Title
Hybrid Poplar based Biorefinery Siting Web Application (HP-BiSWA): An online decision support application for siting hybrid poplar based biorefineries

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An online application for decision support in siting hybrid-poplar woody biomass-to-jet fuel and acetic acid production facilities in Pacific Northwest region

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Keywords
Biofuels, decision support, pacific northwest region, web application

Abstract
Poplar is an excellent feedstock for bioenergy but planning effective placement of biorefineries takes tremendous time and cost to locate the best place to
Need to investigate locations
Create data-driven decision support tool
Accessible and easily configurable.

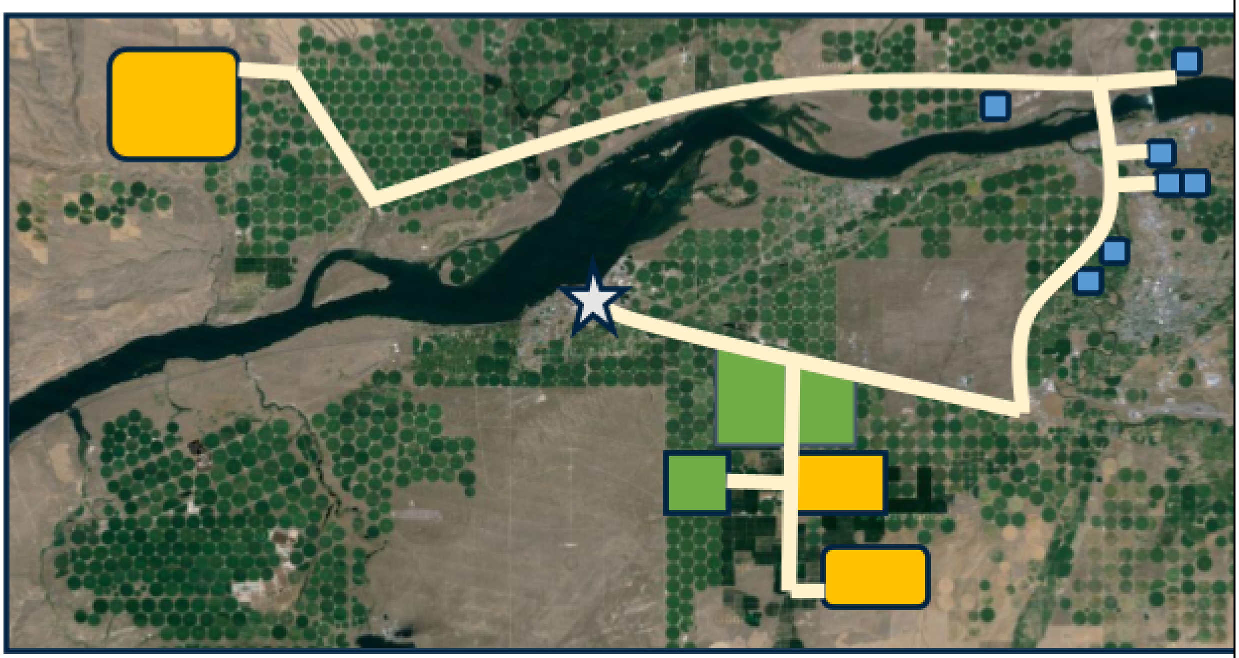
1) Introduction

Hybrid poplar is considered as an excellent feedstock for the production of bioenergy and bio-based products in the U.S. Pacific Northwest (PNW) region. Hybrid poplar has been cultivated for many years in the PNW region, and has seen success in many industries (e.g. pulp and paper industries). There is an existing technology for hybrid poplar production and transportation which makes relatively easily to create poplar based industry. Besides, due to rapid growth rate and coppicing characteristics, they can provide consistent and abundant feedstock material for biofuel production. Further, they offer a wide range of ecosystem services (e.g. positive impact on soil and water quality) (Gan 2007; Hinchee et al. 2009; Camargo et al., 2013).

The Advanced Hardwood Biofuels Northwest (AHB) project, a research and development initiative supported by the U.S. Department of Agriculture National Institute of Food and Agriculture (USDA-NIFA), focuses on laying foundation for the development of sustainable hybrid poplar biomass based industries in the PNW region. The development of industry requires scientific and technical knowledge that demonstrates the feasibility and economic viability of poplar biomass based industries. This knowledge encourages project stakeholders to enter into this industry, and also helps in the establishment of policies and programs promoting industries.

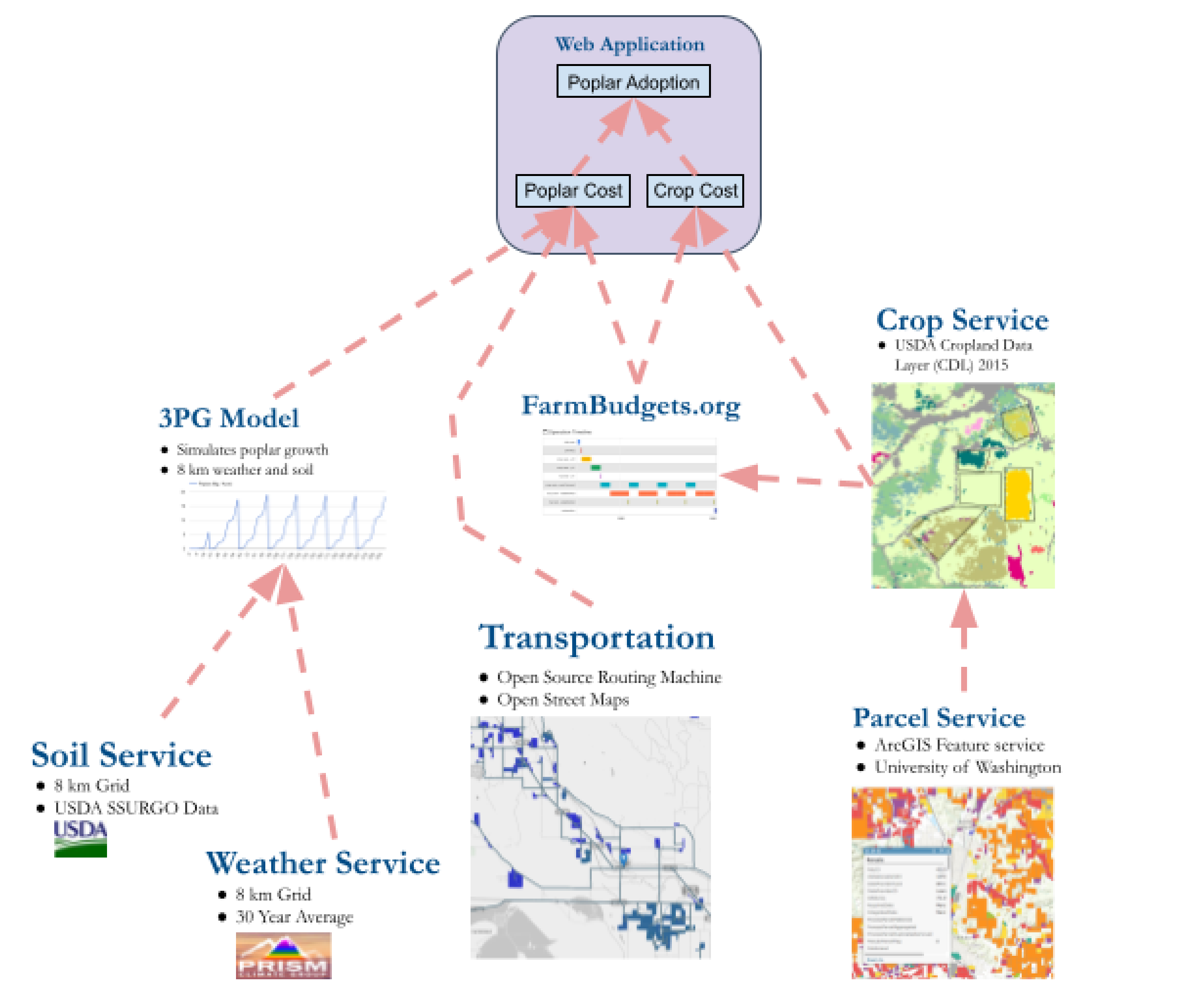
There are various decision options involved in the development of a biomass based industry some of which include economies of scale, conversion technology, policy considerations, and decisions and their interactions have strong influence on investment and returns depending location of the facility and biomass availability and its distribution, thereby affecting long-term viability. Therefore, it is critical to have decision support system that integrates increasingly precise and fine-scale data on polar biomass availability under current and future conditions, transportation and utilities infrastructure, and provides data-driven vision of effects of various decisions and factors affecting success of biomass based industries. Such decision system in a web interface allows stakeholders to quickly assess various decision options at locations of interest and understand the feasibility, barriers and possible solutions and help in formulate strategies and policies that lead to development and deployment of successful industries.

As part of AHB project, we have developed an online decision support system that allows assessment of individual sites across the PNW region to understand the economic competitiveness, and financial risks of hybrid poplar based jet-fuel and acetic acid production facilities. The objective of the paper is threefold 1) describe the architectural design and its development (**Section 2**) so that it enables others, who are interested in similar resource management and decision support tools, to adopt our architectural design 2) describe the usage of the application (**Section 3**) to evaluate any given site under various decision options 3) implement the application (**Section 4**) at currently operated coal plant, Centralia, WA to demonstrate the utility of the application.



Conceptual diagram of the Decision Support Tool.

2) Description of Application Development



AHB-DST Service Overview

The AHB-DST is a complex web application relying on multiple underlying services and modules to run. Two of the modules were prebuilt applications from prior AHB research which include 1) poplar-3PG Poplar Model Application (http://poplarmodel.org/) [1] developed for site specific hybrid poplar biomass estimation, and 2) Farm Budgets Application (http://farmbudgets.org/) developed to maintain and access budget information for various crops across the PNW region.

Several new services needed to be developed to provide the broad range of data required to model the economic decisions. These services include; new soil and weather services to run the poplar-3PG Model at scale, a transportation service for routing hybrid poplar from farm to biorefinery, a parcel service with land use suitability information, a crop type and yield service to lookup incumbent crop information. Finally all of these components need to be integrated to produce a web application that executes inside a modern browser. All economic calculations happen on the client, therefore the amount of data stored could not exceed a modern browsers memory limits and the code had to be optimized to provide results in a reasonable execution time.

2.1) Prior Application Integration

The AHB-DST was built using Software Development Kits (SDK) developed for two prior AHB applications (i.e. Poplar-3PG Model Application and Farm Budgets Application) . The Poplar Model Application was initially designed as a standalone application using a JavaScript port of the original 3PG model code to execute the model in a modern web browser. To reuse this JavaScript version of the 3PG model, the code for running the 3PG model was split from the 3PG applications user interface (UI) into a NodeJS module, poplar-3PG-model [2]. This 3PG module is imported into the AHB-DST as a Node Package Manager (NPM) dependency allowing for 100% code reuse between the two applications.

The Farm Budgets Application was built from the ground up as two separate repositories; the farm-budgets-app [3] and the farm-budgets-sdk [4]. The farm-budgets-app contained API services required to power the farm-budgets-sdk as well as the UI or view in a model-view-controller (MVC) methodology. The farm-budgets-sdk holds the models and controllers, communicating with the view via events and method calls. With the farm-budgets-sdk published to NPM, the AHB-DST imports the SDK as a dependency along with the poplar-3PG-model. With the farm-budgets-sdk fully integrated into the AHB-DST, the AHB-DST was able to search, load and calculate budgets in the same manor as the farm budgets application.

2.2) Application Services

2.2.1 Soil and weather services

To simulate poplar growth over a parcel using poplar-3PG-model, weather and soil information are required. Poplar-3PG web application runs on grid cells, and soil and weather services of popla-3PG web application retrieve soil and weather data for a given grid cell from database based on latitude and longitude of the center of the grid cell. However, AHB-DST application requires to run on multiple parcels. For instance, biomass collection radius is 200 km, then poplar-3PG application need to be run over 27,000 parcels. As such, existing soil and weather services designed for original 3-pg web application will not reasonably scale to the number of soil and weather data requests required to run a AHB-DST simulation, hence, we created new soil and weather service to handle the amount of soil and weather data required by these larger simulations. The new AHB-DST soil and weather services take arrays of latitudes and longitudes as inputs, returning an array of results, one result for each provided latitude and longitude of a parcel. To further optimize the data transfer, AHB-DST groups parcels by 8-km grid cell on which original poplar-3PG application operates. Parcels are smaller than 8-km grid cell therefore, for each 8-km grid cell, there will be multiple parcels. Further, it uses the latitude and longitude of each 8-km grid cell to request soil and weather data to run the simulations for parcels of each grid cell. Only one point is used for each AHB pixel. The weather data is a 30 year average provided by PRISM [5] while the soil data is provided by the USDA SSURGO Data [6].

2.2.2 Transportation routing service

Transportation routes, both time and distance from parcel to biorefinery, are required when calculating feedstock costs at the refinery gate. To calculate optimized transportation routes, the Open Source Routing Machine [7] (OSRM) service is used. OSRM easily imports OpenStreetMap [8] (OSM) data, providing tools to turn individual polylines into a connected graph for routing. While ORSM can be used as standalone service, the NPM ORSM module was used instead. The ORSM module is wrapped inside a NodeJS Express [9] server creating the custom osrm-transportation-server [10]. This standalone server provides optimized query mechanisms for the multiple source, single destination query required by the AHB-DST. Finally, the application needs to be able to scale with the large amount of data that would be sent when routing over 27,000 parcels. To provide user feedback as well as reasonable JavaScript Object Notation (JSON) sized payload to the browser, Socket.IO [10] is used to communicate with the server while transportation routes are being calculated. Socket.IO library opens a websocket allowing data to be pushed to the browser. As routes are calculated, the results are sent back to the browser along with progress information allowing the AHB-DST client to display percent complete information to the user as well as parse reasonably sized JSON payloads.

2.2.3 Parcel service

Parcel information is critical to the success of the AHB-DST. While UC Davis built most of AHB-DST, it is not the only university involved in the AHB project. Several other universities and private industrial partners collaborated to make the AHB project a success. The University of Washington, part of the AHB Sustainability Team along with UC Davis, built the parcel service [12] that powers the AHB-DST. This parcel service runs on ESRI ArcGIS Server [13]. The parcel service is used to load all parcels for a given biorefinery location and radius. This service responds with a parcel geometry, size and percent of parcel that is suitable for poplar growth. The parcel format is ESRI JSON which is then transformed into ISO standard GeoJSON using the terraformer-arcgis-parser [14]. Unfortunately large queries returning thousands of geometries from ArcGIS Server can be slow. To optimize this, the entire parcel service is cached inside PostgreSQL using PostGIS plugin which provides a large performance speedup. The AHB-DST code can be switched, using a single flag, from querying against ArcGIS to the PostGIS cache with the cache being the default.

2.2.4 Crop type service

A crop type service is required for discovery of the current incumbent crops for a parcel. To create the crop service, the USDA Cropland Data Layer [15] (CDL) was imported into to PostGIS. A service was created which takes a GeoJSON feature and returns the crop type information. The resulting information includes the local county and state FIPS code for the parcel. These codes are used later on to lookup crop price and yield information for the parcel. To increase application performance and execution time, this service is called during the parcel caching. So all results from the parcel cache already have the incumbent crop type information included.

Finally a crop price and yield service was created to load crop prices and yields by county. All parcels have their local county FIPS codes included from the crop type service. Every unique crop type and FIPS code for a model simulation is sent to the crop price and yield service which returns crop prices as well as yields for irrigated, non-irrigated and unspecified crops by county.

2.3) Application Design

The AHB-DST web application has two primary components; the front end application client that runs in the browser and the backend server which connects to the database and powers the service API endpoints. The code is split into two repositories, much like the Farm Budgets Application, with the core business logical (models, collections and controllers) in one SDK repository [16] and the backend web service code as well as the front end client UI or view code in the application repository [17]. This separation of concerns and splitting of the application business logic into it's own module allows for reuse of code for additional analysis outside the application's original design.

2.3.1) Front End Design

The applications front end is built using the Polymer web components library. Web components allow for native modular development of UI components inside the web browser. These components can then be composited together to form complex UI structures. LeafletJS was used for the client map, and a custom leaflet-canvas-geojson [18] plugin leveraging the HTML Canvas tag was built to handle the large number of geometries that would be rendered on the map. The Google Charts JavaScript library was leveraged for all charts within the application.

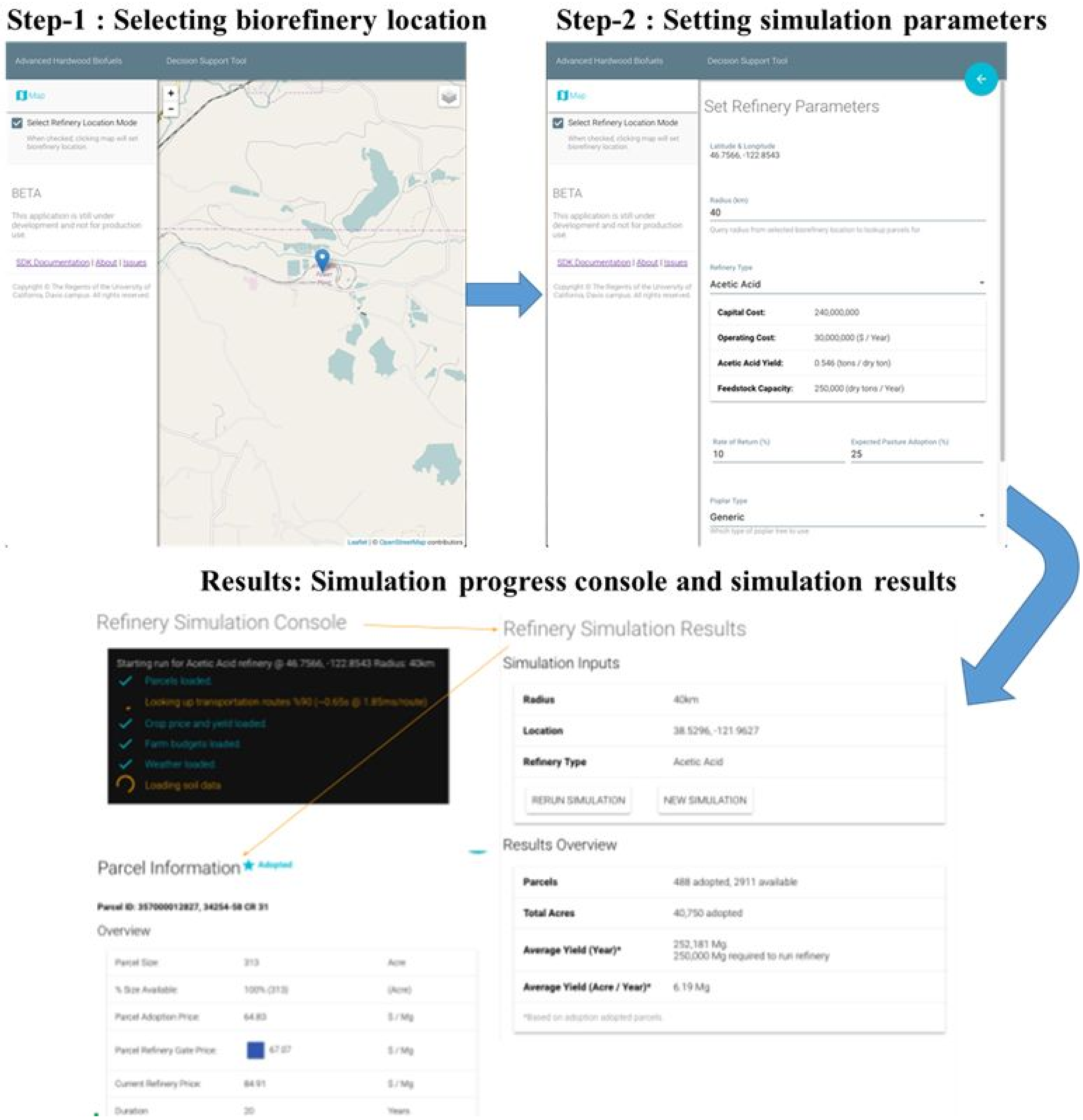
The SDK is composed of many NodeJS modules with dependencies handled using NPM. Currently modern browsers have no native way of loading modules so Browserify [19] is leveraged to bundle all required NodeJS modules into a single JavaScript file which can be loaded in the browser.

Another technological challenge of the AHB-DST is memory management. With the large amount data required to run the application, it's important to only store what data is required. A considerable amount of the data structure design was based on how to best conserve memory by not duplicating data fields. This data structure design process was similar to data normalization for storage in a tabular database except complex structures are still allowed.

2.3.2) Backend End Design

The backend server is a NodeJS Express server. PostgreSQL with the PostGIS plugin is used to store the weather, soil, parcel and crop data. Appropriate indexes have been built to ensure performant queries to the database. The transportation data is stored in OSRM. The backend is run in a container using Docker allowing the AHB-DST to be deployed to any server running Linux.

3. Description of Application Use



As shown in step 1 of figure xx, when AHB-DST is first loaded users are presented with a large map of the pacific northwest. Users can then pan and zoom to a specific location where they wish to place a biorefinery. Next the user clicks or taps the map to set the biorefinery at their desired location. Once the map is clicked, users are presented with a screen for entering information about the refinery and the model simulation (step-2 of figure xx). The model simulation inputs include; 1) a maximum radius from the refinery to collect poplar biomass, 2) a refinery type. Refinery options include acetic acid production technology, 100 MGY jet fuel production technology and 100 MGY jet fuel retrofit technology, 4) a target rate of return (ROR), expected pasture land adoption rate, 5) options to choose a hybrid poplar clone. Currently application models two hybrid poplar types including generic poplar type and Pont Beaupre clone, and 6) a checkbox to specify if transportation route geometry should be returned. Once all input parameters are chosen, the user clicks the Model Refinery button to run the application. As shown in the figure xx, users will then be presented with a console showing the progress of the execution as data loads, transportation routes are calculated and poplar growth is simulated for each parcel. Once the model finishes the simulation, the user is presented with a panel displaying a complete breakdown of the models results. Some of the displayed results include; number parcels available and adopted for poplar production within the selected radius, total acres used, average annual poplar yield per acre, refinery gate price per ton, farmers minimum willingness to accept for poplar production, biorefineries maximum willingness to pay for poplar biomass, biorefinery total cost over twenty years, biorefinery total income over twenty years, return on investment (ROI) based on biorefinery capital cost, chart for adoption of competing parcel, chart for adoption by crop, chart for adoption by price and a chart for adoption yield by price.

Along with overall simulation results, the user can click back on the map and inspect individual parcels. All parcels will be rendered on the map and colored by refinery gate price. The user can click on any parcel to inspect all associated data for that parcel, this data includes; parcel size, percent of parcel suitable for poplar growth, adoption and refinery gate poplar prices, incumbent crop information including cost, price and yield, poplar cost and yield information, transportation time, distance and cost information. Charts showing the revenue per acre of poplar vs the incumbent crop are displayed along with the predicted poplar growth for the parcel.

After a simulation has run the user is able to modify several input parameters without having to rerun the entire simulation. The user can; set the refinery gate price of poplar to see how the poplar adoption and ROI react, adjust the ROR, and adjust the expected pasture adoption rate. Pasture land is often the first to convert to poplar cultivation due to low expectation of returns from pasture when valuing pasture as feedstock. We noticed that application uses all the pasture when available in the given parcel which is not realistic because pasture demand could be increased for other purpose (e.g. dairy industry) after certain pasture land is adopted for poplar production, and farmers will have a greater reluctance to convert pasture for poplar cultivation. For this reason, we have included option to choose expected pasture adoption so pasture conversion can be restricted by a user selected percentage.

3.1) Irrigated vs Non-irrigated Poplar

Currently application uses irrigation in poplar-3PG model to calculate biomass for all parcels except for pasture or grasslands which are considered to be non-irrigated. Application will be updated to include USGS satellite based irrigated maps to distinguish irrigated and non-irrigated parcels. When calculating the cost of poplar, irrigated parcels add the additional cost of water given the county's water price and irrigation used by the poplar-3PG model.

3.2) Economic Optimization

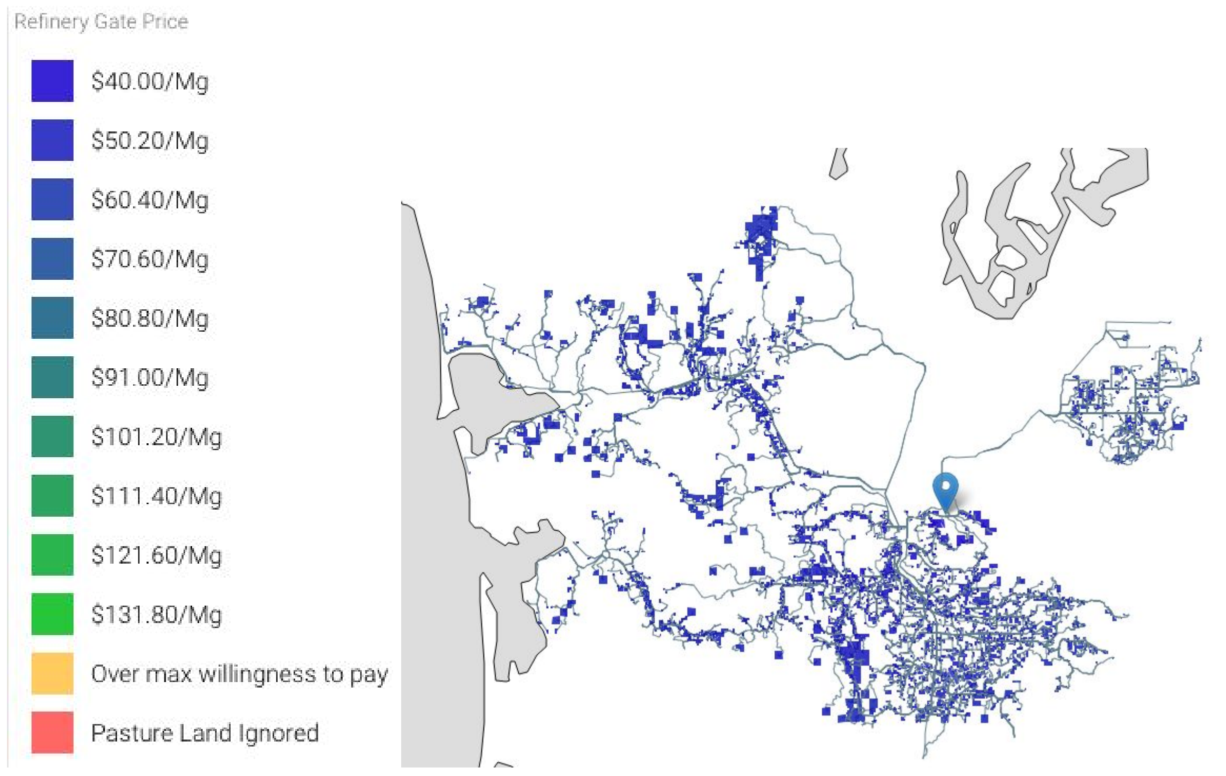
To calculate which parcels to adopt poplar cultivation, the AHB-DST first calculates the adoption price at which the farm will likely convert from its current crop to poplar and the refinery gate price for poplar. The poplar adoption price is assumed to be price where the net income from poplar is greater than the net income from the incumbent crop production and the net income from poplar production is greater than zero. Any parcel with a refinery gate price over the biorefineries max willingness to pay ignored. Only the given percentage of pasture land parcels are used, the extra pasture land parcels are removed starting with the more expensive refinery gate priced parcels. The model then sorts all parcels by refinery gate price and starts to adopt parcels starting with the cheapest refinery gate priced poplar. The model continues to select the cheapest parcels until the yearly average poplar yield for the selected parcels is over the optimal amount of feedstock required to run the biorefinery.

Once the refinery has enough poplar to operate at optimal levels, the last adopted parcel's refinery gate price is set as the price per ton of poplar. Additionally, an average sliding scale price is provided for the biorefinery simulation. The average price is based on a per parcel contract price of 10% over the parcels refinery gate price. The sliding scale price assumes that the biorefinery operator or a second party poplar aggregator will offer individual contracts with farmers, which are enough to induce adoption by improving the farmers' net revenue rather than offer a single price available for anyone who can bring poplar to the biorefinery. The sliding scale price also represents the costs for a biorefinery if operated as a cooperative of farmers.

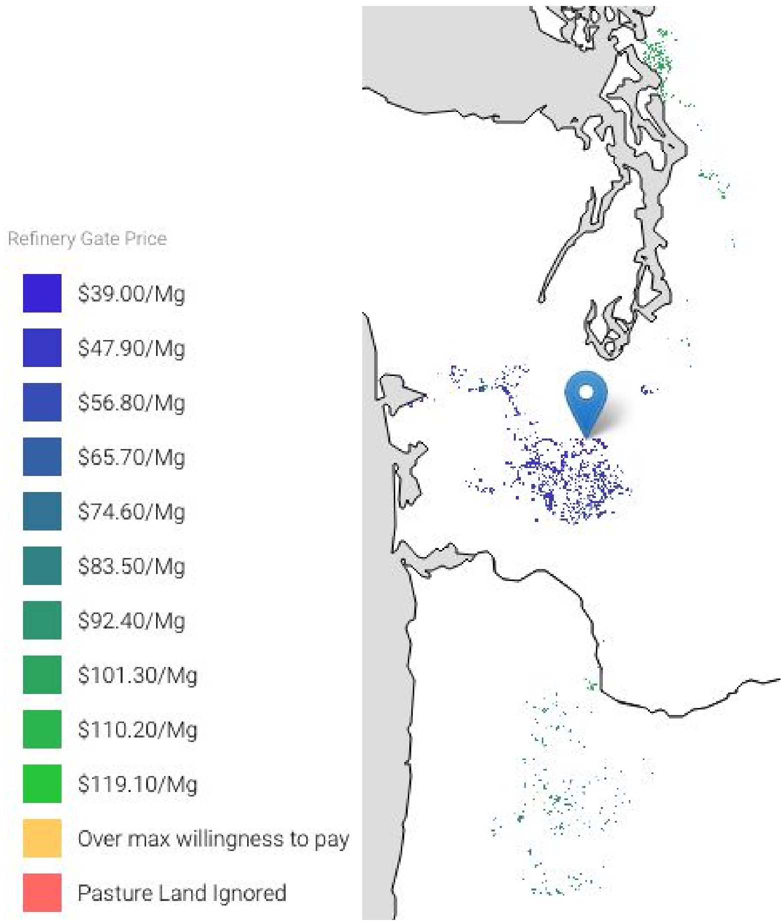
4) Case Study Analysis

To demonstrate the AHB-DST utility, we performed case study analysis with different decision options for assessing the potential for 380 million litres per year (100 MGY) hybrid poplar based jet fuel production facility at Centralia, WA where currently coal plant is under operation. Two scenarios with 10% of minimum rate of return and varied biomass collection radius and pasture percentage use for hybrid poplar cultivation options were selected, Scenario 1: 175 km biomass collection radius with 40% pasture removal option and Scenario 3: 225 km biomass collection radius with 20% pasture removal option. This study used a retrofit of the existing coal power station to be decommissioned in the coming years. The biorefinery retrofit assumed; capital cost of $535 million, operating cost of $168 million per year, jet fuel yield of 80 gallons per dry ton, a optimal capacity of 1.25 million dry tons of poplar per year. A generic poplar clone was used for the poplar-3PG model.

Results suggested that AHB-DST application was able to capture the interactive effects on biorefinery performance with changes in biomass collection area and available resources for operation of biorefinery. In Centralia region, most of the land is pasture land and therefore, decision on pasture percentage use for poplar cultivation has significant impact on rate of return and total cost of operation. When pasture percentage use is increased, biomass cost was reduced because the opportunity cost of pasture land is considerably less compared to croplands, and poplar biomass can be available at lower cost resulting lower total feedstock collection cost and high rate of return. When 40% pasture land is used for poplar cultivation with 175 km biomass collection radius, available land for poplar cultivation is approximately the same and cost of biomass is less ($54.64/Mg biomass) when compared to that of scenario 2 (i.e. 20% pasture percentage and 225 km biomass collection radius) where biomass cost is $106.8/Mg. Also the total cost (Capital cost + Operation cost + Poplar cost) is less and rate of return is higher in scenario 1 than in scenario 2 (table 1). When biomass collection radius is increased and pasture percentage use is minimized as in scenario 2, croplands are required to be adopted (Figure 2). Even though biomass yields are higher in croplands, opportunity cost is very less so total biomass cost is higher. In addition, transportation cost also increases with increase radius of biomass collection. These factors results in low rate of return with scenario 2.
The AHB-DST can be used to assess any location with different decision options and it will provide initial assessment of available resources and appraisal of economic performance of hybrid poplar based biorefineries for jet fuel and acetic acid production.



100 MGY Jet Fuel Biorefinery @ 175 km, adopted parcels.



100 MGY Jet Fuel Biorefinery @ 225 km, adopted parcels.

100 MGY Jet Fuel Biorefinery Results:

Radius to collect poplar biomass	175km	225km
Rate of Return	10%	10%
Max Pasture Adoption	40%	20%
Parcels Available	20466	34321
Parcels Adopted	4216	4277
Total Acres Adopted	175,261	169,133
Average Yield / Year	7.14 Mg / Acre	7.39 Mg / Acre
Price	$54.64	$106.8
Average Sliding Scale Price	$54.62	$72.06
Refinery Max Willingness to Pay	$141.21	$127.5

Net Transportation Cost	$308,375,302	$500,359,598
Net Cost	$5,281,000,000	$6,585,000,000
ROI	13.67%	13.15%

Summary

A decision support system is critical starting a biofuels industry in the pacific northwest. This system must have fine-scale data on polar biomass availability, transportation and utilities infrastructure in order to provide a data-driven model that can be effectively used in decision making. Providing this tool through the web allows open access to all empowering informed judgements by all stakeholders including farmers and investors. The short time frame required to run the model allows stakeholders to quickly run multiple simulations scenarios varying inputs to study the effects on the biorefinery and the growers. Open services, data and code allow the original Poplar Model and Farm Budget applications to be easily extended and included in the AHB-DST. Building upon this paradigm, all component of the AHB-DST are open and available for further, extended analysis.

Acknowledgments

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Conflicts of Interest

The authors declare no conflict of interest.

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