Office of Fossil Energy Overview of Supercritical Carbon Dioxide Technology Effort

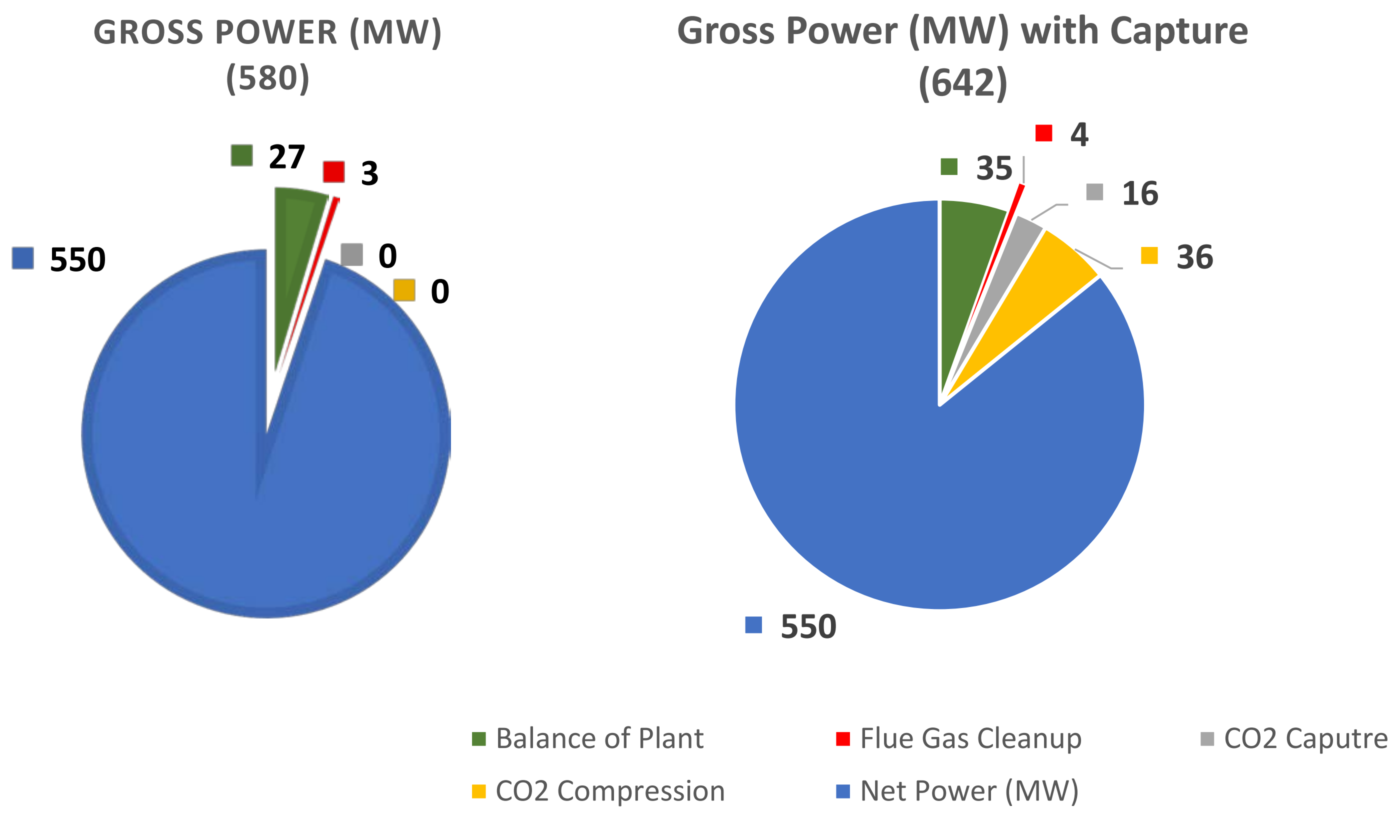
5th International sCO_2 Power Cycles Symposium

March 29, 2016

What we do


OFFICE OF FOSSIL ENERGY
Clean Coal & Carbon Management
VISION
A secure, reliable, and affordable energy future with the environmentally sound use of coal and all fossil fuels
MISSION
Support the research, development, and demonstration of advanced technologies to ensure the availability of clean, affordable energy from coal and fossil fuel resources
GOALS
1. Demonstrate significantly lower-cost CO_2 capture technologies to enable widespread deployment of near-zero emission fossil-based technologies
2. Acceptance by industry, financial institutions, regulators, and the public that CO_2 can be safely injected, monitored, and permanently stored in a variety of geologic formations
3. Conduct high-risk, transformational research and development on coal fossil fuel technologies
4. Drive international collaboration to ensure widespread acceptance and deployment of CCS and advanced coal technologies
5. Provide data and expertise to support policy, legislation, and regulation impacting fossil fuel research
WWW.ENERGY.GOV/FE

Supercritical Pulverized Coal Power Plant Summary Performance



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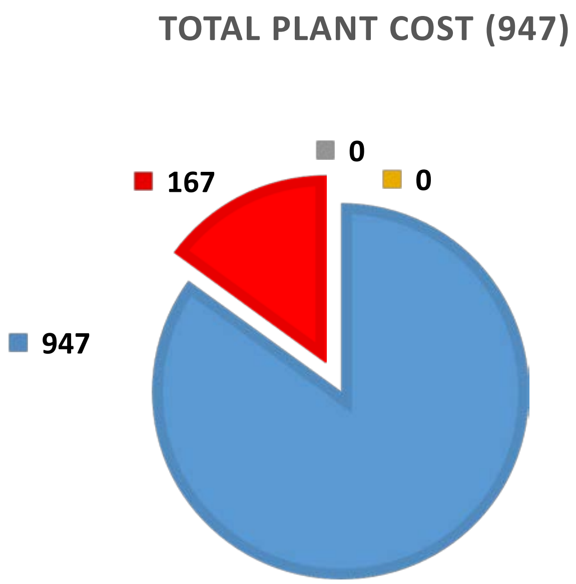
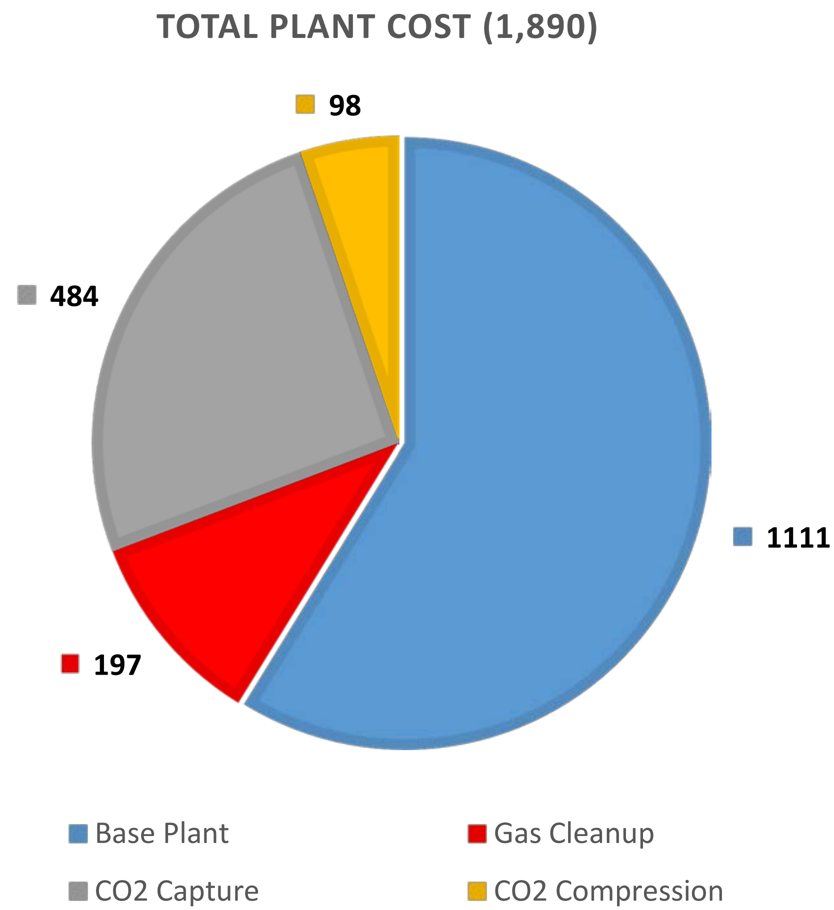


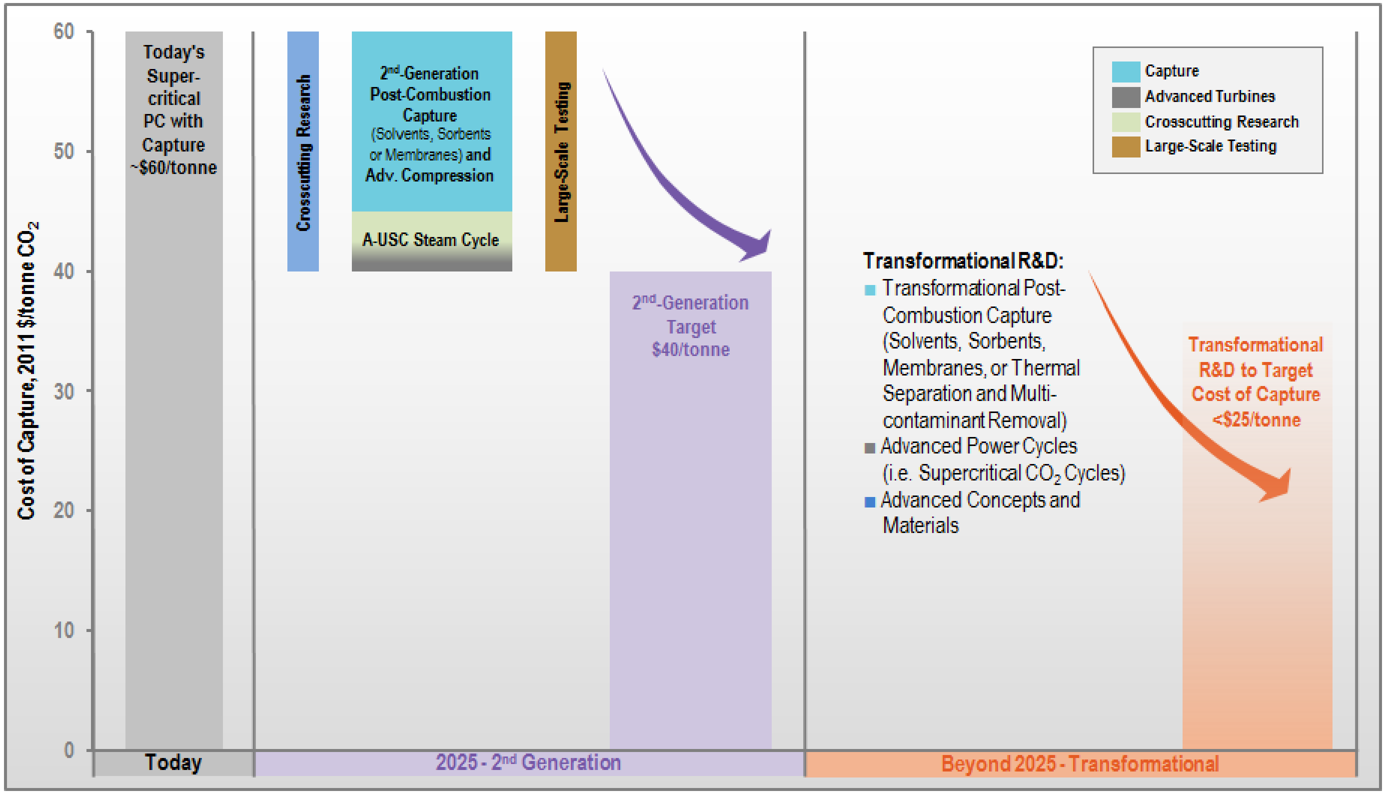


Millions 2011$

The Challenge of Carbon Capture

R&D Driving Down the Cost of CO_2 Capture

Greenfield Post-Combustion Capture Plants

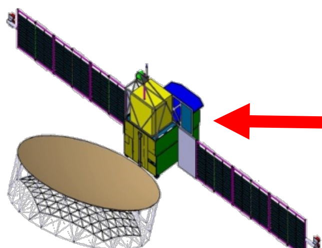


Supercritical CO2 Cycle Has Broad Applicability

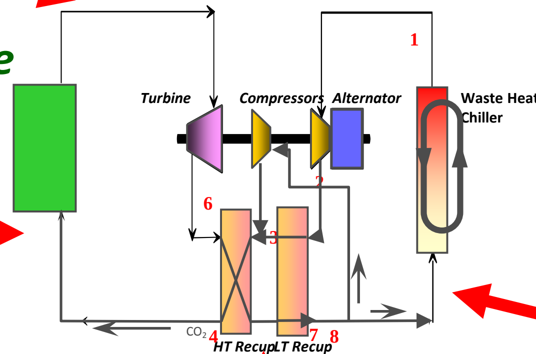
NE
FE
sCO_2
CSP (EERE)
GTO (EERE)

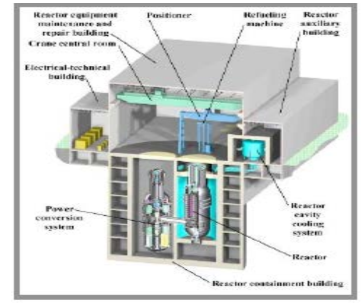
Supercritical CO_2 Brayton Cycle

Solar SunShot Power Cycle



Space Solar Electric Propulsion





Nuclear

Geothermal

Fossil

Sequestration Ready

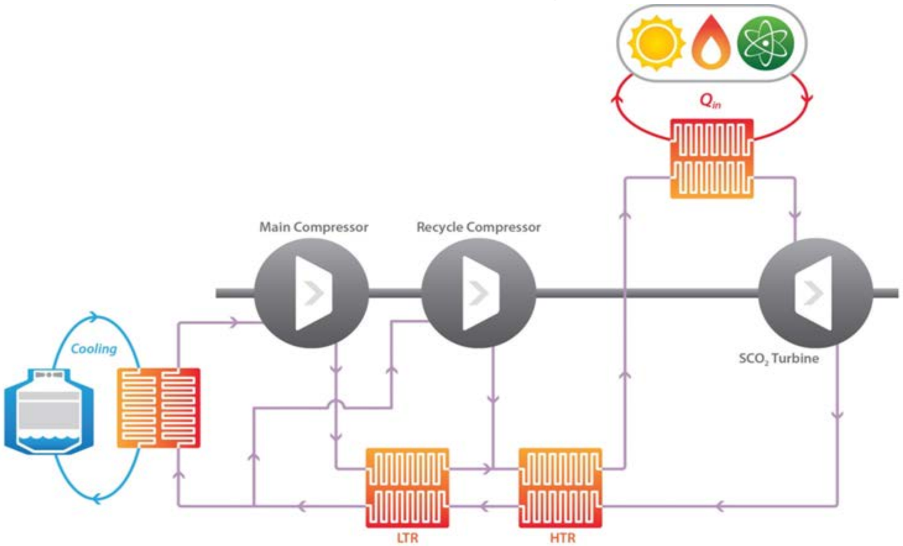
The long-term vision is widespread commercial deployment of a transformational technology

Fossil Energy Supercritical CO2 Power Cycles

Base Program – SCO2 Cycles for FE Applications

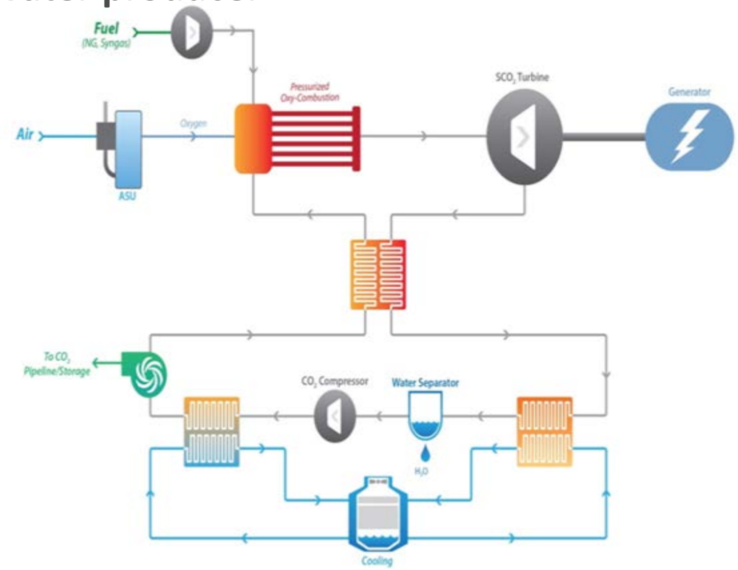
Indirectly-heated cycle

- Applicable to advanced combustion boilers
- Incumbent to beat: USC/AUSC boilers
- Thermal eff. > 50% possible
- High fluid density, low pressure ratio yields compact turbomachinery
- Ideally suited to constant temp heat source
- Adaptable for dry cooling



Directly-heated cycle

- Applicable to IGCC and NGCC
- Incumbent to beat: Adv. F- or H-class NGCC w/ post CCS
- Compatible w/ RD&D from indirect cycle
- Fuel flexible: coal syngas or NG
- 100 % CO_2 capture at storage pressure
- Water producer



FE SCO2 Power Cycles Program - Summary

- **Benefits of Supercritical CO2 Based Power Cycles**
  - Higher efficiency – Lower emissions per MWhr and positively affects COE calculation
    - Indirect (STEP): ~ 3 % pts greater than steam at the same temperature
    - Direct: Depends on TIT, need to beat F / H -class NGCC with CCS
  - Lower Cost and Small Footprint with new high temperature materials and adv. manufacturing
  - Fuel/energy source flexibility
  - Water producer direct fire configuration
- **DOE FE SCO2 Power Cycles Program - two thrusts:**
  - DOE SCO2 Crosscut Initiative (STEP – Indirectly heated SCO2 Brayton cycle)
  - FE SCO2 Power Cycles Base Program (indirectly & directly heated cycles for FE applications)
- **DOE SCO2 Crosscut Initiative (STEP)**
  - Collaboration between DOE Offices (FE, NE, and EERE – CSP & Geothermal)
  - Mission: Address technical issues, reduce risks, and mature technology
  - Objective / goal: Design, build, and test 10 MWe pilot facility (STEP)
  - Major Crosscut procurement actions:
    - Advanced recuperator development (FE FOA: $ 10 M in FY 2015)
    - Cost and technical approach for STEP (NE RFP: 3 awards)
    - Design, build & operate STEP facility (FE FOA Released ~ $ 100 M total value)

FE SCO2 Power Cycles Base Program

- R&D work specific to FE heat sources (funding from: AT, ACS and CCR&D)
- Additional R&D projects on critical components, analysis, simulation, and fundamental properties.
  - Turbomachinery
  - Recuperators
  - Oxy-fuel Combustion
  - SCO2 Heater Integration
  - Materials & Fundamentals
  - Systems Analysis

STEP Activities in Fossil Energy

FE 2016 FOA: Design & Build STEP Facility

- **FY2016 FE STEP FOA**
  - $ 80 M government value (ceiling) with 20 % cost share
  - FOA issued March 2016
  - Cooperative agreement to be awarded August / September 2016
- **Project Objective: Design and build STEP test facility**
  - 10 MWe pilot plant
  - Indirect-fired recompression Brayton sCO2 cycle
- **STEP Test Facility Goals**
  - Show potential for lower cost of electricity (COE) in relevant applications
  - Demonstrate operability of cycle
  - Verify component performance

FE SCO2 Base Program: Project Activities

Technical Challenges - Turbomachinery

Turbomachinery must be designed to address specific requirements of SCO2 power cycle to operate at **higher temperatures with greater power density**, enabling increased efficiencies over steam-based cycles.

Technical Challenges

- Designs for high gas density, high power density and real gas effects of CO_2 near the critical point
- Identification of **materials/coatings** having compatibility with SCO2 at temperatures/pressures of the turbomachinery operation
- Designs for higher temperatures of direct-fired cycle
- **Bearings and low-leakage seals** with long performance lives under high temperature/pressure conditions
- **Pressure containment**
- **Thermal management**

FE sCO2 Base Program: Project Activities

Oxy-fuel Combustion/Turbomachinery Technical Challenges

Achieving the additional **efficiency improvements** operating at **higher temperatures** of direct-fired sCO2 power cycle require unique designs of oxy-fuel combustors.

Technical Challenges

- Development of high inlet temperature combustor with oxy fuel and CO_2 diluent
- **Injector designs**
- Determine optimal fuel and oxygen **injection locations**
  - **Complete combustion**
  - **Minimize hot spots and wall temperatures**
- Understand **combustion kinetics and dynamics** at high temperature/pressure conditions with syngas or natural gas and CO_2 diluent
- **Minimal validation data** and kinetic models at operating conditions

FE sCO_2 Base Program: Project Activities

Recuperators for sCO2 Power Cycles – Technical Challenges

Recuperation of **heat from low pressure fluid at turbine exit to the high pressure fluid** upstream of primary heat source is vital to attaining efficiency improvements of the sCO2 power cycle.

Technical Challenges

- **Low cost,** compact heat exchanger designs
- High surface area for heat transfer to provide required heat duty (surface area density > 700 m^2/m^3)
- Identification of materials compatible with sCO2 at temperatures (>700° C) and pressures (up to 30 MPa) of the cycle
- Designs for **high temperatures** and **high pressures** as well as **high pressure differentials** (up to 30 MPa) between streams
  - Mechanical stability
  - Pressure containment
  - Minimal leakage
- Identification of scalable manufacturing techniques
- Recuperator design requires **optimization of pressure drop, heat transfer coefficient, and temperature difference** (approach temperature)
  - **Balance capital cost versus efficiency**

FE sCO_2 Base Program: Project Activities

sCO_2 Heater Integration – Technical Challenges

Substitution of **indirectly-heated sCO_2** power cycles **for traditional supercritical steam** based power cycles has potential for improved efficiency.

Technical Challenges

- Integrate the sCO_2 power cycle with fossil fuel heat source.
- Consider both **greenfield and retrofit** applications.
- Develop **boiler design**, including heat exchanger, to deliver higher temperature required for the sCO_2 working fluid.
- **Heater surface (boiler) cost challenge** due to high temperature and pressure conditions

FE sCO2 Base Program: Project Activities

Systems Modeling / Analysis – Technical Challenges

Indirect sCO2 power cycles have the potential for **efficiency improvement** over steam Rankine cycles, and **direct** sCO2 cycles **promise 40+% thermal efficiency with carbon capture and storage**

Technical Challenges

- Translation of *cycle* efficiency benefits to *plant* efficiency improvement
- **Identification of cycle conditions** for **optimized cycle performance, cost, and operability**
- **Lack of cost estimates** for most sCO2 cycle equipment at commercial scales hinders COE evaluations
- **Efficient integration of sCO2 power cycles into fossil-fueled heat sources** with widely varying flue gas temperatures
- Efficient **handling** of significantly **increased mass flows** relative to comparably-sized steam Rankine power cycles
- **Uncertainties in combustion** and pollutant cleanup processes in direct-fired sCO2 systems
- **Optimization of component cost vs. performance** to minimize overall plant COE