**TECHNICAL PROPOSAL**

*THE FEASIBILITY OF RENEWABLE NATURAL GAS AS A LARGE SCALE, LOW-CARBON SUBSTITUTE:*

*An Optimization Scheme to Reduce Criteria Air Pollutant and GHG Impacts*

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January 29, 2013

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# Abstract

This work focuses upon the development and analysis of a novel optimization tool that integrates with the state-of-the-science air quality simulation tool CMAQ as a means for assessing the optimal use of renewable resources to meet the Low Carbon Fuel Standard (LCFS) in order to provide a determination of its feasibility. This unique tool will automate the recursive aspects of identification and optimal design of networks of production facilities and fuel transportation routes to maximize renewable resource use and minimize environmental impacts. Criteria that may be established for the optimization include co-location of feedstock resources and production facilities, minimization of health effects, minimization of impact on local areas’ ability to meet national air quality attainment standards, and concurrent maximization of production with minimization of emissions. A thorough literature review will be incorporated to understand the requirements and limitations of the LCFS, the operational characteristics of the applicable renewable gas technologies, the current and projected future state of the market for renewable natural gas, and the life cycle emissions signatures for certain technologies considered. The information gathered by this phase will serve as the basis for the input files utilized in the airshed modeling and optimization phase. An interface between the air quality model and the purpose-built optimization scheme will be developed. This Optimizing Automated Tool for Maximizing Environmental Advantages of the LCFS (OATMEAL) will include routines for reading input and output data related to CMAQ, modifying the input data, and evaluating the output data on the basis of the selected optimization criteria and routines. The majority of the optimizations will be performed considering installed and proven renewable technologies; however, a few optimizations will explore the potential impacts of emerging technologies. Once the optimized production and transport networks are developed, local air quality impact assessments will be presented in order to provide a multi-faceted assessment of the feasibility of meeting the LCFS with renewable technologies and positive air quality impacts. Additionally, the most prevalent technologies within and across optimized networks will be identified and life cycle analysis (LCA) accomplished to provide an estimate of life cycle costs that may be expected for a renewably-generated LCFS. The coupled air quality optimization and LCA study will provide launching points for re-evaluation of the language and technical definitions of the LCFS itself. The focus will be to enable reductions in Carbon Intensities and the merit criteria for Deficit and Credit calculations by optimally guiding simplification of fuel production pathway definitions. The research will provide a comprehensive view of the feasibility of the LCFS, guidance for attaining its goals on statewide and more local scales, to introduce long-term sustainability, and the potential for improvement of the standard itself.

# Introduction

Renewable resources have the potential to contribute significantly to energy and environmental quality. Some renewable resources, such as wind and solar resources, are more likely to be applied in the electric power sector of the California economy while other renewable resources, such as biomass and biogas, have the potential to be converted into electric power, heat, or fuels for transportation. Use of these precious renewable resources in the California economy is governed by a complex set of integrated energy conversion, transmission, and transportation processes. These renewable resource conversion processes ultimately result in the emission of spatially and temporally distributed criteria pollutants and greenhouse gases in various amounts depending upon the suite of technologies and infrastructure used in each case. These complexities, coupled with the non-linear atmospheric chemistry and transport that ultimately determine air quality impacts make it quite challenging to determine the best use of renewable fuel resources.

Furthermore, in an effort to minimize its greenhouse gas impact, the state of California is in the process of pursuing the development of transportation fuel stocks with lower carbon intensity than conventional options. There is also a clear desire to achieve this goal without compromising other aspects of air quality and environmental stewardship. While renewable resources may become substantial and sustainable contributors in a statewide low carbon fuel production network, the local and statewide impacts of conversion from feedstock to usable transportation fuel are unknown. An optimization tool that considers and rigorously analyzes the potential impacts of various scenarios for renewable resource use to meet the Low Carbon Fuel Standard (LCFS) is needed.

One of the renewable fuel resources to consider is biogas, a mixture of methane and carbon dioxide that is typically derived from the biological breakdown of organic matter and water. Significant amounts of biogas can be extracted from landfills, wastewater treatment plants, and dairy farms. There are over 80 landfills with over 20 million tons of waste dumped each year in the South Coast Air Basin of California (SoCAB) alone [1]. Landfills comprise the second largest contributors to methane emissions in the U.S., which provides motive to better capture landfill gases to reduce greenhouse gas impacts, and to better use the resource as a fuel. Wastewater treatment plants are another source of useful biogas. A recent APEP study determined that more than 11.2 MMSCFD (million standard cubic feet per day) of landfill gas and 7.5 MMSCFD of anaerobic digester gas are produced in SoCAB alone [1]. Additional renewable biogas is available from dairies, food processing facilities, and other agricultural processes that use anaerobic digestion.

These precious renewable resources could be used to produce heat locally, or to produce electric power by combustion or conversion in a fuel cell system, or they could be converted into a fuel for transportation as part of the strategy for meeting the LCFS. In addition, further into the future, when nearly carbon-free options like solar and wind power become ubiquitous, otherwise curtailed solar and wind-sourced energy could be stored or converted into a transportation fuel (e.g., hydrogen for fuel cell vehicles). Each of the potential scenarios for conversion, transport, and use results in value added products and a varied and diverse set of criteria pollutant and greenhouse gas emissions. A tool that helps determine the best use of these resources is needed.

**Reference:**

[1] Brown, Tim M., Margalef, Pere, and Samuelsen, G. Scott, “SoCAB Fuel Cell Vehicle Fleet Projections, Biogas Resource Potential, and Preliminary Hydrogen Infrastructure Plan,” Final Report, Shell Hydrogen Program, Grant # 59880, December, 2010.

# Objectives

The proposed project focuses on the development and analysis of a number of renewable natural gas production networks within the state of California. The proposed networks will be designed and evaluated on the basis of a set of optimizing criteria, including co-location of feedstock resources and production facilities, emissions of various greenhouse gases and criteria pollutants, and health effects on the public. The networks to be analyzed will arise from a systematic optimization scheme, but will first undergo a design process that will qualify potential facilities and locations for consideration in the networks based upon realistic assumptions and according to strict industry, economic, and feasibility criteria. The team assembled for the program has more than 10 years of experience in developing realistic scenarios for future energy and environmental technologies upon which these networks will be developed. [2-5] The networks will then play a central role in the broader goal of providing an analysis of the feasible implementation of the currently-written Low Carbon Fuel Standard within California and the ability to maintain this goal sustainably and without secondary harm to the environment from feedstock production. Thus, along with a thorough literature review of the wide array of germane topics, three major research and analysis endeavors will be accomplished in this work: regional and statewide spatially-and-temporally-resolved airshed modeling, Life Cycle Analyses of select technologies identified throughout the course of research, and a critical review of the technical definitions and structure of the LCFS policy itself as described in the following objectives:

1. Develop a thorough understanding of the Low Carbon Fuel Standard (LCFS), technologies that may aide in meeting the standard, and the current state of the renewable natural gas production and transportation fuel use. Focus upon implications for operation and decisions that may be made in the system-wide design processes of the major transportation fuel providers.
2. Understand the air quality and GHG impacts of including various types and numbers of renewable natural gas production facilities in California, using the insights and data to determine the optimally-designed structure of a renewable natural gas infrastructure network according to a number of separately analyzed optimization criteria.
3. Complete a Life Cycle Analysis of the technologies that prove to be potentially the largest contributors to California’s renewable natural gas infrastructure and develop recommendations of the technologies that will likely provide the greatest benefit in the most sustainable manner for the state of California. Determinations must be made on the basis of both maximized potential for volume production and improvements in air quality and GHG emissions.
4. Re-analyze the LCFS documentation and wording in the context of the results from Objectives 2 and 3 in order to provide suggestions for potential challenges in meeting the LCFS and possible improvements to the accounting methods previously developed.

**References:**

[2] Rodriguez, M.A., Carreras-Sospedra, M., Medrano, M., Brouwer, J., Samuelsen, G.S., and Dabdub,   
D., 2006. *Air Quality Impacts of Distributed Power Generation in the South Coast Air Basin of California 1: Scenario Development and Modeling Analysis*, Atmospheric Environment, Volume 40, Issue 28, pp. 5508-5521.

[3] Stephens-Romero S.D., Carreras-Sospedra M., Dabdub D., Brouwer J., Samuelsen G.S., 2009. *Determining Air Quality Impacts of Hydrogen Infrastructure and Fuel Cell Vehicles*. Environmental Science Technology. 43, 9022-9029.

[4] Vutukuru S., Carreras-Sospedra M., Brouwer J., Dabdub D., 2011. *Future Impacts of Distributed Power Generation on Ambient Ozone and Particulate Matter Concentrations in the San Joaquin Valley of California.* Journal of the Air & Waste Management Association. 61, 1319-1333.

[5] Medrano, M., Brouwer, J., Carreras-Sospedra, M., Roriqguez, M.A., Dabdub, D., and Samuelsen, G.S., 2008. *A Methodology for Developing Dsitributed Generation Scenarios in Urban Areas Using Geographical Information Systems*. International Journal of Energy Technology and Policy. 6, 413-434.

# Technical Plan

The four Objectives will be met by the completion of seven Tasks. The identification of the tasks and their correlations to the Objectives are Provided in Table 1. The significant role of computer modeling and simulation is apparent given its contribution meeting two of the four Objectives and completing five of the seven Tasks. Most of the Tasks can be completed in numerically ascending order. The flow of the proposed work is presented in Figure 1. In particular, Objective 1, related to the literature review, is comprised of two tasks; Task I is to be completed at the initiation of the project to obtain all required data to inform the development and implementation of the proposed airshed modeling; Task V is then proposed to be completed later during the project, informed by the results provided by the airshed modeling itself. In addition, the results of the airshed simulation will provide key data not only for the determination of technologies to include in the LCA analysis but also for the final Task of determining alterations to the LCFS that may be necessary to ensure feasibility of the standard in California. Details of the work to be completed within each of the Tasks are presented below.

Table 1: Organization of Project Tasks to Meet Objectives

|  |  |  |
| --- | --- | --- |
|  |  | **TASKS** |
| **OBJECTIVES** | 1) Literature Review | I) Background Literature Review  V) Select Technology LCA Review |
| 2) Airshed Simulation | II) Simulation Scenario Definition  III) Scenario Analysis Tool Development  IV) Simulation and Detailed Analysis |
| 3) Life Cycle Analysis | V) Select Technology LCA Review  VI) Select Technology LCA Analysis |
| 4) Policy Review | VII) Identify Barriers within LCFS via  Synthesis of Tasks IV and VI |



Figure 1: Flow of Progress in Completing Project Tasks

1. Literature Review

The proposed work will bring together information and expertise from a wide range of related, though differing, fields of study within the general scope of energy production and environmental quality. It will therefore be necessary to capitalize on knowledge and expertise of the proposed project leads and staff as well as information available from a wide range of sources. With the appropriate effort and attention given to a thorough and fully detailed literature review, the modeling and analysis Tasks that follow will provide more accurate and insightful determinations and conclusions regarding the feasibility and impacts of the LCFS.

* 1. Low Carbon Fuel Standard

At the commencement of the project, it will be particularly important to complete a thorough **review of the LCFS** itself and become familiar with the technical details, especially the definitions of all technical terms and calculations centering on the Carbon Intensity (CI) and Deficit/Credit calculations.

* + 1. Technical Definitions

A detailed understanding of the technical development of multiple facets of the LCFS will be particularly crucial in the completion of the later modeling-related Tasks. The foremost issue to address will be an understanding of the Carbon Intensity (CI) calculations themselves and the development of the values through the prior modeling work that generated the values. This will aide in designing production networks that will be analyzed for the ability to meet various future target levels of CI. Related to this review will be a full identification of the technologies that meet the standards defined by the language in the LCFS. Qualifying pathways and corresponding CI values are numerous in the standard and it will be necessary to properly assess the full range of technologies with claims to renewable natural gas production and discern between them on the basis of the technologies that are most readily applicable to meeting the standard’s goals.

* + 1. Reduction of Complexity

As mentioned, the pathways for which CI values have been determined are particularly extensive. While such detailed specification is required for the proper understanding and application of the regulation, it is likely that this research project’s modeling efforts will be greatly aided by a reduction in the complexity of the pathways considered. Thus, an effort will be made to develop a condensed but representative model of the LCFS as it will apply to the potential fuel production technologies most likely applicable to the analysis for California.

Reductions in the complexity of the definitions will take place via identification of the most prevalent and likely pathways from the provided options for alternative fuels and combination of pathways that are sufficiently similar. Determination of similarity may be based on any of the following criteria: similar values of the CI presented, similar pathways of resources, or distinctions between resource pathways that are viable for actual regulation but may not be distinguishable during the current work with available information regarding the currently-operating qualifying technologies. Any simplification of the standard’s rules that result from the completion of this task will not be done blindly; all proposed simplifications will be re-evaluated for the implications they may have on the feasibility of the modified standard meeting the original goals of the standard.

* 1. Conventional Gas Production

Given that the LCFS describes the CI to be determined at the level of a gas producer and/or distributor’s full product pool average, it is necessary to **review the conventional** **transportation and natural gas formulation and distribution** **industries**. This effort will provide context for the definitions and goals of the LCFS but will also be crucial to the eventual evaluation of analyzed production networks’ ability to meet the CI goals. The following three major areas of research will receive primary attention.

* + 1. Formulation

A major focus of the proposed project is the analysis of the regional air quality and local health implications of the inclusion of proposed renewable natural gas production networks into the transportation fuel system of the state of California. As such, it will be necessary to have detailed information regarding the emissions of all fuels and technologies considered. Emissions from the production of different fuels, or even fuels of the same classification but different grade, can be expected to vary significantly. Given that the LCFS does not aim for a total replacement of transportation fuel production with options with lower CI, the conventional gases, their formulations, and their emissions signatures must be known for a sufficiently detailed air quality simulation to be realized. Information regarding the conventional transportation fuel production facilities will then be utilized to modify emissions inventories utilized in each of the analyses of fuel networks.

* + 1. Distribution

Another major feature of this work is the analysis of the full life cycle of the fuels that are used for transportation. For both conventional and any proposed new renewable installations, it can be expected that the distribution of the fuel (and likewise, the fuel’s production resources) will play a major role in the full LCA. Additionally, it is likely that any new fuel production facilities will not be able to significantly alter the structure and design of the current distribution system. Thus, it will be necessary to investigate the structure and extent of the current distribution systems. This will include both the distribution systems for conventional transportation fuels as well as the same for the current natural gas pipeline system within California. Analyses will include information regarding distribution by pipeline, truck, and rail.

* + 1. Operating Capacities

In order to evaluate any given producer/distributor’s ability to meet the CI standards (and thus the statewide feasibility), it will be necessary to know the current volumes of the fuels that are produced both within and outside of the state of California. Initially, this information will provide a basis on which to determine the total production quotas of renewable natural gas that must be met with the proposed production networks. However, this step will also provide essential data for evaluating each analyzed scenario’s ability to meet the LCFS itself.

* 1. Renewable Gas Production

Similar to the review of the conventional gas production system, it will be necessary to **review the full breadth of** **technologies that qualify as renewable natural gas producers**. Emphasis will be placed on the technologies that are currently in operation or in the final stages of development and therefore likely to be available to the marketplace within the timeframe of jurisdiction of the LCFS. Technologies in use within the entire United States will be included in the review, especially since technologies operating in other regions of the country may prove to be the most likely to be reasonably included in the designed renewable production networks.

* + 1. Applicable Technologies

The most important task will be to first build from the previously-discussed review of the LCFS to identify and collect information regarding all the renewable technologies that will qualify for the pathways specified. This review of technologies will include selection of a subset of technologies that can reduce the complexity of the LCFS. It will be necessary to collect information regarding potential production capacities of the technologies, the related requirements for feedstock materials and other resources during the production process, and the expected emissions profiles per volume of fuel produced.

* + 1. Current Sites

In all proposed production network designs, it will be necessary to include any currently-operating renewable production facilities within California. Thus, it will be necessary to catalog all of these facilities in California that are of significant size to be included in modeling and simulation efforts. Additionally, it will be necessary to catalog as many of the same facilities nationwide as can be identified. This will help provide perspective during the network design phase as to the relative viability and development stage of the various renewable technologies.

* + 1. Long-Term Technologies

Finally, while the focus of the work will be upon the design and analysis of production networks that have a high likelihood of being installed and utilized within the near-term timeframe of the LCFS, it will be useful to also investigate other, more nascent technologies. Recognition and investigation of these more experimental technologies will provide a means to assess the possibilities for years in the timeframe of 2020+ so that contextual inferences can be made as to the potential of the currently-available options. Any inferences made regarding networks developed for such long-term scenarios will be regarded as more highly uncertain and will not receive the full LCA and policy review but will still be reviewed as a specialized case study.

* 1. Gas-Fueled Fleet

In order to develop an appropriately realistic set of simulation scenarios, it will be necessary to **compile a catalog of the current** **conventional and alternative fuel driving fleet**. In particular, data related to fuel consumption and the driving fleet within California powered by various forms of conventional and alternative fuels will be utilized in conjunction with fuel production quotas to determine the required capacity of the new fuel sources introduced in the modeling Tasks of the project.

* + 1. Conventional

For the purposes of this project, various graders of in-compliance gasoline and diesel fuels will be considered the “conventional” fuels. These fuels are characterized by their long history of widespread utilization and the expectation that their continued use will play a large role in the driving fleets of the coming decades. As such, their inclusion in the simulation efforts is necessary. Well-documented and widely accepted resources (e.g., the EMFAC, MOBILE6, and MOVES models [6-8]) will be utilized to catalog the current driving fleet within the state of California according to the vehicle type (light duty vs. heavy duty, public vs. private, on-road vs. off-road, etc…) as well as representative emissions values within typically of vehicles within the fleet of a given categorization.

* + 1. Current Alternatives

In order to assess the LCFS, it will be necessary to develop a full compilation of the alternative fuel driving fleet within the state of California. Both the fuel consumption/fleet size data for the conventional and alternative fuel classes will be utilized to develop the full quota of renewable natural gas resources. Prior work by Sierra Research Projects completed for the Southern California Gas Company will serve as a springboard for this compilation [9]. However, that work was mostly focused on vehicles that burn natural gas onboard. The project’s scope will be large enough to include other vehicles that incorporate electric power from both onboard and offboard conversion of fuel. Thus, Plug-in Hybrid Electric Vehicles (PHEV), Battery Electric Vehicles (EV), Fuel Cell Vehicles (FCV), and Fuel Flexible Vehicles (FFV) will be at least considered for inclusion depending upon the relative role they will be forecast to have over the course of the LCFS legislation. Along with inclusion of these vehicles, it will be necessary to determine the methods by which electric generation to power vehicles can be accounted for in the LCFS, including power generation emissions profiles and fuel consumption characteristics.

* + 1. Growth Projections

Finally, although the timeframe cited within the LCFS is relatively short, it will be necessary to include methods of projecting the future sizes of the driving fleets for all classifications of vehicles. Thus, resources for projecting population growth and vehicle fleet growth within the state of California will be investigated in order to generate a dynamic set of simulation scenarios that account for the expected growth over the course of the current LCFS lifetime.

* 1. Human Factors

The proposed simulation scenarios include a case that optimizes the renewable gas network based upon minimization of human health impact. Thus, it will be necessary to collect data related to the **population and demographics within California** as well as the latest understanding of **pollutant impacts on increased incidence of health effects**.

* + 1. Demographics

Census data and other resources obtained from appropriate agencies within the state of California will be utilized to develop a map of the state’s population. It will likely be necessary to utilize a mapping utility such as ArcGIS in order to translate the format and resolution of the data from the original source into data of appropriate form to serve as an input file for the modeling platform. Currently, the Community Multiscale Air Quality (CMAQ) model is proposed for the simulation Tasks in this work, which utilizes a resolution of 4km by 4km per simulation cell.

* + 1. Health Effects

Recent work by multiple agencies and university researchers have begun to provide much-needed information regarding the incremental increases in various health effects (mostly cardio-pulmonary and cancer-related) due to increased emissions and/or concentrations of criteria air pollutant species. [10-12] It will be necessary to review and compile these sources and develop appropriate expectations of additional health complications per capita to combine with the demographic data and arrive at expectations for increases in related statewide health issues.

**References:**

[6] California Environmental Protection Agency, Air Resources Board. Emissions Factor Model (EMFAC). EMFAC2011. Computer Software.

[7] United States Environmental Protection Agency. MOVES (Motor Vehicle Emission Simulator). MOVES2010b. Computer Software.

[8] United Sates Environmental Protection Agency. MOBILE6. MOBILE6.2. Computer Software.

[9] Sierra Research. *Effects of Gas Composition on Emissions of Heavy-Duty Natural Gas Engines*. Sacramento: Sierra Research Inc., 2010.

[10]Lipsett MJ, Tsai FC, Roger L, Woo M, & Ostro BD. 2006. *Coarse Particles and Heart Rate Variability among Older Adults with Coronary Artery Disease in the Coachella Valley, California*. Environmental Health Perspectives, 114 (8), 1215-1220.

[11] Tran, T. *Methodology for Estimating Premature Deaths Associated with Long-term Exposure to Fine Airborne Particulate Matter in California.* Sacramento: Air Resources Board, 2008.

[12] Bernstein, JA, et al. 2004. *Health Effects of Air Pollution*. Journal of Allergy and Clinical Immunology. 114(5), 1116-1123.

1. Simulation Scenario Definition

Successful completion of the various background information gathering efforts described in Task I will lead naturally to, and provide a solidified basis for, the completion of Task II. The focus of Task II will be to complete the description of the full breadth of simulations scenarios and evaluation parameters that will be analyzed towards the major Objective of understanding the local and regional air quality impacts of introducing renewable natural gas production facilities within the state of California. It is proposed that a number of criteria may eventually be utilized to evaluate the suitability of any given site or even a full potential network of sites to be developed for meeting these goals. To this end, the major focus of this Task will be to design the criteria by which simulated networks will be evaluated as well as to design the networks themselves.

* 1. Develop Network Scenarios and Candidate Producers

The process of designing and identifying the production networks that are the most feasible and provide the greatest benefits, while simultaneously imparting the least amount of harm, will be comprised of three major efforts, two of which form Task II,A; the final step in Task IV,A will build from these preparatory steps to complete the designs of full networks. The first among the preparatory steps is to develop and finalize the Network Scenario Optimization Schemes themselves. In order to identify an optimal design, there must first be a well-defined and sufficiently quantifiable optimization target against which to evaluate the scenario. In the proposed project, there are currently five different optimization schemes that will be exercised.

**Proposed Optimization Schemes:**

1. Maximize the availability of production facilities co-located with their associated feedstock resources.
2. Minimize the total incremental health effect.
3. Minimize the total GHG emission and formation rate.
4. Minimize the effect on local non-attainment of ozone, and Particulate Matter (PM) standards.
5. If resource availability or production capacity is found to be short of demand in all cases above, maximize the production capability while minimizing the total emissions of criteria pollutants.

While the descriptions in the list above provide the conceptual basis for each optimization scheme, the optimization criteria are not yet sufficiently well-defined for a mechanistic and computationally sound analysis. For example, it must be determined what the most appropriate measure for co-location of facilities would be in order to evaluate a scenario according to the co-location optimization scheme. Such a measure could be taken as the aggregate sum of the distance between a given production facility and all its potential resources. Alternatively, it could be the aggregate sum of just the distance between the production facility and its largest resource, or possibly only its nearest resource. The determination may also be made with or without weighting factors included based upon the production capabilities of each facility. These possible definitions simply provide a demonstrative subset of a larger range of the optimization criteria’s possible technical definitions. It will be necessary to develop a work process that iteratively evaluates these and the other possible definitions throughout the completion of the network design and simulation Tasks of this project. Insights from the results of any given optimization may lead to more appropriate redefinitions that provide the maximum realized benefit to the state of California or are simply more practical, feasible, and intuitive.

Although the final technical definitions for these criteria are unknown, certain features of their development are planned to be consistent across all scenarios. Of primary importance will be that the targeted optimization parameters will be analyzed as a statewide value. Although the optimization will be restricted to the geographical region of the state, more finely-detailed aspects will be analyzed and presented as part of Task IV. It is the intent of the proposed project to provide determinations of optimization and feasibility as a statewide evaluation and to then provide more local impacts as context for the potential extent and severity of any impacts that the designed production networks impart.

Additionally, all of the evaluation criteria will take account not only of the production facilities themselves, but also of their associated transportation routes. For both the incoming resources for fuel production and the outgoing distribution to market and point of sale, the transportation of the fuel via conventional methods will be assumed and may provide a significant portion of the overall air quality impact. It will therefore be necessary to include an accounting of these emissions sources in the overall evaluations of all the proposed production networks; further details will be provided in discussion of Task III.

The second effort within this subtask will be the identification of candidate network producers. In an optimization study with no limitations and constraints, it would be feasible to develop a tool and methodology that could evaluate the inclusion of any or all technologies in every individual simulation cell considered within the boundaries of the state of California. Such an effort may indeed develop the absolutely optimized network of locations and technology mixes to meet any of the given optimization schemes. However, a methodology without practical constraints is not reasonable. Intelligently designed networks must take into account more basic, qualitative factors that contribute to feasibility. The proposed project will utilize automation in evaluating scenarios only to accelerate the computational aspects. Therefore, facilities that satisfy the above mentioned qualitative constraints will first be identified by the investigators. This strictly-defined list of facilities will then be incorporated into a parametric analysis to determine the optimum combination according to each criterion. The execution of this parametric study will be automated given the large simulation times and potentially large number of possible combinations, even with adherence to strict qualitative limits on individual facility feasibility.

The selection of qualified candidate sites will therefore allow the researchers to provide control over the qualitative aspects of feasibility and ensure that the networks considered and which can ultimately be proposed are reasonable and follow intuitive logic for the selection of production facility locations. Thus, the determination of qualified facilities, and the definition itself of what features must be present to qualify a facility, serves as its own step in the progression of Task II,A. Various aspects of the information that will be collected in Task I will invariably need to be considered for inclusion in the definition of a qualified site. For example, information regarding costs for various technologies may serve to restrict the candidate pool. Total production capacities may also eliminate certain technologies outright, though their consideration will still need to be fully completed and documented. However, other factors not based on the technology itself (such as location of other nearby facilities, restrictions on land use zoning, etc…) can lend themselves to further restricting the list of candidate producers.

It is therefore a major goal of this subtask to simply generate a “short list” of locations and technologies that have the highest viability based on qualitative and quantitative factors of the technologies and locations as well as other qualitative externalities that must be considered to provide a realistic determination of the feasibility of the LCFS and the optimized scenario for its implementation. A major focus of this work will be to propose networks that are realizable networks, especially given the focus of the proposal on evaluation of the feasibility. The philosophy being extended is that the feasibility must therefore contain an aspect of practicality. In order to achieve this, it will be necessary to closely evaluate and understand prior design decisions (as well as their consequences) made by conventional gas producers during the completion of Task I. These can then serve as guideposts in the formulation of the proposed qualification criteria.

* 1. Develop Baseline Definition

In order to provide an appropriate context for the environmental and health impacts of the scenarios and networks evaluated, it will be necessary to develop a baseline case scenario to evaluate in the same manner. Current expertise within the research groups headed by both primary investigators demonstrates a long-running familiarity and investigation of the current emissions inventories and sources within the entire California region. In addition, that experience and knowledge has led to the utilization of existing pieces of software as well the creation of novel pieces of software and insight that can be leveraged for use in the current project. Thus, these past experiences will help inform the most accurate accounting of the current state of the emissions throughout California and have already paved the way for additional novel information to be included and tools to be developed.

Although the baseline case is typically a single business-as-usual assessment with all known information included, the nature of the current project may warrant two versions of a baseline case. The first case would be the standard with all current emissions estimates from documented inventories included within the simulation of the air quality for the entire state of California. This case exists from prior work. However, there may also be some insight and context that could be gained from a slightly altered baseline case. This second case would remove all of the currently-operating renewable gas production plants. It should be stressed that none of these plants would be removed for the optimization scenarios. However, evaluating optimized networks against the performance of the current production network can provide context and evaluation of the decision making process that will be involved in choosing qualified candidate facilities. For this reason, it is currently proposed that two baseline cases will be evaluated during the course of this work.

1. Develop Methodology and Tool for Scenario Design Analysis

With the development of the proposed simulation scenarios complete, it will then be necessary to develop a properly-formulated and highly quantifiable methodology for evaluating and modifying production networks to guarantee optimality. Additionally, it will be necessary to develop a tool that is able to facilitate this process with automated switching of qualified producer inclusion in the network and the associated creation of input files required for the air quality modeling platforms used in the study.

The network of qualified producers can be envisioned as an interconnected set of facilities with three main features:

1. A switch that dictates whether or not they are included in a network and thus the network’s overall evaluation according to the optimization criteria.
2. The facility’s operating parameters including emission rates of greenhouse gases and criteria pollutants per unit production and the production capacity.
3. Any transportation corridors utilized for the distribution of the fuel from the production site to the point(s) of sale and/or storage that may be identified as likely to be utilized for that facility.

A conceptual example of this setup for a hypothetical production sub-network within the confines of the South Coast Air Basin is presented in Figure 2. It should be noted that the figure is purely conceptual and demonstrative; none of the indicated features aside from the geography of the coastline and the locations of major cities correspond to actual data.



Figure 2: Conceptual Representative of a Renewable Production Network Scenario

There are a number of features to note in the figure that aide in understanding the intended workflow and development of the automation tool. The first set of concepts relates to the production facilities themselves. In the figure, all of the production facilities depicted should be taken to have already been identified by the qualification process as feasible facilities recognized by the confines of industry practice and conservative assumptions of practicality and siting. Alongside each facility there are a number of data that indicate how each is considered in the analysis of a designed network. First is the switch for whether or not the facility is included as operational within the currently-considered network. In the figure, all but two facilities are depicted as operational, indicated both by the switches in the “on” position and the corresponding shading of the facility itself. The methodology for determining which facilities are included and intelligently automating the network modifications will be discussed below.

In addition to the binary state of inclusion or exclusion in the network, the facilities are each accompanied by a number of performance characteristics that will be utilized in decisions for their inclusion as well as the analysis of the effect of their inclusion. It should be noted that only a subset of the full operational parameterization is indicated in the figure; the chosen information does provide an accurate representation of the full classifications of expected data, however. In particular, information regarding potential output (signified as “Capacity), required inputs (signified as “Resources”), criteria pollutant impacts (represented by “NOx”) and GHG impacts (represented by “CO2”) are shown. Each facility is thus accompanied by its own data in each of these categories, specified as representative levels developed from the average of all information for that facility type identified in the Task I literature review.

The various facility ratings with regard to these four operational characteristics embody some of the major unknowns that will be investigated in this work. For example, the facility turned off near Burbank is one with low GHG emissions but high criteria pollutant emissions. This facility represents the core of this research work; inclusion of such a facility may provide a significant step in meeting the LCFS since the standard is based on CI but it may do so at the expense of significant local increases in criteria pollutants and their related health effects. By contrast, the facility southeast of Anaheim may provide a negative impact on CI but may minimize environmental impact while still contributing significantly to the required production quota. Additionally, there will be questions of capacity and resource consumption that must be addressed; the facility just north of Long Beach and the facility southeast of Riverside exemplify a scenario where production efficiency may help determine the facilities that are or are not included in the network. Lastly, issues of facility production size will certainly enter the optimization scheme. The facility near Los Angeles may provide only a small impact on meeting the production quota but also does so with little negative environmental impact. By contrast, the facility northeast of Riverside does present some significant environmental challenges but does so while providing a significant production capacity; a balance of these factors will help determine the optimized networks.

Finally, each of the facilities is also associated with given distribution routes. Again, it is stressed that the routes presented are not developed from actual data. It can be seen that the state of inclusion of a production facility within the network additionally determines the state of inclusion of the distribution routes associated with that facility. Thus, with the four facilities included in the example figure, some large distribution lines are not included but a sizable network of distribution can still be maintained. It should be noted that, for the sake of clarity, the figure does omit one important feature. Each of the distribution routes is also characterized by an emissions profile of criteria pollutants and GHGs. Thus, the total impact of a given facility eventually becomes defined by both the stationary impact at the site of impact and the mobile impact for distribution of the renewable gas.

It is expected that even the “short-list” of qualified production facilities and their associated distribution routes will be sufficiently large and complex to necessitate the development of an automated computer tool to cycle through the set of total possible combinations of facilities included in the network. However, even with such a tool, it is likely that the computational resources required would be prohibitively large if absolutely every possible network were to be included. Thus, the tool will be designed to have some intelligence in determining the facilities to include, with an iterative final check on initial assumptions. The aim is simply to reduce the total number of networks that must be investigated and analyzed since computational time on parallel computers for a single case will be significant.

Thus, it is proposed that a novel optimization tool entitled Optimizing Automated Tool for Maximizing Environmental Advantages of the LCFS (OATMEAL) will be developed as an interfacing tool between the project’s researchers and the proposed modeling platform CMAQ. The tool will be responsible for iteratively defining the networks according to inclusion and exclusion of individual facilities, creation of appropriate input files for the CMAQ suite of modules, recording of the resultant performance of the network according to the selected optimization criterion, and reporting of the most advantageous production network’s structure along with its rating according to the criterion. In order to aide in the validation of the optimization of the network, the tool will be built with the capability to optionally report the same features of more than just the top performing network; the exact number necessary for sufficient demonstration will be determined during the development phases of the tool.

The optimization scheme proposed is as follows: Starting with the list of qualified producers, all optimization efforts will begin with inclusion of the largest possible units within the potential network, with “largest” determined by expected production capacity of each unit’s technology and/or the availability of nearby resources for feedstock. It should be noted that the qualification process will initially work to ensure that some of these features are already accounted for before the optimization process, but it will still be necessary to choose the potentially most advantageous unit as a basis around which the network can be built. The airshed model will then be run with this single unit included and the result will temporarily be considered the optimal case. Production units will then be added to the network singly in order of decreasing size from next-largest to smallest. After each unit is added, the airshed model will then be executed again and the results according to the chosen optimizing criterion evaluated. Units will then only remain in the network if they improve or maintain the value of the optimization criterion over the most recently identified optimum case. If so then, the currently-considered network will be considered the optimum and the proceeding simulations judged against its performance until another network is identified that has a more favorable performance. At the end of the optimization scheme, it will be necessary to remove the very first assumed unit evaluate the resultant network according to the optimization criterion. If it is determined that the first-assumed unit had negatively impacted the total network’s performance, it is removed and the optimization scheme branches off into a second scenario where previously-discarded smaller units (note that at this point, the list of qualified production facilities will be shortened to only these discarded units) are re-evaluated for inclusion until the desired production volume is achieved. The process will iterate until it is found that a network can be formed with the feature that the only assumed basis unit maintained the optimal nature of the network.

1. Simulation and Detailed Analysis

Once the set of candidate production facilities, the optimization criteria, the method for evaluating networks and arriving at optimality, and the corresponding computational deliverable tools are developed and finalized, the actual simulation of the proposed scenarios can their detailed analysis can commence. Task IV will therefore be a central source of data creation for toward the completion of Objective 2.

* 1. Airshed Simulation via CMAQ

While the methods of defining test cases according to optimization scenarios have been previously discussed, some technical details of the process of completing the simulations themselves have yet to be presented. Given the large geographical scale of the proposed simulation efforts, it is currently planned that CMAQ will be the modeling platform around which the project’s air quality modeling will be built. It should be noted that an integral portion of the successful modeling of air quality impacts of various scenarios lies in the development of appropriately representative emissions and meteorology data for the region chosen as the domain of the modeling effort. A great deal of this work has previously been completed by the efforts of the current project team utilizing the CMAQ platform (most recently in [12]). Thus, in the currently proposed project, it will be advantageous to make use of these prior developments that have already been completed so that more effort and time can be devoted to the subtasks that are novel to this work and pertain more directly to improving the LCFS and enhancing its feasibility.

Accordingly, CMAQ is not a stand-alone program; it is the central simulation module within a suite of modules meant to provide the full range of capability required for simulation of test scenarios in air quality simulations. Figure 3 provides a schematic of the full suite of applications that must be incorporated as well as their relationships to one another in the flow of the proposed work for Task IV. Similar to the way that WRF handles meteorology and CB05 describes the atmospheric chemistry, OATMEAL will develop the emissions input for the CMAQ model based upon the selected optimization criterion and results of prior simulations. Two special features should be noted here. The first is that OATMEAL will actually interface with SMOKE, the currently-available module for Emissions Inventory preprocessing utilized for CMAQ. The other is that OATMEAL plays a dual role, acting to both be informed by a candidate network and serving to define the next candidate network based on the previous outcomes; the latter is indicated by the dashed process line passing from Case Outcomes, through the OATMEAL module, and into the Candidate Network.

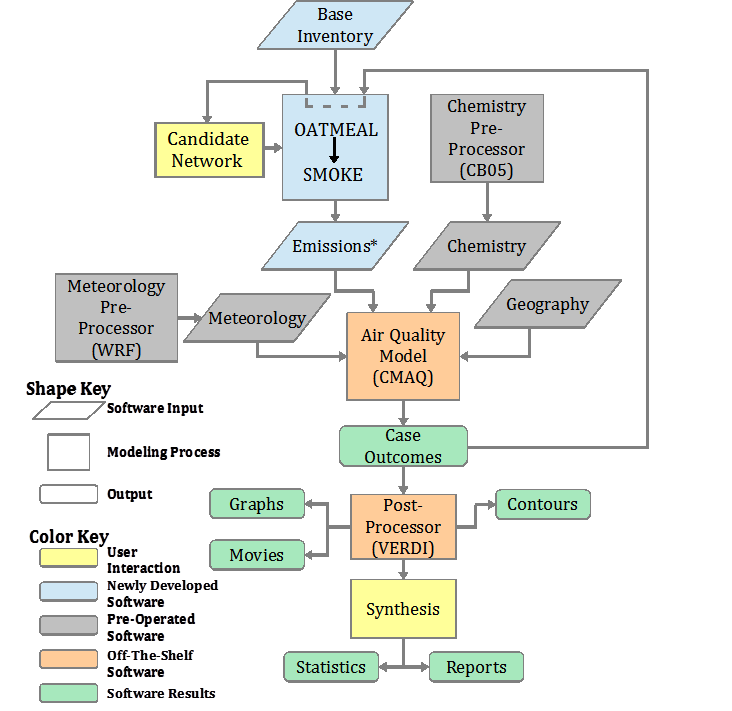


Figure 3: Full Suite and Workflow of Proposed Airshed Modeling Platform

Thus, Figure 3 illustrates the iterative process that is required to complete Objective 2. Given the large scope of the endeavor, it will be necessary to utilize appropriately capable computing resources. The Computational and Environmental Sciences Laboratory at the University of California, Irvine has a substantial history of performing similar computational airshed simulations [2-5, 13-16]. As such, the research group has ensured the availability of computing resources sufficient for the task of simulating multiple days’ worth of air quality calculations on spatial domains as large as the state of California with resolutions as small as 4km by 4km. The currently-available hardware includes exclusive access to 32 cores on a 64-core AMD Opteron CPU 6274, with a 2.2 GHz speed and 256GB DDR3RAM. Internal disk space available is 1TB, with additional amounts available for long-term storage for individual researchers. In addition, the group has access to a university-wide public computing cluster that includes more than 20 64-core machines of various builds, but all with similar characteristics to the privately-accessible computer previously mentioned. All of the hardware and the simulation software proposed have the capability for parallel computation, thereby taking full advantage of the computer cluster’s potential. Finally, individual members of the research group have access to a variety of desktop and laptop computers in order to complete the analysis and synthesis work in support of the computational results.

* 1. Analysis of Local Effects Aided by Visualization in VERDI

Included within the process diagram of Figure 3 is a reference to the post-processing software VERDI. This is a purpose-built visualization module made to interface with the output data from CMAQ and a small set of other similar airshed modeling platforms. VERDI will play a central role in enabling the analysis of localized effects of the optimized (and near-optimized) production networks throughout the proposed project. As mentioned, OATMEAL will be primarily concerned with the evaluation of optimization criteria and network development on the broader statewide level. However, past experience has shown that especially with the diverse geography and population distribution of the state of California, actions that enhance air quality on a state average level may not provide the same benefits for local regions and may even cause harm in smaller regional areas.

VERDI will be the primary tool for analyzing these localized issues through visualization of CO2 emissions (and concentrations) and emissions and concentrations of the criteria pollutants PM, NOx, SOx, O3, and CO. There is one capability particular to this project that is not yet included within the VERDI tool itself. The tool currently does not have a method for calculating human health impacts given input data of CMAQ simulation results, population distribution, and estimates of increased health effects based on local concentrations. At the current time, a number of possible solutions to developing this capability are proposed and all will be evaluated during the development stage of the project, though only one will ultimately be carried out. The possible options, in order of expected total effort for development (from lowest to highest) are:

1. Development of a new version of VERDI that can accept the additional data and perform the computations.
2. Development of a tool that accepts the output data from CMAQ and the additional human factors input data, performs the calculations of human effects, and creates data files in a format compatible with VERDI.
3. Development of a method for performing the calculations and visualization within a completely separate platform, such as ArcGIS.

Additionally, it is expected that ArcGIS may need to be utilized for some visualizations in order to make them more intuitive and accessible in the final reporting. For example, VERDI typically plots atmospheric concentrations of selected species. However, projected increases in non-attainment days, while related to the concentration, would most easily be interpreted on a map of isopleths defined by the number of increased non-attainment days. The removal of one step of interpretation for the viewer of the map will be made possible through integration of CMAQ/VERDI data with a suite of software like ArcGIS.

* 1. Comparative Analysis Between Proposed Production Networks

Finally, although OATMEAL itself will continually compare production networks throughout the course of this project there will still likely be insights that can be drawn by a review of the optimized and near-optimized networks themselves. For this reason, a final comparison of all the top-preforming networks will be carried out by the researchers with a focus on commonalities between the networks. This review will also serve as a crucial step for completing Objectives 2 and 3 and evaluating the technologies and networks according to their merit for sustainable production of the renewably-sourced natural gas.

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1. Identification and Review of Largest Contributors

With the completion of subtask IV,C, the project will enter into the phase of evaluating the long-term viability and feasibility of the LCFS via the completion of Life Cycle Analysis (LCA) for select technologies. As mentioned, a review of the optimized and near-optimized networks according to each of the optimization scenarios will be carried out by the researchers at the conclusion of the simulation phase via CMAQ/OATMEAL. Aside from verifying that the networks make intuitive sense and follow the desired conservative assumptions developed at the beginning of the project, this step will also importantly identify the technologies that appear to most commonly or most greatly provide a benefit in terms of meeting production quotas while minimizing environmental effects. It is expected that number of renewable gas production facility types may be quite large but that their individual characteristic operating capabilities, combined with the conservative expectations of California’s available resources and distribution pathways, will serve to single out technologies with the greatest likelihood of being beneficial contributors. Given that LCA is typically a research task with intensive data collection, we propose to limit the scope of the technologies that receive the treatment of this analysis to only those that play the largest roles.

Thus, a set of technologies will form a “short-list” of those that were found to be the most involved in the near-optimized networks. These technologies will then require a thorough secondary literature review in order to fully understand the environmental impacts of their full life cycle. This will include the impacts of all feedstock resource attainment, growth, and distribution, the lifetime emissions of the facility itself including construction and demolition at end-of-life, and estimates for the associated distribution-related emissions over the full lifetime of the facility. The total amount and type of data will necessarily be affected by the analysis platform utilized for the LCA; it is currently proposed that CA-GREET will be used given the range of emitted species it considers and their correlated pertinence to other phases of this project. However, a brief evaluation of other available LCA platforms for the completion of this analysis will be carried out at the beginning of Task V in order to ensure that the best available tools are implemented.

1. Life Cycle Analysis of Largest Contributors

Once Task V is complete and all the necessary information is gathered, then the full LCA analyses will be carried out for GHG as well as NOx, CO, CO2, SOx, NOx, PM, and O3. It should be noted that the determination of these species is predicated on the assumption of CA-GREET but that these species will likely form the necessary basis of the selection of any alternative platform. Any alternative would only provide an LCA recommendation according to additional species after inclusion of those mentioned above. With the completion of Tasks V and VI, Objective 3 will have been met and the perspectives of the feasibility of the LCFS will be able to provide context for both near-term and long-term expectations of the standard’s ability to meet its stated goals while minimizing the effects that are imparted to the environment and human health.

1. Synthesis of Results to Identify Barriers within LCFS

Finally, Objective 4 will be met entirely by the completion of Task VII. The workflow of the proposed project thus begins and ends with a thorough review and consideration of the LCFS standard with particular attention paid to its technical definitions. At the closing of the project, it is expected that a significant amount of insight and demonstrable technical data will be available to test the technical definitions of the LCFS against the expected performance predicted by the airshed modeling and the LCA. In particular, there will be a need to assess whether or not technologies will be reliably able to positively contribute to LCFS goals in both the long-term and the short-term. Additionally, it will be necessary to consider whether or not the technical definitions provided by the LCFS are structured so that more-preferred options (in terms of minimal environmental impact or carrying a large role in optimized networks) are preferred. There will also be a need to assess the validity and/or potential benefits of the simplification of the LCFS put forth in Task I,A,2.

It is the goal of this final Task to provide a closing, overall synthesis of the insights gained and the data collected through the completion of the first three Objectives. This final Task is expected to therefore provide guidance in policy, especially for the technical aspects that must be included in the LCFS policy literature. Ultimately, this will determine the viability and feasibility of the current definitions of the LCFS text and provide well-supported and thoroughly investigated recommendations for any proposed changes to the text.

# Curriculum Vitae of Scientific Personnel

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## Professional Preparation

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| California Institute of Technology | Chemical Engineering | Ph.D. | 1995 |
| California Institute of Technology | Chemical Engineering | M.S. | 1992 |
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**Academic Appointments / Professional Positions**

*2005 – present Professor,* Mechanical and Aerospace Engineering, U.C., Irvine

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*2000 – 2005 Associate Professor,* Mechanical and Aerospace Engineering, U.C., Irvine

*1995 – 2000* *Assistant Professor,* Mechanical and Aerospace Engineering, U.C., Irvine

**Recent Publications Related to the Proposal:**

1. Air quality impacts of distributed power generation in the South Coast Air Basin of California 1: Scenario development and modeling analysis. Rodriguez M. A., Carreras-Sospedra M., Medrano M., Brouwer J., Samuelsen G. S. and Dabdub D. Atmospheric Environment **40**, (2006) 5508-5521.
2. Air quality impacts of distributed power generation in the South Coast Air Basin of California 2: Model uncertainty and sensitivity analysis. Rodriguez M., Brouwer J., Samuelsen G.S. and Dabdub D. *Atmospheric Environment* **41,** (2007) 5618-5635.
3. Air quality impacts of distributed energy resources implemented in the Northeastern United States. Carreras-Sospedra M., Dabdub D., Brouwer J., Knipping E., Kumar N., Darrow K., Hampson A. and Hedman B. Journal of Air & Waste Management Association **58**, (2008) 902-912. doi:10.3155/1047-3289.58.7.902
4. Determining air quality and greenhouse gas impacts of hydrogen infrastructure and fuel cell vehicles. Stephens-Romero S.D., Carreras-Sospedra M., Dabdub D., Brouwer J. and Samuelsen G.S. Environmental Science Technology, **43**, (2009) 9022-9029.
5. Central power generation versus distributed generation - an air quality assessment in the South Coast Air Basin of California. Carreras-Sospedra M., Vutukuru S., Brouwer J. and Dabdub D. Atmospheric Environment **44**, (2010) 3215-3223 doi: 10.1016/j.atmosenv.2010.05.017

**Synergistic Activities**

1. Principal Investigator on contracts and grants with multiple agencies (National Science Foundation, California Energy Commission, Air Resources Board of California) and industrial sponsors (e.g., Toyota, Electric Power Research Institute) in fields directly relevant to air quality.
2. Organizer of the national meeting for the American Association for Aerosol Research (AAAR) for the past 7 years. AAAR is the leading U.S professional organization for scientists and engineers who wish to promote and communicate technical advances in the field of aerosol research.
3. Organizer of the International Aerosol Conference. This conference is held every four years and brings together much of the worldwide aerosol research community to share state-of-the-science research.
4. Chairman of the Annual Symposium on Kinetics and Photochemical Processes in the Atmosphere.
5. Member of various advisory panels in topics directly relevant to air quality in California: John Wayne Airport; U.S. Department of Defense; California Energy Commission; Air Resources Board of California; Electric Power Research Institute.

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| Massachusetts Institute of Technology | Mechanical Engineering | Ph.D. | 1993 |
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**Academic Appointments / Professional Positions**

*7/11 – present Assistant Professor,* Mechanical and Aerospace Engineering, U.C., Irvine

*7/08 – 6/11 Adjunct Associate Professor,* Mechanical and Aerospace Engineering, U.C., Irvine

*6/04 – 6/08 Adjunct Assistant Professor,* Mechanical and Aerospace Engineering, U.C., Irvine

*8/97 – present* *Associate Director*, National Fuel Cell Research Center, U.C., Irvine

*7/96 – 7/97**R&D Program Manager,*Reaction Engineering International

*6/93 – 7/97**Research Assistant Professor,* Mechanical Engineering, University of Utah

*1/93 - 5/93* *Post-Doctoral Researcher*, Chemical Engineering Department*,* M.I.T.

*9/89 - 12/92* *Research Assistant*, Chemical Engineering Department*,* M.I.T.

*6/91 - 9/91* *Staff Scientist,* Sandia National Laboratories, Livermore, California

**5 Recent Publications:**

1. Auld, A.E., Brouwer, J., Smedley, K.M., and Samuelsen, S., *Internal and External Strategies for Evolution of Solid Oxide Fuel Cells into Model Citizens of the Grid*, IEEE Transactions on Energy Conversion, Volume 24, Issue 3, pp. 617-625, 2009.
2. Mueller, F., Jabbari, F., Brouwer, J., *On the intrinsic transient capability and limitations of solid oxide fuel cell systems*, Journal of Power Sources, Volume 187, Issue 2, pp. 452-460, 2009.
3. Mueller, F., Tarroja, B.J., Maclay, J.D., Jabbari, F., Brouwer, J., and Samuelsen, G.S., *Design, Simulation and Control of a 100 Megawatt Class Solid Oxide Fuel Cell Gas Turbine Hybrid System*, Journal of Fuel Cell Science and Technology, Volume 7, pp. 03107-1-11, June, 2010.
4. Carreras-Sospedra, M., Vutukuru, S.K., Brouwer, J., and Dabdub, D., *Central power generation versus distributed generation – An air quality assessment in the South Coast Air Basin of California*, Atmospheric Environment, Volume 44, Issue 26, pp. 3215-3223, August, 2010.
5. Stephens-Romero, Shane; Carreras-Sospedra, Marc; Brouwer, Jack; Dabdub, Donald; Samuelsen, G. Scott, *Determining Air Quality Impacts of Hydrogen Infrastructure and Fuel Cell Vehicles*, Environmental Science & Technology, Volume 43, No. 23, pp. 9022-9029, 2009.

**Synergistic Activities**

1. 10 years experience in leading multi-disciplinary efforts to develop and rigorously analyze the emissions, air quality, and greenhouse gas emissions impacts of new energy technologies.
2. Testing, experimentation, and evaluation experience with gas turbines, fuel cells and fuel cell systems including the world’s first solid oxide fuel cell gas turbine hybrid system with Southern California Edison, Siemens Westinghouse Power Corporation, U.S. Department of Energy, and others.
3. Testing and experimentation expertise applied to combustion, reforming, single cell fuel cell evaluation (SOFC, MCFC, and PEM fuel cell types), stand-alone fuel processors for natural gas based on steam reforming and autothermal reforming, and integrated reformer SOFC systems.
4. Developing and applying steady state and dynamic models for gas turbines, fuel cells, fuel cell systems and integrated solar and renewable systems in the SimulinkTM framework.
5. Led establishment of National Fuel Cell Research Center and Advanced Power and Energy Program with support from U.S. Department of Energy, California Energy Commission, and 15 industrial partners.

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## Professional Preparation

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| University of California, Irvine | Mechanical and Aerospace Engineering | Ph.D. | 2011 |
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**Academic Appointments / Professional Positions**

*02/12 – present Postdoctoral Scholar,* Chemistry, U.C., Irvine

*2005 – 2011 Graduate Research Assistant,* Mechanical and Aerospace Engineering, U.C., Irvine

*2005 – 2008 National Science Foundation Graduate Research Fellow*

*2002 – 2005* *Undergraduate Research Assistant,* Mechanical Engineering, Georgia Tech

**Recent Publications:**

1. Martinez, A.S., Brouwer, J. and Samuelsen, G.S. (2012). ‘Feasibility Study of SOFC- GT Hybrid Locomotive: Part I. Development of a 3.5 MW SOFC-GT FORTRAN Model.’ Journal of Power Sources, 213, 203-217.
2. Martinez, A.S., Brouwer, J. and Samuelsen, G.S. (2012). ‘Feasibility Study of SOFC- GT Hybrid Locomotive: Part II. Power System Packaging and Operating Route Simulation.’ Journal of Power Sources, 213, 358-374.
3. Martinez, A.S. and Brouwer, J. (2011). ‘Monte Carlo Investigation of Particle Properties Affecting TPB Formation and Conductivity in Composite Solid Oxide Fuel Cell Electrode-Electrolyte Interfaces.’ Journal of Fuel Cell Science and Technology, 8, 051015-1-051015-9.
4. Martinez, A.S. and Brouwer, J. (2010). ‘Modeling and comparison to literature data of composite solid oxide fuel cell electrode-electrolyte interface conductivity.’ Journal of Power Sources, 195, 7268-7277.
5. Martinez, A.S. and Brouwer, J. (2008). ‘Percolation modeling investigation of TPB formation in a solid oxide fuel cell electrode-electrolyte interface.’ Electrochimica Acta 53, 3597-3609.

**Synergistic Activities**

1. Experience with development of system-wide simulation models for solid oxide fuel cell systems based on first principles and the integration of multiple concurrent physics
2. Developed simulation capabilities in FORTRAN for the modeling of stand-alone and system-integrated autothermal diesel and steam methane reformation reactors
3. Experience analyzing advanced energy systems including fuel cell and fuel cell-gas turbine hybrid systems to advance knowledge in their operating capabilities and expected mitigation of environmental impact as a replacement for conventional energy conversion devices
4. Performed statistical analysis of natural gas burner emissions as a function of fuel composition and combustion properties
5. Experience with simulating and teaching simulation fundamentals within the CMAQ framework and developing new purpose-built modules to interface with existing utilities for parametric studies carried out with CMAQ

**Academic Advisors:**

*G. Scott Samuelsen, Jacob Brouwer*

# Proposed Schedule



# Proposed Budget

