Assessment of Natural Gas Combined Cycle Plants for CCS in a Gas-Dominated Electricity Market

CB&I Report Summary and Discussion

April 16, 2015

Agenda

- Introduction
- Report Overview
- Technology
- Cost
- Next Steps
- Questions and Answers

Introduction

- **CB&I/Lummus Consultants Project Team**
  - Power Plant and CO_2 Capture
    - Ed Holden, Chris Wedig, Dave Galpin
  - CO_2 Transportation, Injection, and Sequestration
    - Julian Isham, Bill Kralj
  - Project Economics
    - Debra Richert, Ryan Hannink, Bill Frazier
- **Workshop Focus**
  - CO_2 Capture Technology Screening
  - Design Parameters
  - Cost and Performance Impacts
  - Pathways for a Pilot-Scale Demonstration
- **Transportation and Sequestration – JC Isham**

CB&I Background

Engineering & Construction

- Engineering
- Procurement
- Modularization
- Construction
- Commissioning

Capital Services

- Program and project management
- Remediation and restoration
- Emergency response and disaster recovery
- Environmental consulting and engineering

Fabrication Services

- Fabrication
- Process & nuclear modularization
- Erection
- Pipe fitting and distribution

Technology

- Licensed technology
- Engineering/technical services
- Proprietary catalysts
- Specialty equipment
- Lummus Consultants International
  - Leading independent advisor to Wall Street, lenders, project developers, technology developers, and plant owners in the power and process industries
  - Independent Reviews/Due Diligence, Business Planning and Strategy, Project Development Support, Technical Consulting, Financial Projections, Economic Analysis, Risk Management, Environmental & Regulatory Compliance, Feasibility Studies, Market Studies, Appraisals, Technology Assessment

Study Objectives

- Enhance the information available on Carbon Capture and Sequestration (CCS) at Natural Gas Combined Cycle (NGCC) plants
- Aid power generation planners and policymakers in their decisions on reducing Greenhouse Gas (GHG) emissions from existing and new NGCC plants
- Provide recommendations specific to California sites and initiatives
- Executive Summary on the CEC website:
  - http://www.energy.ca.gov/2015publications/CEC-500-2015-002/CEC-500-2015-002.pdf

Study Tasks

- Compile and perform an evaluation of CO_2 capture technology options for use on NGCC plants
- Compare and contrast CO_2 capture on other fossil plant technologies to CO_2 capture on NGCC plants
- Complete an engineering and economic assessment of the installation and operation of CCS technologies, in retrofit and new-build applications including compression, transportation and sequestration.
- Identify considerations for plant design and permitting that are of particular significance for California sites
- Consider carbon capture system design options that would be beneficial to implementing a CCS to NGCC plants in California

CO_2 Capture and Compression Technologies

- Three general categories of commercial and developmental technologies for CO_2 capture from fossil power plants
  - Post-combustion capture technologies that typically remove CO_2 from flue gas prior to its discharge from the plant stack
  - Pre-combustion capture technologies that remove CO_2 from synthesis gas prior to its use to fire a combustion turbine or power boiler
  - Oxy-combustion technologies that use high-purity oxygen, typically mixed with recycled flue gas, in the place of combustion air
- In 2011-2012, CB&I surveyed over 115 suppliers of CO_2 capture and compression technologies and concluded that a near term application in California would be best represented by a post-combustion capture system with dry cooling

CO_2 Capture and Compression Technologies

- Advanced amine post combustion carbon capture was selected applying to both existing and new plants
- CO_2 capture effectiveness and parasitic power significantly affected by ambient air temperature and cooling water availability
- Design CO_2 capture efficiency of 90%
- Conceptual designs used dry cooling in CCS only
  - CO_2 compressor cooling using direct air cooling
  - Air cooled condenser for new power plant design
  - Fin-fan air coolers for CO_2 capture system heat rejection
- Flue gas recirculation and wet or hybrid wet-dry cooling systems cases were also evaluated for CCS
  - Small net effect on overall economics

Selection of Sites for Evaluation

- Factors considered in site selection:
  - Use of preliminary assessment paper by WESTCARB
  - Use of F-class CTs in 2x2x1 configuration
  - Owner/operator willingness to participate in study
  - Adequacy of space and water for addition of CCS
  - Access to potential CO_2 storage sites
  - Estimated remaining useful life (retrofits)
  - Historical and projected capacity factors
- Host sites selected:
  - Retrofit and also new build evaluated
  - Study sites were in northern California

Preliminary Engineering Activities

- Development of site-specific heat balances and water balances (with and without CCS)
- Obtain CCS supplier data and establish BOP design basis
- Conceptual plant layouts of capture and compression technology equipment for retrofit and new build
- Development of capital and O&M costs for CO_2 capture and compression using vendor cost data supplemented by CB&I cost estimating group
- Development of CO_2 transportation and storage capital and O&M costs based on preliminary routing to injection location

CCS Performance Impact

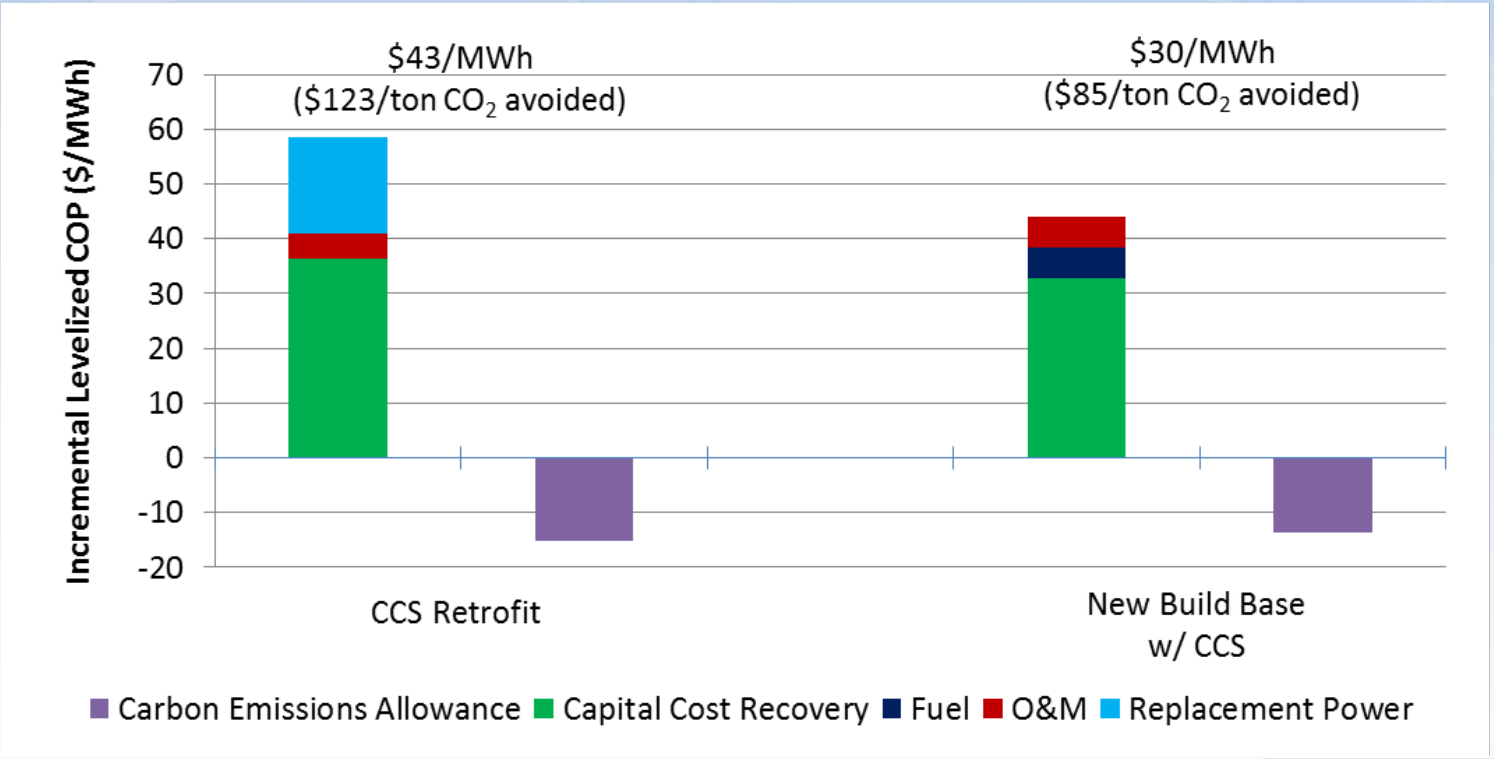
	Retrofit		New Build	
	Without CCS	With CCS	Without CCS	With CCS
Gross Power Generation	543 MW	506 MW	621 MW	597 MW
Auxiliary Power	12 MW	53 MW	14 MW	56 MW
Net Power Generation	531 MW	454 MW	607 MW	540 MW
Net Plant Heat Rate (Higher Heating Value)	6,951 BTU/kWh	8,111 BTU/kW	6,881 BTU/kWh	7,717 BTU/kWh
CO_2 Emissions	461,500 lb/hr	46,150 lb/hr	485,750 lb/hr	48,575 lb/hr
CCS Performance Impact	17% worse		12% worse	

CCS Cost Impact

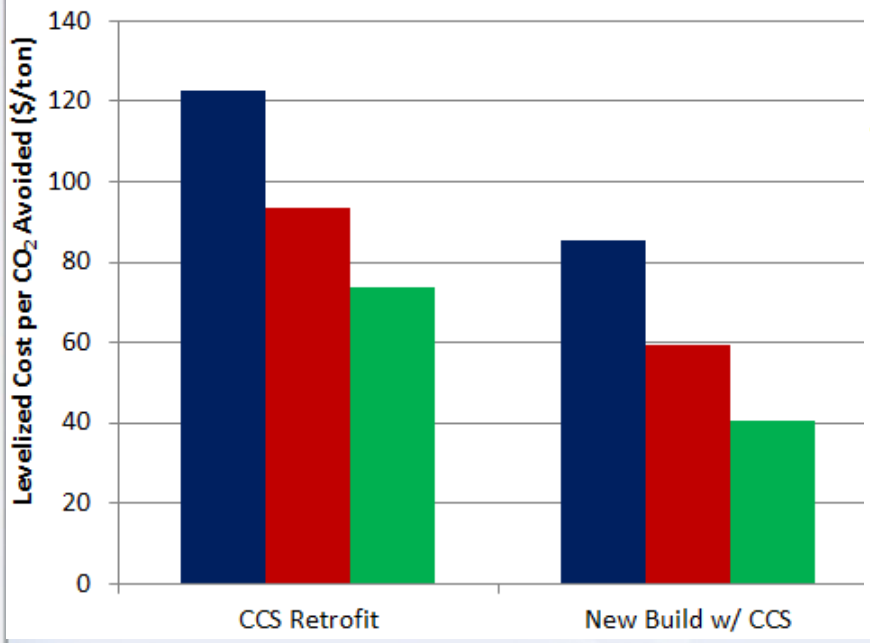
	Retrofit	New Build	
	With CCS	Without CCS	With CCS
Total Capital Cost	+$1,088 million	$865 million	$2,008 million
Fixed O&M	+$9.9/kW-yr (65% CO_2 capture, 35% CO_2 transportation and injection)	$9.5/kW-yr	$19.1/kW-yr (56% base power plant, 28% CO_2 capture, 16% CO_2 transportation and injection)
Variable O&M	+$3.7/MWh (100% CO_2 capture)	$3.2/MWh	$6.7/MWh (54% base power plant, 46% CO_2 capture)

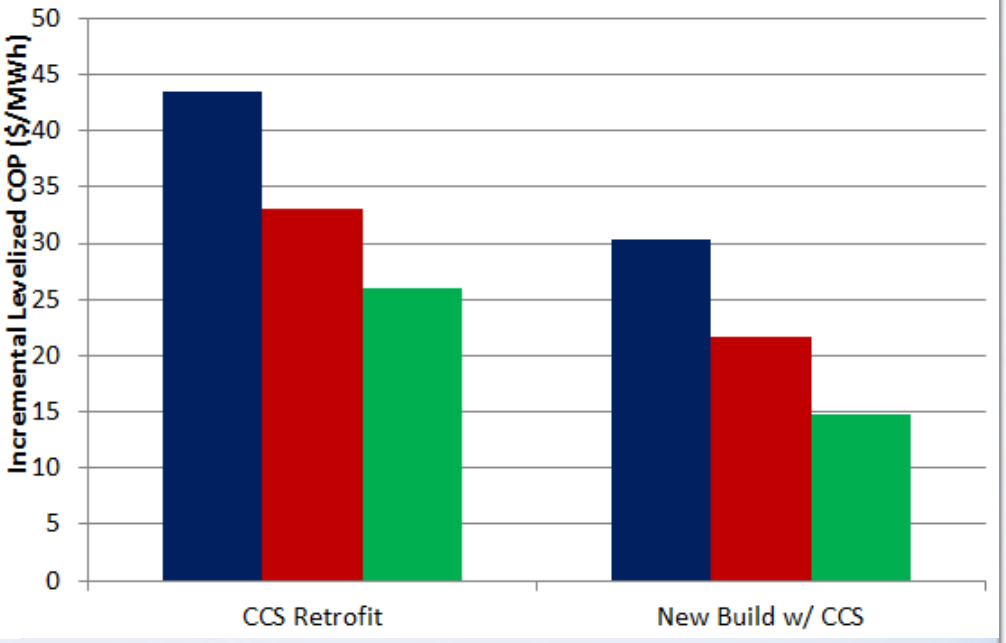
Economic Results

- Lifecycle Levelized Cost Analysis
  - Accounts for performance and capital, operating, fuel costs over the life of the project
  - Assumes a real discount rate of 5% and general inflation rate of 1.7%



Economic Sensitivities





Base Case

w/ 30% lower CCS cost

w/ 30% lower CCS cost and 3% discount rate

Overall Report Findings

- As noted in studies for other locations, implementing CCS adds a substantial premium to the capital and operating costs of an NGCC plant
  - Requirements for dry cooling exacerbate the adverse cost and performance impacts
- Supportive state regulations and policy measures have the potential to greatly reduce the cost premium
  - Encouragement of CCS technology advancements and optimization for California applications
  - Support of high plant capacity factors
  - Reduction of financing cost
- CO_2 pipeline transport, injection, and monitoring are feasible and do not present any significant technical, regulatory, and economic barriers

Next Steps: Technology

- Identify capture solvents and advanced technologies effective at high ambient temperatures and low water consumption.
- Develop CO_2 capture process simulation models to enable design optimization at specific California sites
- Consider supporting a pilot project to test at California design conditions
- Revisit oxy-fuel combustion systems and pre-combustion carbon capture systems.
- Select a host site and CO_2 technology early in the process so preliminary engineering can transition into final design.
- New build (could also be on an existing site) would allow more flexibility in implementing the three technologies
- Jump start identifying CEC requirements for conditions of compliance requirements for this first of a kind effort (permitting).

Next Steps: Policy

- Collaborative funding for CCS RD&D from a combination of stakeholders (e.g., state and federal government, private industry, shareholders, and ratepayers)
- Incentive programs similar to those proposed in federal climate change bills (including cash payments per ton of CO_2 sequestered and possibly direct funding)
- Tax incentives for sequestering anthropogenic sources of CO_2 for enhanced oil recovery (e.g., policy in Texas), and must-run designation for CCS-equipped NGCC units in power markets
- Capital cost subsidies including federal (e.g., DOE cost share grants), and state subsidies (potentially through cap-and-trade auction proceeds or an electric utility surcharge across all utilities and ratepayers), or loan guarantees (similar to DOE loan guarantees)
- Formal recognition and accounting of CO_2 sequestered by CCS projects in the cap-and-trade program
- EPA will issue final rules related to the Clean Power Plan by Summer 2015

Questions & Answers

- **CB&I Team**
  - Technology
    - Chris Wedig (carbon capture)
    - *Julian Isham (CO_2 injection and sequestration)
    - Bill Kralj (CO_2 transportation)
  - Cost
    - All
  - Economics
    - CB&I/Lummus Consultants International
    - Deb Richert
    - *Ryan Hannink
    - Bill Frazier
  - CB&I Power refresh Bruce McCampbell, Steve Courtney

*Present at the workshop