Idea to Alpha Prototype

Electric scooter case study
portable transportation  appointments  short commutes  messenger service

electric,  15 mile range,  17 mph max.,  35 lbs.

Accessories:
Extra 4 hour charger, 1 hour quick charger, front panier bag, trailer, rear view mirror

User-friendly computer control: keyless security, reverse, beeper, regenerative braking, convenient maximum speed presets

Contact: EMPower Corporation, 25 First Street, Cambridge, MA 02141, phone 617-494-1001 ext. 13, fax 617-494-0111
The Starting Point
Idea development phase

Modeling activities

- brainstorming
- market and customer estimates
- sketch models
- feasibility estimates
Idea generation

5 minute exercise

Write your name on the top of the sheet of paper provided in class.

Generate *as many ideas as possible* on ways to improve the experience of using public restrooms.

Anything goes.

Your ideas will be collected at the end of 5 minutes.
Sketches
Quick 2D exploration
Market Estimates

Working in parallel with brainstorming

Electric Diving Vehicles

<table>
<thead>
<tr>
<th></th>
<th>Farallon MK8</th>
<th>Predator 2000</th>
<th>Apollo (AV-1)</th>
<th>Torpedo 2000-20</th>
<th>MAXX Stealth</th>
<th>Oceanic Mako</th>
<th>Marine Corp. DPD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body Length</strong> (inches)</td>
<td>61.86</td>
<td>46</td>
<td>13.4 dia.</td>
<td>24 in. length</td>
<td>20 x 20 x 21</td>
<td></td>
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</tr>
<tr>
<td><strong>Weight lb.</strong></td>
<td>120</td>
<td>65</td>
<td>39.5</td>
<td>42</td>
<td>54</td>
<td>165</td>
<td></td>
</tr>
<tr>
<td><strong>Weight No Battery lb.</strong></td>
<td>65</td>
<td>65</td>
<td>18.7</td>
<td>42</td>
<td>25- 30</td>
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</tr>
<tr>
<td><strong>Run Time (low-high) min.</strong></td>
<td>60-115</td>
<td>40-100</td>
<td>25-60</td>
<td>80</td>
<td>80</td>
<td>20 - 40</td>
<td>200</td>
</tr>
<tr>
<td><strong>Range (min-max) miles</strong></td>
<td>3.5-10.5</td>
<td>1-3 miles</td>
<td>2.48</td>
<td>42</td>
<td>1.8 -3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>max. operating depth (ft)</strong></td>
<td>400</td>
<td>130 - 1000</td>
<td>160</td>
<td>170</td>
<td>130 /tested 325</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>0-3.3</td>
<td>200-250 fpm</td>
<td>1.2 - 2.5</td>
<td>2</td>
<td>3.25</td>
<td>1.5 2.7</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Speed control</strong></td>
<td>trigger</td>
<td>propeller pitch</td>
<td>yes lever</td>
<td>throttles dual /9 pitch propeller</td>
<td></td>
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<tr>
<td><strong>Static Thrust lb.</strong></td>
<td>75-80</td>
<td>17.6 - 39.6</td>
<td>15 - 50</td>
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</tbody>
</table>
Customer Estimates

Working in parallel with ideas - preliminary design contract

Product Description: Portable electric device for lifting automobiles

Intended Customer: Back yard mechanics

Market: Automotive accessories

<table>
<thead>
<tr>
<th>Customer Needs</th>
<th>Design Attributes</th>
<th>Engineering Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can be easily transported in and out of a house</td>
<td>Lightweight, battery powered</td>
<td>Total weight under 30 lbs.</td>
</tr>
<tr>
<td>Is easily stored in the home and office</td>
<td>Compact</td>
<td>14&quot; x 14&quot; x 14&quot; in smallest configuration</td>
</tr>
<tr>
<td>Comfortable to carry</td>
<td>Can be carried easily without snagging or pinching</td>
<td>Has handle and smooth exterior</td>
</tr>
<tr>
<td>Can handle most repair situations</td>
<td>15 up/down cycles per charge</td>
<td>15 cycles at 1” per second for a 3000 lb. automobile</td>
</tr>
<tr>
<td>Can be used on many uneven surfaces</td>
<td>Stable</td>
<td>3000 lb vehicle raised 16 inches will not tip under 400 lb side loading</td>
</tr>
<tr>
<td>Can be used on many vehicles</td>
<td>User configurable</td>
<td>Self adjusting base accommodating broken pavement</td>
</tr>
<tr>
<td>Is fun to use</td>
<td>Variable speed</td>
<td>Bearing point adapters</td>
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<tr>
<td></td>
<td>Easy to control</td>
<td>Up to 7000 lbs.</td>
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<tr>
<td></td>
<td>Lifts and lowers quickly</td>
<td>6” to 24” max. extension</td>
</tr>
<tr>
<td></td>
<td>Total weight under 30 lbs.</td>
<td></td>
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</tbody>
</table>

Is affordable to many customers

less than $600 list price

Less than $220 manufacturing cost

Won’t fail

Reliable

1000 hour MTBF design life

Is comfortable to use

Controllable while under vehicle

Voice activated

Not too loud

80 db at 2 feet

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Sketch Models
Quick 3D exploration
Analogous to sketching
# High-level Feasibility

A reality check—in parallel

## First Order Energy Feasibility

<table>
<thead>
<tr>
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<th>A</th>
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<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>To meet weight constraint of less than 30 lbs</td>
<td>Battery weight must be less than 13 lbs</td>
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<tr>
<td>4</td>
<td>Best known solution</td>
<td>150 W-hr at 1 hour rate</td>
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<tr>
<td>5</td>
<td>To meet cost constraint</td>
<td>12.3 lbs total weight</td>
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<tr>
<td>7</td>
<td>Assume 12.5 mph</td>
<td>For 10 miles</td>
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<td>8</td>
<td>with user weight of 165 lbs</td>
<td>takes 0.80 hour</td>
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<td>9</td>
<td>and scooter weight of 25 lbs</td>
<td>with energy 160 W-hr</td>
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<tr>
<td>12</td>
<td>Rolling resistance of 1.5% (including wheels and bearings)</td>
<td>73 W</td>
<td></td>
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<tr>
<td>14</td>
<td>Wind resistance of 7.5 square feet</td>
<td>frontal area</td>
<td>coefficient of drag</td>
<td>67 W</td>
<td></td>
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<td>15</td>
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<tr>
<td>16</td>
<td>Total mechanical power</td>
<td>139 W required</td>
<td></td>
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<tr>
<td>17</td>
<td>Minimum drivetrain efficiency allowable</td>
<td>74%</td>
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<tr>
<td>19</td>
<td>Current efficiency goals [at 12.5 mph and 140 W out]</td>
<td>Motor</td>
<td>85%</td>
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<td>20</td>
<td></td>
<td>Gearbox</td>
<td>94%</td>
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<td>21</td>
<td></td>
<td>Power electronics</td>
<td>96%</td>
<td></td>
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<tr>
<td>22</td>
<td></td>
<td>Continuous Power (W)</td>
<td>182</td>
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<td>24</td>
<td>Motor efficiency</td>
<td>Gear efficiency</td>
<td>Power electronics</td>
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<tr>
<td>25</td>
<td>77%</td>
<td>0.8 lbs+</td>
<td>90%</td>
<td>0.1 lbs+</td>
<td>95%</td>
<td>-0.3 lbs+</td>
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<tr>
<td>26</td>
<td>72%</td>
<td>1.8</td>
<td>86%</td>
<td>0.7</td>
<td>94%</td>
<td>-0.1</td>
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<tr>
<td>27</td>
<td>67%</td>
<td>2.8</td>
<td>82%</td>
<td>1.4</td>
<td>93%</td>
<td>0.0</td>
<td></td>
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<tr>
<td>28</td>
<td>62%</td>
<td>4.0</td>
<td>78%</td>
<td>2.1</td>
<td>92%</td>
<td>0.1</td>
<td></td>
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<tr>
<td>29</td>
<td>57%</td>
<td>5.5</td>
<td>74%</td>
<td>2.8</td>
<td>91%</td>
<td>0.3</td>
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# Feasibility

**Green Wagon example**

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<tr>
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<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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</thead>
<tbody>
<tr>
<td>Assumptions</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mass of Wagon</td>
<td>50.00 lbs.</td>
<td>22.68 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mass of Cargo</td>
<td>150.00 lbs.</td>
<td>68.04 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Speed</td>
<td>4.00 mph</td>
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<td>30.00 Wh/kg</td>
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<td>Efficiency of Gear Train, etc.</td>
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<td>Distance to Accelerate</td>
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<td>6.71 s</td>
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<td>radius of wheels</td>
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<td>Torque per wheel</td>
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<td>Something to consider - one motor or two, etc.</td>
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<td>Motors should be low voltage DC</td>
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<td>Cruising Force</td>
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<td>ideally should be able to support the radial load on their own</td>
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<td>Radial load per wheel</td>
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The team
A mix of capabilities

Investors

Engineers and designers
- Andrew Forencz (EE)
- Peter Neilson (ME, prototype machinist)
- Jim Schoonmaker (Manufacture)
- Nathan Ulrich (ME, system integration)
- Christophe Rehault (Model maker)
- Gerhd Schimta (Industrial design)
- David Wallace
  (ME, Industrial design, human factors, prototyping)

Business
- Paul Staelin (EE, MBA)
- Doug Tanger (Marketing)
Sketch models ...

Use to get preliminary customer feedback
More Exploration

Based upon preliminary customer feedback
Product Development Process

Concept development phase

Increased detail
Resolve the hard parts

Modeling
concept development
mockups
market analysis
feasibility analysis
### Feasibility Analysis

More predictive modeling

<table>
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<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
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<th>P</th>
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<td>No-Load Speeds</td>
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<td>Motor Drag Loss</td>
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<td>Battery Specific Energy</td>
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<td>4 W/h</td>
<td>0.075 ohm</td>
<td>(4)</td>
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<td>Nominal Battery Voltage</td>
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<td>Total Battery Weight</td>
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<td>Desired Average Speed</td>
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#### Second Order Feasibility Analysis

| A   | B   | C   | D   | E   | F   | G   | H   | I   | J   | K   | L   | M   | N   | O   | P   | Q   | R   |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 17  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 18  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 19  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 20  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 21  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 22  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 23  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 24  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 25  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 26  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 27  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 28  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 29  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 30  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 31  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 32  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 33  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 34  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 35  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 36  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 37  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 38  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 39  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 40  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 41  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
# Feasibility Analysis

## Wagon cost analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Price (Very Conservative)</th>
<th>Price (In Quantity)</th>
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<td>Thermal Paste</td>
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<tr>
<td>Diodes</td>
<td>4</td>
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Total: $101.00

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<th>Price (Prototype)</th>
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<tbody>
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<td>$250.00</td>
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<td>Flexible Coupling</td>
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<td>$5.00</td>
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Total: $590.00

$515.00
Mockups

Functional

Works like ...
Mockups

Visual

Looks like ...
Product Development Process

Detailed development phase

Making the alpha prototype really work

Modeling
detail design
detailed analysis
tests
prototype fabrication