# FOIL BEARING SUPPORTED COMPRESSOR-EXPANDER

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R&D DYNAMICS CORPORATION

DOE Project Reward #DE-EE0009617

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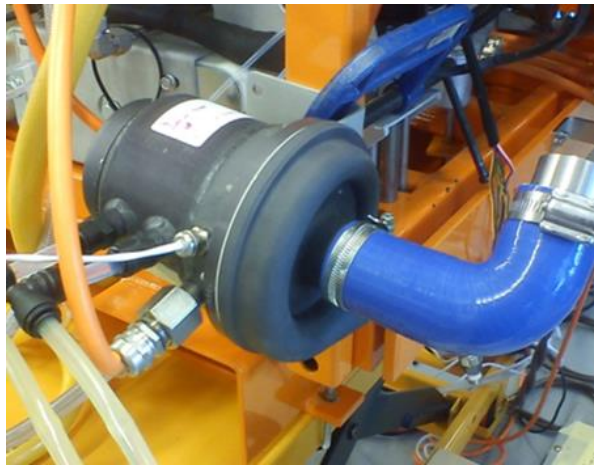
DOE Fuel Cell R&D For Heavy-Duty applications

2022 Annual Merit Review and Peer Evaluation Meeting

Project ID: FC349

# PROJECT GOAL

- Project goal is successful development of fuel cell system Compressor-Expander for heavy-duty vehicle applications. The Compressor-Expander is the key component of balance of plant (BOP), which drives the performance, reliability, service life and cost. The Compressor-Expander must meet pressure and flow requirements (compressor pressure ratio of 2.5 from 143 to 285 g/s of flow) efficiently over a wide operating range. It must be highly reliable and have a long service life. It must also be versatile to allow broad usage across many fuel cell platforms and it must be able to be mass produced at lower cost.



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# OVERVIEW

## Timeline and Budget

- Project Start Date: Expected May 2022
- Project End Date: 30 months from start date
- Total project budget: $2.0M
- Total cost share: $400k
- Total federal share: $1.6M

## Partner

- Loop Energy - Industry Collaborator

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# OVERVIEW

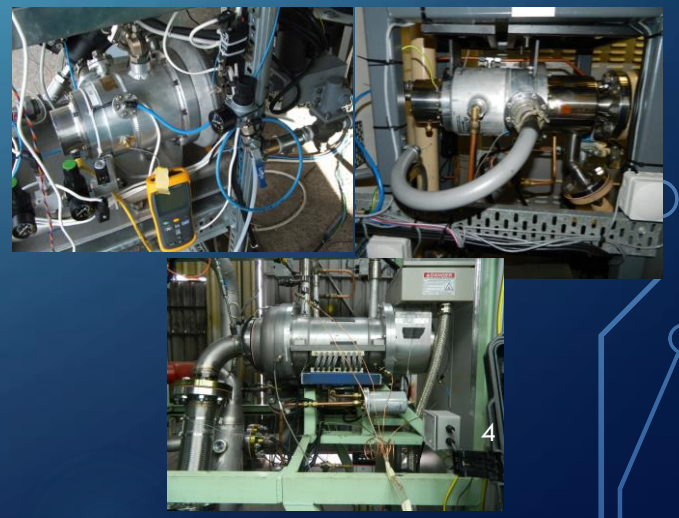
R&D Dynamics (RDD) was started 30 years ago. The Principals, while working for Honeywell and United Technologies Corp, had pioneered the foil bearing supported Air Cycle Machines, the key component of aircraft Environmental Control Systems. The technology developed by them is being used even today by 95% of world's aircraft, civil or military.

R&D Dynamics (RDD) was started with the intention of bringing aerospace technology to the commercial world. RDD Engineers have decades of experience in designing, developing, and production manufacturing foil air/gas bearing supported high speed turbomachinery such as turbo compressors, turbo expanders, and turbo generators. Examples of RDD turbomachinery are shown below.

## Fuel Cell Compressors

## Turbo Expanders

## Turbo Generators



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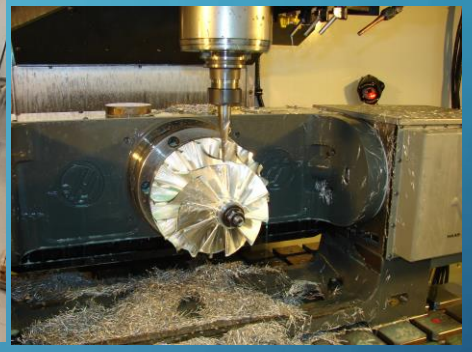
# OVERVIEW

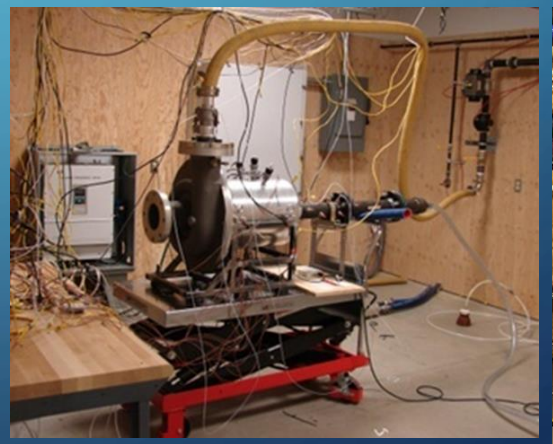
**Complete Solution Provider**

- Machine Design
- Machine Development
- Prototype Manufacturing
- Qualification Testing
- Production Manufacturing

5-Axis Milling Machines



Performance & Durability Test Labs



Production Manufacturing

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# RELEVANCE / POTENTIAL IMPACT

Foil bearing supported CE's will allow automotive and heavy-duty truck fuel cell manufacturers to deliver small, efficient and extremely reliable fuel cell air management systems to their customers at a reasonable price. Centrifugal compressors and expanders are the most effective way to deliver air at the necessary pressure and flow for heavy duty truck fuel cells. The simplicity, reliability and compact size of foil gas bearings are ideal for this application. The inherent oil-free nature of foil gas bearings ensures no oil will ever enter the fuel cell and bearing lubrication will never be an issue.

| Technology | Advantages |
|---|---|
| Oil-free foil air/gas bearings | No oil contamination, increased reliability, high vibration & shock capacity, smaller size/weight, no scheduled maintenance, quieter operation and high start-stop cycles |
| Centrifugal compressor and turbine | Highest efficiency and smallest size/weight |
| Inlet guide vanes and variable turbine nozzles | High efficiency over wide operating range |
| DCPM 4-Pole motor | More power dense, higher efficiency, and smaller size |
| Drive with silicon-carbide (SiC) switches | Higher switching frequency, higher operating temperature and small size |



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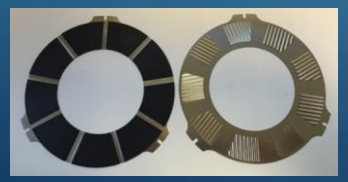
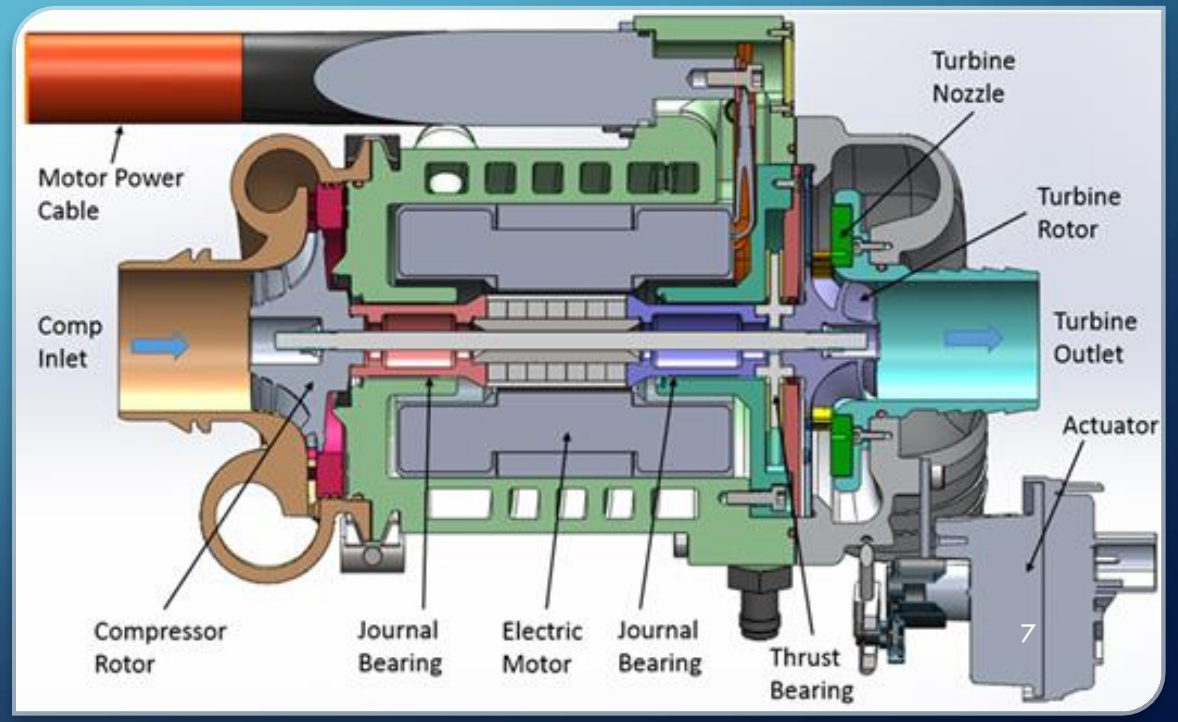
# RELEVANCE / OUR UNIQUE APPROACH

R&D Dynamics (RDD) is proposing an innovative oil-free foil bearing supported compressor-expander (CE) for heavy duty truck fuel cell systems. The CE will have a single shaft containing a compressor, expander (turbine) and motor supported on foil bearings. The CE includes a high-speed motor drive that can be a stand-alone unit or integrated with the CE unit. The CE will be efficient, compact, lightweight, have low noise and high reliability. The unit will meet the performance, efficiency, packaging and cost goals of the M2FCT program. The technology is based on over 50 years of real-world experience ranging from aircraft ACM's, commercial turboexpanders and automotive fuel cell compressors. At the completion of this program, the CE will have demonstrated the performance, durability, efficiency, and life requirements of the FOA.

- High speed centrifugal compressor/expander
- Supported on oil-free foil air/gas bearings
- Inlet guide vanes and variable turbine nozzles
- Permanent magnet motor (DCPM)
- Motor drive with silicon carbide (SiC) switches



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# APPROACH

- Budget Period 1: Design and Manufacturing
- Budget Period 2: Durability Testing

| | |
|---|---|
| Budget Period 1 | Preliminary Design |
| | Detailed Design & Analysis |
| | CE & Drive Manufacturing |
| | Test Rig Design & Assembly |
| | CE & Drive Assembly and Development Testing |
| **Go / No-Go Decision Point** | |
| Budget Period 2 | Cost Estimate & Production Plan |
| | Durability Protocol Testing |
| | Start-Stop Cycles |
| | Start-Stop Power Cycles |
| | Start-Stop Operation Cycles |
| | Freeze Start Test |
| | Cycling Test |
| | High Load Test |
| | Noise Testing |
| | Field Testing by Team Partner |

| Target | Flow Condition | | | Basis |
|---|---|---|---|---|
| | 100% | 50% | Idle | |
| Compressor Efficiency | 77% | 69% | 46% | Predicted Performance Map |
| Turbine Efficiency | 70% | 80% | 0% | Predicted Performance Map |
| Motor Efficiency | 95% | 95% | 80% | Power meter |
| Drive Efficiency | 97% | 97% | 80% | Power meter/thermal balance |
| System Weight | <125 kg | | | <0.50 kg/kWe [a] |
| System Volume | <62.5 liters | | | <0.25 liters/kWe [a] |
| System Cost | <$3,000 | | | $12/kWe [a] |
| Performance | Pressure Rise and Flow at each Operating Point | | | Data taken during testing |

[a] 250 kWe System, @ 100,000 units

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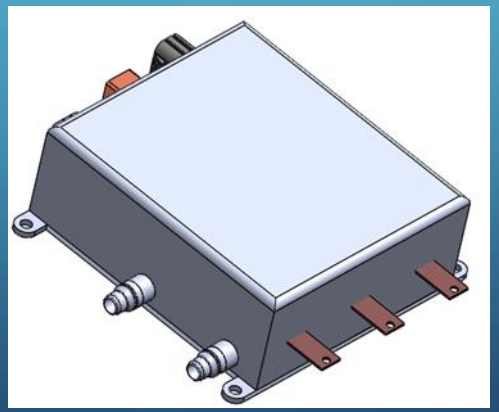
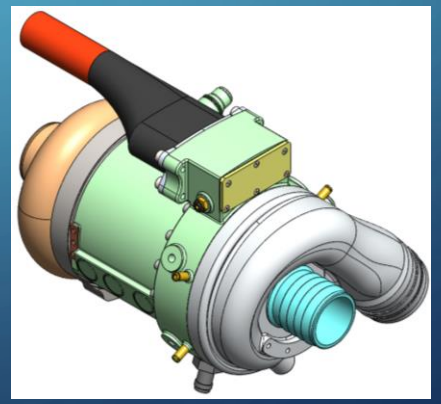
# ACCOMPLISHMENTS & PROGRESS

- Project award expected May 2022
- Pre award work started in October 2021 and includes the following
  - Start of preliminary design for compress-expander
  - Start of preliminary design for drive electronics





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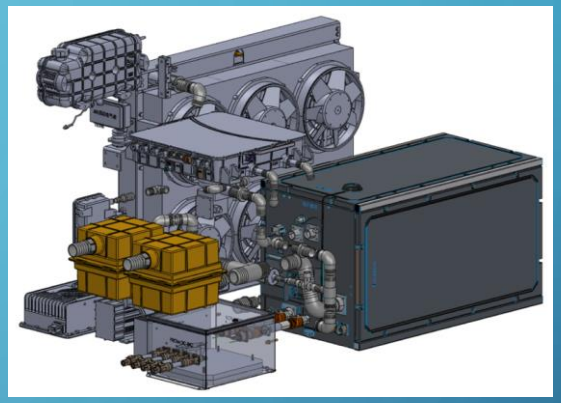
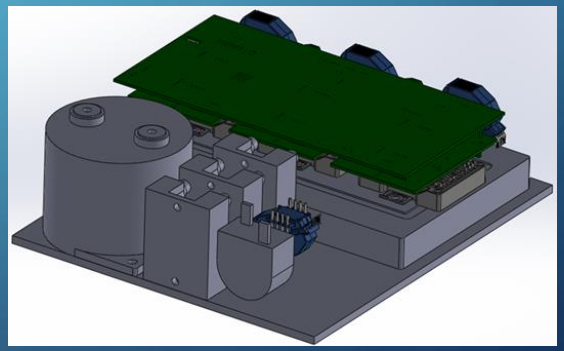
# COLLABORATION & COORDINATION

- Loop Energy
  - Fuel cell development partner
  - Specification development
  - Performing system integration and field testing



- University of Texas – Dallas
  - High frequency drive and control software development



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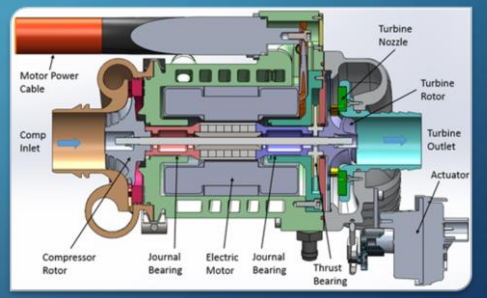
# PROPOSED FUTURE WORK

## FY 2022

- Develop product definition and create a layout in CAD. Detailed calculations will be done to validate the sizing and design for the compressor, turbine, motor, and bearings.
- Final analysis will be done for critical speed, forced response, thrust balance, internal cooling flow, stator cooling, fits & clearances and transient response time to support form, fit and function of the CE and Drive.
- Complete drawings/documentation for CE and Drive manufacturing




## FY 2023

- Fabricate hardware to assemble (3) CE and Drive development units
- Test rig design and manufacturing for development testing
- Assemble (3) Compressor-Expanders and Drives for development testing

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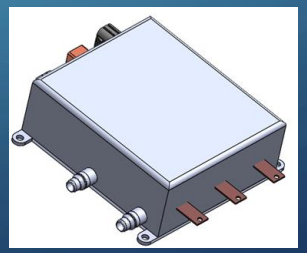
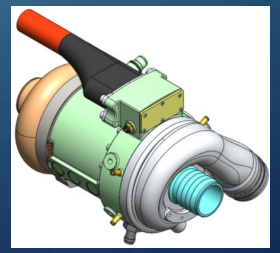
# SUMMARY

- Project award expected May 2022
- Pre award work started in Oct. 2021 and includes the following
  - Start of preliminary design for compress-expander
  - Start of preliminary design for drive electronics
- Foil air/gas bearings offer increased reliability, high vibration & shock capacity with lower lifetime maintenance cost
- Centrifugal compressor and turbine provide highest efficiency and smallest size/weight
- Higher switching frequency and operating temperature with SiC switches in Drive provides high efficiency and reliability





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# TECHNICAL BACK-UP SLIDES

- TBD

# TECHNOLOGY TRANSFER ACTIVITIES

## Commercialization timeline

- The product will be qualified and ready for commercialization 30 months after program start. Up to 10,000 units per year can be manufactured in R&D Dynamics' existing facility.

## Distribution channels for proposed technology

- R&D Dynamics intends to initially sell directly to fuel cell manufacturers. As sales increase, R&D Dynamics intends to partner with existing Tier 1 automotive suppliers.

## Financing

- DOE support and internal cost share will fund the program to the end of the development phase. Committed orders for production units will trigger internal and external investment into production facilities.

## Intellectual property

- R&D Dynamics holds many patents in the field of air bearings, turbomachinery, motor drives and motor control algorithms. R&D Dynamics will retain control of all previous intellectual property and new intellectual property developed under this FOA.



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