GHG BACT Examples
GHG BACT Example:
Natural Gas Fired Boiler
BACT Example: Gas Boiler

Project Scope:

• Existing major source
• New 250 MMBtu/hour natural gas-fired boiler
BACT Example: Gas Boiler (cont’d)

Step 1: Identifying all available controls

Permit application lists the following four controls:

• Oxygen Trim Control:
  – Inlet air flow adjusted for optimal thermal efficiency

• Economizer:
  – Increases thermal efficiency by preheating feedwater

• Blowdown Heat Recovery:
  – A heat exchanger transfers some of the heat in the blowdown water to feedwater for deaeration or preheating
  – Increases the boiler’s thermal efficiency
BACT Example: Gas Boiler (cont’d)

Step 1 (cont’d)

• Condensate Recovery:
  – When hot condensate is returned to the boiler as feedwater, the thermal efficiency increases

Permitting Authority asks for inclusion of air preheater
BACT Example: Gas Boiler (cont’d)

Step 1 (cont’d)

• Public comment asks for consideration of a combined cycle natural gas-fired turbine

• Applicant explains that a boiler is necessary for business purposes:
  – Providing process steam (and not electricity) and
  – Varying steam demand

• Permitting authority rejects a combined cycle natural gas-fired turbine for consideration on grounds it would “redefine the source.”
BACT Example: Gas Boiler (cont’d)

Step 2: Eliminating technically infeasible options
• Permitting authority determines that the six controls are technically feasible; demonstrated or available and applicable to this type of source

Step 3: Evaluation and ranking of controls by their effectiveness
• Applicant ranked control measures for the boiler based on their impact on the thermal efficiency of the boiler (Could also be based on emissions per unit of steam produced)
BACT Example: Gas Boiler (cont’d)

Step 3 (cont’d)

• The permit applicant completed the control effectiveness analysis and found:
  – Most effective single measure is oxygen trim control
  – Air preheater is no more effective than an economizer in recovering exhaust heat
  – The most effective combination of measures is: oxygen trim control, an economizer, condensate recovery, and blowdown heat recovery.
BACT Example: Gas Boiler (cont’d)

Step 4: Evaluating the most effective controls

• Permit applicant completed an analysis of the cost effectiveness:
  – Considered both measures and combinations of measures,
  – Expressed as $/ton of CO$_2$e reduced
  – Given the size and layout of the facility, boiler blowdown heat recovery was not cost effective

• Next most effective combination of measures was:
  – the use of oxygen trim control
  – an economizer
  – condensate recovery
BACT Example: Gas Boiler (cont’d)

Step 4: (cont’d)

• Any significant energy and environmental impacts are to be considered in this step.

• Application identifies recovery and reuse of condensate:
  – Reduces the use of feedwater treatment chemicals
  – Reduces generation of related waste
  – Reduces the amount of water going to wastewater treatment at the site
BACT Example: Gas Boiler (cont’d)

Step 5: Selecting BACT

• Permitting authority determined, and the record showed, that BACT was the combination of:
  – Oxygen trim control,
  – An economizer, and
  – Condensate recovery
BACT Example: Gas Boiler (cont’d)

Step 5: (cont’d)

*Enforceable Permit Conditions:*

- Emission limit: lbs of CO$_2$e per pound of steam produced, 30-day rolling monthly average
- CO$_2$e emissions determined from natural gas use and standard emission factors
- Steam production determined from a gauge
- Installation of boiler as described in the application, as a design standard
- Preventive maintenance program for the air to fuel ratio controller
- Periodic calibration of gas meter and steam flow analyzer
GHG BACT Example:
Coal-Fired Electric Generating Generating Unit
BACT Example: Coal EGU

Project: New greenfield sub-bituminous pulverized coal-fired boiler and steam turbine electricity generating facility.
Coal EGU – Boiler and Steam Turbine

Coal Silo → Burners → Furnace Chamber

- Boiler Wall Watertubes
- Superheater
- Economizer
- Reheater
- Feedwater Heater
- Air Heater

- Coal ballast ash
- Heated combustion air

- Coal Pulverizer

- Steam Drum
- Hot boiler feedwater
- Reheated steam
- Extracted steam
- Low pressure steam

- Multi-stage Steam Turbine
- Generator

- Condenser
- Cooling Tower

- Cooling water
- Boiler feedwater

- Air Pollutant Emissions Controls
- Induced Draft Fan
- Forced Draft Fan
- Ambient air
BACT Example: Coal EGU (cont’d)

Step 1: Identifying all available controls

• Applicant’s BACT analysis had two elements:
  – Efficiency measures, including the design of the boiler and turbine:
    • Supercritical boiler and turbine design
    • Coal drying
    • Optimized combustion with continuous control
  – CO₂ control through CCS.

• State requests that the BACT analysis also include:
  – Ultra-supercritical design
  – Integrated Gasification Combined Cycle (IGCC)
  – Motor efficiency improvements (to increase net output of electricity and thereby reduce fuel use)
IGCC with Pre-Combustion CO\textsubscript{2} Capture

Step 1 (cont’d)

• Pre-combustion capture of CO\textsubscript{2} is an option with coal gasification. In the gasifier, the coal decomposes in the presence of oxygen to syngas, a mixture of H\textsubscript{2} and carbon monoxide (CO), along with minor other constituents.

• To enable pre-combustion capture, the syngas is further processed to convert CO into CO\textsubscript{2} while producing additional H\textsubscript{2}. A solvent absorption system can then be used to separate the CO\textsubscript{2} from the H\textsubscript{2}.
IGCC with Pre-Combustion CO₂ Capture (cont’d)

Step 1 (cont’d)

• After CO₂ removal, the H₂ can be used as a fuel in the combustion turbine.

• Pre-combustion CO₂ capture is less expensive than post-combustion capture. The advantages of this type of system are the higher CO₂ concentration and the lower volume of syngas to be handled, which result in smaller equipment sizes and lower capital costs.
BACT Example: Coal EGU (cont’d)

• Public comment calls for use of natural gas instead of coal. While this happened after the BACT determination and draft permit were out for comment, it relates to the control measures considered in Step 1 of the analysis.

• The permitting agency determines this is outside the scope of BACT, representing a change in basic design and business purpose.
BACT Example: Coal EGU (cont’d)

Step 2: Elimination of technically infeasible options

• All options are considered by the permitting authority to be available and technically feasible:
  – Ultra-supercritical boiler and turbine design
  – Integrated Gasification Combined Cycle
  – Coal drying
  – Combustion control
  – Variable speed motors
  – CCS
BACT Example: Coal EGU (cont’d)

Step 3: Evaluation and ranking of controls by their effectiveness

- Applicant proposes to rank measures based on emissions per unit of fuel used
- State requires that options be ranked by CO$_2$e emissions on a “net” output basis.
- Most effective combination is either ultra-supercritical with CCS or IGCC with CCS. Coal drying and efficient motors included in both instances.
BACT Example: Coal EGU (cont’d)

Step 4: Evaluating the most effective controls

- CCS dismissed for both designs based on excessive costs, siting issues, and parasitic electricity load
- In the absence of CCS, IGCC shown to not be superior to ultra-supercritical design
- Ultra-supercritical chosen as BACT: cost-effective, no adverse collateral impacts
- All energy efficiency measures also required
- Permitting agency documents conclusion with supporting documentation for the record
BACT Example: Coal EGU (cont’d)

Step 5: Selecting BACT

*BACT is determined to be:*

- An ultra-supercritical boiler design w/high efficiency steam turbine,
- Control of boiler air/fuel ratio,
- Coal drier using low grade/waste heat
- High efficiency variable speed motors for electric drives
BACT Example: Coal EGU (cont’d)

Step 5 (cont’d)

Enforceable permit conditions:

• Annual limit in tons of CO$_2$ per net MWh; rolling 12 month totals

• O&M plan addressing combustion controls, steam turbine efficiency and electrical motors
GHG BACT Example: Cement Plant
BACT Example: Cement Plant

Project Scope:
- A new cement kiln is proposed. The product is finished cement for local markets.
- Cement is produced from raw materials such as limestone, chalk, shale, clay, and sands which are quarried, crushed, ground, and blended to the correct chemical composition.
- The raw material is fed into a large rotary kiln (cylindrical furnace) which rotates while the contents are heated to extremely high temperatures. The high temperature causes the raw material to react and form a hard nodular material called “clinker”. Clinker is cooled and ground with gypsum and other additives to produce portland cement.
- \( \text{CO}_2 \) is emitted due to both the decomposition of the limestone and the combustion of fuel in the kiln.
BACT Example: Cement Plant (cont’d)
BACT Example: Cement Plant (cont’d)

Step 1: Identify all available controls
• This BACT analysis has four elements: process technology/energy efficiency, fuel choice, product specification and CO₂ removal and storage.

Process Technology/Energy Efficiency
• Applicant proposes to use a preheater/precinciner (PH/PC) design, which is more efficient than older designs that have less heat recovery.
BACT Example: Cement Plant (cont’d)

Process Technology/Energy Efficiency (Cont’d)

• Applicant presents the following features of the PH/PC design that improve thermal efficiency and reduce emissions of CO$_2$ related to on-site fuel use.
  
  – Modern cement manufacturing facilities incorporate multi-stage preheaters prior to the kiln. A five stage preheater is proposed.
  
  – Grate coolers are used to cool the clinker. The grate cooler is integral to heat recovery from the clinker and higher thermal efficiency. A reciprocating grate cooler, which is the design with the greatest fuel use benefit, is proposed.
  
  – Computerized/automated control system is proposed to optimize fuel combustion conditions.
BACT Example: Cement Plant (cont’d)

Process Technology/Energy Efficiency (Cont’d)

– Kiln seals reduce heat loss. The applicant presents information on the effectiveness and longevity of the kiln seals and proposes a maintenance plan for the kiln seals.

– Significant heat loss can occur through the kiln shell and proper insulation keeps these losses to a minimum. The applicant presents the alternative refractory that were considered and demonstrates that the most effective was chosen.

• The applicant presents data on the energy use per ton of clinker that has been achieved at recently built kilns as a demonstration that the proposed design constitutes BACT for the thermal efficiency aspect of the new kiln.
BACT Example: Cement Plant (cont’d)

Step 1 (cont’d)

Fuel Choice

• Applicant proposes to use a combination of coal as the primary fuel and wood wastes (when they are available).

• Applicant presents data showing that other solid fuels (tires, waste plastics) do not represent a reduction in CO$_2$ emissions at the kiln.

• Permitting Authority agrees.
BACT Example: Cement Plant (cont’d)

Step 1 (cont’d)

Product Composition

• Applicant does not address product composition in the initial application.

• To the extent that one can make a finished product, meeting all of its quality requirements with less clinker, the finished product will be less energy intensive and the emissions of CO$_2$ per unit of product will be reduced. Fly ash from coal combustion can be used in a blended cement. However, the use of fly ash may be limited by product quality requirements and fly ash characteristics.
BACT Example: Cement Plant (cont’d)

Step 1 (cont’d)

Product Composition

• With that in mind, the agency asks the applicant to consider maximum use of fly ash and other additives as blending materials with consideration of the markets to be served.

• Applicant presents information on product specifications in the anticipated markets and indicates that up to 5% fly ash from a nearby coal fired utility could be used in some of their product. A CO₂ reduction in terms of CO₂ per ton of finished cement due to fly ash use is noted.

• This alternative is accepted for further review by the permitting authority.
BACT Example: Cement Plant (cont’d)

Step 1 (cont’d)

CO$_2$ Capture/Removal and Storage

• Applicant presents information on two means of capture and control: conventional Carbon Capture and Storage and the Calera process.

• The Calera process uses a wet scrubber to capture CO$_2$ emissions and chemically convert the captured CO$_2$ to carbonates. Carbonate minerals can then be precipitated from the solution, dried, and used to make blended cement or other building materials.
BACT Example: Cement Plant (cont’d)

Step 2: Eliminating technically infeasible options

Fuel Choice

• During the public comment, use of natural gas in place of coal is raised.

• The applicant points out that it is technically feasible to use gas, with an increase in NO$_x$ emissions. However, there is no natural gas supply infrastructure with sufficient capacity in the area.

• The costs of getting gas delivered and used are addressed and the applicant presents data showing it will not be cost effective. The permitting authority agrees.
BACT Example: Cement Plant (cont’d)

Step 2 (cont’d)

Product Composition

• Applicant presents data showing that use of more fly ash will not allow them to meet product specifications.

• Applicant also presents data on the availability of other product blend materials showing that they can adversely affect product quality and there is no identifiable long term supply.

• As a result, the assessment is limited to 5% fly ash in 80% of the product, averaged over 12 months.
BACT Example: Cement Plant (cont’d)

Step 2 (cont’d)

CCS

- The applicant points out that the Calera process is still under development and not commercially available. The applicant also notes that once it is commercial, issues of markets for the by-product and cost would need to be considered. Lastly the applicant points out that the nature of the Calera process and its products would be a change to their fundamental business purpose.

- The applicant notes that the capture and purification of CO₂ from a cement kiln is under study and is not commercially available.

- The application indicates that CCS is not commercially available or technically feasible and should be dismissed.

- The permitting agency concurs.
BACT Example: Cement Plant (cont’d)

Step 3: Evaluating and ranking controls for their effectiveness

- The measures were ranked based on CO₂ emitted per ton of clinker. (Cement kiln performance benchmarking data is presented on this basis.)
- At the agency’s request the ranking also was done based on CO₂ emitted per ton of finished cement. This change allowed the analysis to capture the impact that fly ash addition could have on emissions.
BACT Example: Cement Plant (cont’d)

Step 4: Evaluating the most effective controls

• The use of the high efficiency kiln design and the use of fly ash in the product were both found to be cost effective on the basis of dollars per ton of CO₂ eliminated.
  – Other environmental issues were identified with efforts to commit to the use of alternative waste as fuels. However, alternative fuels had not shown a clear CO₂ emissions reduction potential for the site emissions.
BACT Example: Cement Plant (cont’d)

Step 5: Selecting BACT

• In this example, BACT is the use of the PH/PC design with all of the efficiency improvements proposed by the applicant.

• Additionally, the applicant is to use 5% fly ash in the cement blend whenever the product specification allows for its use.
BACT Example: Cement Plant (cont’d)

Step 5 (continued)

Enforceable Permit Conditions

• The kiln is to meet a 365 day rolling annual average limit on tons of CO₂ emitted per ton of clinker produced.

• CO₂ determined with a CEMS.

• A maintenance plan for insulation and kiln seal is also required.

• An O&M for the process optimization controls, including instrument calibration and maintenance is required.

• Records of fly ash use in product required. If annual average fly ash addition is less than 5%, the company needs to justify its lower use based on product quality concerns or client restrictions.
GHG BACT Example:
Natural Gas Combustion Turbines

Russell City Energy Center/CALPINE
Hayward, CA
BACT Example: CALPINE

Project Description:
• 612MW natural gas fired combined cycle combustion turbines
• GHG emissions sources:
  - 2 Siemens Westinghouse 501FD3 combustion turbines
  - 2 heat recovery steam generators with supplemental nat. gas firing
  - 1 diesel fired emergency fire pump
  - 5 circuit breakers (SF$_6$)
Process Diagram:
Step 1: Identify Control Technologies

• Combustion Controls
  - No way to alter chemical reaction
    \[(\text{CH}_4 + 2\text{O}_2 = \text{CO}_2 + 2\text{H}_2\text{O})\]
• Thermal efficiency was the only combustion control identified
• Post Combustion Control
  - CCS
• Comments requested evaluation of non-fossil fuels
  - Permitting authority determined this would constitute re-defining the source
Step 2: Eliminate Technically Infeasible Options

• Combustion Controls
  - Energy efficiency is feasible and proven

• Post Combustion Controls
  - CCS not commercially available
  - Appropriate sequestration sites in Bay Area not demonstrated
  - Need further evaluation of environmental impacts of CCS
Step 2: Eliminate Technically Infeasible Options (cont’d)

• It was concluded that high-efficiency power generation technology is the only available and feasible control technology
Step 3: Evaluation and ranking of controls by their effectiveness

- High efficiency power generation the only option

- California Energy Commission data indicated CCGT’s can achieve 56% thermal efficiency

- Original project design featured 501FD2 turbines

- Project revised to FD3 achieving 56.45% efficiency
Step 3: Evaluation and ranking of controls by their effectiveness

- "G" and "H" turbine technologies can be more efficient and were evaluated for the project.

- However, “G” turbines were determined to be less efficient in a 612 MW configuration, and “H” turbine technology has not yet been demonstrated at 60 Hz.
## BACT Emission Limit: Comparable projects

<table>
<thead>
<tr>
<th>Facility</th>
<th>CEC Application Date</th>
<th>Facility Size (MW)</th>
<th>Thermal Efficiency (LHV)</th>
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<tbody>
<tr>
<td>Colusa Generation Station</td>
<td>11/6/2006</td>
<td>660</td>
<td>56%</td>
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<tr>
<td>Blythe Energy Project Phase II</td>
<td>2/19/2002</td>
<td>520</td>
<td>55-58% (est.)</td>
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<tr>
<td>Lodi Energy Center</td>
<td>9/10/2008</td>
<td>255</td>
<td>55.6%</td>
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<tr>
<td>CPV Vaca Station Power Plant</td>
<td>11/18/2008</td>
<td>660</td>
<td>55%</td>
</tr>
<tr>
<td>Victorville 2 Hybrid Power Project</td>
<td>2/28/2007</td>
<td>563</td>
<td>52.7% (w/ duct burn)</td>
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<td>Avenal Energy Power Plant</td>
<td>2/21/2008</td>
<td>600</td>
<td>50.5%</td>
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<td>Palomar Energy Project</td>
<td>8/2003</td>
<td>550</td>
<td>55.3% (w/o duct firing)</td>
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<tr>
<td>SMUD Consumnes Phase I</td>
<td>9/13/2001</td>
<td>500</td>
<td>55.1%</td>
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</tbody>
</table>
Step 4: Evaluating the most effective controls

- With a commitment to a higher efficiency gas turbine design and the dismissal of CCS as technically infeasible, no further analysis of cost and collateral impacts is done.
Step 5: Selecting BACT

- CDC data showed CCGT plants with emission rates ranging from 794 to 1058 lb CO$_2$/mwh
- Significant issues were encountered in trying to convert the high efficiency design into an emissions limit that accounts for differing operating conditions, ambient conditions and system degradation over its useful life.
- Resulted in the following BACT conditions:
  - Mass emission limit for GHGs on a 30-day rolling total
  - An efficiency limit in Btu/kWh, demonstrated in an annual compliance test
BACT Emission Limit: 
CO$_2$e mass based and Output based efficiency based

<table>
<thead>
<tr>
<th>Averaging Period</th>
<th>Heat Input Limit (MMBtu)</th>
<th>CO$_2$</th>
<th>CH$_4$</th>
<th>N$_2$O</th>
<th>CO$_2$e</th>
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<td>1-Hour</td>
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<td>242</td>
<td>0.08</td>
<td>0.14</td>
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<td>24-Hour</td>
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<td>5,797</td>
<td>0.03</td>
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<td>1,107.48</td>
<td>1,928,182</td>
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<table>
<thead>
<tr>
<th>Condition</th>
<th>Heat Rate (Btu/kwh)</th>
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<tbody>
<tr>
<td>Net Design Base (new and clean)</td>
<td>6,852</td>
</tr>
<tr>
<td>Installed Design Base (3.3% design margin)</td>
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<tr>
<td>Degraded Base (degradation between major overhauls and compliance margin)</td>
<td>7,730</td>
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</table>
BACT for other EU’s

• BACT for the Fire Pump was limiting operation to testing and emergencies to achieve annual limit of 7.6 metric tons CO2e

• Circuit Breakers:
  - Each breaker contains ~ 145 lbs. of SF₆
  - No direct emissions, but potential for fugitive emissions (leaks)
5 Step BACT for Breakers:

• Step 1: Identified SF₆ alternatives (oil or air-blast), and breakers with leak detection
• Step 2: SF₆ alternatives eliminated due to space and safety concerns
• Step 3: SF₆ breakers with leak detection ranked highest but alternatives evaluated
• Step 4: SF₆ alternatives would require more land, generate more noise, and have a greater risk of release of dielectric fluid
• Step 5: SF₆ breakers with leak detection selected to maintain emissions below 39.3 tpy CO₂e