Modeling Advanced Designs for Zero Emission Power Plant Technologies

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Introduction and Background

The study, a collaborative project within Columbia University between the Earth and Environmental Engineering Department of the School of Engineering and Applied Sciences and the Lenfest Center for Sustainable Energy of the Earth Institute, is working to develop a computational model that will analyze power plant components and will enable modeling exercise to combine existing technology components into innovative thermal power plant designs. A technology pathway that integrates oxy-fuel combustion concepts with gasification, high temperature oxygen separation membranes, advanced turbines, fuel cells and advanced combustion in pressurized fluidized beds will be developed, based upon the results of the modeling analysis.

Comparing with Different Power Plant Modeling Methods

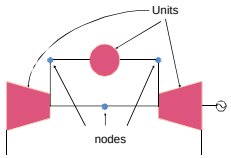
Power plant models	Modeling methods	Accuracy	Runtime	Determinisitic/Dynamic	Example/ Features
Spreadsheet Models	Correlations/algebraic models	Low	short	Deterministic /Stochastic	IECM
Flowsheet Models	Mass and energy balance models, process/reactor models	Medium	short	Deterministic /Stochastic	ASPEN Plus / Hysys/ GTPro /etc¡
Computational Fluid Dynamics (CFD)	More detailed information, include the impact of localized mixing and heat transfer within the reactor, often only used for key plant components	High	Long; running ¡stand-alone¡, off-line simulations is required by users to account for upstream-downstream impact	Dynamic	CFD
Numerical Modeling	Mass and energy balance models, process/reactor models	Medium	Short	Deterministic /Stochastic	?Capable of modeling new components not included in ASPEN Plus ?Capable to integrate with ASPEN Plus environment ?Pathway development

Development Goals

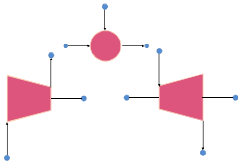
- Modular Approach:
  Independent calculation, easier expandability to new components and new designs
- Flexibility :
  Capable of calculating arbitrary cycle schemes without changing the program
- Expandability:
  The program must allows for easy addition of new components.
- Pathway Development:
  In stead of exploring different end-point designs individually, a wide range of designs are treated as a one big family with shared features, a pathway to outline the possible routes of how one design evolve into another will be developed.

System Modeling

A simple power plant is a system of elementary components, where there are mass and energy flows which undergo chemical, energetic, and thermodynamic transformations solely within the power plant components, such as turbines, compressors, combustion chambers, heat exchangers, and so on.



Example of a power plant (Carcasci, 1996)



Power plant divided in elementary components ((Carcasci, 1996)

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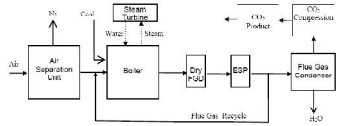
Fundamental Components of a Zero Emission Power Plant

- A mixed oxide membrane air/oxygen separation integrated with oxygen rich combustion of a fuel (MCM)
- integration of air/oxygen separation into a turbine design

- Fluidized bed combustion of coal in mixtures of steam, carbon dioxide and oxygen
- Gasification of coal in mixtures of steam carbon dioxide and oxygen

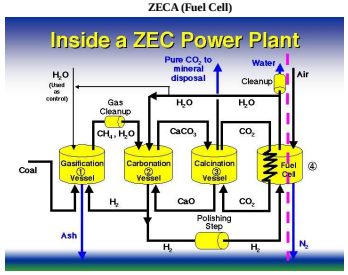
Examples of Cycles to be Modeled

Oxy-fuel combustion with cryogenic (Vattenfall)



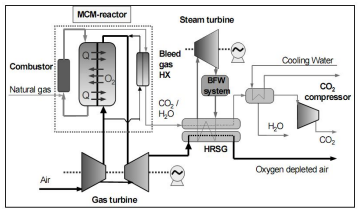
Oxy-fuel plants replace air with the mixture of oxygen and recycled flue gas in a conventional coal plant, producing a concentrated CO2 stream ready for transport and storage.

ZECA (Fuel Cell)



A Zero-Emission power plant using Los Alamos National Laboratories zero emissions coal and carbon technology (ZEC Technology*) produces hydrogen without combustion and converts it to electricity via a solid-oxide fuel cell. Using calcium carbonate from the initial reaction and waste heat from the fuel cell, the plant recycles calcium oxide for further hydrogen production and removes pure CO2 in a concentrated stream for permanent disposal through mineral carbonation..

AZEP (MCM, Griffin 2005)



In the AZEP concept , the combustor in an ordinary gas turbine is here replaced by the MCM-reactor, which includes a combustor, an air pre-heater, a membrane reaction mixed conducting membrane, MCM, and a high temperature heat exchanger section. As shown in the figure, air is compressed in a conventional gas turbine compressor. Typically air can be extracted from the compressor at 20 bar and 450C. A major part, about 90%, of the extracted compressed air is preheated to about 900C-1100C in the lower section of the MCM-reactor. The high pressure high temperature air will then run through the gas turbine and produce electricity.

Chemical Looping (MeO)

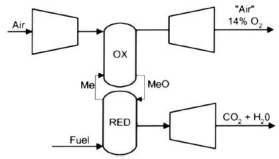
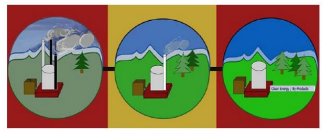


Fig. 1 The chemical looping combustion principle

¡Chemical looping combustion¡ (CLC), is closely related to oxy-fuel combustion as the chemically bound oxygen reacts in a stoichiometric ratio with the fuel. In the CLC process the overall combustion reaction takes place in two reaction steps in two separate reactors. In the reduction reactor, the fuel is oxidized by the oxygen carrier, i.e., the metal oxide MeO. The metal oxide is reduced to a metal oxide with a lower oxidation number, Me, in the reaction with the fuel. In this manner, pure oxygen is supplied to the reaction with the fuel without using a traditional air separation plant, like cryogenic distillation of air.

A Zero Emission Power Plant Roadmap



Based upon the results of the modeling analysis, we intend to develop a technology pathway that integrates oxy-fuel combustion concepts with gasification, high temperature oxygen separation membranes, advanced turbines, fuel cells and advanced combustion in pressurized fluidized beds. There will be multiple pathways and combinations of components that could yield viable designs.

- Oxy-fuel
- ZECA
- AZEP
- Chemical Loopling
- New designs

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