**DRAFT PROPOSAL**

**AN ASSESSMENT OF THE FUTURE OF DROP-IN FUELS**

Principal Investigators:

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Prepared for:

State of California Air Resources Board

Research Division

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Check if applicable:

Animal subjects \_\_\_\_\_\_\_

Human subjects \_\_\_\_\_\_\_

**TABLE OF CONTENTS**

[I. Abstract 3](#_Toc347213558)

[II. Introduction 4](#_Toc347213559)

[III. Objectives 5](#_Toc347213560)

[IV. Technical plan 6](#_Toc347213561)

[Task 1 – Technology Information Gathering 7](#_Toc347213562)

[Task 2 - Technology Analysis 7](#_Toc347213563)

[Task 3 – Identification of Additional Research 9](#_Toc347213564)

[Task 4 – Identification of Barriers to Technology Success 9](#_Toc347213565)

[Task 5 – Technology Monitoring and Tracking Strategy Development 9](#_Toc347213566)

[Task 6 – Draft Final Report 10](#_Toc347213567)

[Task 7 – Amend Final Report 10](#_Toc347213568)

[Deliverables 10](#_Toc347213569)

[Facilities and Other Resources 10](#_Toc347213570)

[V. Project schedule 12](#_Toc347213571)

[VI. Curricula vitae or résumés of the key scientific personnel 13](#_Toc347213572)

[Scott Samuelsen 13](#_Toc347213573)

[Ashok Rao 15](#_Toc347213574)

[VII. Preliminary cost proposal 18](#_Toc347213575)

# Abstract

The ARB adopted the Low Carbon Fuel Standard (LCFS) regulation in January 2010 aimed at reducing greenhouse gas (GHG) emissions from the transportation sector in California by about 16 million metric tons (MMT) in 2020. This corresponds to almost 10 percent of the total GHG emission reductions needed to achieve the State’s mandate of reducing GHG emissions to 1990 levels. The LCFS will also reduce California’s dependence on fossil fuels such as petroleum, creating a market for clean transportation technology while stimulating the production and use of alternative, low-carbon fuels not only in California but also nationally for other states and internationally for other countries since California usually sets the precedence for new clean air performance standards.

Advances in the synthesis of fuels derived from renewable feedstock are essential for California to meet these climate change and air quality goals. The technology and infrastructure needed to develop commercially available renewable fuels still requires significant research, however. Renewable fuels that require the least modifications to the existing infrastructure and vehicle fleet are thus drop-in fuels (i.e., those fuels that are nearly identical to fossil-derived gasoline and diesel). Accordingly, the objectives of this study are to address the techno-economic feasibility and environmental impacts associated with producing such drop-in fuels on a commercial scale.

Process technologies for the production of these drop-in biofuels are in various stages of development and in certain cases have reached a level where pilot- and demonstration-scale plants are being constructed. Potential technology pathways include:

* Upgrading alcohols to hydrocarbons
* Catalytic conversion of sugars to hydrocarbons
* Fermentation of sugars to hydrocarbons
* Hydrotreating algal oils
* Upgrading of syngas (CO and H2) from gasification
* Pyrolysis or liquefaction of biomass to bio-oil with hydroprocessing.

The required primary goals for this study to meet the overall objectives are:

* Technology Information Gathering
* Technology Analysis
* Identification of Additional Research
* Identification of Barriers to Technology Success
* Technology Monitoring and Tracking Strategy Development.

Results from successfully achieving the above goals will provide data that will influence LCFS policy by playing a key role in supporting development of lower-carbon fuels which would be of benefit to regulated parties under the LCFS as well as to California consumers. Furthermore, in the longer term, this data could inform many other initiatives of the ARB that might support the need for drop-in fuels.

# Introduction

The ARB adopted the LCFS regulation in January 2010 aimed at reducing GHG emissions from the transportation sector in California by about 16 MMT in 2020 which corresponds to almost 10 percent of the total GHG emission reductions needed to achieve the State’s mandate of reducing GHG emissions to 1990 levels. The LCFS will also reduce California’s dependence on fossil fuels such as petroleum, creating a market for clean transportation technology while stimulating the production and use of alternative, low-carbon fuels not only in California but also nationally for other states and internationally for other countries since California usually sets the precedence for new clean air performance standards.

The LCFS which is designed to provide a durable framework using market mechanisms to spur the steady introduction of lower-carbon fuels, establishes performance standards that fuel producers and importers will have to meet each year beginning in 2011. Separate standards are established for gasoline and for diesel fuels and the alternative fuels that can replace them to achieve an average 10 percent reduction by 2020 in the carbon intensity of the statewide transportation fuels mix.

The advantages of drop-in hydrocarbon biofuels are that they are substantially similar to gasoline, diesel, or jet fuels and can be made from various types of biomass feedstocks including crop residues, woody biomass, dedicated energy crops, and algae. Since the drop-in fuels meet existing diesel, gasoline, and jet fuel quality specifications, they would be ready to be "dropped-in" to existing infrastructure. This would minimize any compatibility issues with respect to infrastructure, which otherwise would be a major barrier to the fast commercialization of biofuels. Cases of such non drop-in fuels would be ethanol and bio-diesel. Currently, drop-in fuels are in a research and development phase with pilot- and demonstration-scale plants under construction and the current focus is aimed at replacing diesel and jet fuel, which typically fuel vehicles that are not good candidates for electrification.

There are different pathways to creating a drop-in fuel and researchers are exploring a variety of technology approaches.

Potential technology pathways include:

* Upgrading alcohols to hydrocarbons
* Catalytic conversion of sugars to hydrocarbons
* Fermentation of sugars to hydrocarbons
* Hydrotreating algal oils
* Upgrading of syngas (CO and H2) from gasification
* Pyrolysis or liquefaction of biomass to bio-oil with hydroprocessing.

In summary, the benefits of drop-in fuels include:

* Engine and infrastructure compatibility since these fuels are expected to be substantially similar to their petroleum counterparts.
* Increased energy security since these fuels can be produced domestically from a variety of feedstocks and also contribute to U.S. job creation.
* Less GHG emissions since the CO2 is captured by growing the feedstocks.
* More flexibility since these fuels would be replacements for diesel, jet fuel, and gasoline allowing for multiple products from a variety of feedstocks and production technologies.

The Advanced Power and Energy Program (APEP) of the University of California, Irvine (UCI) has conducted several techno-economic feasibility studies for the U.S. Department of Energy as well as industry clients, including those in particular for the production of synfuels using different types of biomass as one of the feedstocks. Furthermore, one of the proposed principal investigators, Dr. Ashok Rao has taught a graduate level course at UCI on the subject of sustainable energy technology and is currently authoring a text-book style book under contract with John-Wiley & Sons on the subject of sustainable fuels technology. Furthermore, Dr. Rao’s real world experience gathered while working in industry for 30+ years will be crucial for the successful execution of this project. One of the areas of research of the other proposed principal investigator, Professor Scott Samuelsen is directed to renewable production of electricity and transportation fuels, and the systems integration of emerging advanced energy technologies. In addition, he has taught thermodynamics for energy systems for number years at UCI. Thus the APEP team is well qualified in successfully delivering the required results for the ARB.

# Objectives

Advances in the synthesis of fuels derived from renewable feedstocks are essential for California to meet its climate change and air quality goals. The technology and infrastructure needed to develop commercially available renewable fuels still requires significant research, however. Renewable fuels that require the least modifications to the existing infrastructure and vehicle fleet are thus drop-in fuels. Accordingly, the objectives of this study are to address the techno-economic feasibility and environmental impacts associated with producing these fuels on a commercial scale. The study will provide data essential to influence and shape the LCFS policy. This data could also support other climate change initiatives within California and world-wide, the Federal Renewable Fuels Standard, and long-term air quality projects.

There are several longer-term goals that will also benefit from the data generated by this study. A necessary step in attaining the state’s air quality and climate goals is the reduction in emissions from the transportation sector while biofuels will be needed to achieve long-term energy and climate goals in this sector, especially for aviation, shipping, and heavy-duty and off-road vehicles that cannot be easily electrified.

# Technical plan

Process technologies for the production of drop-in biofuels consisting of gasoline and diesel are in various stages of development and in certain cases have reached a level where pilot- and demonstration-scale plants are being constructed. Some of these potential technology pathways are:

1. Upgrading alcohols to hydrocarbons. One process consists of passing the alcohols through a fluid bed reactor containing a zeolite catalyst at moderate temperatures of 300° to 400°C and under pressure to achieve 95% conversion of the methanol feed to hydrocarbon products including gasoline boiling range products, and ultimately fractionation to separate the various products.
2. Catalytic conversion of sugars to hydrocarbons. The processing steps include pretreatment/fractionation of the bio feedstock, hydrogenation of the non-lignin fractions, aqueous phase reforming of the resulting oxygenates under moderate temperatures and pressures of 175° to 300°C and 10 to 90 bar, followed by acid catalyzed dehydrations / condensations.
3. Fermentation of sugars to hydrocarbons. One process strategy for the fermentation of lignocellulosic sugars is based on a class of compounds called isoprenoids. A 15-carbon isoprenoid called farnesene can be converted to diesel fuel.
4. Hydrotreating algal oils. Microalgal oils contain fatty acid and triglycerides which can be converted into alcohol esters (i.e., biodiesel) using conventional transesterification technology. Alternatively, the oils can be used to produce a diesel product by catalytic hydroprocessing. An advantage with this second approach is that it minimizes the oxygen content of the final fuel while maximizing its energy content.
5. Upgrading of syngas (CO and H2) from gasification. Both Fe and Co catalyst based Fischer-Tropsch processes for the conversion of syngas with the suitable CO to H2 ratios have been proven commercially for production of straight chain hydrocarbons such as diesel fuel and jet fuel. Production of gasoline, however, requires normally a multi-step process in which the syngas is converted to methanol, methanol to dimethyl ether (DME), and DME to gasoline. Creating a single-step process in which these functionalities may be combined in a single reactor with a multifunctional catalyst bed while achieving high CO conversion and good product selectivity would be highly desirable to increase efficiency and reduce capital cost.
6. Pyrolysis or liquefaction of biomass to bio-oil with hydro-processing. The processing steps include fast pyrolysis to a highly oxygenated liquid product, hydrotreating of this fast pyrolysis oil to a stable hydrocarbon oil with less than 2% oxygen, hydrocracking of the heavy portion of the stable hydrocarbon oil, distillation of the hydrotreated and hydrocracked oil into gasoline and diesel fuel blendstocks, and also H2 production to support the hydrotreater reactors.

The study will be initiated by conducting a kick-off meeting with the ARB staff where the methodologies for executing the various tasks will be presented and the study plan will be discussed in detail. Next, to meet the overall objectives described in the previous section, the following primary goals for this study are defined as five study tasks:

## Task 1 – Technology Information Gathering

This initial task consists of gathering existing information related to production of renewable drop-in fuels by the various technology pathways by conducting a literature review as well as by contacting technology developers and licensors where necessary. This task will also make an assessment to establish if data are available for Life Cycle Assessment (LCA) of these technology pathways and their related costs and environmental impacts. Where gaps in data exist, APEP will fill in the necessary data during Task 2 as explained in the following.

## Task 2 - Technology Analysis

The initial step in performing this task will consist of a techno-economic assessment of each of the technologies at a screening level in order to identify the more promising technologies. Recommendations will be made to the ARB regarding these promising technologies selected and upon ARB’s concurrence, the more detailed assessment of these selected technologies for techno-economic feasibility, costs, and environmental impacts at both demonstration and commercial scale will be developed. Process configurations including the unit operations and unit processes for each of the selected technologies will be critically reviewed while corresponding stream data when available will be analyzed to verify that not only the laws of thermodynamics are not violated but also are consistent with prudent real world engineering practices. Dr. Ashok Rao’s real world industry experience will be crucial for the successful execution of this task in particular.

Next, an estimate of where each of the facilities could potentially be located in order to maximize production while minimizing environmental impacts will be made. For example, the plant facility may be stand-alone or co-located at a petroleum refinery where there are multiple places for the drop-in fuels to be inserted into the refinery process. Another criterion that would be important is the proximity of location of the fuel production facility in relation to its feedstock(s) sources. Once, the material stream and energy requirement data are established, environmental impacts will be assessed on a life cycle basis.

The evolution of new technologies allows a special opportunity for the application of LCA in order to guide the evolution and avoid paths that could lead to less than

satisfactory results. Technologies that are directed to increase energy efficiency, reduce the emission of criteria and other pollutants, and reduce the emission of greenhouse gases are especially suitable for LCA analyses. Assessment of the complete set of energy and environmental impacts of any new technology cannot be accurately made without a proper LCA analysis. In addition to the operation and performance of a technology, LCA considers the full spectrum of impacts from the specification and extraction of raw materials, to the manufacturing of the physical facilities, to the operation and use of the facility, to the disposal (and, to the extent possible, recycling) of the facility. APEP has been engaged in LCA for stationary fuel cells, and has evaluated the LCA implications for hydrogen-fueled internal combustion engines and fuel cell vehicles from a well-to-tank, and tank-to-wheels perspective with emphasis on four key indices: (1) energy consumption (i.e., energy efficiency), (2) emission of criteria pollutants and other key pollutants (e.g., mercury, arsenic), (3) emission of greenhouse gases, and (4) costs. The LCA for this ARB study will be accomplished using the well-regarded SimaPro software package that provides a professional tool to collect, analyze and monitor the environmental performance of products and services. This software package allows simulation and analyses of complex life cycles in a systematic and transparent way, following the ISO 14040 series recommendations.

The process stream data when developed by APEP (i.e., when such data is not available in the public domain), will utilize a predictive computer simulation technique to perform the material and energy balances. The primary material and energy balance code will be Aspen Plus®. Steady state simulations would be developed using thermodynamic models (with approaches to equilibrium specified) where appropriate. The following specific modeling guidelines would be applied to the overall plant system:

* The “plant” will include all necessary support facilities and will include the feed processing, product conditioning / stabilization as required depending upon where and if the drop-in fuel is inserted into the refinery process, losses associated with raw water and boiler feed water treating, condensate handling, and general facilities such as waste water treating and cooling water system.
* Overall performance summaries will be developed taking into account the power generation by each equipment and the power consumed by the plant.
* Heat loss, blowdown amount, pressure drop, mechanical efficiency, auxiliary and miscellaneous power and cooling water requirements will be taken into account for each equipment or plant section.

An overall block flow diagram will be developed showing all major streams labeled and an accompanying table will provide stream data such as composition, flow rate and conditions of pressure and temperature.

Overall plant facility cost estimates when developed by APEP will utilize “in-house” techniques and will factor in any technology licensor/developer provided data. The in-house cost estimates for a major subsystem involved in the estimate will be developed from known cost for a similar system or a factored analysis based on sizing of major equipment. These two types of methodologies will be employed depending upon the type of unit and availability of data in APEP’s in-house data base as well as that available in the public domain.

* Capacity Factored Estimates: These types of estimates are based on multiplying the cost of a unit for which the direct construction costs are known by the ratio of the new unit’s capacity to the capacity of the known unit. Capacity ratios are adjusted by an exponent chosen on the basis of the unit type. The costs are adjusted for design differences, location and time frame.
* Equipment Modeled Estimates: These types of estimates for each mechanical equipment item will be developed utilizing Aspen Costing module which is a part of the Aspen Suite of products. The bare equipment cost as well as the various other associated costs such as piping, instrumentation, foundations etc. are also estimated by this software.
* Vendor Supplied Estimates: Vendors or technology licensors will be provided functional specifications where necessary to obtain individual equipment costs or plant section or subsystem turnkey cost estimates but will be critically reviewed for their reasonableness.

Capital requirements, operating and maintenance costs will be developed to assist in the techno-economic analyses of these facilities and will take into account the projected plant efficiency and cost of produced products, and environmental signature with the ultimate goal of assessing the potential impacts of integrating emerging technologies in the production of drop-in fuels from bio sources.

## Task 3 – Identification of Additional Research

The next task initiated will consist of identifying any additional areas of research to facilitate the growing need for data related to technological advancement, costs, and environmental impacts. An outline will also be developed to include the role universities could play alongside industry in conducting any required additional research.

## Task 4 – Identification of Barriers to Technology Success

Barriers can be technical or economic in nature and can include challenges in the supply of feedstocks or in the conversion technology itself. Accordingly, this task will consist of identifying barriers to the success of these technologies for the production and supply of the drop-in fuels, and where applicable, strategies to overcome these barriers will be identified.

## Task 5 – Technology Monitoring and Tracking Strategy Development

Since these process technologies for the production of the drop-in biofuels are in various stages of development, the next task will consist of developing a strategy to monitor and track progress of these technologies at the various stages as well as supplies and costs.

## Task 6 – Draft Final Report

This task by drafting the final report will document findings of the study for each of the above tasks and will be issued to ARB staff six months prior to contract expiration. The report will be issued electronically in the Microsoft Word format and will include:

* An executive summary
* Introduction
* Study approach
* Design basis
* Results and discussion of Tasks 1 through 5.

## Task 7 – Amend Final Report

The final task consists of amending the draft final report issued under Task 6 to incorporate comments provided by the ARB staff and will be issued prior to contract expiration.

## Deliverables

The following deliverables will be developed during the course of this study:

1. Quarterly progress reports
2. Final report
3. Additional deliverables to be determined in consultation with ARB staff.

## Facilities and Other Resources

The offices, reception, public information, and project planning requirements of APEP are headquartered in a 6,500-square-foot space in the Engineering Laboratory Facility. The APEP is designed around a matrix of four areas of focus: (1) Research, (2) Beta Testing, (3) Education, and (4) Technology Transfer. The Facilities have been established to accommodate each of these focus areas. All of the Facilities support the current project. Some have more tangible and direct support, while others support the project indirectly. Presented in the following is the description of the facilities that will directly support the project. Those that will have a profound but indirect support to the proposed study and a general description of the APEP Facilities are included under the section titled “Equipment.”

The facilities that are directly supporting the proposed research are (1) the modeling and computational resources, and (2) the multi-functional center. The modeling and computational resources will contribute to the tasks presented in the Technical Plan and include:

* Process system computer simulation programs such as:
  + ASPEN Engineering Suite of products which includes ASPEN PLUS® for steady state simulations, ASPEN Dynamic for dynamic simulations and ASPEN COSTING for equipment sizing and costing
  + Advanced Power Simulation Analyses Tool or APSAT, a proprietary model for analyses of advanced energy systems
* Life Cycle Assessment program:
  + License for SimaPro software package will be reacquired
* Other tools if required:
  + Computational Fluid Dynamics (Fluent, Fluent-UNS, CFD Ace+)
  + Chemical Kinetics
  + Dynamic Systems Modeling.

Workstations are equipped with Dell Precision T7600 with a 3rd generation Intel Xeon processor (dual CPU, Quad Core E5-2643) and 24 GB RAM running Windows 7 Professional 64-bit Operating system.  The system is capable of processing large data sets with SSD and fast SAS hard drives utilizing the latest SAS/SATA controller and nVidia Quadro FX5800 graphics card. The system is built to run compute-intensive applications that require intense use of graphics, and both integer and floating-point performance.

High Performance Computing (HPC) resources are available to UCI researchers. HPC resources include facilities at UCI, within UC ("Shared Clusters"), and through national super-computing services such the San Diego Supercomputer Center (SDSC) at UC, San Diego, and at other affiliated universities.  A “Cluster” consists of combining independent computers into a unified system through software and networking and is typically used for high availability, for greater reliability and for high performance computing to provide greater computational power than a single computer can provide.

The multi-functional room is equipped with the latest in tele-conferencing and internet interaction. This capability will serve as the heart of both the management of the various team members, and the technical exchange among the team members. UCI’s Department of Computer and Information Science is a national leader in the evolution of internet software with particular attention to interactive capabilities. The project could potentially benefit from these resources as well.

The tools for acquiring, archiving, and distributing information regarding advanced energy systems are critical elements to technology advancement. The APEP has set aside 2,200 square feet of information exchange and meeting space to accomplish effective technology transfer. The infrastructure that is provided includes a Web site, a training center, an exhibition center, and industrial office space.

Industrial members and other industrial participants in the APEP activities are provided office space to accommodate the need to work closely with and include the participation of the industry in the conduct of Research, Development and Demonstration activities at the APEP. These office spaces are private and equipped with telephones and telecommunication access.

Equipment. The unique composition of activities at the APEP will contribute to the proposed program. In addition to the research conducted at the APEP facility, the daily visits of the marketplace representatives from both national and international locations provides a novel opportunity to assess the market interest, the market potential, and the market liabilities. As a result, this unique mix of activity, bridging research to the market, provides an invaluable dimension of information, understanding and perspective in support of the proposed program. The technical staff and students at APEP, in addition to having the theoretical background required for conducting this study also have the “hands-on” experience with process equipment which is essential for configuring realistic, controllable and reliable plants while having a true appreciation for the technical challenges imposed by a new configuration. The following describes the APEP facilities where these hands-on activities related to advanced energy systems are acquired (in addition to any industry experience that a staff member or student may have):

Research. Sixteen indoor test cell sites and outdoor testing space is allocated for the testing and research of prototype advanced power and energy technologies. The stands are all designed to accommodate both conventional and laser diagnostic methods.

Beta Testing. The Beta Testing of equipment at APEP supports multi-month to multi-year testing of prototype units. It provides critical feedback to the manufacturer prior to commercial launch and determines performance, reliability, and the success of human engineering. The process allows for the demonstration of reliability while concurrent system improvements are made in an objective yet scrutinizing research setting. Furthermore, insight and perspective into the limiting science are provided that, when addressed, could significantly affect the evolution of advanced technology. Research projects are identified by the APEP technical staff through a bridging that promotes interaction between the university, the manufacturer, and the user.

# Project schedule

The project schedule is presented in Figure 1 on the last page of this document.

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# Curricula vitae or résumés of the key scientific personnel

## Scott Samuelsen

Director

National Fuel Cell Research Center

Professor of Mechanical, Aerospace, and Environmental Engineering

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Professor Scott Samuelsen is Director of the National Fuel Cell Research Center (NFCRC) on behalf of the U.S. Department of Energy and the California Energy Commission, co-Chair of the California Stationary Fuel Cell Collaborative in conjunction with the California Air Resources Board, a Professor of Mechanical, Aerospace, and Environmental Engineering, and a Henry Samueli Endowed Chair at the University of California Irvine (UCI). He directs as well the UCI Advanced Power and Energy Program (APEP). His research is directed to building integration and utilization of distributed generation, renewable production of electricity and transportation fuels, gas turbine combustion systems for propulsion and power generation, fuel cells and fuel cell systems for stationary applications fuel cell/gas turbine hybrid technology, the hydrogen infrastructure for mobile hydrogen-fueled combustion and fuel cell vehicles, the systems integration of emerging advanced energy technologies, and the smart grid paradigm. He directs research on advanced coal, natural gas, and biomass power plants for the co-production of electricity and hydrogen, distributed generation in support of energy-efficient and environmentally-preferred power generation, plug-in and battery electric vehicles, hydrogen-fueled vehicles, the nexus of electricity, transportation, and water, and smart grid technology. Professor Samuelsen pioneered the development of octane posting with the Federal Trade Commission and is responsible for the popular (R+M)/2 posting methodology that is utilized around the world today in the design of internal combustion engines and vehicle fuels. He received the Ph.D. degree from the University of California Berkeley in 1970, and is a Fellow in the American Society of Mechanical Engineers.

EDUCATION:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Degree | | Year Conferred | | | Major | | University | |
| Ph.D. | | 1970 | Mechanical Engineering | | University of California, Berkeley | |
| M.S. | | 1965 | Mechanical Engineering | | University of California, Berkeley | |
| B.S. | | 1964 | Mechanical Engineering | | University of California, Berkeley | |

PROFESSIONAL EXPERIENCE:

Jul 70-Present Professor (Assistant, Associate, and Full), Mechanical, Aerospace, and Environmental Engineering, UCI.  
Research in energy systems, fuel cells, combustion, hydrogen, and the environment.

Jul 72-Jun 83 Founder and Chairman, Mechanical Engineering, UCI.

Sep 65-Sep 70 Research Scientist, Stanford Research Institute

Research in structural response to impulsive x-ray induced loads in a vacuum.

Jun 64 – Aug 65 Research Engineer, Lawrence Livermore National Laboratory

Research in initiation of nuclear fission reactions.

RECENT PEER-REVIEWED PUBLICATIONS (Over 250 total):

1. Experimental and Theoretical Evidence for Control Requirements in Solid Oxide Fuel Cell Gas Turbine Hybrid Systems (2012). Journal of Power Sources (in press), Dustin McLarty, Yusuke Kuniba, Jack Brouwer, Scott Samuelsen.
2. Performance and Costs of Advanced Sustainable Central Power Plants with CCS and H2 Co-Production (2012). Applied Energy, 91, pp. 43-50, Mu Li, Ashok Rao, and Scott Samuelsen.
3. Diurnal Temperature and Pressure Effects on Axial Turbo-Machinery Stability in Solid Oxide Fuel Cell-Gas Turbine Hybrid Systems (2011). ASME Journal of Fuel Cell Science and Technology, Vol. 8, pp. 031012-1 to 031012-6, James D. Maclay, Jacob Brouwer, and G. Scott Samuelsen, June.
4. An Experimental Ignition Delay Study of Alkane Mixtures in Turbulent Flows at Elevated Pressure and Intermediate Temperatures (2011). ASME Journal for Gas Turbines and Power, Vol. 133, pp. 011502-1 to 011502-8, D.J. Beerer, V.G. McDonell, G.S. Samuelsen, and L. Angello.
5. Effects of Carbon Capture on the Performance of an Advanced Coal-Based Integrated Gasification Fuel Cell System (2011). Journal of Power and Energy, Vol. 225, Issue 2,   
   pp. 208-218, Mu Li, A. D. Rao, J. Brouwer, and G. S. Samuelsen.

RECENT RECOGNITION

1. UCI Medal, University of California, Irvine (October 2010)
2. Champions of Change, White House (November 2011)

PROFESSIONAL AFFILIATIONS

1. Registered Professional Engineer (PE), Mechanical Engineering, State of California
2. Fellow, American Society of Mechanical Engineers (ASME)
3. Secretariat, Institute for Liquid Atomization and Spray Systems (ILASS-Americas)
4. Member, ASME, ILASS, American Institute for Aeronautics and Astronautics, The Combustion Institute, Sigma Xi, Pi Tau Sigma

PATENTS:

1. Lean Burn Injector for Gas Turbine Combustor, No. 5,477,685, 26 December 1995
2. Optical Patternation Method, No. 6,734,965, 11 May 2004

SELECT SYNERGISTIC ACTIVITIES:

1. Principal Investigator on contracts and grants with agencies (U.S. Department of Energy, California Energy Commission, California Public Utilities Commission, U.S. Department of Defense, U.S. Environmental Protection Agency, National Science Foundation, South Coast Air Quality Management District, Air Products) and industrial sponsors (Toyota, General Motors, General Electric, Siemens Power Generation, Parker Hannifin, Southern California Edison, Southern California Gas) that include strategic alliances.
2. With the Chairman of the California Air Resources Board, Co-Chair of the California Stationary Fuel Cell Collaborative.
3. The NFCRC and APEP both engage collaborations with academic, agency, and industry partners to address the paradigm shifts associated with (1) the generation of electricity,   
   (2) building efficiency and the integration of distributed energy resources (DER) into the built environment, and (2) the transformation of the mobility fuel and vehicle markets.

## Ashok Rao

Chief Scientist, Power Systems

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Dr. Ashok Rao’s research expertise and contributions in advanced and alternative energy technologies, while minimizing the impact on the environment, address today’s major global challenge: to protect the environment while delivering a plentiful supply of clean, low-cost energy that is essential to maintaining economic prosperity. His research interests and contributions to a more complete solution of energy sustainability include alternative energy as well as advanced energy technologies. Alternative energy refers to the energy derived from sources that do not use up natural resources or harm the environment such as biomass fuel derived from agricultural wastes. Prior to joining UCI, Dr. Rao had worked in industry for more than 30 years in the energy conversion technologies area. His work included all phases of energy systems development starting from process conceptualization to techno-economic feasibility studies to detailed design. This combination of real world engineering expertise and his strong understanding of the underlying physics and chemistry make Dr. Rao very unique. The various publications appearing in technical journals, the presentations made at the various technical conferences and the number of patents granted attest to this unique expertise and creativity that Dr. Rao brings to the very important field of energy. Due to his leadership role and expertise in energy technology, he was made a director in Process Engineering at Fluor Corp. where he worked for 25 years and his responsibilities included directing the development of a variety of energy conversion processes while minimizing the impact on the environment, for electric power generation as well as the production of hydrogen, synthesis gas, Fischer-Tropsch liquids, ammonia, alcohols and dimethyl ether from coal, petroleum coke, biomass, liquid hydrocarbons and natural gas; and the conversion of alcohols to higher value products. He was honored by Fluor and by the California Engineering Council in 1994 for his pioneering work in the advancement of energy systems including his work on the Humid Air Turbine (HAT) cycle, a major internationally acknowledged achievement, by making him a Fellow. He was later made a Senior Fellow at Fluor for continuing his significant contributions in the area of energy.

EDUCATION:

* Ph.D. Mechanical Engineering from University of California - Research in Advanced Energy Systems
* M.S. in Chemical Engineering from Washington State University - Research in Partial Oxidation of Coal
* B. S. in Chemical Engineering from Osmania University

PROFESSIONAL LICENSE/CERTIFICATE:

Registered Chemical Engineer, California No. CH4346

HONORS:

* Was made a Senior Fellow at Fluor for expertise and making significant contributions in energy systems.
* Was honored by the *California Engineering Council* for pioneering work in the advancement of energy systems.
* A keynote speaker at the 2011 *International Conference on Applied Energy,* Perugia, Italy.
* Authored chapter titled, "Gas-fired combined-cycle plants," for a book: *Advanced power plant materials, design and technology*, Woodhead Publishing.
* Authored chapter titled, "Coal and Biomass based Integrated Gasification Combined Cycle," for *Encyclopedia of Energy Engineering,* Taylor & Francis Books.
* Authoring book on sustainable energy systems under contract with John Wiley & Sons.
* Editor and authored chapters for titles, *Combined cycle systems for near-zero emission power generation,* under contract with Woodhead Publishing.
* Associate editor for ASME *Journal of Engineering for Gas Turbines and Power,* March 2007 – Dec 2008.

SUMMARY OF EXPERIENCE:

University of California, Irvine (2004 to present).Chief Scientist for Power Systems at the Advanced Power and Energy Program of the University of California. Involved in the development of coal and biomass based energy efficient and cost effective sustainable power systems for central station as well as for distributed power generation that involve fuel cells, gas turbines and/or organic Rankine cycles. Also involved in the development of systems for converting fuels such as coal and biomass into synthetic fuels and petrochemicals.

Fluor (1979 to 2003).Director in Process Engineering till accepting the position at the University of California. Responsibilities included the design and development of a variety of energy conversion processes including gasification for electric power generation as well as the production of hydrogen, synthesis gas, substitute natural gas, Fischer-Tropsch liquids, ammonia, alcohols and dimethyl ether from coal, petroleum coke, biomass, and hydrocarbon feedstocks; and conversion of alcohols to higher value products.

Allis-Chalmers (1977 to 1979).Process Development Engineer on a coal gasification combined-cycle plant. Responsibilities included gasifier design, scale-up of test data and detailed design of a demonstration plant.

McDowell Wellman (1974 to 1977).Research Engineer in the energy conversion and minerals processing fields that included gasification (Wellman-Galusha moving bed gasifier), pyrolysis, biomass conversion, oil shale retorting, calcination of minerals, and direct reduction of iron ore and red mud (in the solid phase) with hydrogen and carbon monoxide. Responsibilities consisted of process development including tube and bench scale test work, analysis and scale-up of test data, pilot plant design and operation.

PATENTS:

1. “Humid Air Turbine Cycle with Carbon dioxide Recovery,” U.S. Patent No. 7,637,093 dated December 29, 2009.
2. “Configuration and Process for Gasification of Carbonaceous Materials,” U.S. Patent No. 6,648,931 dated November 18, 2003.
3. "Process for Making Ammonia from Heterogeneous Feedstock," U.S. Patent No. 6,086,840 dated July 11, 2000.
4. "Integrated Drying of Feedstock in IGCC Plant," U.S. Patent No. 5,685,138 dated November 11, 1997.
5. "Process and System for Producing Power," U.S. Patent No. 5,181,376 dated January 26, 1993.
6. "Method and Apparatus for improving the efficiency of Humid Air Combustion Turbine Cycle," U. S. Patent No. 5,160,096 dated November 3, 1992.
7. "Reactor/Expander Topping Cycle," U.S. Patent No. 4,999,993 dated March 19, 1991.
8. “Process for Producing Power," U.S. Patent No. 4,289,763 dated May 16, 1989.
9. "Method for Producing Pelletized Fixed Sulfur Fuels," U.S. Patent No. 4,111,755 dated September 5, 1978.

SOME TECHNOLOGY ASSESSMENT JOURNAL AND CONFERENCE PAPERS:

1. “An evaluation of advanced combined cycles,” *Applied Energy*, in press.
2. “Performance and Costs of Advanced Sustainable Central Power Plants with CCS and H2 Co-production,” *Applied Energy*, Vol. 91, pp 43-50, 2012.
3. “Gas Turbine based High Efficiency ‘Vision 21’ Natural Gas and Coal Central Plants," *J. of Power and Energy,* Vol. 219, Part A, 2005.
4. "Power Plant System Configurations for the 21st century," *Proceedings of the ASME IGTI Turbo-Expo Conference*, June 2002.
5. "Mitigation of Greenhouse Gases from Power Plants," *Energy Convers. Mgmt.,* Vol. 37, Nos. 6-8, 1996.
6. "An Evaluation of Advanced Gas Turbine cycles," *Proceedings of the ASME Power-Gen '93 Conference*, November 1993.
7. "A Technical and Economic Evaluation of the Humid Air Turbine Cycle," *Proceedings of the* *Seventh Annual International Pittsburgh Coal Conference*, September 1990.
8. "Perspective for Advanced High Efficiency Cycles using Gas Turbines," *Proceedings of the EPRI Conference on Technologies for Producing Electricity in the Twenty-First Century,* October, 1989.

# Preliminary cost proposal

The estimated cost breakdown by task is presented in Table 1 below. As indicated, UCI will cost share one graduate student for the term of the program for a projected total cost of $126,300 over the three years. This results in UCI requiring a funding in the amount of $582,232 from the ARB.

**Table 1: Estimated Study Costs**



**Figure 1: Project Schedule**

