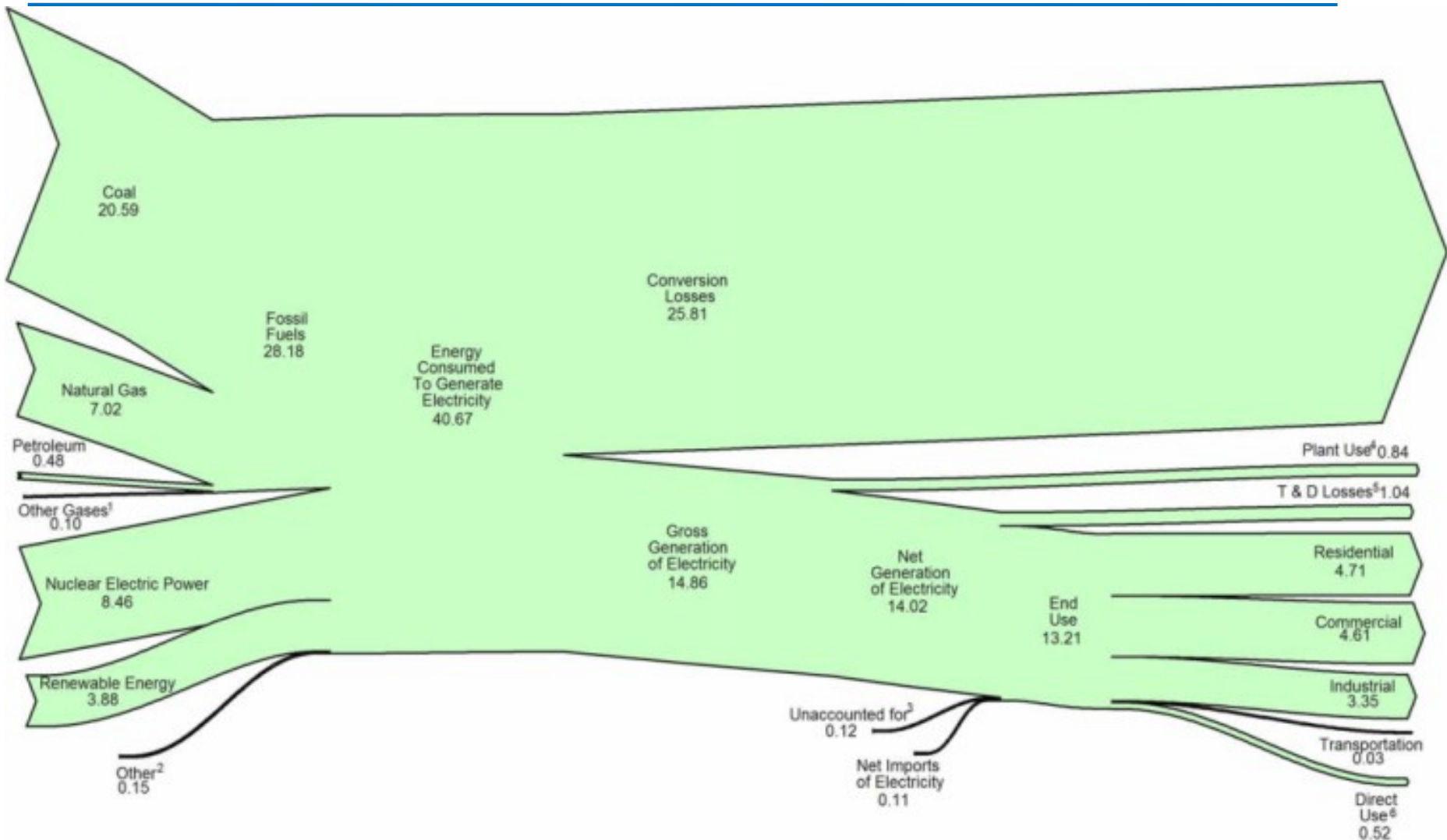


Triple reheat closed Brayton cycle thermal/electric power conversion

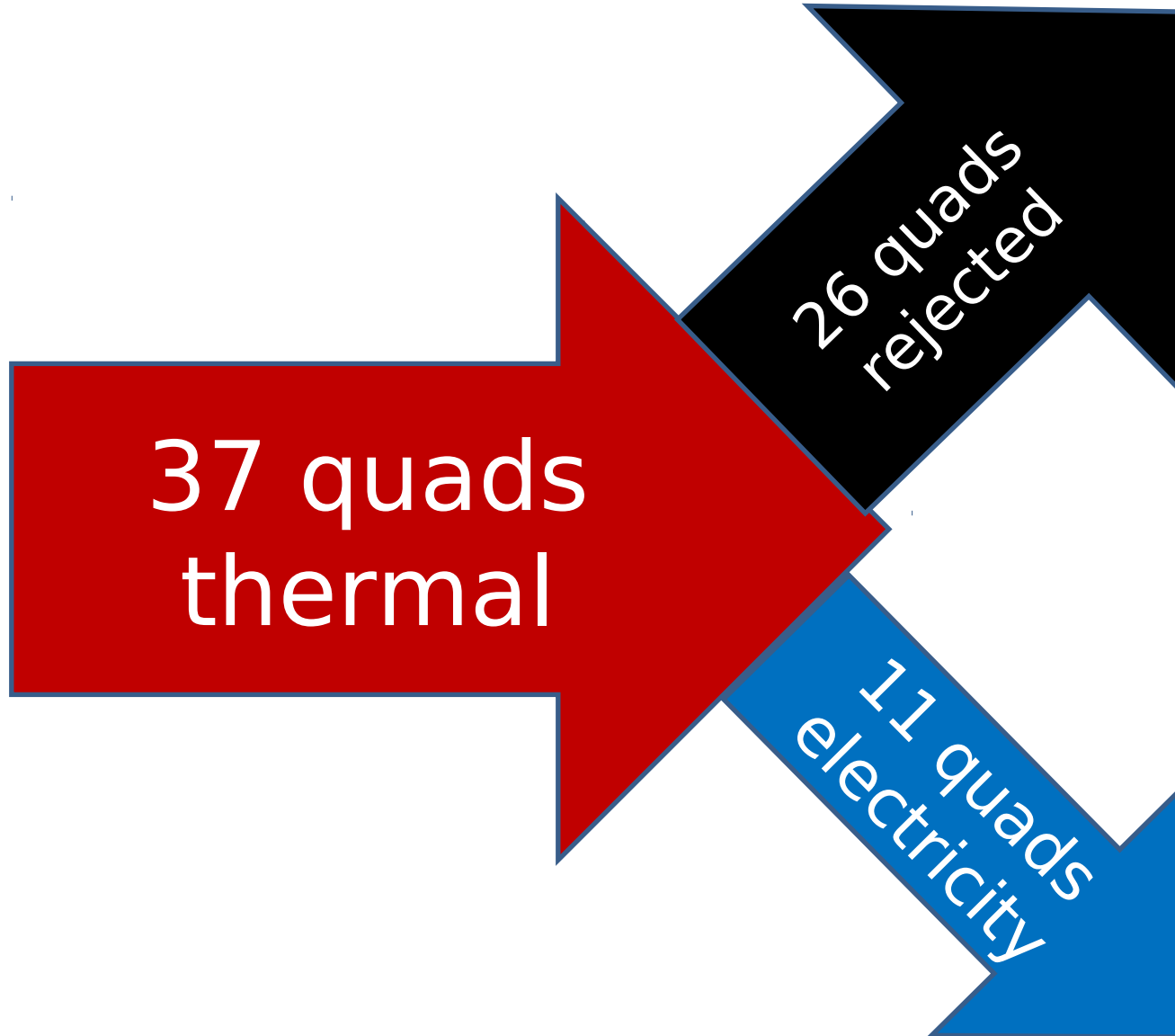
response to August 31, 2009 ARPA-E RFI

Robert Hargraves
603 643 5080
robert.hargraves@gmail.com

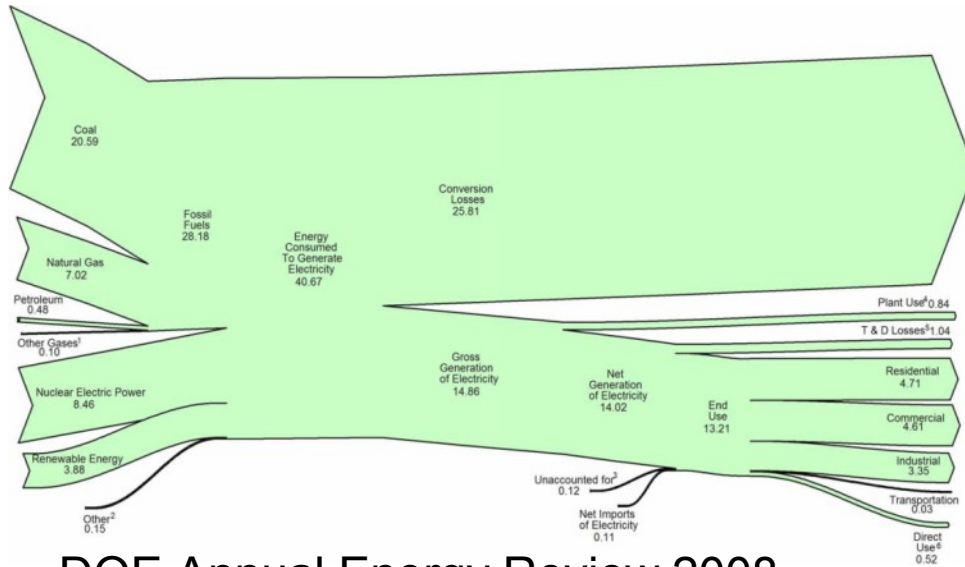
Thermal energy is converted to electrical.



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

$$\text{efficiency } 10.98 / 36.78 = 30\%$$

Higher temperature heat sources can increase efficiency to 50%.

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

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

Carnot Theorem

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.

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

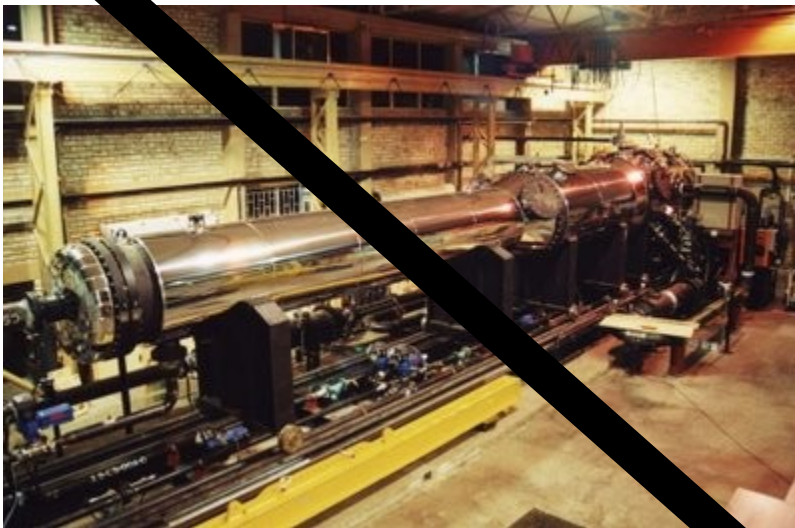
<http://www.inl.gov/technicalpublications/Documents/3479831.pdf>

Brayton Cycle: The Ideal Cycle for Gas-Turbine Engines In Relation to Power Plants

<http://web.me.unr.edu/me372/Spring2001/Brayton%20Cycle.pdf>

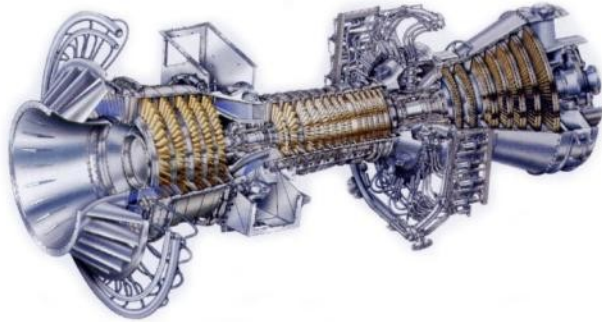
Concept Design for a High Temperature Helium Brayton Cycle with Interstage Heating and Cooling

http://nuclear.inl.gov/deliverables/docs/genivihc_2006_milestone_report_7_1_2006_final.pdf

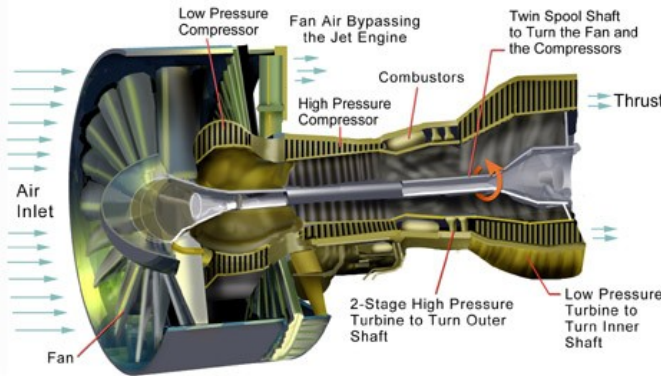


Potchefstroom, S Africa: first closed-cycle, multi-shaft gas turbine in the world

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



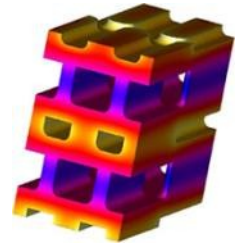
GE LM6000 gas turbine



Pratt & Whitney aircraft turbine

Closed-cycle Brayton conversion work to do:

1. Adapt to lower temperature $\ll 1500^{\circ}\text{C}$.
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

Many entities are highly qualified
for this work

General Electric

Pratt & Whitney

UC Berkeley

MIT

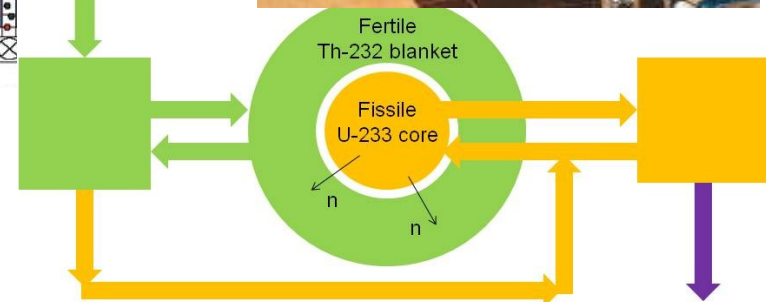
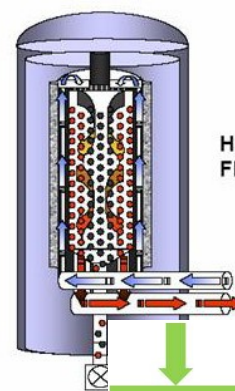
NASA

Sandia

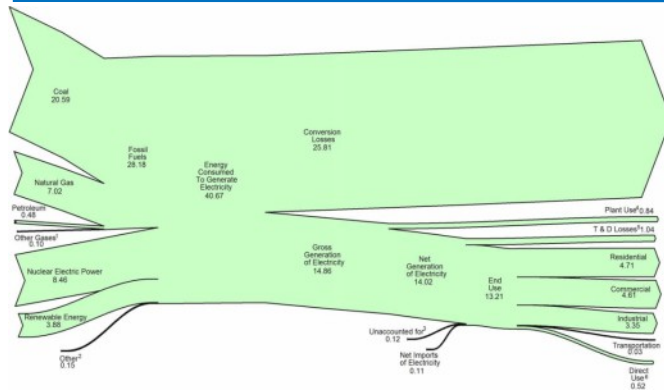
Idaho National Laboratory

Oak Ridge National Laboratory

This work can parallel other projects.



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 sources

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

These projects will share the credit.

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

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.