Computers and Electronics in Agriculture 121 (2016) 12–24

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

# Conceptual design of a biofeedstock supply chain model for eastern redcedar

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ARTICLE INFO

*Article history:*
Received 18 April 2015
Received in revised form 2 November 2015
Accepted 14 November 2015
Available online 17 December 2015

*Keywords:*
GIS
Supply chain
Bioproducts
Biofuels
Economics
Modeling

ABSTRACT

Modeling a biomass supply chain in its entirety, i.e. location selection, harvest, transport, processing, and refining costs, is essential to determining the economic feasibility of a production strategy. Eastern redcedar (*Juniperus virginiana*) has been proposed as a viable biofeedstock in Oklahoma because multiple products may be manufactured from the tree including biofuel, cedar oil, pharmaceuticals, mulch, and lumber products. To facilitate development of eastern redcedar commerce a comprehensive, modular, web-based supply chain model was developed as a computational tool to evaluate biofeedstock markets. Geospatial programming is used to perform location allocation, develop service areas, and biomass yield maps. User input data was employed to approximate costs at each node in the supply chain, while Monte Carlo and one-way sensitivity analysis were used to quantify uncertainty. The model is focused on fully utilizing redcedar by enabling users to evaluate the economic feasibility of producing multiple end products simultaneously. The dynamic and modular framework of the model provides a strong foundation for expanding the model to other biomass feedstocks.

## 1. Introduction

Eastern redcedar is a naturally occurring Oklahoma evergreen and the most widely distributed conifer in the Eastern USA (McKinley, 2012). Formerly limited to rocky outcrops and controlled by natural wildfire, it is rapidly spreading throughout the Great Plains region due to the species' adaptability, passive land management by landowners and suppression of natural wildfire (Oklahoma Forestry Services (OFS), 2014). These factors have allowed redcedar to overrun an estimated 3.5 million ha of Oklahoma land (Starks et al., 2011). The unchecked spread of redcedar has incurred significant economic losses to the Oklahoma Economy in the form of enhanced wildfire, lost cattle forage, lost wildlife habitat, and decreased water availability. Volatile oils, thin bark, and fine foliage make it easily ignitable, complicating wildfire control efforts (Division of Agricultural Sciences and Natural Resources [DASNR], 2012). A tree with a 6 foot crown may reduce plant biomass in the direct vicinity of the tree by 6 lbs. As the land cover transitions to a closed canopy juniper forest (600 trees ac$^{-1}$), herbaceous plants are virtually eliminated (Briggs et al., 2002; Stritzke and Bidwell, 1989). The loss of herbaceous plants is due to a combination of soil water depletion, reduced rainfall interception, reduced light penetration beneath the tree canopy, changes in soil bacterial and fungal species composition, a reduction in soil pH, and an increased soil carbon/nitrogen ratio (Hung, 2012; Williams et al., 2013; Caterina, 2012). These changes may have a serious impact on the surrounding ecosystem and are especially detrimental to grassland birds. Eastern redcedar is known to negatively affect Bobwhite Quail, Song Sparrow, House Sparrow, American Goldfinch, and White-Crowned Sparrow populations (Coppedge et al., 2001; Engle et al., 2008; Guthery, 2001). In 2001, the annual economic impact of redcedar on the Oklahoma economy was estimated at $218 million and expected to increase to $447 million by the year 2013 (Drake & Todd, 2002). Costly management techniques, ranging from $3.00 to $160 ac$^{-1}$ are dependent on stand density and treatment method. These high management costs have allowed redcedar to spread rampantly, despite the obvious economic, environmental, and social implications (Bidwell et al., 2007). Reducing and reversing the advancement of eastern redcedar requires an alternative solution.

Redcedar lumber has long been valued for its color, aroma, decay resistance, and insect repellent attributes. As an industrial biofeedstock, tree components can be used to manufacture essential oils, wood flour, pesticides, particleboard, pharmaceuticals, animal bedding, and biofuels, in addition to traditional wood

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http://dx.doi.org/10.1016/j.compag.2015.11.019
0168-1699/Published by Elsevier B.V.

products such as lumber and posts. Many of the higher value products, e.g. composite panels, essential oils, or pharmaceuticals could be manufactured on an industrial scale to control the spread of eastern redcedar, while simultaneously providing economic stimulus. Due to the risk and uncertainty associated with the industrial scale production of these bio-products, commercial ventures have not developed despite public support and business interest. A biofeedstock supply chain presents unique logistical challenges, depending on the facility location, existence of processing hubs, transport, processing, harvest, storage, and refining costs. To garner confidence in eastern redcedar and other biofeedstock enterprises, the cost and cost variance of each stage in the supply chain must be characterized without over simplification. The purpose of this project was to develop an online, dynamic, whole-system supply chain model to generate cost information for different eastern redcedar supply chain scenarios. The primary goals for the modeling system were:

1. The ability to determine the optimal location for one or more processing facilities based on user inputs and redcedar biomass availability.
2. Provide deterministic and stochastic estimates for harvest/processing, transport, and refining costs specific to redcedar.
3. Make the system easily accessible to government and business entities as a decision aid for implementing redcedar control strategies.
4. Develop the models framework using a modular design to simplify integration of additional analytical capacity, i.e. alternative feedstocks or advanced supply chain systems.

The result of this project, the Geospatial Logistics and Agricultural Decision Integration System (GLADIS) meets these objectives and is currently available in beta form.

## 2. System architecture

### 2.1. Decision support system

Development of GLADIS consisted of three stages: literature review of current biofeedstock supply-chain systems and identification of key model requirements, database development, and decision support system (DSS) development. The purpose of the literature review was to identify and gather information needed to create a biofeedstock model that uses specific user input data, model generated information or a combination of user and model generated data. It was decided the supply chain model should be modular, i.e. individual cost sections for each supply chain stage: location, transport, harvest/process, and refining. Software and specific costing equations for each module were identified during this stage.

The second stage focused on the collection of market equipment values, harvesting efficiencies, fuel cost, biomass availability, and other costing variables to develop probability distribution functions (PDFs) for stochastic analysis. Information collected but not used for PDF development included depreciation rates, personnel salaries, and geospatial data. The later included Oklahoma population centers, transportation nodes from the Freight Analysis Framework Network, and eastern redcedar data (Department of Transportation [DOT], 2013; Natural Resource Conservation Service [NRCS], 2005). The NRCS provided eastern redcedar canopy coverage data for 16 Oklahoma counties, which was used to generate bone dry biomass estimates using an allometric regression equation (NRCS, 2005; Starks et al., 2011). The resulting GIS and biomass information was then aggregated into a grid of 6.25 square mile cells, summing the biomass available in each cell and using the cell centroid as an approximate location.

The DSS includes the modeling system as a whole, which is divided into modules, e.g. site selection, harvesting/processing, transportation, and refining. A module is an independent component of the system that includes all database information, user inputs, and models required to generate specific outputs. The modules capture aspects of specific supply chain nodes and links, such as site selection, material harvesting or transportation. A module is composed of models, which provide abstraction from the main module. One or more models exist within a module to evaluate sub-components of the supply chain node, e.g. labor, fuel, and maintenance costs, or to enhance functionality in another model. Each module was developed using a bottom up approach; outputs were defined then used to determine the required user inputs and database structure. This approach facilitated development by providing a defined information and structural template. A basic outline of the modules, models, and module interaction were delineated as shown in Fig. 1. The user inputs, database variables, and module outputs are not all inclusive. As an example user inputs for the site selection module include the commodity (cedar oil, biofuel, mulch, etc.), facility type (one main facility or multiple distributed processing hubs), facility capacity, service area, and model options. The harvesting/processing and transportation modules include variables such as fuel cost, fuel consumption rate, retail value of machinery and tractor-trailers, labor rates, salvage value, insurance cost, equipment life, utilization rates, and others. Similarly the refining models require inputs for interest rates, inflation rates, sales volume, tax credits, building costs, land value, equipment cost, net present value discount, and the loan term, among other variables. Each of the modules in Fig. 1 may stand alone; only select outputs are transferred between modules. These include the service area, available biomass, commodities to manufacture, and facility capacity which are fed into the transportation and refining modules respectively.

The decision support system (DSS) was created using a MySQL database, HTML, CSS, JavaScript, and PHP. MySQL was selected to store production and distribution data because it is open-source, and capable of storing a large number of records. HTML, CSS, and JavaScript are the de-facto programming languages for web development. The web interface was built and styled using HTML and CSS. JavaScript functions and sub-modules process user inputs and data from the MySQL database before uploading the outputs to a server. This data is processed in PHP, a server side scripting language compatible with MySQL, and stored in the MySQL database.

### 2.2. User interface

Users enter information for simulations through a series of forms as shown in Fig. 2. Clients may use default input values or modify inputs to match their actual or estimated operating structure and costs; including distributed pre-processing hubs, drop and hook transport, custom harvesting machines, and/or multi-product production facilities. An auto-fill data option is available in the harvesting module for small, medium, and large skidders, feller-bunchers, forwarders, loaders, harvesters, dozers, chippers, and grinders, while the refining module provides auto-fill data for employee salaries and benefits. Relevant data from each module feeds into subsequent modules for calculations, e.g. facility throughput is used by the transportation module to estimate the tractor-trailers required for biomass transport. This layout enables users to run simulations using default values or customize data inputs. The user interface allows the user to auto-populate all required inputs, however, they are provided the ability to adjust system input data based on their actual or planned operation.