DRAFT TECHNICAL PROPOSAL

The Future of Drop-in Fuels

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January 31, 2013

Check if applicable:
Animal subjects _______

Human subjects _______

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Abstract.

Meeting California's Low Carbon Fuel Standard requires the sale of fuels with significantly lower carbon intensities. Though advanced biofuels, conventional and renewable natural gas, and electricity are all expected to contribute to achieving these reductions, their use is limited by the engine type and powertrains of California's vehicle fleet. The existing fleet of vehicles and those currently in the product development stage are predominantly designed to operate on gasoline and diesel and will account for roughly 70-80% of CA's fuel demand in 2020. Thus, the use of alternative fuels and energy carriers for vehicles will be limited by the vehicle technologies on the road. Drop-in fuels (hydrocarbon fuels that are chemically similar to petroleum gasoline and diesel) produced from renewable or other low-carbon intensity feedstocks may allow for the use of low carbon fuels in conventional engines, avoiding the need for a significant change in the vehicle fleet to achieve significant carbon reductions from fuels. In the long-term drop-in fuels, have properties – like high energy density – that make them attractive options in the aviation, heavy-duty truck and marine sectors where few other options are available for deep carbon reductions.

This project will provide a comprehensive analysis of the status and prospects for drop-in fuels to play a role in meeting California's near term (2015-2020) and long term goals for climate change mitigation from the on-road transport sector. To achieve this, six tasks will be undertaken; review and analysis of the literature, life-cycle assessment of selected drop-in fuel pathways, assessment of near-term prospects for drop-in fuels, spatially-explicit modeling of selected drop-in fuel pathways, solicitation of stakeholder feedback on research needs and barriers, and development of a monitoring protocol for drop-in fuels. Tasks one through four will leverage existing models developed by the proposed research team including the Geospatial Bioenergy Systems Model (GBSM), along with several life cycle assessment models for biofuel feedstock production and conversion technologies.

Review of the literature will include techno-economic evaluations and life cycle assessment in the academic literature, and industry publications on technology and facility development. The literature review will yield a matrix of economic and environmental impact performance for particular pathways and will facilitate meta-analysis for pathways. If the literature review does not yield sufficient economic and environmental results for pathways identified as likely for commercialization, economic and life cycle environmental performance will be estimated by tailoring existing assessments (e.g., substituting feedstocks of increasing the modeled scale of production) or generating new assessments. Key research needs and barriers to implementation will be identified based on the published literature, and through outreach to industry, NGOs and agencies.

The state of the drop-in fuel industry will be evaluated and recorded by a monitoring protocol for database development. The information recorded will include company, key technologies, project development status, projected capacity and available cost information. The information will be archived to enable analysis of the industry development.

If funded, this project will result in a comprehensive and consistent set of studies on drop-in biofuel pathways and provide essential information on the future prospects for these fuels.

Introduction.

Fuels that are both low carbon and compatible with existing vehicles and fueling infrastructure are essential for meeting California's near term regulatory goals of reduce the carbon intensity of transportation fuels by 10% by 2020 as mandated in the Low Carbon Fuel Standard (LCFS). The fleet of electric, fuel cell, flex-fuel and natural gas vehicles will not significantly shift demand from conventional gasoline and diesel towards electricity or hydrogen to provide significant compliance. In many analyses conducted for the LCFS, flex-fueled vehicles that can consume blends of ethanol greater than 15% by volume are expected to account for at maximum 12% of vehicle miles traveled in 2020 [1]. To rely on ethanol to provide compliance would require a large volume (>3 billion gallons) of very low CI (<20 g/MJ) ethanol and significant fuel switching from gasoline to E85 by those drivers with FFVs. The existing fleet of vehicles and those currently in the product development stage will account for roughly 70-80% of CA's fuel demand in 2020 so the fuels sold in CA in 2020 need to be compatible with these vehicles that are predominantly designed to operate on gasoline and diesel.

Technologies under development can produce mixes of hydrocarbons similar to conventional petroleum fuels. These hydrocarbons fuel products are "drop-in" fuels as they can directly replace gasoline, diesel and jet fuels and are fully compatible with existing infrastructure. It should be cautioned that these processes produce unique slates that will not exactly match petroleum fuels and may therefore be limited in the fraction they can be used as blendstocks. While it is possible to make "designer" hydrocarbons, there is a cost associated with producing higher quality fuels and additional process inputs (most likely hydrogen). The articles in literature are often vague about the mix and properties of the hydrocarbons produced which can sometimes explain the variance in the cost estimates. There are studies [2] analyzing the fuel properties of actual drop-in biofuels from demonstrations. How this impacts performance is not yet known and whether it is best to upgrade the renewable fuel further or blend them with petroleum fractions to get something more like petroleum fuels.

In the long-term drop-in fuels, have properties – like high energy density – that make them attractive options in the aviation, heavy-duty truck and marine sectors where few other options are available for deep carbon reductions. Developing these fuels in the near-term will enable the long-term solutions that have been identified in studies of deep carbon reductions in the 2050 timeframe [3-5].

Drop-in fuels from renewable sources are not yet available in the market. Industry and academic research on the viability of drop-in fuels has rapidly advanced in recent years, as demonstrated by a few technologies that have been, or are expected to be, implemented by 2015 at demonstration scale biorefineries. Most current research, however, is focused on single pathways or single impact categories, which do not consider a suite of potential production pathways and their performance in a regulatory context. Moreover, because commercial scale production has not been achieved for drop-in fuels, the best available information on the feasibility, cost and environmental impacts of drop-in technologies is from engineering design studies. Because of the narrow scope (i.e. single pathway), and reliance on modeled and predicted performance rather than empirical data in current analyses, there is a need for research that objectively examines the environmental and economic performance across a suite of potential pathways for drop-in fuels, and a need for research that anticipates their life cycle performance at commercial scale production to enable informed regulatory decisions.

Members of the proposed research team completed a comprehensive analysis of advanced biofuels in the United States in 2011 that focused on cellulosic ethanol and Fischer-Tropsch diesel as the main advanced biofuel technologies [6], which followed on work conducted at the scale of the Western U.S. region [7] and California [8]. In addition, the UC Davis team has several projects currently underway that are relevant to the research proposed. (1) Under a contract with the California Energy Commission, we are updating conversion cost estimates based on new literature values, analyzing the potential for learning in advanced biofuels, and performing several biorefinery case studies within the Californian context. A detailed analysis of a hybrid poplar to drop-in biofuels pathway in the Pacific Northwest is underway. (2) An assessment of the air quality impacts of future biomass-based electricity scenarios in California has recently begun. (3) Through grants from the Department of Energy, California Energy Commission, and California Department of Food and Agriculture life cycle assessment (LCA) models for algal, cellulosic and advanced starch-based biofuels have been developed, as well as LCA models for a number of perennial agricultural production systems that produce significant quantities of agricultural residues are completed or currently underway. These past and current projects allow us to leverage a significant body of knowledge, existing datasets and modeling tools in fulfillment of the proposed project.

Objectives.

This project will provide a comprehensive analysis of the status and prospects for drop-in fuels to play a role in meeting California's policy goals. The work will be directly applicable to the implementation of the LCFS for the 2015 – 2020 timeframe by providing objective analysis of the expected cost, supply, carbon intensity and air quality impacts of near-term drop-in fuels. The availability of these fuels in the near-term is uncertain, but this work would shed light on expected technological and commercialization progress, and provide a tracking mechanism to evaluate the state of drop-in fuel commercialization. Beyond the immediate policy question this research addresses (the potential for drop-in fuels to contribute to meeting LCFS carbon intensity targets), this project will provide an analysis and repeatable framework to evaluate how drop-in fuels may play a role in long-term policy and climate change mitigation goals.

The proposed project has five objectives, as follows:

Objective 1. Assess the potential for drop-in fuels to contribute towards meeting the Low Carbon Fuel Standard's mandate for the 2015–2020 timeframe.

Objective 2. Assess the potential for drop-in fuels to contribute toward California's long-term climate change mitigation goals with consistent accounting for costs, greenhouse gases and other environmental impacts within the context of the resource base of California and the United States.

Objective 3. Identify areas where greater research is needed to (a) speed commercialization of drop-in fuels and (b) understand the life cycle environmental impacts associated with these fuels.

Objective 4. Identify regulatory and technological barriers to the commercialization of drop-in fuels.

Objective 5. Develop and implement a strategy for monitoring the progress of the industry and the state of knowledge.

In fulfilling these objectives, this project will provide ARB with vital information needed when considering dynamic implementation of the LCFS. For example, by identifying which fuel pathways are on the horizon, when they could come online, and objectively estimating their carbon intensity. The project will also provide a protocol for continuous tracking of status, identifying areas where additional research is needed to move the pathway to commercialization or to understand the impact of the pathway.

The project has 6 main Tasks, as follows.

Task 1: Review and analysis of the literature

Task 2: Life-cycle assessment of selected drop-in fuel pathways

Task 3: Assess near-term prospects for drop-in fuels

Task 4: Spatially-explicit model of selected drop-in fuel pathways

Task 5: Solicit stakeholder feedback on research needs and barriers

Task 6: Develop monitoring protocol for drop-in fuels

The mapping of project Objectives to project Tasks is as follows:

Objective 1 ➔ Tasks 1, 2 and 3

Objective 2 ➔ Tasks 1, 2 and 4

Objectives 3 and 4 ➔ Tasks 1 and 5

Objective 5 ➔ Task 6

Technical plan.

The objectives of this project are best met through a combination of methods to assess the costs, carbon intensity, environmental impacts, and potential supplies of drop-in fuels and when these fuels may become available. The basis of the research will rely on a comprehensive literature review that captures what is currently known about these topics and provides the data required for a more comprehensive analysis through the use of modeling and assessment tools already developed.

Analysis of the techno-economic potential and environmental impact of drop-in fuels will be performed using two tools that are appropriate for different timeframe. For the immediate timeframe, a dynamic model of biorefinery build out based on announced projects and plans within the industry will be developed. For a better view of what these fuels could do in the mid-term, an existing model of the bioenergy system, the Geospatial Bioenergy Systems Model (GBSM), will be adapted to this effort [6].

Task 1: Review the literature.

This task will provide a comprehensive literature review that covers both the academic literature and industry press. The objective of the literature review is to synthesize academic knowledge on the cost, performance (product yield, co-products, feedstocks consumed), and environmental impact (carbon intensity, criteria air pollutants, toxic air pollutants, etc). The review of industry sources will provide an overview on which technologies are being actively pursued by industry, how far along in the development process they are and any estimates provided on costs and performance. In addition, both sources will be reviewed for the degree to which the fuels are expected to directly substitute (i.e. "drop-in") for their conventional petroleum counterparts. Regulatory and testing or certification requirements that might be required before the fuels can be used as replacements will also be explored.

Table 1: Techno-economic studies of drop-in fuel pathways

Fuel Pathway	Studies	Levelized cost estimate
Upgrading alcohols to gasoline	Phillips *et al* (2011), Jones and Zhu (2009), Pham *et al* (2010) [9-11]	$1.25/gge – 3.68/gge
Fast pyrolysis w/hydroprocessing to gasoline, diesel and jet fuel	Wright *et al* (2010), Antares (2009) [12-13]	$2.11/gge - $3.09/gge
Upgrading of synthesis gas to diesel, naphtha and kerosene	Swanson *et al* (2010), Hamelinck (2004), Larson and Jin (2009), Antares (2009) [14-16, 13]	$3/gge - $5/gge
Catalytic conversion of sugars to gasoline, diesel and jet	Blommel *et al* (2008) [17]	$60/bbl
Hydrotreatment of waste lipids to renewable diesel	Antares (2009) [13]	$4/gal - $5/gal

For all fuel pathways where techno-economic assessments are published, a meta-analysis of the cost and performance will be performed. The analysis will enable a better comparison of costs by standardizing financing assumptions, feedstock costs and co-product value as well as adjusting for inflation and exchange rates for standard currency. To the extent possible, we will identify the feedstocks that are feasible for each technology and the approximate yield of fuel from each feedstock type. The standardized descriptions of the drop-in fuel technologies will populate a spreadsheet model of the conversion technologies, which will be made publicly available. Parker has performed similar analysis for biomass-based hydrogen [18], cellulosic ethanol and biomass-based F-T diesel [6-8] in past work. An initial list of techno-economic studies of drop-in fuels that have been currently identified is given in Table 1. More studies will be identified during the literature review conducted as part of this project.

The review of the industry will result in a database of projects that will track the current status of all known drop-in fuel projects. This database would be similar to the Advanced Biofuels and Chemicals Database (ABCD) that is currently maintained by Biofuels Digest [19]. The major difference would be to track the current status of project development and to update quarterly through the timeframe of the project.

Task 2: Life-cycle assessment of selected drop-in fuel pathways.

This task will collect and review LCA results from previously published studies in peer-reviewed and other literature. Studies will be analyzed by disaggregating assumptions, data, and results by life cycle stage (i.e. feedstock production, transport, conversion); by system boundary definition and scope, including the scale of assumed production; and the source of underlying data (laboratory results in an engineering model, pilot scale plant runs, etc.). These findings will be recorded in a critical review matrix, which will facilitate conducting a meta-analysis of particular feedstocks, conversion technologies, or complete pathways if a sufficient number of studies are available.

During meta-analysis some modification of previously published LCAs may be conducted to ensure a fair comparison and synthesis of pathways. To conduct effective meta-analyses, analyzed studies must be made commensurate by ensuring similar assumptions, data sources, and processes are modeled. This requires that some studies be adjusted or modified in order to include them in the analysis. Published studies, the GREET model, and life cycle inventory data from the GaBi software tool (including the PE Americas Professional Database, NREL's USLCI Database, and Ecoinvent Database) will all be used if required to expand or alter studies. Co-products treatment methods and assumptions will be made commensurate where necessary and possible. Many studies are not reported with sufficient transparency and granularity for alterations to be made [20]. In such cases comparisons across studies may not be feasible.

Since the body of literature on LCA of drop-in fuels is limited to handful of studies on renewable diesel and aviation fuels (e.g. [21-23], it may be necessary to draw on or enhance LCAs of other biofuels, or use cost and engineering data to estimate life cycle performance. LCA models for various feedstocks, pretreatment, transport and conversion technologies will also be drawn from existing biofuel LCA models completed by the Kendall research team. Examples include existing production models (with varying levels of detail) for corn, corn stover, switchgrass, canola, orchard biomass, energy beets, and a number of California agricultural residuals (i.e. rice hulls, almond hulls and shells, woody biomass from orchards, etc.), along with models for some typical pre-treatment and conversion processes for ethanol and biodiesel production [24-26].

Task 3: Assess near-term prospects for drop-in fuels.

This task will consider the immediate timeframe 2015-2020. The projects currently announced by the industry represent the potential production occurring within the next 4 years. Some of these projects will inevitably be delayed or fail to materialize. A dynamic model projecting the projects that are currently in process along with scenarios addressing uncertainty for start-up and production success will be developed that will explore near term supply of drop-in fuels by showing the impact of failure rates and delays on the potential supply in the 2015-2020 timeframe that is important for LCFS implementation. The scope will consider projects in California, the U.S. and Brazil as likely fuel providers for the California market.

To assess the carbon intensity of these early projects, the fuel pathways will be matched to fuel pathways for which data exists for LCA in Task 2. If representative LCA fuel pathways do not exist, efforts to estimate likely carbon intensity will be made, such as by altering pathways (i.e. substitution of feedstocks) or selecting pathways that are most similar based on feedstock, location, and conversion technology.

An analysis of the expected cost of fuels from early projects will be performed utilizing the technology models developed in Task 1 to project the costs for pioneer biorefineries anticipated to be the first-of-a-kind. In addition to cost increases due to first implementation, these pioneer biorefineries are likely to suffer from higher capital costs and lower capacity factors compared to the nth-of-a-kind designs found in the academic literature. These additional costs can be roughly estimated using a model developed by RAND [27] and has been used in the assessment of advanced biofuels by Annex [28] and in preliminary work by Parker [29].

Task 4: Spatially-explicit model of selected drop-in fuel pathways.

The future economic supply beyond 2020 will be assessed using the Geospatial Bioenergy System Model (GBSM). The GBSM provides a basis for quantifying potential fuel supply scenarios for the industry by linking technology models of conversion process with spatial resource assessment and emissions modeling. The model was developed to predict optimal bioenery supply chain configurations [6-8]. It is built on an integrated resource and infrastructure geospatial database containing geographic and cost data for all aspects of the bioenergy production chain. The GBSM uses the geographic and cost data as input to a Mixed Integer-Linear Program (MILP) that optimizes geographic location and size for biorefineries. The MILP optimizes the production system based on the feedstock procurement supply curve, feedstock and fuel transport costs calculated from a geographic transportation network, and costs for conversion of biomass into products. The model includes a broad range of technologies as options for utilizing biomass resource. Including emission factors within the optimization model allows for environmental criteria to be integrated into the optimization as either constraints on the feasible set of outcomes or to modify the optimization to minimize release of air pollutants or minimize resource consumption for a given amount of energy provided.

The Geospatial Bioenergy Systems Model (GBSM) has been developed to analyze the question of scaling and system design for bioenergy applications. Optimal system configurations are found using a profit maximizing optimization model. It has been used to consider biofuels production generally for California [8], the western US [7], and nationally [6]. These previous analyses have focused on improving the understanding of the cost and supply potential of biofuels in these three geographies. The California analysis included competition between biofuel and biopower as markets for biomass feedstock. A detailed analysis of a hybrid poplar drop-in biofuel system in the Pacific Northwest is currently underway.

For this project the GBSM will be modified to add the drop-in fuel pathways selected for detailed analysis and to perform multi-criteria analysis on these pathways by solving for alternative objectives including minimizing carbon intensity of the fuels, minimizing criteria air pollutants in air basins with poor air quality and profit maximization including a value for carbon. The GBSM was developed with the capability to consider these alternative objective functions. Past work has focused on simulating the industry based on the economic incentives in place while tracking environmental performance [30]. Two ongoing projects are improving the modeling capability with respect to criteria air pollutant emissions. Pathways will be analyzed individually unless synergies are found in the literature that suggest benefits from combined pathways

The spatial aspect of the modeling framework will allow us to analyze where drop-in fuels should be produced to fulfill different objectives of maximize the supply of fuels, maximizing the profitability of the industry, minimizing the carbon intensity of the fuels and minimizing air quality impacts. The expected results will identify where within California biorefineries might best located and also which regions in the U.S. are most compatible with production of drop-in fuels to supply California given different resources and other constraints.

Task 5: Solicit stakeholder feedback on research needs and barriers.

Research needs and barriers to commercialization of drop-in fuels will be identified and documented through the literature review in Task 1. In order to verify the research needs and barriers identified, we will solicit stakeholder feedback via a survey instrument as well as targeted workshops, meetings, and dynamic web-based interactions. Interviews and/or workshops with industry, NGO, and state agency stakeholders will review, brainstorm and prioritize the research needs and barriers. While statistically significant sampling of industry leaders and quantitative outcomes may be desirable, it is not realistic given the time frame, the scope for the proposed research, and the limited pool of commercial bioenergy leaders to draw from. Instead qualitative research methods will be applied which are suitable for smaller sample sizes and which still provide valuable insights for understanding real and perceived barriers to commercialization of drop-in fuels.

Members of the UC Davis team will attend and present at industry conferences and attend other workshops and events where networking opportunities exist with biofuel industry leaders. Examples of industry conferences include Advanced Biofuels Markets, Advanced Biofuels Leadership Conference, International Bioenergy & Bioproducts Conference, BIO World Congress, and MSW to Biofuels and Bioproducts Summit. The UC Davis team will also attend and participate in relevant public meetings held by state agencies (ARB, CEC and CalEPA). Additionally, industry contacts in the oil and automotive industry will be consulted during the bi-annual NextSTEPS symposia hosted by UC Davis Institute of Transportation Studies.

Task 6: Develop monitoring protocol for drop-in fuels.

The field of drop-in fuels is rapidly developing and will require frequent updates on an on-going basis in order to maintain the databases created during the literature review task. Updates to the database can be facilitated through the creation of alert queries in the major academic literature search engines (Sciencedirect, Google Scholar, JSTOR, etc), news feeds tracking industry developments, and from dynamic web-interactive tools that can be initiated under this effort. For the duration of the project, these queries will be developed and screened to find the appropriate queries for delivering the needed updates while maintaining quality control. UCD will deliver the databases to ARB staff along with a set of query alerts and protocol for updating at the conclusion of the project.

Task 7: Final Report

A comprehensive final report will be provided to ARB six months before the end of the project period. Consultation with the ARB during quarterly meetings will help us tailor the content of our final report to ARB's needs; however, we anticipate the Final Report will include documentation of research performed, research findings including future research needs, and a description of the monitoring protocol developed. In addition to the Final Report, the database created during Task 6 will be provided to ARB with a user guide for implementing the protocol and maintaining the database after the project period.

Data Management Plan.

Tasks 2-4 use models that require input data on, amongst others:

- process and material flows for fuel pathway
- capital and operating costs of future biorefineries
- prices of feedstocks
- conversion efficiencies for biorefineries
- fuels market data

We will collect the data from pertinent sources including but not limited to research articles and technical reports and databases from the US Departments of Energy, Agriculture and Transport, Energy Information Administration, International Energy Agency, relevant industry, and other stakeholders. Data collected will be stored and documented in a database that will be regularly updated. Both valid ranges and average values will be documented. Data uncertainty will be minimized through appropriate statistical treatment. Appropriate aggregation/disaggregation and up- or downscaling techniques will be used for spatial data. When available, peer-reviewed data and spatial datasets will be used. Data will be contrasted with as many alternative data sources as possible. Results from models will be validated against observed data when applicable.

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Project schedule.

The proposed project consists of six main Tasks, identified below, which are proposed to be completed over three years, starting in July of 2013.

Task 1: Review the literature
Task 2: Life-cycle assessment of selected drop-in fuel pathways
Task 3: Assess near-term prospects for drop-in fuels
Task 4: Spatially-explicit model of selected drop-in fuel pathways
Task 5: Solicit stakeholder feedback on research needs and barriers
Task 6: Develop monitoring protocol for drop-in fuels
Task 7: Final report

For the following timeline charts (one for each year of the proposed project):

m = Quarterly meeting with ARB staff
p = Quarterly progress report
dr = Deliver draft final report (to be submitted 6 months prior to contract expiration)
fr = Deliver final report

Year 1	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Task 1												
Task 2												
Task 3												
Task 4												
Task 5												
Task 6												
	m			m, p			m, p			m, p		

Year 2	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Task 1												
Task 2												
Task 3												
Task 4												
Task 5												
Task 6												
	m			m, p			m, p			m, p		

Year 3	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Task 1												
Task 2												
Task 3												
Task 4												
Task 5												
Task 6												
Task 7												
	m, p			m, p			m, p, dr			m, p		p, fr

Curriculum Vitae of Key Scientific Personnel.

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Energy Institute and Institute of Transportation Studies
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Education

University of California, Davis	Transportation Technology and Policy	Ph.D., 2011

Dissertation Title: "Modeling future biofuel supply chains using spatially explicit infrastructure optimization"

Committee: Dr. Joan Ogden (chair), Dr. Bryan Jenkins, and Dr. Yueyue Fan

University of California, Davis	Transportation Technology & Policy	M.S., 2007
Wake Forest University	Physics	B.S., 2001

Research Experience

University of California, Davis, Institute of Transportation Studies (10/03 – present)

My research simulates industries for providing alternative fuels with a unique focus on the spatial design of the infrastructure required. I have worked collaboratively on most projects with my role being the development of the simulation models and detailed techno-economic modeling of key technologies. I use methodologies from operations research including mixed integer-linear programming, stochastic programming, and systems dynamics models.

Awards and Fellowships

Charley V. Wootan Award for Outstanding MS Thesis - 2007
Awarded by Council of University Transportation Centers for the best master's thesis in policy and planning in the U.S.

Outstanding Student of the Year for the UC Davis Sustainable Transportation Center for 2010

U.S. DOE Graduate Automotive Technology Education (GATE) Fellowship, 10/03-09/04.

Selected Publications

Working papers

Holland, Steven, Jonathan Hughes, Chris Knittel and Nathan Parker, 2011. "Some Inconvenient Truths About Climate Change Policy: The Distributional Impacts of Transportation Policies," NBER Working Papers 17386, National Bureau of Economic Research, Inc.

Journal articles

Parker, Nathan. "Spatially-Explicit Biofuel Supply Projection for Meeting the Renewable Fuel Standard," *Transportation Research Record* (2012) (No. 2287), pp. 72–79.

Parker, Nathan, Peter Tittmann, Quinn Hart, Richard Nelson, Ken Skog, Anneliese Schmidt, Edward Gray, and Bryan Jenkins. "Development of a biorefinery optimized biofuel supply curve for the Western United States." *Biomass and Bioenergy* (2010) (34), pp 1597-1607.

Tittmann, Peter, Nathan Parker, Quinn Hart, and Bryan Jenkins. "A spatially explicit techno-economic model of bioenergy and biofuels production in California." *Journal of Transport Geography* (2010) 18(6):715-728.

Parker, Nathan, Yueyue Fan, and Joan Ogden. "From wastes to hydrogen: an optimal design of biohydrogen supply chain," *Transportation Research Part E* (2010) 46(4): 534-545.

Yeh, Sonia, Nicholas P. Lutsey and Nathan C. Parker. "Assessment of technologies to meet a low carbon fuel standard." *Environ. Sci. Technol.* (2009) 43 (18), pp 6907-6914.

Parker, Nathan, Joan Ogden and Yueyue Fan. "The role of biomass in California's hydrogen economy." *Energy Policy* 36 (2008) 3925–3939.

Book chapters

Parker, Nathan, Bryan Jenkins, Peter Dempster, Brendan Higgins, and Joan Ogden. "The Biofuel Pathway," in *Sustainable Transportation Energy Pathways: A Research Summary for Decision Makers*. edited by: Joan Ogden and Lorraine Anderson. 2011.

Technical reports

Parker, Nathan, Quinn Hart, Peter Tittmann, and Bryan Jenkins. "National Biofuel Supply Analysis," prepared for the Western Governors' Association, contract # 20113-03. April, 2011. http://westgov.org/component/joomdoc/doc_download/1456-national-potential-for-biofuels-

Parker, Nathan, Peter Tittmann, Quinn Hart, et al. "Strategic assessment of bioenergy development in the west: Spatial analysis and supply curve development." 2008. Denver, CO.:Western Governors' Association. www.westgov.org/wga/initiatives/transfuels/index.html.

Tittmann, Peter, Nathan Parker, Quinn Hart, et al. "Economic potential of California biomass resources for energy and biofuel." 2008. California Energy Commission/Contract 500-01-016. Sacramento, CA.

Policy Outreach

Jenkins, Bryan, Nathan Parker, Quinn Hart, et al. "National Biorefinery Siting Model: Optimizing Bioenergy Development in the U.S." presented to NRC Committee on the Economic and Environmental Impacts of Increasing Biofuels Production. Washington, D.C. March 5, 2010.

Served as a scientific expert for the California Air Resources Board on the California Low Carbon Fuel Standard regulation. 2009.

Alissa Kendall

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EDUCATION

University of Michigan, Ann Arbor: Ph.D. School of Natural Resources & Environment and Department of Civil & Environmental Engineering (jointly conferred), 2007

University of Michigan, Ann Arbor: M.S. Natural Resource Policy, 2004

University of Michigan, Ann Arbor: Certificate in Industrial Ecology, 2004

Duke University: B.S. Environmental Engineering, 2000

POSITIONS HELD

2007-Present, Assistant Professor, Department of Civil and Environmental Engineering, University of California, Davis, CA

UC Davis Affiliations: Institute of Transportation Studies, Energy Institute, Agricultural Sustainability Institute

2002-2007, Research Assistant, Center for Sustainable Systems, University of Michigan, Ann Arbor, MI

2000-2002, Product Development Engineer, Advanced Powertrain Vehicles, Ford Motor Company, Dearborn, MI

PUBLICATIONS

PEER-REVIEWED JOURNAL ARTICLES IN THE LAST 5 YEARS

1. Li, H., Harvey, J., & Kendall, A. (2013). Field measurement of albedo for different land cover materials and effects on thermal performance. *Building and Environment, 59*(0), 536-546.
2. Kendall, A., Yuan, J., Brodt, S. B. (2012) “Carbon Footprint and Air Emissions Inventories for US Honey Production: Case Studies” *International Journal of Life Cycle Assessment* DOI: 10.1007/s11367-012-0487-7
3. Wang, T., Lee, I-S., Kendall, A., Harvey, J., Lee, E. B., Kim, C. (2012) “Life Cycle Energy Consumption and GHG Emission from Pavement Rehabilitation with Different Rolling Resistance” *Journal of Cleaner Production* 33: 86-96. DOI:10.1016/j.jclepro.2012.05.001
4. Kendall, A. (2012) “Time-Adjusted Global Warming Potentials for LCA and Carbon Footprints" *International Journal of Life Cycle Assessment* 17(3): 1042-1049. DOI:10.1007/s11367-012-0436-5
5. Higgins, B., Kendall, A. (2012) "Life-Cycle Environmental and Cost Impacts of Using an Algal Turf Scrubber to Treat Dairy Wastewater" *Journal of Industrial Ecology* 16(3): 436-447. DOI:10.1111/j.1530-9290.2011.00427.x
6. Price, L., Kendall, A. (2012) “Wind Power as a Case Study: Improving LCA Reporting to Better Enable Meta-Analyses” *Journal of Industrial Ecology* 16(S1): S22-S27. DOI:10.1111/j.1530-9290.2011.00458.x
7. Kendall, A., Price, L. (2012). “Incorporating Time-Corrected Life Cycle Greenhouse Gas Emissions in Vehicle Regulations” *Environmental Science & Technology* 46(5): 2557-2563. DOI:10.1021/es203098j

8. Kendall, A. (2012) “A Life Cycle Assessment of Biopolymer Production from Material Recovery Facility Residuals” *Resource Conservation and Recycling* 61: 69-74. DOI:10.1016/j.resconrec.2012.01.008
9. Kendall, A., McPherson, E. G. (2012) “A Life Cycle Greenhouse Gas Inventory of a Tree Production System” *The International Journal of Life Cycle Assessment* 17: 444-452. DOI:10.1007/s11367-011-0339-x
10. Pelletier, N., Audsley, E., Brodt, S., Garnet, T., Henriksson, P., Kendall, A., Kramer, K., Murphy, D., Nemecek, T., Troell, M., Tyedmers, P. (2011) “Energy Intensity of Agriculture and Food Systems” *The Annual Review of Environment and Resources, 2011*. 36: 7.1–7.24. DOI:10.1146/annurev-environ-081710-161014
11. Chang, B., Kendall, A. (2011) “Life Cycle Greenhouse Gas Assessment of Infrastructure Construction for California’s High Speed Rail System” *Transportation Research Part D* 16(6): 429-434. DOI:10.1016.j.trd.2011.04.004
12. Zhang, H., Keoleian, G. A., Lepech, M. D., Kendall, A. (2010) “Life-Cycle Optimization of Pavement Overlay Systems” *Journal of Infrastructure Systems* 16: 310-323. DOI:10.1061/(ASCE)IS.1943-555X.0000042
13. Kendall, A., Kesler, S. E., Keoleian, G. A. (2010) “Megaquarry vs. Decentralized Mineral Production: Network Analysis of Cement Production in the Great Lakes Region, USA” *Journal of Transport Geography* 18(2): 322-330. DOI:10.1016/j.jtrangeo.2009.06.007
14. Kendall, A., Chang, B., Sharpe, B. (2009) “Accounting for Time-Dependent Effects in Biofuel Life Cycle Greenhouse Gas Emissions Calculations” *Environmental Science & Technology* 43(18): 7142–7147. DOI:10.1021/es900529u
15. Kendall, A., Chang, B. (2009) “Estimating life cycle greenhouse gas emissions from corn-ethanol: A critical review of current US practices” *Journal of Cleaner Production.* 17: 1175-1182. DOI:10.1016/j.jclepro.2009.03.003
16. O’Hare, M., Plevin R. J., Martin J. I., Jones, A. D., Kendall, A., Hopson, E. (2009) “Proper Accounting for Time Increases Crop-Based Biofuels’ GHG Deficit versus Petroleum” *Environmental Research Letters* 4 (024001). DOI:10.1088/1748-9326/4/2/024001
17. Kapur, A., van Oss, H., Keoleian, G., Kesler, S., Kendall, A. (2009) “The contemporary cement cycle of the United States” *Journal of Material Cycles and Waste Management* 11(2): 155-165. DOI:10.1007/s10163-008-0229-x
18. Kendall, A., Kesler, S. E., Keoleian, G. A. (2008) “Geologic vs. Geographic Constraints on Cement Resources in the Great Lakes Region” *Resources Policy.* 33: 160-197. DOI:10.1016/j.resourpol.2008.03.001
19. Kapur, A., Keoleian, G. A., Kendall, A., Kesler, S. E. (2008) “Dynamic Modeling of In-use Cement Stocks in the United States” *Journal of Industrial Ecology* 12(4): 539-556. DOI:10.1111/j.1530-9290.2008.00055.x
20. Kendall, A., Lepech, M. D., Keoleian, G. A. (2008) "Materials Design for Sustainability through Life Cycle Modeling of Engineered Cementitious Composites" *Materials and Structures.* 41: 1117-113. DOI:10.1617/s11527-007-9310-5
21. Kendall, A., Keoleian, G. A., Helfand, G. (2008) “An Integrated Life Cycle Assessment and Life Cycle Cost Analysis Model for Concrete Bridge Deck Applications” *Journal of Infrastructure Systems.* 14(3): 214-222. DOI: 10.1061/(ASCE)1076-0342(2008)14:3(214)

Bryan M. Jenkins

Distinguished Professor of Biological and Agricultural Engineering

Director, UC Davis Energy Institute

University of California, Davis

Prof. Jenkins teaches and conducts research in the areas of energy and power, with emphasis on biomass and other renewable resources. Dr. Jenkins has more than thirty years experience working in the area of biomass thermochemical conversion including combustion, gasification, and pyrolysis. His research also includes analysis and optimization of energy systems. He teaches both graduate and undergraduate courses on energy systems, heat and mass transfer, solar energy, and power and energy conversion, including renewable energy and fuels, economic analysis, environmental impacts, fuel cells, engines, electric machines, fluid power, cogeneration, heat pumps, thermal storage, and other technologies. Prof. Jenkins is a recipient of an Outstanding Achievement Award from the US Department of Energy for exceptional contributions to the development of bioenergy, and the Linneborn Prize from the European Union for outstanding contributions to the development of energy from biomass. Prof. Jenkins is currently Director of the UC Davis Energy Institute.

Education and Training:

University of Maryland, College Park	Agricultural Engineering	B.S., 1975
University of California, Davis	Engineering (Agricultural/Energy)	M.S., 1977
University of California, Davis	Engineering (Agricultural/Energy)	Ph.D., 1980

Research and Professional Experience:

1981-Present	Assistant, Associate, Full and Distinguished Professor of Biological and Agricultural Engineering, University of California, Davis
2007-Present	Director, UC Davis Energy Institute
2003-2008	Executive Director (2003-07); co-director (2008), California Biomass Collaborative
2003-2006	Affiliate Researcher, California Senate Office of Research
2002-2003	Visiting Researcher, Governor's Office of Planning and Research
1993-1994	Sabbatical Professor, Combustion Research Facility, Sandia National Laboratories, Livermore
1979-1981	Senior Resource Engineer, Pacific Gas and Electric Company, San Francisco, California

Graduate Group Membership-UC Davis

Biosystems Engineering	Mechanical and Aeronautical Engineering

International Agricultural Development Transportation Technology and Policy

Selected Relevant Publications:

1. Jenkins, B.M., S.Q. Turn and R.B. Williams. 1992. Atmospheric emissions from agricultural burning in California: determination of burn fractions, distribution factors, and crop specific contributions. Agriculture, Ecosystems, and Environment 38:313-330.
2. Jenkins, B.M., I.M. Kennedy, S.Q. Turn, R.B. Williams, S.G. Hall, D.P.Y. Chang, O.G. Raabe, and S.V. Teague. 1993. Wind tunnel modeling of atmospheric emissions from agricultural burning: influence of operating configuration on flame structure and particle emission factor for a spreading type fire. Environmental Science and Technology 27(9):1763-1775.
3. Lawson, R.J., M.B. Schenker, S.A. McCurdy, B. Jenkins, L.A. Lischak, W. John and D. Scales. 1995. Exposure to amorphous silica fibers and other particulate matter during rice farming operations, Appl. Occup. Environ. Hyg. 10(8):677-684.
4. Jenkins, B.M., A.D. Jones, S.Q. Turn and R.B. Williams. 1996. Emission factors for polycyclic aromatic hydrocarbons (PAH) from biomass burning. Environmental Science and Technology 30(8):2462-2469.
5. Jenkins, B.M., A.D. Jones, S.Q. Turn and R.B. Williams. 1996. Particle concentrations, gas-particle partitioning, and species intercorrelations for polycyclic aromatic hydrocarbons (PAH) emitted during biomass burning. Atmospheric Environment 30(22):3825-3835.
6. Jenkins, B.M., L.L. Baxter, T.R. Miles Jr. and T.R. Miles. 1998. Combustion properties of biomass, Fuel Processing Technology 54:17-46.
7. Thy, P., C.E. Lesher and B.M. Jenkins. 2000. Experimental determination of high temperature elemental losses from biomass fuel ashes. Fuel 79(2000):693-700.
8. Jenkins, B.M., J.J. Mehlschau, R.B. Williams, C. Solomon, J. Balmes, M. Kleinman and N. Smith. 2003. Rice straw smoke generation system for controlled human inhalation exposures. Aerosol Science and Technology 37:437-454.
9. Kim, D.H. and B.M. Jenkins. 2008. Optimal orientation of a liquid-film solar-assisted brine concentrator. Journal of Solar Energy Engineering-TRANS of the ASME 130(2): Article Number 024503.
10. Parker, N., P. Tittmann, Q. Hart, R. Nelson, K. Skog, A. Schmidt, E. Gray and B. M. Jenkins. 2010. Development of a biorefinery optimized biofuel supply curve for the western United States. Biomass and Bioenergy 34(11):1597-1607.
11. Tittmann, P., N. Parker, Q. Hart, and B. Jenkins. 2010. A spatially explicit techno-economic model of bioenergy and biofuels production in California. Journal of Transport Geography 18(6):715-728.
12. Thy, P., B.M. Jenkins, R.B. Williams, C.E. Lesher and R.R. Bakker. 2010. Bed agglomeration in a fluidized bed combustor fueled by wood and rice straw blends. Fuel Processing Technology 91(11):1464-1485.
13. Jenkins, B.M., L.L. Baxter and J. Koppejan. 2011. Biomass Combustion. Chapter 2 in R. Brown (ed.), Thermochemical processing of biomass: conversion into fuels, chemicals and power, John Wiley & Sons, Hoboken, New Jersey.
14. Schick, S.F. and K.F. Farraro, J. Fang, S. Nasir, J. Kim, D. Lucas, H. Wong, J. Balmes, D.K. Giles and B. Jenkins. 2012. An apparatus for generating aged cigarette smoke for controlled human exposure studies. Aerosol Science and Technology 46:1246-1255.

Synergistic Activities:

- **Awards (last 3 years):**
  - Johannes Linneborn Prize for Achievements in Biomass Development, 2009
  - ASABE Academic Bioenergy Pioneer Award, 2009
  - Distinguished Engineering Alumni Achievement in Public Service Award, 2011
- **Member:**
  - American Society of Agricultural and Biological Engineers (ASABE)
  - American Society of Mechanical Engineers (ASME)
  - American Chemical Society (ACS)
- **Professional Service:**
  - Director, UC Davis Biomass Laboratory
  - Founding co-chair, UC Davis Bioenergy Research Group
  - Faculty director, Chevron-UC Davis Joint Research Agreement
  - Principal Investigator, California Renewable Energy Center

Preliminary Cost Proposal.

Task	Labor	Travel	Supplies	Administrative Support	Employee Fringe Benefits	Overhead	Total
Task1	$45,900	-	-	$3,300	$19,500	$5,900	$74,600
Task 2	$36,300	$1,000	$-	$2,800	$18,100	$4,300	$62,400
Task 3	$29,000	$-	$-	$2,000	$10,300	$4,100	$45,500
Task 4	$41,800	$1,000	$-	$3,000	$18,000	$5,500	$69,300
Task 5	$13,800	$5,500	$-	$1,200	$4,900	$2,500	$27,900
Task 6	$4,800	$-	$-	$300	$1,700	$700	$7,600
Task 7	$16,000	$-	$-	$1,100	$7,000	$2,000	$26,100
Subtotal	$187,500	$7,500	$-	$13,700	$79,500	$25,100	
						Grand Total:	$313,400