Carbon Dioxide Reduction and Carbon Sequestration by Co-Firing Tree Energy Crops in Florida's Coal-fired Power Plants[1]

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[1]Peer reviewed by: Mark Hornick (Tampa Electric Company); Dr. Don Rockwood (University of Florida); Dr. Evan Hughes (Electric Power Research Institute); Phil Badger (Southern States Energy Board); Lynn Wright and Stan Wullschleger (Oak Ridge National Lab); Steve Clemmer (Union of Concerned Scientists).

Introduction: In our educational outreach to key interest groups, we have encountered widely held misperceptions as to the environmental benefits of co-firing biomass fuel in existing coal-fired power plants. A common belief is that while co-firing biomass may be somewhat better than the use of traditional fossil fuels (oil, coal), it is less environmentally desirable than implementing other renewable energy options. In efforts to gain broad-based support for co-firing among policymakers (setting energy policies and incentives) and environmentally conscious electricity consumers (who voluntarily pay a premium to purchase green electricity)[2], these misperceptions are creating significant obstacles.

The nexus of this educational challenge is to change public perception from an existing "micro-view" of the benefits of renewable energy options (focusing solely on individual technologies) to a "macro-view", which focuses on what happens in the "real world" when renewable energy technologies are implemented on an integrated electricity power grid system. Under a "micro-view", only the stand-alone impact of a renewable energy option is considered, where it would appear counterintuitive that any combustion technology that emits NOx (smog creation), SO_2 (acid rain), and CO_2 (global warming) could compare favorably to zero air emission options such as wind or solar power.

But in using this "micro-view" approach, a flaw in logic is readily apparent. While wind and solar technologies have zero air emissions, implementing these technologies in and by themselves can not improve air quality – they can only achieve a status-quo non-increase in air pollution. Only by comparing the fossil fuel use displaced by the renewable energy option can an argument be made that "net" air emission reductions will occur. And this is exactly our point: **not all renewable energy options displace the same fossil fuel use**.

We believe that it is critical for Policy-makers, Environmental Organizations, and Electricity Consumers to understand how the power industry works and the paradigm/model of "electricity generation and the environment" – where, based on sound science and engineering, biomass fuel co-utilization with coal can achieve SO_2, NOx, Mercury, and CO_2 reduction benefits comparable or even exceeding that of renewable energy technologies such as wind or solar power.

We wish to emphasize that the Common Purpose Institute strongly supports the advancement of all renewable energy technologies into the marketplace, and it is not the intent of the following discussion to discredit any renewable energy option. In fact, many of the following arguments can also be applied to solar thermal (water heating for use in peak and non-peak electricity demand periods). It is only our objective to elevate

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[2] There are numerous examples of voluntary green electricity marketing programs by Energy Providers throughout the U.S. For more information visit our website at http://www.treepower.org/green-e/main.html.

perceptions (based on sound science and engineering) of co-firing biomass fuel at existing electricity power plants equal to that of other renewable energy technologies.

Objectives of Paper: While NOx, Mercury, and SO_2 emission issues will be addressed, the main objective of this paper is to establish a sound science/engineering based argument that:

As a Global Warming/Greenhouse Gas mitigation strategy, co-firing tree energy crop biomass at existing coal-fired power plants will achieve the ***greatest reduction*** *of any renewable energy resource option, as:*

- Electricity produced from biomass fuel is carbon cycle neutral -- just like the most advanced wind or solar energy technologies.
- However, unlike other renewable energy options, use of tree energy crop biomass also sequesters sizable amounts of carbon (e.g., a sustainable long-term storing) through the trees' root system.
- Co-firing energy crop biomass fuel in base load power plants directly displaces/reduces coal use, which can achieve more than two times the Greenhouse gas reduction benefit of placing wind or solar power facilities on an integrated electricity power grid.

Empirical Research on Below ground Carbon Sequestration of Tree Energy Crops: In 2001, as a collaborative research effort between Common Purpose and the University of Florida's (UF) School of Forest Resources/Institute of Food and Agriculture Sciences (IFAS), 14 month-old whole eucalyptus trees were excavated and weighed at the Common Purpose/ UF Energy Crop Research Demonstration Plantation, located in Lakeland. The trees averaged ~20 feet in height, and had ~ 3 inch trunk diameters at their base. The procedure used a Caterpillar back-hoe to excavate whole trees including their root system.

Above and Below Ground Tree Weight

Component of Whole Tree:	Kilograms	Pounds	Percent
Stem Mass	16.85	37.07	
Leaf Mass	6.65	14.63	
Branch Mass	4.85	10.67	
Total Above Ground Mass	28.35	62.37	61.55%
Main Root Mass	16.55	36.41	
Feather/Small Root Mass[3]	1.16	2.55	
Total Root Mass	17.71	38.96	38.45%
Total Whole Tree Mass	46.06	100.33	100%

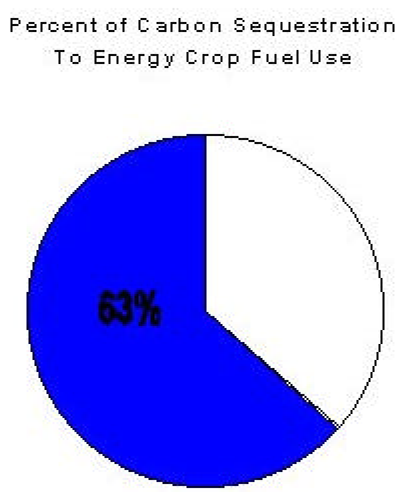
[3] In excavating trees, small feather roots were left in the ground. According to University of Florida Scientists, approximately 7 to 10% of a tree's total root system is comprised of small feather roots.

Significance of University of Florida Findings: While the overwhelming "main-stream" scientific research concludes that that the combustion of biomass fuels (e.g., in our case, the harvested above ground mass of energy crop trees) is carbon cycle neutral, our research clearly shows that this does not tell the complete story. In using harvested energy crop trees as fuel at electricity generation power plants, an additional benefit occurs at the agriculture source of the trees -- through long-term carbon sequestration below ground.

The overall "net impact on carbon emissions" of using tree energy crops can be illustrated in the following formula:

Energy Crop Carbon Component:	**CO_2 Emissions Impact:**
Carbon Released in Fuel Combustion	Increase (+)
Minus, Carbon Stored in Tree Fuel	Decrease (-)
Equals, Fuel Carbon Cycle Neutrality	Net of Zero (0)
Minus, Carbon Stored Below Ground	Overall Net Reduction (-)

To estimate the amount of below ground sequestration that will occur through tree energy crop use, we can take the above University of Florida measurements -- dividing the percent of below ground weight of whole trees (i.e., 38.45%) by the percent of above ground weight (i.e., 61.55%). By doing this simple math, we can estimate that for every 100 green tons of energy crop fuel harvested (i.e., the above ground mass of the trees), that approximately 63 green tons of biomass will be sequestered below ground.



Conversion of Tree Weights to Carbon Sequestration and CO_2 Reductions: Based on a fuels analysis performed by SRI (a research unit of the Southern Company) on our energy crop trees, the percent carbon content in green (as received) tree fuel is ~25%. A final step is to use the molecular weights of Carbon and O_2 to calculate the Carbon to CO_2 conversion factor of 3.6667.[4]

Example Calculation of Carbon Sequestration & CO_2 Reductions Through Tree Energy Crop Fuel Use

Component:	Tons	Notes:
Harvested Energy Crop Weight	100	(in green tons)
Trees' Root System Weight	63	(in green tons)
Ground Carbon Sequestration	16	(25%, by green weight)
CO_2 Reductions	58	(3.67x conversion factor)

Thus, based on the empirical research performed by the University of Florida, for every 100 green tons of tree energy crop fuel used, 58 tons of CO_2 emissions reductions would occur as a result of the agriculture source carbon sequestration.

Sustainable Agriculture and Short Rotation Woody Biomass Crops: Within the Agri-Forestry Industry, energy crop trees are technically described as "short rotation woody crops" (SRWC). Understanding the basis of this technical description is a key point in all sustainability and carbon sequestration arguments presented in this paper.

Energy crop trees are fast growing species of trees (with growth of up to 20 feet in height a year) such as cottonwoods, willows, and eucalyptus, which **re-grow** (called "coppice") **from their stump after harvest**. Because of their fast growth and ability to coppice, these tree species can be repeatedly harvested on short crop rotations of every 2 to 5 years without having to replant. In fact, the fastest growth (and highest crop yields per acre) will occur **after** the trees are first harvested, since their root system will be already established. This ability of tree energy crops to coppice provides the scientific basis that co-firing SRWCs is a sustainable renewable energy option.

It is important to note that while the high growth yields of energy crop trees are the result of decades of scientific research within the Agri-Forestry Industry and Universities (such as IFAS at the University of Florida), propagation techniques to achieve these high yields **have not included** the use of GMO genetic engineering.[5]

Long-Term Sustainability of Tree Energy Crop Carbon Sequestration: It is well established in atmospheric sciences that soils can store only a given maximum level of organic carbon. At this maximum saturation point, the soil carbon will reach an equilibrium with the atmosphere and be returning as much carbon as it is taking in. However, the length of time it would take for any ecosystem to reach a maximum saturation level of carbon is highly dependent on a myriad of site specific factors such as initial soil quality, carbon content, sand, silt, clay content, climate, and rainfall. According

[4] The molecular weight of Carbon to CO_2 ($C + O_2 = CO_2$) equals 12 lbs. of carbon + 32 lbs. of O_2 = 44 lbs. of CO_2. Dividing 44 lbs. of CO_2 by 12 lbs. of Carbon, results in a Carbon to CO_2 conversion factor of 3.6667.

[5] Currently, there are only two commercial size energy crop plantations in the U.S. (1) The University of Florida/Common Purpose project; (2) the Antares Group/State University of New York (SUNY) project. The above representation of non use of GMO genetic engineering techniques can only apply to what we are aware of, which are these two projects.

to Ranney et al.[6] and other empirical studies, estimates for the length of time before the saturation effect occurs on short rotation woody biomass crop sites may be 75 to 100 years. We often hear the misperception that the carbon sequestration effect of growing tree energy crops is temporary. Such a belief is clearly not based on established sound science. Although the maximum carbon level for any site is fixed, when carbon is stored in the ground it will stay there. It is just that forestry management practices can be implemented for perhaps 75 to 100 years before a maximum saturation level is realized. After this point, the site will be in equilibrium.

Thus, all carbon sequestration that raises initial site organic carbon levels to the fixed saturation point is permanent. This point is especially relevant to environmentally damaged lands, such as growing tree energy crops on thousands of acres of closed phosphate mining sites in central Florida. Prior to phosphate mining, these sites were in various stages of native habitat/ecosystems for thousands of years (probably reaching a carbon saturation equilibrium). After the cessation of mining activities, the soils had been altered from "native soils" to a soil type heavy in phosphatic clays. In excavation work at the Common Purpose/UF Energy Crop Research Demonstration Plantation in Lakeland, we have seen that these clays reach depths of up to 60 feet until original "native soils" are present. At such depths, the original soils can provide no benefit to growing trees or any other vegetation because of the anaerobic conditions.

As a result of changing the soil type from mining activities, these sites have been overtaken by cogongrass (according to the U.S. Department of Agriculture, one of the most highly invasive, non-native noxious weed in the world) -- creating a prairie of weeds where native hammocks existed prior to mining. One of the surprising soil condition observations at the Common Purpose/UF tree plantation is that even though phosphate mining activities ceased over 50 years ago, there has been almost non-existent organic buildup in the heavy clay soils over this period.

Thus, by growing energy crop trees on environmentally damaged lands, in addition to fuel use air quality issues, significant remediation benefits also will occur -- where energy crop trees can perform the role of a "bridge crop", increasing soil organics to support permanent native ecosystem restoration.

<u>Safeguarding Against Potential Environmental Harm</u>: In developing Green-e Accreditation Standards for renewable energy products in Florida (a voluntary green energy pricing program), the Center for Resource Solutions (CRS) has developed several excellent safeguards to protect against potential environmental harm from energy crop use. In order for **any** energy crop to be included in the Green-e Program, the potential crop must undergo an independent evaluation by the University of Florida's Institute for Food and Agriculture Sciences (IFAS) to insure the following:

- No GMO genetic engineering was performed on the crop.
- No non-native plant species that is **invasive** is allowed.
- Agriculture practices must follow "best practices", especially with water use.

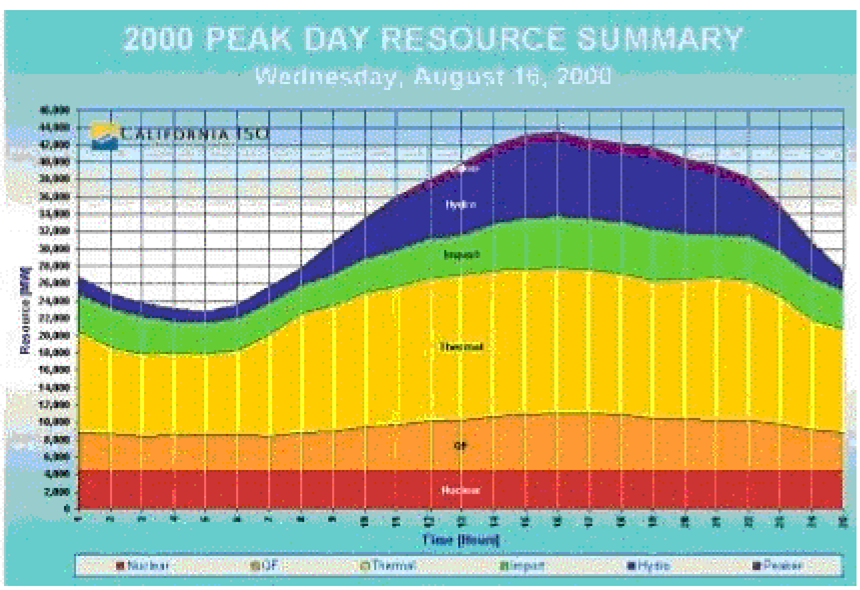
[6] "The Potential Impacts of Short-Rotation Woody Crops on Carbon Conservation; Wright et al., p. 142.

The CRS Florida Green Accreditation Program should be applauded for its use of “sound science” in developing its Standards – providing a roadmap that hopefully other Green Pricing Programs, Regulatory Agencies, and Lawmakers will follow (e.g., in developing renewable energy programs like Renewable Portfolio Standards and/or Public Benefits Funds). Dealing with emotionally charged environmental issues and widely held public misperceptions is clearly not an easy task.

An example of this is the use of non-native plants (called exotics) – where public perception believes that the terms “exotic” and “invasive” are synonymous terms, when in reality they are not. Just because a plant is “exotic” (not existing at the time of first European settlement) does not mean that it is harmful.[7] In Florida, perhaps the best example of this is the citrus industry, where the origin of citrus trees is from northern Africa.

By following “sound science”, the CRS Green Accreditation Program allows for the use of exotic/non-native energy crop trees (such as eucalyptus trees, originating from Australia) – if an independent scientific review by IFAS determines that the plant species **will not be invasive**.

Understanding the “Basics” of Electricity Grid System and Air Emissions: The below graph illustrates the concept of how electricity providers dispatch their power plants to meet demand of their customers. While the graphs' data is from California, the "bell type shape" of electricity demand is representative of most "load shapes" for Utilities throughout the U.S. (e.g., lower demand at night, increasingly higher demands for electricity during the day).



While nuances exist with each Utility to meet electricity demand, generally, a Utility decides on which power plant to dispatch/run based on a unit's marginal cash operating cost. Power Plants are generally ranked into three categories of (1) Base-load units which have the lowest operating costs; (2) Intermediate-load units; and (3) Peaking-load

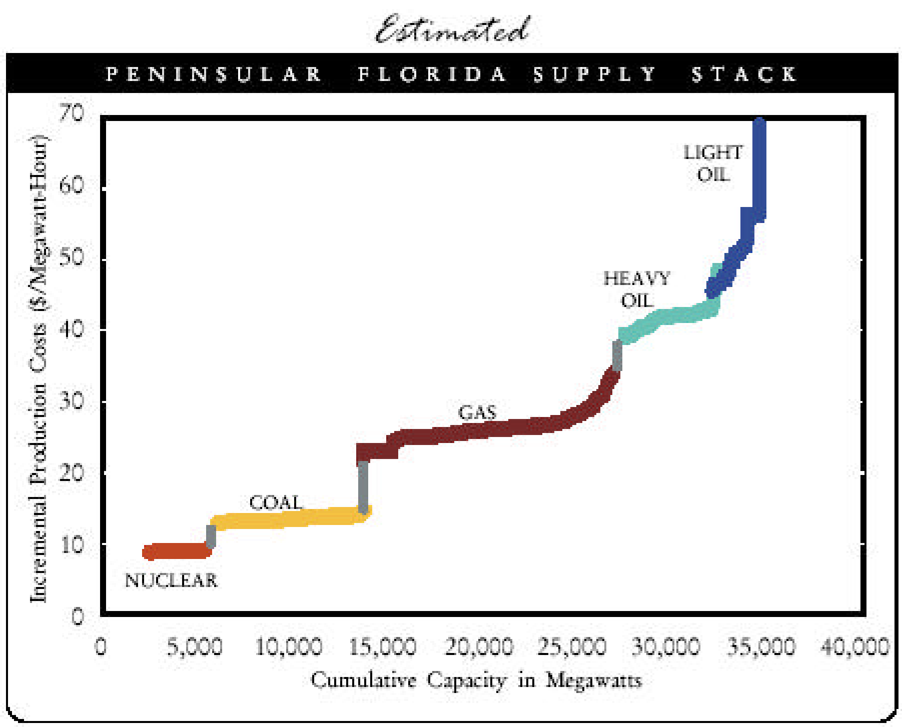
[7] According to the University of Florida, approximately 98% of everything we eat in the United States comes from “exotic” plants.

units which have the highest operating costs (but with fast start-up, are very flexible in generating electricity to the grid quickly).

FUEL COSTS BY PLANT TYPE

	FUEL ($mmbtu)	HEAT RATE (btu/KWH)	COST ($/MWH)
Nuclear	$ 0.42	11,000	$ 4.62
Coal	$ 2.00	10,000	$ 20.00
Natural Gas	$ 3.50	7,500	$ 26.25
Heavy Oil	$ 4.00	10,000	$ 40.00
Light Oil	$ 4.50	14,000	$ 63.00

In the above chart, the first column reflects an example of fuel costs in Florida based on a dollar-per-million British Thermal Units (BTU) basis.[8] The heat rate shown in the second column is a measure of efficiency – the amount of heat needed to produce a given amount of electricity. A lower heat rate implies a higher efficiency. A more efficient plant requires fewer BTUs to produce a given megawatt-hour (MWh) of electricity. The third column is the production cost in dollars per MWh. Thus, fuel costs depend on the cost of fuel and plant efficiency. Nuclear for example, is about $4.62 per MWh while coal is $20 per MWh, and a combustion turbine running on a peak period day could have fuel costs of $63 or higher per MWh.



The above supply stack diagram illustrates how energy production costs determine which fuel and type of generation are deployed to serve customers. The bottom of the chart reflects the amount of energy demanded in Florida on any given day (assuming that cost of

[8] The above table list the type of plants operating in Florida with estimates of their average fuel costs and typical heat rates. Because of fluctuating fuel prices, these figures are for illustration purposes only. (Florida Energy 20/20 Study Commission, December 2001, p. 27).

production is the sole determinant of deployment), ranging from near zero demand up to 40,000 megawatts, where demand of 35,000 megawatts would be a peak summer or peak winter day. On the left axis is the cost per megawatt hour from the previous diagram. In Florida, because of the low fuel costs, nuclear and coal-fired plants are dispatched first. As load increases, different gas-fired plants are dispatched, then heavy oil, and finally combustion turbines, which are the least efficient and burn the most expensive fuel. On the hottest or coldest days, incremental fuel cost rise to $60 or higher. This diagram is called the economic dispatch, and all utilities that own generation perform this function.

In this economic dispatch, large coal-fired and nuclear power plants are very representative of base-load units, and are dispatched/run at high capacity factors (~60 to 80%). For example, a base-load unit may run 24 hours a day for the entire year except for times when maintenance is being performed on the unit. Conversely, smaller MW peaking-load units such as a natural gas fired combustion turbine will have lower capacity factors (sometimes running only a few hours a year to meet summertime air-conditioning peak demand).

Paradigm/Model of Electricity Generation and the Environment: Understanding load shapes, how power plants are dispatched to meet demand, and how Power Providers plan new generation capacity additions is extremely important in understanding the paradigm/model of "electricity generation and the environment", where:

- Biomass co-firing will directly reduce/displace fossil fuel use from high capacity factor, base-load power plants. With co-firing in Florida, the fuel displaced will overwhelmingly be coal, which typically has higher emission levels of NOx, SO_2 and CO_2 than peaking or intermediate-load natural gas fired units.
- Generally, renewable energy generation facilities such as wind or solar PV have capacity factors of ~30-35% as a result of natural resource limitations (e.g., sunlight, wind speeds) – producing electricity/energy primarily during day-light hours.
- Implementing small amounts (in KWs) of renewable energy electricity technologies (in Florida, primarily solar) will not generally displace generation from large MW base-load units, but rather displace existing generation from smaller natural gas fired peaking and intermediate-load units (i.e., combustion turbines, combined cycle) in the dispatching of power plant resources to meet demand.
- Also, recognizing the reality that the overwhelming majority of new power plant construction is peaking and combined cycle units, placing in-service new wind or solar facilities will displace or reduce in size, the amount of new natural gas-fired capacity built to meet demand (often referred to as “avoided capacity additions”).
- Under Federal and Florida Environmental Law, while older coal-fired power plants are “grand-fathered” for air quality requirements, all new power plants (primarily natural gas units) are required to implement “best available control technology” (BACT) for air emissions.

As the below data from the Electric Power Research Institute (EPRI) reflects, the amount of fossil carbon emissions avoided on an integrated grid by using a renewable resource depends on the combination of:

- The fossil fuel type that is “avoided”.
- The efficiency of the technology that would have been used to make the electricity.

As previously discussed, the efficiency of power plant technology is measured by the unit's heat rate (i.e., the amount of Btus required to produce 1 KWh of electricity). For example, the higher a unit's heat rate, the **lower** its efficiency will be. Conversely, the lower a unit's heat rate, the higher its efficiency (using less fossil fuel and producing less air emissions of CO_2, NOx, and SO_2 to generate1 KWh of electricity).

Fuel Effect on Fossil Carbon Intensity

Type of Fossil Fuel	Heat Content -- (Btu/lb.)[9]	Carbon Content – (lb.-C/lb.)	Fossil Carbon Intensity (lb.-C/Mbtu)
Coal	13,700	.78	56.9
Oil	18,000	.85	47.2
Natural Gas	23,800	.76	31.9

Technology Effect on Fossil Carbon Intensity

Power Plant Technology:	Carbon Content (lb/Mbtu)	Heat Rate (Btu/KWh)	CO_2 Emissions (ton/MWh)	CO_2 Benefit of Displacing Coal vs. Natural Gas
Coal (typical existing unit)	56.9	10,000	1.04	
Adv. Combined Cycle	31.9	6,350	0.37	2.8X
Adv. Combustion Turbine	31.9	8,000	0.47	2.2X

Thus, as the above EPRI data reflects, co-firing biomass to displace/reduce coal use would achieve CO_2 reduction benefits over two times that of wind or solar resources that displaced advanced natural gas combustion turbines or combined cycle units.[10]

Combining the Effects of Coal Displacement and Soil Sequestration: By using EPRI (fuel and technology) and University of Florida (below ground sequestration) empirical data[11], we can combine these data sources to reflect the total CO_2 emissions that could be displaced by co-firing energy crop tree fuel in coal-fired power plants:

Combined CO_2 Effect of Technology and Sequestration

Power Plant Technology:	CO_2 Below Ground Sequestration (ton/MWh)	CO_2 Technology Emissions (ton/MWh)	Combined CO_2 Emissions (ton/MWh)	CO_2 Co-Firing Benefit vs. Displacing Natural Gas
Coal (typical existing unit)	0.64	1.04	1.68	
Adv. Combined Cycle	-	0.37	0.37	4.5X
Adv. Combustion Turbine	-	0.47	0.47	3.6X

However, we need to emphasize that the University Florida data for below ground carbon sequestration reflects **only** a one-point-in-time estimate. Clearly, additional research is needed to fully understand the dynamics of tree energy crop soil carbon sequestration not only through time on un-cut trees, but the effects of coppice when tree energy crops are

[9] Higher Heating Value, HHV.

[10] Avoided coal use CO_2 emissions of 1.04 tons/MWh divided by avoided natural gas use CO_2 emissions of 0.37 tons/MWh for advanced combined cycle units, equals 2.8 times; using the same methodology for advance combustion turbines with CO_2 emissions of 0.47 results in a multiplier of 2.2 times.

[11] See Appendix 1.

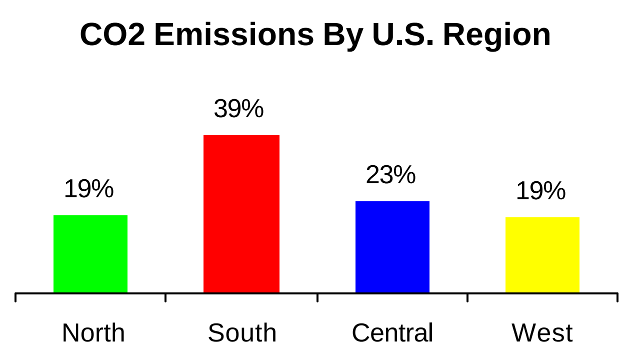
harvested and re-grow from the stump. Research performed by Misra[12] et al. on 34 month eucalyptus trees (E. nitens) indicates that growth in root system mass increases in a non-linear relationship with above ground tree mass through time. Consequently, while total root biomass increases as trees age, above ground biomass increases more rapidly, resulting in a decreasing ratio of below ground mass to total tree mass. However, as Misra et al. acknowledge in their research on fertile soils, tree growth dynamics can vary widely depending on site specific conditions – where total root mass tends to be more in non-fertile soils as found on the Common Purpose/UF 140 acre research plantation in Lakeland (an environmentally damaged, closed phosphate mining clay settling pond).

In U.S. Department of Energy sponsored research by Birdsey and Ranney et al.[13], generalized forestry data assumptions were used to develop a carbon sequestration model of growing short rotation woody crops on typical cropland in North Carolina. While we would not consider this to be solid empirical scientific research, model results showed that the net carbon sequestered in trees and soil would increase the benefits of coal displacement by 23%. Combining the previous EPRI data (fuel and technology) with DOE model derived estimates of tree energy crop carbon sequestration (instead of the single point UF measurements) results in the following:

Combined CO_2 Effect of Technology and Sequestration

Power Plant Technology:	CO_2 Below Ground Sequestration (ton/MWh)	CO_2 Technology Emissions (ton/MWh)	Combined CO_2 Emissions (ton/MWh)	CO_2 Co-Firing Benefit vs. Displacing Natural Gas
Coal (typical existing unit)	0.24	1.04	1.28	
Adv. Combined Cycle	-	0.37	0.37	3.5X
Adv. Combustion Turbine	-	0.47	0.47	2.7X

Global Warming and the Southeastern U.S.: While it is widely known that the U.S. is the largest contributor to greenhouse gas emissions globally, we doubt that the General Public recognizes the magnitude of South's role in total U.S. emissions[14]:



[12] Forest Ecology and Management 106 (1998); pp. 283-293 for 34 month old eucalyptus nitens averaging 6.3 m tall and 8.5 cm stump diameter (slightly smaller than our 14 month eucalyptus grandis).
[13] "The Potential Impacts of Short-Rotation Woody Crops on Carbon Conservation; Wright et al., p. 142.
[14] U.S. Environmental Protection Agency: http://yosemite.epa.gov/globalwarming/ghg.nsf/emissions/CO2EmissionsBasedOnStateEnergyData?OpenDocument&Start=1

The tremendous global responsibility of the South in addressing greenhouse gases becomes even clearer when comparing the Region's CO_2 emissions to other whole countries, where Southern States' emissions are[15]:

- Approximately 70% of China's (the 2nd largest Global Contributor)
- Comparable to Russia and its former States (the 3rd largest Global Contributor)
- Greater than Japan and Germany combined (the 4th and 5th largest Global Contributors)

SO_2, Mercury, and NOx Benefits Associated with Biomass Co-firing: In the combustion science of power generation, there is a relative straight-line correlation between sulfur content of the fuel and SO_2 formation (i.e., the higher the sulfur content, the higher SO_2 emissions will be to the Stack). This straight-line correlation also is applicable to Mercury (Hg) emissions. Thus, since biomass fuels contain almost no sulfur or mercury, the acid rain (SO_2) and water quality (Hg) environmental benefits resulting from biomass co-firing are very comparable to zero pollutant emission technologies such as wind or solar.

Although typical biomass fuels have ~50% the nitrogen content of most coals, NOx formation (leading to smog creation) is a more complex issue than SO_2 or Hg to understand. Unlike the relatively straight-line relationship between the sulfur content in coal and the level of SO_2 emissions, NOx formation is a result of two variables: **Fuel NOx** and **Thermal NOx**.

NOx formation during the combustion process occurs mainly through the oxidation of nitrogen in the combustion air (thermal NOx) and nitrogen bound in the fuel matrix (fuel NOx). Thermal NOx formation during the combustion process can be suppressed by reducing flame temperatures (such as co-firing higher moisture biomass fuels) and limiting oxygen concentration. Fuel NOx formation is a more complex process involving local concentration of oxygen and nitrogen and is reduced by minimizing the availability of oxygen during the early stages of the combustion process. Combustion zone geometry is particularly important, with higher heat release rates and shorter residence times all contributing to higher NOx levels. For example, Utility boilers are far from isothermal, and adding biomass to a pulverized coal-fired boiler can significantly change the flame structure and characteristics.

Since NOx formation is a complex and highly technical subject, some engineering liberties will be taken in order to explain in laymen terms, why biomass co-firing has the potential (not a guarantee) to be such an effective NOx reduction strategy. Through numerous U.S. Department of Energy sponsored test burns at coal-fired power plants, the introduction of biomass fuel has been shown to reduce NOx emissions **usually well beyond** the reductions expected from just the lower nitrogen content of biomass versus coal.

By using NOx stack emission rates from biomass co-firing test burns at Tampa Electric's Gannon Generation Station[16] (coal-fired cyclone units) – again. using some engineering liberties – we will attempt to illustrate this point in a way that hopefully, laymen (e.g.

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15 Oak Ridge National Laboratory: http://cdiac.esd.ornl.gov/ftp/ndp030/nation98.ems

16 All Stack emissions associated with biomass co-firing test burns at Gannon have been filed with the Florida Department of Environmental Protection, and are public record.

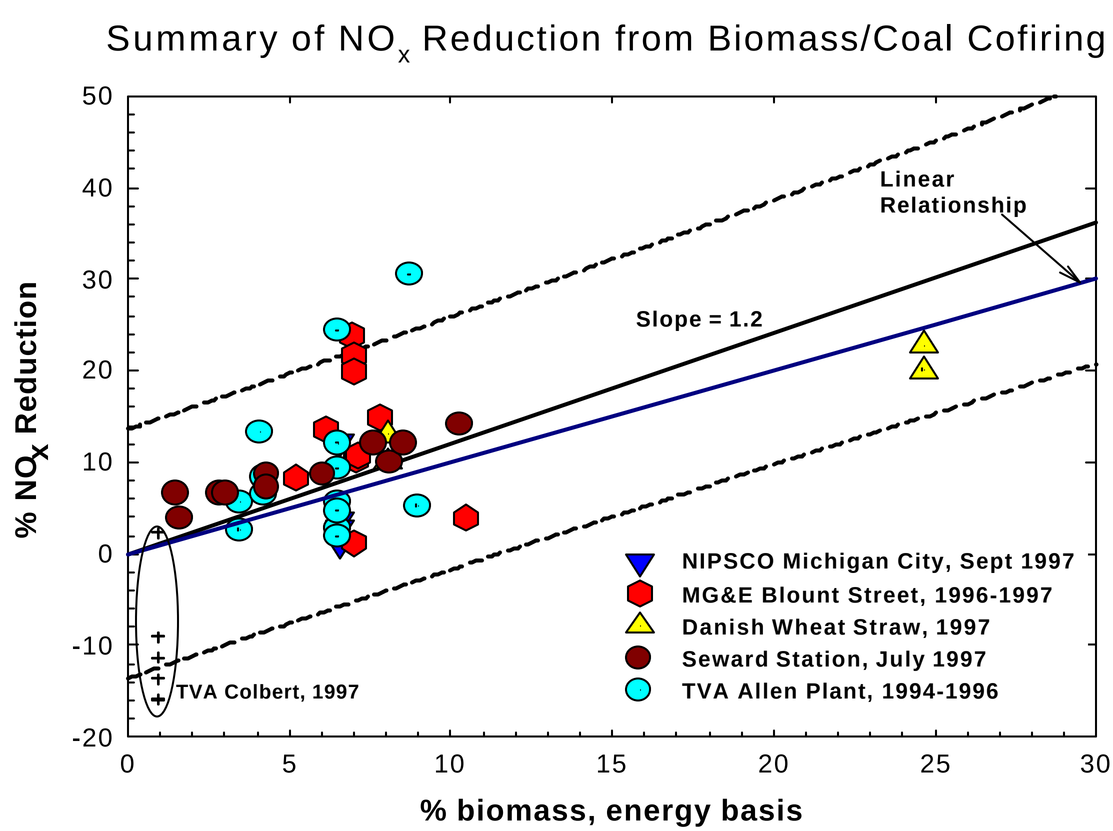
environmental organizations, policymakers, etc.) will understand. In one series of test burns at Gannon where the biomass co-firing percentage was ~2.5% by generation (e.g., 98.5% coal, 2.5% biomass), NOx emission rates were:

Gannon Generation Station Cases:	Coal Percentage (by generation)	Biomass Percentage (by generation)	Lbs. NOx/ MMBTU
Control Base Case	100%	0%	.767
Co-Firing Case	~97.5%	~2.5%	.715
NOx Reduction			(.0328)
% NOx Reduction			~7%

For layman illustration purposes only, if we assumed:

- The biomass fuel's nitrogen content was 50% of coal.
- NOx formation operated in the same relatively straight-line relationship as between sulfur content and SO_2.
- We would **expect** at a co-firing rate of 2.5%, NOx emissions to be **reduced 1.25%**.
- Another way to look at this would be if 2.5% of Gannon's electricity output were replaced with zero emission wind or solar facilities, then "Net" NOx" emissions would be reduced by 2.5%.

But the Gannon Unit's actual NOx emission rate did not decrease just by 1.25%, the **decrease was almost 7%.** As the following graphic illustrates, this "NOx Reduction Multiplier" effect is not unique only to Gannon, but has been experienced in other U.S. Department of Energy sponsored biomass co-firing test burns at coal-fired power plants.



In layman's terms, this "NOx Reduction Multiplier" illustrates the potential significance of **thermal NOx**, where:

- NOx emissions can be reduced on the "biomass co-firing component" (e.g., Gannon's 2.5% rate) by substituting lower nitrogen content biomass fuel for coal (Fuel NOx).
- But, by co-firing higher moisture content fuel (where green biomass fuel typically has 50% moisture content), **NOx emission levels for the entire power plant can be reduced** as a result of lowering the flame temperatures within the combustion zone.

However, it can not be emphasized enough how power plant specific NOx formation is (e.g., combustion zone geometry, etc), and even within the same power plant how the impact of biomass co-firing's effect on NOx emissions can vary widely (i.e., based on different operating conditions, such as the level of co-firing). This last point is illustrated in the previous graphic, where, under certain operating conditions, biomass co-firing actually increased NOx emissions. Clearly, with biomass co-firing and NOx emissions there is not a "One Rule Fits All".

<u>The Need for Pragmatic Examples:</u> In efforts to build broad-based public support from local to national levels, we believe that advocates of biomass co-firing need to be much more effective in communicating the "whys" in ways that general, non-technical audiences can relate to. For example, recognizing the tremendous size of power plants (in MW's) where biomass co-firing would likely occur (base-load, high capacity factor, coal fired units), relatively small percentages of biomass fuel use can result in a very significant renewable energy resource.

As the following table illustrates, co-firing only 3% (by generation) of biomass fuel at one medium size 250 MW base-load unit (like Tampa Electric's Polk Power Station) would generate the same amount of renewable energy of 20,000 relatively large (1 KW) solar panels.

Size of Coal-Fired Unit:	250 MWs	Size of Solar Facility:	1 KW
Co-Firing % (generation):	3%		
Co-Firing Capacity:	7.5 MWs		
Assumed Capacity Factor:	80%	Assumed Capacity Factor:	30%
Yearly Unit Dispatch:	7,008 hours	Yearly Unit Dispatch	2,628 hours
Yearly Mwh Generation:	52,560 Mwhs	Yearly Mwh Generation	2.628 Mwhs
		Needed 1 KW Solar Units:	20,000

The significance of the above illustration becomes even more dramatic by recognizing that the entire state of California (which leads the U.S. in the development of solar energy) only has ~10,000 KWs of installed solar capacity.

Another way to effectively communicate with the general public is to compare energy crop biomass use to CO_2 emissions from automobiles. Using the methodology shown in Appendix 2 (utilizing automobile data supplied by the Union of Concerned Scientists) – a 3% (by generation) energy crop co-firing program at Tampa Electric's 250 MW Polk Power Station would achieve the CO_2 reduction equivalent of removing over 17,000 automobiles off the road.

Conclusions: The goal of this Paper is to challenge Key Interest Groups (e.g., Policymakers, Environmental Organizations) to ***get involved*** in understanding how the paradigm of "electricity generation and the environment" truly works. Key Interest Groups must not abrogate this responsibility, especially through a common practice of turning to economic models that provide "answers" consistent with one's ideology. An example that illustrates this point is the (1) Renewable Energy Policy Project's (REPP) Paper on "Powering the South" and the Cato Institute's Paper "Evaluating the Case for Renewable Energy - Is Government Support Warranted?"[17]

Considering that REPP is a renewable energy advocacy group and the Cato Institute is a very politically conservative "think-tank", it should not be surprising that these two studies (involving complex economic modeling by highly prestigious authors) come to completely opposite conclusions. So who is right? The answer is they both are – given the data assumptions underlying the respective economic analysis. Herein lies the problem with using long range, or life-cycle economic modeling. It has been our experience that once all the layers of complexities are peeled away, the overall conclusions of any economic modeling analysis on renewable energy comes down to basically one assumption: Over the next 20, 30, 40 years, what will be the price of oil, natural gas, or coal? Under higher cost fossil fuels scenarios, renewable energy will be shown to be economic. Under lower cost fossil fuels scenarios, renewable energy options be will be non-economic.

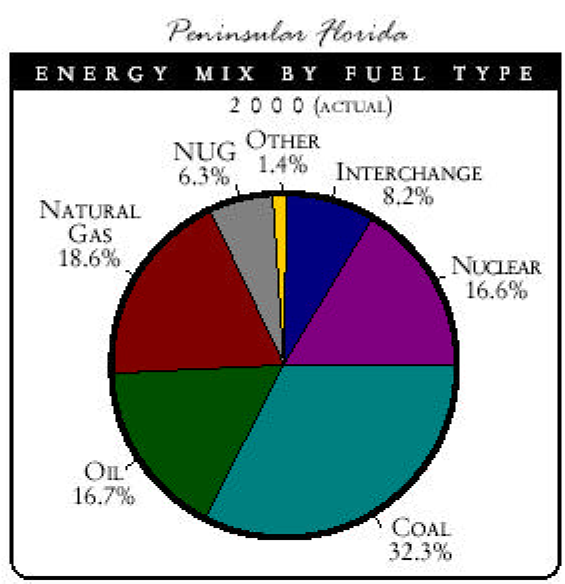
Recognizing historical precedence that a major influencing factor for the U.S. launching a major commitment to nuclear energy in the 1980's was economic projections that the price of oil would soon climb to $100 (where today, bottled water is more expensive than gasoline) – hopefully, one can understand our wariness of economic modeling.

In the Renewable Energy Debate for Florida (and other Southern States), it is hoped that Key Interest Groups will accept some basic and unquestionable facts:

- Coal-fired power plants **are and will continue** to represent a significant resource in providing Florida's energy needs (which is even greater than the graphic, as a majority of imported Interchange Power comes from coal-fired power plants).

- With continued "life extension" engineering advancements, coupled with Federal Regulatory initiatives being pursued by President Bush (e.g., NSPS), the time horizon of coal's significance may very well be extended even further.

- **"THE"** major impediment in developing renewable energy resources is costs.



[17] Both of the Papers are hyper-linked in this Microsoft Word document. However, the Renewable Energy Policy Project Paper can be assessed at http://www.poweringthesouth.org; and the Cato Institute's paper can be assessed at http://www.cato.org/pubs/pas/pa-422es.html.

Biomass co-firing directly addresses these "facts", by utilizing the existing infrastructure (i.e., boilers, turbine/generators, transmission) of Florida's vast resources of coal-fired power plants -- thus avoiding the high capital cost per KW of building new stand alone facilities (as exists with solar power).

We believe that in the debate over renewable energy, that Leaders must emerge; from unbiased State Public Service Commissions and Environmental Protection Agencies; from members within Environmental Organizations willing to replace hard-line ideologies with realities and facts; from Power Providers willing to look at renewable energy as a market opportunity rather than a threat; and from Policymakers willing and knowledgeable enough, to ask the tough questions.

Want More? For additional information on biomass co-firing and the use of energy tree crops, visit our webpage at http://www.treepower.org. Our latest public presentation to the Florida Public Service Commission's Renewable Energy Workshop (entitled, "Doing the Right Thing – For the Right Reasons") is also on the Internet at http://www.treepower.org/papers/FPSC-July2001.doc.

Appendix 1

Item:	EPRI & UF Data:	Notes:
Heat Rate of typical Coal Unit:	10,000 Btu/KWh	(Btus to produce 1 KWh)
Btus required to produce 1 MWh	10 MMBtus	(10 million Btus)
Energy Crop Fuel needed for 1 MWh	1.1 green tons	(4,500 Btus per green ton)
Equivalent CO2 sequestered:	0.64 tons/MWh	58% conversion factor[18]

[18] Page 4, Conversion of Tree Weights to Carbon Sequestration and CO_2 Reductions.

Appendix 2

Example Calculation Tampa Electric's Polk Power Station Unit 1

Step 1: Calculation of Coal Displaced.

(1) Capacity of Generating Station Unit (in KW)	250,000
(2) Capacity Factor Assumed For Unit (in percent)	80%
(3) Unit's Number Of Yearly Operating Hours	7,008
(4) Yearly KWH Produced At Unit	1,752000,000
(5) Heat Rate Of Unit (BTUs required to produce 1 KWH)	10,000
(6) Total Input MMBTUs For Unit	17,520,000
(7) BTU Content Of Coal Per Pound (as received)	12,000
(8) MMBTU Content Of Coal Per Ton	24
(9) Biomass Co-Firing Ratio For Unit (in percent, by generation)	3.00%
(10) MMBTU Coal Displacement	525,600
(11) Tons Of Coal Displaced Through Co-Firing	21,900

Step 2: Calculation of CO2 Reductions By Coal Displacement

(12) Carbon Content Of Coal (by weight, as received)	75%
(13) Tons Of Carbon Reduction By Co-Firing	16,425
(14) Molecular Weights Of Carbon To CO2	12 (C) +32 (02) =44 (CO2)
(15) CO2 Multiplier	3.67
(16) Tons Of CO2 Reduction	60,225

Step 3: Calculation Of Sequestered CO2 At Plantation Site Through Tree Root System

(17) MMBTUs of Biomass Needed to meet Co-firing Ratio	525,600
(18) BTU Content Of Energy Crop Fuel Per Pound (as received)	4,238
(19) MMBTU Content Of Energy Crop Fuel Per Ton (as received)	8.5
(20) Tons of Energy Crop Fuel Needed to be Harvested (green basis)	58,400
(21) Root System Weight to Above Ground Weight	67%
(22) Carbon Content of Energy Crops (by weight, as received)	24.91%
(23) Tons Of Carbon Sequestered in Root System	9,747
(24) CO2 Multiplier	3.67
(25) Tons of CO2 Sequestered in Root System	35,738

Step 4: Calculation Of Car Elimination Equivalent By Biomass Co-Firing Program

(26) Tons Of CO2 Reductions From Coal Displacement	60,225
(27) Tons Of CO2 Reductions from Root System Sequestration	35,738
(28) Total Tons Of CO2 Reduction from Energy Crop Co-firing	95,963
(29) Pounds Of CO2 Per Gallon Of Gasoline Combusted	20
(30) Miles Per Gallon Of Average Automobile	20
(31) Average Miles Traveled By Average Automobile	11,000
(32) Yearly Pounds Of CO2 From Average Auto	11,000
(33) Yearly Tons Of CO2 Emitted From Average Auto	5.5
(34) Equivalent # Autos Displaced By Energy Crop Co-firing	17,448

Estimated Percentage Of Automobile Displacement

Registered Vehicles In Polk Co.	341,212
Polk County Population Demographics	
Total For Polk County	465,858
Unincorporated Polk County	289,399
Incorporated Cities In Polk County	176,459
City Of Lakeland	77,113
Lakeland Pop/Incorporated Polk Co.	44%
Estimated Lakeland Unincorporated	126,468
Estimated Lakeland Population	
Incorporated	77,113
Un-Incorporated	126,468
Total	203,581
Lakeland To Total Polk County	44%
Estimated Vehicles In Lakeland	149,110
Car Equivalent Removal From Biomass	32,716
Percentage Of Cars Removed To Total	12%