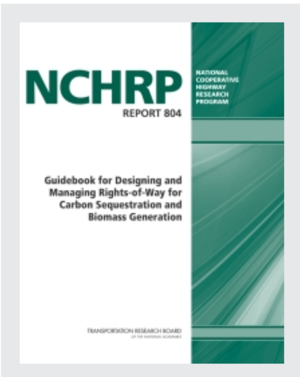

Guidebook for Designing and Managing Rights-of-Way for Carbon Sequestration and Biomass Generation

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 804

Guidebook for Designing and Managing Rights-of-Way for Carbon Sequestration and Biomass Generation

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

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FOREWORD

By David A. Reynaud
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This report provides a Guidebook and Toolkit that describes the state of the practice of using highway rights-of-way (ROWs) vegetation for carbon sequestration and biomass generation for use as feedstock for biopower and biofuel production. This Guidebook merges the knowledge of market conditions and regulations for environmental commodities that are energy- and/or greenhouse-gas based, regulations governing the highway ROWs for commercial or revenue purposes, the best practices of highway vegetation management and agronomic practices for raising feedstock crops for carbon sequestration, biopower, and biofuels. The Guidebook and Feasibility Toolkit will be useful to operations and maintenance managers, vegetation managers, alternative finance officers, and environmental managers seeking to extract greater financial and environmental value from roadside vegetation.

At the time of this research, an FHWA Carbon Sequestration Pilot Project estimated that the National Highway System had nearly 5 million acres of ROW in vegetation or that could be in vegetation for the purpose of carbon sequestration. Given that operations and maintenance personnel already dedicate significant time and resources to vegetation management for roadway integrity, habitat, native plant restoration, invasive plant reduction, aesthetics, water quality, and erosion control, the question remained whether or not the DOTs could leverage this effort for additional greenhouse gas benefit. Given also that ROWs often need mowing and significant vegetation removal, the concept of selling the material for bioenergy and biofuels feedstocks seemed to be another way to leverage resources, reduce costs and reduce greenhouse gas emissions through the production of lower carbon electricity and fuels.

Concurrent with this research was a rise in voluntary carbon markets, regional and state regulations, and executive orders requiring increases in renewable energy and fuels (including those from bio-based feedstocks). Also during this time, the value of the Gas Tax for the Highway Trust Fund was eroding and fuel and energy prices were high. During the research, there were dramatic developments in domestic methane extraction and the EPA issued rules for boilers, process heaters, and incinerators that regulated biomass carbon emissions arrived. Also at the beginning of the research, a national cap and trade system for greenhouse gas emissions seemed imminent and the arrival of lower cost natural gas and the uncertainty of EPA's stance on bio-power changed the tone of the market.

Good Company was selected to answer the question of whether or not roadside vegetation could be raised to reduce atmospheric carbon and generate a net financial improvement for the ROW operators. The researchers surveyed the literature to identify all existing pilot projects with similar goals in ROWs of all kinds, including power, water, and gas transmission corridors. Following the literature review, the research team interviewed DOT personnel, greenhouse gas regulators, carbon and energy brokers, agronomists, equipment vendors, alternative fuel producers, and biopower producers to understand the complete supply chain of the markets involved. The researchers also studied the legal and safety frameworks of ROW operators. At the time this research was conducted, the team found that while technically feasible, the market conditions were not conducive to cost reduction or new revenue sources.

The resulting report, Guidebook, and Feasibility Toolkit* will help interested DOT or ROW personnel evaluate the technical and financial feasibility of ROW carbon sequestration or biomass generation projects that are specific to the resources and regional context of their agencies.

*Notice to readers regarding the CD accompanying this report, CRP-CD-165: the CD menu will only open in Silverlight-compatible browsers. If your browser does not have the Silverlight plugin installed, you will be prompted to install or activate the plugin. See the readme file on the disk for further information.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Guidebook for Designing and Managing Rights-of-Way for Carbon Sequestration and Biomass Generation

This Guidebook provides an overview of the operational and programmatic issues and market conditions associated with utilizing highway rights-of-way (ROWs) to develop carbon sequestration projects to generate saleable carbon offsets or to grow marketable biomass for sale into bioenergy markets. The goal is to provide state departments of transportation (DOTs) with the knowledge and context necessary to make informed decisions and a roadmap for evaluating the feasibility of implementing such projects.

While it is technically feasible to grow a variety of vegetation types along roadsides that could serve either the bioenergy or carbon offset markets, given current market conditions and the operational constraints of the ROW, the practical opportunity to implement such activities is limited. That said, there might be local circumstances in which these conditions and constraints do not prevail. This Guidebook provides state DOTs a roadmap to determine if local conditions are favorable to project development. This right-of-way carbon sequestration and bioenergy feedstock Feasibility Toolkit provides a DOT with a suite of decision support tools to systematically evaluate opportunities in a local context. The Feasibility Toolkit also includes tools to model a proposed project's financial viability based on default values that the user can modify to develop a customized analysis.

Notably, some of the current limitations to project implementation may not hold in the future, given the dynamic nature of both the carbon offset and bioenergy markets. Both markets are rapidly evolving and changes in energy prices, technology, or public policy could provide more favorable conditions. For this reason, interested DOTs should periodically revisit market conditions and operational constraints identified in the Guidebook and the NCHRP Project 25-35 final report.

DOT Motivations

There are two primary motivations for DOTs to consider implementation of a carbon sequestration or bioenergy feedstock project in the ROW. First, decreasing revenues and increasing costs are driving many DOTs to consider alternative vegetation management approaches in an effort to reduce operating costs or generate new sources of revenue. Second, increasing concern about the effects of climate change on human and ecological systems, including transportation systems, has prompted many DOTs to seek measures to mitigate the emission of greenhouse gasses (GHGs). These efforts are often in response to a policy mandate, but can also be prompted by a general concern about social and environmental welfare.

Establishing a clear understanding about these underlying motivations at the outset of a feasibility assessment is important because even if a project is not financially viable, a DOT might still pursue implementation for altruistic reasons. While implementing projects in order to showcase environmental leadership is valid and laudable, the focus of this Guidebook is on evaluating project viability in terms of revenue potential.

Organization of the Guidebook

This Guidebook is arranged by the following topics:

DOT management considerations—This chapter provides an overview of the management issues DOT managers should consider when evaluating the feasibility of implementing carbon sequestration and bioenergy feedstock projects within the highway ROW. These include motorist safety, asset management, environment, other regulations and policies, and programmatic considerations. In addition to discussing each of these issues, this chapter identifies strategies to address the issues.

Carbon sequestration activities and markets—This chapter provides a primer on the types of activities that could potentially result in saleable carbon offsets, the prospects for such projects under current conditions, and criteria to monitor in the future.

Biomass feedstocks and markets—This chapter provides a primer on bioenergy markets and feedstocks, the prospects for cultivating bioenergy feedstocks in the ROW under current conditions, and criteria to monitor in the future.

Feasibility Toolkit—This chapter gives a brief description of the tools included in the accompanying Toolkit, including high-level financial analytics to support feasibility screening. The Feasibility Toolkit is a spreadsheet workbook that is pre-populated with rates and norms for quick assessments, and can be customized further for greater accuracy as the information becomes available.

CHAPTER 1

Primer on DOT Management Considerations

Overview

This chapter discusses the management issues likely to confront a DOT embarking on a carbon sequestration or bioenergy feedstock project. Specifically, it discusses some of the objectives of traditional vegetation management programs and how those might inform the development of a carbon sequestration or bioenergy feedstock project.

This chapter identifies five topic areas for DOTs to consider when evaluating the feasibility of implementing carbon sequestration and bioenergy feedstock project activities within highway ROWs—motorist safety, asset management, environment, other regulations and policies, and programmatic considerations. While the considerations discussed below are familiar to most DOT staff, they are summarized here for convenience.

Motorist Safety

The safety of the traveling public is of paramount importance in considering the feasibility of intentionally growing vegetation for carbon sequestration or bioenergy feedstocks. Table 1 summarizes the main motorist safety considerations.

Collectively, these safety considerations limit the areas in the highway ROW where potential projects would be appropriate. Project activities that involve tree planting or other tall vegetation are only suitable to areas outside of the clear zone. While lower growing vegetation does not pose a collision or sightline hazard, other potential hazards like wildlife collision and frequent equipment access make growing some crops in the clear zone inappropriate.

Clear Zone

The clear zone is the area beyond the edge of the travel lane adjacent to the roadway that must remain clear of fixed obstacles that would prevent an errant vehicle from safely stopping or returning to the roadway. The recommended clear zone ranges from seven to 46 feet, depending on design speed and traffic volumes. Fixed objects greater than four inches in diameter are considered a hazard. Where guardrails or other safety barriers are present, larger diameter vegetation may be permissible closer to the roadway (AASHTO, 2011a).

Potential project activities that involve tree planting should take place outside of the clear zone. See the AASHTO *Roadside Design Guide* (AASHTO, 2011a) and state-specific setback standards for more complete guidance. Figure 1 shows an illustration of the roadway cross-section including the clear zone.

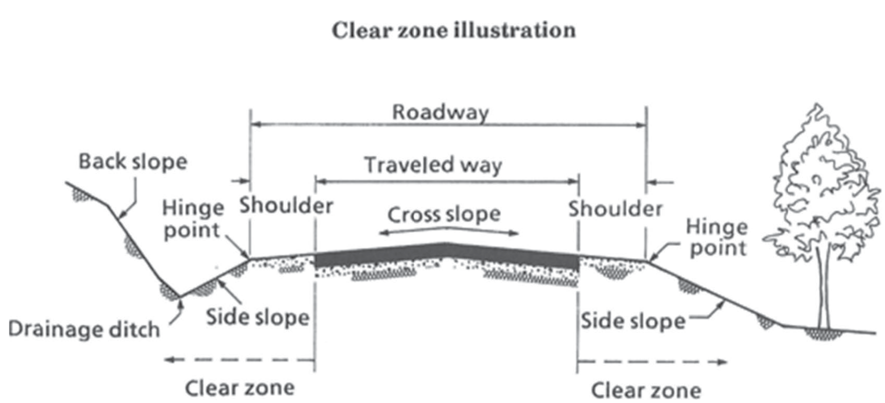
Table 1. Motorist safety.

Issue	Standard/Practice
Clear zone	No vegetation >4 inches in diameter within ~30 feet of edge of roadway.
Sight distance	Limits on placement and maximum allowable height of vegetation depending on road design: typically less than 3 feet in height in the "operational zone."
Access control	Ingress and egress from roadway discouraged: prioritize ROW ingress from adjacent property or service road, access on Interstate requires FHWA approval.
Equipment operation in the ROW and work zone safety	Traffic control required: Warning signs or equipment-mounted safety lights required for work beyond the shoulder and Warning signs or arrow board as well as channelizing devices to close shoulder for work on the shoulder. Limit equipment operation in the clear zone and highway medians. Limits on the equipment storage and hours of operation.
Wildlife collision	Maintain vegetation to keep clear sightlines, minimize the nutritional value of vegetation grown in the ROW.
Shading and hazard trees	Avoid high growing vegetation on southern and western sides of roadway to avoid road shading, prune or remove damaged or diseased trees to prevent falling on roadway.

Sight Distance

Clear lines of sight allow motorists to see roadway conditions, signs, other motorists, and the shape of the road to navigate safely. There are limits on the placement and maximum allowable height of vegetation at intersections, along horizontal and vertical curves, and near roadway signs. For example, vegetation must be kept below two feet nine inches in height within 10 feet of the travel lane on curves with radii of 6,470 feet or greater (AASHTO, 2011b).

Potential project activities that involve tall vegetation should take place a sufficient distance away from the roadway. See the AASHTO *Policy on Geometric Design* (AASHTO, 2011b) and state-specific design standards for more complete guidance.



Hinge Point	Point where the slope rate changes.
Clear Zone	A traversable area that starts at the edge of the traffic lane, includes the shoulder, and extends laterally a sufficient distance to allow a driver to stop or return to the road before encountering a hazard or overturning

Source: Federal Highway Administration

Figure 1. Roadside vegetation management zones.

Access Control

Access to and from the roadway is managed to limit and separate traffic conflict points in order to promote the safe and efficient flow of traffic. In general, access to and from the roadway along limited- and controlled-access facilities is discouraged. In the case of Interstate highways, new or revised access requires approval from the Federal Highway Administration (FHWA) (U.S. Department of Transportation, FHWA, 2010).

When considering potential project activities, attention should be paid to the frequency of access from the roadway that would be required.

Work Zone Safety

The design, installation and use of traffic control devices to warn and guide motorists about and around traffic hazards and to protect workers and equipment is described in FHWA's *Manual on Uniform Traffic Control Devices.* Requirements for type of signage and its distance ahead of the work area vary based on the location of the work and prevailing roadway speed. Warning signs or equipment-mounted safety lights are required for work beyond the shoulder. Work on the shoulder requires warning signs or an arrow board, as well as channelizing devices to close the shoulder (U.S. Department of Transportation, FHWA, 2009a).

Many states also have supplemental standards that may be more restrictive, including prohibitions of the operation of equipment within a certain distance from the edge of the traveled way, limits on the placement of equipment and hours of operation, and prohibitions of causing and blowing dust and debris (Colorado Department of Transportation, 2003; Kansas Department of Transportation, 2010; Michigan Department of Transportation, 2013; Missouri Department of Transportation, 2012; South Dakota Department of Transportation, 2010).

See the FHWA *Manual on Uniform Traffic Control Devices* and state-specific guidelines (e.g., mowing permit requirements) for more complete guidance.

Wildlife Collision

The presence of trees and other vegetation close to the roadway can increase the incidence of wildlife–vehicle collisions when that vegetation provides either cover or a food source. In general, best practices indicate either the removal of such vegetation up to 130 feet from the edge of the pavement, managing the palatability of the vegetation through selection of unpalatable species, and minimizing forage quality through mechanical or chemical controls—or both (Huijser et al., 2008).

See the FHWA *Wildlife Vehicle Collision Reduction Study: Best Practice Manual* (Huijser et al., 2008) for more complete guidance.

Shading and Hazard Trees

In some circumstances, trees and other vegetation located outside of the clear zone may pose a safety risk by casting shadows on the roadway that inhibit the melting of snow or ice or by diseased or damaged portions of trees falling onto the roadway. Additionally, vegetation growing too close to the roadway can cause the formation of snowdrifts. If properly placed—upwind from the roadway and up to 250 feet from the centerline—vegetation can serve as a living snow fence (AASHTO, 2011c).

See the AASHTO *Guidelines for Vegetation Management* (AASHTO, 2011c) for more complete guidance.

Asset Management

Vegetation can impact the integrity of several structural elements of the roadway cross-section, from the roadbed itself to storm water facilities and utility installations. Potential project vegetation must be managed to avoid damage to roadway, utility and other facilities, accumulation of water, and soil erosion. DOTs also need to consider the impact of project vegetation management activities on surrounding vegetation and vice versa. Finally, DOTs should also consider potential future uses of the ROW, including lane expansion or alignment reconfigurations, as this may conflict with the requirements of certain carbon sequestration or bioenergy feedstock project activities that establish long-standing vegetation.

Environment

The environmental considerations of roadside vegetation management have and will continue to evolve over time. This section discusses three environmental considerations relating to carbon sequestration or bioenergy feedstock generation projects—control of invasive and noxious weeds, storm water and water quality, and genetically modified organisms (GMOs).

Control of Invasive and Noxious Weeds

Highway and road corridors enable the distribution of plant species beyond the environment in which they evolved. Non-native species that have great potential to spread by replacing native or desirable species in a particular area if not managed immediately are referred to as "invasive." Invasive species that are injurious to public health, the environment, public roads, crops, livestock, or other property and result in severe economic or ecological harm are designated by a federal, state, or local agency as "noxious." DOTs have a regulatory responsibility to manage the spread of both invasive and noxious weeds.

Management protocols include preventative and eradicative measures. Preventative measures include requirements that equipment operated in the ROW be cleaned before entering and leaving a project site; that imported materials such as mulches, compost, and seed mixtures be certified weed-free to minimize soil disturbances; and that disturbed areas are monitored for weed infestations. Eradicative measures include mechanical and chemical controls including burning, pulling, mowing, and herbicide applications (Venner, 2006).

Potential carbon sequestration and bioenergy feedstock projects should proactively address the potential to increase the spread of noxious and invasive weeds and adopt best practice measures to mitigate that risk. See *NCHRP Synthesis 363: Control of Invasive Species: A Synthesis of Highway Practice* for additional information.

Storm Water and Water Quality

The impervious surface of roadways interrupts the natural process of storm water infiltration and can lead to the diminishment of water quality in nearby streams and waterways due to storm surges and the channeling of debris, sediment, and residual chemicals. Properly maintained roadside vegetation can mitigate some of these impacts by filtering storm water runoff before it reaches the receiving waters. Notably, the systems of conveyances that carry runoff from the state highways are considered municipal storm sewer systems and are subject to regulations under the federal Clean Water Act. These facilities require a permit that sets constraints on many DOT activities, including vegetation management.

When considering potential carbon sequestration or bioenergy feedstock projects, care should be taken to understand the potential risks and benefits these projects might pose in terms of moderating or exacerbating storm water runoff. Potential carbon sequestration and bioenergy feedstock projects should adopt best management practices to mitigate potential risks.

GMOs

While not an issue that typically confronts DOTs, potential carbon sequestration or bioenergy feedstock projects may raise questions about the safety of GMOs. Several biomass feedstocks, including corn, soybeans, and canola, are widely grown using GMO varieties.

Though GMOs have been widely adopted and accepted by many agricultural producers in the U.S., many in the public continue to perceive GMOs as unsafe for the environment. In addition to public perception issues, GMOs may present a risk of gene flow of certain traits, including herbicide resistance, to related native or naturalized species, thereby making their control more difficult (Schafer et al., 2011).

Potential carbon sequestration and bioenergy feedstock projects should proactively address potential public and environmental concerns.

Other Regulations and Policies

Allowable Uses of the ROW

The use and management of the ROW for Federal-Aid Highways must comply with applicable federal rules and policies. The over-arching purpose of the federal policy framework is to ensure that the safety of the public and the current and future operation of the transportation facility are not impaired by any non-transportation uses of the ROW.

Title 23 of the *Code of Federal Regulations*, Chapter 1, Part 23 (23 CFR § 1.23 "Rights-of-way"), stipulates that ROWs acquired for Federal-Aid projects shall be used exclusively for highway purposes. An exception is provided to this restriction for non-highway purposes where FHWA determines that the non-highway purpose is in the public interest and will not adversely impact the safe flow of traffic.

Air Space Leasing

The requirements for leasing property interests acquired with federal transportation funding for alternative or non-highway uses are spelled out at 23 CFR § 710. The lease of a property interest in the areas located adjacent to the roadway, as well as the area above and below the roadway, is referred to as an airspace lease. Airspace lease agreements are subject to approval by FHWA, and prior to entering such agreements, the DOT must evaluate the environmental effects of leasing the property under the procedures described at 23 CFR § 771 [23 CFR § 710.403(c)]. Airspace lease agreements must also charge a fair market rent and proceeds must be used for transportation purposes [23 CFR § 710.403(c)]. The requirement to charge fair market rent can be waived if it can be shown that such an exception is in the overall public interest for social, environmental, or economic purposes. FHWA has suggested elsewhere that projects that positively address climate change may be an appropriate activity for this type of exception (AASHTO, 2011c; Hernandez, 2012; U.S. Department of Transportation, FHWA, 2009b).

Potential carbon sequestration and bioenergy feedstock projects could be developed using air space leasing and could potentially be allowed to proceed without charging full fair-market rent.

Landscape Development

Federal rules also prescribe policies related to landscape development within the ROW of Federal-Aid Highways. Landscape development is defined to include both formal landscape projects aimed at enhancing roadside aesthetics as well as "other highway planting programs" (23 CFR § 752.4). These rules require that such activities include the planting of native wildflower seeds or seedlings, unless a waiver is granted by FHWA. A waiver to the native wildflower requirement can be granted if the planting is used for agricultural purposes [23 CFR § 752.11(b)(3)].

Potential bioenergy feedstock projects in the Federal-Aid ROW would likely receive a waiver to FHWA's native wildflower requirements since the activity clearly involves an agricultural purpose. It is less clear if potential carbon sequestration would be eligible for such a waiver.

Liability

DOTs are charged with managing their roadways and attendant properties in a manner that minimizes or eliminates risks to the traveling public. The failure to safely maintain roadsides can expose a DOT to civil lawsuits in the event of an accident that results in personal injury or damage to property. In order to minimize the risk of negligence claims, the DOT must act in accordance with generally accepted vegetation management practices. Particular care should be given to mitigate collision hazards and maintain sightline distances.

This obligation extends to DOT contracts with others to maintain or utilize the roadside. At a minimum, DOTs should require permittees or contractors to obtain liability insurance to cover potential damages. Such insurance should include the state as a named insured to offer further protection to the state. The permit or use agreement should also specify other safety requirements.

State Regulations

States may have a variety of laws or rules that could impact the use of the ROW for anything other than purely highway purposes, even if those laws and rules were created without specific uses in mind. For example, although not likely intended to prevent growing and harvesting bioenergy feedstocks on ROWs, Iowa and Minnesota limit the dates of mowing in the ROW. Such dates may not be consistent with those desirable for bioenergy feedstock establishment, maintenance, and harvest. A thorough examination of specific state laws and rules will be required on a state-by-state basis for DOTs pursuing value extraction of roadside ROW. The examination should include land-use or zoning laws and rules as well.

Also, states may have restrictions or dedications on use of highway or transportation funds. There are federal requirements that dictate the use of any revenues derived from the ROW where federal funds were involved in the purchase. Similarly, state restrictions or dedications would likely apply to revenues received if dedicated funds were involved in the purchase of the ROW, as that would likely make the ROW an asset of a restricted or dedicated fund.

Programmatic Considerations

Internal and External Stakeholders

Evaluating, planning, and implementing carbon sequestration or bioenergy feedstock projects are complex and highly technical tasks and most agencies are unlikely to possess all the expertise necessary to bring a project to fruition. As a result, a DOT will likely need to engage and seek the advice of outside experts. Depending on the type of project pursued, some of the partners that

Table 2. Business model pathways.

Type	Advantages	Disadvantages
Self-service model	Familiarity with the planting and managing of vegetation in the ROW. Do not need formal FHWA approval to change the management regime.	Lack of the agronomic or other expertise necessary to implement a particular production system or find suitable markets for harvested materials or carbon offsets. Lack of the necessary equipment to establish, maintain, and harvest vegetation or crops. The private sector might balk at the prospect of a DOT directly engaging in such an enterprise.
Contract for service model	DOT could rely on the expertise of qualified bidders for the establishment, harvest, and marketing of the agricultural crop. Avoid federal restrictions on accessing the ROW from the established grade of the highway.	DOT would not have direct control over the implementation of a particular production system.
Private entity leasing model	Relies on a proven pathway for developing non-highway uses of the ROW. Many DOTs have established procedures for developing and executing ROW property leases for other non-highway uses. Relies on the expertise and resources of the private entity.	The process for awarding lease agreements can be cumbersome and carries with it other restrictions that make it difficult to implement a project. Federal rules prohibit airspace agreements from allowing access to the leased land adjacent to the Interstate directly from the roadway. The restriction on accessing ROWs from Interstate highways may make leasing for growing biomass impractical.

might be engaged include: university agronomists and soil scientists, professional foresters and restoration experts, carbon offset developers and brokers, and economists. These experts may be found in other state and federal agencies or in the private sector.

As potential projects become more developed, it also prudent to perform a context-sensitive evaluation that engages local stakeholders and inventories potential issues and concerns. Utilizing such an approach helps ensure that a project fits its location and provides the opportunity to identify and resolve potential conflicts early on, thereby avoiding costly delays. The list of audiences to engage should include adjacent property owners, impacted transportation users, local and regional officials, local businesses, and civic and environmental interest groups.

Business Model

There are three basic pathways a DOT might utilize to facilitate the use of the ROW to grow biomass for carbon sequestration or bioenergy feedstock purposes. Each approach has its advantages and disadvantages, as shown in Table 2.

Self-service model—DOTs could develop and structure a program to intentionally plant, grow, harvest, and market the carbon offsets or bioenergy feedstock in the ROW.

Contract for service model—the DOT would contract with a private party to grow, harvest, and market the carbon offsets or bioenergy feedstocks. The private party would provide all necessary labor, equipment, and material inputs, while the DOT would make the land available at no cost.

Private entity leasing model—the DOT would enter into an airspace lease with a private entity that would then use the leased land to generate carbon offsets or grow and harvest a bioenergy feedstock. The private party would provide the necessary labor, equipment, and material inputs. This model would require a permit from the DOT to delineate the specific details and any requirements of use.

CHAPTER 2

The Carbon Offset Market: A Primer for DOTs

Overview

The scientific consensus is that the Earth's climate is changing as a result of human-caused emissions of greenhouse gasses (GHGs) and that a changing climate poses severe risk to human and ecological systems. Many of the anticipated impacts of climate change, including higher temperatures, rising sea levels, and more severe storms will directly affect transportation systems physically and at a policy level.

In response, the public and private sectors have developed both voluntary and regulatory mechanisms to limit and reduce GHG emissions. One of the outcomes of these efforts is the emergence of carbon offset markets, where market participants can buy, sell and trade instruments—carbon offsets—that represent the reduction, avoidance or sequestration of GHGs. One carbon offset is equivalent to the reduction or removal of one metric tonne of carbon dioxide equivalent (tCO_2e).

While these markets may eventually open up new revenue opportunities for DOTs, it is important to note that these markets are currently still developing. In particular, the markets for agriculture, forestry, and other land-use carbon sequestration offsets are some of the least developed. The nascence of these markets limits demand and leads to weak pricing, presenting a challenge to DOTs seeking to monetize changes to their vegetation management practices through carbon offsets. Current carbon offset prices are generally not sufficient to recover the vegetation establishment and transaction costs of carbon sequestration projects in the highway ROW.

Developing carbon sequestration projects in the ROW is further hindered by considerations about motorist safety and long-term asset management. A primary method for enhancing carbon sequestration is through the planting of trees. The potential safety risk associated with planting trees in the highway ROW is well established and planting trees is only permissible in areas outside of the clear zone, significantly limiting the total area of ROW available for project implementation. Perhaps the more significant constraint is the common requirement that carbon sequestration projects be committed to maintaining and monitoring for a minimum period of 40 years to more than 100 years. These timeframes are well beyond what is typically planned for by most DOTs.

That said, these limitations may not rule out all possible projects and some may not hold in the future. Moreover, if a DOT is motivated by more than pure monetary gain, it may still be able to benefit from project activities that result in increased carbon sequestration, even if they do not produce saleable carbon offsets. DOTs can generate education and reputation value by implementing projects that showcase environmental leadership. Moreover, the types of project activities that increase carbon sequestration often have other environmental co-benefits such as improvement to local air quality, aesthetic enhancement, and enhanced storm water filtration.

This chapter describes the basics of carbon sequestration, types of project activities that technically can be implemented in the ROW, the current state of carbon offset markets and protocols to bring projects to market, the considerations for selecting a potential site and vegetation types, and how to conduct an evaluation of a potential opportunity.

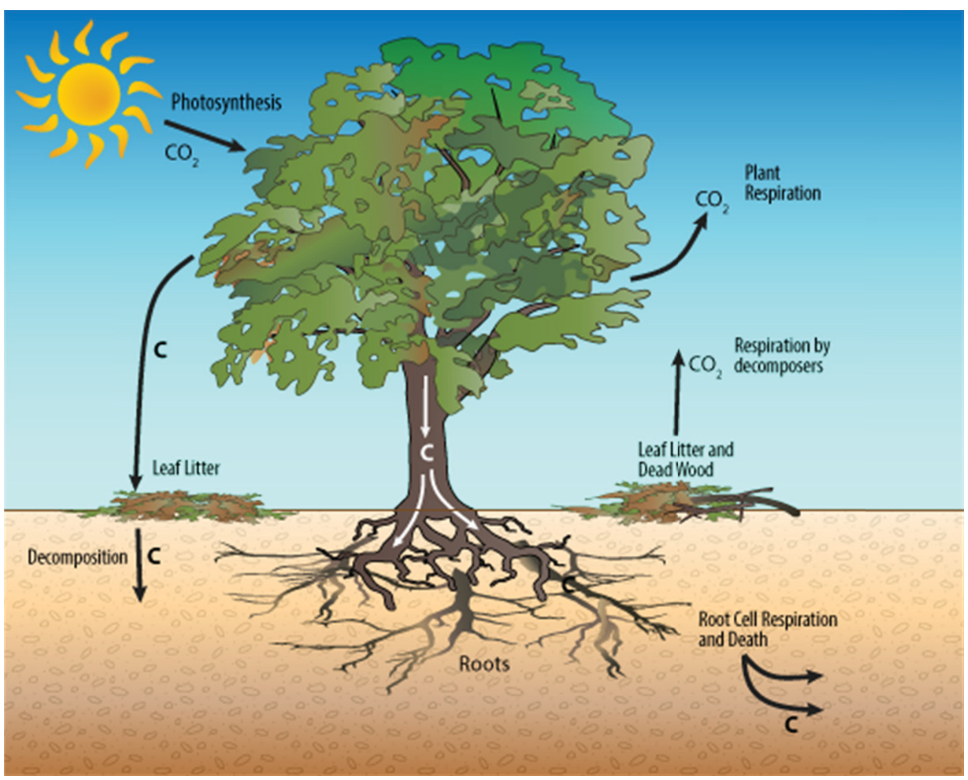
What Is Carbon Sequestration?

Terrestrial carbon sequestration is the process through which carbon dioxide (CO_2) from the atmosphere is absorbed by plants through photosynthesis and stored as carbon in plants and soils. Figure 2 illustrates the process. Most scientists believe that implementing management practices that enhance terrestrial carbon sequestration can reduce atmospheric concentrations of CO_2, thus mitigating some of the effects of global climate change. However, to be effective, the stored carbon must be sequestered in long-lived "pools."

The major terrestrial carbon pools are above-ground living woody biomass (e.g., the trunks, branches, and limbs of trees and other vegetation) and soil organic matter (e.g., decomposed and partially decomposed biomass and microorganisms). Carbon is also stored in dead organic matter (e.g., lumber in structures, fallen branches, leaf litter, and standing dead trees) and below-ground living biomass (i.e., the living biomass of root systems) (Intergovernmental Panel on Climate Change, 2003).

Terrestrial carbon sequestration can be enhanced primarily in two ways:

- Increasing the amount of carbon stored in living above-ground biomass by increasing the amount of woody biomass. This can be accomplished by leaving plants in place that otherwise would be removed or increasing the amount of woody vegetation by either establishing new vegetation or adopting management practices that provide for existing vegetation to grow larger and



Source: TERC

Figure 2. Terrestrial carbon sequestration process.

- Increasing the amount of carbon stored below ground in soils by increasing the amount of soil organic matter, decreasing the loss of soil organic matter, or a combination of both. Increased plant growth, less plant removal, and less soil disturbance generally aid in increasing soil organic matter.

Enhancing Above-Ground Biomass Carbon Sequestration

There are two primary methods of enhancing above-ground biomass carbon sequestration. The first is to change management practices so that perennial vegetation is allowed to grow longer and thus store more carbon. This could include extending harvest rotations, avoiding deforestation, or permanently setting aside an area for conservation. These types of activities are generally not applicable to the highway ROW since the limited forested areas along highways are not managed for timber production and little opportunity exists to increase the rate of carbon sequestration above what already occurs.

The second is to plant additional perennial vegetation so that more carbon can be stored. This approach is known as afforestation when it is applied to lands that previously did not have perennial vegetative cover or reforestation when it involves the restocking of existing forests or woodlands. In urban environments this method is referred to as urban forestry. These types of activities may be applicable to the highway ROW, if they are conducted in a manner consistent with other DOT management priorities such as motorist safety.

Enhancing Soil Carbon Sequestration

There are also two primary methods for enhancing soil carbon sequestration. The first is to increase the amount of organic matter incorporated in the soils by maximizing the return of plant biomass to the soil. This might be accomplished by converting annual croplands to perennial grasslands; or by increasing species diversity; or replacing existing species with better adapted, higher producing species in existing grasslands. Generally native or improved perennial grasses can produce more biomass than annual crops and non-native grasses. These types of activities may be applicable to the highway ROW.

The second method is to decrease the rate at which soil organic matter is lost to soil disturbance and erosion. This can be accomplished by reducing soil disturbances from livestock grazing and cropland tillage. These types of activities are generally not applicable to the highway ROW since lands along highways are not typically subject to these types of disturbances.

Sequestration Activities Potentially Applicable to the Highway ROW

Table 3 summarizes the types of carbon sequestration activities that might be applicable to the highway ROW and notes some of the potential constraints. While each of these project activities is technically applicable to the ROW context, implementation of these activities in a manner that results in saleable carbon offsets is subject to additional requirements and guidelines and market constraints.

Carbon Offset Markets, Standards, and Protocols

Carbon offsets are tradable instruments that represent the reduction or removal (i.e., sequestration) of GHGs below a business-as-usual level. Offsets are typically denominated in tCO_2e. While a wide variety of activities could result in a net decrease in GHGs, not all of these activities may be able to generate saleable offsets. To generate a saleable offset, the activity must be

Table 3. Carbon sequestration activities potentially applicable to the highway ROW.

Activity	Description	ROW consideration
Afforestation/Reforestation	Planting trees to establish or re-establish forest	Trees pose potential risk to motorist safety, requires substantial acreage to be profitable
Urban forestry	Planting trees in urban and other developed areas	Trees pose potential risk to motorist safety
Restoration of native vegetation	Replace low biomass producing vegetation with higher biomass vegetation	Generally compatible

implemented in accordance with strict eligibility, accounting, and verification rules, variously called "protocols" or "methodologies." These rules, promulgated by various offset issuers, are intended to provide offset buyers assurance that the offset project results in credible GHG reductions or removals.

To be considered credible, a project must meet five quality criteria:

Real—Projects should result in actual emissions reductions or removals (i.e., sequestration) and not be the result of incomplete or inaccurate accounting. The basis for issuing offsets should be the net emissions reductions or removals.

Additional—Projects should result in emissions reductions or removals that are in excess of those that would have occurred in the absence of the project. Projects that are required to be undertaken for a regulatory purpose or are otherwise a common practice are not considered additional.

Permanent—Projects must result in reductions or removals that will not be reversed at some future time. In order to guard against the risk of a reversal, sequestration projects are often required to set aside a percentage of offsets or must commit to long-term management horizons ranging from several decades to more than a century.

Verifiable—Projects should be audited by an independent third party to ensure they conform to eligibility requirements, that monitoring and reporting procedures are in place, and that the project activities have actually been implemented. This review typically occurs both prior to and after implementation, and is ongoing through the life of the project.

Enforceable—As a tradable commodity, project offsets must have clear property rights established through a contractual assignment or other legal instrument. These legal instruments should have a mechanism to ensure program rules are followed and to spell out who bears the risk of project failure. Project offsets should also be serialized and accounted for in a transparent tracking and registration system, often called a registry.

Size and Scale of Carbon Offset Markets

In 2011, the total value of the global market for new carbon offsets exceeded $3.8 billion, representing 379 million tCO_2e (Kossy and Guigon, 2012). Table 4 shows carbon offset transactions in 2011 according to primary market. The carbon offset market is composed of compliance and voluntary segments. While the compliance market dwarfs the voluntary market both in terms of volume and value, compliance markets are overwhelmingly composed of projects related to implementation of the Kyoto Protocol, and, as such, are not accessible by project developers in the United States.

Table 4. Carbon offset transactions volumes and values by primary market 2010–2011.

	Volume (million tCO_2e)		Value ($, millions)	
	2010	**2011**	**2010**	**2011**
Compliance market	69	87	414	569
Voluntary market	265	292	3,205	3,319
Total	**334**	**379**	**3,619**	**3,888**

Source: World Bank *State and Trends of the Carbon Market 2012* (Kossey and Guigon, 2012)

Voluntary Carbon Offset Markets

Until U.S. compliance markets more fully develop, the more significant market segment for U.S.-based projects is the voluntary offset market. For-profit corporations are the primary drivers of the voluntary offset market. While individual motivations vary in general, buyers purchase offsets either to fulfill voluntary pledges to mitigate their own GHG emissions or in anticipation of some future regulatory obligation. While some buyers seek out projects with "storytelling appeal" aligned with their customers' interests, many buyers are simply motivated to find the lowest-cost reputable offset (Peters-Stanley et al., 2011).

In order to ensure that the offsets purchased result in credible emissions reductions, buyers prefer to acquire offsets from projects that have been vetted and issued by an offset standards organization. These offset standards organizations have developed specific procedures and protocols that projects must follow in order to be issued carbon offsets. The leading standards organizations in North America, measured by market share of offsets issued in 2011, are: Verified Carbon Standard; Climate Action Reserve; and American Carbon Registry (Peters-Stanley and Hamilton, 2012).

Verified Carbon Standard

The Verified Carbon Standard (VCS, v-c-s.org) is the most widely used offset standards program in the voluntary market, accounting for 58% of global and 34% of North American voluntary market transactions in 2011 (Peters-Stanley and Hamilton, 2012). Rather than directly developing project protocols, VCS provides quality assurance standards for project proponents and other interested parties to develop their own protocols and procedures for the critical review and approval of those protocols. VCS refers to project protocols as methodologies. In addition, VCS allows projects to follow methodologies developed under the Kyoto Protocol's Clean Development Mechanism (CDM) and certain Climate Action Reserve (CAR) methodologies. In addition to providing a framework for protocol development, VCS also specifies the procedures and guidelines for independent third-party validation and verification. VCS-issued carbon offsets are called verified carbon units (VCUs).

Climate Action Reserve

The CAR (climateactionreserve.org) is the second-most utilized voluntary carbon offset program, accounting for 12% of global and 30% of North American voluntary market transactions in 2011 (Peters-Stanley and Hamilton, 2012). CAR directly develops project protocols that include project-level eligibility criteria, accounting rules, and validation and verification procedures in a single document. CAR-issued carbon offsets are called climate reserve tons (CRTs). The protocols developed by CAR also served as the basis for the initial protocols adopted by California rulemakers to generate compliance carbon offsets under that state's cap-and-trade program.

American Carbon Registry

The American Carbon Registry (ACR, americancarbonregistry.org) is the third most utilized voluntary carbon offset program accounting for 6% of global and 14% of North American voluntary market transactions in 2011 (Peters-Stanley and Hamilton, 2012). ACR relies on project proponents and other interested parties to develop project protocols. New protocols are subjected to a rigorous scientific review process. ACR also allows projects to follow methodologies developed under the Kyoto Protocol's CDM. ACR also specifies the procedures and guidelines for independent third-party validation and verification. ACR refers to project protocols as methodologies. ACR-issued carbon offsets are called emissions reduction tons (ERTs).

Compliance Carbon Offset Markets

Globally, the compliance market for carbon offsets is driven by implementation of the Kyoto Protocol—the international treaty that set a goal for most industrialized countries to reduce their GHG emissions. Under the rules of the Kyoto Protocol, carbon offsets can only be generated from projects in developing countries and former Soviet bloc countries.

While U.S.-based projects are not eligible for the Kyoto offset compliance market, there are two important domestic compliance programs that allow U.S.-based carbon offsets—the Regional Greenhouse Gas Initiative (RGGI) and California's Cap-and-Trade program.

Regional Greenhouse Gas Initiative

The RGGI is a mandatory, regional cap-and-trade program targeting the electric power industry in nine northeast and mid-Atlantic states. The program establishes a regional cap on carbon dioxide emissions from power plants through the issuance of a finite number of tradable emissions allowances. Capped entities are required to purchase allowances equal to their emissions through a quarterly auction. Over time, the number of available allowances is reduced, effectively requiring capped entities to reduce their emissions.

The program also allows capped entities to meet up to 3.3% of their compliance obligation by acquiring qualifying carbon offsets including afforestation and reforestation. The RGGI forest protocol was updated in 2012 and is ultimately based on the *Forest Project Protocol* developed by CAR.

To date, no carbon offsets have been issued by RGGI because there is no market incentive to do so, as the program is over-supplied with emissions allowances and allowance prices are not expected to exceed about $7 per tCO_2e (Regional Greenhouse Gas Initiative, Inc., 2012).

The combination of very low allowance prices and protocol restrictions (see discussion under Climate Action Reserve above) makes pursuit of RGGI-issued carbon offsets an unlikely pathway for sequestration projects developed in the highway ROW at the time of publishing this Guidebook.

California Cap-and-Trade

California's Global Warming Solutions Act of 2006 (Assembly Bill 32 or AB 32) requires the state to reduce GHG emissions to 1990 levels by 2020. One of the ways the state intends to meet this goal is through a mandatory cap-and-trade program. The program caps GHG emissions through the issuance of a finite number of tradable emissions allowances. Over time, the number of available allowances is reduced, effectively requiring capped entities to reduce their emissions. Unlike the RGGI program, the California program regulates all sources with emissions above a certain threshold—25,000 tCO_2e annually.

Under the program rules, capped entities can meet up to 8% of their compliance obligations with carbon offsets. This equals approximately 201 million tCO_2e through 2020 (Hernandez, 2012). The California Air Resources Board (CARB), the regulator charged with implementing the program, has adopted four project types eligible to be awarded Cap-and-Trade-compliant carbon offsets—including afforestation and reforestation and urban forestry projects. Each of the project protocols is derived from a protocol originally developed by CAR.

Project Development and Origination Process

While there is some variation in the specific sequence of events, there are some common steps a project must go through in order to bring a carbon offset to market. Notably, developing carbon offset projects, and in particular those involving carbon sequestration activities, is a complex and highly technical undertaking that involves a substantial commitment of time and money. Figure 3 below provides a generalized overview of the process.

Feasibility Assessment

Prior to developing a project, it is prudent to assess the technical and economic feasibility of the project concept.

The key elements of a feasibility assessment are the identification of an applicable protocol or methodology, the preliminary identification of project location, vegetation selection, estimation of sequestration potential, and a preliminary financial analysis.

Guiding a DOT through this type of feasibility analysis to determine if a project is worth pursuing further is the primary purpose of the Carbon Sequestration Feasibility Tool described in detail in the Feasibility Toolkit. If a decision is made to move forward with a project, it is advisable to consult with a professional project developer to review findings of internal feasibility assessment before moving forward with formal project development.

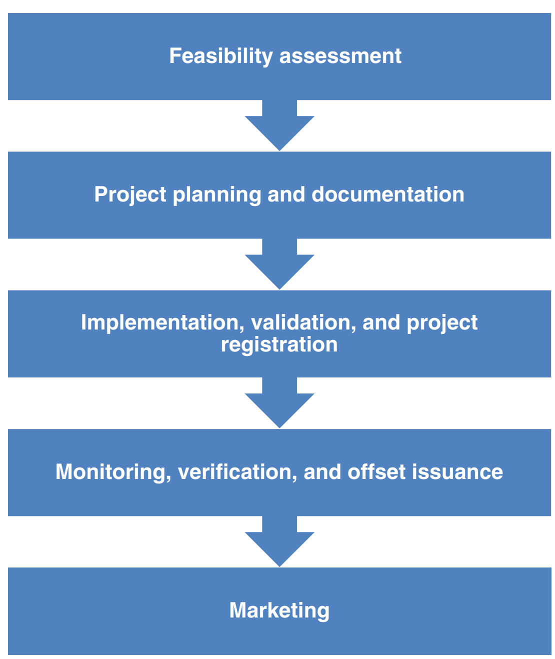


Figure 3. Steps to bring a project to market.

Identify Applicable Protocol or Methodology

The pre-development feasibility analysis should include the identification of an applicable protocol or methodology. Each offset program has different project eligibility rules, management requirements, and carbon accounting procedures. Determining if the proposed project complies with these criteria is critical for generating saleable carbon offsets.

While some programs allow project developers to propose new methodologies, this approach is costly, takes years to move through the process, and may not result in a viable protocol. That said, it may be worth pursuing the development of a protocol if the cost and effort were shared by many states through a representative body. The status and applicability of current methodologies for project types suitable to the highway ROW from the leading offset programs are discussed below.

Site Selection

The assessment of a project's feasibility should also include an evaluation of the areas available for project implementation. Site selection should consider project eligibility requirements, land tenure, and compatibility with DOT management considerations.

Key elements of feasibility assessment

- Identify applicable protocol or methodology
- Site selection
- Vegetation selection
- Estimate sequestration potential
- Examine financial feasibility

Each carbon offset program has different project eligibility rules that specify where projects can be implemented. In general the eligibility requirements limit project implementation to specific land uses or conditions. A common requirement for carbon sequestration projects is that the project must be located on lands that have not been cleared of vegetation within a minimum period of time, typically 10 years. This requirement is in place to avoid the incentive to clear vegetation in order to claim credit later for carbon sequestered from revegetation.

Another common requirement of carbon offset programs is that projects be maintained for long periods of time. This requirement not only binds the project proponent to maintain the area in its improved condition, but also to continue to monitor the project and verify to the carbon offset program that all terms and conditions continue to be met. The term of the project commitment ranges from several decades to more than a century.

Importantly, all carbon offset programs require that project proponents have a clear legal claim to the GHG benefits generated by the project and projects should only be implemented where these rights can be clearly established. For DOTs, this essentially restricts eligible sites to property held in fee simple. Where the DOT's title interest is limited to an easement, developing an offset project is more problematic. In such circumstances, offset issuers often require that the easement be amended or require other documentation to clarify which party has the right to be issued carbon offsets.

Sites should also be selected in order to minimize conflict with the DOT management considerations described in the preceding chapter. For example, tree-planting project sites should be located outside of the clear zone or otherwise located where project activities will not pose a risk to motorist safety. Likewise, projects should be implemented in areas where they will not conflict with other current or planned uses. This is especially important given the requirement that projects make long-term commitments to maintain and monitor project activities.

Additionally, potential sites should be subjected to a context-sensitive evaluation that considers the sites' environmental, economic, and community attributes; engages local stakeholders; and inventories potential issues and concerns. The Feasibility Toolkit includes a checklist of environmental, economic, and community attributes likely to be encountered in the development of a carbon sequestration project in the ROW. For further understanding of context-sensitive site selection and project development, see contextsensitivesolutions.org.

While offset issuers generally do not specify a minimum acreage for a project, given current market conditions, professional project developers look for projects offering annual emission reductions on the order of 20,000 tCO_2e. While carbon sequestration rates vary by species and growing conditions, in order to achieve this threshold, an afforestation project would require an area at least 5,000 acres in size. Grassland and urban forestry projects would require substantially larger tracts of land, given their higher establishment costs and lower rates of carbon sequestration.

Vegetation Selection

Once a potential site, or sites, has been identified, the next step is to identify the mix of species and planting arrangements the project would likely include. The goal is to identify those plant species that are 1) suitable to the site's growing conditions, 2) adapted to survive and thrive in the roadside environment, and 3) able to maximize the quantity and rate of carbon sequestration. Notably, offset issuers often require that project proponents design projects so that they encourage a diversity of native or naturalized species.

In the pre-development stage it is not necessary to develop a specific landscape plan—this is required during actual project development—but it is important to get an understanding of the scale of a project's sequestration potential and establishment costs by estimating the type and number of species.

The categories of growing conditions to consider include macro-climatic and micro-climatic variables, soil type and conditions, topography, and hydrology. Climatic variables that influence plant growth include seasonal temperature ranges, length of growing season, amount and timing of precipitation, and wind exposure. Soil characteristics that influence plant growth and survival include surface pH, texture, drainage, structure, compaction, contamination, depth, and available nutrients. Topographic features to consider include slope, aspect, and surrounding terrain, all of which influence sunlight exposure. Hydrological factors to consider include drainage and propensity to flooding, the presence and relative location of ground water, and surface water features. Each of these factors will influence the ability of a plant species to grow and survive, with most species best adapted to a specific combination of conditions.

It is not enough for a particular species to be generally adapted to a given area; the selected species must also be well suited to survive and thrive in the roadside environment. Roadside environments are typically harsher than those found in the natural environment. These harsh growing conditions make it more difficult to establish and maintain plantings. Commonly encountered conditions include extensive soil disturbance and compaction, drier or wetter than normal soils, exposure to vehicle emissions and de-icing chemicals, and pressure from invasive and noxious weeds. The type of vegetation selected for a roadside planting should be able to tolerate these conditions. Special attention should also be paid to the quality of plant materials and techniques used to establish plantings.

Many DOTs have developed lists of species adapted to the roadside environment. These lists also frequently include information about a species' preferred growing conditions. Where statewide lists do not exist, there may be other regionally-specific lists developed by municipalities, regional planning organizations, or local agriculture extension services.

A final factor to consider in plant selection is the quantity and rate at which selected species sequester carbon. The quantity and rate of carbon sequestered is directly related to the accumulation of above-ground and below-ground living biomass—that is, the dry weight of all living plant materials including roots, trunks, and branches. The carbon content of vegetation is fairly consistent across the type of plant material and plant species, and is between 45–50% on a dry-weight basis. While all plants sequester carbon, trees sequester considerably more, given their size. Fast-growing trees sequester carbon more quickly than slow-growing trees, yet slower-growing trees tend to live longer and therefore sequester more carbon over their lifetime. Where there is no plan in place to ensure that fast-growing, short-lived species are harvested and utilized in a long-lived wood product, e.g., dimensional lumber, the better choice is to select a long-lived species. In choosing among long-lived species, larger tree size at maturity should be prioritized.

Estimating Potential Volume of Carbon Offsets

The quantity of offsets generated is a function of project size, sequestration rate, and discounts applied to satisfy protocol requirements.

A number of tools are available to help estimate the quantity of carbon sequestered by vegetation, each appropriate for a different context. At this stage, the purpose of using such a tool is to provide a rough estimate of the carbon sequestration potential of the project. It should be emphasized that the estimates provided by these tools do not satisfy the project carbon accounting that will be required during full project development. They should be used only to provide a sense of scale and should be conservative.

For afforestation projects, the most appropriate tool is the Reforestation Afforestation Project Carbon On-Line Estimator (RAPCOE), developed for the U.S. Environmental Protection Agency (U.S. EPA) and based on data developed by the U.S. Forest Service. The tool allows a user to select a project location, specify baseline conditions, and designate the acres of a given forest type that will replace the baseline condition. It is important to note that these estimates are available only for generic forest types and not for a specific planting composition. (*See http://ecoserver.env.duke.edu/RAPCOEv1)*

The RAPCOE tool makes certain assumptions about the rate of land-use change in order to determine the baseline condition. The most appropriate scenario for the highway ROW context is "pastureland conversion." While the conversion rate assumption is plausible for ROW projects, the leakage estimates are not plausible and should be modified to 0%. This is because afforestation of lands in the ROW is unlikely to result in a land-use conversion outside of the project boundaries.

One shortcoming of the RAPCOE tool is that it only provides carbon sequestration data for the first 20 years of a project. In order to model a project's carbon sequestration potential for a longer period, the user must manually look up the volume of accumulated tCO_2e and calculate an annual sequestration rate. For a given forest type, these values can be looked up by selecting the forest type on the "Step 2. Set the project size" page of the RAPCOE tool. This average annual sequestration rate can then be entered into this Guidebook's accompanying Afforestation & Soil Pro Forma in the Feasibility Toolkit.

For urban forest projects, this Guidebook's accompanying Urban Forest Pro Forma tool (part of the Feasibility Toolkit) has integrated sequestration look-up tables for urban forest sequestration listed in the U.S. Energy Information Administration's (EIA) *Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings* (U.S. Department of Energy, EIA, 1998). These tables list carbon sequestration per tree age for 100 different tree species organized into six categories. The Urban Forest Pro Forma tool allows the user to select any of these six categories to derive a project's gross carbon sequestration.

There are no tools for estimating changes in soil carbon applicable to the highway ROW context. In order to provide a sense of scale estimate of the rate and quantity of carbon a given project activity may sequester, the project proponent should review the academic literature to identify similar projects that may have quantified changes in carbon stocks. The types of studies that would likely be most helpful are those that look at the carbon sequestration rates of projects that convert annual croplands to native perennial grasses.

It is important to use such values cautiously, since they may over-represent the project potential. Since existing ROW grasslands are already in perennial vegetative cover, the existing ROW vegetation is already sequestering some carbon, whereas annual croplands can actually result in net emissions of GHGs due to cultivation, soil loss, and biomass harvest. This is the approach used in this Guidebook's accompanying Feasibility Toolkit.

Protocols typically require that projects account for the emissions from the combustion of fossil fuels associated with the establishment and maintenance of a project. The default emissions factor for establishment and maintenance activities for urban forest projects is 4.17 kgCO_2e per tree per year and 90 kgCO_2e per acre in the first year for afforestation and soil carbon enhancement project types.

In order to mitigate the risk of intentional or unintentional project reversals, protocols also typically require projects to contribute a percentage of offsets to a buffer pool. Each offset issuer has different procedures for determining the risk of a project reversal with the percentage of credits required to be set aside ranging from 10% to 60%. The default percentage in the Feasibility Toolkit is 15%. A buffer pool discount is not applied to the urban forest project type because it is assumed, per the protocols, that any project reversals are made up for annually by replanting lost trees.

In 2011, the average price for a carbon offset in the voluntary market was about \$6 per tCO_2e. While the implementation of policy frameworks designed to set a price on GHG emissions may have some positive effect on carbon offset prices, they are not expected to result in prices in excess of \$30 per tCO_2e over the near to medium term. The default offset price in the Feasibility Toolkit is \$10 per tCO_2e.

Examine Financial Viability

The purpose of the financial analysis is to determine if expected revenues would be sufficient to recover expected costs. For carbon sequestration projects, expected revenues are a function of the quantity of offsets generated and the price received for those offsets. Expected costs include those associated with plant establishment and maintenance activities as well as the "transaction costs" associated with bringing the project to market.

It is vital that initial estimates of costs and revenues in the analysis are conservative, since much uncertainty about the ultimate design of the project remains. Those projects that cannot demonstrate profitability or are only marginally viable at this stage are not likely to withstand additional scrutiny by project financers during formal project development and should not be pursued further.

Typical project development and transaction costs, as well as potential project revenues associated with the three project types that are suitable for the ROW are discussed below. Additionally, the pro forma tool included in the Feasibility Toolkit allows the user to calculate the net present value of a proposed project's cash flow at various geographic scales and carbon offset prices. The Feasibility Toolkit includes default values for discount rate; establishment, maintenance, and transaction costs; sequestration rates; and carbon price based on a review of the literature conducted for this research project. These default values can be modified by the user in order to develop a customized analysis.

Project costs—Typical project costs include vegetation establishment and maintenance as well as transaction costs, the costs associated with project development, documentation, monitoring, reporting, and marketing. Some of these costs only occur once while others are ongoing. Transaction costs can easily exceed several hundred thousand dollars, generally making development of small projects prohibitive. The various costs are described briefly below and in more detail in the Feasibility Toolkit.

- **Vegetation establishment and maintenance**—The initial and ongoing labor and material costs associated with plant selection, site preparation, planting, weeding, and replanting. Total establishment and maintenance costs are a function of project size (e.g., acres) and the unit cost of establishment and maintenance (e.g., dollars per acre). These costs can vary widely depending on project activity, geographic region, preexisting site conditions, and terrain.
- **Project documentation**—The initial cost of preparing a report describing the planned project activities, the monitoring and quantification procedures that will be used to estimate changes in the level of GHG emissions or removals, and how the project meets the eligibility requirements of a given protocol.
- **Define baseline scenario**—The initial cost of producing an estimate of the level of GHG emissions or removals that most likely would occur without implementation of the project. Baseline emissions or removals are those associated with current management activities. This task includes an initial inventory of project carbon pools.
- **Project validation**—The costs for the pre-implementation review of a project by an independent third party to confirm project eligibility, the adequacy of monitoring and quantification procedures, and the accuracy of the baseline scenario. Some offset programs require these activities to occur post implementation.
- **Monitoring and data collection**—The ongoing cost associated with collecting, recording, compiling, and analyzing data to support the quantification of changes in emissions or removals.
- **Project verification**—The periodic post-implementation review by an independent third party to check the project's adherence to the stated project design, record keeping and data collection systems, and calculations used to estimate credits.
- **Carbon credit brokerage fees**—An ongoing fee, typically in the form of a percentage of a project's total credits, charged by market brokers who serve as intermediaries between buyers and sellers of carbon offsets.
- **Registration/issuance fee**—An ongoing fee, typically a fixed amount per credit, charged by the offset issuer or registry to track credits in voluntary markets to provide accountability and assurance regarding issuance, holding, and acquisition of credits.

Project revenues—Project revenues include both the value of the sale of offsets and potential savings from avoided or reduced maintenance costs that might be realized as a result of project implementation. The various revenues are described briefly below and in more detail in the Feasibility Toolkit.

- **Gross carbon offset revenues**—The total proceeds from the sale of carbon offsets. These proceeds are a function of the quantity of offsets generated by a project and the price for which those offsets are sold.
- **Avoided maintenance cost**—In some cases, a sequestration project may displace or reduce the need for traditional maintenance activities on the ROW, like mowing, resulting in a cost savings to the agency. However, the default assumption in the Feasibility Toolkit is that no such savings are likely to occur since project implementation is likely to occur in areas where DOTs have already reduced or eliminated routine mowing.

Finally, it should be noted that the Feasibility Toolkit does not seek to quantify the potential value of co-benefits that might result from project implementation, such as reduced storm water treatment costs, improvements to local air quality, and improved aesthetics.

Project Planning and Documentation

If, after completing a feasibility assessment, a project proponent decides to proceed, the next step is to assemble the necessary information to complete a formal Project Design Document (PDD).

A PDD summarizes the project's activities, defines a project's geographic boundaries, documents how the project meets eligibility requirements, estimates the project's GHG benefits, and describes the monitoring plan and procedures. Project implementation must follow the PDD exactly, as it is the basis by which a project will be formally evaluated for carbon offset issuance. It is therefore critical that the PDD be carefully thought through.

As noted above, developing a carbon offset project is a highly technical endeavor. It is common for a landowner to work with a professional project developer to guide a project through the planning and documentation phase. These project developers are often professional foresters or restoration experts that specialize in carbon offset projects.

Key elements of project planning and documentation

- Identify and assemble project team
- Define project activities and boundaries
- Document project eligibility
- Perform inventory and document baseline and project sequestration scenarios
- Define monitoring plan
- Prepare formal project documentation
- Arrange project financing

The project developer will work with the project proponent to define and describe the specific activities the project will implement. The definition of project activities should include a vegetation establishment and maintenance plan that describes project timelines as well as the techniques and resources that will be employed.

The delineation of the project's geographic boundaries will need to be documented with proof of ownership or control. The PDD will explain and document how the proposed project activities meet the eligibility requirements of the applicable protocol. This may require researching and assembling evidence, such as satellite imagery or aerial photographs, to document the project area's historic land-use characteristics.

The PDD will also include an estimate of the level of GHG removals expected through project implementation. This is accomplished by comparing the effect of the project activities to a business-as-usual, or baseline, scenario. In order to determine the baseline scenario, it is first necessary to perform an initial inventory of the carbon stocks in the project area. Next, a prediction is made as to what would likely happen to these starting conditions in the future and how project implementation will modify that outcome. The specific procedures for performing this analysis vary by offset issuer.

The monitoring plan includes a description of the measurement techniques that will be used to quantify the actual GHG removals achieved by a project.

Another critical element of this phase of project development is the arrangement for project financing. Since revenue from the sale of carbon offsets does not accrue until after the project has been implemented, arrangements must be made to pay for the upfront costs of project development. The required capital is typically provided through equity investments or debt financing, and can be either provided by the project developer, a third-party financing partner, or a designation of agency funds.

Validation, Registration, and Implementation

Following completion of the PDD, a third-party validator reviews the PDD to ensure that the project meets the requirements of the carbon offset issuer and the applicable methodology. Project validation is an iterative process where the validator may request additional information or adjustments to the PDD before a final report is issued.

Following validation, the project can be officially registered with the carbon offset issuer. Registration consists of submitting the PDD, the validation report, and other supporting documentation.

Once the project has been registered, project activities are eligible for implementation. It is important that implementation follow exactly the activities described in the PDD, as the issuance of carbon offsets depends on the future verification that the project has followed these plans.

Monitoring, Verification, and Offset Issuance

While the procedures and intervals vary, each carbon offset issuer requires ongoing project monitoring and verification. Monitoring consists of recording, compiling, and analyzing data to support the quantification of emissions reductions and must follow the methodology laid out in the PDD.

Verification is the periodic review—every five years—by a third-party auditor to check that the project is being implemented as described in the approved PDD. During verification, the auditor also reviews and certifies the volume of carbon the project has sequestered. The audit is based on the data collected through project monitoring.

Once the auditor has completed a final verification report, the project proponent can then formally request issuance of carbon offsets from the offset issuer.

Marketing

A brokerage firm that specializes in arranging carbon offset market transactions typically manages the marketing and sale of carbon offsets. These firms do not buy the project carbon offsets directly, but rather identify buyers and negotiate contract terms in exchange for a commission.

Existing Protocols and Methodologies

Verified Carbon Standard

Afforestation protocols—While VCS has not approved an afforestation/reforestation protocol, several U.S.-based afforestation and reforestation projects have registered under VCS by following a CDM-approved protocol. Only one CDM-approved methodology for afforestation and reforestation projects is currently applicable to the highway ROW context: “AR-ACM0003: Afforestation and reforestation of lands except wetlands” (CDM Executive Board, 2012).

The methodology details the means for determining additionality and calculating a baseline scenario, defined as following the CDM’s “combined tool to identify the baseline scenario and demonstrate additionality in A/R (Afforestation/Reforestation) CDM project activities” (CDM Executive Board, 2007) as well as the methods for calculating net changes in the aboveground and below-ground biomass carbon pools resulting from project implementation. The approved techniques and procedures for estimating changes in carbon stocks require the physical measurement of key variables, such as the height and diameter of planted trees within designated sample plots.

Key project requirements include:

- Eligible areas must not have been cleared of native vegetation within the past ten years;
- Projects must commit to maintaining sequestered carbon for a minimum of 100 years; and
- Based on the outcome of a risk analysis, a certain percentage, with a minimum 10%, of the project’s offsets must be set aside as non-saleable.

Notably, VCS does not require projects developed following a CDM-approved methodology to meet a strict definition of forest, as required by other carbon offset standards programs. As a result, it is possible that a tree-planting project in the highway ROW could generate carbon offsets via VCS using a similar pathway to the CDM-approved protocol.

Urban forest protocols—There are no VCS-approved methodologies specific to urban forestry project activities. However, it may be possible to develop such projects using a CDM-approved afforestation methodology and seeking VCS registration in a similar manner as the afforestation projects described above. Notably, no example of a project utilizing such a pathway existed at the time this Guidebook was written.

Soil carbon protocols—VCS has approved one methodology for projects designed to increase soil carbon sequestration: "VM0021: Soil Carbon Quantification Methodology." This methodology is for projects that implement changes to cropland and grassland management practices that result in net increases in soil carbon levels. The methodology is intended to be applicable to a wide range of soil carbon projects from agricultural projects to ecosystem restoration (Earth Partners, 2012).

The methodology is identical to the methodology for Afforestation. As written above, it details the means for determining additionality and calculating a baseline scenario—defined as following CDM's "combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities" (CDM Executive Board, 2007)—as well as the means for calculating net changes in the soil carbon and other pools resulting from project implementation. The approved techniques and procedures for measuring changes in soil carbon levels require the physical sampling and laboratory analyses of key variables within designated sample plots.

Key project requirements include:

- Eligible areas must not have been cleared of native vegetation within the last ten years;
- Projects must commit to maintaining sequestered carbon for a minimum of 100 years; and
- Based on the outcome of a risk analysis, a certain percentage, with a minimum 10%, of the project's offsets must be set aside as non-saleable.

The protocol appears sufficiently broad to be applicable to projects in the ROW aimed at enhancing soil carbon levels, such as by increasing species diversity in existing grasslands through the establishment of native grasses. As a result, it is possible that such a project could generate carbon offsets via VCS using this methodology.

Climate Action Reserve

Afforestation protocols—CAR's *Forest Project Protocol* describes the project eligibility criteria, the methods for calculating net changes in carbon pools, and the verification and monitoring requirements for carbon sequestration projects implemented on forestlands. Reforestation projects are one of three eligible project types—the other two being improved forest management and avoided conversion—described in this protocol (Climate Action Reserve, 2012).

In general, the CAR protocol is more restrictive than the VCS protocol described earlier, and these restrictions likely preclude use of this protocol for projects developed in the highway ROW.

Key project requirements include:

- Adoption of management practices to encourage habitat for native wildlife and plant species,
- A requirement that projects restore and maintain a minimum density of 10% tree cover,

- That project areas be monitored and maintained for a period of 100 years following issuance of any offsets, and
- A prohibition on the harvest or removal of reforested or preexisting trees within the project area for a period of 30 years.

Urban forest protocols—CAR's *Urban Forest Protocol* is the only carbon offset protocol specifically designed for tree-planting activities in urban and other built-up lands. The protocol describes the project eligibility criteria, the methods for calculating net changes in carbon pools, and the verification and monitoring requirements for such projects (Climate Action Reserve, 2010).

Two key restrictions likely preclude the use of this protocol for projects developed in the highway ROW:

- Project eligibility is limited to tree-planting activities on lands owned or controlled by municipalities, universities, or electric utilities and
- Project trees must be maintained for a period of 100 years with trees lost to natural or human disturbance, such as disease or land-use changes, required to be replaced.

While the protocol in its current form is not applicable to ROW projects, CAR periodically reviews and revises existing protocols and might consider expanding its eligibility criteria if it can be demonstrated that a significant opportunity exists. In making this determination, CAR would seek evidence that a standardized approach for establishing additionality and baseline emissions were possible.

Soil carbon protocols—There are no CAR-approved protocols specifically for soil carbon enhancement project activities. While CAR is currently developing protocols aimed at enhancing soil carbon sequestration through implementation of improved agricultural management practices, none of the proposed protocols are applicable to the highway ROW context, as they are narrowly tailored to lands that support crop production.

American Carbon Registry

Afforestation protocols—ACR has approved one methodology for afforestation and reforestation projects: "Methodology for Afforestation and Reforestation of Degraded Land." The methodology describes the eligibility criteria and methods to account for GHG removals from projects that occur on "degraded lands" (American Carbon Registry, 2011). The concept of land degradation is typically associated with poor agricultural management practices, deforestation, overgrazing, and industrial pollution.

Several features of the eligibility restrictions included in this methodology restrict its applicability to potential projects developed in highway ROW.

These restrictions include:

- A requirement that projects restore and maintain a minimum density of 10% tree cover,
- A requirement that projects be monitored and maintained for a period of 40 years following the project's start date, and
- A requirement that the project be implemented on "degraded lands."

While this methodology may not be applicable to projects developed in the highway ROW, it may be possible to use a CDM-approved methodology, such as AR-ACM0003, described previously, to develop a project via ACR. This approach would essentially remove the "degraded lands" requirement, but would not eliminate the other ACR eligibility requirements described above.

Urban forest protocols—There are no ACR-approved methodologies specifically for urban forestry project activities. However, it may be possible to develop such projects via ACR using a CDM-approved afforestation methodology, so long as the project meets ACR's project eligibility requirements, such as minimum canopy cover and project duration. Notably, no example of a project utilizing such a pathway existed at the time this Guidebook was written.

Soil carbon protocols—There are no ACR-approved protocols specifically for soil carbon enhancement project activities at this time.

Feasibility Toolkit

A DOT interested in evaluating the specific opportunity for developing a carbon sequestration project in its state should use the accompanying Feasibility Toolkit (described in additional detail in Chapter 4) to determine if local conditions are favorable to project development.

CHAPTER 3

The Biomass Energy Market: A Primer for DOTs

Overview

A number of existing technologies can convert biomass feedstocks, such as wood, starchy grains, and oilseeds, into heat, electricity (biopower), or transportation fuels (biofuels). Over the past decade, biomass energy consumption in the United States has increased more than seven fold.

A number of states have explored the potential to utilize highway ROWs to grow biomass feedstocks. These pilot projects have focused primarily on the potential to grow oilseed crops to produce biodiesel, though a few have also experimented with growing switchgrass (*Panicum virgatum)* or harvesting existing grassy biomass. Notably, the focus of all these efforts has been limited to identifying the technical constraints of growing feedstocks in the ROW. Little attention has been paid trying to understand the business model or market development issues required to move up from pilot to commercial scale.

While it is technically possible to implement biomass feedstock projects in the highway ROW, under current conditions, the practical opportunity for such projects to produce marketable bioenergy feedstocks is limited by a number of factors.

First, there are considerable challenges in ensuring that feedstocks grown in the ROW would ultimately serve a bioenergy end use. Second, management considerations about motorist safety—including fixed-object hazards in the clear zone, risk of vehicle–wildlife collisions and potential for sightline obstruction—present additional complications for potential bioenergy feedstock projects. While many of these issues can be managed through careful site selection, the effect is to substantially restrict the areas within the ROW where feedstocks can be grown. Third, the soil conditions, geography, and land configuration of highway ROW make farming in the ROW more difficult, and therefore more expensive than normal agricultural conditions. Fourth, the prevailing prices for bioenergy feedstocks are not currently sufficient to recover production costs, even assuming yields comparable to normal agricultural conditions.

Conditions to Monitor

As noted above, the limits to produce marketable bioenergy feedstocks in the highway ROW are largely market constraints, not technical constraints. Some of these constraints may not hold in the future. The conditions to monitor that might alter project viability include the deployment of new technologies, the development of higher yielding crop varieties, and increases in electricity and fossil fuel prices.

There are a number of next generation technologies in varying phases of development that offer great promise for future energy generation and market expansion. Some of these technologies have been successfully demonstrated on a pilot scale and are in the early stages of commercial deployment, while others remain in the research and development phase. Technologies to watch include dry anaerobic digestion, cellulosic bioethanol, torrefaction, pyrolysis, and gasification. Opportunities for bioenergy feedstock crops will increase as these technologies are further developed and achieve commercial scale.

Similarly, researchers continue to investigate opportunities to enhance bioenergy feedstock crop yields through traditional plant breeding and selection as well as genetic engineering. Yields can also be enhanced and production costs reduced through improvements in agronomic practices, which can significantly improve project economics.

Finally, rising electricity and fossil fuel prices would improve the financial viability of projects by increasing the competitiveness of bioenergy technologies, thereby increasing the value of feedstocks. The minimum feedstock price for woody biomass must generally exceed $60 per dry ton for projects in the ROW to be viable. Rising fossil fuel prices also make decentralized bioenergy conversion technologies, like small-scale integrated seed crushing and biodiesel production, economically possible. These small-scale, decentralized systems are generally better suited to the volumes of bioenergy feedstocks that can be efficiently grown in highway ROWs.

Direct Combustion for Heat and Power

Direct combustion, the burning of a bioenergy feedstock in the presence of oxygen from the air, is the most common technology used to release the energy stored in biomass. Wood and wood-derived fuels are the primary bioenergy feedstocks for direct combustion technologies. While dedicated woody energy crops, like poplar and willow, could potentially serve as a suitable feedstock for some direct combustion technologies, they are not currently widely utilized for this purpose. Grassy biomass feedstocks, like switchgrass, are not widely utilized because high mineral silica content causes increased slagging of combustion equipment.

The energy released from direct combustion is either used directly as heat or indirectly to produce steam that can be used for process energy or to generate electricity. Most biomass combustion occurs in the residential (25% of U.S. wood energy consumption) and industrial sectors (62% of U.S. wood energy consumption). The electric power sector (9% of U.S. wood energy consumption) and the commercial and institutional sector (4% of U.S. wood energy consumption) comprise the rest of the market (Energy Information Administration, 2012a).

Residential scale biomass combustion systems include fireplaces, wood stoves, pellet stoves, and centralized wood and pellet boilers and furnaces. The primary feedstocks in the residential sector are local, self-sourced cordwood and wood pellets that are manufactured from fine mill residues (e.g., sawdust) from wood product manufacturers or high-quality wood chips.

Industrial-scale biomass combustion systems primarily produce thermal energy, typically in the form of steam, for use in the manufacturing process. Systems can also be configured to generate electricity in addition to thermal energy, a so-called combined heat and power (CHP) application. Industrial combustion systems typically feature fuel handling and preprocessing equipment, a combustion chamber and heat exchanger (i.e., a boiler) and, where designed to generate electricity, a steam turbine.

On the industrial scale, the primary feedstocks are manufacturing by-products, often self-sourced, from the paper and wood products industries like pulping liquors and hog fuel. Hog fuel, named for the type of grinder used to produce it, is a mixture of wood product mill wastes, most often ground bark and trim mixed with fine mill residues. Hog fuel can also be derived from small-diameter whole trees (e.g., forest thinnings), logging residues (e.g., slash), and urban wood waste (e.g., tree trimmings).

Most electric power sector combustion systems are located at dedicated biomass electric power plants, where wood and wood waste are the only fuel sources. Some electric power plants also combust woody biomass in combination with a fossil fuel, usually coal, in what is called a co-firing plant. Dedicated biomass electric power plants feature many of the same system components as industrial-scale systems except that electric power systems always include a steam turbine to generate electricity. Co-fired plants typically are retrofits of preexisting plants to which biomass feedstock preprocessing and fuel handling have been added.

Dedicated biomass electric power plants accept a wide variety of woody biomass feedstocks, including hog fuel, wood chips, logging residue, urban wood waste, and whole logs. The type of feedstock accepted by a given facility depends on the capabilities of its preprocessing equipment, with some facilities only capable of accepting previously chipped or ground fuels, while others can accept whole logs up to six feet in diameter. Co-firing facilities tend to have more stringent feedstock requirements and generally prefer fine mill residues and wood chips.

Commercial- and institutional-sector biomass combustion systems primarily produce thermal energy as steam to heat buildings. While this sector is small relative to others, interest in these types of systems is strong, particularly in rural and historically timber-dependent communities. For these communities, the deployment of biomass heating systems is seen as a boon for local economic development since feedstocks are generally sourced from local firms. Several states have developed programs specifically designed to encourage rural school districts to evaluate the feasibility of implementing biomass combustion projects. These systems are similar in design to industrial systems, with a fuel handling system and steam boiler, though at a much smaller scale. The primary difference is that commercial and institutional systems typically lack preprocessing equipment and therefore have stricter feedstock requirements.

Most commercial and institutional biomass heating systems prefer paper-grade woodchips, so called because they are the primary feedstock for the pulp and paper industry, because of the uniformity and low ash content. Paper-grade chips are a by-product of sawmill operations or a primary product of chip mills, facilities that debark and chip small-diameter logs. Lower grade woodchips, like those made from logging residue or urban wood waste, are generally not suitable for commercial and institutional systems because their irregular size, bark content, and the presence of debris can interfere with safe and efficient equipment operation. Some commercial and institutional systems utilize high-quality wood pellets. Table 5 summarizes the direct combustion market.

Table 5. Commercialized biomass conversion technologies—direct combustion.

Sector	Technology	Feedstock Requirements and Availability	Market Characteristics	Drivers
Residential wood and pellet heating	Fireplaces, wood pellet stoves	Cordwood, wood pellets	25% of U.S. wood energy consumption	Socioeconomics, proximity to fuel source
Commercial and institutional wood, wood chip, and pellet heating	Centralized boiler for hot water and steam	Paper-grade and bole chips, pellets	4% of U.S. wood energy consumption, schools, hospitals	Proximity to fuel source, local value-add
Industrial biomass combustion for thermal energy and electric power	Fixed or fluidized bed boiler, CHP	Pulping liquor, hog fuel, sawdust, shavings, chips; primarily self-consumption of manufacturing by-products	62% of U.S. wood energy consumption, concentrated in the pulp and wood products industry	Proximity to fuel, avoid landfill tipping, natural gas substitution
Electric power sector direct combustion	Dedicated, co-fire	Hog fuel, logging residue, urban wood waste	9% of U.S. wood energy consumption; competing with natural gas	Proximity to fuel, renewable power mandates

Direct Combustion Feedstocks Potentially Applicable to Highway ROWs

Fast-growing woody biomass species, such as poplar and willow, could potentially be grown in highway ROWs to serve some direct combustion biomass systems, specifically in industrial- and utility-scale direct combustion facilities. Advances in harvesting techniques that improve chip quality may also create opportunities to serve commercial and institutional scale biomass combustion systems.

While perennial grassy biomass species, like switchgrass, have been extensively investigated as a potential bioenergy feedstock, concerns about high mineral contents potentially damaging combustion equipment have created resistance among potential end users, and markets for these feedstocks do not currently exist. Widespread commercialization of next generation bioenergy technologies, like cellulosic ethanol, thermochemical conversion, and dry anaerobic digesters, may create new opportunities for grassy biomass. Table 6 provides a summary of these potential feedstocks.

Hybrid Poplar

The genus *Populus* is composed of almost 30 species and is a well-established component of the native North American landscape. Intentionally cultivated poplars are usually hybridized varieties that have been selected to maximize productivity. While poplar has the ability to be coppiced and is often mentioned as a potential bioenergy feedstock, it is primarily managed as feedstock for paper or grown to mitigate runoff from land-applied wastewater biosolids.

While various *Populus* species are adapted to every state in the continental U.S., the intentional planting of hybrid poplars is concentrated in the Pacific Northwest, lower Mississippi River Valley, and Upper Midwest. Hybrid poplars prefer sites with deep, medium-textured, moist, and nutrient-rich soils. Sites with slopes greater than 8%, highly alkaline or acidic soils, and those with a hardpan in the root zone are less productive and should be avoided.

Hybrid poplar is established by mechanically planting dormant stem cuttings in weed-free seedbeds. As a bioenergy feedstock, it is recommended that poplar be planted at a density of about 700 trees per acre (just under eight foot by eight foot spacing). Stands are usually established in minimum blocks of 25 acres in order to simplify planting, maintenance, and harvest operations. Once planted, it is necessary to eliminate weed competition until the tree canopy closes, which is usually by the end of the second or third year after planting. Harvest can occur between years six and eight. While poplar can be coppiced, the practice of cutting a plant to just above ground level and allowing new growth to emerge from the stump, there is little research

Table 6. Woody and herbaceous energy crops summary.

Crop	Agronomics	Market Potential	ROW Considerations
Poplar	Plantation; 2–6 dry tons/acre/year; 8 yr. harvest & rotation cycle	Industrial and electric power sector; bioenergy use is secondary to pulp and lumber use	Limited maintenance; >4” diameter at maturity; >40’ tall at maturity; requires >20 acre blocks
Shrub willow	Coppiced; 20–25 yr. rotation, 3-4 yr. harvest cycle; 2–6 dry tons/acre/year	Industrial & electric power sector; no active buyers	Low maintenance, small diameter, potential co-benefits; requires >20 acre blocks; potential sightline obstruction; potential wildlife attractant
Switchgrass	Widely adapted, low input, perennial, 2–10 tons/acre/year	Co-fired in electric power; cellulosic bioethanol; no active buyers	Low maintenance; >8’ tall at maturity

on the optimal management regime. Poplar biomass yield is generally between two and six dry tons per acre per year.

Poplar is incompatible with many DOT management considerations, most notably limits on the size of fixed objects in the clear zone, since it reaches up to 15 inches in diameter in just seven years. While hybrid poplar could technically be grown outside of the clear zone, the irregularly shaped parcels found outside of the clear zone are likely not large enough to accommodate the preferred large rectangular planting blocks that facilitate ease of planting and harvest.

Moreover, utilization of poplar as feedstock for direct combustion facilities is largely nonexistent in the U.S. Where it does occur, it is limited to the collection of harvest residues from hybrid poplar grown for pulp or timber. The primary challenge to the utilization of poplar as a bioenergy feedstock is its cost of production, even in less constrained contexts than the highway ROW, relative to the price of equivalent bioenergy feedstocks and fossil fuel substitutes.

Shrub Willow

Shrub willow (*Salix* spp.) has several characteristics that make it an attractive feedstock, including its potential to produce high yields in a short amount of time, relative ease of establishment, ability to be coppiced, and chemical and energy characteristics similar to hardwood tree species. Besides use as a bioenergy feedstock, shrub willow also has potential applications in the establishment of riparian buffers, brownfield remediation, and as a living snow fence.

Shrub willow is best adapted to the colder climates of the Northeast and Upper Midwest. Willow can be grown in a range of soil conditions but grow best on sites with soils that are well-drained, nutrient rich, and moderately deep—at least 18 inches. Sites with slopes greater than 8% or with standing water should be avoided, as they conflict with the safe, efficient operation of planting and harvesting equipment.

Shrub willow is established by mechanically planting dormant stem cuttings called “whips” in weed-free seedbeds. Plants are typically placed every 20 inches in double rows spaced 2.5 feet apart with spacing between these double rows of six feet to achieve a density of about 6,000 plants per acre. Effective weed control, especially in the first years of establishment, is essential and typically accomplished through a combination of mechanical and chemical controls. After the initial growing season, plants are cut back close to the soil surface to force coppice regrowth. Once established, willow requires little to no annual crop maintenance. Harvest occurs in the third or fourth growing season and every three years thereafter. Well-managed stands can remain productive for more than 20 years and yield between two and six dry tons per acre per year.

Shrub willow is largely compatible with the operating constraints of the highway ROW and under the right economic conditions could be a viable bioenergy feedstock option for DOTs looking to grow marketable biomass. While initial establishment requires intensive management, once established, shrub willow is relatively self-sustaining and requires little maintenance. The tri-annual coppicing rotation keeps stem diameter below four inches, making it potentially acceptable inside the clear zone. Existing cropping systems could be easily adapted to the narrow linear confines of the longitudinal ROWs. Further, willow stands could serve other DOT interests, such as mitigating storm water runoff and controlling blowing snow.

A DOT should keep in mind that shrub willow can reach heights greater than 20 feet, creating a potential sightline obstruction. Willow is also a potential wildlife attractant, as the plant’s tender shoots are highly palatable to deer. Shrub willow stands also provide habitat for birds and small mammals, so special care should be given to the timing of maintenance and harvest activities so as not to harm these species.

While willow has been utilized as a feedstock for direct combustion facilities in Northern Europe for more than two decades, in the U.S. its utilization remains largely limited to research and development trials. The primary challenge to the widespread commercialization of willow is its high production costs, even in less constrained contexts, relative to prices of other feedstocks and fossil fuel substitutes.

In order to be economically viable some combination of the following must occur—yields must increase, production costs must fall, bioenergy feedstock prices must rise, or emerging technologies must open new markets.

Biomass for Transportation Fuels

Technologies that transform bioenergy feedstocks into liquid fuels for use primarily in the transportation sector account for about 40% of U.S. bioenergy consumption (Energy Information Administration, 2012b). The primary biofuel technology in the U.S. is starch hydrolysis and fermentation to produce bioethanol (ethyl alcohol) and transesterification to produce biodiesel (fatty acid methyl ester). Starch-derived bioethanol accounts for about 90% of all U.S. biofuel energy consumption, with the balance consisting of biodiesel consumption. Bioethanol can be substituted for, or blended with, gasoline. The average bioethanol content of gasoline sold in the U.S. is approximately 10%. Likewise, biodiesel can be blended or substituted for petroleum diesel, and is commonly blended at 5% and up to 20% by volume.

Starch-derived bioethanol is produced by fermenting sugars extracted from starchy grains, in a process similar to liquor production. The grain is first milled and then mixed with water and enzymes to convert the complex starches into simple sugars. The resulting mixture is then combined with yeast and allowed to ferment. During fermentation, the yeast converts the sugars into ethanol and carbon dioxide. The ethanol is then distilled and a denaturant is added to make it unfit for human consumption.

The primary feedstock for bioethanol production in the U.S. is corn, though some other starchy grains, like grain sorghum (milo), are common in some parts of the country. Corn is preferred because of its relatively high starch content and ready availability. Ethanol plants are often operated as a part of a vertically integrated supply chain where the producer controls feedstock sourcing, transportation, grain storage, manufacturing and marketing. Corn and other starch grains are typically sold into commodity markets where the grower has little or no control over its ultimate end use.

Most biodiesel manufactured in the U.S. is produced using a process called transesterification, where vegetable oils or animal fats are reacted with methanol and a catalyst (e.g., potassium or sodium hydroxide) to yield biodiesel and a co-product, glycerin. The biodiesel is then separated from the glycerin and further refined to remove impurities. Feedstocks high in free fatty acids, like animal fats and recycled vegetable oils, are subjected to a preprocessing step called acid esterification.

Virgin soybean oil is the leading feedstock for biodiesel production, followed by virgin animal fats, virgin canola oil, and used cooking oil. Feedstock sourcing is driven by tradeoffs between quality, price, and availability. Virgin vegetable oils are preferred because they are readily available and do not require preprocessing; however, they are more expensive than other feedstocks. Virgin oils are typically sourced from large oilseed crushing facilities that use a capital-intensive chemical extraction technique and source oilseeds on a commodity basis from regional grain elevators. Notably, biodiesel is only one potential, and not the most common, end use for virgin vegetable oils. While some very large oilseed firms have co-located biodiesel production facilities adjacent to preexisting crushing facilities, it is an uncommon practice for biodiesel producers to have integrated crushing capabilities. Table 7 summarizes biofuel considerations.

Table 7. Commercialized biomass conversion technologies—biomass for transportation fuels.

Sector	Technology	Feedstock Requirements and Availability	Market Characteristics	Drivers
Biodiesel	Transesterification	Soybean oil, animal fats, canola oil, recycled cooking oil and grease	6% of U.S. biofuel energy consumption; few producers crush own oilseeds	Blending mandates, biodiesel tax credit, renewable and low-carbon fuel standards
Bioethanol	Dry mill and wet mill fermentation	Corn	94% of U.S. biofuel energy consumption	Renewable fuel standard

Biofuel Feedstocks Potentially Applicable to Highway ROWs

A number of common biofuel feedstocks, including starchy cereal grains, such as corn or grain sorghum, and vegetable oils from annual oilseed crops, such as soybeans or canola, could potentially be grown in the highway ROW. However, the primary markets for these crops are regional grain elevators where the ultimate end use is not discernable, making it a challenge to purposefully grow these crops for biofuels. If local small- to medium-scale biofuel producers exist, delivery contracts for feedstocks may be possible; these opportunities are very limited at this time.

A number of non-food crops, including camelina (*Camelina sativa*) and switchgrass, have received considerable attention as potential biofuel feedstocks, but markets for these feedstocks have yet to mature as of the time of writing this Guidebook. Table 8 summarizes key characteristics of biofuel feedstock crops.

Corn

Corn (*Zea mays*) is the preferred feedstock for bioethanol production in the U.S. because of its abundance and high starch content. Because of high nutrient demands, corn is typically grown in rotation with a nitrogen-fixing crop such as soybeans or alfalfa.

Table 8. Biofuel feedstock crops summary.

Crop	Agronomics	Market Potential	ROW Considerations
Starchy Cereal Grains and Sugar Crops (bioethanol feedstock)			
Corn	High input, intensive production system; part of multi-year crop rotation; prefers deep fertile soils; yield 3.4–4.6 tons/acre; widely adapted	1^{st} generation bioethanol producers; commodity value chain	Potential sightline obstruction; potential wildlife attractant; requires high rates of fertilizer and pesticides; GMO
Grain sorghum	Dry-land farmed in multi-year rotation; yield 11–16 tons/acre (50–70 bushels/acre)	1^{st} generation bioethanol producers	Potential sightline obstruction; potential wildlife attractant
Oilseed Crops (biodiesel feedstock)			
Soybeans	Bi-annual rotation; 1–1.3 tons per acre (34–44 bushels /acre); widely adapted	Biodiesel producers; commodity value chain (grown primarily for protein content, not oil production)	Potential wildlife attractant; requires modest rates of fertilizer and pesticides; GMO
Canola (Rapeseed)	Spring/winter cultivars; part of multi-year crop rotation; rotated with cereal or grass crops; 1,200–1,800 pounds/acre	Biodiesel; commodity value chain; competes in food oil market; limited market opportunity (less than 2% of canola oil serves biodiesel)	Technically feasible

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Corn is a warm season, annual grain grown throughout the continental U.S. in areas receiving 20 or more inches of annual precipitation, though its production is concentrated in the Midwest. Most of the corn grown in the U.S. has been genetically modified to tolerate a number of herbicides and has pesticidal properties that provide insect protection. Corn prefers deep, fertile, well-drained, medium- to coarse-textured soils. Sites with steep slopes and droughty soils should be avoided. Dry-land farmed (i.e., without irrigation) corn requires 18 to 20 inches of available precipitation during the growing season.

Corn can be established either with conventional or conservation tillage, if soils are not compacted. Corn is typically planted in rows with 15- to 38-inch spacing at seeding rates between 20,000 and 50,000 seeds per acre. Corn is intensely managed in order to provide supplemental fertilization and to control weeds, pests, and disease. At maturity, corn can reach heights in excess of 15 feet. Harvest is conducted with a combine that separates the kernel from the cob in the field. Yields vary depending on growing conditions, but on average, U.S. corn yields over the last decade have ranged between 122 and 164 bushels (3.4 to 4.6 tons) per acre.

A number of challenges make growing corn in the highway ROW an unlikely fit for widespread adoption. First, the irregularly shaped and fragmented parcels found in the ROW are inefficient to farm. Corn demands intensive management that requires frequent field access, and it is not practical to have to frequently load and unload farm equipment to farm such small areas. Second, the intensive use of synthetic fertilizers, pesticides, and herbicides could imperil water quality. Third, corn can pose a sightline obstruction; encroachment of corn fields on the ROW, especially along rural roads, is a frequently mentioned management concern among state DOTs and local public works departments. Fourth, the suboptimal soil conditions of the ROW may not be suited to corn cultivation. A final factor disfavoring corn production in the ROW is its potential as a wildlife attractant.

Grain Sorghum

Sorghum (*Sorghum bicolor*) is a semi-tropical grass that can be cultivated for grain production (i.e., grain sorghum or milo). A small number of U.S. bioethanol producers currently use grain sorghum as a feedstock for bioethanol production.

Grain sorghum production is concentrated in areas considered too dry for corn. Most grain sorghum is grown in the Great Plains states of Kansas, Texas, Oklahoma, Colorado, and South Dakota, where it is dry-land farmed in rotation with soybeans and cotton or wheat. While grain sorghum prefers deep, moist, fertile soils, it is resistant to drought and can still produce respectable yields on more marginal lands. Sorghum has the highest water use efficiency—highest yield per inch of available water—of commonly grown crops.

A variety of tillage systems can be used to prepare a seedbed for sorghum planting, though conservation tillage is common in the erosion prone Great Plains states where production is concentrated. Grain sorghum is typically planted in rows 30 inches apart and, depending on annual rainfall, at a density of 37,000 to 153,000 seeds per acre. Similar to corn, grain sorghum is intensely managed in order to provide supplemental fertilization and to control weeds, pests, and disease. At maturity, grain sorghum reaches a maximum height of six feet, but there is considerable variation among modern hybrids. Grain sorghum is harvested with a combine that cuts the plant and separates the grain from the seed head. Yields for grain sorghum over the last decade have ranged between 11.4 and 16 tons per acre (50 and 70 bushels per acre).

Growing grain sorghum in the highway ROW faces many of the same challenges as growing corn, including inefficient farming, encroachment that causes a sightline obstruction, and its potential as a wildlife attractant. However, grain sorghum's ability to tolerate adverse growing conditions makes ROW soil conditions less of a concern.

Soybeans

Oil from soybeans (*Glycine max*) is the primary feedstock for biodiesel production in the U.S. Soybeans are most frequently grown as a part of an integrated cropping system where soybeans are planted in two-year rotation with corn or another grain crop (e.g., wheat).

Soybeans are a warm season, leguminous crop grown throughout the U.S., though production is concentrated in the Midwest. More than 90% of the soybeans grown in the U.S. are genetically modified varieties developed for herbicide resistance. Soybeans prefer deep, well-drained, fertile soils. Sites with wet, poorly drained soils should be avoided because of increased risk of disease.

While conventional tillage prior to planting continues as a common practice, it is no longer considered necessary to maximize crop yields, and no-till planting is now considered the best practice. Soybeans are typically planted in rows of less than 30 inches at a seeding rate between 125,000 and 140,000 seeds per acre. While soybeans do not generally require supplemental fertilization, they are intensely managed to control weeds, pests, and disease. Soybeans have a relatively low growing habit and at maturity reach a height of four feet or less. Most soybeans are harvested with a combine that separates the seed from the rest of the plant. U.S. soybean yields over the last decade have ranged between 1 and 1.3 tons per acre (34 and 44 bushels per acre).

Several factors make growing soybeans in the highway ROW an unlikely fit for widespread adoption. As with other annual crops, the irregularly shaped and fragmented parcels found in the ROW are inefficient to farm. Likewise, the compacted soil conditions are generally not suitable for growing soybeans without substantial improvement. Additionally, soybeans are highly palatable to deer and other wildlife. Unlike some other oilseed and grain crops, the low stature of soybeans does not present the same concerns for sightline obstruction.

Canola (Rapeseed)

Oil from canola is the second most common biodiesel feedstock in the U.S. canola is actually a type of rapeseed (*Brassica napus Linnaeus* or *Brassica rapa*) that has been bred to have qualities that make it suitable for both human and livestock consumption. There are two basic types of canola cultivars that can be grown in the U.S.: spring canola, planted in the spring and harvested in the late summer, and winter canola, planted in the fall and harvested in the following summer. Because of susceptibility to disease, canola is most often grown on three to four year rotations with other crops.

Most canola grown in the U.S. is spring canola with production concentrated in the Northern Plains. Winter canola is grown in the Pacific Northwest, the Southeast, and parts of the Midwest. Most canola grown in the U.S. is genetically modified for herbicide resistance. Canola prefers well-drained silt loams that do not crust. Canola will not tolerate poorly drained, wet soils.

Spring and winter canola can be planted into soils that have been prepared via conventional or conservation tillage. Canola is typically planted in rows with seven- to eight-inch spacing at a seeding rate of about five to eight pounds per acre. While growing canola is less intensive than other oilseed and grain crops, it still requires the application of herbicides and pesticides to manage weeds, pests, and disease. At maturity, canola reaches a height of four to six feet. Most canola is harvested by first swathing (i.e., cutting down) and windrowing (i.e., piling up) the plant, allowing uniform drying for 10 to 14 days. Later, a combine is used to thresh the seed from the plants. Canola yields vary by growing conditions, region, and cultivar type, with winter canola often outperforming spring canola by 20 to 30%. On average, U.S. canola yields over the last decade have ranged between 1,200 and 1,800 pounds per acre.

Growing canola in the ROW presents fewer complications than other common biofuel feedstock crops. Canola is less intensively managed than other oilseed and grain crops and its low stature is unlikely to pose a sightline obstruction. Moreover, canola's root structure, which features a long, strong taproot, is capable of penetrating and breaking up compacted and hardpan soils, making it better suited to thrive in roadway conditions.

While canola may be better suited than other oilseeds and grains to be grown in the ROW, challenges remain. First, as with other annual crops, the fragmented and irregularly shaped parcels in the ROW are inefficient to farm. Second, canola may act as a wildlife attractant. This is especially true of winter canola, whose leafy greens may stand out in contrast to other vegetation that goes dormant in the winter. Third, the widespread planting of genetically modified canola could increase the risk of genetic cross-contamination with brassica species, such as broccoli and cabbage, grown as cash crops, potentially creating conflict with neighboring agricultural producers. The risk of cross-contamination also extends to brassica species listed as noxious weeds, potentially creating management challenges in controlling those species.

Emerging Technologies

In addition to the commercialized biomass energy conversion technologies discussed above, there are a number of next generation technologies in varying phases of development. Some of these technologies have been successfully demonstrated at a pilot scale and are in the early stages of commercial deployment, while others remain in the research and development phase. Three of the most promising are dry-fermentation anaerobic digestion, cellulosic bioethanol, and thermochemical conversion.

Anaerobic digestion is the biological process in which microorganisms decompose organic material in the absence of oxygen, producing biogas. Biogas is primarily composed of methane and can be combusted to generate electricity and heat, or cleaned and compressed to power vehicles. So-called "wet" anaerobic digestion systems have long been utilized to treat municipal wastewater and livestock manure. More recently, dry-fermentation anaerobic digestion systems have been developed to process drier materials, such as yard waste and crop residues. Though there are only two dry-fermentation biogas plants currently operating in the U.S., more than 30 additional plants are in the planning stages. While it is anticipated that this technology will primarily be deployed as a way to manage organic material in municipal solid waste streams, widespread commercialization may create opportunities for other feedstocks, such as grassy biomass harvested from the highway ROW.

Cellulosic bioethanol technologies seek to convert lignocellulosic biomass, like agricultural residues and grassy and woody biomass, into bioethanol. This is accomplished by first separating the feedstock into its constituent parts—cellulose, hemicellulose, and lignin. The cellulose and hemicellulose are then further treated to convert them into fermentable sugars that can be used to produce bioethanol. While widespread commercialization of the technology remains elusive, there is robust public policy support for the technology that may generate a substantial market for lignocellulosic feedstocks.

Thermochemical conversion technologies transform lignocellulosic biomass into solid, liquid, or gaseous fuels through the manipulation of heat, oxygen, and pressure. There are three basic types of thermochemical conversion processes: torrefaction, pyrolysis, and gasification. These processes produce fuels that have higher energy densities and are more easily utilized in conventional energy systems than their original feedstocks. While these technologies have successfully been validated at demonstration and pilot scales, they have not gained widespread commercial adoption.

Initial Feasibility Assessment

Prior to developing a bioenergy feedstock project, a DOT should assess the technical and economic feasibility of the project concept. The purpose of this assessment is to take a critical and comprehensive look at a prospective project and make an objective determination of whether the project should move forward or be abandoned until conditions improve.

The key elements of a feasibility assessment for a bioenergy feedstock project are the identification of a potential market buyer, the preliminary identification of project location, the evaluation of potential feedstock crops, and a preliminary financial analysis.

Key elements of feasibility assessment

- Identify a potential buyer
- Site selection
- Feedstock crops evaluation
- Financial analysis

The primary purpose of the Biomass Checklist in the Feasibility Toolkit described below is to guide a DOT through this type of feasibility analysis to determine if a project is worth pursuing further. If a decision is made to move forward with a project, it is advisable to consult with relevant agronomic experts to review the internal feasibility assessment before moving forward with formal project implementation.

Identify a Potential Buyer

The first step in assessing the feasibility of a bioenergy feedstock project is determining if there is an end-user interested in purchasing the feedstock and understanding the buyer's quality specifications, pricing, and payment terms.

Woody biomass feedstocks—Potential buyers of woody biomass feedstocks, like willow or poplar, might include industrial facilities with existing woody biomass–fired boilers, most likely in the wood products industry; dedicated or co-fired electric power generators; or commercial and institutional facilities with woody biomass combustion systems. Pellet producers may also be a potential buyer.

There are a number of public and private databases listing existing biomass combustion facilities. Notably, there is no single source listing all such facilities and some of the databases overlap. Some of the leading databases are described below.

The National Renewable Energy Lab's *BioEnergy Atlas* is a web-based interactive map that shows the location of all wood and wood waste–fired industrial CHP and dedicated biomass electric power plants in the U.S. The site also shows the location of electric power plants co-fired with biomass. Notably, not all of the facilities listed have the capacity to accept woody biomass.

See: http://maps.nrel.gov/biomass

Biomass Magazine, a leading industry trade publication, maintains an online list of existing and proposed "biomass plants" and pellet producers. The list of biomass plants includes both industrial and dedicated biomass electric power facilities and is sortable by feedstock type.

See: http://biomassmagazine.com/plants/listplants/biomass/US/
http://biomassmagazine.com/plants/listplants/pellet/US/

The Biomass Energy Resource Center maintains a database of commercial- and institutional-scale facilities that use biomass energy for heating or CHP. The database is searchable by state and feedstock type used.

See: http://www.biomasscenter.org/database.html

The University of Tennessee Office of Bioenergy Programs also maintains a database, called Wood2Energy, of proposed and existing facilities that utilize woody biomass for heating or electricity production. The list also includes wood pellet producers. The list is searchable by state and facility type. Notably, many of the listings are incomplete and do not specify the type of feedstocks utilized.

See: http://www.wood2energy.org/Database%20Connection.htm

Biofuel feedstock buyers—Identifying buyers of biofuel feedstocks, like starchy grains and oilseeds, is complicated by the fact that many biofuel producers do not buy directly from growers. Most often these crops are sold to regional grain elevators from where the ultimate end use is not discernable. This is especially true for oilseed feedstocks that require intermediate processing. However, there may be localized opportunities to contract directly with a bioethanol production facility or work creatively with an oilseed processor and biodiesel production facility. In the latter case, the objective would be to identify a small-scale biodiesel producer willing to work with a DOT and regional oilseed processor that would "toll crush" the crop.

There are a number of databases listing existing biodiesel production facilities and oilseed processors. Notably, there is no single source listing all such facilities and many of the databases overlap or are out of date. The leading databases are described below.

The Renewable Fuels Association, a national bioethanol industry trade association, maintains a list of operating and proposed bioethanol production facilities on its website. The list includes the plant location, production capacity, and primary feedstock.

See: http://www.ethanolrfa.org/bio-refinery-locations/

Ethanol Producer Magazine, a leading industry trade publication, also maintains an online list of existing and proposed bioethanol facilities. The list is sortable by feedstock type, capacity, or location. The list also includes existing demonstration-scale cellulosic bioethanol plants and proposed full-scale facilities. State grain grower associations also often maintain a list of bioethanol plants operating in the respective state. While the aggregated plant lists do not specify if a facility accepts direct delivery from growers, the individual websites for the facilities often do.

See: http://www.ethanolproducer.com/plants/listplants/US/Existing/All

The National Biodiesel Board, a national biodiesel industry trade group, maintains a list of member biodiesel plants (http://www.biodiesel.org/production/plants/plants-listing). The list includes contact information for the plants but does not specify feedstock preference. *Biodiesel Producer Magazine*, a leading industry trade publication, also maintains a list of biodiesel production facilities. The list is sortable by location, capacity and preferred feedstock.

See: http://www.biodieselmagazine.com/plants/listplants/USA/

The National Oilseed Processors Association, an industry trade group, maintains a list of its 13 members' plants on its website. The list provides the plant name, ownership, and location but does not specify the types of oilseeds processed or if the facilities accept direct delivery.

See: http://www.nopa.org/content/oilseed/oilseed.html

Another potential source to identify oilseed processors is the National Institute of Oilseed Products, a trade group that includes firms across the oilseed supply chain.

See: http://www.oilseed.org/member_list.html

Soyatech, an oilseed research and consulting firm, also maintains a list of U.S. oilseed crushing and processing plants. This list, organized by state, includes the plant owner as well as the seeds processed and production method.

See: http://www.soyatech.com/oilseed_reference.htm

Identify Feedstock Requirements, Pricing, and Level of Interest

A DOT interested in developing a bioenergy feedstock project should compile a list of facilities in its state from these resources and seek to identify those facilities that directly accept external feedstocks, or in the case of oilseed biodiesel would be interested in developing a collaborative project. Calling on each facility directly and surveying it on its feedstock sourcing strategy can accomplish this.

It may benefit a DOT to first call on experts in state agencies or other interested parties in the state's bioenergy industry who may be able to provide insight on the facilities most likely to accept these types of feedstocks. Potentially helpful agency resources include state departments of agriculture, forestry, energy, or commerce. Potentially helpful industry resources include trade associations, other biomass suppliers, and market intermediaries such as brokers or aggregators.

If a facility does accept external feedstock supplies, then the DOT should inquire about the conditions of a potential supply agreement, including minimum quantities, quality specifications, storage, handling, and pricing and payment terms. Moreover, the DOT should seek to gauge the potential buyer's level of interest for the project concept. The prospect of growing bioenergy feedstocks in the highway ROW remains a novel concept and the commercialization of the concept is untested. A successful project will require an enthusiastic partner to work through the inevitable challenges.

The purpose at this point is to start establishing a relationship with the potential buyer and collect information to be used at latter stages of the feasibility assessment.

Site Selection

Once a potential buyer, or set of buyers, has been identified, the next step should be to identify those areas potentially available for project implementation. Site selection should consider proximity to potential buyer; field shape, size, and access; and compatibility with DOT management considerations.

Transportation costs are an important variable component in determining the profitability of any agricultural enterprise. This is particularly true for woody biomass crops that have low bulk energy densities, the ratio of energy content to volume. These voluminous materials are expensive to transport because it generally takes more trips to deliver a given quantity of energy. Biomass combustion facilities typically source feedstocks from within 50 to 75 miles because transporting fuels beyond this distance is usually not economical. In addition to having higher bulk densities, the grain and oilseed crops also tend to have valuable co-products that increase the distance these crops can be economically transported. That said, most producers initially deliver their crop to market by truck to either a local elevator or value-added processor within a few hundred miles.

Potential sites should also be able to accommodate the safe and efficient use of equipment for land preparation, vegetation establishment and maintenance activities, and crop harvest. In general, agricultural fields should be large, flat, rectangular, and contiguous. Larger fields are more efficient to farm than smaller fields with a given piece of equipment because on the larger field the equipment will spend more time operating in the field and less time in the headlands, the area at the end of the field used to turn around equipment. Flat fields are more efficient to farm than sloped fields because sloped fields require rows to be planted along the contours of the slope to prevent erosion, slowing equipment operation and increasing operating costs. Irregularly shaped fields are less efficient to farm than rectangular fields because they require farm equipment to pass over an area more than once in order to ensure full coverage. Not only does this increase equipment operating time and expense but it also tends to result in greater inputs like seed, fertilizers, etc., because of more overlap areas needed to completely plant and harvest the field. Contiguous fields, or at least those in close proximity to one another, are more efficient to farm because moving and setting up equipment between fields takes time and expense.

These issues are especially acute for intensely managed annual crops, like grains and oilseeds, which require access multiple times a year. In general, these types of crops will require fields at least 20 acres in size, though in many parts of the country, the typical field size is much larger. While these issues are less acute for longer standing woody biomass feedstocks like poplar and willow, they also benefit from the production efficiencies of large, rectangular, and contiguous fields. In general these types of crops will also require areas of at least 20 acres.

Sites should be selected to avoid conflict with DOT management considerations (described in Chapter 1). A project should be located where it will not pose a risk to motorist safety or conflict with other current or planned highway uses. Potential sites should also avoid both direct and indirect impacts to sensitive environmental resources.

As the list of candidate sites is finalized, they should be subjected to a context-sensitive evaluation that considers environmental, economic, and community attributes at each site; engages local stakeholders; and inventories potential issues and concerns. Utilizing such an approach helps ensure a project fits into its location and provides the opportunity to identify and resolve potential conflicts early on, thereby avoiding costly delays.

Feedstock Crop Evaluation

Once potential buyers and sites have been identified, the next step is to evaluate the type of feedstock that should be grown. This evaluation should consider both the requirements of a potential buyer and the growing conditions of candidate sites.

The feedstock requirements of potential buyers will largely determine feedstock selection since the buyer is likely specialized for one feedstock type—either woody biomass, starchy grains, or oilseed. The buyer may also have a preference for a specific feedstock crop. In the event there are multiple buyers or more than one feedstock crop is acceptable, it is advisable to consider how each crop fits site growing conditions.

The types of growing conditions to consider include macro-climatic and micro-climatic variables, soil type and conditions, topography, and hydrology. Climatic variables that influence plant growth include seasonal temperature ranges, length of growing season, quantity and timing of precipitation, and wind exposure. Soil characteristics that influence plant growth and survival include type, texture, structure, compaction, drainage, toxic contamination, and available nutrients. Topographic features to consider include slope, aspect, and surrounding terrain—all of which influence sunlight exposure. Hydrological factors to consider include drainage and propensity to flooding, the presence of and relative location of ground water, and surface water features. Each of these factors will influence the ability of a plant species to grow and survive, with most species best adapted to a specific combination of conditions.

Examine Economic Feasibility

The purpose of the financial analysis is to determine if expected revenues will exceed expected production costs. Expected revenues are a function of crop yield and the price received for that crop. Expected production costs are a function of the type of site preparation, vegetation establishment and maintenance, harvest and transportation activities, and the unit cost of those activities.

It is vital that initial estimates of costs and revenues in the analysis are conservative since at this point in the project analysis much uncertainty about the ultimate design of the project remains. Those projects that cannot demonstrate profitability or are only marginally viable are not likely to withstand additional scrutiny and should not be pursued further.

Typical project costs and potential project revenues associated with the three different bio-energy feedstocks best suited to be grown in the highway ROW are discussed below. Additionally, the accompanying Feasibility Toolkit provides a spreadsheet that allows a user to calculate the net present value of a proposed project's cash flow over a 25-year period based on a project's establishment, maintenance and harvest costs, expected yield, and commodity price. The 25-year period was selected in order to address various crop rotation lengths and be able to make like comparisons across bioenergy feedstock crops. The Feasibility Toolkit includes default values for discount rate, production costs, expected yield, and commodity prices based on a review of the literature conducted for this research project. The Feasibility Toolkit is designed to allow the user to define alternative values or model other crops to develop a customized analysis.

Project Costs

Project costs include costs associated with project development, vegetation establishment and maintenance, harvest, and transportation. Some of these costs are one-time costs while others are ongoing costs.

Site reconnaissance—The cost of onsite scouting of potential sites in order to identify potential hazards or conflicts (e.g., trash, debris, culverts, wetlands, etc.) and for soil testing. The default value included in the Feasibility Toolkit is $60 per acre and is based on estimates from a Wisconsin study that considered the feasibility of harvesting existing grassy biomass from the highway ROW.

Safety—The cost of mobilizing traffic and safety equipment. The default value included in the Feasibility Toolkit is $30 per acre for each incursion into the ROW and is based on the pilot project experience in North Carolina and Michigan.

Labor and equipment costs—The labor and equipment associated with site preparation, planting, maintenance, and harvest activities. Total labor and equipment costs are a function of a given feedstock's management regime, a set of recommended activities, and the unit cost of a given activity. The Feasibility Toolkit includes default values for the type and frequency of recommended activities as well as for unit costs. The management regime for a given feedstock is based on best practice recommendations found in the literature and described in fuller detail in the final research report. The unit cost of a given activity is derived from recent state-level reports on custom farm rates, typical charges for contracted farm services, and other literature sources.

Inputs—The cost of materials associated with site preparation, planting, and maintenance activities including seed or nursery stock, herbicides, fertilizers, other soil amendments, etc. Total input costs are a function of the feedstock management regime and the unit cost of a given input. The Feasibility Toolkit includes default values for the type and quantity of recommended inputs as well as the unit cost of those inputs. The recommended type and quantity of a given input is based on best practice recommendations found in the literature and described in fuller detail in the NCHRP Project 25-35 final research report. The unit costs of various inputs were also derived from the literature.

Transportation—The cost to deliver harvested crops from the field to a buyer's gate. The default value in the Feasibility Toolkit is $0.25 per ton-mile. Total transportation costs are calculated by multiplying the transportation rate by total yield by total distance traveled. The default value for distance traveled is 25 miles.

Project Revenues

Project revenues include both the value of the sale of the biomass feedstocks and potential savings from avoided or reduced maintenance costs that might be realized as a result of project implementation.

Estimated yield—The quantity of harvested material per acre. Yield affects the cost of transportation, the cost of harvest, and the total project revenues. The analysis considers a range of yields for each feedstock based on historic U.S. averages and other published studies.

Price paid to farmer—The price received per unit for feedstock sold at the producer's gate. The default values in the Feasibility Toolkit are based on recently reported prices for the same or similar commodities.

Avoided cost—In some cases, the cultivation of a bioenergy feedstock may displace or reduce the need for traditional maintenance activities, like mowing, on the ROW, resulting in a cost savings to the agency. However, the default assumption in the Feasibility Toolkit is that no such savings will occur since project implementation is likely to occur in areas where DOTs have already reduced or eliminated routine mowing.

Feasibility Toolkit

A DOT interested in evaluating the specific opportunity for developing a bioenergy feedstock project in its state should use the accompanying Feasibility Toolkit (described in additional detail in Chapter 4) to determine if local conditions are favorable to project development.

CHAPTER 4

Feasibility Toolkit

The accompanying Right-of-Way Carbon Sequestration and Bioenergy Feedstock Feasibility Toolkit provides a DOT with a suite of decision support tools to systematically evaluate opportunities for project implementation in a local context. The Feasibility Toolkit also includes tools to model a proposed project's financial viability that the user can modify to develop a customized analysis. The Feasibility Toolkit can be found with the CD accompanying this Guidebook (CD contents also available online at TRB.org).

Each of the Toolkit components is discussed in brief below.

Decision Tree

The Toolkit includes a decision tree that provides an overview of the critical decision points likely to be encountered when conducting a project feasibility assessment.

DOT Management Considerations Checklist

The purpose of the "DOT Management Considerations Checklist" is to prompt the user to review the management issues identified in Chapter 1 in the context of his or her own DOT, to identify state-specific policies or practices as they relate to these issues, and to start to think about the conditions under which the agency would be willing to proceed with project implementation.

Context Tool

The purpose of the "Context Tool" is to support the user in the conduct of a context-sensitive site evaluation. The tool prompts the user to identify potential benefits and concerns associated with a set of environmental, economic, and community attributes at various stages of project development. The identification of potential benefits and concerns should be an outcome of engagement with relevant stakeholders.

Carbon Checklist

The purpose of the "Carbon Checklist" is to guide the user through each step of a feasibility assessment of a potential carbon sequestration project. The checklist prompts the user to complete certain tasks related to identifying applicable protocols or methodologies, selecting suitable sites, selecting among vegetation alternatives, and evaluating a project's financial viability.

Bioenergy Checklist

The purpose of the "Bioenergy Checklist" is to guide the user through each step of a feasibility assessment of a potential bioenergy feedstock project. The checklist prompts the user to complete certain tasks related to identifying potential buyers, selecting suitable sites, selecting among feedstock crop alternatives, and evaluating a project's financial viability.

Financial Pro Forma Tools

There are three pro forma tools included in the Feasibility Toolkit to help the user through the evaluation of potential project financial viability according to project type. The "Afforestation & Soil Pro Forma" will guide the user through afforestation and soil carbon sequestration project types. The "Urban Forest Pro Forma" will guide the user through the urban forest carbon sequestration project types. Finally, the "Bioenergy Pro Forma" will guide the user through the bioenergy feedstock generation project types. All of these pro forma tools contain default values and can be modified by the user for site-specific analysis.

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Chapter 3

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation