ENERGY PRODUCTION IN A CARBON-CONSTRAINED WORLD

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The talk will present the status of carbon dioxide capture and geological sequestration options, as well as the potential to combine fossil and renewable energy sources. Both existing and emerging technologies for carbon capture will be presented, discussing gasification and combustion systems. A description of near-term CO_2 scrubbing systems for flue gas will be contrasted with ongoing research to develop advanced sorbents for CO_2, new CO_2 solvents, and novel systems such as chemical looping. The potential of mixing biomass and coal in gasification systems (e.g. co-gasification) will also be described. Recent DOE studies suggest that with sequestration, the liquid fuels produced via co-gasification and the Fischer-Tropsch process can have a lower life-cycle CO_2 emission than conventional petroleum fuels. Ongoing research to enable co-gasification will be presented.

LOW EMISSIONS COAL TECHNOLOGY IN AUSTRALIA

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Australia is the world's largest exporter of coal and coal provides the nation's largest export income. Over 80% of Australia's electricity is sourced from coal and coal is responsible for 40% of the nation's greenhouse gas emissions. Consequently developing low emissions coal technologies remains a focus of the Australian Government, coal based utilities and the Australian research community.

In May 2009 the Australian Government announced its $4.5 billion Clean Energy Initiative (CEI). The CEI provides $2 Billion (AUD) to accelerate the deployment of large scale integrated carbon capture and storage (CCS) projects in Australia and $1.5 billion for solar energy. These programs aim to support government emissions reduction policies and to drive large scale GHG emission cuts. In the CCS area the aim is to leverage the $2B with a further $4B from State governments and industry to provide $6B for low emissions CCS technologies. The intention is to accelerate the deployment of 1000MW of low emissions electricity from fossil fuels.

In addition to the above there are a number of low emissions technologies that are being developed or trialled in Australia. These include

- The Callide Oxyfuel project which aims to retro-fit oxyfuel technology to an existing pulverised coal power station.
- Four post combustion capture pilot plants being operated at black and brown coal power stations utilising amine and ammonia technology.
- The Otway pilot injection program which has injected some 60,000 tonne CO2 into a saline aquifer.
- The Gorgon project which expects to inject some 120 million tonne CO2 at a rate of ~4 million tonne pa.

This paper will provide an overview of these projects as well as describing the research framework supporting their deployment.

STUDY OF THE GAS-LIQUID CO2 ABSORPTION IN AQUEOUS MONOETHANOLAMINE SOLUTIONS: DEVELOPMENT OF A NEW EXPERIMENTAL TOOL

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The gas-liquid carbon dioxide (CO_2) absorption by aqueous solutions of amine mixture is one of the up-to-date CO_2 capture technology. This work is realized in collaboration with Cansolv Technologies Inc., which is a design office specialized in the development of amine solutions for CO_2 scrubbers. These solutions consist in various mixtures of several amines, which combine a fast reaction rate with the CO_2, a high absorption capacity, a high stability and a low energetic regeneration cost.

An accurate identification of the gas-liquid CO_2 absorption kinetic parameters is required to select the best amine mixture. Besides, this identification is necessary to design the scrubbers. This work deals with the development of an original experimental method to identify the gas-liquid CO_2 absorption parameters in aqueous amine solutions. The monoethanolamine (MEA) is used as a reference case, as physico-chemical parameter values and reaction kinetic models can be found in the literature.

The absorption of pure gaseous CO_2 in an aqueous MEA solution is realized in Hele-Shaw cell. During this absorption, chemical reactions occur in the solution. Small refractive index variations of the liquid phase take place in the vicinity of the gas-liquid interface and are observed using a digital holographic Mach-Zehnder interferometer.

A calibration curve is determined using a refractometer, by measuring the refractive index of MEA solutions for various dissolved CO_2 amount. The calibration curve allows comparing the experimental profiles with numerically simulated refractive index profiles, which are computed using a penetration model in a semi-infinite liquid phase.

The physico-chemical parameters are identified by fitting the simulated refractive index profiles to the experimental ones, considering the same operational conditions, using a parametric least-square fitting method. A good agreement between the simulated and the experimental profiles is obtained with the fitted parameter values and it is observed that these values are close to those referenced in the literature. Therefore, the developed procedure is applied to study the gas-liquid CO_2 absorption parameters in a solvent provided by Cansolv.

SOLID FUELS CONVERSION USING THE IRON-BASED CHEMICAL LOOPING PROCESS

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The chemical looping strategy utilizes the redox reactions of metal oxides to convert carbonaceous fuels into separate streams of product and sequesterable CO2. The chemical looping schemes that directly convert solid fuels such as coal and biomass pose economical and technical attractiveness since it directly converts the relatively cheap solid fuels in a simple manner. For the solid fuel chemical looping processes to be feasible, however, the slow kinetics of solid-solid reaction between the solid fuels and oxygen carriers must be overcome. A two-stage counter-current moving bed is proposed for effective conversion of solid fuels. In the first stage, the oxygen carriers in the upper section convert the gaseous volatiles from the solid fuels. Then, the bottom stage converts char, as the metal oxides are reduced to the lower oxidation states. For the demonstration of solid fuel conversion in the two-stage moving bed, 25KWth cold model reactor was designed. During cold model testing, handling of solid fuels were studied with the focus on smooth fuel injection and proper contacting pattern between the fuel and the oxygen carrier in the moving bed. In addition to the cold model study, a thermogravimetric analyzer (TGA) and fixed bed were used to study the chemistry of chemical looping process for the solid fuel conversion. The reactive characteristics of oxygen carrier and the char gasification enhancement were investigated in the TGA and fixed bed, respectively. These studies show that the oxygen carrier developed at the Ohio State University is capable of converting coal and biomass to CO2.

GREENHOUSE GAS CAPTURE AND MITIGATION TECHNIQUES FOR DIFFERENT INDUSTRIES

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Air Liquide is actively participating in green house gas (GHG) emission reduction from several industries to reduce its environmental carbon footprint. Today majority of the industrial CO2 emission comes from fossil fuel combustion. Power plant and metal industries use fossil fuels like natural gas or coal and emit large amount of CO2 in the flue gas. This CO2 can be further extracted, purified and sequestered or used for enhanced oil recovery. Air Liquide offers oxy-combustion technology for power plant to concentrate CO2 in the flue gas and reduce the cost of CO2 capture. The concentrated CO2 in the flue gas can be further purified using CO2 Compression and Purification Unit (CPU) to produce high purity CO2 for storage. Air Liquide is involved in several pilot studies with partners to capture CO2 from the power plants by retrofitting existing boiler using oxy-combustion technology. Air Liquide is also involved in the European project ULCOS (Ultra Low CO2 for Steelmaking). The aim of this project is to reduce the CO2 emissions from the steel industry by 50%. One of the promising routes is Top gas Recycling Blast Furnace process (TGR-BF) which aims at capturing the CO2 and recovering CO and H2 from the blast furnace gas. In partnership with the European steelmaker, Air Liquide built and successfully operated the world's first reference of CO2 capture unit (based at MEFOS site, Lulea, Sweden) from Blast Furnace gases using adsorption technology. This paper will describe the different case studies by Air Liquide for CO2 capture on power plant and metal industry.

TOWARDS SUSTAINABLE ENERGY: SYNTHESIS OF CLEAN FUELS FROM COAL, BIOMASS AND MUNICIPAL SOLID WASTES WITH INTEGRATED CARBON CAPTURE AND STORAGE

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Production of hydrogen or liquid synthetic fuels from indigenous resources, such as coal, biomass and municipal solid wastes, is an attractive option to break the United States' addiction to the foreign oil. Currently, synthetic fuels are mainly produced via Fischer-Tropsch (F-T) synthesis process using natural gas or syngas generated from coal gasification. The advances in gasification technology has led to modern entrained flow gasifiers with much higher efficiency; however, the syngas produced from these gasifiers has much lower H2/CO ratios ranging from 0.5 to 0.7 than the required value of ~2 for liquid fuel synthesis. The Water-gas-shift (WGS) process is commonly utilized to meet this hydrogen deficit in the syngas. The WGS, however, is costly and the subsequent CO2 removal step is energy intensive. The Syngas Chemical Looping Reforming (SCLR) process is developed to reform the excessive amount of syngas and byproducts from F-T reactor into H2. With this novel technology, the overall liquid fuel yield can be significantly increased for a Coal-to-Liquid (CTL) or Biomass-to-Liquid (BTL) processes, while producing sequestration-ready CO2 stream. Most of current carbon capture and storage (CCS) technologies are developed independently from each other. Thus, the integration of material flux between carbon capturing chemical looping and carbon mineral sequestration technologies will lead to improved carbon mitigation efficiencies during the production of hydrogen and liquid fuels.

A MULTI-OBJECTIVE EVALUATION OF PC PLANTS WITH AQUEOUS AMINE CARBON CAPTURE SYSTEMS

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Previous analysis indicates that water use at conventional pulverized coal (PC) power plants is expected to nearly double if aqueous amine-based carbon capture systems are deployed at commercial scales [1]. The majority of additional freshwater consumption associated with using aqueous amines results from the cooling requirement for the stripper [1]. The purpose of this study is to more rigorously examine the interaction between water use and carbon capture.

A predictive steady-state process model of a hypothetical existing 550 MW PC power plant was developed to assess scenarios for retrofitting with carbon capture systems. The model explicitly considers the effects of steam extraction and can rigorously predict changes in freshwater use and operating cost resulting from plant modifications. Predictive steady-state models of aqueous amine-based carbon capture technologies have also been developed. The PC power plant and capture models were developed in Aspen Plus and validated against other computer models and plant operating data where available.

The PC plant and carbon capture systems were integrated through the use of an external framework that supports multi-objective optimization. This presentation discusses the tradeoffs among capital cost, operating cost and water use resulting from different potential retrofit configurations and levels of integration between the base plant and the carbon capture system. Various approaches for heat integration and alternative cooling are investigated. The results are presented as Pareto curves.

[1] U.S. Department of Energy, 'Water Requirements for Existing and Emerging Thermoelectric Plant Technologies,' Publication No. DOE/NETL-402/080108, NETL Office of Systems Analyses and Planning, (April 2009).

ENHANCED PHOTOSYNTHETIC GROWTH, BIO-OIL AND ELECTRICITY PRODUCTION USING CHLORELLA VULGARIS AND PSEUDOMONAS PUDITA

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Microalgae are a promising source of bio-oils and a biological algae-bacteria based, microbial fuel cell (MFC) can be an attractive mode for electricity production to create alternative sources of energy. The objectives of this study are to investigate photosynthetic growth kinetics of Chlorella vulgaris in a circulating loop photbioreactor, to maximize bio-oil yield and to produce electricity by developing a C. vulgaris-Pseudonomas pudita MFC.

Four different conditions were set up to study the photosynthetic growth kinetics of C. vulgaris in an external airlift photobioreactor. The highest growth rate (0.05 hr-1) for C. vulgaris was found with a carbon dioxide gas phase concentration of 5%, 6 lights around the riser, 8 hour dark phase and sodium nitrate replacing ammonium chloride in Bold's media. The slowest growth rate (0.01 hr-1) of C. vulgaris was observed using Bold's medium under the conditions of 10% carbon dioxide flow rate, 16 lights around the riser and 10 lights around the downcomer and with no dark phase. This was likely due to photoinhibition. However, high cell density was achieved under these conditions.

In order to maximize the oil yield, the effects of light intensity, carbon dioxide concentration, sodium nitrate and ferric chloride were investigated. Only the light intensity showed a potential to significantly increase the bio-oil yield. The highest oil yield (31.82%) was observed when C. vulgaris grew in a Bold's media with 10% carbon dioxide, 16 lights around the riser and 10 lights around the downcomer and without a dark phase. Increases in sodium nitrate and ferric chloride concentrations decreased the oil yield.

A microbial Chlorella v.-P. pudita fuel cell was constructed to generate electricity. The photosynthetic culture C. vulgaris at the cathode acted as the electron acceptor while capturing CO2, while P. pudita at the anode acted as the electron donor while consuming phenols in the wastewater. Carbon rods as electrodes were inserted in both cultures and voltages were continuously recorded as electrical loads and dilution rates were varied. A potential voltage across the cathode and anode demonstrated a successful, complete MFC for the production of electrical energy. The effect of different resistances during loading and unloading were studied by placing 10000, 8000, 5000, 2000, 1000 and 250Ω in a closed circuit and determining the dynamic voltage histories. The experimental potential differences and response times were fit to the first order equation: [Vmodel = Vfinal – (Vfinal –Vinitial) x e-kt] to predict the effect of loading and unloading at different resistances. Response times varied from 12 min up to 84 minutes depending on the magnitude of the resistance and whether loading or unloading experiments were being performed.

SUSTAINABLE AND INNOVATIVE PROCESSES FOR CARBON CAPTURE AND RECYCLING

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The ENVIROFRIEND-CONSOLIDER-Ingenio 2010 is a research project proposal of high level scientific activities within the framework of the CONSOLIDER-Ingenio 2010 Programme of the Spanish Ministry of Science and Innovation. The main aim of this project proposal is to make a significant progress in the knowledge and development of Sustainable and Innovative Processes for Carbon Capture and Recycling. This activity places strong emphasis upon new knowledge in cleaner combustion processes (oxycombustion, chemical looping), CO2 separation/concentration processes using membrane technologies, catalytic and electrocatalytic processes for CO2 recycling and integration and optimization of the processes based on sustainability criteria.

The most mature and applied technology for the post-combustion capture of CO2 from the flue gas and subsequent release is cycling chemical absorption/ desorption using an aqueous amine solution. However, the identification of a capture process which would fit the needs of target separation performances, together with a minimal energy penalty, is a key issue. According to this issue, innovative absorption-desorption processes based on membrane technologies intensified by ionic liquids is one of the main innovations of this project proposal.

This project will also focus on the optimization of the direct electrochemical reduction to convert the previously captured CO2 into various organic products, fuels for fuel cells or chemicals with added value for the chemical industry. In order to supply the process with such as an energy source that allows the process to perform with a positive carbon footprint, emphasis will be placed on the integration of photovoltaic solar energy with the electrochemical reduction in order to supply the required energy for the transformation.

This CONSOLIDER 2010 project proposal involves 11 research groups from Spanish Universities and CSIC Institutes: Instituto de Carboquímica ICB-CSIC, Universidad Autónoma de Madrid (UAM), Universidad Complutense de Madrid (UCM), Universidad de Alicante (UA), Universidad de Cantabria (UC), Universidad de Castilla La Mancha (UCLM), Universidad de las Palmas de Gran Canaria (ULPGC), Universidad de Santiago de Compostela (USC), Universidad de Vigo (UVigo), Universidad de Zaragoza (UNIZAR), Universidad del País Vasco (UPV/EHU), Universidad Rovira i Virgili (URV), Universitat Politècnica de Catalunya CTM-UPC.

Knowledge transfer to the Technology Platforms and Cenit projects and promotion of the international cooperation are also priorities in the Programme. In this sense, this project takes a special interest in developing demonstration projects and finding industries that could act as innovation partners for technology transfer.

CO2 CONVERSION TO ORGANIC COMPOUNDS AND POLYMERIC PRECURSORS

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This work has the main objective to study the conversion of CO2 into organic compounds such as methanol, formic acid and its derivatives as well as into some precursors of polymers.
The conversion into organic compounds has been analyzed through direct hydrogenation reaction with catalysts of ruthenium and nickel. All catalysts have been characterized by X-ray fluorescence and diffractometry, FTIR spectroscopy, elemental analysis (C, H and N) and MAS-NMR (27Al, 31P) techniques and were used for the first time in the CO2 catalysis. Lower cost catalysts such as lamellar
aluminiumphosphate-supported Ni(II) complexes have also been tested. The conversion reactions were observed in a temperature range of 150-200 ºC and at 1 atm, which are very mild conditions that need low energy consumption. The initial percentage of conversion obtained has been 15-35 %. It has been observed a great influence of the architecture of the catalysts into the selectivity of the products.

The study on the synthesis of polymeric precursors has employed tin complexes as catalysts in reactions with methanol and CO2 (150 C and 60 bar/CO2) in a Parr reactor. These catalysts were based on tin alkoxides synthesized from modified methodologies from literature. The catalysts were characterized by elementary analysis, Raman spectroscopy, infrared and 1H and13C NMR.
The main results of the mass spectra analysis showed peaks characteristic of the presence of ethyl esthers.

For both CO2 conversion reactions we have tried to use lower cost catalysts in lower profile energy cost reactions and the already analyses done indicated promising results. This project may contribute to a proposal of conversion of CO2 into organic products of economical value, which may be useful in the very near future.

THE ROLE OF TECHNOLOGY IN ENERGY OUTLOOK

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The presentation will highlight the role of technology in ExxonMobil's *Outlook for Energy*, which reflects an assessment of global supply and demand through 2030 based on the underlying factors that are shaping important energy challenges around the world. Meeting these global energy challenges requires an integrated set of solutions: moderating demand through energy-efficient technologies and practices, expanding access to all economically viable energy sources, and mitigating emissions related to the use of energy.

This presentation will cover a few examples of technologies for energy efficiency (light duty vehicles), expanding supply (unconventional gas, algae biofuels), and mitigating emissions (early applications of CCS) will be shared.

RENEWABLE ENERGY: CHALLENGES & OPPORTUNITIES IN DEVELOPING A SUSTAINABLE BIOMASS INFRASTRUCTURE

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Global primary energy demand is projected to increase by almost 60% over the next two decades, driven in large part by robust economic growth in China and other major developing economies. All forms of energy will have to grow to meet this future demand. Renewable Energy will play an increasingly important role in the future primary energy mix accounting for about 20% of the primary energy demand. Sustainably produced renewable energy will also play a pivotal role in mitigating Green House Gas emissions. This presentation will examine key technological developments in the production of renewable transport fuels and biomass based heat and power. The presentation will cover feedstock, technical, economic and sustainability issues related to the various technology pathways examined.

BIO-ENERGY GREENHOUSE GASES LIFE CYCLE ASSESSMENT REVIEW

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A major barrier to the full support and deployment of biomass based energy systems is the lack of robust conclusions about whether their use will provide substantial life cycle greenhouse gas (GHGs) reduction benefits. A number of life cycle assessments (LCA) of bio-based energy systems exist, but the generation of informative conclusions has been difficult because of the apparent variability in literature estimates. In some cases this may be due to faulty assumptions and human error, but mostly it can be attributed to justified differences in study contexts and methodologies. Too much attention has been given to finding the <">true<"> estimate for a given bio-energy pathway when such an estimate probably cannot be found because of many contextual factors implicit within LCA results. Little attention has been focused on a comprehensive analysis of existing bio-energy LCAs to instead identify when these contextual factors have an impact and then produce alternate life cycle estimates at various levels of resolution and with alternative study boundaries.

A broad review was conducted of direct emissions reductions (over the life cycle) from the use of bio-based pathways. A broad search and sampling of major bio-energy LCA studies led to the collection of GHG estimates for most major terrestrial and aquatic biomass – thermal, chemical, biochemical, and biological synthesis pathways. For most of the major bio-energy pathways the studies collected spanned a broad variety of biomass types, geographic locations, current and future technologies, and combined bio-refineries worldwide. After some initial harmonization of results such as conversion to common global warming potentials, a series of estimates for various geographic, temporal, methodological, and technology variations were produced using basic statistical methods. Results also identified situations in which these factors did not significantly affect LCA results and areas where additional LCA research is needed to fill in gaps in the literature. Several other major issues affecting LCA results, outside the scope of direct emissions such as indirect land use changes, will be discussed in the context of study results.

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A MOBILE PYROLYZER FOR CONVERTING AGRICULTURAL AND FORESTRY RESIDUES INTO LIQUID BIO-OIL AND BIO-CHAR

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The Institute for Chemicals and Fuels from Alternative Resources (ICFAR) at the University of Western Ontario, in cooperation with Agri-Therm, is developing a mobile pyrolyzer for the production of bio-oil and bio-char. Its mobility makes it ideal for the processing of diffuse sources of biomass, such as forestry or agricultural residues, which would be too expensive to transport to a central plant for processing. Its mobility also makes it ideal for seasonal sources of biomass. It is designed for easy operation. The unit consists of an annular fluidized bed reactor where biomass is pyrolyzed. It surrounds a central cylindrical fluidized bed combustor where the non-condensable gases generated in the reactor are burned. The heat required by the endothermic pyrolysis reactions is transferred from the combustor to the reactor through special lift tubes, which circulate solids from the reactor through vertical tubes immersed in the hot combustor. Because there are fluidized solids on both sides of the tube wall, very high heat transfer coefficients are achieved. An additional benefit is that hot sand particles exit the top of the lift tubes just above the reactor bed surface, dragging down into the bed any biomass particle that would float on the bed surface. This innovative design is compact, flexible, safe and simple to operate. Because the combustion of product gases provides the required energy, the process is self-sustainable from an energy standpoint. This work presents a possible application to the conversion of agricultural residues. Different tests were carried out under selected conditions in the mobile pyrolyzer, at a feedrate of about 400 kg/hr. The product yields were determined. The liquid bio-oil was analyzed to establish its chemical composition and fuel properties. The elemental composition and heating value of the biochar co-product were obtained. Results were compared to data obtained in a small pilot plant reactor.

GHG IMPACT OF USING FAST PYROLYSIS OIL FOR ELECTRICITY AND BIOFUEL GENERATION

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Fast pyrolysis has emerged as a promising pathway for producing renewable oil for use in the generation of electricity and transportation fuel. Envergent Technologies, LLC, a joint venture of UOP LLC and Ensyn Corp., is now licensing Ensyn's commercially proven Rapid Thermal Processing (RTP™) technology to convert biomass to pyrolysis oil for use in power and heating applications. Within the next three years, Envergent Technologies will develop technology to produce higher quality, hydrocarbon transportation based fuels from pyrolysis oil. A unit initially installed for energy production can easily be used to produce feedstock for liquid transportation fuels at a later stage. The RTP technology is capable of processing a wide variety of second-generation feedstocks including woody biomass, agricultural waste, construction & demolition waste, and municipal solid waste. It is also feasible to consider the use of on-purpose sustainable energy crops like miscanthus or switchgrass as process feedstock. A general description of the RTP technology will address both near term and future applications. A discussion of yields, product quality, and commercial applications provide the context for the specific cases selected for evaluation. A life cycle assessment will quantify the significant greenhouse gas (GHG) impact that can be realized by substituting pyrolysis oil for fossil fuel in both power generation and transportation fuel production applications. This life cycle assessment specifically investigates the GHG emissions and fossil energy demands for energy products obtained from forest resources through pyrolysis-based processing. The GHG emissions of producing pyrolysis oil from different forest resources are first investigated; logging residues collected from natural regeneration mixed hardwood stands, hybrid poplar cultivated and harvested from abandoned agricultural lands, short rotation forestry (SRF) willow plantations and waste wood available at the site of the pyrolysis plant. Effects of biomass transportation are then investigated through a range of distances to a central pyrolysis facility through road transport by semi-truck. In the power application, pyrolysis oil is assumed to be converted to electricity through co-combustion in conventional fossil fuels power plants, gas turbine combined cycle (GTCC) and diesel generators. Life cycle GHG emissions are then compared with power generated using fossil fuels and power generated using biomass direct combustion in a conventional Rankine power plant. In the transportation fuel application, the results of bench scale testing and UOP's experience with commercial scale-up of oil refining processes are used to estimate the life cycle impacts of the pyrolysis oil upgrading steps. Results of a preliminary well-to-wheel GHG analyses are summarized and compared with conventional petroleum based transportation fuels.

CHARACTERIZATION AND GENETIC ENGINEERING OF A STRAIN OF SACCHAROMYCES CEREVISIAE CAPABLE OF UTILIZING XYLOSE FOR GROWTH AND ETHANOL PRODUCTION

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The yeast Saccharomyces cerevisiae is incapable of fermentation or efficient uptake of the pentose sugar xylose, which is a major constituent of cellulosic biomass hydrolysates, to produce bioethanol. This inability to ferment xylose is a major hindrance in the production of an economically feasible source of cellulosic bioethanol. By introducing specific genes into S. cerevisiae, which will enable xylose metabolism through fermentation and increase the rate of xylose uptake into the yeast cell, efficient fermentation of xylose should be achieved. We hypothesized that overexpressing the enzymes xylose isomerase from Piromyces sp. E2 and xylulokinase from S. cerevisiae, along with a glucose/xylose facilitator from Candida intermedia should enable S. cerevisiae to uptake and ferment xylose to produce bioethanol. Three yeast expression vectors have been constructed to facilitate the overexpression of these three genes, each selectable by a separate antibiotic through different dominant negative selectable markers. Genetically modified strains of yeast overexpressing combinations of the xylose isomerase, xylulokinase, and the glucose/xylose facilitator yeast expression vectors have been produced through single-, double-, and triple-transformations of an industrial strain of S. cerevisiae called NRRL-Y132. Fermentation experiments are being performed on each of these genetically modified strains of S. cerevisiae by performing batch fermentations in yeast media containing varied ratios of glucose and xylose. Preliminary data suggests that the single transformation overexpressing xylose isomerase and the double-transformation overexpressing both xylose isomerase and xylulokinase enables xylose metabolism for production of biomass. Further fermentation experiments of the remaining double- and triple-transformed S. cerevisiae will be presented.

ANALYSIS OF GLOBAL WARMING MITIGATION BY WHITE REFLECTING SURFACES

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The rapid increase in greenhouse gas (GHG) concentration over the last 50 years has produced approximately 0,64 Celsius degrees rise in global mean temperature. The most worrisome effects of global warming include severe weather and related hydro-geologic events, many of which have been already occurring. Global warming consequences are touchable also in agricultural field; species extinctions and increases in the ranges of disease vectors are actually going on. Earth's global surface temperature strongly depends on its surface radiative properties. Solar radiation absorbed by surface, together with a natural atmospheric greenhouse effect, represents the mechanism regulating Earth's temperature. Therefore, Earth's albedo modification by proper surfaces would reduce the portion of solar radiation absorbed by the Earth, and consequently decreased average global temperature. Quantification of reflecting surface effectiveness has been accomplished in this work through a mathematical relation, based on the energy balance among sky, atmosphere and earth surface. The correlation between the temperature reduction and the greenhouse gases decrease in the atmosphere has been calculated on the hypothesis that the temperature increase in the last century has been caused exclusively by the GHG concentration variation occurred in the same period. It has been estimated by the proposed model that the reflecting surface area (reflecting coefficient equal to 0.9) which is required to offset the effect, in terms of global mean temperature, of introducing in the atmosphere of 1 ton of CO2eq is equal to 8 square meters. In terms of Radiative Forcing, a drop of 0.28 W/m2 is obtained for each 106 km2 of the same kind of reflecting surfaces. Comparing earlier literature models, results that one tonne of emitted CO2 offset is obtained increasing the albedo by 25% for a surface of 23 m2 using our method, of 26 m2 in Harte's model and of 23 m2 in Berkeley study. In terms of Radiative Forcing, a drop of 0.28 W/m2 is obtained for each 106 km2 of surfaces with reflection coefficient of 0.9. Furthermore, greenhouse gas "abatement" cost through reflecting surfaces has been compared to the one obtained by the main renewable energy sources. The technologies for renewable energy sources which have been considered in this study are solar panels for the generation of thermal energy, photovoltaic panels, wind generators and hydroelectric power plants.

MICROALGAE BIOMASS PRODUCTION POTENTIAL IN THE US

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Microalgae have been of interest as a feedstock for biofuels but until recently have not been economically feasible. Recent energy uncertainty coupled with technological improvements and the potential for mitigation of carbon dioxide has made microalgae more appealing as an alternative feedstock for the conversion to transportation fuel. Microalgae characteristically have many advantages over traditional terrestrial based biofuel feedstocks, year round production, high growth rates, carbon dioxide sequestration, no land quality requirement, low quality water utilization, and scalability potential. A literature based bulk growth model has been developed based on 16 species specific inputs (molecular weight, light saturation, absorption coefficient, maximum growth rate, maintenance reparation rate, biosynthetic efficiency, optimum temperature, activation energy, maximum and minimum cell quota of nitrogen, cell quota of nitrogen of inoculums, half saturation constant for nitrogen uptake, maximum nitrogen uptake rate, max photosynthetic rate, and photon efficiency) with primary growth inputs of light, temperature, and nitrogen availability. This model coupled with a light model has been validated utilizing data from scalable photobioreactors (PBR) cultivating Nannochloropsis oculta. The validated bulk growth model integrated with historical PAR and temperature data is used to generate biomass productivity potential map of the US. This map was then overlaid with land, CO_2, and water availability to show the realistic biomass potential in the US. Results show the realistic near term microalgae based biomass potential in the US.

BIOFUELS AND BIO-BASED CHEMICALS: OPPORTUNITIES & BARRIERS

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Biofuels offer significant potential to reduce the carbon footprint of the transportation sector, while also addressing energy security and diversity of supply. Progression from “first generation” feed stocks to energy crops and residues offers the greatest potential in carbon intensity reduction. Challenges include impact of land use change and agricultural footprint, water use, transportation of low density feed stocks, and efficient conversion processes that are adaptable to distributed or smaller-scale production. Just as the petrochemical industry arose via synergy with larger-scale refining of petroleum to fuels, large scale production of biofuels can also be expected to impact feed stocks for the future chemical industry. These drivers will result in a plethora of new development opportunities in both fuels and chemicals.

UNLOCKING BIOFUELS WITH MICROCHANNEL TECHNOLOGY

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Multiple studies have indicated that producing fuel from lignocellulosic biomass can substantially reduce life cycle carbon dioxide and other greenhouse gas emissions. One promising route to convert biomass to fuels is via gasification combined with Fischer-Tropsch (FT) synthesis followed by hydrocracking. The resulting products from this process are ultra-clean, infrastructure compatible transportation fuels that emit approximately 90% less life cycle greenhouse gas than petroleum derived fuels. Conventional FT reactors are optimized for massive coal-to-liquid (CTL) and on-shore gas-to-liquid (GTL) facilities. These slurry and fixed bed reactors are much larger than the sizes needed to tap abundant, but distributed, biomass resources. Similarly, hydrocracking units have been optimized for large scale refining operations. By reducing heat and mass transfer resistance, microchannel process technology can greatly reduce the size of chemical processing hardware while maintaining high throughput; thereby, allowing the next generation of FT reactors and hydrocrackers suited for biofuel installations. A pilot-scale microchannel FT reactor passed 4,000 hours time on stream. Utilizing an advanced catalyst, the performance of the test reactor exceeded expectations. Single pass conversion of carbon monoxide (CO) at commercial conditions was over 70%, and selectivity to methane was well under 10%. The pilot reactor produced over 2 gallons per day of high quality distillate and waxes from a pressurized stream of synthesis gas (2:1 hydrogen to CO ratio). These positive results provide a high level of confidence as final preparations are made for a 25 gallon per day demonstration of microchannel FT on live biomass derived synthesis gas at the biomass gasification plant in Güssing, Austria. Microchannel hydrocracking also has been shown to be advantageous in over 1,500 hours of laboratory testing. If selected, detailed updates of both microchannel FT and hydrocracking will be provided during the oral presentation.

NET ENERGY AND GREENHOUSE GAS EMISSIONS EVALUATION OF BIODIESEL DERIVED FROM MICROALGAE

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Biofuels derived from microalgae have the potential to replace petroleum fuels and first-generation biofuels, but the efficacy with which sustainability goals can be achieved is dependent on the lifecycle impacts of the microalgae-to-biofuel process. This study proposes a detailed, industrial-scale engineering model for the species *Nannochloropsis* using a photobioreactor architecture. This process level model is integrated with a lifecycle energy and greenhouse gas emissions analysis based on the methods and boundaries of the Argonne National Laboratory GREET model. Results are used to evaluate the net energy ratio (NER) and net greenhouse gas (GHG) emissions of microalgae biodiesel in comparison to petroleum diesel and soybean-based biodiesel. The NER of the microalgae biodiesel process is 0.89 MJ of energy consumed per MJ of energy produced. In terms of net GHGs, microalgae-based biofuels avoids 78 g of CO_2 equivalent per MJ of energy produced. The scalability of the consumables and products of the proposed microalgae-to-biofuels processes are assessed in the context of 40 billion gallons of annual production.

USE OF GENETICALLY MODIFIED *SACCHAROMYCES CEREVISIAE* TO CONVERT STARCH DIRECTLY INTO BIOETHANOL

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Saccharomyces cerevisiae is normally used for industrial ethanol production, but is unable to directly utilize starch for fermentation. A novel yeast strain of *S. cerevisiae* has been genetically engineered in such a way that the starch-hydrolysing enzyme, barley alpha-amylase, is constitutively expressed and secreted into the culture media. The gene encoding barley alpha-amylase was fused with a secretion signal at its 5' end, and the gene transcription is under control of a constitutive promoter, *ADH1*. A dominant selection marker, blasticidin resistance gene, was used to select the transformed yeast. The transformed yeast showed amylolytic activity by generating visible halos on iodine stained starch plates. In batch fermentation studies, the constructed amylolytic yeast showed the ability to hydrolyse and ferment on soluble potato starch. And improved starch hydrolysis rate and ethanol production (up to 92% of the theoretical yield) were observed with the addition of exogenous glucoamylase. This strain of yeast is currently being improved to be able to directly ferment on starch particles.

COMPATIBLE POWERTRAIN FUEL FROM MUNICIPAL SOLID WASTE PLASTIC

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Train is a major form of transportation around the world today. These trains produce much less carbon emission compared to everyday passenger and commercial vehicles. Most of these trains run on electricity however to produce the electricity huge amount of fuel in required considering the fact that fuel is very limited in the world. To overcome this limited amount of fuel, alternate fuel sources are in the process of being developed. Municipal Solid Waste Plastics have the potential to be an alternative fuel through a simple unique process. Waste plastics are all around us however, the presence of these waste plastics in the landfill causes various sorts of health and environmental problems. Municipality waste management system spends a lot of money each year to remove these waste plastics from landfill by recycling and incinerating. With the help of the newly developed Natural State Research Inc. (NSR) technology (patent pending process) these waste plastics are converted into liquid hydrocarbon fuels. The highly combustible fuel is test proven to generate electricity using generators and it is compatible with all types of internal combustion engines. The fuel produced in economically viable and environmental friendly. Using raw materials that are already at our disposal will cut the production cost of the NSR fuel substantially.

PAINTING THE FUTURE PICTURE OF ENERGY FROM DIFFERENT ANGELES

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Reducing imported oil and minimizing CO2 & other emissions are the two major driving forces of different energy R&D programs today in most part of the world. In transportation sector, the major alternatives for reducing imported-oil are: 1). New electric vehicles (EVs), fuel cell cars and hybrids, or natural gas or bio-fuels that do not need oil; 2). Using more efficient diesel or diesel hybrid to minimize oil consumptions. In the power generation sector, the major alternatives for reducing CO2 & other emissions are: 1). Non-fossil fuel based power generation such as nuclear, wind, solar and biomass; 2). Cleaner coal for post capture for retrofitting existing coal power plants, or IGCC with CO2 pre-capture for new coal power plants. Based on many years of experience in 3 different sectors of Energy: Oil & Gas at Exxon-Mobil, Hydrogen and Fuel Cells at UTC Fuel Cells & Shell, and Power Generation, Coal Gasification & IGCC at GE, the author will try to give his perspectives on the future pictures of Energy, and try to assess what is going to happen in different alternatives mentioned above. The audience can draw their own conclusions based on certain data and picture of different sectors of energy to be presented in this lecture.

TOWARD SUSTANABLE CO2 CAPUTRE

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Keynote Lecture: Global warning and climate changes can be closely related to the increased concentration of Green House Gases (GHGs) emitted from anthropogenic activities. One of the major activities is to harness energy by burning fossil fuels. Carbon dioxide (CO2) is one of the final combustion products and is one of GHGs. CO2 concentration in the atmosphere steadily increases from 270 ppm before the industrial revolution to almost 400 ppm at the current era. At this level, the contribution of CO2 to the Green House effect is 60% out of all GHGs. One well established technology for CO2 separation from power plants and chemical industries is based on liquid absorption (amine or ammonia). The process is energy-intensive because the operating temperature difference between absorption and solvent recovery is larger than 100 0C. The current cost related to CO2 capture occupies almost 40% out of total costs of CO2 capture, transport, and storage. In this regard, it is essential to improve the efficiency of the current absorption technology as well as to develop new energy efficient processes. One of emerging techniques for CO2 capture is the chemical looping, in which metal oxides like FeO2 react with CO2 to form metal carbonates in the capturing stage and these metal carbonates are decomposed into metal oxides and CO2 in the regeneration stage. CO2 capture via CO2 clathrate formation and dissociation is another novel option because the temperature difference between CO2 capture and recovery is less than 30 0C. Moreover, this process only requires water and a small amount of hydrate formation promoters. In this talk, these new approaches for CO2 capture will be presented and compared with the traditional liquid absorption, and some aspects of process intensification will be discussed in the CO2 capturing process.

LIFECYCLE ENERGY MODELING - INPUT INTO UPSTREAM DESIGN PROCESS

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Lifecycle energy modeling can be used as a primary design input during early project development. This requires the use of an operating model so that design change influence on operational costs and revenue collection can be considered against capital cost impact. Significant overall project savings can be discovered with this analysis even in cases where CAPEX impact is unfavorable. An example West African FPSO development will be compared with several different production concepts on the basis of CAPEX, OPEX, and revenue analysis. OPEX costs will include cost of fuel gas and carbon emissions. The revenue analysis will be based on estimated annual production including the effects of availability and uptime. OPEX costs and projected revenues will be brought back to a net present value to aid in decision making during the concept development phase. A design model based on a production depletion curve will be used both to inform the engineer of the various system peaks (e.g. separation sized based on year two, compression sized based on year six) and to allow operational data such as yearly production achieved, fuel gas usage, carbon emissions value, and deferred production due to downtime. The methods presented can be applied to any development currently in the concept development or selection stages. While a user may indicate a different base datum value for e.g. fuel gas, the rationale and approach for the comparison remains valid. Sensitivities will be presented to illustrate a qualitative analysis of external influences (e.g. facility throughput, additional of incremental reserves midway through field life, effect of fuel price, carbon emissions cost, etc.). The observations described will indicate the net present value impacts based on use of an all electric concept with major users (typically gas injection compressors and water injection pumps) utilizing variable frequency electric motors rather than individual gas turbines, as well as other hybrid concepts. This paper is significant in that the methods and analyses described therein can influence initial design and concept selection phases of onshore and offshore facilities, a period in which some of the most important facility design decisions are made.

MONITORING CONSUMPTION – THE FIRST STEP IN DEVELOPING AN ONLINE ENERGY MANAGEMENT SOLUTION

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Energy and emissions management is critical in the current economic and regulatory environment. With higher energy prices and increasingly tight environmental regulations expected over the long term, an Energy Management solution can identify opportunities leading to improvements in energy efficiency and associated greenhouse gas emissions. The first step in developing an online Energy Management solution is to develop an Energy Dashboard to measure real-time energy consumption against a reasonable set of benchmarks. This involves capturing energy data related to the process and organizing it in a way that allows operations quickly to identify where the big energy consumers are and how well they are doing. To determine how well a plant or a unit is doing, it is necessary to be able to compare current energy use against a consumption target that reflects the current operations. Only then is it possible to do some analysis to determine the cause of deviations from target and take appropriate remedial action

Honeywell's Energy Dashboard improves energy efficiency in process plants by helping plant operators, engineers, and managers track actual and target energy. The Energy Dashboard calculates actual energy use, estimates the energy needed when operating efficiently, tracks energy metrics, highlights performance issues, and prepares regular statements of energy use. The Energy Dashboard gathers information from various instruments and systems to report energy and emissions consumption broken down by unit of major item of equipment. Capturing and analyzing this data allows users to understand Key Energy Indicators and how they affect overall energy consumption enabling users to establish specific goals for improving energy use and emissions reduction objectives.

This presentation will describe how the Honeywell Energy Dashboard works, a general implementation methodology, and potential benefits. It will not go into details on any specific component. The Energy Dashboard may be applied to individual units, areas of operation, or an entire plant.

ACHIEVING PROCESS ENERGY EFFICIENCY VIA INNOVATIONS

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This paper will describe a methodology that can be used to substantially improve industrial profitability and reduce CO2 emissions by unlocking energy savings opportunities. It will discuss how energy efficiency can be improved in existing facilities through relatively inexpensive capital and operational improvement projects. These projects can increase process unit heat recovery and typically improve energy efficiency by more than 10-15% energy savings. These savings can then be used to fund advanced technology capital projects that will provide additional savings of 5-10%.

EXERGY ANALYSIS AND HEAT INTEGRATION OF AN OXY-COMBUSTION PROCESS FOR COAL-FIRED POWER PLANTS WITH CO2 CAPTURE

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Oxy-combustion is a competitive technology to capture CO2 from coal-fired power plants. The core concept of this process is to use high purity oxygen instead of air for the combustion process so that the flue gas is composed mainly of CO2 and water. The CO2 can be separated simply by condensing the water and then purified by chilling. The cryogenic air separation process is selected since current state of the art indicates that this is the only oxygen production technology on such a large industrial scale. The power efficiency penalty of this process for CO2 capture is around 9% points, and this penalty is mainly caused by two units: the air separation unit (ASU) and the CO2 purification and compression unit (CPU). Each unit contributes similarly to the reduced power output.

This paper presents a detailed exergy analysis of an oxy-combustion process for coal-fired power plants with CO2 capture. The purpose of the study is to investigate the energy saving potential and heat integration opportunities of this process. The minimum theoretical work for the ASU and the CPU is calculated and compared with the actual work consumed for different purities of O2 and CO2. Exergy analysis can be an efficient way to study the causes of the reduced power efficiency in this case since the two units ASU & CPU do not involve any chemical reactions. An exergy flow chart for the entire process, which indicates the exergy losses, is presented and analyzed for process improvements.

A heat integration study is performed following the exergy analysis. Streams in two different temperature levels are investigated. The first one is the cryogenic level (-196 to 0ºC) existing in the ASU, the inert gases removal process of the CPU, and the CO2 liquefaction process by refrigeration (if ships are chosen to transport the CO2). The second one is the steam level (40 to 600ºC) existing in the air compressor, the CO2 compressor and the steam cycle. The energy consumption in each unit and the new power efficiency after integration are also presented. The work indicates various ways to mitigate the power efficiency penalty of this process related to CO2 capture.

EFFICIENT COMBUSTION - THE CHEMICAL ENGINEER'S QUEST?

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Much of our energy reserves are locked in the chemical potential of chemicals such as fossil fuels. The majority of CO2 emissions caused by human activities come from the combustion of these fuels. Typically the fuel is burnt with oxygen (air) and heat is released. This heat is then used to drive power cycles to produce, for example, electricity in a power plant or motion in the motor car engine. Very often we look at the efficiency of these process in terms of how much of the heat that is released in the combustion process can be turn into work. This however is not a very good representation of how efficient the process is, as an idealised Carnot engine is reversible and thus takes all the work potential (exergy) of the heat and converts this to work. Thus the Carnot engine might only have an efficiency in term of converting heat to work of 40%, but it is fully reversible and thus generates no entropy. Thus in effect the Carnot engine is 100% efficient.

However there is a much more fundamental efficiency that we should consider; namely how much of the chemical potential that was in the fuel are we able to turn into work. When we look at combustion processes in this way we see that some of the major inefficiencies are in the chemical transformations that produce the heat rather than in the power cycles that convert heat to work.

A very important question, perhaps in a sense the Holy Grail of chemical engineering, is can we do these transformations more efficiently and thereby conserve the work potential or chemical potential in fuel. We will show from a very fundamental thermodynamic analysis that it is not possible to combust carbon based materials efficiently, that is that the process of combustion of coal based materials is irreversibly, and about half of the chemical potential of the fuel is lost during the combustion process. However we will explore other substances or chemistries and show that some of these have the potential for more reversibly combustion. We will explore these options, what it means and how it could be implemented by looking at a coal based power plant as an example. In particular we will show that there is the potential to significantly reduce CO2 emissions by using different chemical pathways to do the combustion and by combining power and chemical production.

INTEGRATED ASSESSMENT OF STRATEGIES PROPOSED TO REDUCE CO2 EMISSIONS

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Carbon capture and storage (CCS) is considered a promising technology to mitigate anthropogenic greenhouse gas emissions. However, CCS currently faces multiple obstacles prior to being economically feasible. Among these challenges are the cost for CO2 separation, very limited parallel benefits, and the introduction of significant environmental risks. An economic comparison between the carbon avoidance of CCS and that of two alternative energy technologies has been performed here. It was found that, with a current estimate of the cost of CCS, wind energy avoids 190% more CO2 per dollar than CCS and nuclear energy avoids 430% more CO2 per dollar than CCS. These alternative energy technologies also generate profits, whereas profit potential for CCS is expected to be negligible. Based on these calculations, target costs of CCS that allow it to be competitive, on a carbon avoidance basis, with alternative energy technologies have been determined.

EFFICIENT SYNGAS TO ETHANOL TECHNOLOGY

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This presentation will highlight the successful application of Coksata's feedstock flexible ethanol production process at the company's semi-scale facility in Madison, Pennsylvania. The industry leading yield of the process will be illustrated with up-to-date data on ethanol productivity for the variety of feedstocks currently being tested at the facility, which include wood biomass, agricultural waste, sustainable energy crops, and construction waste. The presentation will also cite Argonne National Laboratory's GREET analysis of the process, as part of an overview on the emissions, energy efficiency, water use, and production cost advantages that Coskata's syngas-to-ethanol technology brings to the advanced biofuels arena.

LIFE CYCLE ANALYSIS OF OIL SANDS WELL-TO-WHEELS

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The starting point for determining the carbon intensity of a fuel is a well-to-wheels (WTW) life cycle assessment. This methodology evaluates the energy used and greenhouse gas (GHG)impact in each step from producing a crude oil or bitumen, converting it to transportation fuels, and consuming the fuel in a vehicle. This Life Cycle well-to-wheels Study compares WTW GHG emissions from producing transportation fuels from a representative basket of crudes and bitumens that supply US refineries.

HOW TO MAKE CEMENTS AND CONCRETES WITH LOWER CO2 EMISSIONS

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Although concrete is an intrinsically low-energy construction material with low manufacturing CO2 emissions per unit mass, it is produced in enormous volumes (about 10 cubic kilometres per year) to meet an ever-growing societal demand, so these emissions are nevertheless very significant globally. The main emissions source is in Portland clinker (PC) manufacturing, hence the desire to reduce the PC content per unit volume of concrete while retaining equivalent performance. There are two possible alternative approaches to this: either substitute some of the PC with less CO2-intensive materials that also have some activity as hydraulic binders in the PC/water system (i.e. supplementary cementitious materials - SCMs); or else replace PC completely with an alternative hydraulic binder. Most cement makers are currently adopting the first approach, making use of SCMs such as fly ash and glassy blast-furnace slag, which are considered to have low manufacturing energy costs and CO2 emissions by virtue of the fact that they are industrial by-products. However, their global supplies are limited and their quality tends to be very variable. Primary manufacture of similar SCMs would, of course, be far more energy- and CO2-intensive. Thus, the second approach is also pertinent. Possible alternatives include belite-sulfoaluminate clinkers, MgO-based binders, and alkali-activated aluminosilicate binders or 'geopolymers'. All of these approaches have their strengths and weaknesses but the high investment cost of new manufacturing plant suggests that systems that can be manufactured in existing plants are far preferable if a rapid change in technology is to be achieved. Evidently, cement and concrete norms and building codes will also have to be changed quickly, and this could be an even greater challenge.

MINIMIZATION OF EMBODIED ENERGY AND CO2 EMISSION IN REINFORCED CONCRETE

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Reinforced concrete is a widely used energy intensive composite material that offers a significant potential for embodied energy reduction. To create an effective incentive for CO2 emission reduction such emission can be penalized via a tax commensurate with the exceedance of an allowable emission limit. In an optimization approach aimed at satisfying both the requirements of efficient construction and effective carbon emission reduction it is appropriate to use an objective function consisting of the sum of two costs: (1) the cost of the reinforced concrete construction and (2) the tax aimed at limiting emissions. The objective function can be employed in simple problems, for example the design of simple prefabricated beams, or in problems of increasing complexity. These can include low-and mid-rise rise structures, for which the constraints pertain predominantly to material strength, or high-rise structures, where the constraints pertain to both strength and serviceability (building top floor accelerations and inter-story drift at each building floor). The proposed approach accounts for the typical recycling of reinforcing steel and of formwork, and offers the advantage that it also allows the same optimization procedure, with small, mathematically inessential changes in the form of the objective function, to be used for optimization with respect to cost, embodied energy consumption, and total costs including cap-and-trade taxes. Thus, much of the powerful apparatus already available or being developed for structural optimization can easily be adapted and used for the purpose of helping to reduce future emissions inherent in reinforced concrete construction. Our work includes the detailed description of the optimization procedure, requisite input from the embodied energy and cap-and-trade literature, examples of application to simple construction, and the the detailed description of the complex but highly effective approach applied to tall buildings, for which design is dominated by large numbers of strength and serviceability constraints.

COMPRESSION AND PUMPING TECHNOLOGIES AND EXPERIENCE FOR EOR/CCS APPLICATIONS

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In the arena of GHG abatement measures, the safe capture and re-injection of CO2 is identified as a large and effective technology. It represents a method that enables a continued use of fossil fuels, and it is strategically important as a bridge technology towards a lower carbon footprint economy. CO2 compression, liquefaction, and pumping are key technologies for EOR /CCS applications. A dedicated CO2 management system needs to be designed starting from a clear assessment of the gas properties (equation of state) and potential contaminants. GE has conducted an extensive experimental validation campaign to optimize the model. This knowledge allows an extremely efficient compressor and pump design able to handle both low-density, and dense supercritical CO2 covering a large range of pressures ranging from atmospheric up to more than 7250 psi which is required for some EOR applications. The proposed technical paper will investigate the CO2 transport chain to identify optimal, cost-efficient compression/pumping solutions for various scenarios according different CO2 mixtures. 1. Compression train can be used to reach the requested delivery pressure. All design aspects related to rotor-dynamics and bearings behavior validation through dedicated test will be shown. 2.Compression+pumping: according to boundary conditions (such as cooling media availability, temperature, chiller use), different options with the relevant existing experience will be evaluated Thanks to its domain expertise and portfolio on both compressors and pumps (unique among industry OEM) GE is able to provide an optimized CO2 management system with a compressor and/or compressor plus pump with the possibility to integrate them in a flexible system optimizing absorbed power and footprint.

IMPROVING EFFICIENCY OF FIRED HEATERS IN THE OIL REFINERIES

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Fired heaters are one of major energy consumers in the refining and petroleum industry. In the current scenario, it is important to maximize fired heater efficiency to the maximum practical achievable levels of 92%. Our field experience indicates that several heaters are operating at lower efficiency. There are two major approaches to improving the efficiency. First one is training the current operating working force and making minor changes in the equipment. This can improve thermal efficiency by 2-3% at a very low cost or not cost. Second approach is revamping the existing fired heaters.Revamping is a cost effective way to maximize fired heater efficiency: FIS has carried out several heater revamp projects in the past 5 years to improve heaters efficiency. We intend to present 2-3 case studies showing the systems approach taken during projects to help improve efficiency of heaters. We were able to improve the thermal efficiency of the heaters from 8% to 20%.