>
<td><strong>NOK</strong></td>
</tr>
</tbody>
</table>

**OPEX**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (NOK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standby power</td>
<td>7,000</td>
</tr>
<tr>
<td>Floating charge per string</td>
<td>1,000</td>
</tr>
<tr>
<td>Service (twice a year, total is shown)</td>
<td>6,000</td>
</tr>
<tr>
<td>Installation &amp; removal of batteries (every 5th year)</td>
<td>30,000</td>
</tr>
<tr>
<td>New batteries (every 5th year)</td>
<td>2,000</td>
</tr>
<tr>
<td>Battery swap admin costs (every 5th year)</td>
<td>7,000</td>
</tr>
<tr>
<td><strong>Sum yearly OPEX</strong></td>
<td><strong>NOK</strong></td>
</tr>
<tr>
<td><strong>Sum year 5 OPEX</strong></td>
<td><strong>NOK</strong></td>
</tr>
</tbody>
</table>
# Fuel Cell & Battery System Cost Calculations

<table>
<thead>
<tr>
<th>Year</th>
<th>SYSTEM 1: 5 kW &amp; 4 hours</th>
<th>SYSTEM 2: 10 kW &amp; 4 hours</th>
<th>SYSTEM 2: 10 kW &amp; 72 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fuel cell</td>
<td>Total Costs</td>
<td>Yearly Costs</td>
</tr>
<tr>
<td>0</td>
<td>213 000</td>
<td>213 000</td>
<td>134 400</td>
</tr>
<tr>
<td>1</td>
<td>4 430</td>
<td>217 430</td>
<td>18 000</td>
</tr>
<tr>
<td>2</td>
<td>4 430</td>
<td>221 860</td>
<td>18 000</td>
</tr>
<tr>
<td>3</td>
<td>4 430</td>
<td>226 290</td>
<td>18 000</td>
</tr>
<tr>
<td>4</td>
<td>4 430</td>
<td>230 720</td>
<td>18 000</td>
</tr>
<tr>
<td>5</td>
<td>9 430</td>
<td>240 150</td>
<td>123 000</td>
</tr>
<tr>
<td>6</td>
<td>4 430</td>
<td>244 580</td>
<td>18 000</td>
</tr>
<tr>
<td>7</td>
<td>4 430</td>
<td>249 010</td>
<td>18 000</td>
</tr>
<tr>
<td>8</td>
<td>4 430</td>
<td>253 440</td>
<td>18 000</td>
</tr>
<tr>
<td>9</td>
<td>4 430</td>
<td>257 870</td>
<td>18 000</td>
</tr>
<tr>
<td>10</td>
<td>9 430</td>
<td>267 300</td>
<td>123 000</td>
</tr>
<tr>
<td>11</td>
<td>4 430</td>
<td>271 730</td>
<td>18 000</td>
</tr>
<tr>
<td>12</td>
<td>4 430</td>
<td>276 160</td>
<td>18 000</td>
</tr>
<tr>
<td>13</td>
<td>4 430</td>
<td>280 590</td>
<td>18 000</td>
</tr>
<tr>
<td>14</td>
<td>4 430</td>
<td>285 020</td>
<td>18 000</td>
</tr>
<tr>
<td>15</td>
<td>214 430</td>
<td>400 450</td>
<td>123 000</td>
</tr>
</tbody>
</table>

| NPV | kr 396 805 | kr 568 332 | kr 744 749 | kr 898 422 | kr 1 310 954 | kr 11 984 199 |

**Fuel Cells**

**Batteries**
Fuel Cells vs. Batteries – Break-Even Points

5 & 10 kW systems
4 hour backup
NPV Calculations with Default Parameters

Fuel Cell stack cost: 20000 NOK/kW
NPV when FC stack cost is Reduced by 50%

Fuel Cell stack cost: 10000 NOK/kW

Lead-acid batteries
Fuel cell technology
NPV when FC stack cost is Increased by 50%
NPV when Battery Life is Increased to 8 years

Graph showing NPV in NOK over years for different battery configurations.

- 10kW 4 hours Battery
- 10kW 4 hours FC
- 5kW 4 hours Battery
- 5kW 4 hours FC
NPV with System Lifetime $n = 15$ years

5 kW System
4 hour backup
NPV with System Lifetime $n = 15$ years

10 kW System
4 hour backup
Hydrogen Storage – Renting vs. Owning?

- Renting
  - 300 bar steel bottles:
  - 1000 NOK/bottle (OPEX)
  - Bottle swaps included in price

- Owning
  - 350 bar composite cylinders:
  - 3500 NOK/cylinder (CAPEX)
  - 200 NOK/swap (OPEX)

NPV Calculations (NOK)

<table>
<thead>
<tr>
<th>System</th>
<th>Renting</th>
<th>Owning</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 kW, 4 hours</td>
<td>396 805</td>
<td>383 396</td>
</tr>
<tr>
<td>10 kW, 4 hours</td>
<td>744 749</td>
<td>726 870</td>
</tr>
<tr>
<td>10 kW, 72 hours</td>
<td>1 310 954</td>
<td>1 114 286</td>
</tr>
</tbody>
</table>
NPV when owning H2 Storage Cylinders
Summary & Conclusions

• Technology & Systems
  • Hydrogen Fuel cells systems have long life and are highly scaleable

• Techno-Economic Study with Sensitivity Analysis
  • Batteries mostly suitable for system with short term backup < 2 hours
  • Hydrogen fuel cells suitable for medium to long term backup > 4 hours

• Business Case for Hydrogen Fuel Cells (versus Batteries)
  • Increased requirement for power capacity (5 kW → 10 kW)
  • Longer backup power periods (2-4 hours → 24-72 hours)
  • Efficient hydrogen logistics improves business case
Thank You for Your Attention!