IECM Overview
and Update

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The Integrated Environmental Control Model (IECM)

• Title: Integrated Environmental Control Model (IECM)
• DOE Funding (via URS) : $245,300

• Also a related project: “The Role of Simulation and Modeling in Accelerating CO₂ Capture Technology”

The Integrated Environmental Control Model (IECM)

• A desktop/laptop computer simulation model developed for DOE/NETL
• Provides systematic estimates of performance, emissions, costs and uncertainties for preliminary design of:
  • PC, IGCC and NGCC plants
  • All flue/fuel gas treatment systems
  • CO₂ capture and storage options (pre- and post-combustion, oxy-combustion; transport, storage)

• Free and publicly available at: www.iecm-online.com
IECM Modeling Approach

- Systems Analysis Approach
- Process Performance Models
- Engineering Economic Models
- Advanced Software Capabilities
  - User-friendly graphical interface
  - Probabilistic analysis capability
  - Versatile input/output features

IECM Software Package

Fuel Properties
- Heating Value
- Composition
- Delivered Cost

Plant Design
- Conversation Process
- Emission Controls
- Solid Waste Mgmt
- Chemical Inputs

Cost Factors
- O&M Costs
- Capital Costs
- Financial Factors

Plant & Process Performance
- Efficiency
- Resource use

Environmental Emissions
- Air, water, land

Plant & Process Costs
- Capital
- O&M
- COE

IECM Technologies for PC Plants
(excluding CO2 capture, transport and sequestration)

Boiler/Turbine Types
- Subcritical
- Supercritical
- Ultra-supercritical

Furnace Firing Types
- Tangential
- Wall
- Cyclone

Furnace NOx Controls
- LNB
- SNCR
- SNCR + LNB
- Gas reburn

Particulate Removal
- Cold-side ESP
- Fabric filter
- Reverse Air Pulverized

SO2 Removal
- Wet lime stone • Conventional, Forced oxidation • Additives • Wet lime • Lime spray dryer

SDM Management
- Ash pond, Landfill, Co-mixing
- Byproducts (for export)

Cooling and Wastewater Systems
- Once-through cooling
- Wet cooling tower
- Dry cooling tower
- Chemical treatment
- Mechanical treatment

IECM Technologies for IGCC Plants
(excluding CO2 capture, transport and sequestration)

Air Separation Unit
- Cryogenic

Slurry Preparation
- Solidification
- Gasification
• Slurry-feed gasifier (GE-Q)
• Dry-feed gasifier (Shell)

Gas Turbine
- GE 7FA
- GE 7FB

Heat Recovery Steam Generator

Steam Turbine

Boiler Feedwater System

Process Condensate Treatment

Auxiliary Equipment

Cooling Water System
• Once-through
• Wet cooling tower
• Air cooled condenser

Sulfur Recovery System
• Claus Plant
• Beaumont-Stryford Unit

Auxiliary Equipment

Cooling Water System
• Once-through
• Wet cooling tower
• Air cooled condenser
IECM Technologies for CCS

**CO₂ Capture Options**
- **Pre-Combustion (IGCC):**
  - Water gas shift + Selexol
  - Chemical looping
- **Oxy-Combustion (PC):**
- **Post-Combustion (PC, NGCC):**
  - Amine systems (MEA, FG+)
  - Chilled ammonia
  - Membrane systems
  - Chemical looping
  - Auxiliary NG boiler or power plant (optional)

**CO₂ Transport Options**
- Pipelines (six U.S. regions)

**CO₂ Sequestration Options**
- Geologic: Deep Saline or Other Formations
- Geologic: Enhanced Oil Recovery (EOR)

IECM Performance Parameters for Amine Capture System

- Flue gas composition
- Flue gas temp/pressure
- CO₂ removal efficiency
- SO₂ removal efficiency
- NO₂ removal efficiency
- HCl removal efficiency
- Sorbent concentration
- Lean solvent loading
- Acid gas sorbent loss
- Sorbent oxidation loss
- Nominal sorbent makeup
- Ammonia generation
- Cooling water makeup
- Reclaimer chemical req’t
- Flue gas pressure drop
- Fan efficiency
- Sorbent pumping head
- Pump efficiency
- Regeneration heat
- Equiv. elec. requirement
- CO₂ product pressure
- CO₂ product purity
- Compressor efficiency
- Compression energy

Process Performance Models

- Detailed mass and energy balances for each major component and overall plant
- For components with complex chemistry and/or heat integration schemes, multi-variate regression or other reduced-order models are derived from experimental data and detailed process models
- Approximately 10-20 performance parameters for each component technology

Technology Cost Models

- Direct cost models for each major process area (typically 5-10 areas per technology) based on detailed engineering design studies
- Explicit links to process performance models via key parameters (e.g., flow rate, temp., pressure, etc.)
- Calculate total capital cost, variable O&M costs, fixed O&M costs and annualized cost of electricity
- Approximately 20-30 cost elements per technology
IECM Cost Model Parameters for Amine Capture System

- Process Area Costs (12)
- Operating Labor
- Maintenance Labor
- Admin./Support Labor
- Maintenance Materials
- Amine Sorbent Cost
- Other Chemicals Cost
- Waste Disposal Cost
- Water Cost
- (Power Cost)*
- CO₂ Transport Cost
- CO₂ Storage Cost

- Process Facilities Cost
- Engineering & Home Office
- General Facilities
- Contingency Costs (2)
- Interest during Construction
- Royalty Fees
- Pre-production Costs
- Inventory (startup) Cost
- Total Plant Cost
- Total Capital Reqm’t

- Royalty Fees
- Maintenance Labor
- Admin./Support Labor
- Maintenance Materials
- Amine Sorbent Cost
- Other Chemicals Cost
- Waste Disposal Cost
- Water Cost
- (Power Cost)*
- CO₂ Transport Cost
- CO₂ Storage Cost

Probabilistic Capability

- Allows users to explicitly model and quantify the effects of uncertainty and/or variability on component and system performance, emissions and cost
- Values for user-selected parameters are specified as a probability distribution function, which is sampled using a selected method and sample size
- Results are displayed as a cumulative distribution function, yielding confidence intervals and probability of different outcomes for selected parameters

Probabilistic Results: Uncertainty in COE

Model Applications

- Process design
- Risk analysis
- Technology evaluation
- Environmental compliance
- Cost estimation
- Marketing studies
- R&D management
- Strategic planning

Recent IECM versions downloaded by:
>2200 individuals in >800 organizations in > 50 countries
The IECM Team

- Performance and Cost Models of Advanced CO₂ Capture Systems
  - Advanced liquid solvents (Peter Versteeg)
  - Solid sorbent systems (Justin Glier)
  - Membrane capture systems (Haibo Zhai)
  - Advanced oxy-combustion (Kyle Boege)
  - Chemical looping combustion (Hari Mantripragada)
- Software Development & Dist. (Karen Kietzke)

Recent Developments

Since Last Year’s Meeting (1)

- Developed reduced order models (ROMs) for several advanced CO₂ capture processes, now implemented in new IECM test versions:
  - Chilled ammonia process (post-comb.)
  - Membrane capture system (post-comb.)
  - Chemical looping system (pre-comb.)
- Additional process models under development:
  - Advanced oxy-combustion system
  - Solid sorbent capture system (post-comb.)
  - Chemical looping system (post-comb.)
- Prepared draft technical reports documenting new CO₂ capture process models

Since Last Year’s Meeting (2)

- Posted beta version 7.0 for testing
  - >500 downloads to date
- Additional new capabilities in v. 7.1.0, being used for two IECM workshops at this meeting
- Conducted case studies of CCS designs to characterize performance, cost, and uncertainties, including:
  - CCS costs for NGCC plants
  - Effect of proposed CO₂ NSPS for coal plants
  - Effect of EOR credits on capture system cost
  - Comparisons of advanced capture technologies with current amine-based systems.
Illustrative Results:
Sensitivity Analyses
(Deterministic Cases)

Ammonia-Based CO₂ Capture System
(Detailed performance model in Aspen Plus)

Ammonia-Based CO₂ Capture System
(Reduced Order Model in IECM)

Some of the IECM Parameters for the New Chilled Ammonia Capture System Model
Sensitivity of performance and cost results to selected ammonia system parameters*

*All other parameters held constant

New 2-Stage Membrane System Model in IECM

Sweep-based 2-Stage, 2-Step Membrane System Model

Some IECM Parameters for the New Membrane Capture System Model
Effect of Membrane Properties on Cost of CO₂ Avoided

(Sweep-based Membrane System)

Membrane CO₂ Permeance (gpu)

Cost of CO₂ Avoided ($/mt CO₂)

Membrane CO₂/N₂ Selectivity

Membrane Facilities Price ($/m²)

New Chemical Looping Capture System Model in IECM

Some IECM Parameters for the New CLC Capture System Model
Effect of Air Reactor Temperature on Net Power Output of IGCC Plant

Illustrative Results: Full Uncertainty Analyses (Probabilistic Cases)

Two Classes of Research Questions

Questions about a particular technology, e.g.:
• What is the likelihood that Technology A will meet a specified target for a key performance and/or cost metric?

Questions of a comparative nature, e.g.:
• What is the likelihood that Technology A will cost X% less, or perform Y% better, than Technology B in a particular application?

Examples of IECM Parameter Uncertainty Distributions

NORMAL  UNIFORM  LOGNORMAL

TRIANGULAR  ½ -NORMAL  FRACTILE
Stochastic Simulation

Parameter Uncertainty Distributions → Stochastic Sampler → Results

SAMPLING LOOP (n iterations)

Power Plant Model

I.E.C.M. Probabilistic Cost Difference
(accounting for all correlated variables)

IECM Probabilistic Cost Difference (accounting for all correlated variables)

Probabilistic Difference in LCOE for Ammonia vs. Amine Capture

Case Study:
SCPC Plants with and w/o CCS
(13 uncertain parameters specified)

Question: What’s the probability that the added cost of CCS will be no more than $40/MWh?

40% 60% 80% 100%

0% 20% 40% 60% 80% 100%

Cumulative Probability

Plant Levelized Cost of Electricity (2010 $/MWh)

without CCS with CCS

0 20 40 60 80 100 120 140 160

Increase in Plant Levelized Cost of Electricity for CO₂ Capture and Storage (2010 $/MWh)

~10% chance of ≤ $40/MWh

-20 -10 0 10 20

Difference in Plant Levelized Cost of Electricity for Ammonia versus Amine CO₂ Capture (2010 $/MWh)

0% 20% 40% 60% 80% 100%

Cumulative Probability
Future Work This Year

- Workshop session II for IECM users (today)
  - Intermediate/Advanced; 530p – 730p
- New IECM release this fall with:
  - Final performance and cost models of chilled ammonia process, post-combustion membrane capture, and chemical looping pre-combustion system
  - Other updates and enhancements (e.g., capability for probabilistic difference between two uncertain systems)
  - Technical reports and model documentation
- Continued model development, including:
  - Preliminary models for post-combustion solid sorbents, advanced oxy-combustion systems, and post-comb. CLC

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