APPENDIX C
TOPIC PAPER ABSTRACTS

TRANSPORTATION DEMAND

Paper #1: Air Transportation Demand

Authors: *Air Travel Subgroup of the Demand Task Group*

This paper provides an overview and assessment of the long-term outlook for jet-fuel demand in the United States out to 2050, using the U.S. Energy Information Administration (EIA) 2010 Annual Energy Outlook (AEO2010) as the basis for evaluation. In particular, it addresses the key macroeconomic assumptions that drive future air traffic demand, the long-term traffic and capacity growth projections for both domestic and international operations from U.S. airports, the effect changing energy prices would have on these projections, how AEO2010 projections compare with industry expectations, and what issues may materially impact future jet-fuel demand.

After a review of the AEO2010 Reference Case projections for aviation, the paper provides an overview of the team's Travel Demand Model, which was developed based on the demand equation developed by the U.S. Commercial Aviation Partnership (USCAP) in consultation with the Transportation Security Administration (TSA). As expected, the team's model produced results that were in line with industry stakeholder expectations, projecting an average annual revenue-passenger-mile growth rate of 3.2% out to 2035, as compared to the AEO2010 projected growth rate of 1.4%. Higher traffic levels ultimately translate into greater jet-fuel demand, although that effect is dampened by expected fuel efficiency gains.

The paper then assesses the potential future impacts of alternative fuels, which are expected to become commercially viable in the aviation sector in the study time period. And finally, the paper assesses the potential future impacts of industry- and government-imposed restrictions on greenhouse gas emissions, which have the potential to materially impact the emission profile of the sector.

Paper #2: Rail Transportation Demand

Authors: *Rail Subgroup of the Demand Task Group*

The United States is served by the most efficient, affordable, and environmentally responsible freight-rail system in the world. The seven large Class I railroads, in conjunction with more than 500 local and regional railroads, carry 43% of intercity freight ton-miles—more than any other mode of transportation. This paper provides an overview and assessment of the long-term outlook for freight-rail demand in the United States out to 2050, using the U.S. Energy Information Administration (EIA) 2010 Annual Energy Outlook (AEO2010) as the basis for evaluation.

The paper begins with an overview of U.S. historical trends in freight-rail volume, fuel usage, and price, and continues with an assessment of the AEO2010 Reference Case for freight-rail demand relative to the expectations of the freight-rail industry. Noting that it is not possible to accurately predict freight-rail demand 40 years in the future, the paper then provides an overview of key determinants of future freight-rail demand. Key determinants will include possible increased economic and environmental regulations impacting the industry, possible regulation of the coal industry—which accounts for nearly 50% of Class I railroad tonnage—and possible modal shifts to freight-rail due to energy-consumption and environmental advantages.

The paper also assesses the potential impact of changing regulations regarding heavy-duty truck size and weight restrictions, possible increases in passenger-rail service, the potential for increased operational- and energy-efficiency of the rail system, and possible use of alternative fuels (e.g., electricity, natural gas, or biofuels). The paper concludes with alternative assessments of the potential future rail fuel consumption.

Paper #3: Truck Transportation Demand

Authors: *Truck Transportation Subgroup of the Demand Task Group*

According to a recent estimate, the total tonnage of primary freight shipments in the United States will increase from approximately 13 billion tons in 2009 to more than 16 billion tons in 2021—an increase of roughly 25% over 12 years. Trucks' share of this tonnage is expected to increase from 68.0% in 2009 to 70.7% by 2021. Based on these projections, the number of trucks, the miles driven, and fuel consumed is expected to increase in future years. This paper focuses on two policy areas where public policy changes could decrease the amount of fuel consumed by large trucks between now and 2050: state and national policy regarding use of higher productivity vehicles (HPVs), and national infrastructure policy related to congestion mitigation.

With respect to HPVs, the paper provides an overview of current and proposed regulation at the national and state levels, highlights the fuel economy benefits, and assesses the prospects for industry adoption of such vehicles. With respect to congestion mitigation policy, the paper summarizes the effect of congestion on fuel consumption and transportation costs, summarizes current and projected-future levels of congestion, and outlines steps that can be taken by policymakers to mitigate truck congestion.

VEHICLE PLATFORM TECHNOLOGIES

Paper #4: Alcohol Boosted Turbo Gasoline Engines

Authors: *Leslie Bromberg, Daniel R. Cohn, and John B. Heywood (Massachusetts Institute of Technology and Ethanol Boosting Systems, LLC)*

Alcohol boosted turbo gasoline engines are a low cost route to widespread incremental efficiency gains for light-duty vehicles. High-pressure turbo-charged gasoline engines can operate with up to 30% greater efficiency than naturally aspirated engines when combined with an alcohol boost that eliminates the engine knock constraints of high-pressure and high-torque operation. Alcohol is held in a separate tank and directly injected into the cylinders at a ratio of approximately 1% of the total fuel volume. The technology is cheap relative to diesel, as it avoids the need for costly exhaust gas after-treatment and fuel injection systems. The primary challenge is the requirement to periodically refill the alcohol tank, although analysis suggests this could be limited to a refill every 10,000 miles. Greater availability of E85 fueling stations would greatly facilitate the alcohol replenishment process.

Paper #5: The Connected Car: Smart Technologies to Reduce Congestion (Intelligent Transport Systems)

Authors: *Elaine C. Horn (Accenture) and Clay Phillips (General Motors)*

Congestion is a large problem in America's urban areas causing wasted time, money, and fuel. In addition to technology improvements to the traditional internal combustion engine (ICE) to improve fuel economy and reduce greenhouse gases, there are information and communication technologies that can also be incorporated into the vehicle and the surrounding transportation infrastructure to further improve fuel efficiency and reduce greenhouse gas emissions. The application of "telematics," or the integration of telecommunication and informatics, has created the potential for vehicles to communicate with road infrastructure, for vehicles to communicate with each other, and for vehicles to obtain information about the traffic environment in which they are operating. The primary benefit of "connected vehicles" is in ensuring that cars drive smoothly and safely and that traffic moves as efficiently as possible, thus reducing congestion. This paper provides an overview of the necessary technologies for an Intelligent Transport System (ITS) and highlights two case studies: Nissan's Eco Route in-car navigation system in Yokohama, Japan, and New York City's *Midtown in Motion,* a technology-based traffic management system used to monitor and respond to Midtown Manhattan traffic conditions in real time, improving traffic flow on the city's most congested streets.

Paper #6: Low Temperature Combustion

Author: *David E. Foster (Engine Research Center, University of Wisconsin – Madison)*

Compression ignition combustion processes with volumetric energy release, described as Low Temperature Combustion (LTC), is a potential thermodynamic pathway to maximizing the efficiency of internal combustion engines. The underlying objective of Low Temperature Combustion is to keep in-cylinder temperatures low through volumetric energy release via auto-ignition of dilute air fuel mixtures, as opposed to flame propagation. Because the energy release is volumetric, it is a challenge to operate at low loads with good combustion stability and at high loads without excessive rates of pressure rise. Strong progress is being made in addressing these challenges, but overcoming them will put additional burden on the gas exchange and control systems of the engine.

Paper #7: Mass-Market Adoption of Ultralightweight Automobiles

Author: *Amory B. Lovins (Rocky Mountain Institute)*

Weight is responsible for two-thirds of the energy requirements of a typical car, and therefore reduction in vehicle mass can significantly improve automotive efficiency. Advanced composites such as carbon fiber have been used in concept vehicles, and mid-volume production of carbon fiber cars from some manufacturers is anticipated in 2013. Many new processes for mass-production of carbon fiber are in development and prices are projected to fall to below $6/lb. Ultralightweighting will require a fundamental change in design approach for some auto makers, as a coordinated effort to reduce mass in the vehicle as a whole, rather than individual component design targets, is needed. Transition from production process based on metals to other materials involves a radical shift in supply chains for manufacturers, and will certainly meet resistance from metals suppliers. There will be significant scale-up challenges for manufacturing processes for products such as carbon fiber.

HYDROCARBON LIQUIDS

Paper #8: Production of Alternative Liquid Hydrocarbon Transportation Fuels from Natural Gas, Coal, and Coal and Biomass (XTL)

Authors: *David Gray (Noblis, Inc.) and Harold Schobert (Pennsylvania State University)*

Large domestic reserves of natural gas, coal, and biomass make technologies that convert these resources into hydrocarbon fuels highly attractive. A handful of commercial coal-to-liquid (CTL) and gas-to-liquid (GTL) plants are in operation today, mostly in South Africa and Qatar, demonstrating their technological viability. Many technologies to improve the processes are in development. The main challenges for U.S. adoption of CTL are technical barriers in coal gasification steps needed to facilitate capture of process carbon emissions, and the water usage requirements. GTL is inherently less carbon intensive and the technical risks lower. For coal/biomass-to-liquid (CBTL) plants, additional barriers include the high cost of biomass feedstock and supply chain logistics of co-feeding biomass into high-pressure gasification systems.

BIOFUELS

Paper #9: Analysis of the Fatty Acid Biosynthetic Pathway for the Production of Fuels in Genetically Engineered Bacteria

Authors: *Padma Sengodon and Dirk. B. Hays (Department of Soil and Crop Sciences, Texas A&M University, College Station, Texas), and Eric Steen (Joint BioEnergy Institute, Berkeley, California)*

Producing biofuels through the bacteria fatty acid biosynthesis pathway is a promising renewable fuel technology. Using bacteria as a host system can benefit from its well-understood fatty acid metabolic pathway, rapid growth rate, and efficient utilization of various biomass sources as feedstock. Key challenges faced by this technology include feedstock cost, productivity, and conversion efficiency. Advances in metabolic engineering and synthetic biology have helped to optimize the fatty acid synthetic pathway, to develop high yield host strains with industry scalability, as well as advanced feedstock. Fatty acids and their derivatives are valuable molecules for fuel and other industrial uses if the challenges can be overcome.

Many academic research programs are actively involved in fatty acid production for biodiesel and other fuel derivatives. Researchers are now focused on producing new fuel-generating microorganisms and characterization of genes for efficient and high yield production of desired fuel molecules using various advanced tools to make these fuels cost competitive with petroleum products. Multiple approaches are currently employed by start-up companies, and government support through policy initiatives and funding has dramatically increased the level of scientific research in this field. Future research is likely to be focused on generating advanced bacteria strains to maximize production yield through genetic engineering of the host metabolic pathway. If new research continues to maximize the yield of fatty acids, then the fatty acid pathway has the potential to serve as an important fuel in the future. With joint effort from government, academic institutions, and private companies, bacteria fatty acid derived biofuel can become cost competitive for commercialization.

Paper #10: Are We Going to be Able to Meet World Food and Biofuel Demands in 2050? (Long Term Food and Biofuels Projections)

Authors: *Swatilekha Bhattacharjee and John Miranowski (Department of Economics, Iowa State University)*

The growing world population and increasing biofuel consumption are increasing agricultural commodity demand for both food and biofuels. This has the potential to cause food and feed shortages. This paper evaluates the economic literature on agricultural crop production and demand projections to 2050. Based on an intuitive model and the literature projections, the paper discusses whether the long run supply will be sufficient to meet the growing agricultural crop demand in the presence of increased demand for biofuels.

Technological advancement will be the main factor affecting aggregate agricultural crop production and food availability in 2050. Though the expansion of arable land may play a major role in increasing production, most studies report that yield growth has more significant impact on production projections. The paper notes that world aggregate supply of agricultural crops will be more than world aggregate agricultural crop consumption in 2050. Although most projections conclude that world agricultural crop production will exceed world agricultural consumption, some studies anticipate significant malnutrition and undernourishment in 2050—especially in Sub-Saharan Africa—due to low yield improvements resulting from less biotechnology adoption and lower per capita income growth.

Production is significantly and positively affected by advancement and adoption of agricultural technology and all of the studies assume that adoption and application of yield-improving technology will further increase production beyond projected levels and will help keep food prices low. Investment in R&D for agricultural development and the adoption of agricultural biotechnology will help increase production beyond the predicted levels and reduce undernourishment. With the adoption of improved agricultural technology, increased use of biofuels will not pose a threat to the availability of food and feed crops.

Paper #11: Genetic Engineering to Add Traits Not Natural to the Feedstock

Author: *Tom Binder (Archer Daniels Midland Company)*

Until the global population stabilizes sometime in the latter half of this century, there will be a need for deployment of more intensive agricultural practices on all arable land. As a counterpoint to this, there will be simultaneous pressure to implement long-term sustainability practices to protect ecosystems needed for genetic diversity and to ensure ongoing health of farmland. Continued development of agronomic traits that provide more opportunities for integrated pest and weed management will be needed to overcome the development of resistance in nature.

With increased demand for agricultural and forestry output, research that focuses on productivity gains and cultural practices to promote those gains (while protecting the environment) will need to be supported at higher levels by both government and industry. Technologies proven to increase production while decreasing inputs will need continued public support for rapid deployment and adoption. Some of the traits relevant to yield improvements of both conventional and non-conventional crops include drought tolerances, water and nitrogen use efficiency, saltwater tolerance, and increased photosynthetic efficiency. While this list is not comprehensive, it does illuminate the extent to which an increased understanding of how natural adaptation of plants to every environment will help our agricultural and forestry industries develop crops for increased yields with less intensive inputs.

Paper #12: Macroalgae (Seaweeds)

Authors: *Julie Rothe and Dirk Hays (Department of Soil and Crop Sciences, Texas A&M University), and John Benemann (Benemann Associates)*

Macroalgae, or seaweeds, are carbohydrate-rich and have been studied as a potential source of energy since the late 1960s. While the claim of high biomass yields remains unproven, macroalgae have the advantage of not requiring any freshwater, land, or (potentially) fertilizer, and can be harvested relatively easily if near shore. Offshore cultivation has not been proven, poses a number of challenges due to open ocean conditions, and would require selection and genetic improvements of suitable species, as well as development of commercially feasible cultivation systems. For processing to ethanol or butanol, macroalgal polysaccharides need to be broken down to make them accessible for fermentation, and both of these processes would require development of specialized microorganisms.

Anaerobic digestion of macroalgal biomass would not require any pretreatment or bacterial selection, but gas scrubbing may be needed due to high sulfur content. The major challenge facing fuel production from macroalgae is the technical feasibility of off-shore cultivation and the economics of even near-shore production processes. This paper describes physical attributes and growth conditions of macroalgae and outlines their potential as a fuel by reviewing existing studies and literature. It also describes a number of recent projects on macroalgae-to-fuel pathways, and the challenges that the industry is facing at the conceptual stage.

Paper #13: Microbial Fuel Cells

Authors: *Padma Sengodon and Dirk Hays (Department of Soil and Crop Sciences, Texas A&M University)*

Microbial Fuel Cells (MFCs) are a carbon-neutral technology capable of converting chemical energy within organic substrate to electric energy using microorganisms as a biocatalyst. MFCs have potential applications including bioelectricity generation, wastewater treatment, and biosensors for pollution analysis. With recent advances in new types of MFC designs, electrode materials, microorganism/substrate optimization, and a number of pilot-scale demonstration projects, it is hoped that we may see MFCs deployed for commercial production in a few years in the area of wastewater treatment and energy production. However, remaining technical challenges, such as low voltage and scale-up cost, limits commercial application of MFCs. Future research should focus on improving power density, low cost implementation in large scale, and genetically engineered microbes to accelerate commercialisation of MFCs.

Paper #14: Separations Landscape for the Production of Biofuels

Author: *Jose L. Bravo (Royal Dutch Shell)*

The objective of the bio-separations paper is to survey the landscape of biofuels separations technologies, including current and emerging technologies in organic-water liquid separation, solid-liquid separation, and lipid removal via cell lysis. The paper also aims to assess the viability of such technologies and processes in practice, including any recommendations for specific processes. Some of the key challenges facing bio-separations today are that efficient and scalable solutions (in terms of materials and processes) do not currently exist, and that the maturity level of separations techniques for biofuel applications are still in developmental stages. Some of the most promising bio-separations technologies include hybrid systems composed of a combination of novel technologies with or without conventional separations techniques. In the case of removal of organics from water, particularly in the case of ethanol separation from dilute fermentation broth, the most promising technology is a hybrid solution involving membrane-based techniques (such as pervaporation) in combination with traditional techniques (distillation) with the ability to achieve up to 99.5% product recovery.

For solid-liquid separations, filtration systems prove favorable for the future, particularly VSEP technology as a promising dewatering technique.

For algae harvesting and lipid removal from algal cells, autoflocculation and supercritical extraction processes (e.g., supercritical CO_2 extraction) are considered key potential technologies. In summary, combinations or hybrids of novel and conventional separation techniques are recommended as potential solutions to overcome efficiency and scale challenges facing bio-separations. In addition, existing separations technologies used in other industries should be further adapted for use in biofuels applications.

Paper #15: U.S. Woody Biomass Yields at the State and Regional Level

Authors: *Jesse Caputo and Tim Volk (SUNY ESF)*

This paper highlights a number of tables detailing yield data for four of the most promising short rotation woody crops in the United States (willow, hybrid poplar, eucalyptus, and loblolly pine) within those regions of the country where each crop is expected to be grown. Experimental yields are reported, as well as the future potential yield in 2050 under each of two crop improvement scenarios: one in which improvements result in an average annual yield (AAY) of 2% and one in which AAY improvement is 4%. These crop improvement scenarios summarize possible yield improvements from improved culturing practices as well as from crop breeding and genetic improvements. For each crop, there are two tables: one summarizing information from trials in which neither fertilization nor irrigation were used, and one in which these more intensive practices were used. In addition, there is discussion of the role forest management activities in the United States have in creating biomass supply for use in energy production.

Paper #16: Yield Projections for Major U.S. Field Crops and Potential Biomass Crops

Authors: *Alicia Rosburg and John Miranowski (Department of Economics, Iowa State University)*

This paper summarizes the literature on potential yields for corn/soybeans/wheat (three major commodity crops in the Midwest United States), corn stover, and switchgrass/miscanthus. Using literature on expected yield increases, this paper provides projections for each crop out to 2030 and 2050 under various market scenarios and conditions. In its evaluation of global- and country-level crop yields, the paper notes that the specific yield projections assumed determines whether there is potential for yield gains to meet growing food, feed, and fuel demand or whether we are nearing a "technological plateau."

If global cereal yields remain on 1960–2009 linear trends, production will not be sufficient to meet growing demand and result in significant commodity price increases. On the other hand, an increase of only 0.4% in yield growth rates can reverse the expected price impacts. Although crop yields in general have seen continual increases over the past half century, it is important to recognize the potential limitations to future yield growth. Growth in agricultural productivity will require significant financial investment in research and development. Yield and ultimately food, feed, and fuel supply may be limited by hesitancy to fund or adopt biotechnology crops and therefore could be hindered by political or social resistance to new technologies. Given current yield trends and growth rates, agricultural production is expected to continue increasing in the near future but economic and social limitations may hinder the ability to meet growing food, feed, and biofuel feedstock demand.

ELECTRIC

Paper #17: Advanced Batteries: "Beyond Li-ion"

Authors: *William H. Woodford, R. Alan Ransil, and Yet-Ming Chiang (Department of Materials Science and Engineering, Massachusetts Institute of Technology)*

Despite the extensive progress made in research, development, and commercialization of lithium-ion batteries for transport, long-term vehicle electrification—especially affordable 200 mile all-electric range models—requires batteries with three times greater energy densities at approximately one-third of the cost per kWh. This paper explores technologies that have the potential to significantly disrupt the landscape, focusing on the potential impact of these technologies, their major challenges, and current research trends. The paper is divided into two core sections: Advanced Lithium Ion, which discusses research on new materials (e.g., advanced cathode and advanced anode materials) acting largely as drop-in replacements for conventional materials; and Beyond Lithium Ion, which discusses chemistries (e.g., metal air batteries) and new device architectures (e.g., flow systems) that are currently being researched to meet the long-term battery requirements of vehicle electrification. The paper concludes that improvements in the next five to ten years will largely be driven by discoveries in Advanced Lithium Ion, and that these batteries may well meet the targets set by the U.S. Advanced Battery Consortium (ABC) for PHEV40 models. Targets set for BEVs are more challenging to reach, however, and are more likely to be met by Beyond Lithium Ion research breakthroughs. The paper further concludes that, while significant materials-level improvements are required to meet ABC targets, these must be supported by improved cell-to-pack design efficiency through improved integration strategies that reduce the mass, volume, and cost of ancillary components.

Paper #18: Emerging Electric Vehicle Business Models

Authors: *Eric Cahill (Adaptiv Consulting), Mike Waltman (BetterPlace), and Elaine C. Horn (Accenture)*

The complexity and novelty of the electrification value chain—which merges the utility value chain with the automotive, battery, and charging infrastructure value chains—suggest a number of challenges as to how cost-effective business models will be defined and how electrification of the transport industry will be successfully delivered. Creative models are being devised to overcome key challenges related to technology cost, scale, and grid management, with different distribution of roles, responsibilities, and relationships across the industries.

These activities will expand traditional value chains, creating opportunities for incumbents and new market entrants. This paper covers two distinctly different charging infrastructure business models, both of which offer a comprehensive end-to-end solution for the customer. NRG's eVgo℠ offers customers a subscription model in which NRG acts as an end-to-end solution for installation, permitting, maintenance, and repair of charging equipment, as well as unlimited public charging for a fixed monthly fee. BetterPlace's comprehensive network operator model strives to seamlessly and simultaneously coordinate all aspects of the electric car ecosystem and provide range extension for electric car drivers through an electric car charging network and a switchable battery model.

Paper #19: The Interaction Between Plug-in Electric Vehicles, Distributed Generation, and Renewable Power (Electric Vehicles for Distributed Storage)

Authors: *Tim Brown and Scott Samuelsen (The Advanced Power and Energy Program, University of California, Irvine)*

Greenhouse gas emission reduction goals lead to an increase of intermittent renewable energy sources in the generation mix. The utilization of intermittent power sources can lead to supply disruptions on a number of timescales. Three solutions are available to mitigate these disruptions: load shedding, energy storage, and dispatchable power generation. Currently, there are various techniques for load shedding, distributed generation, and storage available to act as any of these. However, careful integration of transportation systems and the electric grid can allow vehicles to facilitate any or all of these intermittency solutions. Concurrently, the addition of clean, environmentally preferred distributed power generation can provide a more sustainable fuel for transportation.

Paper #20: Vehicle to Grid (V2G)

Author: *Gary Helm (PJM Interconnection, LLC)*

U.S. electricity infrastructure relies on competitive markets for energy, capacity, and ancillary services in order to obtain the lowest cost operation of the system. The technical specifications of EVs, more specifically the battery in the EV, allow for EVs to add value in the ancillary services market. There are six defined ancillary services, and EVs can add value to all of these by either stop/start charging or stop/start discharging. To achieve this, two-way communication is necessary between PEVs and an aggregator that can bring the functionality of the EVs to market. To achieve this, standard-based interoperability between vehicles, charging infrastructure, and network systems is necessary.

NATURAL GAS

Paper #21: An Initial Qualitative Discussion on Safety Considerations for LNG Use in Transportation

Authors: *Tom Drube and Bill Haukoos (Chart Industries), Peter Thompson (UC Berkeley/ Accenture), and Graham Williams (GPWilliams Consulting)*

The use of liquefied natural gas (LNG) as a transport fuel offers significant potential to reduce costs and emissions in the heavy-duty sector. The potential use of LNG in transportation has, however, raised public concerns over the safety of a cryogenic hydrocarbon fuel being stored and transported at significant scale on the nation's roads. Just as experience has led the public to accept the risk of diesel use due to its significant benefits, the relative risks and benefits of LNG as an alternative fuel option to diesel must be assessed. A qualitative assessment of LNG bulk transport, refueling site storage, and vehicle tank storage concludes that the additional risks of a cryogenic gas have led to more durable and robust storage materials and processes which often mitigate these risks.

Paper #22: Renewable Natural Gas for Transportation: An Overview of the Feedstock Capacity, Economics, and GHG Emission Reduction Benefits of RNG as a Low-Carbon Fuel

Authors: *Panel of Authors*

The paper provides a broad assessment of the potential for RNG as a transportation fuel in terms of feedstock capacity, cost estimates, and life-cycle greenhouse gas emission reduction. An analysis of the potential organic feedstock inventories in the United States indicates that approximately 4.8 tcf/ year of RNG is potentially available from domestic sources. This separates into approximately 0.5 tcf of liquid waste (e.g., municipal solid waste or farm manure), which can be converted into RNG using traditional anaerobic digestion, and approximately 4 tcf of drier waste such as energy crops and forestry/crop reside, which can be converted into RNG using emerging Thermal Gasification technologies. This is a significant potential, but does not consider the economic challenges that will reduce commercial production potential. The paper's findings highlight the potential 90% GHG emissions reductions over gasoline but notes the costs and challenges of upgrading the biogas to RNG for pipeline and vehicle use, and the competing use of the gas in power generation.

HYDROGEN

Paper #23: Development of Non-Precious Metal Catalyst for Oxygen Reduction in PEM Fuel Cells

Author: *Branko Popov (University of South Carolina)*

Due to the high cost and limited availability of platinum, there has been considerable research on non-precious metal catalyst alternatives. However, no alternatives to date fully meet the performance requirements due to: (1) low catalytic activity, (2) poor stability, (3) low selectivity toward four-electron reduction (producing too much hydrogen peroxide by-product instead of water), and (4) high electronic resistance. This review presents one potential disruptive catalyst: a new method for synthesis of nitrogen modified carbon-based catalysts. The synthesis process involves the modification of the carbon surface with nitrogen-containing organic precursors followed by heat-treatment at elevated temperatures.

HYDROGEN/NATURAL GAS

Paper #24: Advanced Storage Technologies for Hydrogen and Natural Gas

Author: *Peter Thompson (UC Berkeley/Accenture)*

Using current technologies, in order to store hydrogen or natural gas at sufficient volumetric energy densities for use as a transport fuel, these gases must be compressed or liquefied. Such storage presents a range of economic and technical challenges to widespread deployment, particularly critical infrastructure issues around compression and storage. Technologies that allow gas fuel storage at high densities, low pressures, and ambient temperatures would support low-cost home natural gas refueling systems and reduce land requirements for hydrogen refueling sites—a major infrastructure challenge.

This paper focuses on three storage methods: adsorption, absorption, and chemical storage. Adsorption research is focused on Metal Organic

Frameworks (MOFs) and Porous Aromatic Frameworks (PAFs) which achieve high storage levels but are still in materials research. Absorption research is focused on metal hydrides, with research assessing which metal-hydrogen compounds offer the greatest potential. Chemical storage is the most technically mature, with stationary systems being developed, but with practical performance challenges to overcome for transport use.

Paper #25: Hydrogen-Compressed Natural Gas (HCNG) Transport Fuel

Author: *Peter Thompson (UC Berkeley/Accenture)*

Use of HCNG blends in internal combustion engines has been the subject of a number of pilot projects that have sought to understand its potential to reduce emissions from CNG fleets, while also supporting deployment of hydrogen infrastructure for fuel cell vehicles. Studies to date have assessed both the optimal blend mix, as well as the emissions effects compared to pure CNG with a range of reported results. Overall conclusions suggest that blends between 8 and 20% hydrogen by volume offer the best emissions performance. Although emissions results have varied significantly, CO_2 emissions reductions appear relatively low (approximately 10%), but other emissions (e.g., NOx, SOx, particulate matter) appear to have been reduced more significantly.

NEW FUELS

Paper #26: Artificial Photosynthesis

Authors: *Victoria L. Gunderson and Michael R. Wasielewski (Department of Chemistry and Argonne-Northwestern Solar Energy Research Center, Northwestern University)*

Rising energy demand has driven the search for more cost-effective, carbon-neutral, and geopolitically favorable energy sources. Artificial photosynthesis is one of the technologies that have gained in research popularity given its potential to meet these criteria. Artificial photosynthesis is the direct conversion of solar energy into fuels through a fully integrated system. Applying the principles that govern natural photosynthesis to develop a man-made technology, it takes advantage of the efficient primary solar energy conversion steps of photosynthesis and produces fuel via two main pathways: carbon dioxide reduction to ultimately yield hydrocarbon, and water oxidation to generate hydrogen. This paper provides an in-depth overview of the technology, its challenges, and current research advancements with the potential to yield a step-change in development. The paper recognizes the revolutionary potential of artificial photosynthesis but stipulates that currently no comprehensive and cost-effective artificial photosynthetic system exists, and that the technology will remain in the research and development stage in the near term (an estimated five years). The paper further concludes that future progress is heavily reliant upon intensified research efforts, and ultimately upon the discovery of new materials and catalysts to support the production of efficient, scalable and sustainable solar fuels that are economically viable.

GREENHOUSE GASES AND ENVIRONMENT

Paper #27: Carbon Capture & Storage (CCS)

Authors: *Robert Bailes (ExxonMobil), Steve Crookshank (API), and Nick Welch (GCCSI)*

This paper provides an assessment of the role that carbon capture and storage (CCS) could play as a technology to reduce GHG emissions over the next four decades in the United States. It concludes that CCS is a promising technology to mitigate GHG emissions from stationary sources on a substantial scale, though with significant barriers to overcome for widespread deployment. In particular, the cost remains high: there is both a high cost of capture in most sectors near to medium term and substantial infrastructure investments needed for gathering and injection of CO_2. Other prerequisites to successful deployment are a clear direction for climate policy, flexible regulatory frameworks with clear authorities, appropriately skilled technical personnel requirements, and public awareness and acceptance.

Enhanced oil recovery (EOR) can be an enabler for CCS demonstration, but potential EOR storage capacity is limited relative to total stationary source emissions. In reviewing CCS application across various sectors—including natural gas processing, coal power, gas power, refining, biofuels manufacturing, hydrogen production, oil sands production, and natural gas production—it is shown that costs and component technologies vary widely between industry sectors and are not directly applicable to each other. Overall, the greatest long-term opportunity for CCS is in the coal- and gas-fired power sector.

Paper #28: Criteria Air Pollutants

Authors*: Karen Hamberg (Westport Innovations), Don Furseth (Acorn Solution Development Services)*

On-road vehicles, marine engines, rail locomotives, and aircraft are sources of criteria air pollutant (CAP) emissions that affect air quality and impact human health. The primary CAPs of concern associated with transportation are ozone and particulate matter. Criteria air pollutants are emitted in the entire fuel cycle from resource extraction through fuel production, storage, distribution, dispensing, and vehicle operation and are dependent on the vehicle/fuel systems. The well-to-wheel CAP emissions of vehicle/fuel systems differ significantly in terms of amounts, the fuel type under consideration, and method of production.

This paper reviews the contribution from transportation for each CAP and the numerous regulatory, technological, and voluntary mechanisms that have been introduced to reduce CAP emissions from the transportation sector including the Clean Air Act, the EPA fuel and vehicle standards (e.g., the Tier 2 Vehicle and Gasoline Sulfur Program), and the new proposed CAFE standards. An analysis was performed using GREET 1.8d to compare 2020 CAP emissions of the fuel-vehicle systems in the study to a 2005 gasoline vehicle CAP emissions on a per-mile basis.

Paper #29: Greenhouse Gas Life Cycle Assessment/Analysis

Author: *Mike Leister (Marathon Petroleum Corporation)*

Life Cycle Assessment/Analysis (LCA) is a methodology that seeks to examine and estimate the impacts of a manufacturing/production/utilization pathway or process over its entire life span from cradle to grave. LCA can be applied to all aspects of manufacturing/production/utilization pathways including energy usage/production, environmental emissions/impacts, costs, water usage, etc. This paper provides an overview of LCA models available, and how the FTF study utilized the **G**reenhouse Gases, **R**egulated **E**missions, and **E**nergy Use in **T**ransportation (GREET) model developed by Argonne National Laboratory.

Paper #30: Data Variability and Uncertainty in Greenhouse Gas Life Cycle Assessment

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Life cycle analysis (LCA) is a computational approach based on models and available data. Like other models (e.g., economic, meteorological), these calculations are not perfect. Given this propensity for variability, researchers suggest the use of uncertainty bars for each pathway to represent both uncertainty and variability, and argue that life cycle GHG inventories for transportation fuels be presented as ranges rather than absolute values. This approach provides the researcher or policy maker with an indication of those areas or key variables in the model where additional data or new model approaches are required in order to make informed decisions. This paper provides an overview of the drivers of uncertainty as well as various analysis options—such as process models or Monte Carlo analysis—and presents a range of GHG emissions reported by several studies. The paper also highlights how the uncertainty for GHG LCA can increase dramatically when indirect impacts are considered, such as indirect land use change (ILUC), and provides several studies that compare the results for GHG LCA with and without ILUC.

Paper #31: Water Usage

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Water availability is an essential part of the fuel life cycle, from feedstock production to conversion to final fuels and power. While water consumption for fossil fuel and electric power production is a relatively small portion of total fresh water consumed in the United States, there are a number of challenges facing water management for energy production. In addition to quantifying volumes of water for different fuel options, the quality of water is also an important concern.

Water consumption for this report is considered on a life cycle analysis basis. Water consumption for a given energy feedstock can vary significantly depending on feedstock production technology (e.g., electricity from various sources, biofuels from agriculture, oil production by primary recovery vs. waterflood, or gas production by primary recovery vs. hydraulic fracturing). Similarly, the process configuration of a fuel manufacturing facility or power plant impacts net water consumption. This includes the choice of cooling technology, plant operating conditions (e.g., power plant operating temperature), and extent of internal recycling of water.

This paper compares water consumption requirements for relevant fuels and includes a comparison of Fresh Water Consumption (gallons/MMBTU) by Well-to-Tank Hydrocarbon Transportation Fuel Pathways (including conventional and unconventional oil and gas pathways) and a discussion on key activities within the pathways for water use and reuse. Multiple biofuel pathways were also evaluated for consumptive water use in feedstock production and conversion to fuels in the biofuel value chain. The paper also compares the water use characteristics of various methods of power generation including Life Cycle Water Consumption (gallons/MWh). Finally the paper provides a comparison on the basis of gallons used per distance traveled in selected fuel/vehicle systems.