Marketing New Powertrain Technologies

February 14, 2018
Achates Power, Inc.

Founded In
2004

by
Dr. James Lemke &
John Walton

$185M+
Invested

Global IP portfolio
✓ 2,500 claims
✓ 213 issued patents
✓ 194 pending patents

30% more efficient than

50% more efficient than

Clean
Dramatically more efficient
Multi-fuel capable
Lower cost, mass and complexity

11,000+ dynamometer test hours

4.9L 3-Cylinder Engine – 275 HP, 1100 Nm
OP Engines are Dramatically Better
Diversity of Applications

EXAMPLE APPLICATIONS

2.7L / 270 HP
5L / 280 HP
10L / 450 HP
14L / 1000 HP
200 L / 4000 HP
The ARPA-E Rules

Any new powertrain technology has to be comparable to or better than the baseline in:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Explanation</th>
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<tr>
<td>Power</td>
<td>Power density (or energy density including the fuel/energy storage capacity) ➔ Customer acceptance</td>
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<tr>
<td>Efficiency</td>
<td>Fuel economy (over real-world dynamic driving) ➔ Regulation</td>
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<tr>
<td>Emissions</td>
<td>Regulated criteria pollutants (and now CO₂) ➔ Regulation</td>
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<tr>
<td>Cost</td>
<td>Total cost of ownership (including capex and fuel cost)</td>
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<tr>
<td>Reliability</td>
<td>Mean time between failures, maintainability</td>
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<tr>
<td>Utility</td>
<td>Acceleration, driveability, NVH, cold start, off-cycle operation, ease of use, transparency to the user, and acceptable range</td>
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<td>Fuel acceptability</td>
<td>Use a readily available fuel or energy source.</td>
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**Wankel “Case Study”**

“There are four ways to make your corporation’s stock bound up:

1. Rename your company ‘The Wankel Works’
2. Announce that you have just received a contract to make a screw that might be used in Wankel engines
3. Announce that you have just hired three scientists to look into Wankel engine research.
4. Announce that the clerk in your shipping room has a brother-in-law who is thinking about buying a car that has a Wankel engine.”

Wall Street Journal, June 1972

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EV “Case Study” – Cost and Power Challenges

Criterion
- Power
- Efficiency
- Emissions
- Cost
- Reliability
- Utility
- Fuel acceptability

EV

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- Power
- Efficiency
- Emissions
- Cost
- Reliability
- Utility
- Fuel acceptability

EV

DENSITY OF FUEL AND STORAGE CONTAINER

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<tr>
<th>Fuel Type</th>
<th>Energy Per Mass</th>
<th>Energy Per Volume</th>
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<tr>
<td>Gasoline</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Diesel</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Ethanol</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>LPG</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>CNG @ 3,600 psi/250 bar</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Hydrogen @ 10,000 psi/700 bar</td>
<td>10</td>
<td>40</td>
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2014 US$ per kWh

- 95% conf interval whole industry
- 95% conf interval market leaders
- Publications, reports and journals
- News items with expert statements
- Log fit of news, reports, and journals: 12 ± 6% decline
- Additional cost estimates without clear method
- Market leader, Nissan Motors, Leaf
- Market leader, Tesla Motors, Model S
- Other battery electric vehicles
- Log fit of market leaders only: 8 ± 8% decline
- Log fit of all estimates: 14 ± 6% decline
- Future costs estimated in publications
- <$150 per kWh goal for commercialization

IHS Markit Forecast

OR

?
90% of vehicles have an ICE in 2030.
An optimized 2-S OP Diesel engine can achieve a 10% improvement on brake efficiency at full load, in comparison to an equivalent conventional 4-stroke engine.

The opposed-piston diesel engine had about 13-15% potential [lower CO2 emissions]...compared to a state of the art four-stroke diesel engine.

Achates Power’s OP engine is 30% more efficient than conventional engines.
Critical Decisions

Manufacture or license?

Toyota City, Japan, February 6, 2018—Toyota Motor Corporation (TMC) today announces its financial results for the nine-month period ended December 31, 2017.
Confidential and proprietary information of Achates Power, Inc.

**Intellectual Property**

- 213 worldwide patents
- 194 worldwide pending applications
- U.S., China, Japan, India, Germany, France, Great Britain, Italy, Sweden, Russia, Mexico

**Opposed Piston Engine Technology**

- Closed cycle CFD (Converge)
- Open cycle CFD (Converge)
- 1D (GT-Power)
- Thermal-structural FEA & Conjugate heat transfer
- Proprietary Bearing Analysis Tool
- Multi-body Simulation (MSC Adams)

**Patents**

- Calibration guidelines
- Test set-up
- Formulae for real-time calculation
- Post-processing
- Analysis tools

**Development Tools**

- Prototype controller including ECU
- Control requirements (Written guide or Simulink)
- Support

**Test Tools**

- System engineering considerations
- Design processes for mechanical system design, air system design, combustion system design, piston design, piston ring design, cylinder design, port geometry, wrist pin design, geartrain design
- DFM, design for assembly, design for cost

**Designs**

- Pistons (hot & cold sides)
- Liners
- Wrist pin bearings
- Fuel sprays
- Air handling system
- Cooling & lubrication systems
- Gear train
- Front end accessory drive
- Gear noise mitigation
- Oil consumption control measures

**Training & Support**

- On-site
- San Diego
- Detroit
- Remote

**Control Software**

- Pistons (hot & cold sides)
- Liners
- Wrist pin bearings
- Fuel sprays
- Air handling system
- Cooling & lubrication systems
- Gear train
- Front end accessory drive
- Gear noise mitigation
- Oil consumption control measures

**Know-How**

- Pistons (hot & cold sides)
- Liners
- Wrist pin bearings
- Fuel sprays
- Air handling system
- Cooling & lubrication systems
- Gear train
- Front end accessory drive
- Gear noise mitigation
- Oil consumption control measures
Current Patent Portfolio Status

- Issued/Allowed: 71 US patents
- Pending US Utility patent applications: 45
- Pending US Provisional patent applications: 10
- Pending PCT applications: 11
- Granted/Allowed Foreign Patents: 142
- Pending Foreign patent applications: 128
- Rated Invention disclosures: 156
- Global Patents: 213
- Global Patent Applications: 194
Achates Power Opposed Piston Engines

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<thead>
<tr>
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<tr>
<td>Power</td>
<td>Beats</td>
</tr>
<tr>
<td>Efficiency</td>
<td>30% improvement</td>
</tr>
<tr>
<td>Emissions</td>
<td>Meets w/ conventional A/T</td>
</tr>
<tr>
<td>Cost</td>
<td>Same, with conventional process and material</td>
</tr>
<tr>
<td>Reliability</td>
<td>meets, with C/O maintenance and oil consumption</td>
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<tr>
<td>Utility</td>
<td>drivability and NVH</td>
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<td>Fuel acceptability</td>
<td>use existing infrastructure</td>
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PROVE IT!
How to Prove It…

Vehicle Demonstrations

Technical conferences and publications

OEM engagements

Data

Gasoline Combustion with Diesel-like Efficiency

Map shows the logos of all existing and potential customers, globally
Support Along the Way…

Investors

Suppliers

Technology grants

Government

Partners

Common Sense Regulation / Incentives
90% less NO$_x$ – 0.02 g / bhp-hr  
15% less CO$_2$ – 391 g / bhp-hr
Achates Power Impact

- 50% Fuel Economy Improvement
- Beats CAFE 2025
- Achieves 37 MPG

Using OP GCI engines in full-size light trucks would have the same CO₂ impact as eliminating more than half of the cars sold each year.