# Triple reheat closed Brayton cycle thermal/electric power conversion

response to August 31, 2009 ARPA-E RFI

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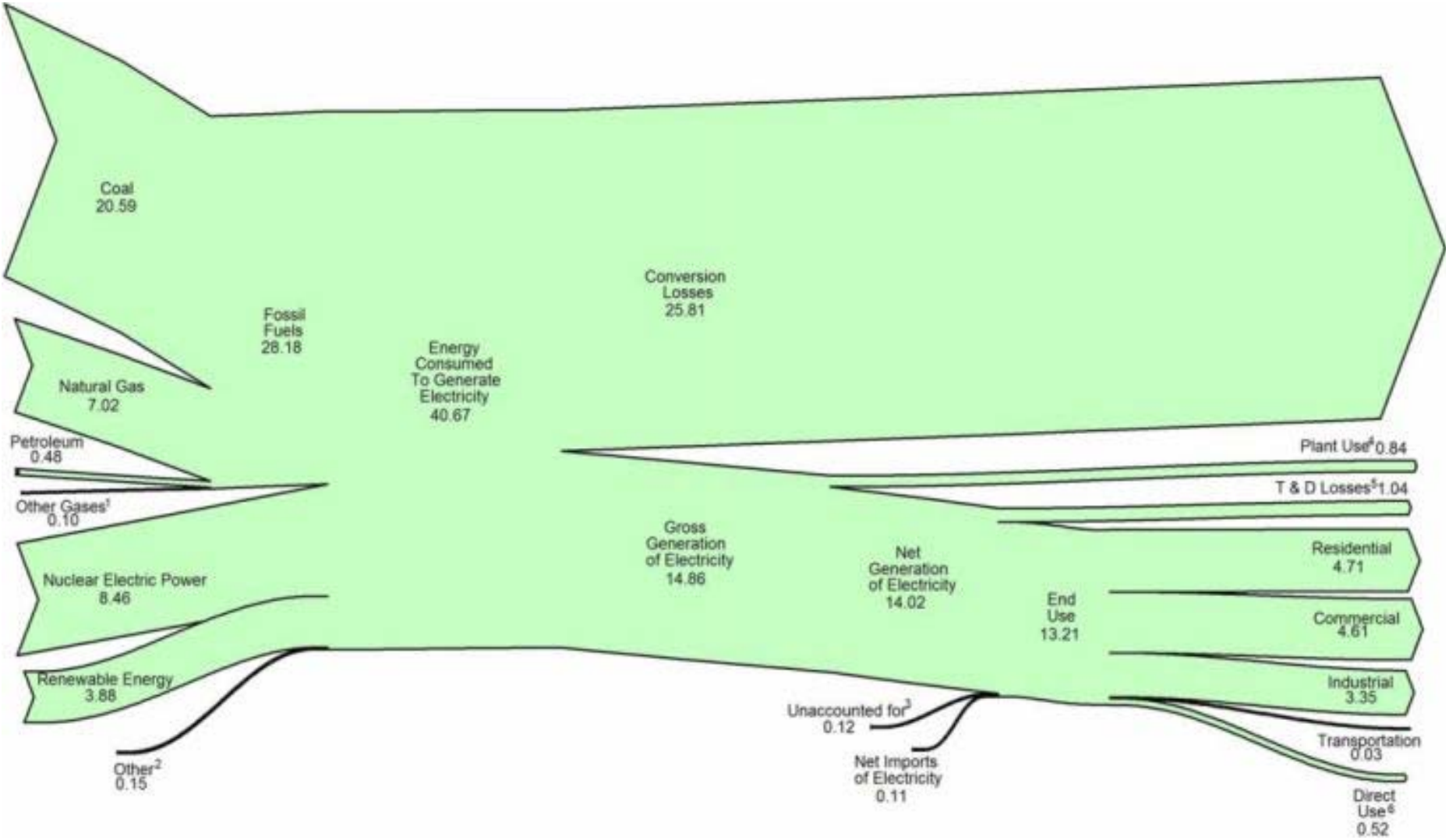
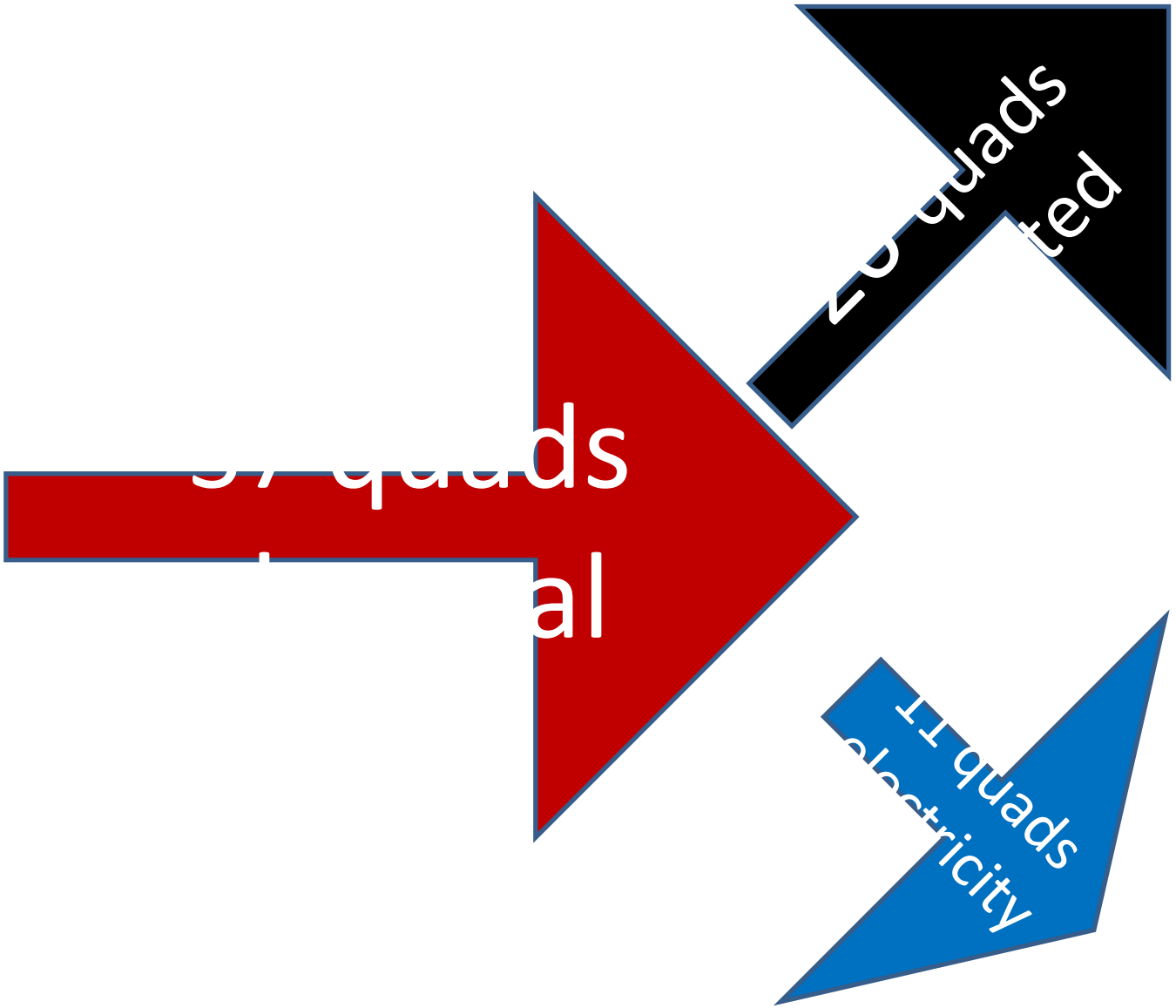
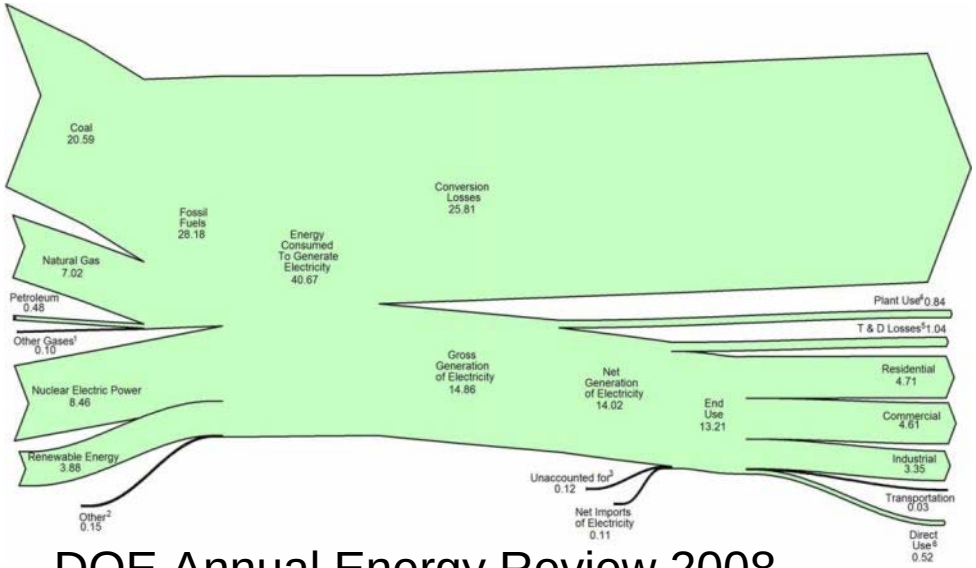
# Thermal energy is converted to electrical.



# US 2008 thermal/electrical conversion.



# US thermal/electrical power conversion efficiency in 2008 was just 30%.




DOE Annual Energy Review 2008

| | |
|---|---|
| Gross generation, less hydro | 10.98 quads |
| Thermal sources, excl hydro | 36.78 |
| Rejected heat | 25.81 |

efficiency 10.98 / 36.78 = 30%

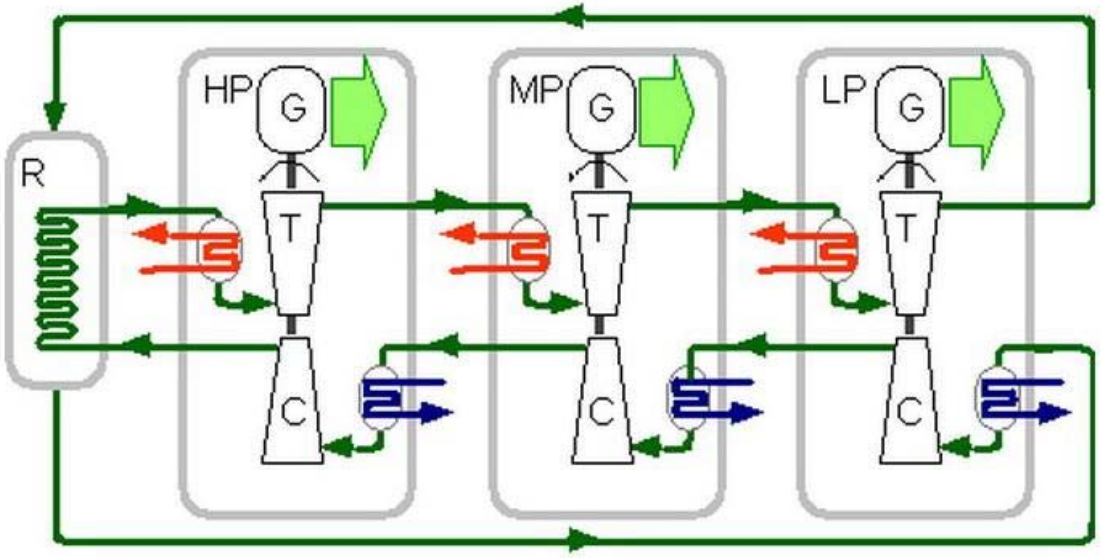
$$Efficiency = \frac{T_{in} - T_{out}}{T_{in}}$$

Carnot Theorem

<u>Higher temperature heat sources can increase efficiency to 50%.</u>

- Concentrated solar
- High temperature gas reactor
- Molten salt thermal heat storage
- Molten salt cooled pebble bed reactor
- Liquid fluoride thorium reactor

# High efficiency, high temperature power conversion needs the Brayton cycle.




1. Helium, $CO_2$ or nitrogen gas is successively heated by a 700°C molten salt heat exchanger as it passes through high, medium, and low pressure Turbines.

2. The gas cycles back through three successive Compressors, cooled by fluid that transfers rejected heat externally.

3. The Recuperator transfers some energy from the compression cycle back to the expansion cycle.

4. The Generators produce electricity.

Brayton cycle has efficiency of 45% at 700°C, over 50% at 950°C.

# Reducing rejected heat is environmentally positive.

Today's 1,000 MW coal or nuclear plant cooling tower evaporates 20,000 gal/min.

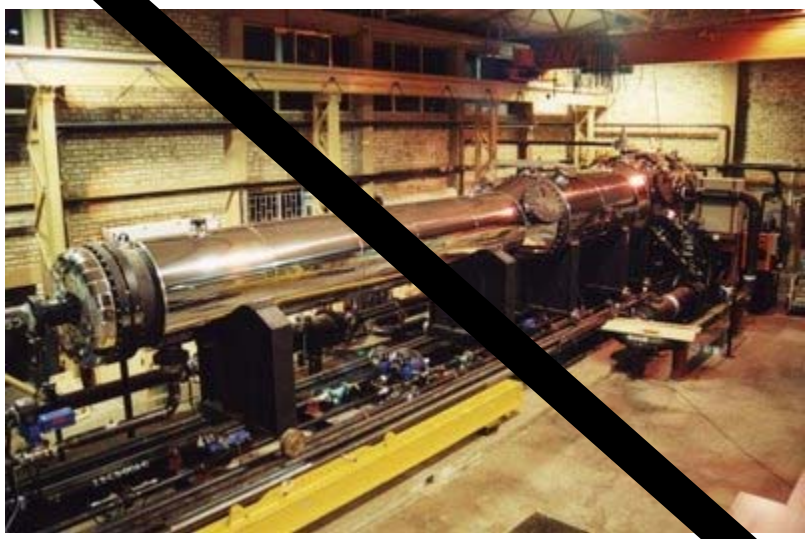
River or sea water cooling heats 600,000 gal/min.

Increasing efficiency 33% → 50% halves rejected heat per MW generated.

Makes air cooling possible in arid lands.

# First of a kind Brayton power conversion turbine development is stopped.

PBMR Pty Ltd (South Africa) pebble bed reactor project has run out of funds for this Brayton cycle power conversion turbine.



**Potchefstroom, S Africa: first closed-cycle, multi-shaft gas turbine in the world**

Yet theoretical analyses abound:

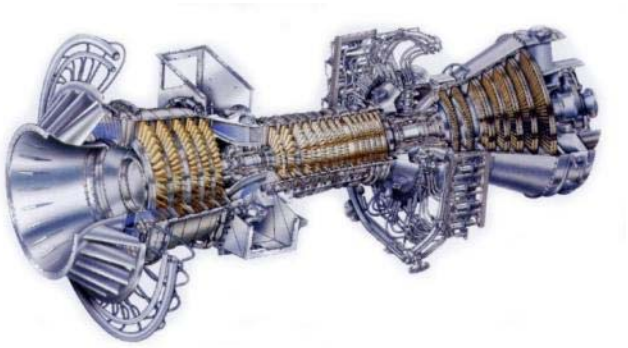
High-Temperature Liquid-Fluoride-Salt Closed-Brayton-Cycle Solar Power Towers
http://www.ornl.gov/sci/scale/pubs/SOL-05-1048_1.pdf

Effects of Interstage Cooling on Brayton Cycle Efficiency
http://www.inl.gov/technicalpublications/Documents/3479831.pdf

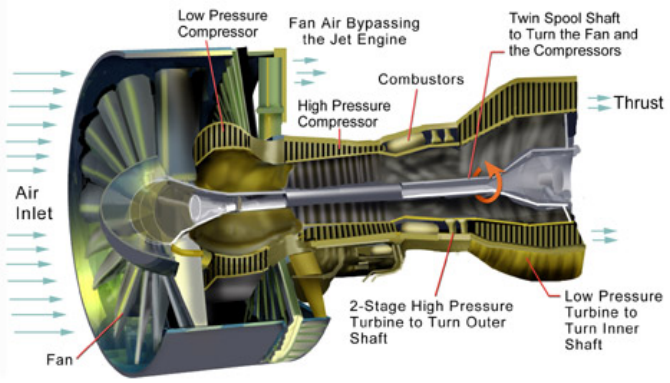
Brayton Cycle: The Ideal Cycle for Gas-Turbine Engines In Relation to Power Plants
http://web.me.unr.edu/me372/Spring2001/Brayton%20Cycle.pdf

Concept Design for a High Temperature Helium Brayton Cycle with Interstage Heating and Cooling
http://nuclear.inl.gov/deliverables/docs/genivihc_2006_milestone_report_7_1_2006_final.pdf

# Open-cycle Brayton turbine technology is well established, but not closed-cycle.



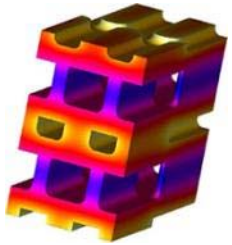
GE LM6000 gas turbine




Pratt & Whitney aircraft turbine

Closed-cycle Brayton conversion work to do:

1. Adapt to lower temperature << 1500°C.
2. Remove internal fuel combustion.
3. Develop compact heat exchanger.
4. Contain helium leaks.
5. Develop closed gas management system.
6. Engineer air-cooled heat rejection.



OVERCOME CHOKE POINT

PHYSICALLY BUILD AND TEST

First-of-a-kind closed cycle Brayton conversion

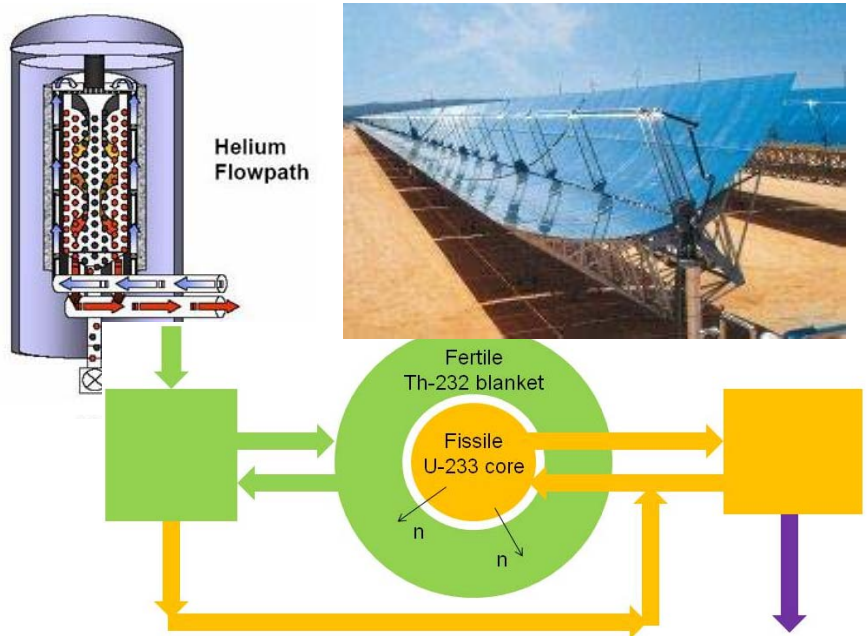
# Project plan and budget scenario.

| $ 50 M | $ 100 M | $ 300 M | $ 50 M |
|---|---|---|---|
| Review R&D, design | Qualify vendors, materials | Build, test | Transfer technology |
| 2010 | 2011 | 2012 | 2015 |

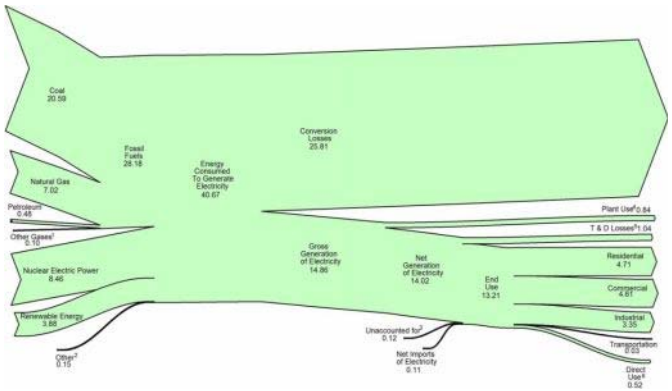
This work can parallel other projects.

<u>Many entities are highly qualified for this work</u>

General Electric
Pratt & Whitney
UC Berkeley
MIT
NASA
Sandia
Idaho National Laboratory
Oak Ridge National Laboratory



# Investing $500 million in Brayton power conversion helps save > $23 billion/year.




- HALVES this 25.81 quad of rejected heat

  costing $ 46 billion if from coal
  costing $183 billion if from natural gas

Brayton cycle power conversion enables all expected new high-temperature energy sc

- Concentrated solar
- High temperature gas reactor
- Molten salt thermal heat storage
- Molten salt cooled pebble bed reactor
- Liquid fluoride thorium reactor

to be implemented in the coming few decades, replacing existing 30% efficient thermal sources.

These projects will share the credit.

# Brayton cycle power conversion merits ARPA-E funding.

**$500 million invested helps return over $23 billion/ year.**

**Building the first-of-a-kind Brayton power conversion system will be a breakthrough.**

**Brayton conversion benefits many new energy technologies.**

**It is a 'disruptive new approach to…thermodynamic power cycles' requested in the RFI.**

**It is a 'Revolutionary approach for overcoming…"choke points" within a technology value chain', requested in the RFI.**