What We Do

Czero takes ideas and designs for energy conversion, energy use, and energy storage technologies and makes them

• More efficient
• More effective
• More robust and longer lasting
• Simpler
• Lower cost
• More easily manufactured
• Less polluting
• Safer
Expertise

We specialize in early-stage R&D engineering, proof-of-concept and systems integration for

- Advanced machines
- Mechanical, electromechanical and electrohydraulic systems
- Subsystems and components

We excel at quickly and cost-effectively turning client R&D concepts into robust designs and prototypes using principles for high-volume production.
### History

Founded in 2007 in Fort Collins, CO

Located in the CSU Engines and Energy Conversion Laboratory

### Primary Industries

- Automotive
- Oil & gas
- Cleantech
- Heavy & mobile industrial
- Transportation
- Aerospace
- Defense

### Clients

**Broad array of clients served**

- Startups and Fortune 500s
- Universities
- Non-profits
- DOE and DOD

### Recognition

- **MERCURY 100**: 2015, 2016 Awardee
- **Inc. 500**: Top 10 Engineering Companies (2015)
- **COLORADO COMPANIES TO WATCH**: 2015 Winner
- **White House Demo Day**: 2009 Award
- **Bravo Entrepreneur AWARDS**: 2010 Awardee
### Focus

**Advanced mechanical systems, hydraulic power systems, and energy-conversion systems**
- Engines/transmissions
- Hybrid systems
- Fuel systems
- Renewable energy

**Proven track record**
- Rapid design and development of new technologies
- Readying technology for high-volume manufacturing

### Core Expertise

**Mechanical Design – Solid Modeling, GD&T, Structures & Mechanisms**

**High-bandwidth Hydraulic Systems – Design and Analysis**

**Dynamic Modeling**

**Analysis – Thermodynamic, Structural, Thermal, CFD, Magnetics**
Methods

Rapid Development

- First Principles
- Sophisticated analysis tools
- Creativity
- Experience
- Hard work

Virtual engineering methods

- Quick, efficient iterations
- Numerous design explorations
- Develop understanding
- Build
- Save our clients time and money

Process

Analysis Lead Design

Requirements Analysis

- Techno-economics
- First Principles Evaluations
- 0-D Models
- Tradeoff Studies

Concept Design

- Brainstorming
- Sketches
- Stick Diagrams
- Solid Models

Simulation and Analysis

- CFD
- FEA
- Thermal
- Magnetic
- Multiphysics

Detailed Design

- Solid Models
- Drawings and GD&T
- Tolerance Stacks
- Assembly Drawings

Build and Test

- Prototype Manufacture
- Inspection/Metrology
- Assembly
- Test fixtures
- Data Acquisition

Results and Feedback

- Save our clients time and money
### Bringing Technology Transfer Across Industries

#### Automotive/Hydraulics
- Fuel Injectors
- High-bandwidth Hydraulics
- Solenoids
- Transmission Subsystems
- Hybrid Powertrain Analysis
- Hydraulic Hybrids
- Cylinder Head
- Valvetrain Design
- Camless Valve Actuation
- Actuators
- Dynamometer Systems

#### Oil and Gas
- Offshore Drilling Equipment
- Natural Gas Gensets
- CNG Fuel Systems
- CNG Engines
- Anchoring Systems
- Casing Operation Subsystems

#### Cleantech
- Biodiesel Processors
- CO2 Cleaning Machines
- Molten Salt Test Skids
- Tidal Energy Harvesting
- Compressed Air Energy Storage
- Vertical Axis Wind Turbines
# Software Tools and Expertise

## Solid Modeling and Design
- 3D Modeling
- Layout Studies
- Tolerance Stack-ups
- Detailed Drawings (GD&T per ASME Y14.5)
- P&ID Drawings

## Analysis
- Thermodynamic Analysis
- Finite Element Analysis
- Computational Fluid Dynamics
- Magnetic Modeling
- Dynamic System Modeling
- Hydraulic Simulations

![Software Tools and Expertise](image)
Software Tools and Expertise

**Embedded Systems**

Rapid Prototyping of Real-Time Control Systems

Programming

- Matlab/Simulink Coder
- C, C++, etc.

Communication Protocols

- J1939, J1857
- Modbus, XCP, CCP

Instrumentation and Data Acquisition

- Measurement Computing
- SCADA
Feature Project - Natural Gas Genset

Czero designed a novel CNG tender car system for diesel-electric locomotives:

• Developed containerized custom genset, with a Cummins QSK60 (1.5MW) engine, to supply electrical power fueled by bank of CNG tanks
• Designed and analyzed thermal management system
• Designed and developed control system to manage locomotive operation and auxiliary power input

**Design Challenge:** Complex systems integration and packaging of custom genset and all ancillary systems into 30’ ISO container

**Result:** Successfully operating in field tests with Bright Rail Energy
Feature Project - CO₂ Based Cleaning Machines

Czero supported the design and development of a novel CO₂ based textiles cleaning system:

• Designed and built first double-door commercial laundry system (2011) as virtual engineering team
• Design and developed full drum as well as closed-loop process system for CO₂
• Czero providing ongoing development support
• Multiple patent applications filed
Feature Project – Dual-mode CNG Engine

This dual-mode CNG engine can propel the vehicle as well as refuel the onboard tank using commonly available low-pressure natural gas supplies.

**Design Challenge:** Redesign the cylinder head for natural gas compression in addition to normal combustion mode:

- CNG porting design
- Custom check valve for CNG metering
- Deactivation system for the standard valvetrain
- Revised PFI intake and exhaust ports
- Simulation of check valves and combustion system
- Control system for fueling and pumping modes

**Result:** From production cylinder head to assembled prototype in 4 months. Second phase underway and vehicle demonstration planned for Q2 2017.
Feature Project – Subsea Hydraulic System

Czero was enlisted to design a prototype subsea pump assembly for oil drilling systems.

**Design Challenge:** Integrate pumps, valves, and regulators with control system:
- Subsea environment
- Extremely high-pressure demands
- Redundant system for fail-safe operation

**Result:** The system has been successfully tested and is undergoing evaluation for next steps.
Thank you for your time!

Questions? Please contact us:

**Mark Pickett**  
Director of Business Development  
(231) 313-4310 (cell)  
mark.pickett@czero-solutions.com  
www.czero-solutions.com

**Lyle Shuey**  
Chief Operating Officer  
(317) 340-9656 (cell)  
lyle.shuey@czero-solutions.com  
www.czero-solutions.com

Czero, 430 N. College Avenue, Suite 425, Fort Collins, CO 80524
Additional Project Examples
The Bright Rail Energy system required a custom fuel skid to accommodate a wide range of temperatures and flow requirements.

Czero was responsible for design and build of the entire skid:

**Fuel Inlet Conditions:**
- Gas temperature: -30°C to 40°C
- Gas pressure: 300psi to 3,250psi

**Fuel Outlet Requirement:**
- Fuel Flow: 2,210SCFH to 14,500SCFH
- Fuel Pressure: 4.8psi to 6psi
- Fuel temperature: 5°C to 50°C

Detailed analysis of gas flow and temp across a wide operating range
Custom Valve Deactivation System

The OBDI engine requires a deactivating valvetrain to convert cylinders from firing mode to pumping mode.

**Design Challenge:** Redesign the valve rockers to allow deactivation of the inlet and exhaust valves:

- Rocker arm design
- Hydraulic actuation system
- Shaft mounting
- Integration into cylinder head

**Result:** Success demonstration of the system on the prototype Phase 2 engine, accumulating run time without failure
Valve Chatter Root Cause Investigation

Client was struggling with a valve chatter problem in their hydraulic system and asked Czero to analyze the issue and develop a solution.

**Approach:** A dynamic model of the system was build in MATLAB Simulink using custom blocks. Simulations were run with excellent correlation to real-world results.

**Solution:** Simulation showed that the chatter was caused by an inability to fully vent pilot port and decreases in outlet pressure due to motor flow. Chatter was valve cycling between reducing and relieving modes.

**Result:** Czero determined necessary changes to the valve porting to eliminate the chatter condition. Prototypes were tested and confirmed successful resolution.
Compressed Air Energy Storage Analysis

Renewable energy sources are often rely on storage systems. Client wanted to leverage conventional IC engines to serve as air pumps.

**Design Challenge:** Analyze the suitability of the base engine design and determine necessary modifications

- Overall Efficiency Analysis
- Component stress/loading evaluations
- Definition of design requirements for prototype engine build

**Result:** Engine concept was proven with clear understanding of required design changes. Program moved forward and prototype systems were built based on Czero designs.
Compressor Valvetrain Analysis

- Ideal Valve Motion not achievable (very short duration, with high lift)
- Performed trade studies to assess the thermodynamic efficiency with various valve profile traces
  - Varying both lift and duration to achieve optimal performance

<table>
<thead>
<tr>
<th>Compressor Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Double-harmonic</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>lift</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>12</td>
</tr>
</tbody>
</table>

| **6th order polynomial** |
| | durations |
| lift | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
| 8 | 87.4 | 89.3 | 89.5 | 88.7 | 87.0 | 84.7 | 81.9 |
| 9 | 88.6 | 90.2 | 90.2 | 89.2 | 87.4 | 85.0 | 82.1 |
| 10 | 89.5 | 90.8 | 90.6 | 89.4 | 87.6 | 85.1 | 82.1 |
| 11 | 90.1 | 91.2 | 90.8 | 89.5 | 87.5 | 84.9 | 81.8 |
| 12 | 90.6 | 91.4 | 90.9 | 89.5 | 87.3 | 84.6 | 81.4 |

| **Double-dwell, mod sine, dwell = 10** |
| | durations |
| lift | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
| 8 | 90.1 | 91.3 | 91.0 | 89.8 | 87.9 | 85.4 | 82.4 |
| 9 | 91.0 | 91.9 | 91.4 | 90.1 | 88.1 | 85.4 | 82.4 |
| 10 | 91.6 | 92.2 | 91.7 | 90.2 | 88.0 | 85.3 | 82.1 |
| 11 | 91.9 | 92.4 | 91.7 | 90.1 | 87.8 | 85.0 | 81.7 |
| 12 | 92.2 | 92.5 | 91.6 | 89.9 | 87.5 | 84.6 | 81.1 |
Czero’s Solenoid Design Optimization Process

Generate large number of solid models from file of parameters automatically

Import data into magnetic analysis software. Force maps created for each case

Magnetic data files used in simulation for each case to see how the actuator AND system perform

Performance metrics automatically plotted and rated allowing various trades to be quickly identified

Detail CAD Design

500-1000 design iterations day. Optimal designs arrived at very quickly saving time and money

Test

Iterate as needed to get final design

Fluid Forces and Internal Losses

Structural Analysis
Czero Hydraulic Hybrid – Gen III

Czero completed an in-house project to design and develop a hydraulic hybrid retrofit system for medium duty trucks

- ~5 months from concept to installation
- Tested in Class 6 truck for 2 years with only minor seal leak and no appreciable wear or degradation
Hydraulic Hybrid – Vehicle Demonstration by Czero
Fuel Injection Design/Analysis/Modeling

The Czero team has extensive experience modeling high-bandwidth hydraulic systems including fuel systems.