NATIONAL ENERGY TECHNOLOGY LABORATORY

Life Cycle Analysis: Power Studies Compilation Report

Robert James, Tim Skone

Office of Strategic Energy Analysis and Planning (OSEAP)

National Energy Technology Laboratory (NETL), U.S. DOE

November 3, 2010

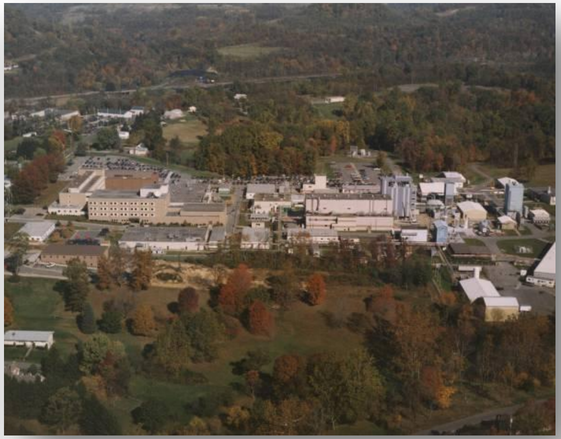
National Energy Technology Laboratory

MISSION

Advancing energy options to fuel our economy, strengthen our security and improve our environment

Oregon

Pennsylvania



West Virginia

The Case for Life Cycle View of Power

- **Environmental impacts of electricity generation occur at the power plant**
  - In 2005, 30% of U.S. greenhouse gas emissions came from coal combustion (for power) (EIA, 2005)
- **Regulation and technology are reducing those impacts**
  - Flue Gas Desulfurization for SOX
  - Selective Catalytic Reduction for NOX
  - Electrostatic Precipitators for Particulates
  - Carbon Capture & Sequestration for CO_2
- **As this happens, the *relative* impact from other stages of power production gets larger**

The Case for Life Cycle View of Power

- **To accurately account for and compare inventories from these different forms of power production, we need an inventory for each at every stage of their life cycle**

LC Stage #1 Raw Materials Acquisition (RMA) → **LC Stage #2** Raw Materials Transport (RMT) → **LC Stage #3** Energy Conversion Facility (ECF) → **LC Stage #4** Power Transmission (PT) → **LC Stage #5** End Use

- **The tool we use for this accounting is life cycle assessment or LCA**
  - For each stage, we perform mass and energy balances of the processes it contains
  - There can be a single process per stage, or multiple, including construction, operations and decommissioning

The Life Cycle Inventory, Impacts and Costing

- **At NETL, our inventory is comprehensive, and includes:**
  - Greenhouse gases (CO_2, CH_4, N_2O, SF_6)
  - Criteria Air Pollutants (CO, SOX, NOX, PM)
  - Toxic Materials (Hg, Pb)
  - Land Use
  - Water use

- **We do not convert these inventories into impact (such as effect on the ecosystem or human health), with one exception**
  - We convert greenhouse gas inventories into Global Warming Potential (GWP)
  - GWP is measured in 100-year CO_2 Equivalents (CO_2e), using 2007 IPCC conversions

- **We include a traditional life cycle cost (LCC) analysis of each technology pathway**

The Power LCA Studies

- **This report compiles the results from four technology life cycle assessments**
  1. Integrated Gasification Combined Cycle (IGCC)
  2. Natural Gas Combined Cycle (NGCC)
     - Case A: Foreign Liquefied Natural Gas (LNG)
     - Case B: Domestic Natural Gas (DNG)
  3. Super Critical Pulverized Coal (SCPC)
  4. Existing Sub-Critical Pulverized Coal (EXPC)
- **Each case was modeled without and with Carbon Capture and Sequestration (CCS)**
  – EXPC – w- and wo-Replacement Power

Approach: The Importance of Assumptions

- **The ability to compare different technologies depends on the functional unit**
  - 1 MWh of electricity delivered to the end user
- **When comparing systems this complex, it's never quite that easy**
  - All need to perform similar roles, e.g. baseload generation
  - All need fair access to resources and infrastructure
  - New technology needs to be fairly compared to existing plants

Major Data Sources

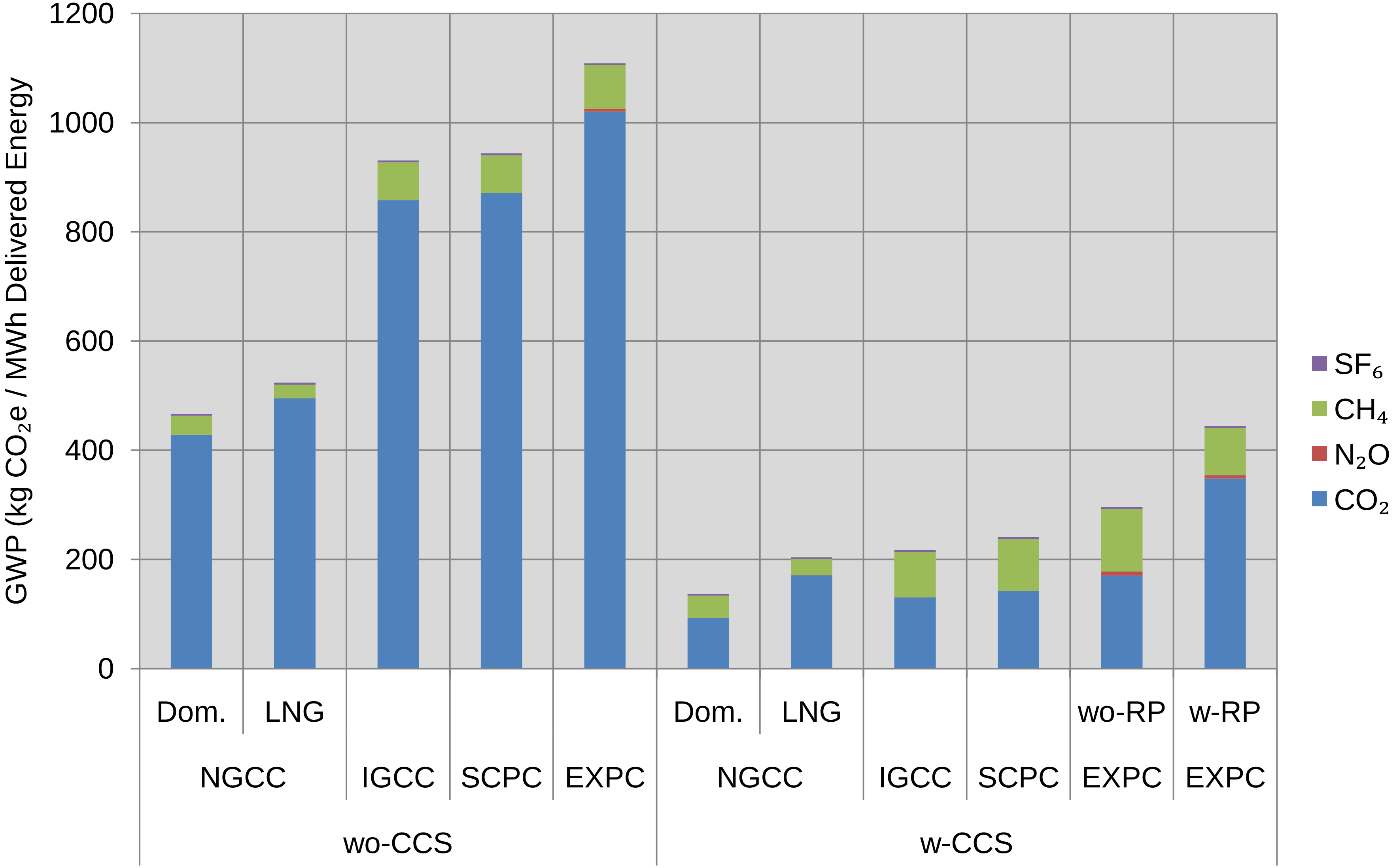
- **Power LCA Builds Upon the Following NETL Techno-economic Analysis Studies:**
  - *Cost and Performance Baseline for Fossil Energy Plants; Volume I (Bituminous Coal and Natural Gas to Electricity)*; Revision Expected October 2010
  - *Carbon Dioxide Capture from Existing Coal-Fired Power Plants*; November 2007 http://www.netl.doe.gov/energy-analyses/refshelf/PubDetails.aspx?Action=View&PubId=225

Key Modeling Assumptions

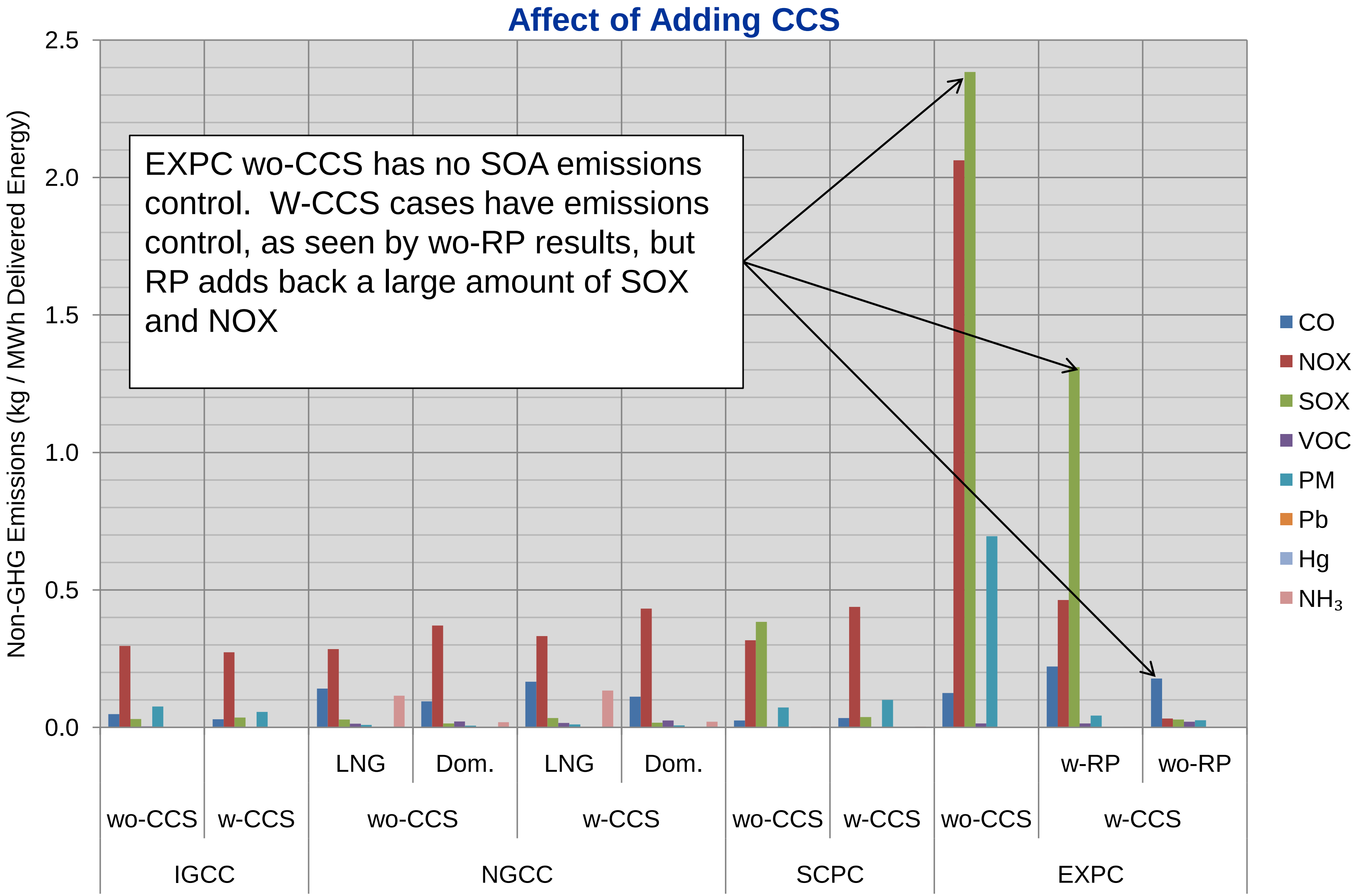
Assumptions	IGCC	NGCC		SCPC	EXPC
		Foreign Liquified Natural Gas (LNG)	Domestic Natural Gas (DNG)		
Temporal / Cost Boundary	30 Years / Overnight				
LC Stage #1: Raw Material Acquisition					
Extraction Location	Southern Illinois	Trinidad & Tobago	Domestic Onshore/Offshore	Southern Illinois	Southern Illinois
Feedstock	Ill. #6 Coal	LNG	NG	Ill. #6 Coal	Ill. #6 Coal
Extraction Method	Underground	Offshore Drilling	Multiple Pathway	Underground	Underground
C&O Costs	In Delivery Price				
LC Stage #2: Raw Material Transport					
Round Trip transport Distance (Miles)	1170	4520	NA	410	400
Rail Spur Length (Miles)	25	NA		25	Pre-Existing
Main Rail/Pipeline Length (Miles)	Pre-Existing	208	900	Pre-Existing	Pre-Existing
C&O Costs	In Delivery Price				
LC Stage #3: Energy Conversion Facility					
Location	Southern Mississippi			Southern Illinois	
Net Output (MW)	622	555		550	434
Net Output w-CCS (MW)	543	474		550	NA
Net Output w-CCS with Replacement Power (w-RP) (MW)	NA				434
Net Output w-CCS without Replacement Power (wo-RP) (MW)	NA				303
Capacity Factor	80%	85%			
Trunk line Constructed Length (Miles)	50				Pre-Existing
CO_2 Capture Rate	90%				
CO_2 Pipeline Pressure (psia)	2215				
CO_2 Pipeline Length (Miles)	100				
CO_2 Loss Rate	1% / 100 yrs				
LC Stage #4: Product Transport					
Transmission & Distribution Line Loss	7%				
Transmission Grid Construction	Pre-Existing				

Life Cycle GHG Emissions

Technology Comparison – Without and With CCS

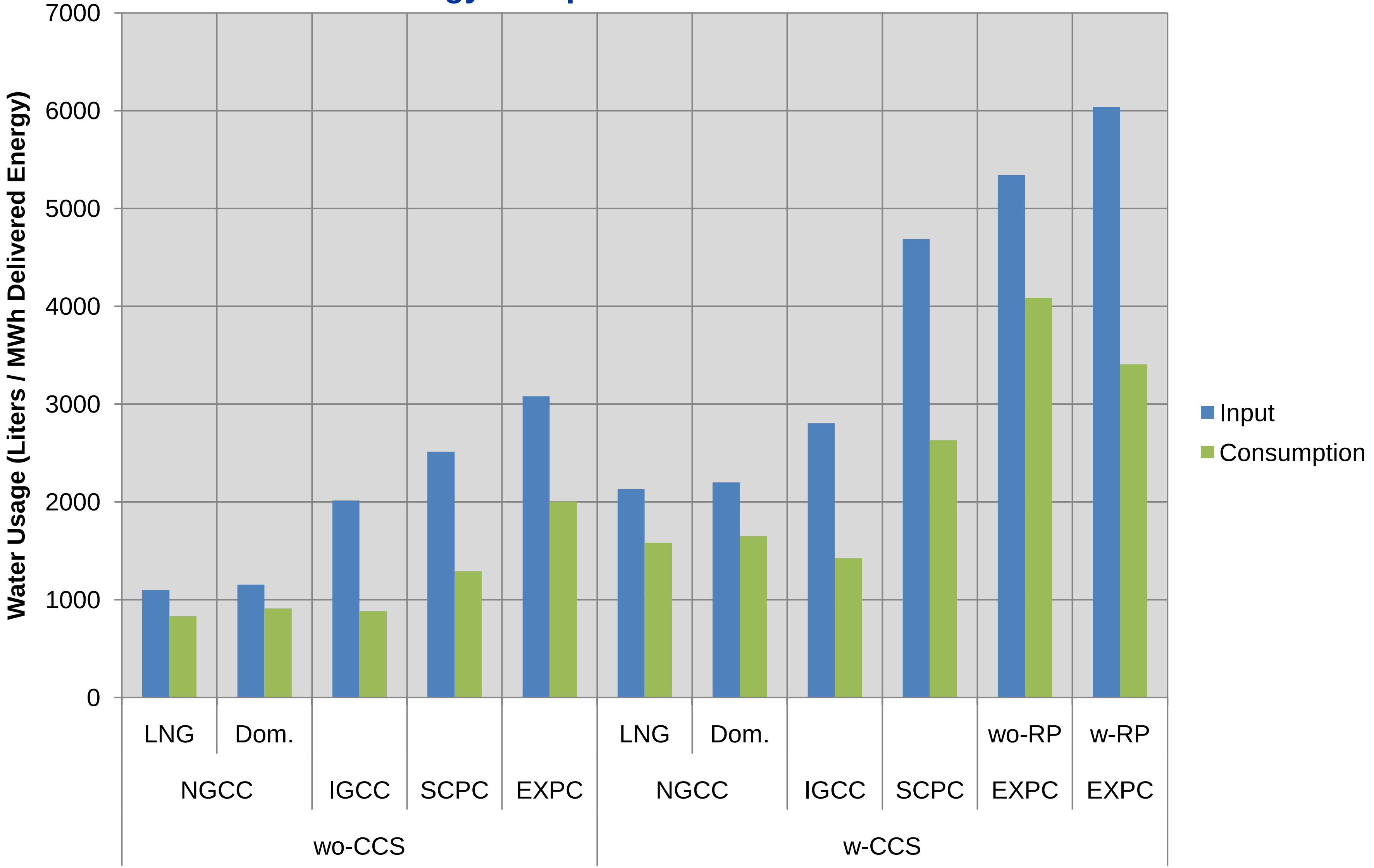


Life Cycle Non-GHG Air Emissions



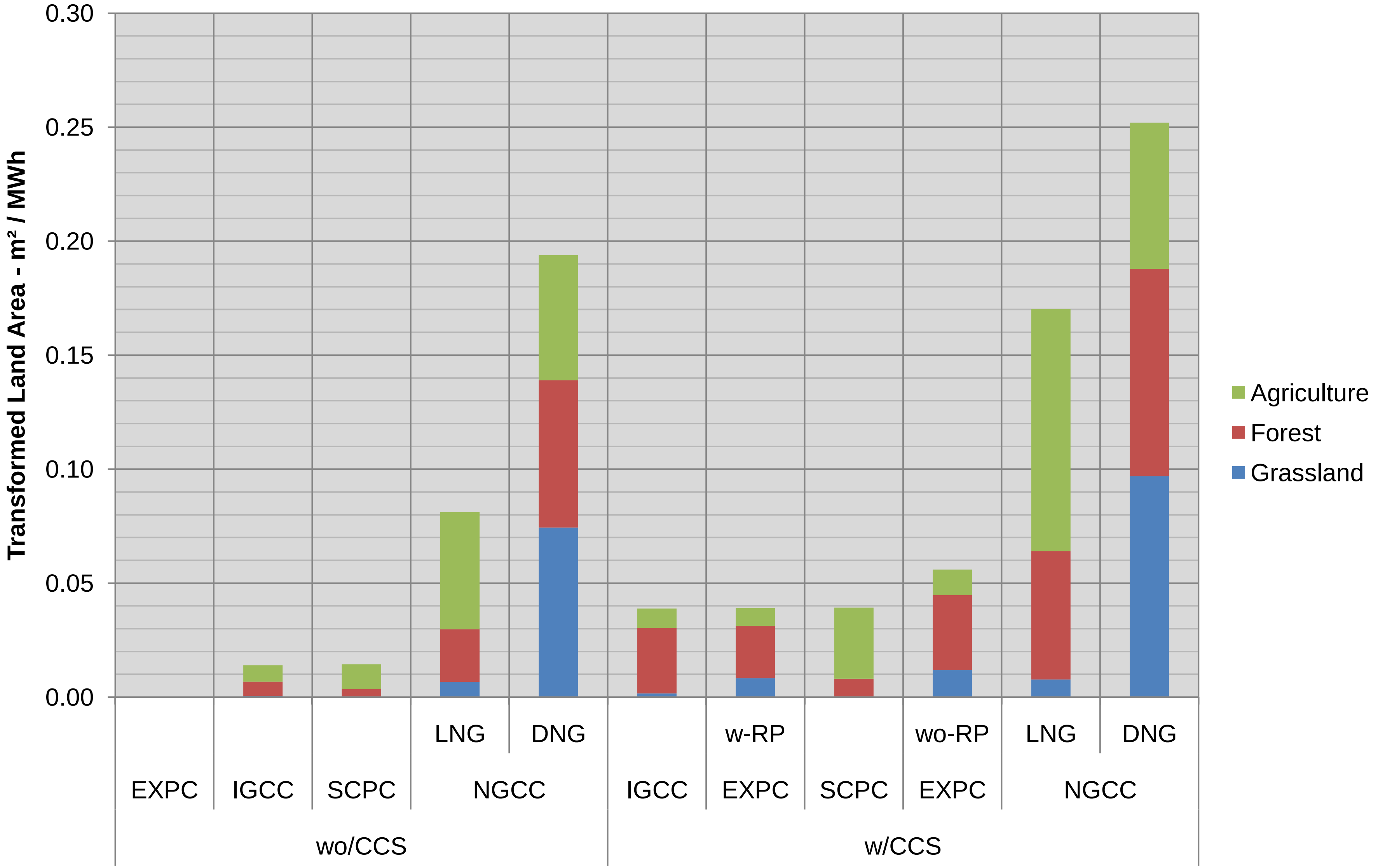
Life Cycle Water Usage

Technology Comparison – Without and With CCS



Transformed Land Area

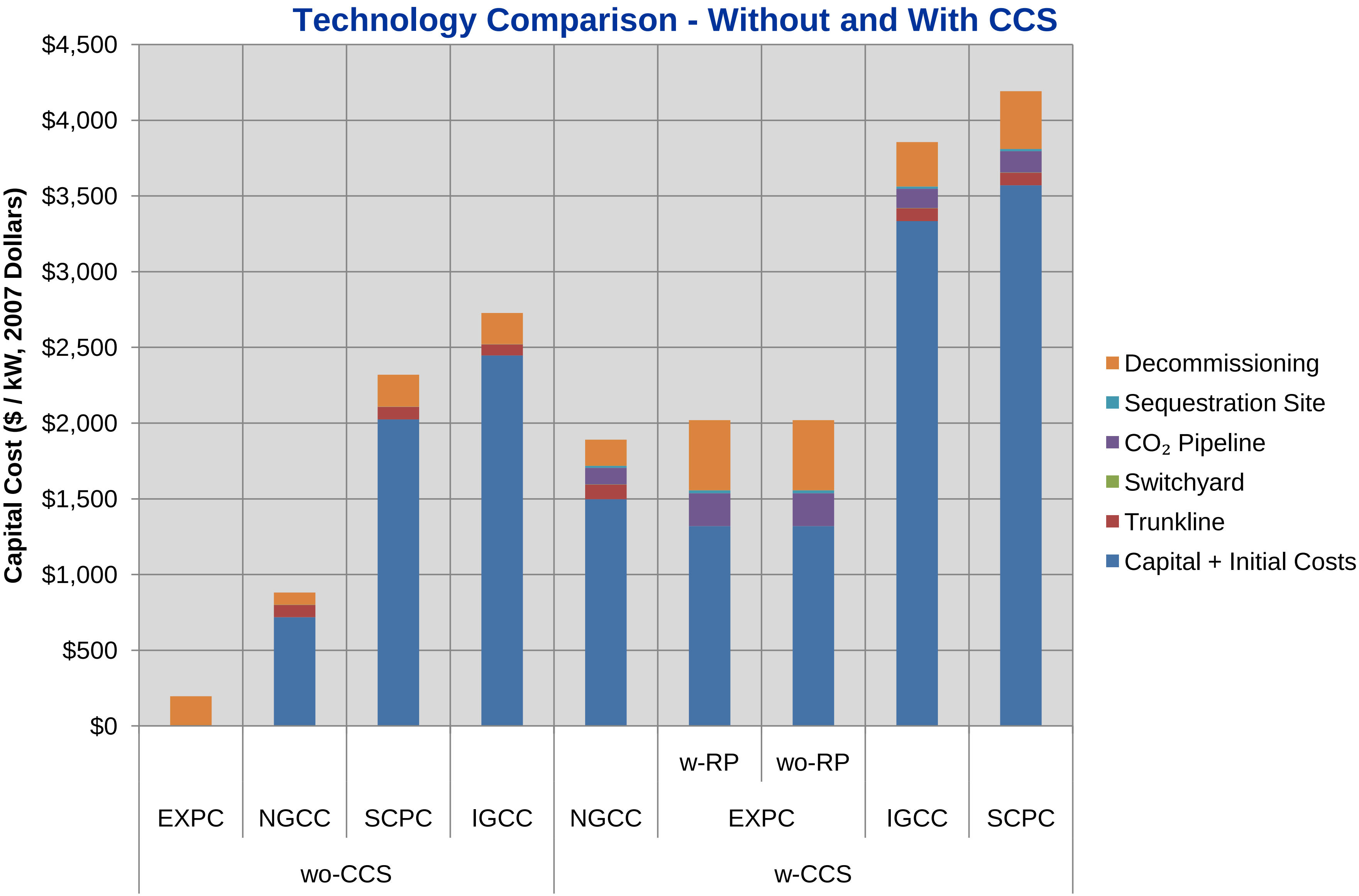
Affect of Adding CCS



Financial Parameters

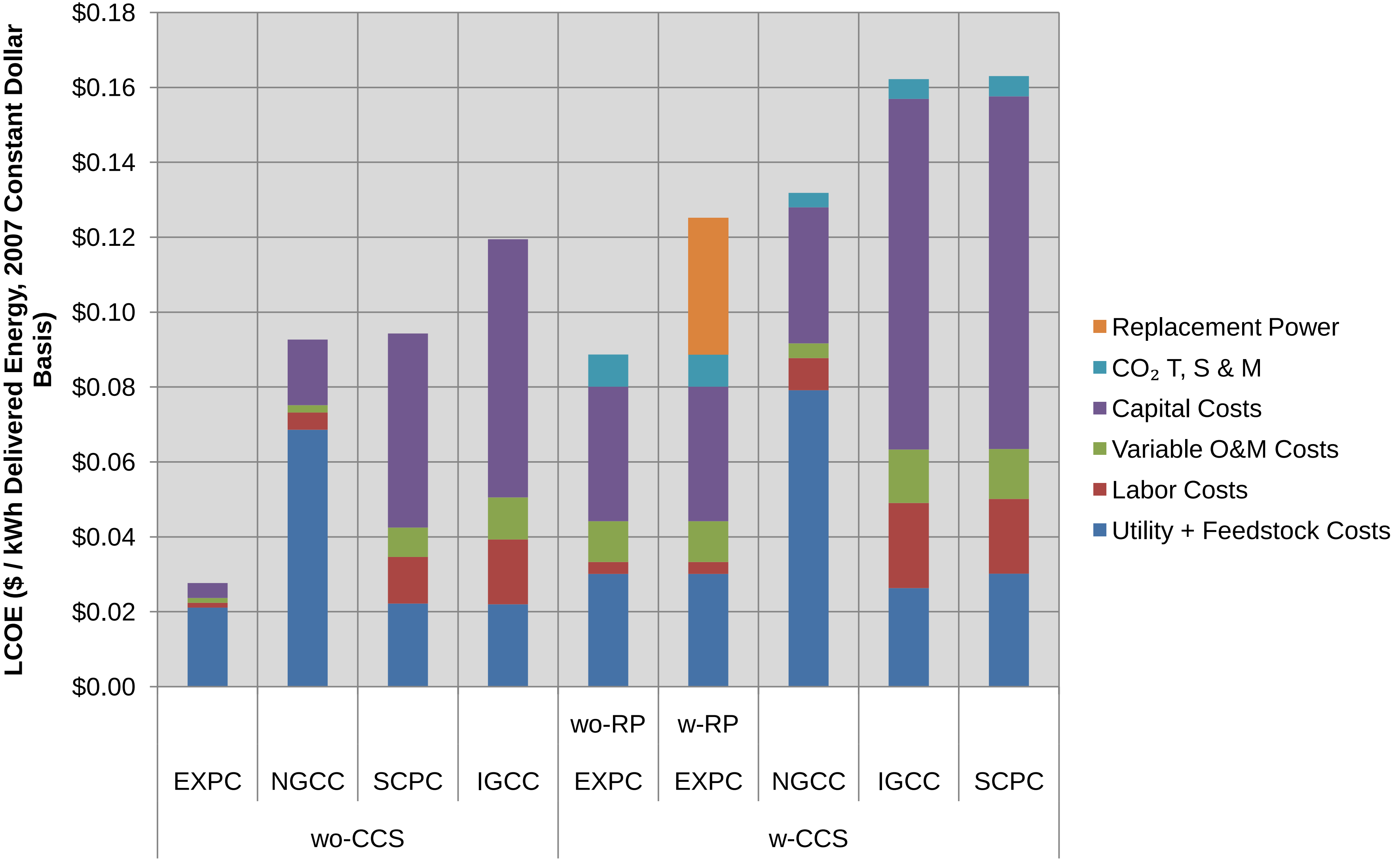
Property	Value	Units
Reference Year Dollars	December 2006/ January 2007	Year
Assumed Start-Up Year	2010	Year
Assumed Study Period	30	Years
MACRS Depreciation Schedule Length	Variable	Years
Capital Charge Factor	Variable	NA
Levelization Factor	Variable	NA
Inflation Rate	1.87	Percent
State Taxes	6.0	Percent
Federal Taxes	34.0	Percent
Total Tax Rate	38.0	Percent
Start Up Year (2010) Feedstock & Utility Prices	***$2007 Dollars***	**Units**
Natural Gas	6.76	$/MMBtu
Coal	1.51	$/MMBtu
Process Water	0.00049 (0.0019)	$/L ($/gal)

Life Cycle Capital Cost



Levelized Cost of Electricity (LCOE)

Technology Comparison – Without and With CCS



Key Findings for GHG Footprint

GWP (CO_2e) – 2007 IPCC 100 yr. Average

- **CO_2**
  - 95-99% of the GHG emissions from Energy Conversion Facility Stage
  - 58-95% of overall GHG Emissions for all Technologies
  - The only other major source of CO2 is from Foreign Drilling operations for LNG
    - wo-CCS – 16% of Total GHG Emissions
    - w-CCS – 47% of Total GHG Emissions

- **Methane**
  - Coal Cases - RMA Stage
    - Coal Bed Methane – 96% of RMA Emissions
  - NG Cases – Highest percentages from RMT
    - Foreign LNG Regasification accounts for 75-81% of the overall Methane emissions

Key Findings for GHG Footprint (Cont.)

GWP (CO_2e) – 2007 IPCC 100 yr. Average

- **Addition of CCS with a 90% CO_2 Capture system results in an overall Life Cycle GHG reduction of:**
  - IGCC – 77% Reduction
  - NGCC
    - 61% Reduction - LNG
    - 70% Reduction - DNG
  - SCPC – 75% Reduction
  - EXPC
    - 60% Reduction – w-Replacement Power
    - 73% Reduction – wo-Replacement Power
- **EXPC**
  - Replacement Power for the EXPC w-CCS case adds 50% to the total GHG Emissions
- **NG Source – Domestic LC Emissions less than Foreign LC Emissions**
  - wo-CCS – 12% lower
  - w-CCS – 48% lower

Key Findings – Non-GHG Emissions

- **NOX was found to be the dominant Non-GHG emission for most cases**
- **SOX was the dominant species in SCPC wo-CCS, EXPC wo-CCS, and EXPC w-CCS w-RP**
- **Particulate Matter – Coal cases only**
  - Emission due to Fugitive Dust from Coal transport
- **Ammonia was typically less than 1% of the NOX emissions, except for these NGCC Case sources:**
  - Selective Catalytic Reduction Unit
    - Ammonia slip – amounted to 5% of the NOX emissions
  - Liquefaction plant for Foreign LNG
    - Operation - 40% of the NOX emissions

Key Findings – Water Usage

- **Energy Conversion Facility**
  - Primary water usage in all technologies – 88 – 97% of total water usage
- **Coal Cases**
  - There is a net production of water at the Mine
  - This net production affects the overall Consumption
- **Domestic NG versus Foreign LNG**
  - There is a 3 - 5% increase in overall water consumption for DNG
- **CCS**
  - Increase in water input and consumption for all technologies
  - Due to increased cooling load needed for operation of the CCS systems

Key Findings – Life Cycle Capital Cost

- **Bare Erected Equipment Costs**
  - 79 - 90% of the total LC Capital Cost
- **Without CCS**
  - IGCC more expensive than SCPC
  - NGCC is cheapest option
  - EXPC accounts for decommissioning
    - Other plant costs are covered by existing plant
- **With CCS**
  - LC Capital Cost increased for all technologies
  - SCPC becomes more expensive than IGCC
  - NGCC still the cheapest option
  - EXPC – Replacement power does not affect Capital Cost

Key Findings – LCOE

- **Adding CCS**
  - Increased the LCOE between 36 - 75%
- **Coal Cases**
  - Capital Costs for IGCC and SCPC are the largest component - 30 – 56%
- **NG Cases**
  - Utility Costs are the largest component - 60 – 74%
  - Capital Costs are ½ (w-CCS) to ⅓ (wo-CCS) of the Utility Costs
- **EXPC with CCS**
  - Replacement Power increases LCOE 4 cents/kWh (41% LCOE increase)

Visit Our Websites

Office of Fossil Energy

www.fe.doe.gov

NETL

www.netl.doe.gov

Timothy Skone
Lead General Engineer
OSEAP - Planning Team
(412) 386-4495
timothy.skone@netl.doe.gov

Robert James
General Engineer
OSEAP - Planning Team
(304) 285-4309
robert.james@netl.doe.gov