Linking Bioenergy Crop Development with Soil and Water Phytoremediation

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INTRODUCTION

This paper explores potential use of Short-Rotation Woody Crop (SRWC) trees for production of biomass to serve as clean feedstock for renewable energy and biofuel generation. Concurrently, that same tree can be utilized for phytoremediation of contaminated soils and subsurface water resources. The two projects can operate as independent elements, each economical in its own right. Industries and agencies can capitalize on the synergies available by closely integrating process flows and infrastructure, coordinating input and off-take agreements, and leveraging financing by packaging the two developments.

California's bioenergy industry is attempting a broad recovery, a resurgence that will see many idle plants brought back on-line, and even new facilities constructed. Renewable Energy, especially the "firm" electrical generation that bioenergy provides, is in high demand now. Restarting California's idle bioenergy facilities has become something of an informal mandate; Utilities are vying for bioenergy-sourced power purchase agreements (PPAs). Going beyond electricity production, woody feedstock now shows great promise for conversion to biofuels and other commodities. Long-term feedstock supply is difficult to secure, suggesting supply chain investment in biocrop agro-forestry development.

The paper is based upon work initially completed in 2007 examining potential for a biomass facility (the "Facility") located in Imperial County, California. The assessment is also applicable to many biomass feedstock supply infrastructure development efforts. The original Facility remains idle and can be rapidly restarted; it is a fully functional gasification-based bioenergy facility, mothballed almost a decade ago due to changes in the collapsing energy market coupled with difficulty inherent in gasifying steer manure. The Facility's biomass conversion is accomplished by twin Lurgi™ gasification chambers; corrosive salts in the manure coupled with high fractions of soil from poor manure collection methods produced very low heat rates per unit of feedstock, and caused excessive down-time with increased operations and maintenance (O&M) costs.

Central Imperial County is a vast, arid region, a non-draining groundwater basin; storm water, agricultural run-off, and all of the underground hydrostatic gradient flows toward the Salton Sea with no outlet. The Imperial soil group comprising most valley soils consists of saline silty clay and silty clay loams, of low permeability. Central to concern over salt and nitrogen contamination of basin soils and groundwater, and increasing concentration in the Salton Sea, are controls on Confined Animal Feeding Operations (CAFOs). Suits against state and federal environmental quality management recently culminated in water quality regulatory changes impacting all activities under the purview of Waste Discharge Permit requirements.

The following discussion touches on the need for bioenergy, the remediation imperative driving water quality regulatory changes, and the choice of the principal SRWC tree. A proposed project outline is presented. Expectations for both feedstock production and soil/water conservation are summarized.

BIOENERGY IMPERATIVE

Many have attempted to develop economical “grow-your-own bioenergy” scenarios. Commonly, some form of subsidy or cost-offset is needed at today’s land use and biomass handling costs. Returns on energy generation, even for dependable and clean *renewable* bioenergy under California’s Renewable Portfolio Standard, are usually insufficient or marginal at best. Ways to monetize the many recognized yet undervalued environmental benefits of bioenergy (carbon sequestration, air quality improvements, forest fuel loading control efforts, urban and agricultural waste management) have yet to provide an economical safe-haven for the struggling bioenergy industry. In this project, it is the integration of bioenergy generation, optimal produced-biomass utilization with options for off-take of products, and broad-scale soil and groundwater remediation that create an economical, environmentally sound and sustainable path forward.

Past History - In such an arid location, supplies of easily-obtainable woody biomass are quickly depleted, and long-distance transport of wood as a fuel source is always difficult to justify environmentally or economically. Waste fuels may provide fees when wastes are diverted from traditional disposal practices, yet contaminant control for waste-derived fuel presents another challenge to state and federal permitting, economics and environmental quality control. The early operations at the Facility sought to use one type of biomass found in great local quantity: steer manure. Problems with the amount of salt and sand in the manure proved the operator’s nemesis, causing excessive down-time for repairs. This eventually lead to too much natural gas firing to remain under the permitted 25% fossil-to-renewable fuel blend constraint, invalidating the PPA, and closing the plant.

Proposed Operation - Recent engineering studies on the twin Lurgi™ gasifiers clearly show that corrosion and slagging due to salts in feedstock present problems beyond acceptable expenditures for O&M. The manure would probably need to be washed first, which then would require energy for re-drying and result in unusable brine, very difficult to dispose. Rather than physically move the manure to the facility, this resource can be used to feed SRWC trees, and transport the energy-dense *trees* to the Facility.

SRWC hybrids can provide a significant long-term feedstock supply, provided that sufficient acreage is available to grow the biomass. It is the project’s early intent to provide 30% to 50% of the biomass fuel necessary to generate between 15 and 18 megawatts of electricity (MWe). Given promising results, the biocropping could be expanded until the balance of plant consumption could come from “grow-your-own” biomass. The Facility’s existing permits allow expansion to 49.9 MWe; *upper* biomass production/consumption limits are not a problem.

The Facility will consume roughly 500 dry tons of feedstock per day to service this scale of initial bioenergy generation. Given heat values of the intended biocrop, this could convert 165,000 to 175,000 dry tons of biomass (allowing for 10± % variance in feedstock heat rate) into renewable energy annually. The chosen SRWC trees are planted 450 trees per acre on typical 8 ft x 8 ft spacing, and bio-accumulate about 25 bone-dry tons (bdt) per acre per year of new biomass growth. Trees are harvested every three years; the first-cycle harvest production approaches 80± bdt/acre. The hybrids basal-sprout when cut down; once root masses are established, successive harvests increase to stabilize for the third cycle at 120± bdt/acre. Using the higher Facility conversion through-put and only the lower production rate, this sustainable tonnage requires 2200± acres. To consume so much land, even *very* marginal acreage, a strong imperative in addition to generating clean renewable energy must drive this project.

REMEDIATION IMPERATIVE

Nutrient Management Planning - Release of waste to surface and groundwater is regulated in California by Regional Water Quality Control Boards (RWQCBs), who implement and enforce combined state and federal controls through Waste Discharge Requirements (WDRs). These in turn reflect the broader federal jurisdiction of the US Environmental Protection Agency (EPA) through regulation and enforcement of National Pollution Elimination Discharge Permits (NPDES). Imperial County falls under the jurisdiction of Region 7, RWQCB, and Region 9, EPA. Although conditions vary in other water basins, the applicability of the imperative remains.

Regional soils in Imperial County are deeply deposited, relatively tight red silty clays and silty clay loams. Water tables are often high, within 5 to 40 ft of ground surface. Intensive agricultural and animal husbandry practices leach a wide diversity of nutrients and contaminants into subtending soils and aquifers. Controls over effluent concentrations, waste storage and release practices, and impact mitigation are changing. Through a lengthy series of actions including legal appeals and binding judgments, Region 7 now must develop and impose a far more stringent contaminant management plan than previously enjoined under existing WDR and NPDES permits, including all discharges currently protected under the Region's "General Permit".

The EPA modified the 2003 CAFO Rule to extend two compliance deadlines for operators of CAFOs. Newly defined CAFOs had until July 31, 2007 to seek NPDES permit coverage, while all CAFOs had until that date to implement nutrient management plans. The extension is in response to changes required by the Second Circuit Court of Appeals decision in Waterkeeper Alliance et al. v. EPA. The EPA is proposing to revise the NPDES permitting requirements (Section 122) and Effluent Limitations Guidelines (Section 412) for CAFOs in response to the order issued by the Second Circuit Court of Appeals in Waterkeeper Alliance et al. v. EPA, 399 F.3d 486 (2nd Cir. 2005). The extended comment period closed on August 29, 2006.

Salton Sea Remediation - Constant high evapotranspiration over millennia have concentrated salts entering this basin via precipitation and in the imported Colorado River water, compounded by man's agrarian and municipal activities. The Imperial Irrigation District distributes agricultural water supplies through piping to in-field concrete lined canals. Much of the agrarian soils only maintain their high productivity as a result of subsurface "tile" drains, an intricate network of porous piping lain from 6 to 10 foot below tilled surface, 30 to 60 ft on-center that draws off salt, nutrient- and contaminant-laden sub-surface water flow. The tile drains discharge to unlined canals, to empty into either the Alamo or the New River, thence to the Salton Sea.

Remediation efforts to reduce salinity and contamination in Salton Sea waters have long been underway and are coordinated by the Salton Sea Authority (SSA), a Joint Powers Authority (JPA; see www.saltonsea.ca.gov) with over a decade of experience in the area's management. The SSA released a multi-faceted Restoration Plan in July 2006. Receipt of agricultural run-off remains one of the recognized benefits and challenges of this inland sea.

Concerns regarding increases in Salton Sea salinity and eutrophy with decreasing inflows must be taken into account. A draft Salton Sea Multi-Purpose Plan released July 2006 provides in-depth assessment of options and responsibilities. Higher humidity from evapotranspiration will accompany expansive phytoremediation. This in turn will reduce transpiration and evaporation from plants and water bodies, and micro-climatic changes may evince greater localized precipitation. The regional water balance can be expected to shift slightly with implementation of remediation.

This water balance is already an international concern. Mexicali authorities intend to reclaim treated effluent and agricultural run-off that now flows through the New River into the Salton Sea. The 75-year Salton Sea restoration period coincides with the term of the Quantified Settlement Agreement (QSA) that reallocated Colorado River usage and decreased inflows to the sea, signed in 2003; greater amounts of flow will be available to those outside of the Imperial County region.

Reductions in inflow as a result of these two factors are minor, compared to that attributed to agricultural run-off and spillage. In excess of 80% of the total inflow to the water body cycles first through Valley agriculture before being discharged into the New River, the Alamos, and the subtending aquifer. While salinity may be most closely related to evaporation and volume reduction, nitrogen-contaminant eutrophication can be primarily linked to nutrients entering the inland sea with this run-off.

Phytoremediation - One of the approaches recognized in the federal water regulations for managing and improving groundwater quality involves planting permanent vegetation. Active root uptake can act as a “bio-filter”, intercepting and removing or at least stabilizing salts, nitrogen and a plethora of other contaminants before they are released into surface water. Using vegetation to mitigate environmental contamination is not new, but has recently seen a dramatic increase in its application and diversity. The General Permit is a basin-wide management tool; implementing remediation to satisfy the new mandates must be approached as a basin-wide program.

The term “phytoremediation” refers to a group of methods and technologies that use plants to significantly reduce, remove, stabilize, volatilize and/or degrade the amount of environmental toxins in soils and groundwater, and involves growing combinations of plant species tolerant of the specific conditions of the contamination to be remediated. Contaminants are taken up by root activity, modified by the plant’s chemistry, and incorporated in the plant structure. Modifications tend to stabilize contaminants, reducing or stopping further down-gradient transport via the groundwater, and facilitating additional microbial breakdown.

Plants used to extract and sequester contaminants should, in addition to tolerating high levels of the target contaminants, be fast growing and easy to cultivate and harvest. SRWC candidates chosen for this bio-cropping project are recognized as “hyper-accumulators”. These are plants that rapidly pump groundwater laden with nutrients, salts and contaminants from the root zone up into the woody and leaves, and accumulate those contaminants in orders of magnitude greater concentrations than present in the site to be remediated. Trees of the *Paulownia* genus have been known to uptake 700± pound nitrogen per year, by the third year’s growth at proposed plantation densities.

When contaminants are taken up and sequestered in the SRWC plant, they must be removed from the area to truly extract and remediate the problem, or eventually natural decay would simply return contaminants to the same soils. Bio-cropping effects this removal, and ash management concentrates and controls the extracted contaminants.

The short-rotation woody crop trees under consideration for this project meet the basic criteria both as an effective feedstock for bioenergy generation and for basin-wide phytoremediation: salt tolerance, hyper-accumulation of target contaminants, fast and significant growth of energy-dense biomass, ease of cultivation and harvest.

CHOICE OF PRIMARY BIOFUEL / PHYTOREMEDIATON CROP

Conditions in Imperial County present a daunting challenge, yet provide an excellent opportunity for basin-wide implementation of an effective remediation plan. An integrated program coupling broad-scale phytoremediation with advanced conversion of the produced biomass into bioenergy, biofuels and bioproducts holds considerable promise. Much of the potential rests upon making the correct decisions, both economically and environmentally, for the SRWC species to plant.

Paulownia, known as the "Empress" or "Princess" tree, is broadly available in the US and elsewhere for landscape and wind-row use. The tree's naturally occurring species are alien to the United States. They are extremely fast growing trees that bear beautiful lavender flowers in abundance, are resilient to environmental extremes and are resistant to most disease and pest risks. They have even been promoted as the next "forest tree" choice for timbering and reforestation.

Paulownia regrows from a cut stump (known as the ability to be *coppiced*) and produces a harvestable trunk in from three to four years depending on planting conditions. The wood tends to be knot-free for much of the main trunk, especially true for trees harvested after three, four and five years of growth. The upright habit produces strong, even-grained and light-colored timber with densities that fall between that of balsa or poplar, around 15 to 19 pounds per cubic ft, about half the density of pine. *P. tomentosa*, one of the more commonly available species, has a much higher strength to weight ratio than balsa. Strong and light weight: an excellent combination of traits for many commercial lumber applications.

Although the Empress Tree may have proven excellent for lumber, many of the Paulownia species fail both as a biofuel and as a tool for cleaning up environmental contamination. The light weight, coupled with a relatively low heat value, would dramatically increase shipping costs per unit of bioenergy to be generated, and some species' invasive nature precludes introduction into either farm or natural habitats. *Paulownia* (especially *P. tomentosa*) ranks high on the federal government's black-list of invasive species: the tree can produce 10,000 tiny, highly viable seeds per pod. When cut down, the stump resprouts and aggressively establishes far-reaching roots that send new sprouts to the surface.

The National Park Service manages the "Alien Plant Working Group"; their informative discussion of bad habits of the "Princess Tree" can be found at www.nps.gov/plants/alien in an article dated May 2005. Such invasiveness is not acceptable for large-scale phyto-remediation, and in all likelihood, one could not receive the critical federal approval for this use of the typically available species.

Not all species of *Paulownia* are as invasive as *P. tomentosa*, and each species exhibits differing traits. Selection of non-invasive species can alleviate most concerns; hybridization provides another possible way to diminish the negative characteristics through resultant clone selection. Hybrids of *Paulownia elongata* with carefully-chosen hardwood tree species, with the most likely candidate clones being a cross with black locust *(P. elongata x Robinia sp.*), cottonwood *(P. elongata x Poplar spp.)* and willow *(P. elongata x Salix spp.)*. All such hybrids are seed-sterile, as you would expect with trans-genera clones (example: peach x apricot = sterile nectarine). This was the first major challenge established as criteria for phyto-remediation usage by the EPA many years ago.

Salt tolerance is required for planting in all Imperial Valley soils, a positive trait exhibited by some *Paulownia* species more than others, and a useful trait that may be amplified in hybrid clones. Salt tolerance and uptake go hand-in-hand, but the hybrids push a tap root 35 foot deep within the first year or so after planting, establishing main root masses well under the near-surface saline accumulations. Where salt uptake and removal are of particular remediation importance, inter-row planting and under-planting with more surface-feeding species should be incorporated in the planting design. Additional highly specialized hybrids of willow (*Salix*) and cottonwood (*Poplar*), along with under-plantings of various fast-uptake wetland plants (cattails, rushes, and grasses) should be used to complement plantings of the primary hybrids, where conditions and intended remediation targets dictate.

Paulownia planted in relatively tight clays will develop a root mass roughly the width of the canopy, centered on the deep tap root. Tightly spaced trees develop tall trunks with narrow canopies, largely curtailing near-surface feeder root spread beyond canopy's edge and greatly reducing the risk of root invasion into adjacent cropland or tile drains. Care needs to be taken where tile drains cross SRWC planting areas to protect that section of pipe from root invasion.

The leafy fraction of the tree contains valuable concentrations of protein and may be an economically attractive animal feed. Of the 700± pounds of nitrogen uptake per year, per acre, conservatively 2± % by weight of the deciduous leaf crop is composed of nitrogen entrained as protein. The leaves fall before the nutrients can be transferred back to the root mass. In the Imperial Valley, high-protein fodder is a needed commodity.

Fine branches and leaves can also provide excellent bulking organics for manure composting, which will be necessary for manure pathogen control when used as a fertilizer for the trees planted near truck crops. Studies have shown that direct application of dry leaves can also significantly improve crop yields. Optimal use of all parts of each tree will be a continuing imperative.

The SRWC produce harvestable biomass after only two to three years of growth. Trees rapidly increase in biomass at the rate of 30± bdt/acre per year when planted on an 8 ft x 8 ft grid, as would suit canal bank plantings. It remains to be assessed what the specific conditions will produce, but it is useful to note that for many other regionally grown crops such as cabbage, sugar cane, and sugar beets, Imperial County agriculture regularly claims national records for yields per acre. Much of this is a result of the combination of "bottomless top-soil", abundant Colorado River water allocations, a 10-month growing period with over 330 days of sunshine annually and, in many areas, the constant removal of salt via the network of tile drains.

PROJECT OUTLINE

Time is the most critical component for integration of this broad series of elements into a cohesive, synergistic program. Time is needed to procure, treat, plant, select and propagate appropriate SRWC. Considerable time is required for out-planted scion to mature for harvest, for internal and external testing and validation to take place and for the results to be incorporated in further planning.

Time is necessary for retrofitting the Facility itself for testing cycles as the engineering design nears completion, for development of the "front gate" that can efficiently accept, process, and deliver diverse woody biomass as feedstock to the conversion units and to other uses.

Subsequent phased developments could have been consecutively funded and initiated once the Facility had been securely restarted, and then run concurrent to these timelines. Future Facility development should seek three goals: (1) improve efficiencies and emissions profiles of the facility, (2) increase the diversity of acceptable feedstock, and (3) increase the product diversity of the Facility, beyond generation of renewable electricity.

Permitting Considerations:

Definition of "Project" - To meet economic goals of timing and market demand, the restart of the idle Facility must remain strictly within the bounds of all extant permits, requiring review and approval, perhaps reauthorization as in the case of the Permit to Operate from the Air Quality Management District (AQMD), but constraining redevelopment such that no major permit issues are raised. The Restart would be a stand-alone effort; economical and self-sufficient on its own.

Consequently, remediation efforts (and any other discrete activities) must be addressed as separate, although highly integrated, projects. Eventual "energy park" build-out must, for permitting purposes, be seen as a series of inter-related but discrete projects, similar to the way a City will grow over time. No single, over-all guidance has been developed, nor can the organic growth projected be dictated by such a single-project plan. This is important to differentiate, as the regulatory basis divides on this point and "piece-mealing" large projects to sequester permit risk is not allowed.

Existing permits for the Facility incorporate feedstock handling operations. The biomass handling activities of the "front gate" will change permitted activities in nature and footprint, but not enough to require other than an amendment to documents on file at agencies with purview. As these activities would, if anything, *improve* environmental quality parameters (less dust, managing wood over manure) and are not part of the conversion/generation equipment train, cumulative capital expansion should not trigger "New Source Review" reassessment of air quality emissions under state and federal permits. Plantation development, by itself, would be considered a separate "project" under state and federal environmental quality protection regulations (CEQA & NEPA), and not part of the Facility project.

Categorical Exemptions - Phytoremediation using approved SRWC stock will fall under environmental quality management of the mandatory inter-agency coordinated "Comprehensive Nutrient Management Plan" (and other associated remediation projects) as an element of regional strategic mitigation and remediation planning. Mandatory environmental mitigation is a categorically exempt activity under CEQA, and should be similarly defined under the federal NEPA project definitions. Agricultural harvesting of the hybrid trees used in such a broad program should not initiate regulatory actions outside of those necessary for approval of the basin-wide remediation efforts. Early coordination efforts with these inter-agency remediation programs are thus critical to ensuring long-term feedstock supply for renewable energy generation.

Planting and Harvesting Characteristics:

The project design starts with commercial greenhouse and open-air plantings. Monitoring begins immediately for uptake, growth rates, and crop characteristics.

Greenhouse & Root Farm - SRWC tree root stock must be able to acclimate to Imperial County site conditions. Initial potting in this project design should approach 120,000± root segments, planted in sterile preformed peat pots; each 4" x 4" x 5" deep pot is equipped with a pressed, donut-shaped wafer containing dry planting medium and nutrients specific to the hybrid growth needs. When watered, the wafer swells around the root segment. This can produce 108,000± saplings following a six-week growth cycle in a tightly controlled 60 ft x 144 ft greenhouse and accounting for 10± % mortality. The new saplings are ready to be planted out in their surrounding peat liner.

30,000± saplings would be planted in an outdoor "root farm" and cultivated for an additional 18 month growth cycle. To hasten root growth and ease root harvesting, root farm soils would need to be amended to provide a sandy loam. Spacing in the root farm would also be more open than field plantings, using a 12 ft x 12 ft spacing grid; 100 acres are required to plant 30,000 saplings. A portion of each tree's root system would be harvested after 18 months growth, providing 750,000 root segments. Part of this root stock initiates the project's first self-sufficient production cycle; the root farm trees are then harvested for another 750,000± root segments every 12 months.

As soon as the first potted saplings are removed from the greenhouse, a second cycle can be initiated. Each time the greenhouse is emptied, another cycle is begun; this would generate 108,000± additional saplings roughly every two months, until (in 18 months), the Facility can provide its own root stock. Five to six cycles of over 100,000 trees could be completed each year; 500,000 trees could be made available for phytoremediation within one year of project initiation.

Plantation Stock - With treatment and potting, saplings emerge in about two months to provide the first 78,000± plantation stock. Young saplings 6" to 8" tall have the best chance to acclimate to field soils with careful planting. An 8 ft x 8 ft grid is used for field plantations. Discounting set-backs from field edges; this spacing provides 450 trees per acre. At this planting rate, the initial cycle would provide sufficient saplings for 173± acres. Two months later, 108,000± saplings would be ready for planting on an additional 240 acres.

Imperial Valley temperatures preclude planting saplings during June, July, or August. Assuming early spring start-up, two cycles of sapling production could be completed for valley planting needs before summer, and an additional two cycles completed during the fall. This could generate 400± saplings for out-planting to over 800 acres, to meet initial remediation needs. Existing off-take agreements outside of the region can absorb any production not needed for remediation. Most other regions do not allow for three full planting cycles, making Imperial an excellent choice for an initial project.

Particularly amenable regional soil and available nutrient conditions can be expected to produce harvestable trees every two years; in such locations, spacing tighter than an 8 ft x 8 ft grid may also be appropriate. Tighter spacing in excellent conditions yields faster vertical growth for more rapid harvesting; mixed species plantings optimized for remediation decrease the total tonnage per acre of available biomass. "Hedge row" plantings can be as close as 2 ft on center, and form a virtual wooden wall of trunks. For initial plantings with this acclimated SRWC stock, total acreage and inter-tree spacing are dependant on both land availability and desired stand / remediation characteristics. Planting designs for all components of the Master Plot will be developed on an 8 ft x 8 ft grid.

Planting Locations & Conditions:

Drip or flood irrigation would be needed for the first four to six months; once the tap-root reaches subtending groundwater, the trees would no longer need irrigation. Saplings should not be planted in standing water or in water-logged soils. The need to supply early stage irrigation may impact cost and choice of planting locations where new water delivery systems would need to be created.

Diverse conditions of soil, water, nutrient and contaminant load occur within the region. Monitoring initial plantings and choosing hybrid characteristics to meet locational demands will provide long-term improvements in both production and remediation efficacy. Four general types of land-use are discussed below that can act as initial categories for plantation development.

CAFOs – Central Imperial County hosts nearly a half-million head of steer and dairy cattle. Stock is generally fed a high-protein grain-based diet in feedlots, rather than on open range grazing allotments. These Confined Animal Feeding Operations (CAFOs) are the focus of recent court-forced regulatory and enforcement changes (discussed further, below). Concentrated accumulations of nitrogenous, saline animal wastes provide a continuous source of groundwater contamination as leachate permeates subtending soils.

The hydrostatic action that moves groundwater toward the New River and the Alamos River and downward to the Salton Sea basin would indicate that pytoremediation could be effective in intercepting much of this nitrogen-rich contaminate plume as it moves down gradient. Hybrid plantings could be located adjacent to active feedlots; alternating active lots with dense linear plantations would develop a “sieve” of roots, an aggressive underground bio-filter through which water would pass, and be stripped of a large percentage of deleterious compounds.

Inter-planting CAFOs with *Paulownia* has been shown effective in other regions for animal waste and odor control. Wind-breaks of the tall SRWC trees bring additional benefits: (a) Cross-field wind velocity is dramatically reduced, and with it, loss of the fine particulate nitrogen-laden dust; (b) foliar uptake of gases should help clean rising ammonia from animal wastes; (c) providing shade for the stock is already recognized as essential to animal health with concomitant economic benefits; (d) cattle can be grazed among trees three years and older, allowing understory use as fodder prior to tree harvesting; and (e) movement of “fertilizer” to the trees is taken to the absolute minimum distance.

Canals – The saline strips of land adjacent to Imperial County’s network of irrigation and drainage canals provide the second type of planting area. Width would generally allow three to four rows of trees on each side of the canal complement, facilitating a linear cultivation and harvesting program. Minimal truck-crop productivity in this saline strip, ready access to canal water for initial irrigation, constant recharge of subtending soil moisture even in very hot and dry years, and proximity in most areas to sources of composted manure for fertilizer combine to present an encouraging and extensive biocrop location. The network can be mapped, ownership established, access negotiated, and cultivation begun with minimal preparation.

Soils along each canal complement generally exhibit sufficient salinity to seriously retard crop productivity; this creates a strip of relatively useless (yet taxed) land extending 30 ft or more on either side of the canal segment. Similarly, soils along the drainages of the two rivers are highly saline, and surface flows are unacceptably high in particulates, salts, nitrogen and organics. Taken together, the riparian belts and strips along discharge canals present a very substantial inter-connected land surface comprising hundreds if not thousands of acres. A 100 ft wide strip of land one mile long equals 12.12 acres; if a total of 60± ft were available bordering each side of a canal, the combined strips would equal 7± acres of accessible planting area per mile of canal.

The canals already include a complement of access roads, usually dirt tracks between the canals and the adjacent fields. Some have been watered and packed until the clay resembles brick. Many however would need considerable treatment to sustain heavy vehicle use without producing great boils of fine-particulate dust, a pollutant condition that the Imperial Valley – Mexicali Air Basin certainly does not need exacerbated.

Dust control necessary for SRWC harvesting along these strips would thus provide a long-term, real and quantifiable reduction in particulate matter pollution compared to existing conditions. Environmentally friendly polymer-based surfactant dust retardants, albeit not cheap, are available at rates considerably less than petroleum-based surfacing. Access road management is an expected and necessary element of any large-scale cultivation and harvesting program, and relatively minor when compared to overall program expenditures. Dust control will also be provided by planting cover crops under the hybrids, which has the added benefits of stabilizing loose soils for simpler harvest access, and increasing near-surface contaminant bio-filtration.

Riparian - Central valley riparian belts present a third, more complex challenge and opportunity for growing and harvesting an energy crop. All indications are that this zone has long been accumulating contaminants, and now will require a strategic basin-wide approach to implement the new water quality regulations. A concerted effort along the Alamos and New River corridors could certainly include extensive biocrop hybrid plantings, although in these areas, multi-species biofiltration planning should probably take precedence over mono-crop bioenergy plantings. Permanent mixed-species vegetative bio-filters can be designed to remove particulates from surface flows, in addition to sub-surface activity; stream siltation and total suspended solids reduction is a reasonable goal.

The candidate SRWC trees can provide the pivotal hyper-accumulator vegetative complement; mixed species under-plantings and inter-row combinations can be designed to optimize remediation. Coordination with inter-agency planning currently under way can incorporate project-bred hyper-accumulator hybrids in combination with native species complements.

Salton Sea Inlet Deltas - The ability of the Salton Sea to accept agricultural run-off is highly valued; the deleterious impact of contaminants and nutrients in this run-off has on the overall health of the water-body is significant. Broad expanses of the Salton Sea inlet deltas of New River and the Alamos River present a third potential plantation location. On-going remediation of the Salton Sea could be substantially aided by establishing sweeping mixed species bio-filters to pre-process incoming agricultural run-off.

Although hybrids are sensitive to water-logged root zones, they do quite well with periodic flooding and inundation. Bio-filtration prior to final release into the Salton Sea should be considered as an element of the over-all remediation effort, scaled appropriate to the volumes of run-off needing treatment.

Bioenergy Production:

SRWC trees grown as a bioenergy crop are normally harvested on a three-year cycle; first year’s plantings are coppiced three seasons later, resprout from the base, and are ready for harvesting again in another three seasons. As noted, a certain percentage of planting conditions will allow two year coppicing. Production numbers presented only assume the more conservative three-year cycle.

Hybrid growth under field conditions is dramatic; within months, the trees reach 3 ft to 5 ft in height. External validation found “... a staggering 28.5% increase in its growth rate …” during the monitoring period. At one year, sturdy trees with diameters measured at breast height (dbh) of 10” reach 15 ft, with 100± wet pounds of biomass accumulated. Three years of growth produce a tree 30 ft to 40 ft tall, weighing 700± dry pounds, and ready for first harvest. Once cut to 1 ft above ground, trees re-sprout almost immediately.

Biomass Accumulation - Biomass accumulation for the first three years of growth is stronger for root establishment than for other parts of the tree. Once the primary tap root, auxiliary roots, and surface roots are well-established, trunk and branch growth rates dominate. Above ground portion biomass increases are thus incrementally stronger on this mature root mass for the second and third harvests in the three-year cycle. Trunk growth rates stabilize on the nine-year-old root mass; the fourth and forward harvest cycles produce tonnages very similar to that of the third harvest.

First harvest biomass accumulations, three year trees, three year old root mass:
- Planting on an 8 ft x 8 ft grid produces 450 trees per acre
- Trees accumulate 25± bone dry tons (bdt) per acre of biomass annually
- Three years growth @ 25± bdt per acre, per year
- 1 acre produces 100± wet tons @ 27± % field m.c. = 75± bdt/acre

Second harvest accumulations, three year old trees, six year old root mass:
- 30± bdt accumulation per acre, per year (bdt/acre/year) = 90± bdt/acre at harvest
- Field moisture of 27± % = 130± wet tons harvested per acre

Third harvest, three year old trees, nine year old root mass:
- 35± bdt/acre/year = 115± bdt/acre = 150± wet tons/acre

Fourth (and forward) harvests, three year old trees on the mature root mass:
- 35± bdt/acre/year = 115± bdt/acre = 150± wet tons/acre

25 to 35 bdt/acre of biomass accumulation per year for *Paulownia* is significantly greater than for other SRWC biocrops, and the three-year harvest cycle compounds the production. Increase in biomass is not linear, but geometric with the increase in trunk volume during this extended growth cycle.

Biomass Energy Density - Heat value of biomass for energy production is less dependent on species than on moisture content. Most wood ranges from 5500 to 6500 Btu, dry weight, but the energy needed to drive off moisture decreases the net energy available. As water is lost during processing, biomass increases in energy value per unit weight, or “energy density”. The measured “Lower Heating Value” (LHV) accounts for the energy needed to drive off fuel moisture; the “Higher Heating Value” (HHV) does not.

The energy production capacity per unit of biofuel for a bioenergy generation system is a combined result of the energy density and the system efficiency. Systems that can recover the heat used to evaporate the moisture from the fuel are more efficient at higher fuel moisture contents. The Facility converts biomass to a synthetic gas (syngas) via gasification, then combusts the syngas to heat water and produce steam. The steam drives turbines, and generates electricity. The gasification chambers work best at 30± % m.c. Water must literally be added to the feedstock stream, for drier fuels.

The Facility has previously generated electricity from biomass. Although re-engineering will improve plant efficiencies, the known through-put rates and resultant power generation experienced in prior operation can be used as a conservative starting-point for planning feedstock through-put for the proposed restart. Using past parameters, 760± bdt/day of feedstock at an LHV of 4,500± Btu generated from 15 to 18 megawatts electricity (MWe), when moisture content of the gasification chamber was maintained between 30-40% with make-up water.

A conservative LHV for the hybrids is 4,800± Btu/pound, at 12% m.c.; LHV for bone-dry hybrid fuel is 6000± Btu/pound. Required through-put rate decreases to 500± bdt/day with the increased feedstock energy density, for generation of the target MWe. Harvesting trees with this energy density at the rate of 75± bdt/acre, and given 330 operating days per year, the product of 2200± acres would need to be coppiced, transported to the facility and processed on an annual basis to supply the entire feedstock requirement.

Feedstock Supply Considerations - Long-term assurance of adequate feedstock supply is critical to securing Facility project funding as it is to the overall economics of the facility. Time will pass prior to first harvest, during which the bioenergy facility must subsist on spot-market and short-term contract supply acquisition of potentially less economical and less reliable feedstock. This early out-sourced supply acquisition should be minimized. It is anticipated that rather than assume all of the feedstock provision from start-up, SRWC harvests will augment acquisition of woody biomass from the surrounding region. The balance of waste wood to biocrop as feedstock can thus accommodate fluctuations in availability and economics, reducing feedstock supply risk. As plantation acreage and harvest tonnage increase, greater percentages of the fuel requirement can be met, and plant efficiency and economics improved.

While future bioenergy crop production assures long term feedstock supply, hastening the increase in tonnage of early-term harvesting can significantly improve economics, lower O&M costs, and reduce risk. Projections regarding this integration of facility and plantation timing are provided in the chart, below.

Plantation development will continue, with addition of acreage, re-planting as needed, redesign and expansion of remediation using the SRWC trees, optimization of harvest and processing methods. All will progress from this initial funding as economically self-sufficient on-going efforts.

Agro-Forestry – Design & Development:

Design and construction of greenhouses and an amended-soil root farm adjacent to the Facility would find cost-saving synergy through provision of thermal and electrical energy. Other cost-saving synergies include water and sewer infrastructure, highway access, centralized computer controls, testing facilities, and security and labor integration. The SRWC tree production facility then becomes the first tenant in an “energy park”, projected to surround and integrate with the bioenergy generation facility.

Greenhouse, chiller-room, and any other energy-using development could be located on-site within the Facility parcel if sufficient physical space is available. Provision of electrical and thermal energy to improved feedstock management activities would simply be considered incremental increases in the Facility’s operating energy balance (parasitic load). If necessary to provide an adequate footprint, additional acreage could be acquired and added to the current Facility site through a minor parcel line adjustment.

Root farms need little electrical energy, and location may be dictated by cost of available acreage. Ease of management and infrastructure synergies argue for placement of the 100 to 200 acre farm immediately adjacent to the Facility parcel. Separate parcels ease all future transfers of land that might prove useful, and while merging parcels or adjusting parcel boundary lines may be relatively simple, separating parcels is not.

Stock Growth, Testing and Selection - All saplings are monitored; those exhibiting desired characteristics become stock for plantations, as well as for harvesting hybrid rootstock. Only after treatment with proprietary compounds under tight controls, will hybrid roots sprout to saplings in potted regional soils; this aids property security and reduces the potential for inadvertent root fragment re-sprout outside of project operational control.

Sufficient variation occurs naturally among scion to provide a range of vigorous strains with varying tolerances and characteristics, when properly monitored. 10% mortality is assumed, to allow for selection prior to further use. Early sapling assessment will allow optimization of matches between specific hybrid strains, and the valley’s varying soil types, water conditions and remediation needs. It is reasonable to assume that multiple distinct hybrid strains will show promise, acclimated to slightly different conditions typical of available planting locations. As part of a regional remediation effort, state and federal agency oversight and assessment is not only anticipated, but critical to the long-term success of all efforts. The assessment attendant to the remediation programs would hold significant value for this project, providing external validation of the efficacy of hybrids as phytoremediation tools.

Plot Design, Planting and Harvest - The first 200± acre plantation of 90,000± trees should constitute a Master Plot complex, with locations representative of typical regional soils and contaminant conditions. Initial Master Plot field planting locations should be designed to facilitate growth and uptake parameter monitoring. The Master Plot approach can achieve two objectives: first, to grow, harvest and deliver feedstock as early as possible to the bioenergy facility and second, to provide in-field monitoring of the identified variants in field conditions for comparison to root farm matched variants.

As soon as one complement of saplings is removed from the greenhouse, new treated roots are potted and begin another six-week growth cycle. The entire production of cycles following the first will be available for out-planting. With treatment, potting and growth time accounted for, new crops of saplings can emerge, ready for plantations, every two months. Under Imperial Valley climate conditions, planting can occur during March, April, May, must cease during June, July and August, and can resume during September, October and November. As noted earlier, this could provide two to three planting cycles in the spring and another two to three cycles in the fall; conservatively five cycles could see 500,000± trees in the field, the first year. At 450 trees per acre on the 8’ x 8’ grid, this would provide remediation plantings totaling over 1,000 acres.

All trees in one plantation area need to be harvested at one time whether this is a linear canal planting, an even and rectangular block adjacent to feedlots, or an amorphous shape conforming to the riparian landscape. A “Plot” therefore is unit scaled for harvest, wherever located. Multiple plots can of course be contiguous, but the three-year harvest cycle determines when specific plantings are coppiced. Regrowth starts within weeks following harvest, so remediation uptake remains effectively continuous. Ancillary benefits such as shade, dust control, foliar absorption, and habitat conservation should be considered when Plots are planted, such that harvest does not completely deplete these factors for sensitive locations. A patchwork planting scheme is thus suggested, filling an area in over three consecutive years.

Figure 1 directly compares the timing associated with the Facility to the timing of planting and harvesting. For this example, the Master Plot and four additional Plots are scheduled for planting and harvest times, through one full series of three-year cycles for all four Plots. Plot A is planted in the spring of 2007 from the second and third cycles of saplings to emerge from the greenhouse; Plots B, C & D are planted with saplings from three cycles starting in September 2007; trees for B are assumed ready at the start of the fall planting cycle. For ease of visualization, it is assumed 100,000± trees are planted at each cycle, evenly distributed among the five Plots, over a total of 1,100± acres. Four further planting years are shown, with respective harvests, totaling 5,500 acres.

Figure 1. Schedules Compare Bioenergy Facility Restart and Agro-Forestry

Bioenergy Facility:	***2006***	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***
PPA, Feedstock Agreements									
Financing Agreements									
Permitting, Engineering & Reconstruction									
"Front Gate" Design & Development									
Recommissioning Assessments									
100% Woodwaste Processing			*25% SRWC*						
Increasing SRWC Processing					*50% SRWC*		*77% SRWC*		
100% SRWC Processing									*110% SRWC*
Full Operations, Servicing PPA(s)									

Agro-Forestry:	***2006***	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***
Teaming, Land Use Agreements									
Financing Agreements									
Permitting, Engineering & Construction									
Stock Growth, Testing & Selection									
Plot Design & Development									
2007 Plantings									
* 2008 Plantings									
** 2009 Plantings									
*** 2010 Plantings									
**** 2011 Plantings									
***** 2012 Plantings									
1^{st} & 2^{nd} Harvest, Spring 2007 Trees									
1^{st} & 2^{nd} Harvest, Fall 2007 Trees									
* 1^{st} & 2^{nd} Harvest, Spring 2008 Trees									
* 1^{st} & 2^{nd} Harvests, Fall 2008 Trees									
** 1^{st} & 2^{nd} Harvest, Spring 2009 Trees									
** 1^{st} Harvest, Fall 2009 Trees									
*** 1^{st} Harvest, Spring 2010 Trees									
*** 1^{st} Harvest, Fall 2010 Trees									
**** 1^{st} Harvest, Spring 2011 Trees									
**** 1^{st} Harvest, Fall 2011 Trees									
***** 1^{st} Harvest, Spring 2012 Trees									
Number of SRWC Trees Planted		**500K**	**500K**	**500K**	**500K**	**500K**	**500K**		
Annual Acreage Planted		**1,100**	**1,100**	**1,100**	**1,100**	**1,100**	**1,100**		
Biomass Accumulation per Acre, bdt				**75**	**75**	**75**	**75 & 90**	**75 & 90**	**75 & 90**
Acreage Harvested				**500**	**1,100**	**1,100**	**1,600**	**2,200**	**2,200**
Annual Fall Harvest, bdt				**37,500**	**82,500**	**82,500**	**127,500**	**181,500**	**181,500**

SUMMARY

Biomass Expectations:

Initial spring plantings of 500± acres would begin to deliver feedstock to the Facility three years from first planting, netting 75± bdt/acre, to provide 37,500± bdt of feedstock. The Facility would consume 500± tons per day of feedstock, or 165,000± bdt/year (330 day-year); third year's harvest would thus provide 25±% of the supply needed.

First Harvest, 2009 - Initial year fall harvest would mature three growth seasons with second-year spring plantings. 1,100± acres would produce 82,500± bdt harvest.

Second Harvest, 2010 - Second year fall plantings would mature with third year spring trees; harvesting 1,100 ± acres would again provide 82,500± bdt, equal to 50% of the supply needed.

Third Harvest, 2011 - Third year fall plantings would mature with second year spring plantings and the second harvest of trees form the initial 2007 planting. This second harvest of 2007 trees now have accumulated significantly more biomass per year on their larger, more mature root mass. Total third harvest is now from 1,600± acres for 127,000± bdt. This constitutes over 75% of the facility fuel demand.

Fourth Harvest, 2012 – Fourth year fall plantings and third year spring plantings mature for harvest in 2012. Total planted area now stabilizes at 2,200± acres; half of the trees are now on 2nd-cycle root masses, and expected tonnage of 181,500± bdt surpasses the facility fuel load by 10%.

The maturation of the root mass will increase the acre/year biomass accumulation from 75± bdt to 115± bdt; all trees are being harvested off of completely mature 3rd-cycle roots in 2021. At that time, the 2,200± planted acres should produce 253,000± bdt. This could allow a 50% increase in facility generation, at the current plant efficiencies.

Phytoremediation Expectations:

Continuous measurements of nitrogen uptake within and outside of *Paulownia* plantations have shown little difference in the upper soil layers (0 – 23 inches) within the effective root zone of the trees, but significant decreases in deeper soil layers (31-40 inches). Paulownia trees utilize nutrients mostly from deeper soil layers. Conversely, calcium and magnesium increased as litter decomposed in the near-surface soils (0-8 inches) under the trees, compared to control plots outside of the canopy drip-line.

The following quote is from http://www.worldpaulownia.com/html/remediation.html:
"Over the years many Universities from all parts of the World have conducted extensive tests and field trials on the attributes of Paulownia for a wide range of applications. A lot of this information is well documented and extensively publicized and can be easily researched on the Internet. The most recent up take studies were conducted by North Carolina State University 1998 to 2000. The University of Kentucky and University of Maryland have published several papers on Paulownia's exceptional characteristics for mine site reclamation and soil stabilization."