Smaller/Lighter, More Efficient, More Powerful Motors

December 5, 2014
2.2 Billion Motors
Magnetic cores are an essential component of motors.

Silicon Steel

Stator (electromagnet)

Unstack

Remove wire: core magnetic material
MANCs can be easily integrated into existing motors

MANCs Ribbon

Stamp → Stack → Wind → Drop → Motor

MANCs Ribbon
MANCs transcend traditional tradeoffs

Limitation of conventional materials

Magnetic Amorphous Nanocomposite (MANC)

More Efficient

Permeability ($H/m^2$)

Magnetic flux density (T)

Magnet Strength
Today’s magnetic cores are limited by heat losses

Electrical Power In

Silicon Steel

Heat = Lower Efficiency

Mechanical Power Out
Today’s magnetic cores are limited by heat losses.

- Electrical Power In
- Mechanical Power Out
- Silicon Steel
- Heat = Lower Efficiency
Motors have three main engineering levers:

- **Size**
- **Power**
- **Losses**
1) MANCs enable energy efficient motors

7% More Efficient
2) MANCs enable more powerful motors

>5X More Power
3) MANCs enable smaller and lighter motors

- 70% Smaller
- Power
- Losses
- Size

70% Smaller
More efficient, stronger, and/or smaller/lighter motors
Our MANCs will *enhance* today’s motors through greater efficiency.
Motors are ubiquitous; many are industrial

230 MM industrial size motors globally

By application:
- Compressor: 32%
- Pumps: 19%
- Mechanical: 30%
- Fans: 19%
Industrial motor inefficiency is an enormous challenge

- Global electricity demand by end use
- Electric motor electricity demand by sector

- Others
- Motors 46%

- Non-Industrial
- Industrial 64%

30% of global electricity demand
Industrial motor inefficiency is an enormous challenge

Global Electricity Consumption: 2.5% annually

Shift in market share of electric motor efficiency classes

Shift in market share of electric motor efficiency classes

Slow progress for adoption of premium efficiency (IE3) electric motors
MANC-enhanced motors will close the efficiency gap

Efficiency scale

90% 96% 100%

10% Inefficiency gap

Silicon Steel

MANCs

Annual Cost Reduction

$34 BN

Annual CO₂ Emission Reduction

360 MM tons
Trends in the industrial motor market are favorable for MANC-enabled motors

- **Market**: Steady industrial growth worldwide
- **Competitors**: Siemens
- **Regulations**: U.S. Department of Energy
- **Other**: Hitachi

**Premium**
Our MANCs will *enable* tomorrow’s motors through greater efficiency, more power and reduced size.
EV adoption has come a long way but still has further to go.
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Source: Goldman Sachs, company filings, website, and Wall Street research.

Note: Geographic expansion is an illustrative representation. Each dot represents 50 vehicles sold.
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One of the largest barriers remains limited range
Everyone’s focusing on the battery
Imagine the motor was replaced by one that was more efficient and smaller.
A more efficient, lighter MANC-enabled motor can extend vehicle range

80km

25%

100km
Our MANCs will *enable* tomorrow’s motors through greater efficiency, more power, and less size

*An electric revolution in the air* – Safran Magazine

*Electric aircraft take off, as Europe leads the way* – Engineering & Technology Magazine
Airplanes have a lot of moving parts, but only a few are electric.
Aircraft electrification is happening now, in the commercial…
… and the military spaces
Power density remains critical to pushing this trend forward

![Horsepower per pound graph](image)

- Current electric motors
- Jet engine requirements
Power density remains critical to pushing this trend forward

**Horsepower per pound**

- **Current electric motors**
- **Jet engine requirements**
MANCs enable progress toward electrification
Enabling electrification leads to valuable outcomes

- Reduce fuel use
- Reduce emissions
- Increase range
- Save money
- Save lives

Electrification using MANCs

Reduce weight
There are many promising apps. How do we select and develop the initial killer app?
We possess existing capabilities to serve these markets

**Capable Team**

- **Carnegie Mellon University**
- **Industry Experience:** 45 years
- **Patents:** 2
- **Grants Received:** 3 NSF, 1 ARPA-E
- **Journal Articles:** 250+

**Incorporated Entity**

- **South Pole Magnetics (SPM)**
- **Founded:** 2014
- **HQ:** Pittsburgh, PA
- **Industry:** Fabricated Metal Product Manufacturing

**Production Capabilities**

- **Equipment:** Castors
- **Capacity:** 250kg, 5kg
- **Production Capabilities:** 4” and 2” ribbons
We possess existing capabilities to serve these markets

**Significant Funding**

Over 10 years

$\sim 4\text{mm}$

**Established IP & Prototype**

- 2 Content of Matter Patents
- 1 Operational Prototype

**Key Partners**

*Prototype Design*

- Los Alamos National Laboratory
  Established 1943
- GTM Plans
  - University of Pittsburgh
  - UC Berkeley
SPM: From Lab to Market

Phase I
Secure Funding (~$500k)

Phase II
Develop Partnership for Prototype

Phase III
Determine Killer App
Paths to funding face different advantages and open questions

Venture Capital
- Validation, network, mentorship
- Difficult to secure
- Ownership dilution

Public Funding
- Non-dilutive
- Long process
- Follow-on funding

Strategic Corporate
- Validation, network, mentorship
- Follow-on funding
- Customers
- Ownership dilution
SPM’s initial killer app will be driven by funding strategy and partner needs.
With a differentiated product, an array of potential apps, and a viable GTM strategy …
SPM is poised to become the platform to accelerate the electrification of motors
UC Berkeley Team

Becky Xilu Li  
*MPP Candidate*

Chad Reed  
*MBA Candidate*

Paul Hogan  
*MBA Candidate*

Alex Chun  
*MBA Candidate*

Danny Hellebusch  
*PhD Candidate*

David Liu  
*MBA Candidate*
We offer the performance of MANCs and the durability of Si-Fe

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Advanced</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Silicon Iron (Si-Fe)</td>
<td>Ferrites</td>
<td>Amorphous</td>
</tr>
<tr>
<td>Saturation (T)</td>
<td>2.0</td>
<td>0.25-0.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Permeability (10^3)</td>
<td>10-50</td>
<td>0.01-10</td>
<td>50</td>
</tr>
<tr>
<td>Coercivity (A/m)</td>
<td>6</td>
<td>10-1600</td>
<td>3.5</td>
</tr>
<tr>
<td>Brittleness</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Curie Temperature (degC)</td>
<td>745</td>
<td>120-500</td>
<td>415</td>
</tr>
<tr>
<td>AC Power loss density (W/kg)</td>
<td>0.84</td>
<td>N/A</td>
<td>0.66</td>
</tr>
<tr>
<td>Power conversion density (W/kg)</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
</tr>
</tbody>
</table>
Experimental motors made by others gives us a baseline for performance

**EV Motor Prototype (Light Engineering)**

<table>
<thead>
<tr>
<th></th>
<th>Industry</th>
<th>LE Prototype</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Motor</strong></td>
<td>25 kw ACPM</td>
<td>M32L2-ACPM</td>
</tr>
<tr>
<td><strong>Motor Weight</strong></td>
<td>163kg</td>
<td>42kg</td>
</tr>
<tr>
<td><strong>Motor Efficiency</strong></td>
<td>88%</td>
<td>95%</td>
</tr>
<tr>
<td><strong>Cargo Capacity</strong></td>
<td>1000kg</td>
<td>1500kg</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>80 km @ 40 kph max</td>
<td>100 km @ 70 kph max</td>
</tr>
<tr>
<td><strong>Grade Ability</strong></td>
<td>8%</td>
<td>30%</td>
</tr>
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We believe we can make a motor with the same output at ~25% the weight and volume

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<th>Silicon Steel</th>
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<tr>
<td>Rated Output (kW)</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Rated Torque (Nm)</td>
<td>200</td>
<td>136</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>48</td>
<td>160</td>
</tr>
<tr>
<td>Volume (L)</td>
<td>15</td>
<td>60</td>
</tr>
<tr>
<td>Power Density (kw/L)</td>
<td>4.717</td>
<td>0.82</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>95</td>
<td>94.90</td>
</tr>
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