CHANGING WHAT'S POSSIBLE

ARPA-E
Gas-Turbines Overview

Bryan Willson, ARPA-E Program Director

Outline

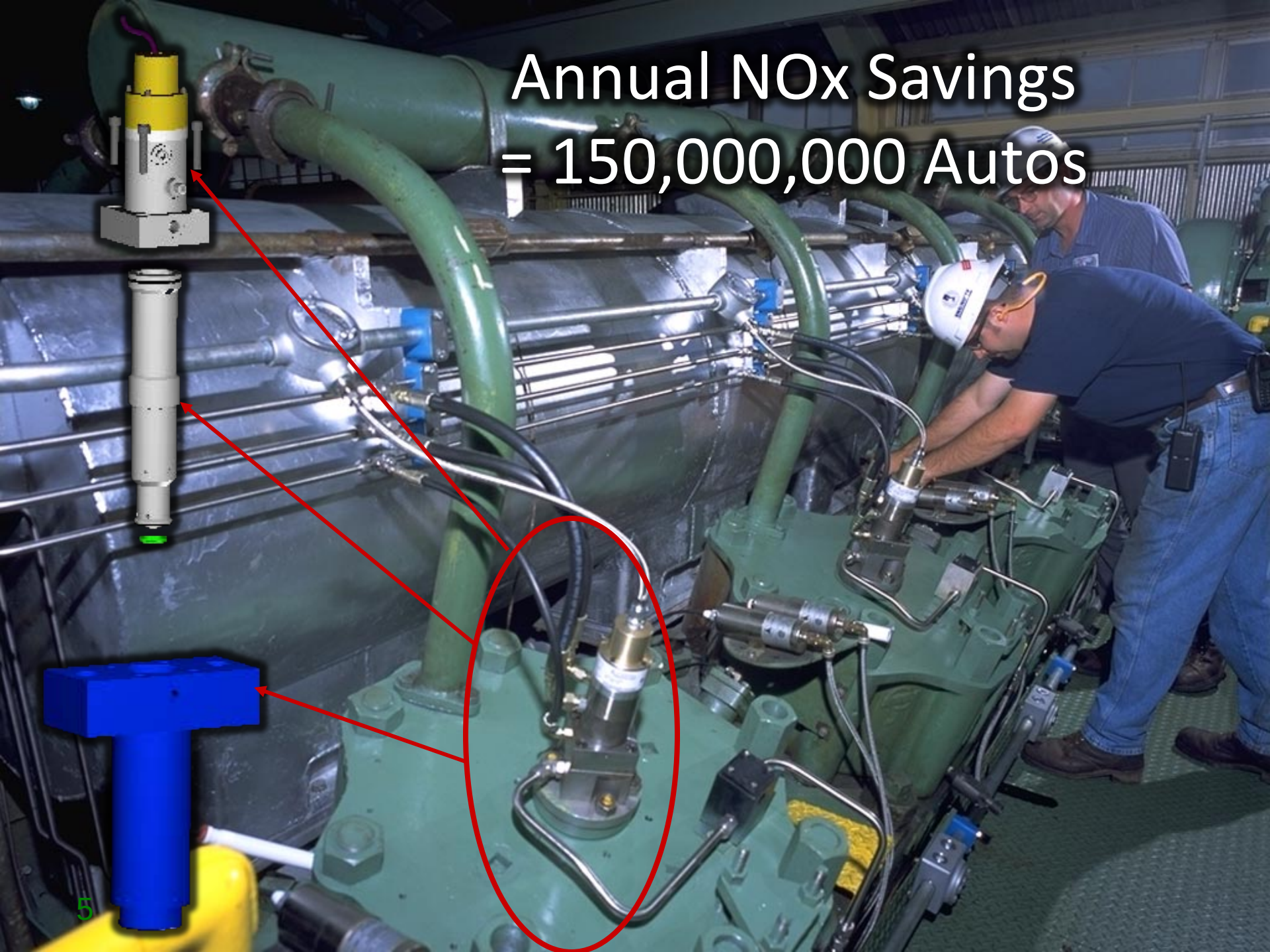
- **My background**

- Introduce ARPA-E
- Make a pitch for program directors
- Talk about our turbine projects
- Talk about upcoming programs of interest


Engines & Energy
Conversion Laboratory
430 North College Avenue
Colorado State

Powerhouse: Transforming Energy

Large Engines at the EECL


Annual NOx Savings
= 150,000,000 Autos

Gen III Stove

Factor(E) Ventures

Factor(E) Ventures

Founded in 2013, Factor(E) is a joint venture between the Energy Institute at Colorado State University and Shell Foundation.
It was born out of a need for more effective investments in early stage energy-access technology ventures.

- 1.3 billion people without access to electricity
- 2.6 billion people without access to clean cooking
- 1.0 billion people without access to clean water
- $1 trillion in investment required to achieve universal access by 2030
- 84% are in rural areas

Taking great ideas from Whiteboard to Board Room

Analyze

We monitor market challenges and needs, constantly evaluating potential barriers and risks to energy innovation in developing markets.

Identify

We seek out brilliant ideas and promising entrepreneurs that have the potential to solve global energy problems.

Invest

We provide these entrepreneurs with risk capital and resources to support the development of their technologies.

De-Risk

Working collaboratively, we roll up our sleeves and partner through an iterative process of development, testing and validation to reduce technology risk.

Connect

We leverage our network and resources to connect entrepreneurs to follow-on funders and help build a strong investment case.

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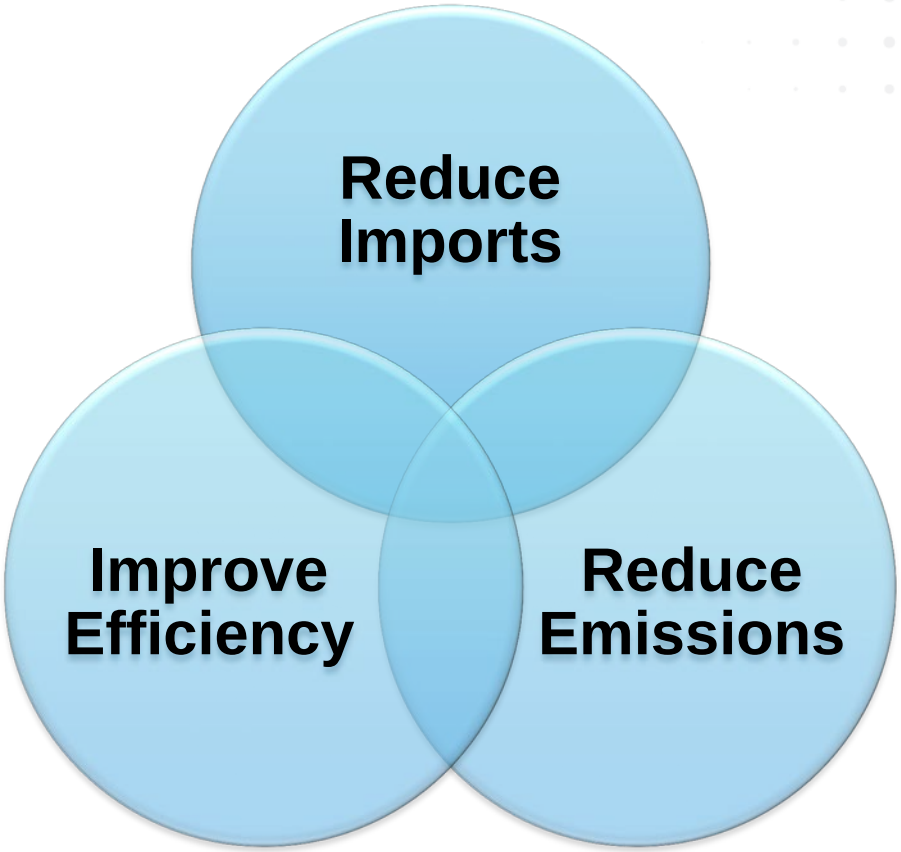
The ARPA-E Mission

Catalyze and support the development of transformational, high-impact energy technologies

Ensure America's

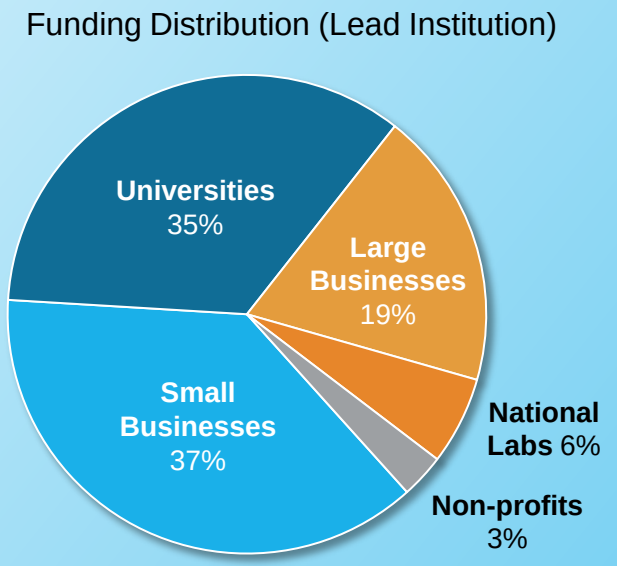
- National Security
- Economic Security
- Energy Security
- Technological Competiveness



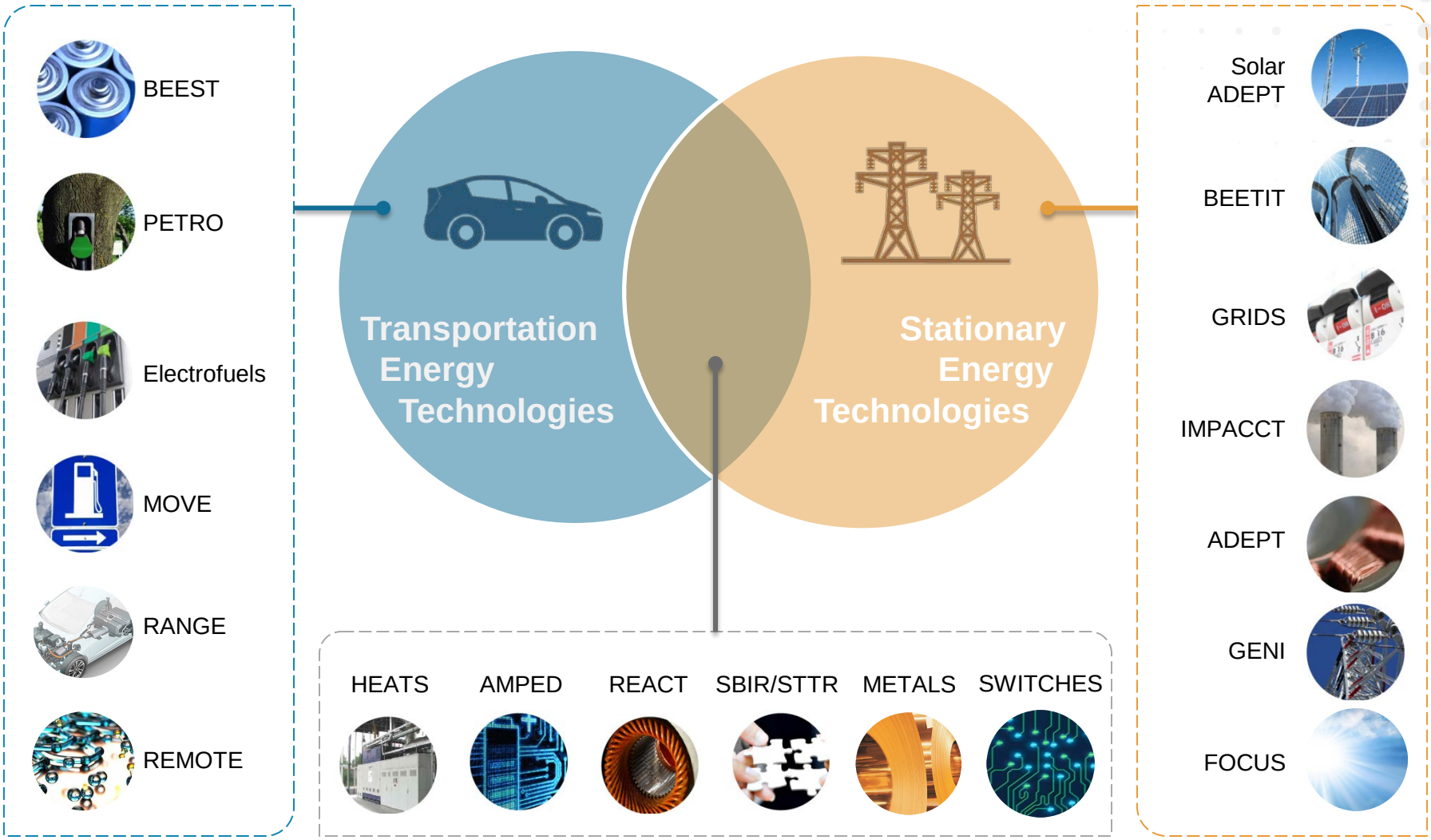
A Brief History of ARPA-E

- **2007**
  - *America COMPETES Act* signed, authorizing ARPA-E
- **2009**
  - *American Recovery & Reinvestment Act* signed, providing $400M to establish ARPA-E
- **2014**
  - *Over $900M invested in 362 projects funded*
  - *22 projects have attracted >$625M in private-sector funding*
  - *24 new companies formed*
  - *>16 projects partnered with other agencies for further development*

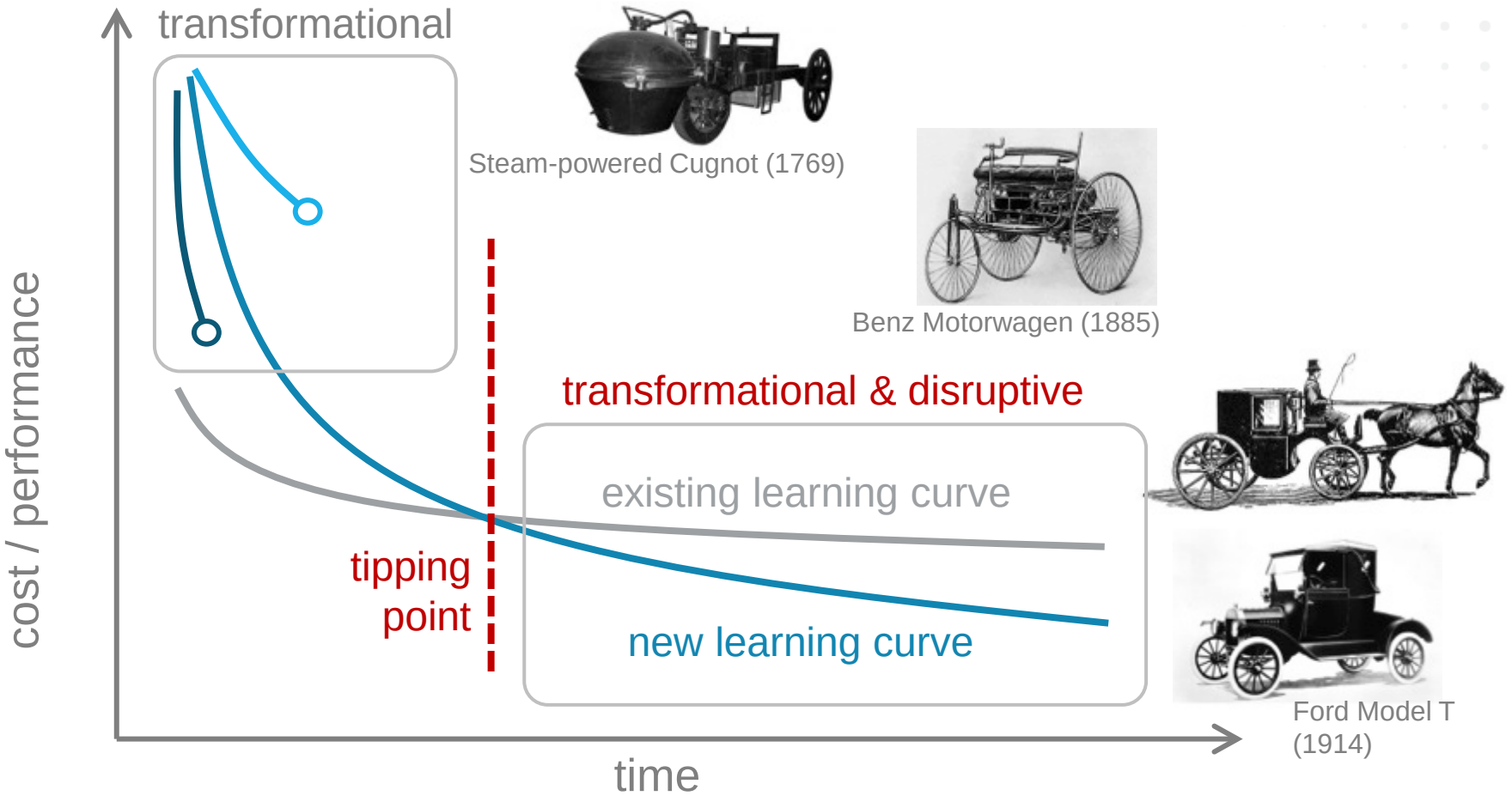
Investing in America's Best and Brightest



Focused Programs



Creating New Learning Curves



Developing ARPA-E Programs

ARPA-E Program Directors

Transition Toward Market Adoption

2014

ENVISION

Program Conception (Idea/Vision)

ENGAGE

Workshop

Program Approval

FOA Development & Issuance

EVALUATE

Merit Review of Proposals

Proposal Rebuttal

ESTABLISH

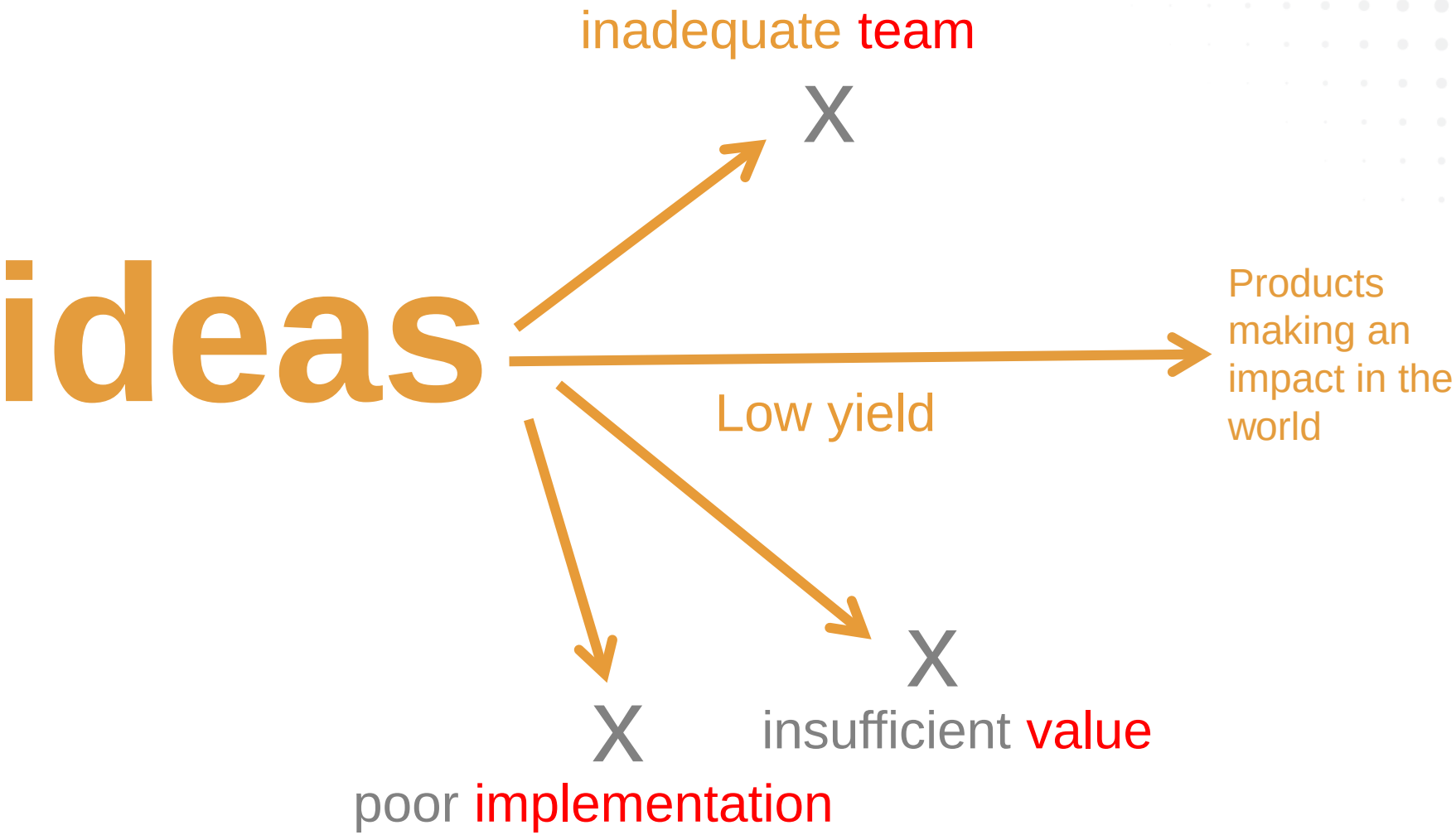
Project Selection

Contract Negotiations & Awards

EXECUTE

Ongoing Technical Review

Improving the Yield



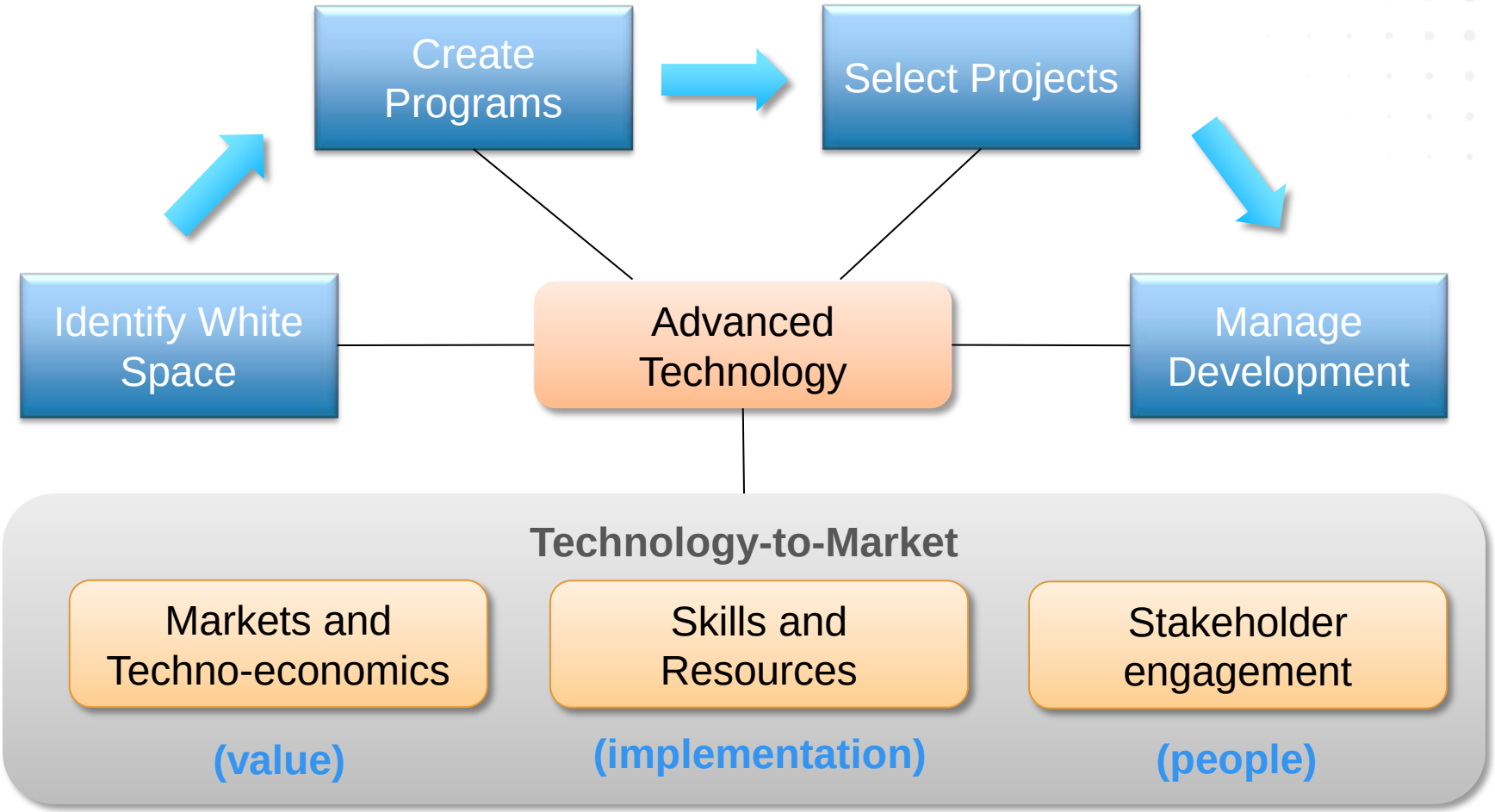
Changing the Model

ideas

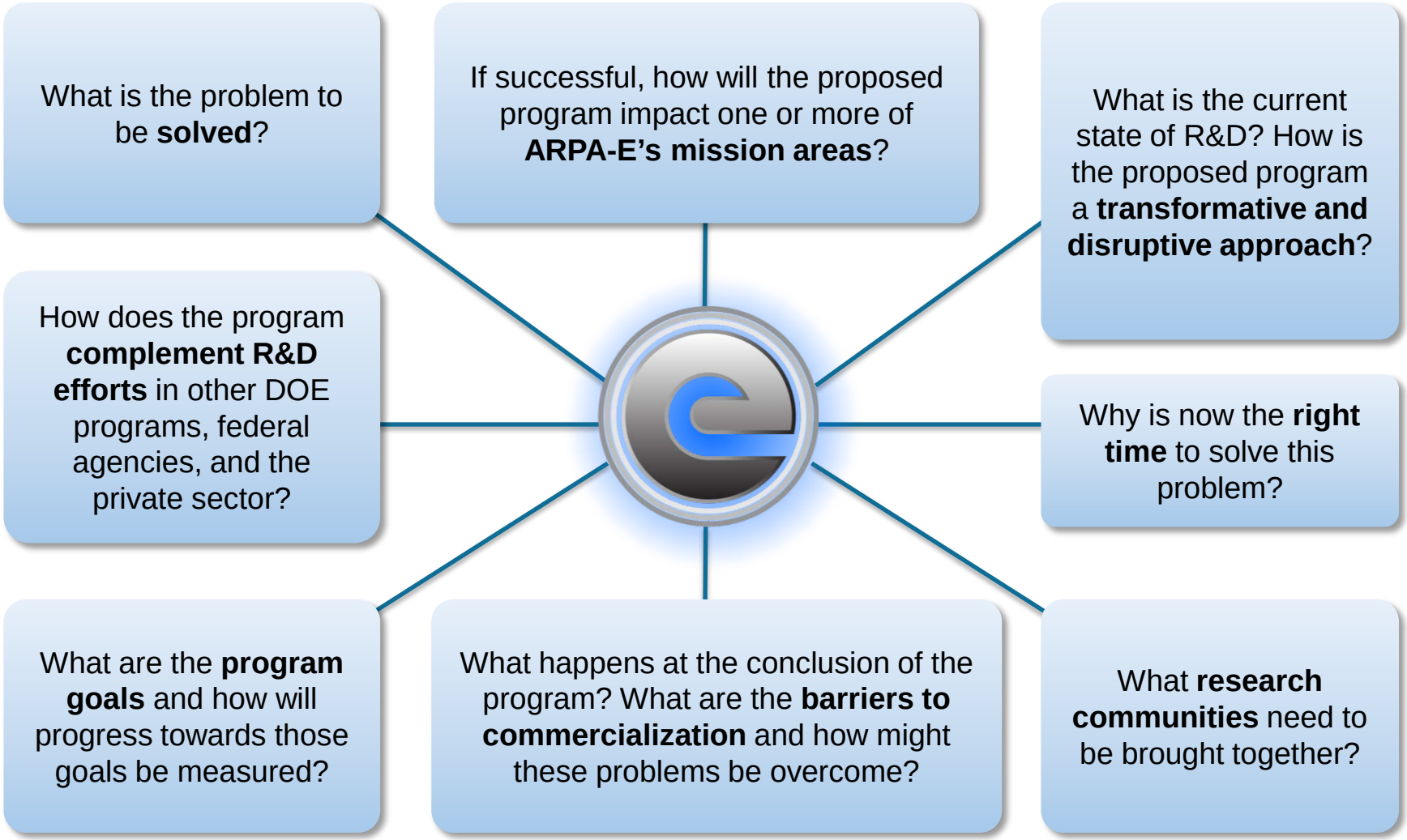
Products making an impact in the world

+ value
+ team
+ implementation

Changing the Model



ARPA-E Program Framing Questions



ARPA-E Programs

ARPA-E has invested in over 375 energy technologies across 19 focused program areas and 2 OPEN solicitations

Transportation Energy Technologies

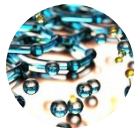

BEEST


Electrofuels


RANGE


PETRO


MOVE


REMOTE

Stationary Energy Technologies


Solar ADEPT


GRIDS

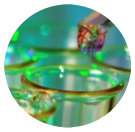

IMPACCT


FOCUS


BEETIT


GENI


ADEPT


REBELS

Transportation and Stationary Energy Technologies

HEATS

AMPED

REACT

METALS

SWITCHES

FY14 Focused Solicitations

REBELS
Reliable Electricity Based on ELectrochemical Systems

Selections announced 6/19/14

DELTA
Delivering Efficient Local Thermal Amenities

FOA released 4/29/14;
Concept Papers submitted 6/13/14

MONITOR
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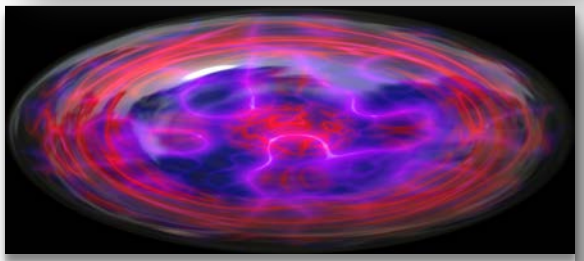

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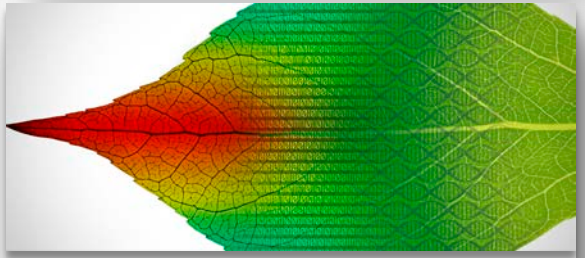

TERRA
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Concept Papers Due 11/17/14

Outline

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Always recruiting Program Directors

- Opportunity to deploy $30M-$100M for high impact R&D
- Close-knit PD community
- Great support staff
- Great performer community
- Typical profile: PhD, strong scientific / R&D accomplishments, strong credentials in commercialization
- Expectations: Conceive program, deep dive, workshop, program management, travel, travel, travel

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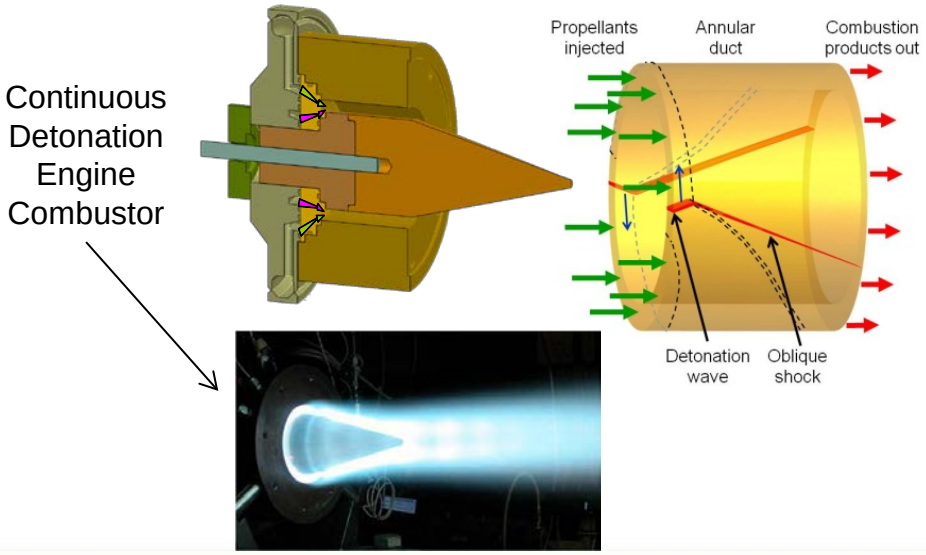
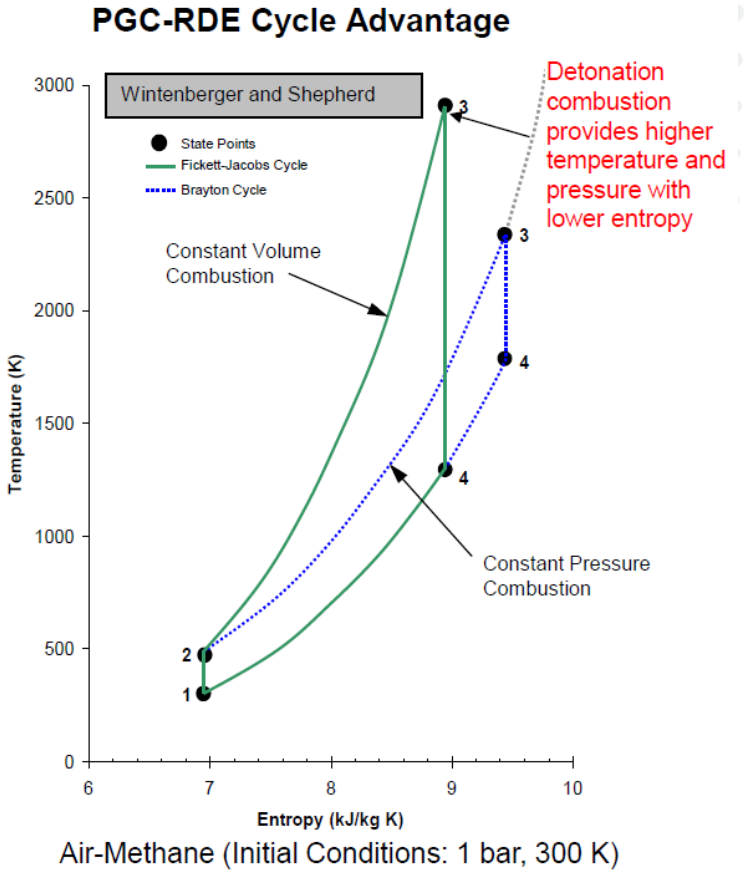
Continuous detonation combustor

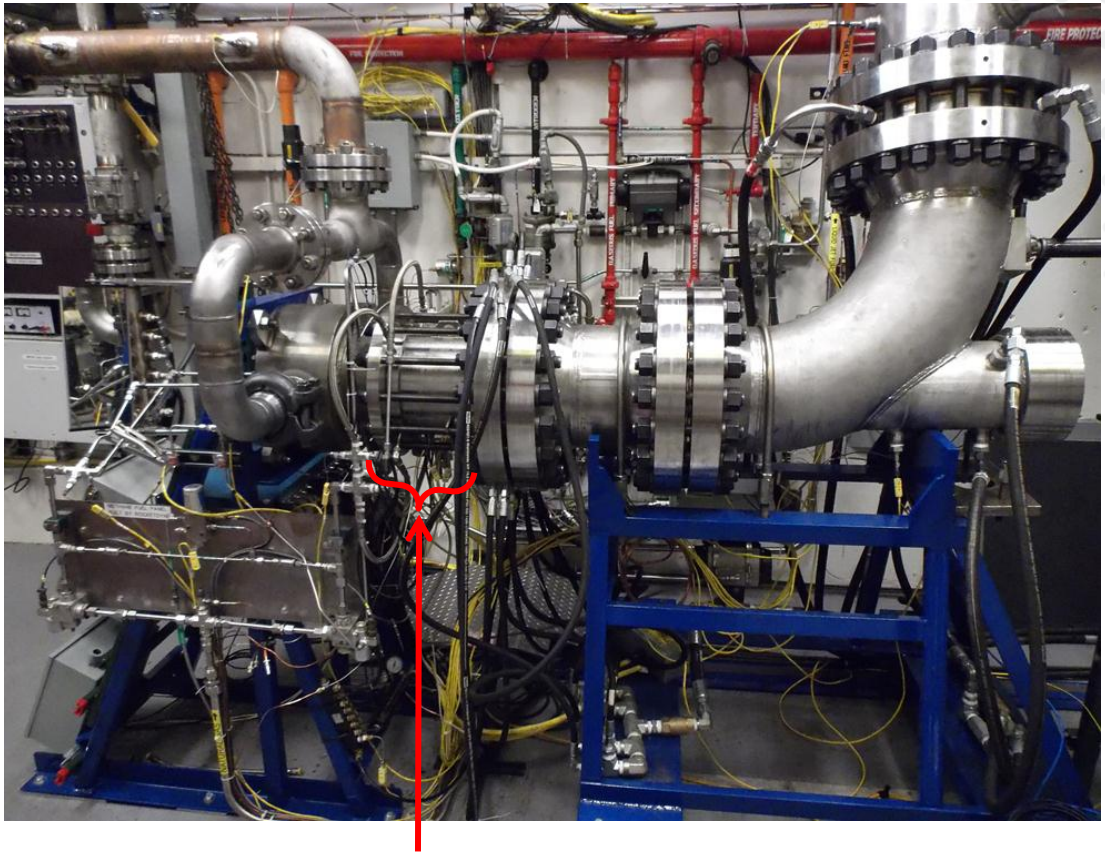
- Benefits of continuous detonation
  - More efficient
  - Pressure rise during combustion
  - Short combustion time may limit NO_x production
- Project designed and built a combustor and tested it in a simulated gas turbine environment





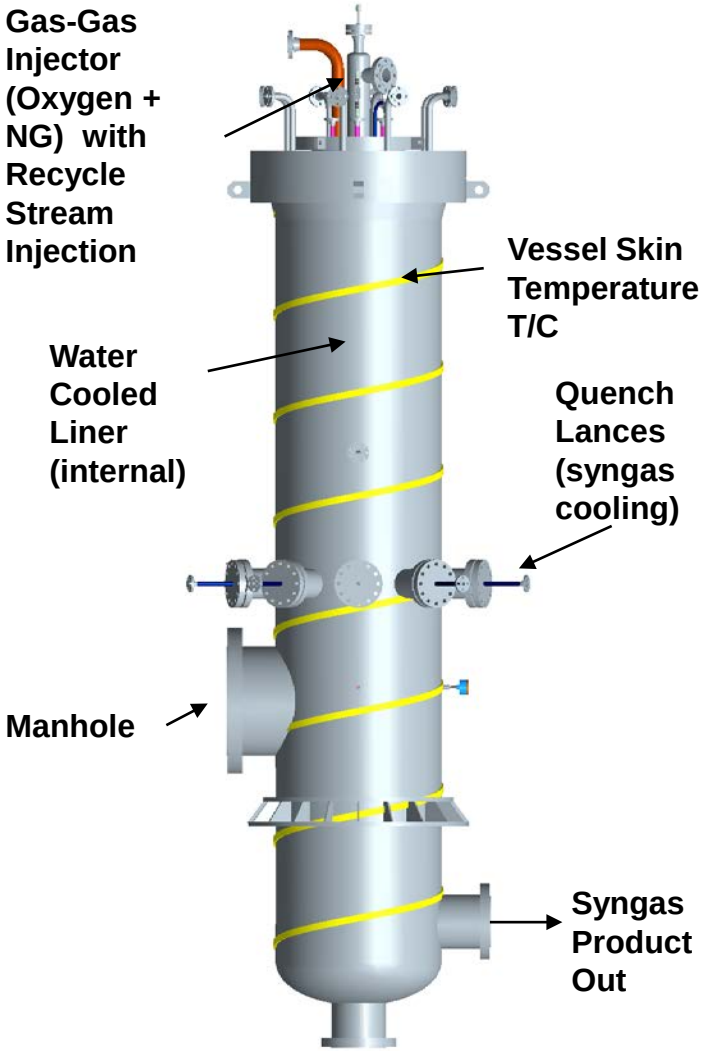
Continuous detonation combustor program status

- Test hardware designed, built, and activated in test facility
- Testing under conditions typical of combustors in power generation gas turbines
- 13 Hot fire tests completed
  - Exploring for conditions conducive to detonation
  - Covered about 1/3 of tests in exploratory test plan after initial test point did not produce detonation
- Facility in stand-down state – funds exhausted



Awarded follow-on funding in September 2014 by NETL

Turbo-PO_x For Ultra-Low Cost Gasoline



POx Development Combustor at GTI

- Efficiently facilitating natural gas conversion into a liquid fuel
- Partially oxidizes natural gas in a high-temperature, high-pressure turbine combustor
- Simultaneously improves the efficiency of gas conversion and generates high-quality waste heat

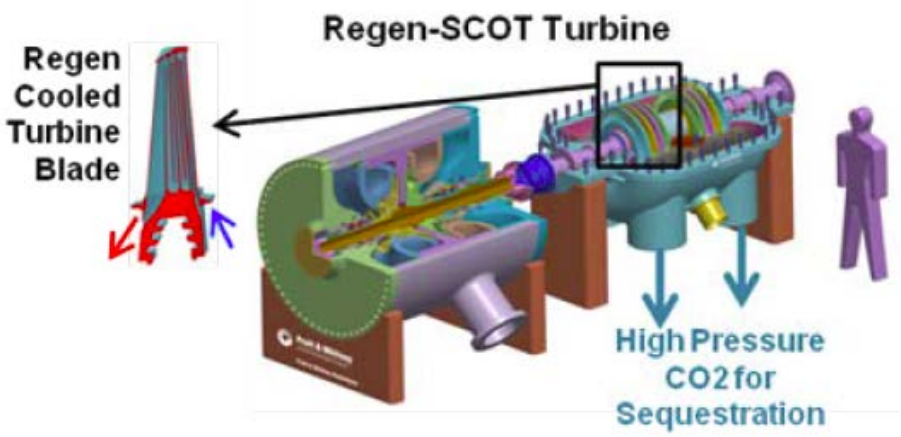
Advantages of the Rocketdyne POx technology for distributed natural gas conversion

- Lower GTL Plant CAPEX by ~15%
  - Eliminate requirement for Water Gas Shift and PSA through H_2:CO ratio optimization in POx unit
  - Reduce BOP CAPEX by recycling by-product/waste streams to POx unit
    - Wax, light hydrocarbons, contaminated water, etc.
- Shortens Construction Schedule
  - Minimizes exposure of project economics to NG, oil price volatility
  - Construction less than 12 months
- Operational Simplicity and Flexibility
  - Eliminates pre-heat and start-up/shut-down requirements for refractory
  - Active cooling/materials selection avoids metal dusting, achieve long life

Aerojet Rocketdyne POx Technology Provides a High Degree of Plant Integration Flexibility to Increase Capital Efficiency

Rocket Engine Derived High Efficiency Turbomachinery for Electric Power Generation

- Regeneratively cooled super critical CO_2 turbine
- Cooling allows for the turbine to operate at higher temperatures and pressures than standard terrestrial turbines
- Potential to more than double power plant efficiency which would reduce cost and emissions



AEROJET ROCKETDYNE

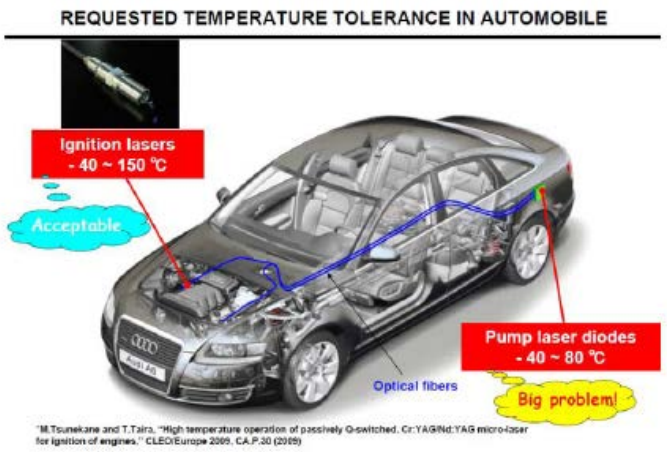
PennState

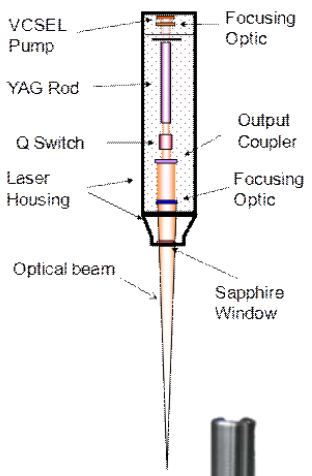
Awarded follow-on funding in September 2014 by NETL

Laser Ignition System for Next Generation High Efficiency, Low Exhaust Emission Combustion Engines

- Develop a laser ignition system capable of operating at “under hood” temperatures of 200°C
- Target is 10 mJ, 20 Hz, M^2<2
- Cost target is $150/spark head
- VCSEL pump laser with gain offset to compensate for temperature, up to 120°C, 10nm shift over 150°C
- Increase pumping period of Yb:YAG rod to compensate for gain reduction from increased temperature

The Problem





	SOA	Advancement
Configuration	Single pump, fiber coupled to laser	Individual pump + laser on each cylinder
Gain medium	Nd:YAG	Nd or Yb:YAG
Pump laser	50°C	140°C
Solid state laser	100°C	200°C
Cost / cylinder	$5,000	$150, 1M $60, 5M

POTENTIAL IMPACT

- 10% increase in engine efficiency on natural gas
- 27% increase in gasoline engine efficiency with high EGR
- Increased durability

The Solution

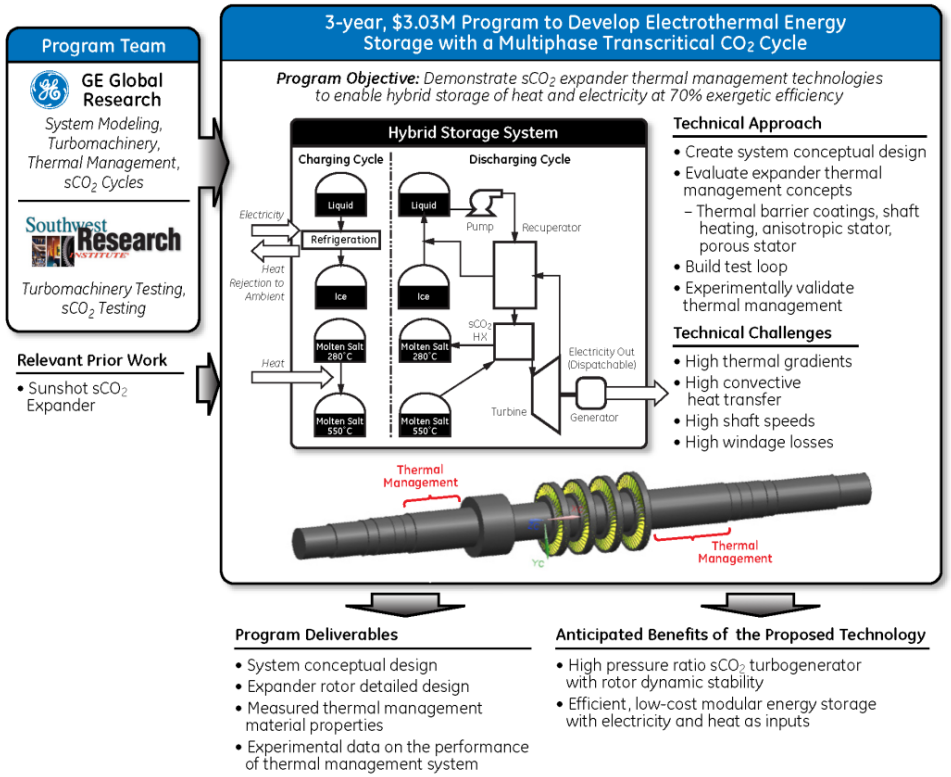
Electrothermal Energy Storage using Transcritical CO_2 GE Global Research

- Hybrid energy storage system using electricity and heat storage to drive high efficiency and compact supercritical CO2 power cycle to generate dispatchable power.
- Electric energy storage used to establish solid-liquid phase change heat sink and heat storage using molten salt – providing high energy density and low cost.
- Compact, high efficiency, and low cost power cycle using supercritical CO2 high pressure ratio turbomachinery.
- Novel thermal management technology: thermal barrier coatings, shaft heating, anisotropic stator, porous stator.

	SOA	Advancement
Round trip exergetic efficiency	50% (CAES) 65-70% (ACAES)	70%
CAPEX	$165 /kW-hr (CAES) $180/kW-hr (ACAES)	$100/kW-hr
Shaft thermal gradient	100°C/inch	>150°C/inch

Technology Impact

Transformational advancement in the economically sustainable deployment of hybrid energy storage at exergetic efficiency 70% and CAPEX of $100/kW-hr.



arpa·e CHANGING WHAT'S POSSIBLE

Demonstrate sCO2 expander thermal management technologies to enable hybrid storage of heat and electricity at 70% exergetic efficiency

Other “Somewhat Related” Programs

- Stationary Vortices, “Dust Devils”, Georgia Tech
- Rich engine reformer, MIT & RTI
- Fabric covered wind turbine blade, GE
- 3D printed induction motor, UTRC

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FY15 Solicitations

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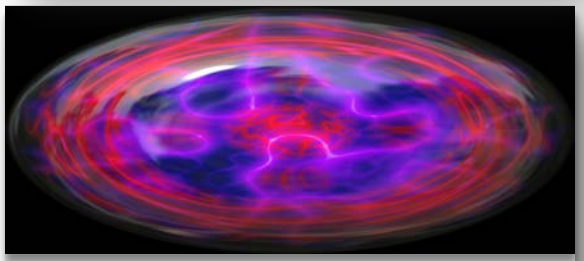

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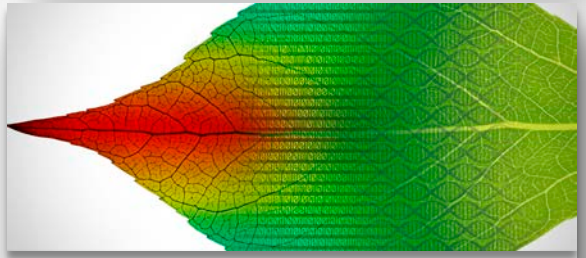

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Potential FY15 Solicitations

2015 Open FOA (certain)	**GenSets (maybe)**	**Transportation (maybe)**
Grid structure (maybe)	**Windows (maybe)**	**Micro Conc PV (maybe)**

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