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Evaluation of Methods for Control of Vegetation in Utility Corridors

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This Master's Project

Evaluation of Methods for Control of Vegetation in Utility Corridors

by

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Abstract

For more than 100 years trees growing in or adjacent to electric right-of-ways have been one of the leading causes of power outages, which will have a significant impact on the people. Vegetation management programs are now one of the largest budget items for most of the utility companies in the United States. Control methods used in line clearance activities include mechanical trimming (either removing the trees, or pruning branches close to the power lines), planting management (by promoting the planting of low growing plants under the power lines), or use of tree growth regulators (chemicals that suppress the production of plant hormones that control stem elongation). Choosing the appropriate control method is a decision that vegetation program managers should take based on many factors, like costs, environmental impacts, existing agreements with the landowners, terrain, public perception etc. To find a balance between competing interests – a reliable and economic electric system on one side, and public perceptions and environmental concerns on the other, a successful program must use a combination of control methods.

Acknowledgements

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"Electricity seeks the ground. This is a law of physics. It can't be vetoed or legislated away. Trees grow up. This is a law of nature. You can't negotiate with nature." (Robert Bell)

Chapter 1 - Introduction

Modern civilization is heavily dependent on electric power; it is necessary for transportation, communication and industry. Without a doubt, the quality of human life has improved in the last century through the spectacular advances in science and technology, which were made possible through the use of electricity. But for many people, the electricity is taken for granted until it is no longer available. With growing populations and increasing use of electronic devices, dependency on electricity is increasing. Whether the electricity is, or will be, produced by coal, oil, natural gas, nuclear fission or by renewable resources, one thing will remain the same – the electrical grid infrastructure, the electrical network that transports electricity from the sources to the consumers. If this network is disrupted, either through source variability or downed or damaged power lines or wires, the consumers are impacted to a substantial degree.

To prevent these electrical outages, preventive maintenance of power stations and transmission lines is critical. One threat to the integrity of power lines is vegetation growth which results in substantial industry costs to mitigate impacts. To fully appreciate this threat it is important to understand, regulations pertaining to electric power, electrical infrastructure, and potential impacts to electrical infrastructure, as discussed in the following sections.

1.1 Power Regulatory Agencies and Authorities

Federal and state standards and regulations pertaining to electrical infrastructure are designed to ensure public safety, service reliability and fire prevention, and address potential vegetation conflicts. Power regulatory agencies and authorities are discussed for the Federal Energy Regulatory Commission (FERC), Public Utilities Commission (PUC) and other agencies more peripherally involved in electrical infrastructure regulation. Electric power right of way and easements are also discussed.

To maintain the required clearances mandated by the regulations described in the following sections at all times, there are some factors to be considered (PG&E 2014):

- Voltage levels
- Height of the electrical conductor
- Length of the span between poles
- Line sag under emergency loading conditions
- Wind sway — for trees and for power lines
- Type of tree and maximum tree height
- Annual tree growth

1.1.1 *Federal Energy Regulatory Commission (FERC)*

The FERC is an independent agency that regulates the interstate transmission of electricity, reviews the siting applications for electric transmission projects, protects the reliability of the high voltage interstate transmission system through mandatory reliability standards and enforces regulatory requirements through imposition of civil penalties and other means (FERC 2014).

The Transmission Vegetation Management Standard FAC-003-1 is a FERC mandated standard, enforced by North American Electric Reliability Corporation (NERC), which requires utilities to take preventative action to reduce widespread outages caused by vegetation conflicts on critical electric transmission lines over 60,000 volts (V). In 2006, the FERC approved 83 standards, marking official departure from reliance on the industry's voluntary compliance with reliability standards and the transition to mandatory standards under the FERC's oversight. Utilities must have a formal vegetation management program that meets specific standards and maintains required clearances between vegetation and transmission electric facilities at all times in all conditions (NERC 2006).

1.1.2 *Public Utilities Commissions (PUCs)*

Distribution lines (generally lines below 200 kilovolts [kV]) are regulated by the utility regulatory commissions within each state. Individual state regulatory commissions have the authority to set vegetation management standards for distribution lines. The California Public Utilities Commissions (CPUC) regulates privately owned electric companies and serves the public interest by protecting consumers and ensuring the provision of safe, reliable utility service and infrastructure at reasonable rates, with a commitment to environmental enhancement. Investor-owned utilities are required to obtain a permit from the CPUC for construction of certain specified infrastructure listed under Public Utilities Code sections 1001 (CPUC 2014).

In the state of California the clearance regulations for vegetation are (CPUC 2014):

General Order 95, Rule 35 – requires an 18 inches minimum clearance between vegetation and wires carrying more than 750 V, at all times, regardless of location.

Public Resource Code 4293 – requires a 4 feet minimum clearance between vegetation and wires carrying more than 750 V, in State Responsibility Areas (mostly outside urban area), which are under Department of Forestry and Fire Protection (CDF) jurisdiction.

Public Resource Code 4292 – requires a 10 feet minimum clearance around the base of utility poles.

1.1.3 *Other Agencies*

In addition to the CPUC permits, the utility companies may be required to obtain other federal, state, and local permits from the following agencies:

California State Water Resources Control Board requires Section 401 Water Quality Permit, under the Clean Water Act. The permit is needed if there are any potential impacts to state water quality standards (CPUC 2009) resulting from electrical infrastructure construction or access roads.

California Department of Fish and Wildlife may require several permits, including:

- Section 1602 Lake and Streambed Alteration Agreement (SAA), under the Fish and Game Code. The permit is needed if electrical project activities are within 100 feet of a water body or have the potential to affect the water body.
- California Fish and Game Code 2080.1 Consistency Determination permit is required if project may result in take of species that are both federal and state-listed endangered or threatened species (CPUC 2009).

U.S. Army Corps of Engineers requires 404 Permit, under the Clean Water Act. The permit is needed if there is placement of dredge material into U.S. waters, including wetlands (CPUC 2009) such as would occur during placement of transmission lines.

U.S. Department of Agriculture, Forest Service requires a Special use authorization permit, if a transmission line is on federal lands managed by the USDA Forest Service (CPUC 2009).

U.S. Fish and Wildlife Service requires a Section 7 consultation, under the Federal Endangered Species Act. This permit is needed if there is any potential impact to a federally listed threatened or endangered species (CPUC 2009), in this case resulting from electrical infrastructure placement or servicing.

U.S. Department of the Interior, Bureau of Land Management – Right of way grant for the use of federal lands managed by the BLM for a transmission line. Typically constitutes a Major Federal Action which in turn triggers NEPA analysis (CPUC 2009).

California State Historic Preservation Officer requires a Section 106 permit, under the National Historic Preservation Act. The permit is needed if there are potential impacts to cultural and/or historical resources that are listed or eligible for listing on the National Register of Historic Places (CPUC 2009) resulting from electrical infrastructure placement or servicing.

1.1.4 *Electric Power Right of Way and Easement*

In order to provide consumers with safe, economical and reliable electricity, the utilities have agreements (right of way, or easements) that allow them to clear and maintain the electrical infrastructure and any electrical equipment along those lines. To obtain right of way for an electric line, a utility company can either purchase the land on which the power line will be installed, or purchase the rights to the land (as an "easement") (CPUC 1985). An easement, which represents the most common agreement, is a contract between the utility company and the landowner that allows the utility to install and maintain the power lines and at the same time allows the landowner to keep the ownership and control of the land. Generally, a one-time lump sum is negotiated and is paid to the landowner, but there might be exceptions in certain farmland situations (CPUC 1985). This easement is an irrevocable agreement, and many times it is in perpetuity, and the utility company, the landowner and all future owners of the property must abide by this contract. The easement becomes part of the property deed and is transferred with the property until the utility removes the line and releases the easement rights. Sometimes the agreement is renegotiated with the current owner when it is necessary for the utility to improve the existing infrastructure, and the new easement contract will specify the new width of right-of-way, the voltage of the line, and the type and height of the new structures (poles or towers) (CPUC 1985).

There are sometimes situations when an agreement cannot be reached between a utility company and the landowner to allow for a new electric line installation. "*Eminent domain*" represents the power of the government to take private property to be used for public use. It is the policy of the United States to protect the rights of Americans to their private property, including by limiting the taking of private property by the Federal Government to situations in which the taking is for public use, with just compensation, and for the purpose of benefiting the general public and not merely for the purpose of advancing the economic interest of private parties to be given ownership or use of the property taken (Executive Order 13406 of June 23, 2006).

1.1.4.1 *Easement processing*

For the State of California, Public Utilities Code section 1001 states that no electric utility shall begin the construction of a power line "…*without having first obtained from the commission a certificate that the present or future public convenience and necessity require or will require such construction*…" (CPUC 2014). The CPUC reviews permit applications under two concurrent processes: (1) an environmental review pursuant to the California Environmental Quality Act (CEQA), and (2) the review of project need and costs pursuant to Public Utilities Code (PU Code) sections 1001 et seq. and General Order (G.O.) 131-D Certification of Public Necessity and Convenience (CPCN) or Permit to Construct (PTC).

The commission shall give consideration to the following factors (CPUC 2014):

- Community values
- Recreational and park areas
- Historical and aesthetic values
- Influence on environment.

As shown in Figure 1, the time frame for planning, permitting and construction of a transmission line can be between 7 and 10 years (CPUC 2014). For upgrades or minor changes to an existing line, it could take less time.

Planning includes the utility company evaluating and identifying transmission lines that need to be upgraded or constructed, and putting a plan together for California Independent System Operator (CAISO) evaluation and approval.

Permitting includes 1 to 2 years for the utility company to prepare a Proponent's Environmental Assessment (PEA) and application. Average time for CPUC decision is 18 months (includes permits from Resource Agencies). Average construction time is approximately 1 to 2 years. (CPUC 2014).

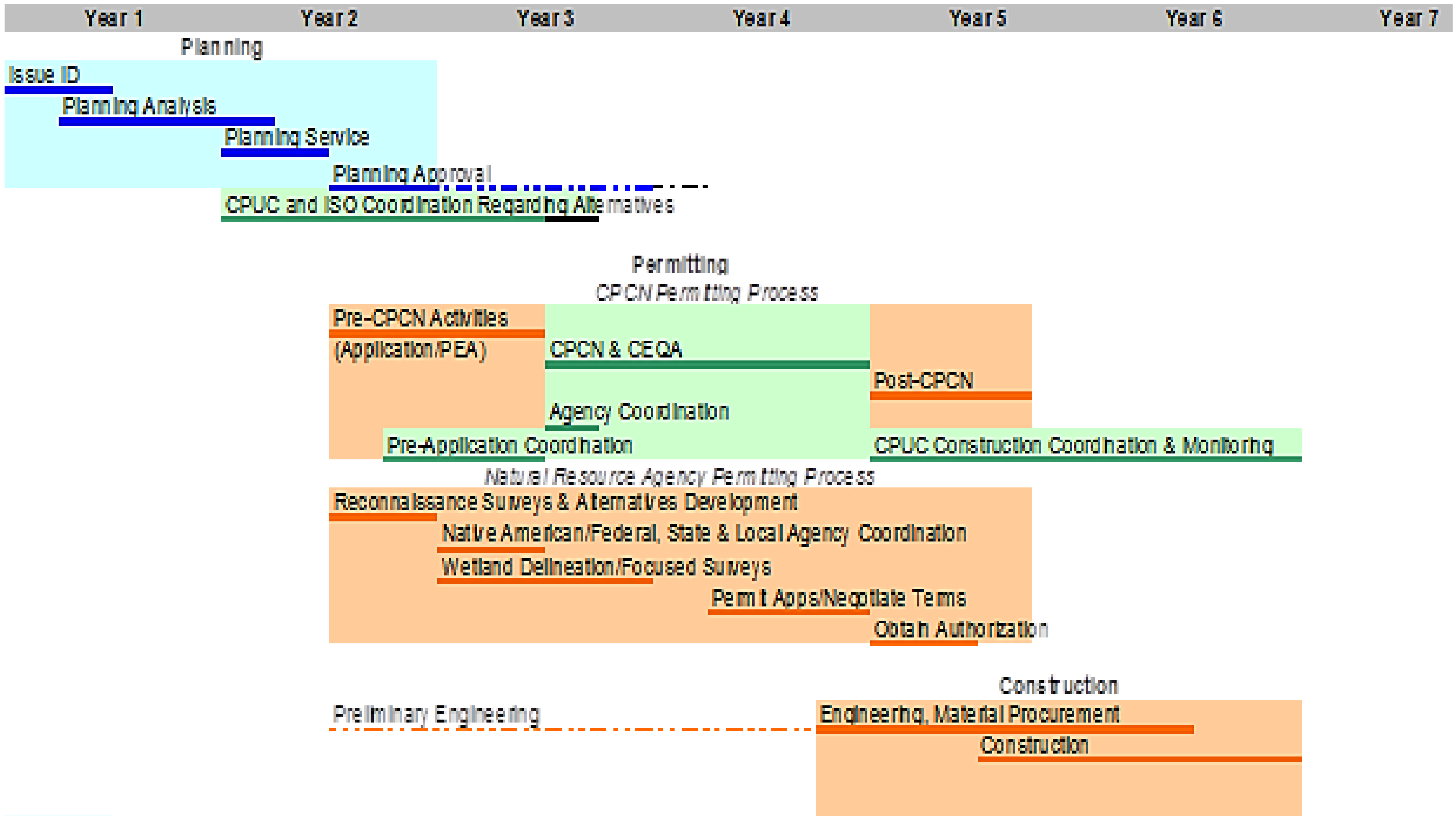

Figure 1. Timeframe for Planning, Permitting and Construction of a Transmission Line (Source: CPUC 2014)

Modern day easements are granted after a laborious and enduring process, in which many federal and state agencies are actively involved, and opinions of the public or other non-governmental organizations are considered. Public environmental groups, or individuals, may oppose the siting of electrical power lines, either because of possible environmental impacts of the construction, or concerns related to property rights (CPUC 2014). A hundred years ago, when the first utility easements were granted, the idea of progress was prevailing, and the grantee was given a very broad range of permissible activity (no specified widths, for example) (Crane Hollow, Inc. v. Marathon Ashland 2000). The environmental concepts of those times were that nature will find a balance ("that nature was self-healing and that whatever was done, the land would eventually restore itself"). All the current parties involved are bound to follow the terms of the easement contract as agreed a long time ago, subject to what the original parties regarded as acceptable at that time (Crane Hollow, Inc. v. Marathon Ashland 2000).

1.2 Electrical Infrastructure

The North American electrical grid represents a considerable engineering accomplishment of the last century, which continues to be renewed and improved continuously. The grid connects Americans with 5,800 major power plants and includes over 450,000 miles of high voltage transmission lines (ASCE 2011). There are three distinct power grids in North America: the Western Interconnection (11 Western U.S. states and 2 Canadian provinces), the ERCOT Interconnection (most of the state of Texas), and the Eastern Interconnection (the Eastern two-thirds of United States and of Canada) (Figure 2). The three grids are electrically independent one from another (except for few small connections that link them), which might be considered an advantage in case one of the interconnections is affected by a large outage (as occurred in August 2003) (Final Report 2004). Approximately 62 percent of utilities are publicly-owned; however, investor-owned utilities serve the majority of customers (68 percent) (APPA 2012).

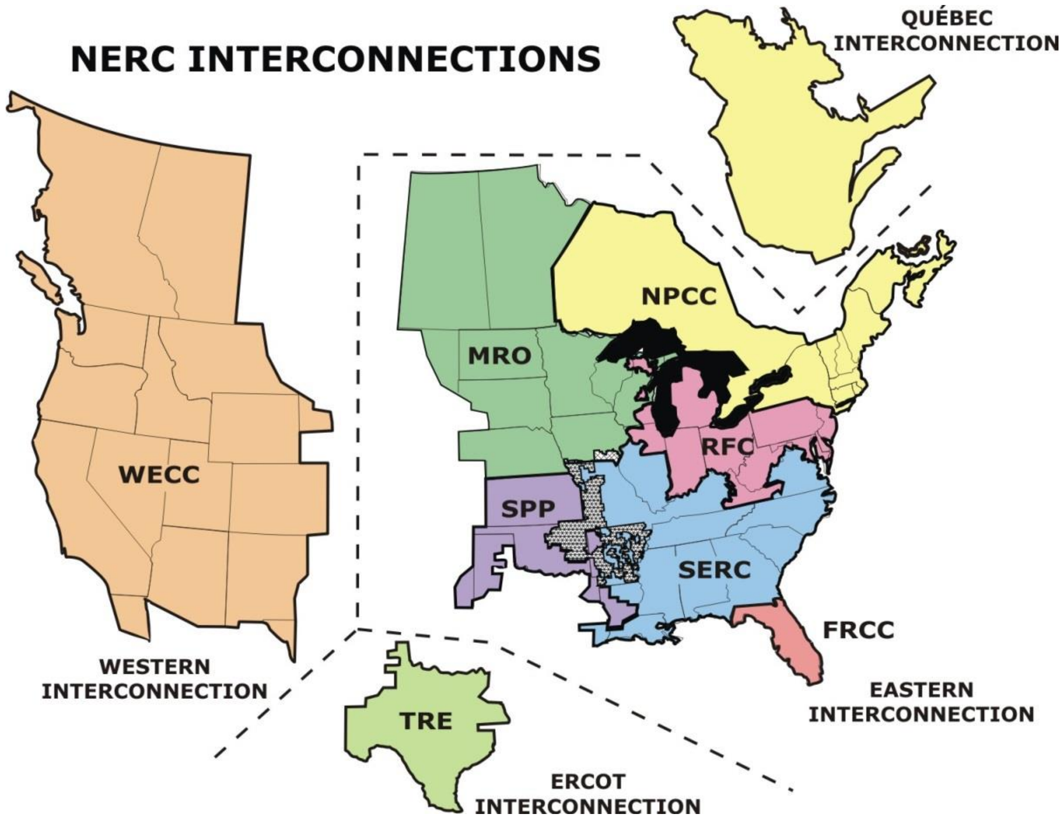

Figure 2. North American Interconnections System (Source: U.S.-Canada PSOTF 2004)

Because electricity travels almost at the speed of light (186,000 miles per second) and because it cannot be easily stored, it is produced at the same time it is used by the consumers (USDOE 2004). From the generators to the customers, the electricity flows along the paths that have the least resistance, which represent the interconnected and dynamic network of transmission and distribution lines, substations and switching stations, as well as a multitude of protective devices along the lines (Figure 3).

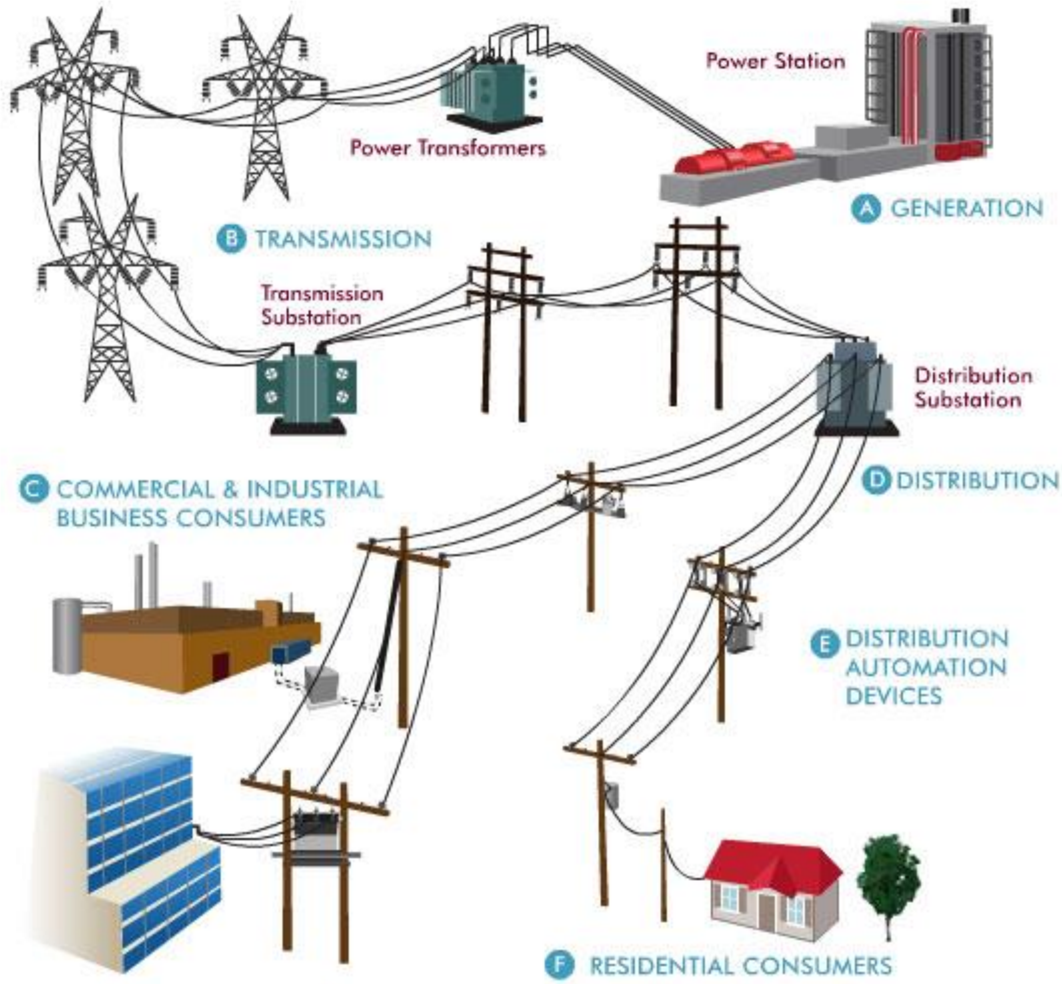

Figure 3. Basic Structure of the Electric System (Source: PG&E 2014)

The following bullets describe the basic components of the electrical system as shown in Figure 3:

- Power station or power plant – consist of a generator that converts mechanical power into electrical power. Most of the power plants use fossil fuels (coal, oil or natural gas) as an energy source to convert water to steam in order to drive a turbine generator, falling water as a mean to turn the turbine generator, or a renewable source (solar, wind or hydro). The power plants may be owned by the utility company, by independent power producers, or by the consumers (i.e. large industrial facilities). Here the electricity is produced at a low voltage (2.3kV to 30kV), which is stepped up by a transformer for long-distance transmission (more economical for shipment, and reduces losses from conductor heating).

- Transmission systems – usually in the 60 kV to 765kV range, transmit the electricity between power plants and distribution substation or industrial consumer through overhead power lines, located in right-of-way corridors (like highways on a road map) (USDOE 2004).
- Distribution substations – switching points in the electrical grid, used to reduce the voltage of electricity from transmission lines and distribute it to one or more distribution circuits.
- Distribution systems – usually in the 4kV and 34kV range, and transmit electricity from substation to consumers. As circuits progress from substation, they break into main lines and side branches.
- Individual systems – from the distribution lines the voltage is reduces by transformers to 110V to 240V and conveyed through a "service drop" to the consumer

With only few exceptions, the high voltage lines are comprised of bare conductors that are not insulated. Some older conductors have a "weather-proofing" covering of cloth or rubber, but with no insulation properties. In some situations the conductors have a plastic cover (called "tree-wire"), that can give the conductor some protection from tree contact, but they should not be considered insulated and safe to touch without proper protective equipment. Service drop lines have covered conductors, but they should not be touched with bare hands.

Because electricity is carried through power lines at high voltage, an electric arc, which is creation of a spark between the electric wire and another object, can occur between the conductors and a nearby object (e.g., tree). A direct contact is not necessary to produce a short circuit or a fire; the arcing distance depends on the conductor's voltage, as well as other factors, such as temperature or wind (USDOE 2004). As a result, the power lines are located on the highest levels on a utility pole, with the telephone and cable television lines located at lower levels (Figure 4). The higher the voltage in a conductor, the highest position that conductor has on a utility pole. Transmission lines are on the top level, and have larger insulators between the conductor and pole. Distribution and secondary lines are also insulated from the pole. The service drop lines, the telephone and cable television lines can carry few volts, but a problem can occur if vegetation rubs off the wire's insulation (PG&E 2014).

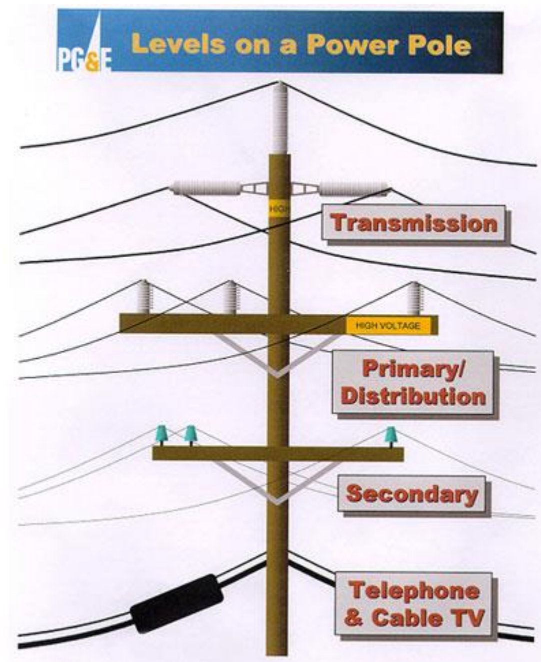

Figure 4. Levels on an Electrical Power Pole (Source: PG&E 2014)

In addition to the conductors that transport the electricity from a source to the consumers, there are also a multitude of devices that are part of the electrical grid, which have the role of helping control the flow of electricity. All of the electrical equipment is considered to have the same voltage as the line on which they are installed. If there are problems in an electrical system, without these protective devices, those problems might spread and escalate at a very rapid rate. All of this equipment (e.g., switches, fuses, reclosers, transformers, fault indicators, surge arrestors) is indispensable for supplying the electricity, not only in a control role, but also offers the advantage of sending information about the grid (e.g., status, loads, malfunctions) to the local center in real time, allowing for a quick response from an intervention crew. With a system so complex, and with so many challenges in operations, the chances are high that something might go wrong at some point. Most of the problems in an electric grid start as small, local problems, and is important to resolve and contain the problems before they grow to larger proportions (USDOE 2004).

1.3 Potential Impacts to Electrical Infrastructure

The annual U.S. economic loss due to power outages is estimated to range from $50 billion (EPRI 1995) to $100 billion (Lewis 2001). These costs take various forms including lost output and wages, spoiled inventory, delayed production and inconvenience and damage to the electric infrastructure, and much of these costs can be attributed to power outages caused by vegetation. In addition to private costs, power outages also produce externalities – both monetary and non-monetary. Power outages that affect air transport, for example, produce negative network externalities throughout the country. Generally speaking, the costs of major outages are borne not only by those without power, but also by the millions of people inconvenienced in other ways (Executive Office of the President, 2013). Although the grid cannot be 100% secure, there are measures and strategies that are taken into consideration for achieving grid resilience, such as reliability or technology improvements (Executive Office of the President, 2013). In 2009 the American Recovery and Reinvestment Act allocated $4.5 billion to the U.S. Department of Energy (DOE) for investments in modern grid technology which have begun to increase the resilience and reliability of the grid (Executive Office of the President 2013).

The 2003 Northeast blackout was caused by an overgrown tree contacting the high voltage lines, resulting in a local outage, which was spread very fast affecting 55 million people, and costing an estimated $7 to 10 billion. The reports for this blackout showed that real-time monitoring tools were inadequate to alert operators to rapidly changing system conditions and contingencies (FERC/NERC 2012). Continued investment in grid modernization and resilience will mitigate these costs over time – saving the economy billions of dollars and reducing the hardship experienced by millions of Americans when power outages happened.

Reliability represents "the degree of performance of the elements of the bulk electric system that results in electricity being delivered to customers within accepted standards and in the amount desired. Reliability may be measured by the frequency, duration, and magnitude of adverse effects on the electricity supply" (USDOE 2004).

The need for reliable service has increased dramatically in the recent years, with the expansion of digital economy, and the electricity system that was designed in the 1950-1960s needs to be updated and improved. Due to the large costs to the American economy, the consumers and regulators are almost intolerable of outages, and the reliability of the electric infrastructure has a significant importance (Lewis 2001). One aspect that large investor-owned utilities might consider in improving the reliability is the possible competition with community- and municipality-owned utilities that are expanding their area of business, or municipalities that want to create their own public utilities, generating and distributing their own electricity (APPA 2014). In a 2001 survey conducted by RKS Research & Consulting, 75% of the respondents said it “doesn’t matter which company supplies electricity, as long as delivery is reliable.” (Guggenmoos, 2003).

The 1978 Public Utility Regulatory Policy Act authorized the independent power producers (IPPs) to operate and sell their power to utility companies, and this led to considerable non-utility producers development and an increase in their electricity sales (USDOE, 2004). The electricity purchased by investor-owned utilities from IPPs increased from 17.8% in 1989 to 37.3% in 2002, and the electricity purchased by large public power companies increased from 36.3% in 1992 to 40.5% in 2002 (USDOE, 2004). The peak demand across the U.S. also grew by 26% between 1986 and 2002, and the generating capacity for the same period grew by 22%. However, the transmission capacity grew little, and is possible that the increased loads and flows in the electric grid might cause a great stress on the infrastructure, the equipment, the software and the personnel (Hirst, 2004).

Potential outage impacts that may occur to the electrical infrastructure can be caused by many different factors, both anthropogenic (e.g., equipment failure) or natural (e.g., weather events).

1.3.1 *Impacts from Weather Events*

For both transmission lines and distribution lines, the majority of tree-related outages are caused by trees located outside the right of ways (approximately 75%) (Guggenmoos 2003). Electric power lines cover a large surface, and many times (especially in the case of transmission lines), they are located in remote areas, with a high vegetation density. The majority of the outages caused by trees located outside of easements happen during adverse weather events, when branches overhanging the power lines or dead trees failed and as a result broke the conductors or brought the phases in contact. Reliability programs try to assess and eliminate hazard trees that may pose a threat to power lines, based on an identification program from arborists that inspect the lines on a fixed cycle, but the remediation practices vary widely among the utilities (Russel 2011). Climatologists have predicted that there will be a great variability in the weather in the future, due to the global warming, and that the number and severity of major weather events will increase (Guggenmoos 2003), and the impacts from vegetation to transmission lines are expected to correspondingly increase.

1.4 Research Summary

The electrical infrastructure needs to be reliable, with electric power grids delivering power when needed and within an acceptable quality range. Occasionally, electric outages happen, caused by equipment failure, human error, extreme weather events, or vegetation in contact with lines, with vegetation impacts being the primary impacts to power disruption (Chapter 2), and the focus of this research. Vegetation control and management in utility corridors is discussed in Chapter 3.

The best option to avoid the tree-power line conflicts is prevention. The three principal means of managing vegetation along transmission right-of-ways are planting management (Chapter 4), trimming vegetation adjacent to the line clearance zone or removing vegetation completely by mowing or cutting (Chapter 5), and using chemicals to retard or regulate further growth (Chapter 6). A comparison of that advantages, disadvantages and overall effectiveness of these methods is provided in Chapter 6, followed by research conclusions and recommendations.

Chapter 2 - Utility Corridors and Impacts from Vegetation

Since the beginning of electricity distribution from a generating source to consumers, one of the most significant negative impacts on reliability has been vegetation encroaching into overhead power lines. Utility companies are in the business of generating and delivering electricity, and invest time and money into building an infrastructure system and maintaining this system to effectively transport electricity. The infrastructure and the equipment represent assets, and anything that might affect the electric system represents a financial liability (Guggenmoos, 2003). Additionally, utilities are committed to deliver electricity following certain standards to reduce the frequency and duration of power outages, and failing to do so could cost them in fines from the monitoring agency.

2.1 Transmission Line Monitoring

In the United States the electrical transmission system is monitored by the North American Electric Reliability Corporation (NERC), whose mission is to establish a reliable power system. NERC is an organization subject to oversight by the Federal Energy Regulatory Commission (FERC), and it has been certified to establish a national reliability standard for right of way vegetation management on the transmission system. Most of the utility companies must have a line clearance plan, with minimum standards that depend on the voltage or construction type, in order to be able to provide safe and reliable electric power (USDOE, 2004). As specified in the right of way or easement agreements, utility companies have extensive power to do whatever work they seem necessary maintaining the line clearances, which is removing the vegetation under the power lines, trimming limbs, and using chemicals to retard or kill further growth. Most of the times on transmission right of ways the vegetation is removed, either through mechanical or chemical means, to minimize future encroachment (USDOE, 2004). A utility easement influences more than the narrow strip of land itself, such that outside of the right of way the utility company may conduct additional tree work. Transmission owners are required to trim or remove the trees located outside the easement limits if those trees might be a threat to the transmission line. These “hazard” trees are trees that pose an unacceptable risk of failing and contacting the line before the next right of way maintenance cycle. If identified, these hazard trees must be topped, pruned, or felled so that they no longer pose a hazard (Guggenmoos, 2003).

2.2 Vegetation Management Standards

Customer complaints about reliability have motivated legislators and regulators to create standards and regulations to address this issue. In 2001, 27 states had reliability standards in place, compared to three states in 1996 (Bush 2002). In 2006 NERC developed an updated version for reliability standards, (FAC – 003), with the purpose to improve reliability of electric transmission systems through preventing outages from vegetation located on transmission right of ways and minimizing outages from vegetation located adjacent to right of ways, maintaining clearances between vegetation and transmission lines on and along transmission right of ways, and reporting outages of the transmission systems related to vegetation to the respective Regional Reliability Organizations (RRO) and the North American Electric Reliability Council (NERC). This vegetation management standard formalized transmission vegetation management program and reporting requirements, and additionally, the utility companies could be fined $1million per day for each outage occurrence. As a result, vegetation-related transmission outages continued to improve due to industry’s improved management programs. Between 2004 and 2010, there were 63 reported “grow-in” outages, and between 2010 and 2013, only one “grow-in” outage was reported (Figure 5) (NERC 2014).

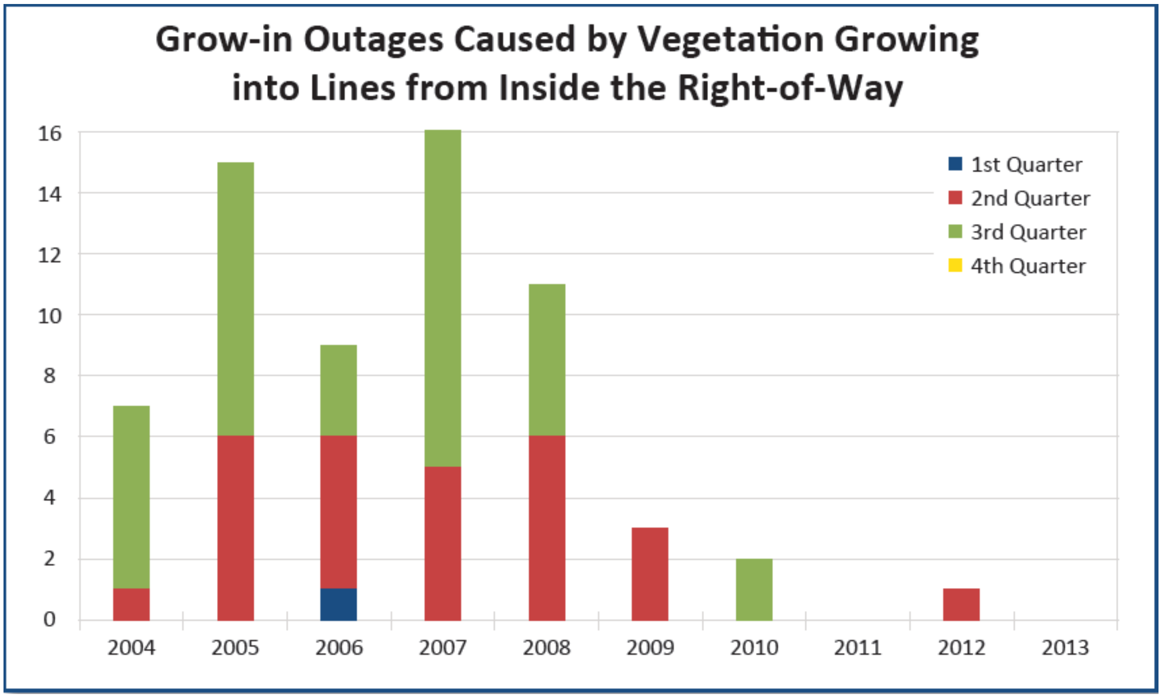

Figure 5. 2004-2013 Grow-in outages caused by vegetation (source: NERC 2013 Annual Report)

2.3 Transmission Line Maintenance and Vegetation Impacts

Proper maintenance of right of way and associated equipment and facilities are important to ensure a reliable electricity delivery, and this maintenance includes vegetation management. Utilities spend between $2 billion and $10 billion (ESRI 1995) per year on vegetation management programs, which represent one of the largest maintenance expenses for many utilities (Guggenmoos, 2003). Vegetation-related power outages vary from utility to utility (type of vegetation, growth rate, climate), but it is generally thought that they represent between 20% and 50% of all unplanned outages (Russel 2011), but sometimes the importance of this problem is understated, given the fact that outage statistics related to severe storms are excluded (CPUC 2000).

Every year more than 40 million trees are trimmed or removed in the U.S., with costs to utilities of $1.5 billion (Redding 1994). In California, in PG&E service area, 1 million trees are trimmed annually, with costs of approximately $168 million (PG&E 2014). Utility companies are exploring tools and techniques to extend the time interval between trim cycles.

It is important to understand how trees impact transmission lines and cause power outages. Trees can provide a path for the flow of electricity from one phase conductor to another, causing a ‘short circuit’. This short circuit happens when a limb or branch falls onto or sags into two or all three-phase conductors. Tree limbs can also provide a path for electricity to flow to the earth, causing a grounding situation, when a tree grows into the energized conductors (PG&E 2014).

Trees or branches can break and fall onto electric lines and their weight can physically bring live conductors or a live conductor and ground wire into contact and cause a short circuit or grounding. The heavy weight of falling trees or branches caused by snow, ice or rain can also cause conductors to break apart and fall. Sometimes the prolonged contact between a tree and an electric line can cause the metal conductor to heat up and melt at the point of contact and fall, which can initiate a fire (PG&E 2014).

Service cables in hard contact with stiff tree parts, such as branches or trunks, can have the plastic covering worn away, and a short circuit or grounding can occur, which may result in flickering lights and/or blowing of the transformer fuse (EPRI 2000c).

2.4 Fire Liability

Although not as common as power outages, fires initiated from trees and power lines contact (Figure 6) are another reason for a utility company to have a comprehensive vegetation management program. It is estimated in California that approximately 2% of the state’s wild land fires are caused by power lines fires (CalFire 2009). The danger of starting a fire is higher on transmission lines than on distribution lines, partly because the distribution lines carry less voltage, and most of the time a tree in contact will cause an outage, and partly because the transmission lines are also located in remote areas, with a larger fuel base of flammable vegetation, and difficult access for emergency vehicles (CNUC 2004).

Figure 6. Fire Initiated by Tree-Power line Contact (Source: CalFire 2014)

Power line fires have a significant importance not just for lost service to the consumers, but also for the great devastation caused by the fires, destroying electrical equipment and structures, private properties, and sometimes loss of human lives. Fire liability settlements are also costly for the utilities, and may also lead to negative publicity.

Pacific Gas & Electric Co. v. Superior Court, 95 Cal.App.4th 1389 (2002) - fire liability settlement required that $28.7 million to be spent on public safety programs and activities, quality assurance programs, tree removal and replacement, and contribution to the state general fund. It also required PG&E to establish an electronic database for customers who refuse PG&E permission to trim trees on their property.

In 2009 the Southern California Edison Company (SCE) agreed to pay $37 million for starting the Malibu Canyon Fire in October, 2007, which burned 3,830 acres and 33 structures. $20 million were to be paid to the state, and $17 million were to be spent on pole loading assessment (CPUC 2009).

2.5 Chapter Summary

The consequences of contact between vegetation and power lines are significant (PG&E 2014):

- Personal contact with a fallen or sagging line would cause severe injury or even death.
- Because transmission lines are part of an interstate grid, a local outage could cause instability of the whole electric grid across the U.S., potentially leading to a widespread blackout.
- Fire can ignite anywhere along the line, even miles away, putting both individuals and distant neighborhoods at risk.

Because of the serious consequences resulting from contact between vegetation and power lines, it is important to establish effective vegetation control in utility corridors.

Chapter 3 - Vegetation Control in Utility Corridors

The electric infrastructure cannot operate without a proper line clearance program. Without this program, a large number of power outages would occur on distribution systems, especially during weather events, and the higher voltage lines simply would not operate. It is estimated that there are 5 million miles of poles and lines in the United States, and approximately 500 million trees on the distribution system alone (UAA 2014). This extensive network might be one of the reasons why for some utilities the vegetation management program is one of the largest budget items. It is also a visible activity, and these factors raise the public's interest in the program's procedures and methods (EPRI 1995). Generally, the public understands the necessity of vegetation management in the right of ways to ensure reliable electricity delivery, but the methods used may be questionable. Sometimes, there can be misunderstandings on the part of the public, or vegetation management professionals, about the nature of electrical faults, and this happens because most people do not have enough knowledge about electrical science. Utility foresters are facing many challenges, and have to find a balance between competing interests – a reliable and economic electric system on one side, and public perceptions and environmental concerns on the other (Guggenmoos, 2003).

3.1 Vegetation Control and Management

Prior to 2003, most of the transmission owners did have an extensive vegetation management program, which should have enhanced reliability of the nation's transmission network. There was, however, a wide range of practices and procedures among different utilities, especially with respect to the right-of-way widths, inspection frequency, vertical clearance between the conductors and vegetation, trimming cycles, and vegetation management guidelines (FERC 2004). After the 2003 Northeast blackout, a joint U.S. – Canada Task Force was established, which investigated the causes of the blackout. The final report, issued in April 2004, stated that inadequate vegetation management was one of the primary causes of the fire (USDOE 2004). In response to this report, the Federal Energy Regulatory Commission (FERC) asked the transmission owners to report on the results of their vegetation management practices. The FERC report, issued in Sepember 2004 (Utility Vegetation Management and Bulk Electric Reliability Report), concluded that the utility industries' standards at that time were inadequate, and there was indeed a need for improvement (FERC 2004).

Some practices variations were expected, due to terrain, climate, vegetation species, local laws and regulation. But most of the reports from utilities, however, showed that many times the vegetation management programs were impeded by federal regulations and their enforcement programs, creating a conflict between the goals and requirements for electric reliability and environmental protection (FERC 2004). Permitting processes from various federal or state agencies were delaying operations, increasing the risk of outages, arcing, or fires. The New York State Department of Environmental Conservation, for example, required utilities to file "Temporary Revocable Permits", which could take up to two years to process. U.S. Forest Service required impact studies on wildlife and habitat impacts, environmental impact assessments, and limited the use of access roads to right-of-way corridors. U.S. Fish and Wildlife Services restricted the time when trees could be trimmed, and the use of herbicides, and the U.S. Department of Transportation repeatedly planted trees in right-of-ways and restricted tree trimming or removal in the name of "beautification" efforts (FERC 2004).

At the FERC recommendation, the U.S. Congress enacted legislation to make reliability standards mandatory. EPAct 2005 Section 1211c – "Access approval by Federal agencies" provided a better coordination between state and federal regulators and transmission owners, for a more effective vegetation management (Energy Policy Act 2005).

3.2 <u>Reclaiming Right of Ways</u>

Maintaining the right of ways and easments was also one of the problems in the pre-2003 vegetation managements programs. Ideally, once the easments and permits are obtained, the utility company would clear the land and build the line, and on a scheduled and routine basis, perform the necessary vegetation clearance. But many times that last step, regular maintenance of the corridor, was overlooked, for different reasons, and occasionally out of the control of the utility. Although it was proven that the wire zone – border zone approach was effective in the long term (Bramble 1991), there were times when utilities allowed these areas to be overgrown by vegetation, either by making poor long term decisions, or for budgeting reasons. Once this overgrowth happened, it became more expensive and difficult to re-establish and clear the corridor. Allowing multiple uses of right-of-ways was also an ineffective strategy, when the landowners planted inappropiate trees for landscaping puproses, or tree farms and nurseries were located under the power lines, with the utility company not monitoring them, or allowing them to exist over an extended period of time (EPRI 2007).

Reclaiming the right-of-ways can be a difficult and expensive process. Enforcing the rights granted in the easement contract may cause conflict between the utility company and the landowner, and this conflict could lead to lenghty court proceedings and negative publicity for the utility. The importance of implementing and maintaining the standards were at times overshadowed by public relations concerns, which led to restrictions of trimming or removing the trees from easements or even from right-of-ways owned in fee by some utilities (CNUC 2004). Customers refusing the work are also increasing the likelihood of having trees growing into power lines, which can cause outages or fires. Although the majority of the refusals are resolved in a timely manner, there may still be a few landowners who can successfully stop the work, due to concerns regarding the aestethics of the trees, or prior negative experiences with the utility or the trimming contractor.

On August 14 2003, the very same day when the 2003 Northeast blackout occurred, another tree-related outage happened on another transmission line, Columbus – Bedford 345 kV, which is in the same Eastern Interconnection. This outage had no impact on, nor was it a contributing factor to the Northeast Blackout outage that was on the same day, but could have triggered another massive blackout. Work had been repeatedly refused by the property owner, and the parties have been unable to reach an agreement to negotiate a long-term settlement. On the morning of August 14 crews arrived to perfom tree work, but after only a few trees were trimmed, the property owner requested the crew to stop the work and leave the property. A few hours later, the line locked out, and the investigation showed the reason was a tree in contact with the lines, on this property (CNUC 2004) (Figure 7).

Figure 7. Transmission Easement before Line Clearance (Source: CNUC 2004)

Tree crews returned and cleared the wire zone, allowing the line to return to service later that day. This event, as well as the massive blackout, caused an urgency to fully address vegetation issues, and the utility company developed an Action Plan to clear the vegetation on this property. The property owner, however, obtained a Temporary Restraining Order, to prevent any further work, but the case was dismissed in court, and the utility company was allow to continue with the work (Figure 8).

Figure 8. Transmission Easement after Line Clearance (Source: CNUC 2004)

After analyzing the reports from various utilities in 2004, FERC recommended that for better vegetation management practices, there was a need for clear, unambiguous and enforceable standards. Also, it was recommended that the utilities should fully exercise their easements rights for vegetation management (FERC 2004). In 2006, NERC updated the reliability standards (NERC 2006, FAC-003 Standard).

3.3 Chapter Summary

This chapter presented vegetation control and management and reclaiming of utility right-of-ways for the purposes of minimizing contact between utility infrastructure and vegetation and associated impacts.

The following chapters discuss in more detail three potential vegetation control methods appropriate for utility corridors, specifically planting management (Chapter 4), mechanical vegetation trimming (Chapter 5), and use of tree growth regulators (Chapter 6).

Chapter 4 - Planting Management

Trees are beautiful, come in all sizes and colors, and many times they are the dominant elements of a landscape. Trees bring both aesthetic and economic value to a neighborhood, acting as a wind or sound barrier, controlling erosion, or having an important role in controlling energy use, if used as part of an energy conservation strategy. Utility companies also have interest in trees, but for different reasons - trees are a major cause of power outages, especially during inclement weather. By far, the best way to maximize the benefits provided by trees is to have them planted where they will not interfere with electric lines. The simple act of choosing the appropriate species of vegetation to plant near overhead lines would save hundreds of millions of dollars annually for electric ratepayers in North America (CNUC 2004).

4.1 Effective Planting Management

Planting management is the best method for vegetation control in utility corridors, and the most beneficial, but requires considerable cooperation between utility companies and local governments, regulatory agencies, municipalities or homeowners, and it also relies on education and incentives (PG&E 2014). Most of the utilities with vegetation management programs use some form of public education, public awareness, and public involvement, to provide the landowners, municipalities, and other agencies and groups with accurate information regarding vegetation management activities and practices. These efforts may include participation in public meetings, seminars, notifications of upcoming vegetation operations in the area, information on brochures, internet websites, or other forms of media. Occasionally, there could be phone messages call-out to inform the customers about inspection and tree trimming activities. Utilities also may use post-operation surveys, as a method to measure customer satisfaction (EPRI 2007).

Many utilities partner with institutes and universities in their efforts to reach the public and to outline the safety issues concerning planting trees under power lines. To avoid future conflicts, a list of suitable trees is offered, as well as guidelines on where to plant the trees, depending on the maximum mature height. When selecting a tree, there are many factors that should be taken into account, like moisture, soil, wind exposure, sunlight, pollution, stressful conditions, snow cover and available growing space (CalPoly 2014). General planting guidelines under distribution lines include the following (CalPoly 2014):

Low-growing trees (under 25 feet when mature) may be planted in “small zone”, which extends 20 feet on each side of overhead power lines. Generally, planting directly under the lines is not recommended by utility companies, especially near the middle of the span.

Medium-growing trees (over 25 feet when mature) may be planted at least 30 feet away from overhead power lines, in “middle zone”. It is recommended that the selected trees should not grow more than 35 feet tall, as it may become necessary to remove them if they have structural defects, or are dying, and may fall into the power lines

Trees that grow taller than 35 feet when mature should be planted more than 50 feet away from overhead lines, but property owners should be aware that trees may be removed or topped, if they have structural defects, or are dying (Figure 9).

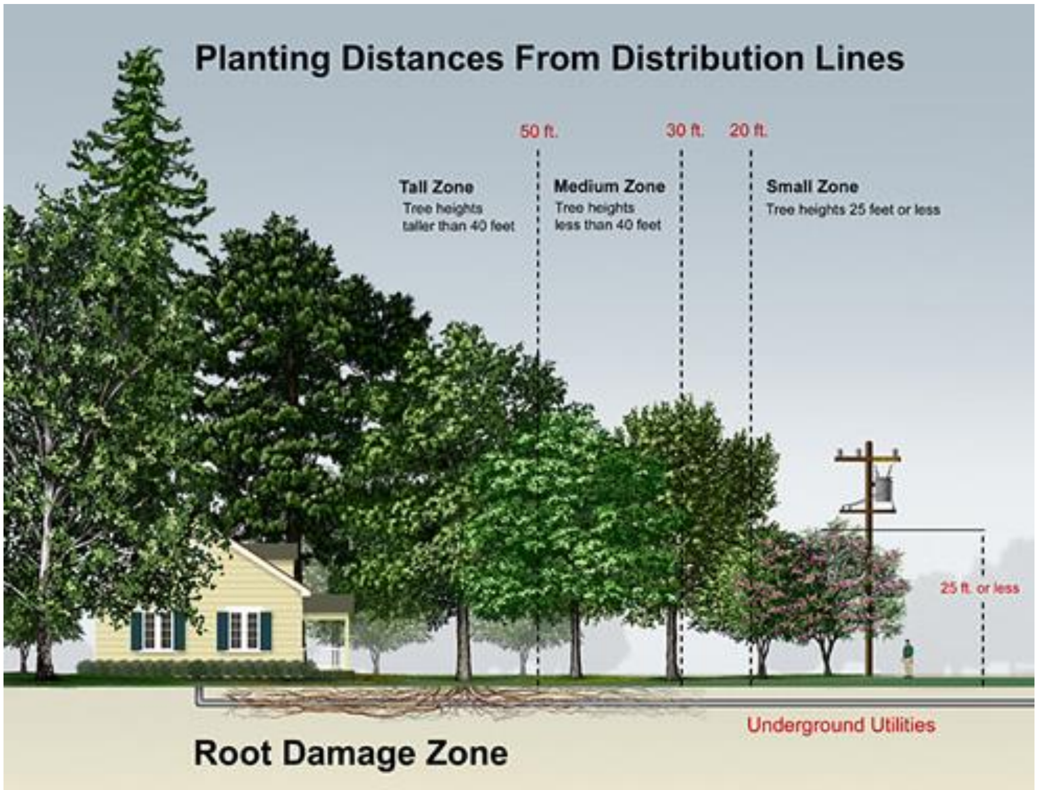

Figure 9. Suggested Planting Distances – Distribution Lines (Source: PG&E 2014)

For transmission right-of-ways, where electricity can arc from the very high voltage lines to the taller vegetation, it is recommended that the area under the wires, as well as on both sides of the corridor, can be best maintained if all the tall growing trees are removed and replaced with lower growing vegetation (EPRI 2007). Also, tall trees located outside of the corridor that are found to be a potential hazard, such as dead or dying trees, or those with structural defects, may be removed. The wire zone – border zone approach was found to be both environmentally friendly and effective in ensuring reliability, and proved to be effective in reducing or eliminating outages related to vegetation on transmission right of ways (Bramble 1991). In addition, the long-term maintenance costs can be reduced, and improve the fire mitigation, wildlife habitat and biodiversity. The wire zone - border zone may be the best practice in many instances, but not necessarily universally suitable. Sometimes the standard approach may be unnecessary where transmission lines are high off the ground, such as across low valleys or canyons, so the technique can be modified without sacrificing reliability.

The wire zone extends 10 feet outside of the transmission lines, and no trees should be planted in this area, as it is very possible that they may be removed, being in conflict with the easement agreement (CalPoly 2014). Generally, the maximum height for vegetation in this area should be 5 feet.

The border zone extends between 10 feet and 40 feet outside of transmission lines, and the maximum height for vegetation in this area should be 10 feet (CalPoly 2014). It is recommended that no trees should be planted in this area, as they may be removed to ensure safe and reliable electric service, and also to maintain compliance with state laws.

The tall zone extends more than 50 feet from transmission lines, but tall trees with the ability to reach energized conductors may be topped or removed, if they have structural defects, or are dying (CalPoly 2014) (Figure 10).

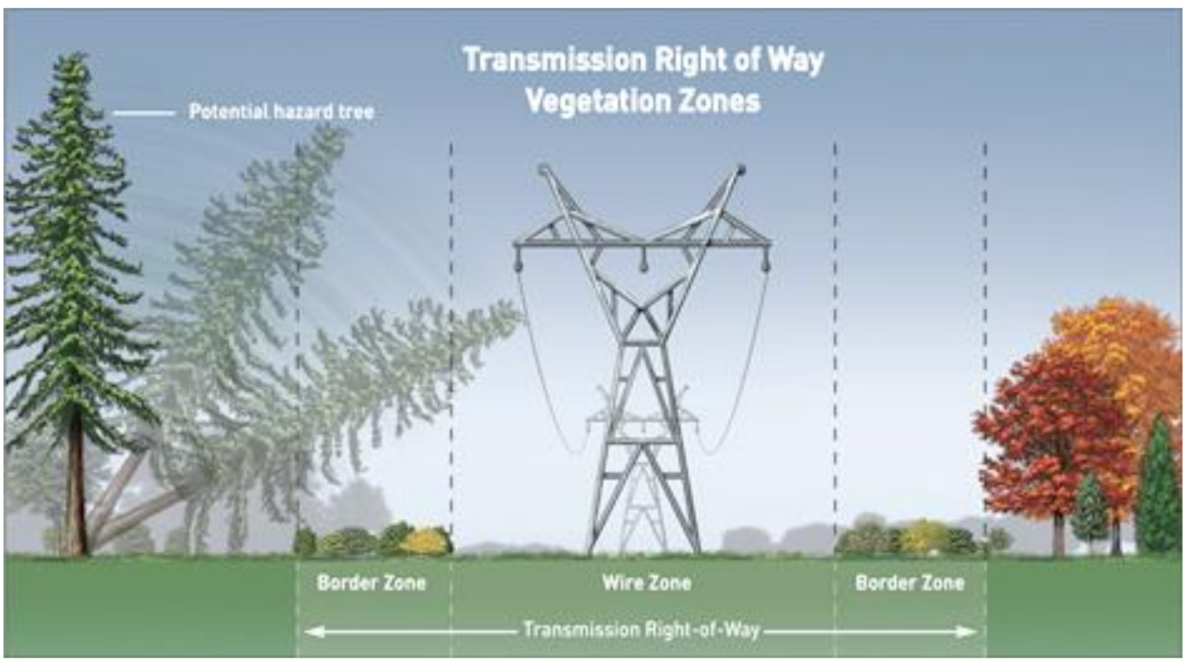

Figure 10. Suggested Planting Distances – Transmission Lines (source: PG&E 2014)

When planting trees near power lines, in addition to preventing future contact between trees and power lines, public safety also must be taken into consideration. Dense vegetation may hide power lines, which may be a danger for children climbing trees. Trees that are not easily climbable should be selected, with the trunk clear of branches 6 to 10 feet above the ground. Also, tree-houses should be relocated, as the tree becomes electrified when branches are in contact with the power lines, or children may place "flagpoles" that may come in contact with high voltage lines (PG&E 2014).

4.2 Planting Specifications and Maintenance Requirements

Planting trees with bare roots should be done in the dormant season, November to March, and the containerized or balled-and-burlapped trees may be planted at any time (ISA 2014). Before digging the hole, the location of underground utilities should be marked, as damages to an electric line or water or gas pipe might cause service interruptions, or serious injuries. The hole should have the same depth as the root ball, and be twice as big around. The sides of the hole should be roughened up, to allow the roots to spread, otherwise the trees may grow stunted or topple in winds (ISA 2014). After placing the tree in the hole, the native soil should be returned to the hole, avoiding too much compaction. Topsoil amendments, like sand, manure, or moss, should be avoided; wood chips may be used, to keep the root ball from drying out too fast. Stakes to support the tree may be used in the first year, until the roots are established, and they should not be tied too tight to the tree, a mature tree will be stronger if it is allowed to bend in the wind when young. Trimming the new planting should be avoided, except to remove dead or broken branches (Figure 11) (ISA 2014).

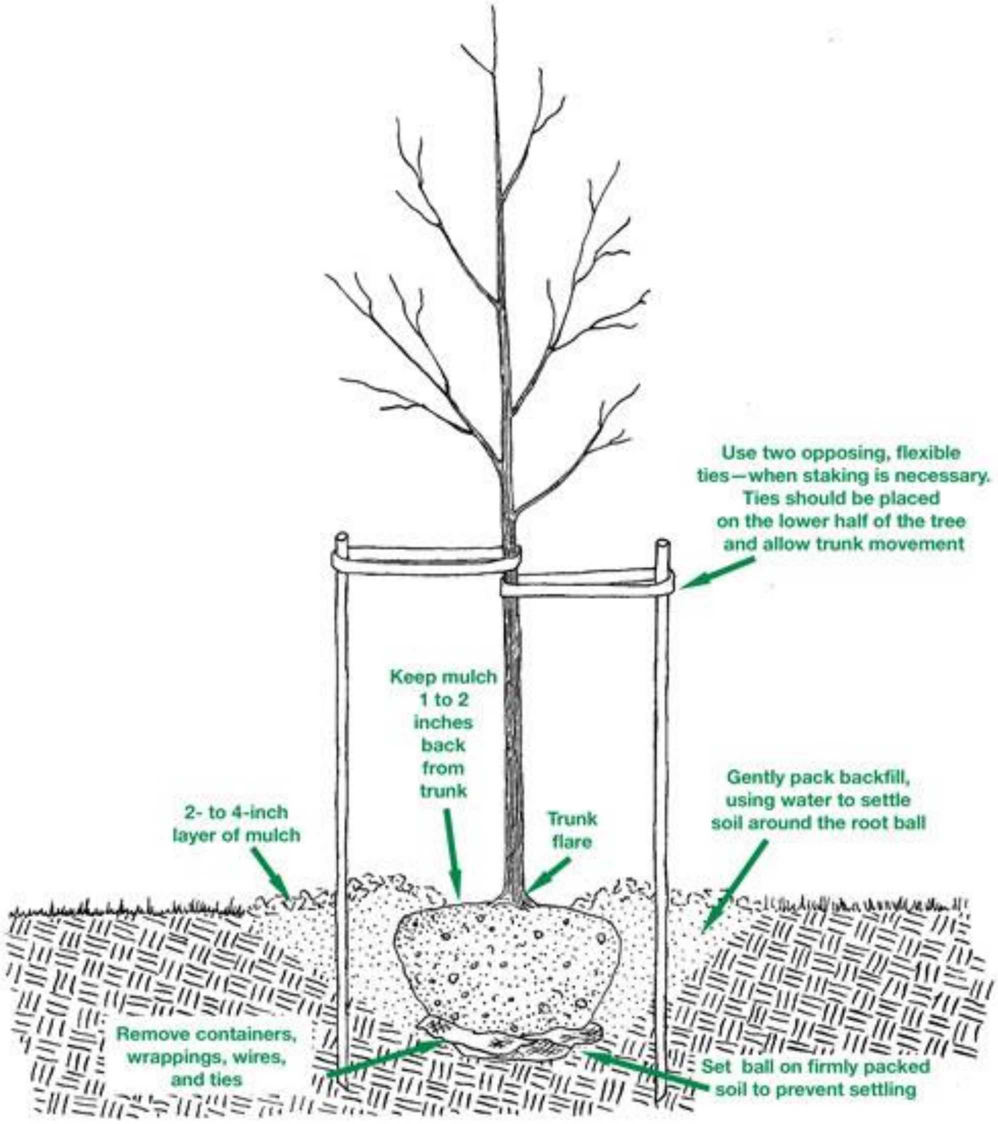

Figure 11. Planting a Tree (Source: ISA 2014)

4.3 Advantages of Planting Management

Planting the right tree in the right place, and conversely not planting the wrong tree in the wrong place, is referred to collectively as "planting management".

Advantages of planting and integrated vegetation management include (EPRI 2000):

- reduction of future outages and fires associated with contact between electrical infrastructure and vegetation.
- improvement in the health of urban and rural forest ecosystems in the vicinity of electrical corridors
- reduction in use of herbicides and related chemicals
- reduction of biomass waste being produced and disposed of as a result of unnecessary pruning, and/or removal of healthy trees and vegetation (EPRI 2000b).

4.4 Disadvantages of Planting Vegetation Management

Because planting management is a proactive, planned activity, disadvantages are less numerous and can be managed as part of the planning process. These disadvantages include:

- Tree ordinances and regulations often do not require private property owners to maintain tree branches to allow for line clearance.
- Tree ordinances sometimes require planting of new trees in new developments, and suggest a list of desirable trees (native trees) which may not necessarily meet the "right tree, right place" guidelines.
- Planting of appropriate tress to avoid contact with electrical infrastructure requires proactive interaction with developers, municipalities and other interested stakeholders and significant time commitment on the part of the utilities to work through the planning process, and "sell" the concept.
- Prohibiting the planting of certain species within specified distances of utility right of ways might be considered an oppressive measure and a violation of the right of homeowners to use property as they wish.

4.5 Effectiveness of Planting Management

Planting management can be an effective vegetation control method to avoid or minimize contact between electrical transmission lines and vegetation. Possible mechanisms for effective implementation of this method include:

- Utilities can implement a tree replacement program, or offer incentives for property owners who remove nuisance trees under the power lines and replace them with appropriate trees (PG&E 2014). The disadvantage is the upfront costs for the utility company are high.
- Landowners can share the cost of tree work, or pass a state law (which would override the city ordinances) to allow a utility company to remove and replace problem trees with more appropriate vegetation. In New Zealand, for example, the tree owner is responsible for keeping the power lines clear of vegetation, unless he declares a "no interest" notice, and the utility company has the right to remove the tree. Failure to comply with the requirements will result in fines to the tree owner (New Zealand Legislation 2003).

It is difficult to find a balance, but planting methods are worth considering, if future vegetation management costs can be reduced. Contact between vegetation and power lines and the resulting and serious consequences of power outages and fires are challenges that have affected utilities since the first overhead line was installed. This challenge continues.

Chapter 5 - Mechanical Vegetation Trimming

A second method for vegetation control in utility corridors is mechanical vegetation trimming. This method consists of a variety of techniques and strategies to establish a plan for effective and scheduled trimming of vegetation within utility corridors. The 2003 Northeastern blackout incident, along with $ 1 million per day fines, raised the stakes for tree trimming near transmission lines, and many utilities decided not to take chances, developing new procedures for their vegetation management program.

5.1 Vegetation Management – Best Management Practices (BMPs)

The utility tree trimming programs should comply with nationally recognized best practices for vegetation management, including the American National Standards Institute (ANSI) A300 standards, National Electric Safety Code (NESC), Occupational Safety and Health Administration (OSHA), and the Shigo Guide.

5.1.1 *American National Standards Institute (ANSI) A300 Standards*

The ANSI A300 standard, although not a requirement of the NERC FAC-003 standard, is considered to be an industry best practice. The ANSI A300 standards are the generally accepted industry standards for tree care practices.

5.1.2 *National Electrical Safety Code (NESC)*

The National Electrical Safety Code (NESC) (2012) provides general guidelines applicable to line maintenance, worker safety, and approach distances. It also sets forth general provisions establishing the need for appropriate and suitable vegetation management practices, as determined by each electric utility, to ensure the safe and reliable delivery of electric power over electric power lines (NESC 2012). The NESC does not establish specific trimming distances, trim cycles, or explicit rules but rather in Section 218 provides a broad foundation for vegetation management as an important function of the utility industry. Section 218 states that trees which may interfere with ungrounded supply conductors should be trimmed or removed, and when trimming or removing the tree is not possible, the conductor should be insulated from the tree with suitable materials (NESC 2012).

5.1.3 *Occupational Safety and Health Administration (OSHA)*

The Occupational Safety and Health Administration (OSHA) provides rules for safe work practices for workers and are almost universally accepted as applicable to the electric utility workplace, including vegetation management activities. These rules include working with energized power lines and in inclement weather.

Line-clearance tree trimming refers to the pruning, trimming, repairing, removing, or clearing of trees that are less than 10 feet from energized power lines, and this work should be performed only by trimmers who received specialized training (OSHA 1994). It is recommended that the workers be certified and trained annually on safety-related work practices and procedures. No work should be performed during adverse weather conditions, unless the lines have been de-energized. For unqualified workers the minimum approach distances are specified in OSHA standard 1910.333(c)(3)(i), and the minimum distance starts at 10 feet for systems 50kV and below and increases 4 inches for every 10 kV over 50 kV (OSHA 1994).

Working near electric power lines assumes a serious potential electric shock hazard for a tree trimmer, which is why at least two people are required to work in the crew, so that one person can provide first aid to the other, if needed. Workers are required to wear approved personal protective equipment, and attend job briefings that supplement any training and make them aware of any potential hazards. Tools used in utility trimming operations should be insulated, and inspected daily for defects. At least every two years, the tools should be examined and retested (OSHA 1994).

5.1.4 *Shigo Guide*

Dr. Alex Shigo was a tree pathologist whose research on trees decay and on the pruning methods led to the improvement of modern arboriculture practices. He used the chainsaw as a research tool to dissect the wood, and his studies showed that the trees do not heal themselves if they are injured, like animals do, but they compartmentalize the damage by walling off the decay to protect the healthy tissue. He was also the main critic of the "flush cut" method that used to be the most common practice of pruning prior to 1980s, and supported the directional pruning (or "natural target pruning") method that is currently used in line clearance trimming (Shigo 1990).

5.2 Vegetation Trimming Methods

The amount of trimming necessary is prescribed by a qualified utility forester, based on tree growth and structure, wind sway and line sag (PG&E 2014). Factors that influence the amount and type of trimming necessary include species of tree, environmental factors, irrigation, proximity of tree to a line, anticipated pruning response of the specific tree, and line configuration. Property owners should not be allowed to prescribe the amount of clearance that should be obtained, as this would be a violation of federal and state standards (EPRI 2007).

For decades, utilities trimmed trees for line clearance by topping or rounding them over, which proved to be a method that gave little consideration to the structural integrity or the health of the tree. This procedure, similar to shearing a hedge, was relatively fast, but stubs were left in the tree because the cuts were not done properly, and those stubs created points of entry and open pathways for wood decay. "*Stubs are food for organisms that start rot and cankers*"(Shigo 1990). Internally the tree was weakening, and the loss of foliage could have led to dieback of the remaining parts, with the tree's life shortened dramatically (ISA 2014).

Directional pruning is a technique that began in the early 1990s, after it was proven that it was more beneficial for the health of the tree than other methods (Shigo 1989). This method (also called "drop crotch" pruning), tries to remove the tree branches that are growing toward the lines and to encourage the growth of a lateral branch away from lines.

Pruning and trimming techniques follow this progression (Figure 11) (ANSI 2001):

- First cut is on underside of the branch to prevent tearing
- Second cut is from above to remove bulk of weight
- Final cut is clean slice just above thickened collar of bark
- After cutting is done, the wound should not be dressed or painted. Painting is only cosmetic and may be detrimental to the health of trees.

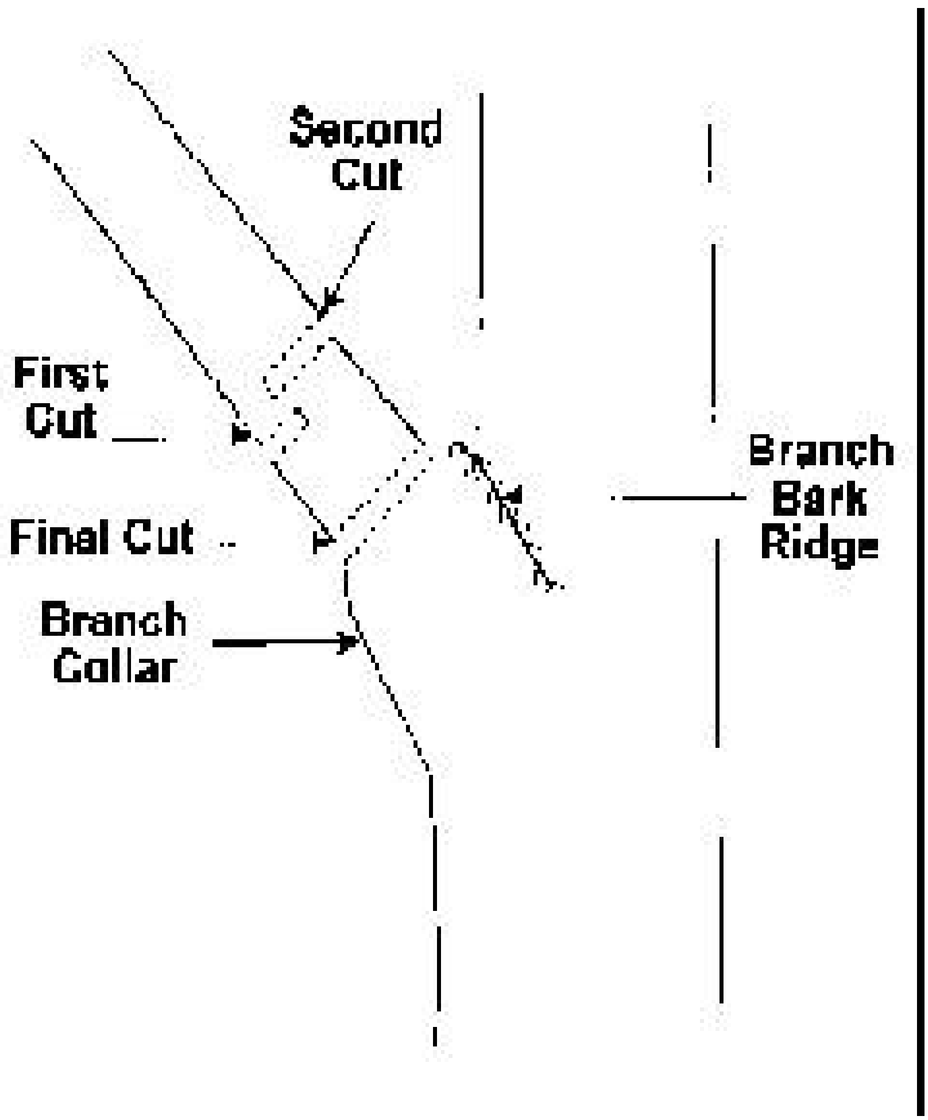

Figure 12. Correct Pruning Method (Source: ANSI 2001)

Biomass resulting from pruning and trimming may be chipped, piled or scattered on the ground, if safe to do so. The wilted leaves of wild cherry are toxic when consumed by livestock (EPRI 1995).

Mechanical vegetation trimming is discussed below in terms of advantages, disadvantage and effectiveness, as discussed below.

5.3 Advantages of Mechanical Vegetation Trimming

Mechanical vegetation trimming or pruning is the most common method of vegetation control used to minimize contact with utility lines (UAA 2014).

Advantages of mechanical vegetation trimming include:

- Targeted method applied to only “problem” trees and other vegetation
- Biologically, directional pruning is better for the tree, as the sprouting is minimized, and the growth is directed away from the transmission lines
- Less material may be removed in future pruning events, which will mean that pruning costs will go down over time, and may create a safer environment for the community.

5.4 Disadvantages of Mechanical Vegetation Trimming

Although mechanical vegetation trimming or pruning is the most common method of vegetation control used to minimize contact with utility lines (UAA 2014), there are multiple disadvantages associated with the method. These disadvantages include:

- Each year, nearly 50 tree workers are killed by contact with overhead power lines—and many more are seriously injured. Workers who contact electric or gas utility lines also create life threatening hazards for those who live or work nearby. Workers are also exposed to gasoline fumes from power tools used to do the trimming. Yet, trimming remains the main method of controlling the vegetation in the proximity of power lines (UAA 2014).

- Trimming trees is an inefficient solution for maintaining safe clearances to power lines, as it is expensive and temporary, and it takes more time to implement. Some fast growing trees must be re-trimmed every year. In addition, corrective tree pruning is often severe, ruining the appearance and sometimes the long-term health of trees.
- Topping trees is destructive pruning that weakens trees and makes them susceptible to disease and rot, and more material may be removed.

5.5 Effectiveness of Mechanical Vegetation Trimming

Mechanical vegetation trimming may be a temporary solution that increases risk and should be avoided as a vegetation control method on utility right of ways, particularly within the wire zone and mid-span.

In the long run, mechanical vegetation trimming is a more expensive method than other vegetation control methods, but is often chosen over other methods because of public perception. If trees require repeated pruning or continually contact power lines, often the best solution is tree removal (especially around transmission lines). Many times it is also the case near distribution lines that pruning alone cannot achieve safe clearance or if it can, repeated pruning is too expensive for utility ratepayers.

Chapter 6 - Tree Growth Regulators

The annual high costs to utility companies of line clearance vegetation trimming operations prompted much research focused on finding a non-mechanical method to control the regrowth of trees following trimming (Arron 1990). In the early 1960's utility arborists initiated research on tree growth regulators (TGRs) as a potential method for reducing trimming costs and biomass disposal (Bowles, 1985). TGRs can also be helpful where vegetation removals are prohibited or trimming is impractical, by reducing the growth rates of some fast-growing species, and by reducing the amount of biomass removed during trimming.

6.1 Chemical Effects and Structure of TRGs

TGRs are chemicals that suppress the production of gibberellins and auxins, the plant hormones that, among several physiological functions, control cell elongation, and without changing developmental patterns or being phytotoxic. A plant hormone is an organic compound produced in one part of a plant, and it may be transported to another part where, in very low concentrations, it causes a physiological response (Moore 1998). Most of the growth regulator compounds have a complex molecule (Figures 13, 14, 15), that contains a heterocyclic structure, with more than one kind of atom (carbon or nitrogen, in these cases) (Rademacher 2000).

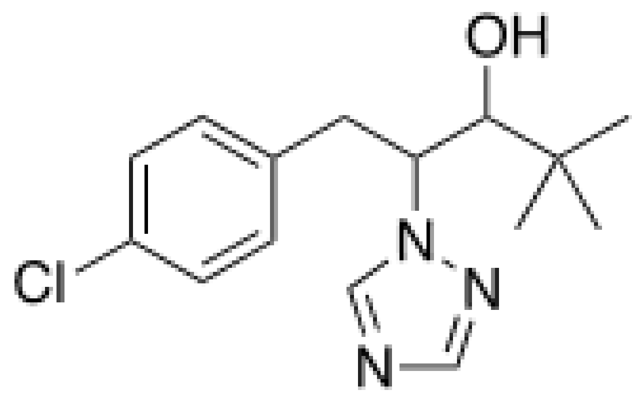

Figure 13. Paclobutrazol Molecular Structure (Source Rademacher 2000)

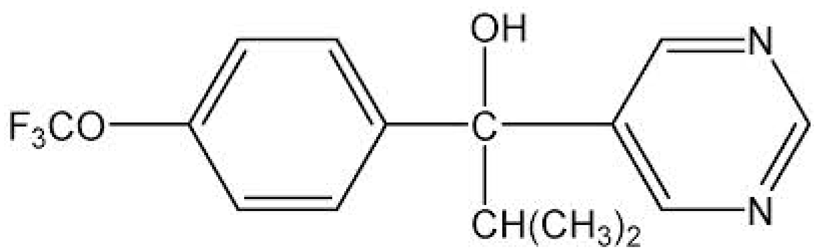

Figure 14. Flurprimidol Molecular Structure (Source Rademacher 2000)

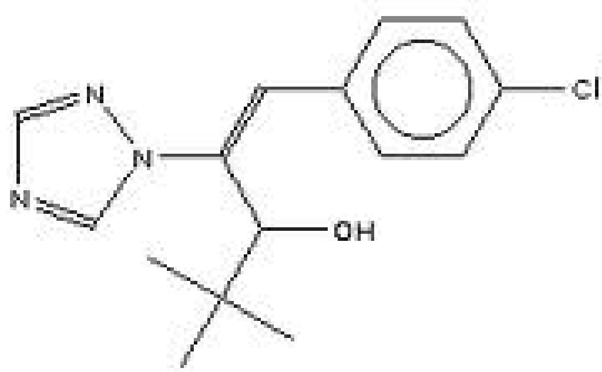

Figure 15. Uniconazole Molecular Structure (Source Rademacher 2000)

An important attribute of the heterocyclic structure is that these molecules are unsaturated, due to their double bonds and an unshared pair of electrons in the sp^2 orbital, and this makes the end of the molecule very reactive, allowing the compound to react with plant hormones and affect the metabolic pathways (EPRI 2000b). The plant hormone (gibberellins) synthesis in the subapical meristems of shoot tips is inhibited, and the primary effect is a reduction of extension growth of the shoots. (EPRI 2000b). Gibberellins also have other major effects on tree biology, such as causing the production of seedless fruits, inducing flowering, enhancing geotropic responses, and breaking some plant dormancies (Moore 1998).

6.2 <u>Evolution of Tree Growth Regulators</u>

Chemical growth regulators have been used in agriculture for field crops, or in horticulture, since the late 1940's (Rademacher, 2000). The gibberellins were first discovered in Japan, in the 1930s, when a fungal disease of rice caused the plants to grow very tall, and the heads felled under their own weight, which resulted in a significant reduction in grain production. It was discovered that the fungus *Giberella fujikuroi*, which infected the rice plants, produced a substance (gibberellin) that caused the internodes to elongate very much (Moore 1998). Since that time, and building on the initial knowledge of growth inhibition and enhancement, chemical growth regulators have been developed for more focused purposes.

6.2.1 First Generation of Tree Growth Regulators *(Early 1960 to Circa 1980)*

The first generation of TGRs had as an active ingredient naphthalene acetic acid, maleic hydrazide, or dikegulac. These TGRs were used to inhibit the terminal bud and affect apical dominance and/or cell division, often producing undesirable phytotoxic effects, inconsistent results, or causing the plants to die, if the dosage of the active ingredient was not applied correctly (Arron 1997).

Mostly, the application method for the first generation TGRs was aerial spraying, bark banding, or trunk injection. Naphthalene acetic acid used to be applied on the surface of the pruning wounds, which was not a cost effective method, because application took a very long time (Chaney 2005). Most of the growth retardants containing maleic hydrazide and dikegulac were applied as a spray, to be absorbed via the leaves and translocate to the growing shoot tissues. The problem was that the plants could break down maleic hydrazide into several products, one of which, hydrazine, was a mutagen and carcinogen, and although it proved to be of low toxicity to mammals, in some instances it decreased the fertility of rats (Swietlińska 1978). The carcinogenic effects of maleic hydrazide on rats raised the question of its risks to humans. Dikegulac was also applied as spray, but it was observed that it increased the development of adventitious shoots and stimulation of branching. When used in higher doses, dikegulac didn't stimulate additional shoots and node formation, and the results were a growth reduction (Litwińczuk 2010). Foliar spraying might have been the least expensive application method, but was also the least efficient, because many times the spray was missing the target, and it could not be applied in populated areas (Bowles 1985).

Due to concerns from environmental groups about pollution from the foliar spraying method, there was a need to develop new techniques for application of chemicals to control the tree growth, such as bark painting (also called bark banding), or trunk injection. Those methods were more expensive compared to foliar spraying, and the treatment took considerably more time, but did have an economic advantage over tree trimming. Pacific Gas & Electric estimated costs of $1.50/tree for bark banding and $9.00/tree for tree injection, compared to $20.00/tree for tree trimming (1986 dollars) (Sachs 1986).

The bark banding procedure, compared to foliar spraying, presented a problem, because the compound had to penetrate a barrier that was different than the surface of leaves. To move from trunk or root zone to the top of the tree, the chemicals have to be pulled into the xylem tissue, but they have to pass through the spongy, fibrous cork layer (Figure 16), which absorbs most of the solution, then the cortex, which is a more impenetrable tissue, and the phloem tissue, which in the lower trunk area flows downward, toward the roots (Chaney 1986). To promote the transport of the compound to the xylem it was necessary to use of a carrier, but many formulations were causing considerable damages to the tree (Sachs 1986). A diesel and toluene mixture was very effective as a carrier, but it was very flammable and unstable, and on certain species it caused bark aging and splitting, and occasionally, death of the tree. A less efficient carrier used was an oil surfactant and water mixture, which had the advantage of not being flammable, and resulted in less wood darkening and fewer odors (Bowles 1986). The bark banding method may be most effective on young trees (Kimball 1990), or on young shoots near the top of the tree (Bowles 1986).

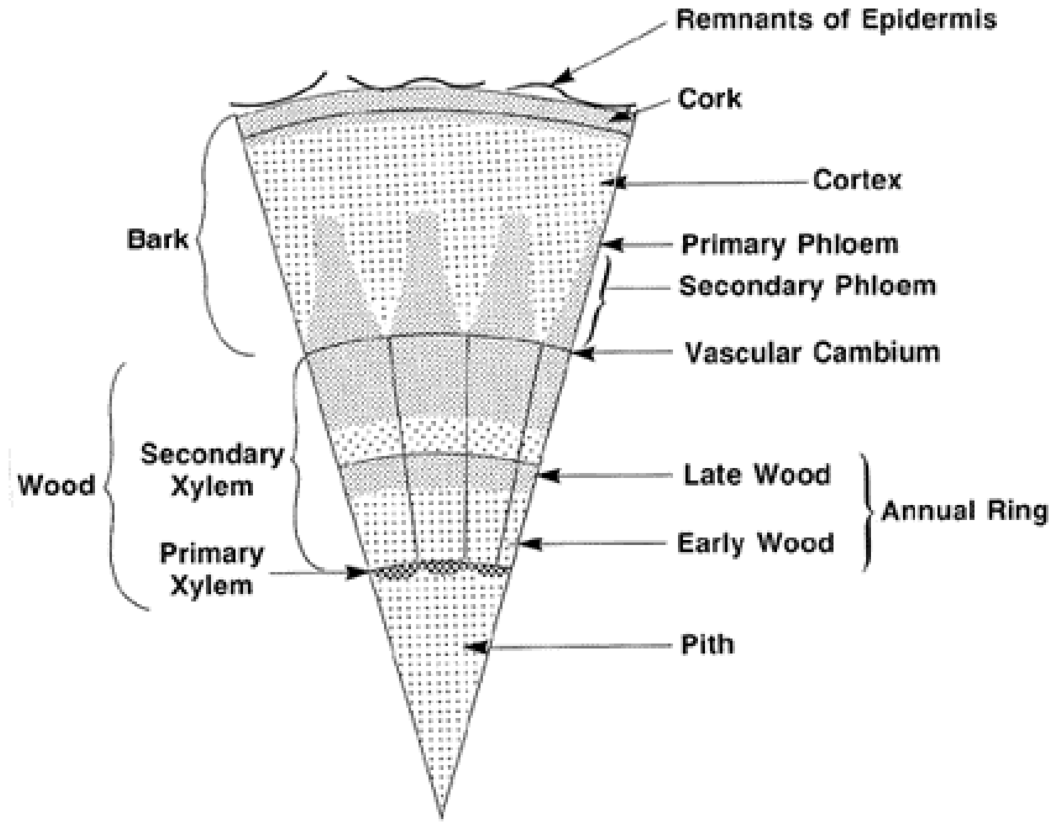

Figure 16. Cross Section of Tree Trunk (Source: North Carolina University Extension 2014)

The trunk injection method has the advantage of pushing the TGR into the xylem vessels, therefore getting all the solution on target. Additionally, this method avoided the ecological risks of spraying or bark banding, because it did not contaminate the surrounding landscape (EPRI 2000b). To move in the xylem tissue, the chemicals had to be water soluble, or be mixed with other compounds (alcohol based) that permitted them to be water soluble, otherwise the compound would precipitate in the xylem (Sachs 1986). The disadvantage of using alcohol-based carriers was that the tree trunk showed wood discoloration, which may have an effect on wood strength (Wasniewski 1993). Another drawback was the limited number of species that were labeled for use, and the high volume of solution that was necessary to be injected (Bowles 1986). The drilled holes had to be sealed with silicone grease or a vinyl plug after the injection to prevent pathogen entry, or for a public relations benefit (Watson 1987), but some weeping and fluxing was evident on some of the trees (Redding 1994).

6.2.2 Second Generation of Tree Growth Regulators (Mid-1980s to Mid-2000s)

The second generation of TGRs used as active ingredients flurprimidol (Cutless TP), paclobutrazol (Clipper 20UL), and uniconazole (Prunit). These TGRs were unquestionably more effective than first generation TGRs in reducing cell elongation and retarding the growth of trees without the undesirable phytotoxic effects (Chaney 2005). Before the 1990s, most studies on the efficacy of the second generation TGRs were short-term, 1 or 2 years, and the majority of those studies were performed in the eastern United States, and thus the efficacy on the species and conditions in the western states was not well understood (Arron 1997).

Initially, the most used application method was trunk injection, but at that time the three compounds had low water solubility (8-135 ppm) (Kimball 1990), and had to be dissolved in an alcohol-based carrier (methyl or isopropyl alcohol). The injection process had some advantages, compared to other methods used previously, but required special training for application personnel, different injection systems and techniques needed to be developed, and there was wide variation in distribution of chemicals, dose response, and wound closure (Watson 1987). By the end of 1980s, after a few years of use, there were identified problems associated with this method. The alcohol-based carrier caused discoloration of the wood, there were cracks in the bark, and weeping and fluxing from injection holes (Wasniewski 1993), or cambial death, if the holes were not sealed properly, as the alcohol carrier killed the cambial cells it contacted (Kimball 1990). The application was also found to be too slow, complicated, and difficult to evenly dose (Redding 1994).

In the early 1990s there was a decline in the use of TGRs by the utilities. One of the companies decided to withdraw its product (Prunit) from the tree care market, but the other two products (Clipper 20UL and Cutless TP) received full registration from the U.S. Environmental Protection Agency (EPA) (Kimball 1990).

Flurprimidol compounds were in ready-to-use tablets, which presented the advantage that no further preparation was needed for application. The tablets were pressed in holes drilled in the trunk of the tree, close to the ground line, and the number of tablets was determined by the diameter of the tree (the required dosage was calculated by grams of active ingredient per inch of diameter) (EPRI 2000c). The holes were drilled about 1 inch below the bark surface, deep enough to insert the tablet and allow room for a dowel to cover the hole. This method was based on the concept that the xylem tissue is a self-plugging filter that will allow for the fast movement of chemicals from an implant location to the rest of the tree.

In contact with water, the tablets became a formless powder in less than 30 seconds, so to facilitate the process the implants were flushed or misted with water after being inserted in the drilled holes (Redding 1993). The best time to place the implants was determined to be just before or during the most rapid period of water uptake (spring to fall), when the transpiration process is more active. This tree implant application method, however, showed that flurprimidol was slow to translocate within the plant, and sometimes the desired effects on reducing the growth did not show until the next season. In the long term, even with the unregulated growth, the results were favorable (Figure 17) – right tree was untreated, left tree was treated, two seasons after the treatment (Redding 1993).

Figure 17. Flurprimidol Treated Tree (left) –Two Seasons After Treatment (Source: Redding 1993)

Some of the TGR compounds, like paclobutrazol or uniconazole, are not easily absorbed by shoot parts, if the method of application is foliar spraying or bark banding, and their movement within a plant is acropetally, starting from the base of the stem toward the apex. For best results, the preferred methods of application are basal drench (also called soil drench) (Figure 18), or soil injection (Figure 19) (Rademacher 2000) for these compounds. A trunk injection method was also used, but it was a more difficult method, and the results were comparable with the other methods (Mann 1995).

Figure 18. Basal or Soil drench Method (Source: Chaney 2005)

Figure 19. Soil Injection Method (Source: Chaney 2005)

Paclobutrazol application also had the advantage of not using alcohol as a carrier agent, as it was applied as a water suspension. The dose of the active ingredient is determined by measuring the diameter of the tree (Watson 1996), and the treatment could be done anytime as long as the soils was not saturated with water or frozen (Chaney 2005).

6.2.3 Present Day Tree Growth Regulators (TGRs)

In the present day, the TGR most commonly used by the electric utility industry for vegetation control is the paclobutrazol compound (Profile 2SC, or Cambistat 2SC) (Chaney 2005). The flurprimidol-based compounds have been removed from the tree care market, as the method of drilling holes in the trunk of the tree was no longer appealing to the arborists, and the results of the treatment were not always positive, due to the compartmentalization of the wood around the tablets, which prevented the release of the active ingredient into the transpiration stream (Chaney 2005). In 2009 the European Food Safety Authority (EFSA) evaluated the flurprimidol toxicology and decided to no longer authorize it within the European Union, due to insufficient data to demonstrate that the product will satisfy the environmental requirements (EFSA 2013).

The application method is either by basal drench, or by soil injection. A new application method, tree microinjection, is currently under development, and it may offer the advantage of treating the trees where soil treatment is not practical. The basal drench method presents the advantage that no special equipment is required, and the compound is evenly applied around the tree. For a higher productivity, soil injection is a better option; it also prevents runoff, it may be used on high slopes, and places the compound close to the roots.

The possibility that an error might happen during the application of a TGR does exist. It could be an accidental spill, dosage errors, or treating trees that were already treated. Because the role of TGRs is to suppress the biosynthesis of gibberellin, it may be reasonable to expect that a reversal of the effect of an overdose may be accomplished by applying gibberellin acid (GA) (EPRI 2000c). Studies have shown that treatment with GA is very effective on flowering plants and crops, but very important was the timing of the treatment. If GA was applied within one week after the TGR treatment, the dwarfing effect was reversed, and the applications performed 15 days or more after the TGR treatment showed little or no stimulation effect in growth (EPRI 2000c). It is likely that a GA antidote for TGR effects may be developed, but no studies have been published.

6.3 Environmental and Human Health Risk Assessment

6.3.1 Soil Persistence and Leaching to Groundwater

Paclobutrazol-based TGRs are persistent compounds, with a relatively slow degradation in soil or in plant tissues. Its half-life period in soil varies in the range of three to twelve months, depending on the soil factors, such as organic matter, clay content, pH, or cation exchange capacity (Rademacher 2000). Under optimal conditions for microbiological degradation the paclobutrazol half-life was 13 days, which demonstrated that it is quite resistant to microbial attack (Jackson 1996). Paclobutrazol also binds strongly to soil particles, and shows little tendency to leach into soil profile. When applied as recommended, it remains localized at the point of application, 95% remaining in the surface layer (6 to 10 inches depth) (EPRI 2000c). Given its limited mobility, the possibility of leaching to groundwater is remote, but special care should be used on heavily compacted soils or steep slopes, where it may run-off, or in wetlands.

6.3.2 *Vegetation*

Although most of the compound remains localized in the soil at the base of the treated tree, any plants with their roots in the zone of the soil containing the growth regulator may absorb some of the material. Once absorbed, the compound moves through the xylem to the stems. Initially, high concentrations are found in leaves, especially in those located in the lower segments of the stems, but studies have shown that the rate of degradation is also higher in the plant, 80% to 90% of the paclobutrazol being converted to other forms after 9 days. As a general precaution, trees that will be harvested for nuts or fruits within one year should not have the treatment (EPRI 2000c).

6.3.2 Air

Because the current method of application is either by soil injection or soil drench, and not by foliar spray, there may be very little or no residues of paclobutrazol in the air (EPRI 2000c).

6.3.4 Human Health

Paclobutrazol has a low toxicity, the median lethal dose being between 500 and 1200 mg/kg. It may cause a moderate eye irritation, but washing the eyes within 30 seconds diminished the effects, and a mild skin irritation if in contact for a long time. The applicators are most exposed during dilution of the concentrate. Spilling 0.5 L of concentrate on the skin would provide a dose of 4.4 mg/kg, and a diluted solution would provide a dose of 0.36mg/kg (EPRI 2000c).

6.4 Advantages of Tree Growth Regulators (TGRs)

Use of TGRs is becoming more common as the technology has improved to a large degree over time. Use of these compounds has been shown to be useful in vegetation control in utility corridors.

Advantages of the use of TGRs include:

- Increased stress and drought tolerance in treated trees
- Reductions in tree growth, biomass, and trim time which makes this method more cost effective
- Prevention of tree rot and fungal infections due to fungicidal properties of TGRs
- Enhancement of tree root system with the use of TGRs as a possible cure for declining trees, or as preventive measure
- Use of implants where there is no room for soil drench (e.g., sidewalk).

6.6 Disadvantages of Tree Growth Regulators (TGRs)

Because use of tree growth regulators is a relatively new method of vegetation control in utility corridors, there are a number of relatively new disadvantages to the method. These disadvantages include:

- Wound closure in treated trees
- Cultural divide – chemical control vs. environmental movement: a 40+ years old conflict
- Costs and time for filing an Environmental Impact Statement (EIS) discourages utilities
- Public perception

6.6 Effectiveness of Tree Growth Regulators (TGRs)

As a newer method of vegetation control in utility corridors, TGRs are not yet used extensively. As these compounds have improved over time, they are becoming more effective, as well as cost effective, with easier, less labor intensive application methods and more successful growth inhibition for vegetation in utility corridors.

Chapter 7 - Conclusions and Recommendations

7.1 Conclusions

The results of the comparison between the three methods of vegetation control in utility corridors (planting management, mechanical tree trimming and tree growth regulators) are presented in Table 1, at the end of this chapter. Results are presented in terms of advantages, disadvantages and effectiveness.

7.2 Recommendations

7.2.1 Burying Existing Power Lines

Cost-benefit analysis of burying existing overhead power lines underground, is an area of research that would be helpful in the selection of vegetation control methods in utility corridors. Placing utility lines underground eliminates the distribution system's susceptibility to wind damage, lightning, and vegetation contact. However, underground utility lines present significant challenges, including additional repair time and much higher installation and repair costs. Burying overhead wires costs between $500,000 and $2 million per mile, plus expenses for coolants and pumping stations. Perhaps the most important issue for coastal regions is that underground wires are more vulnerable to damage from storm surge flooding than overhead wires. (Executive Order of the President 2013)

Rule 20, approved by the California Public Utilities Commission, is a program to underground existing overhead lines in areas where there will be general public benefits from the undergrounding, as recommended by local counties and cities (CPUC 2014).

7.2.2 Allelopathy

Allelopathy is the suppression of growth of one plant species by another due to the release of toxic substances (from Merriam-Webster dictionary). Inhibition produced by allelopathic plants represents one option of vegetation control in right of ways, but at present more research needs to be conducted. To date, most of the studies and articles concerned the allelopathic effects on herbaceous plants, but very few on the effects on trees. One of the possibilities that will need to be investigated further is about the allelopathic effects of mycorrhizal fungi on large trees (EPRI 2000a).

Another highly promising option is the development of herbicides from microbially-produced phytotoxins, which will offer some advantages over the synthetic herbicides that are safer, they break down naturally, and may exhibit greater selectivity.

7.2.3 Integrated Vegetation Management (IVM)

The goal of integrated vegetation management is to convert tall growing plant communities in transmission right-of-ways to communities dominated by low growing plant species. This may be accomplished by selectively removing tall growing plants while preserving low growing native plants, like grasses, herbs and woody shrubs (PG&E 2014). Initially, the right of way is cleared mechanically of tall growing and incompatible plant species. After clearing, the right of way is monitored for re-sprouting and reinvasion by incompatible vegetation, and selective herbicides application may be used to control only the undesirable plants (EPRI 2002). Once monitoring shows effective removal of incompatible vegetation, the right of way will be enhanced through various methods to provide the desired outcome of a low growing plant community. With proper management, the low growing vegetation can eventually dominate the right-of-way and retard the growth of the tall growing vegetation, providing control of incompatible plants and reducing the need for future herbicides applications. Studies show the type of meadow-like setting will enhance wildlife habitat by promoting vegetation preferred by birds, deer and other small animals (Bramble 1991).

7.3 Research Summary

Choosing a method of vegetation control is a decision that the vegetation management managers should take based on many factors, like costs, environmental impacts, existing agreements with the landowners, terrain, public perception. For the last 100 years vegetation control practices on right of ways had been one of the most important maintenance programs for all the utility companies. Until the end of 1940s, the only method of control has been mechanical trimming, by cutting and mowing. Starting with 1950s until the early 1980s, the main method of control was the use of herbicides, with much of the application conducted aerially. Starting with the 1980s, many utilities moved away from the use of chemicals, due to human health and environmental concerns, and returned to maintaining the vegetation through mechanical means, but by the end of 1990s, it became clear that in order to have a successful vegetation management program it is necessary to use a combination of control methods (EPRI 2002). All the control methods currently used present advantages, and disadvantages as well, that should be taken into consideration.

Table 1. Advantages and Disadvantages of the Three Vegetation Control Methods

Methods	Advantages	Disadvantages	Effectiveness
Planting Management	- Improvement of rural and urban forest - Reduction of chemicals use, reduction of biomass	- Hard to prohibit planting of "nuisance" trees by private owners - Requires a long term commitment	- Very effective in long term
Mechanical Trimming	- Very selective - Wide application	- Aesthetics - Biomass disposal - Workers safety	- Short term effective
Tree Growth Regulators	- Growth, biomass, trim time reduction - Trees can be more stress and drought tolerant - Fungicidal properties	- Environmental concerns - Additional training is required - May affect non-target plants	- Effective for the treatment period (1-3 years)

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