Removing and Sequestering Atmospheric Carbon Using Trees

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Trees by Joyce Kilmer

I think that I shall never see
A poem lovely as a tree.

A tree whose hungry mouth is prest
Against the sweet earth's flowing breast;

A tree that looks at God all day,
And lifts her leafy arms to pray;

A tree that may in summer wear
A nest of robins in her hair;

Upon whose bosom snow has lain;
Who intimately lives with rain.

Poems are made by fools like me,
But only God can make a tree.

INTRODUCTION

In our evolutionary history, we lived in and among forests.

Then we began cutting trees and making our homes of wood.

More and more, we now live among concrete and asphalt deserts in homes constructed of less and less wood.

We, who consider ourselves to be the most intelligent of all beings, are slowly admitting to ourselves that we have made a terrible mistake by extracting fossil fuels from the Earth and burning them indiscriminately.

We can be partially forgiven for if we had not begun eating the Earth itself, we would have consumed all the trees on the planet by now and desertification would have run rampant.

Since 1945, we have understood that through nuclear war we could destroy much of life on Earth, including ourselves. Reinforcing this understanding was the remembrance by many that we had recently fought two world wars. Perhaps the immediacy of this possibility distracted us from understanding other long-term threats.

We did not admit to ourselves that our waste disposal actions could also threaten ourselves until the 1980s when we discovered that wasted Chlorofluorocarbons were causing depletion of the Ozone layer in the atmosphere.

Our scientists have warned for over a half-century that growing levels of Carbon Dioxide (CO2) in the atmosphere could cause heating of the Earth. We told ourselves that the level of CO2 was so low that small increases would not cause a significant effect.

Also, we did not wish to admit that emissions of CO2 were a threat because we had become so dependent the upon the luxuries in our lives that burning fossil fuels provided us. We had become blinded by <u>greed</u>.

Nearly all life on Earth is dependent upon photosynthesis. Plants, like trees, capture sunlight energy and use it to convert CO_2 and water (H_2O) into organic compounds. These organic materials are the source of food and energy for the plants themselves, animals, fungi, and bacteria.

In the equation for life, atmospheric CO_2 is the most limiting factor. Changing the CO_2 concentration is like pressing the <u>accelerator</u> in your car!

Scientists, engineers, and technologists have devoted great effort measuring the changing levels of atmospheric CO_2 and found it is rapidly increasing. Clearly the major reason for this increase is human waste generated while burning fossil fuels.

We have squandered many decades arguing against this evidence. Now we are experiencing world changing effects in climate, species distribution and destruction, disaster damages, and diseases.

It is too late to <u>only</u> reduce our dependence upon burning fossil fuels; we must also take actions to reduce CO2 levels in the atmosphere.

Our consumption of fossil fuels has accelerated for two centuries. There are many dreams of developing great machines to suck CO2 from the atmosphere and sequester within the Earth. Unfortunately, such ideas are impractical and could result in serious unintended results. Burning fossil fuel and releasing CO2 into the atmosphere is far easier and quicker than capturing and fixating CO2.

Humans take heart. We have an old ally who can help.

<u>Trees</u>.

WHY TREES?

Trees are long-lived compared to most of our agricultural crops such as grains and pastures. Trees are placed in a separate management field named silviculture. A large collection of living trees is called a forest.

Trees are a great recycler of Oxygen. To humans and most all other living organisms, Oxygen is an essential substance. The production of food is powered by sunlight, but living organisms are powered by oxidizing food. The concentration of Oxygen gas (O_2) in the atmosphere is 740 times greater than the concentration of CO_2 in the atmosphere. Sequestering Carbon in trees removes both CO_2 and O_2 from the atmosphere; however, the effect upon O_2 concentrations is miniscule.

As a tree grows, visible rings are formed within the wood of the trunk. These rings are particularly evident in trees growing in Temperate Regions. With careful and complicated analysis, the rings can be interpreted to show the growth history of the tree, including its age and periods of drought and other environmental factors.

A Bristlecone Pine in the Southwest USA has been estimated through interpretation of growth rings and radiocarbon dating to have lived for 8,500 years.

Tree growth varies between species. The character of soil and climate also control tree growth. Disease and pests can severely damage trees. Tornadoes, hurricanes, and fire can also significantly damage forests. Important environmental factors which humans may be able to control through management (silviculture) are exposure to sunlight, water, minerals, disasters, disease and pests.

This small group of Loblolly Pines planted as seedlings 40 years ago shows the effect of sunlight and disease.

The trees were planted in rows generally running in the South to North direction. The largest trunk-diameter tree is in the clearest, southern-most position. Moving along this row northward, each succeeding tree has a smaller trunk-diameter. The end tree has died. Today these trees are about 70 feet in height.

Silviculturists have been continuously developing better management practices for growing and harvesting timber. With the increasing concern for climate change, studies and estimates of Carbon sequestration by trees have been assembled.* The following graphs describe these estimates:

* USDA FOREST SERVICE, Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States, April 2006, http://www.fs.fed.us/ne

THE NITTY-GRITTY

The contiguous 48 states were divided into 10 forest regions.

Within each of these regions, forestland species-growth categories were defined as shown in the following slide.

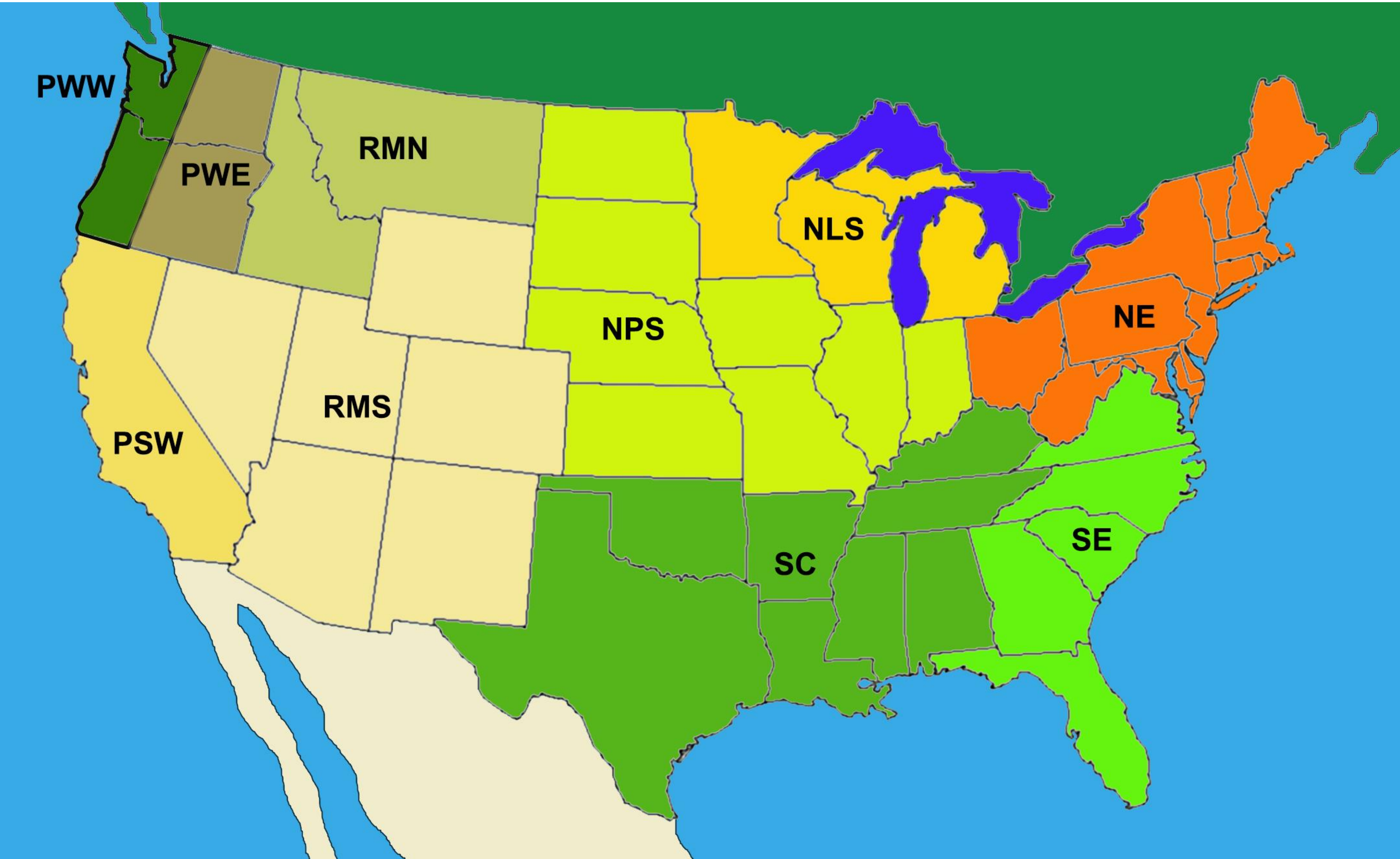
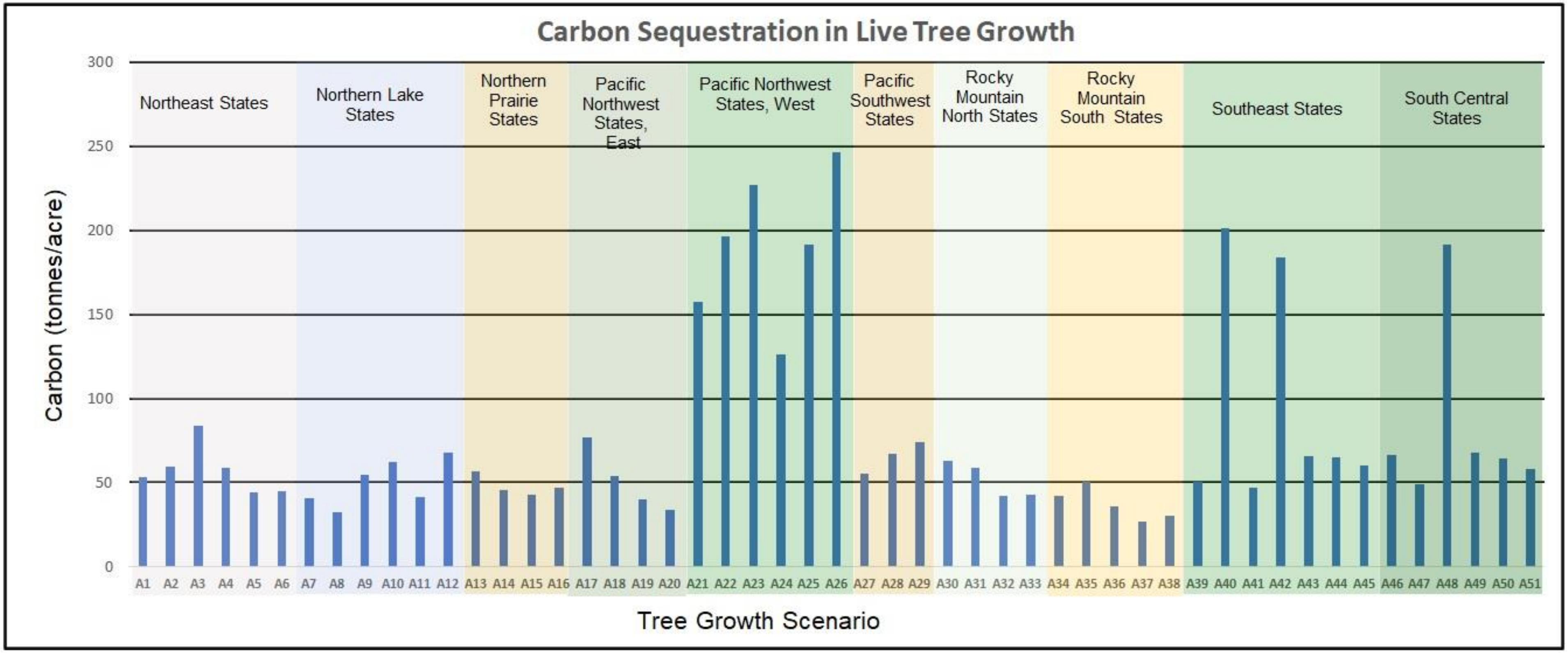


Table 2. Forestland Growth Categories

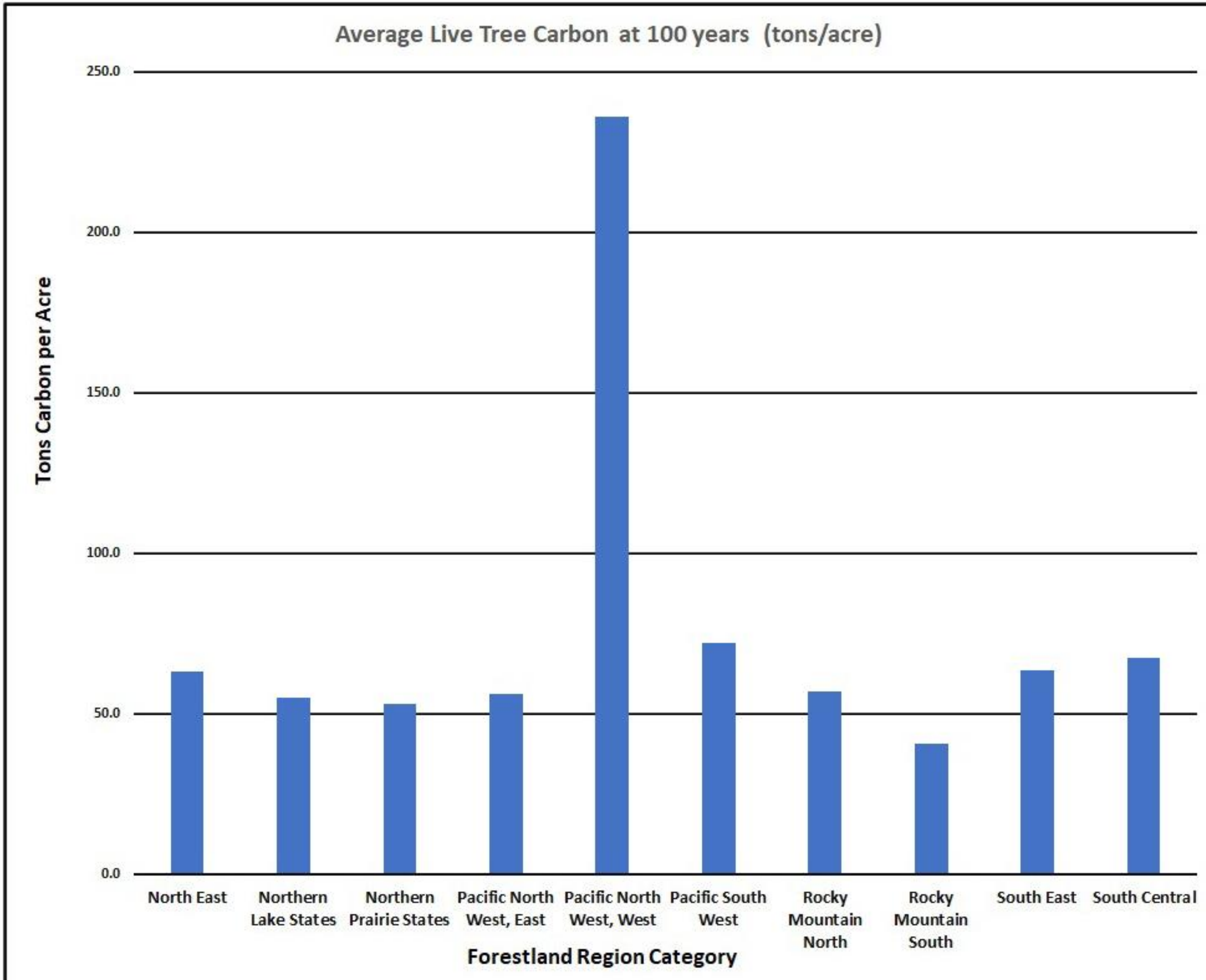
Category	Description	Category	Description
North East	A1. Aspen-birch, Northeast	Pacific South West	A27. Mixed conifer, Pacific Southwest
North East	A2. Maple-beech-birch, Northeast	Pacific South West	A28. Fir-spruce-mountain hemlock, Pacific Southwest
North East	A3. Oak-hickory, Northeast	Pacific South West	A29. Western oak, Pacific Southwest
North East	A4. Oak-pine, Northeast	Rocky Mountain North	A30. Douglas-fir, Rocky Mountain, North
North East	A5. Spruce-balsam fir, Northeast	Rocky Mountain North	A31. Fir-spruce-mountain hemlock, Rocky Mountain, North
North East	A6. White-red-jack pine, Northeast	Rocky Mountain North	A32. Lodgepole pine, Rocky Mountain, North
Northern Lake States	A7. Aspen-birch, Northern Lake States	Rocky Mountain North	A33. Ponderosa pine, Rocky Mountain, North
Northern Lake States	A8. Elm-ash-cottonwood, Northern Lake States	Rocky Mountain South	A34. Aspen-birch, Rocky Mountain, South
Northern Lake States	A9. Maple-beech-birch, Northern Lake States	Rocky Mountain South	A35. Douglas-fir, Rocky Mountain, South
Northern Lake States	A10. Oak-hickory, Northern Lake States	Rocky Mountain South	A36. Fir-spruce-mountain hemlock, Rocky Mountain, South
Northern Lake States	A11. Spruce-balsam fir, Northern Lake States	Rocky Mountain South	A37. Lodgepole pine, Rocky Mountain, South
Northern Lake States	A12. White-red-jack pine, Northern Lake States	Rocky Mountain South	A38. Ponderosa pine, Rocky Mountain, South
Northern Prairie States	A13. Elm-ash-cottonwood, Northern Prairie States	South East	A39. Loblolly-shortleaf pine, Southeast
Northern Prairie States	A14. Maple-beech-birch, Northern Prairie States	South East	A40. Loblolly-shortleaf pine, high productivity and management intensity, Southeast
Northern Prairie States	A15. Oak-hickory, Northern Prairie States	South East	A41. Longleaf-slash pine, Southeast
Northern Prairie States	A16. Oak-pine, Northern Prairie States	South East	A42. Longleaf-slash pine, high productivity and management intensity, Southeast
Pacific Northwest, East	A17. Douglas-fir, Pacific Northwest, East	South East	A43. Oak-gum-cypress, Southeast
Pacific Northwest, East	A18. Fir-spruce-mountain hemlock, Pacific Northwest, East	South East	A44. Oak-hickory, Southeast
Pacific Northwest, East	A19. Lodgepole pine, Pacific Northwest, East	South East	A45. Oak-pine, Southeast
Pacific Northwest, East	A20. Ponderosa pine, Pacific Northwest, East	South Central	A46. Elm-ash-cottonwood, South Central
Pacific Northwest, West	A21. Alder-maple, Pacific Northwest, West	South Central	A47. Loblolly-shortleaf pine, South Central
Pacific Northwest, West	A22. Douglas-fir, Pacific Northwest, West	South Central	A48. Loblolly-shortleaf pine, high productivity and management intensity, South Central
Pacific Northwest, West	A23. Douglas-fir, high productivity and high management intensity, Pacific Northwest, West	South Central	A49. Oak-gum-cypress, South Central
Pacific Northwest, West	A24. Fir-spruce-mountain hemlock, Pacific Pacific Northwest, West	South Central	A50. Oak-hickory, South Central
Pacific Northwest, West	A25. Hemlock-Sitka spruce, Pacific Pacific Northwest, West	South Central	A51. Oak-pine, South Central
Pacific Northwest, West	A26. Hemlock-Sitka spruce, high productivity, Pacific Northwest, West		



We will take a closer look at this data on the following slides:

There are 46 categories evaluated based upon allowing the trees to grow more or less naturally. Five of these natural categories have alternative categories using high productivity seedlings and intensive management. For all categories, the beginning point is clear-cut forestland planted with seedlings.

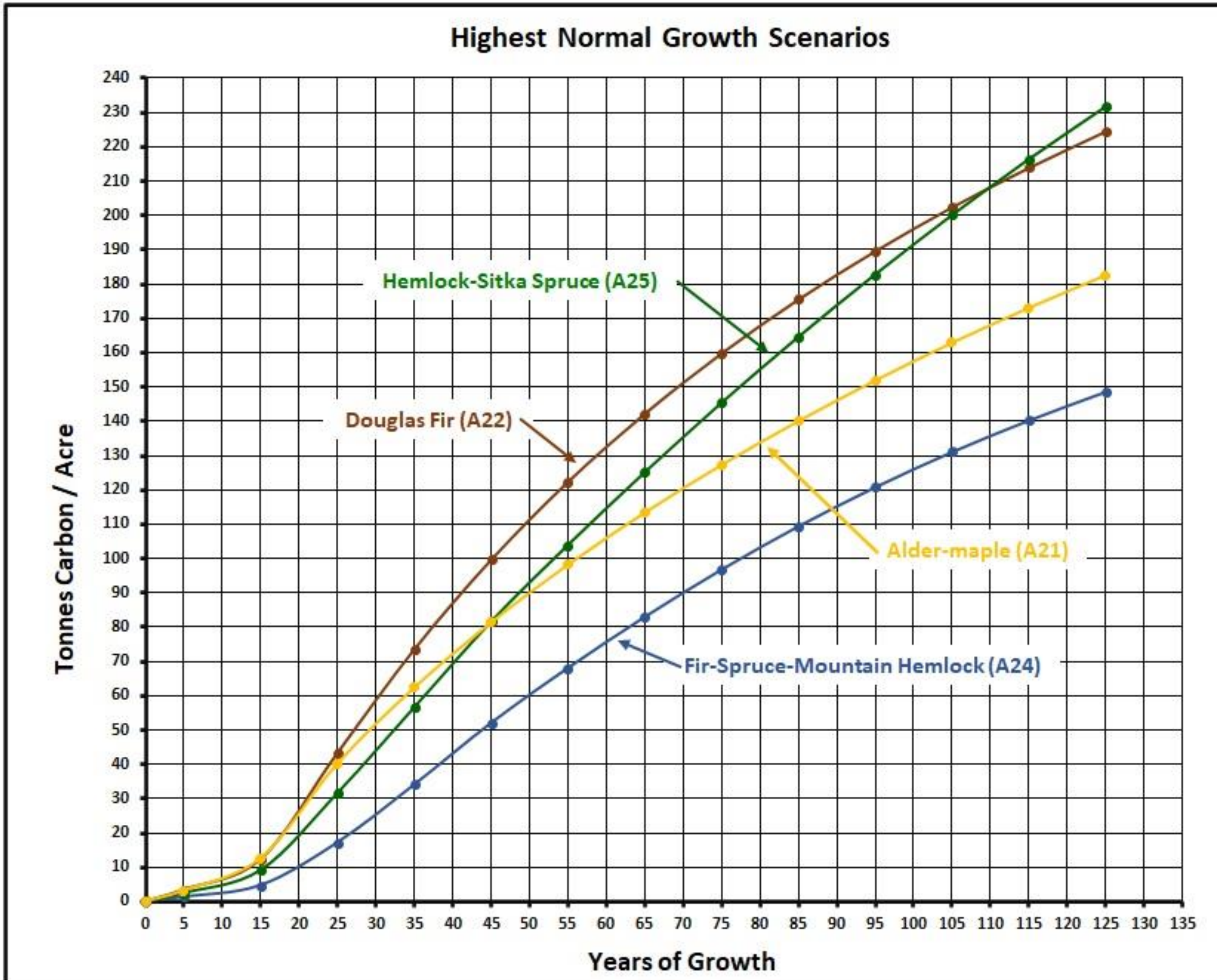
Notice in the next graph that one region stands head, shoulders, and waist above all others, the Pacific Northwest, West region.


Average Live Tree Carbon at 100 years (tons/acre)
250.0
200.0
150.0
100.0
50.0
0.0
Tons Carbon per Acre
North East
Northern Lake States
Northern Prairie States
Pacific North West, East
Pacific North West, West
Pacific South West
Rocky Mountain North
Rocky Mountain South
South East
South Central
Forestland Region Category

The Pacific Northwest, West region is a Temperate Rainforest. Winters are long and very wet. Summers are cool and drier; however, considerable moisture is supplied by fog. The forests have very large, evergreen trees which are long-lived. There are few fires and deadwood decays slowly.

The Pacific Northwest, West region is composed of the portions of Washington and Oregon from the Pacific Ocean through the western slope of the Cascade Mountains. The remainder of these states form the Pacific Northwest, East region which is much drier.

The next slide shows growth of forests in the Pacific Northwest, West region.



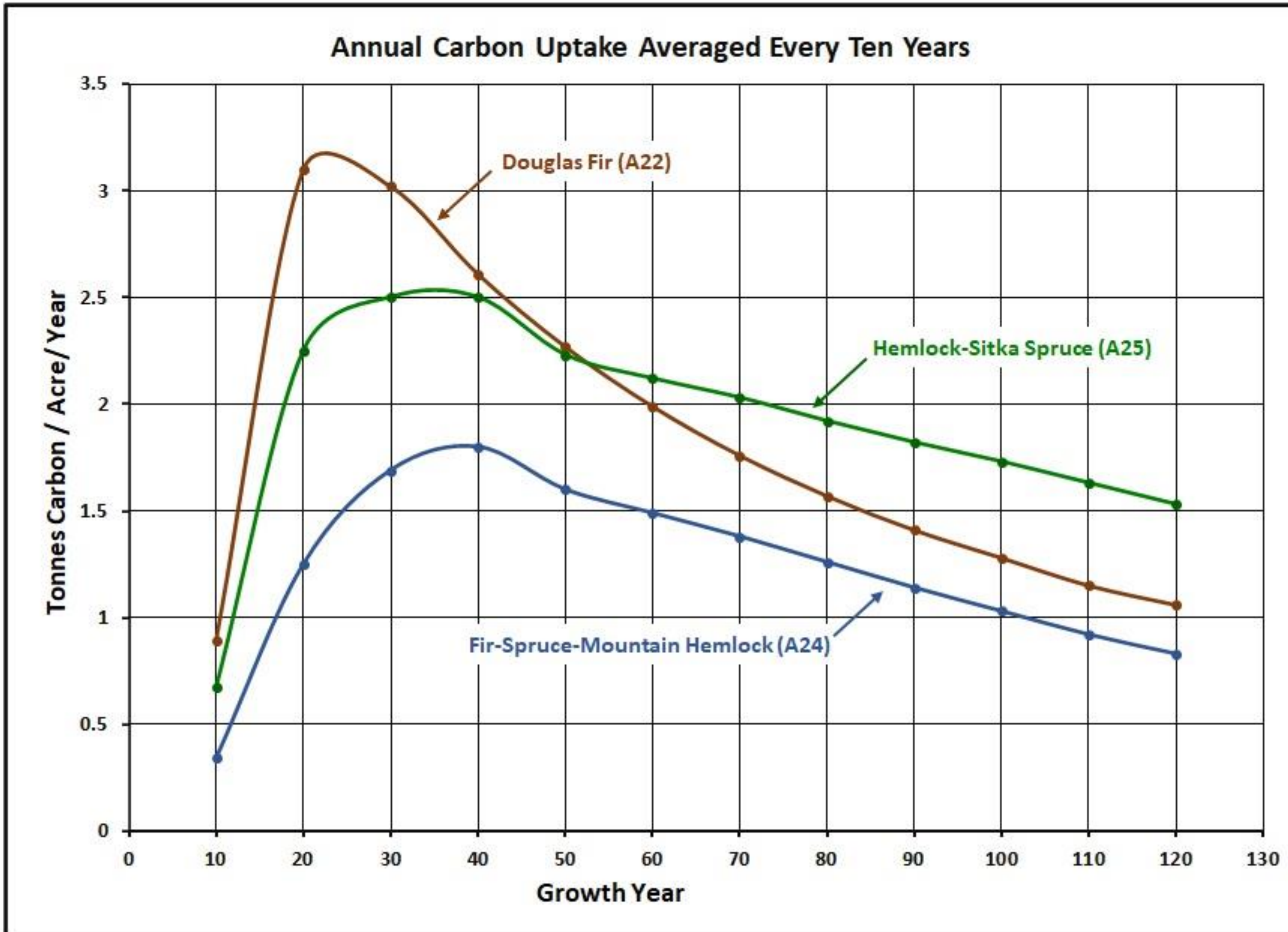
Highest Normal Growth Scenarios
Tonnes Carbon / Acre
Years of Growth
Hemlock-Sitka Spruce (A25)
Douglas Fir (A22)
Alder-maple (A21)
Fir-Spruce-Mountain Hemlock (A24)
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135

Growth rates of trees generally follow an exponentially increasing path as the forest grows from seedlings into small trees. Substantial growth continues until the trees begins approaching their typical maximum height. Thereafter, growth rate begins to decline. Species within a forest that have the lower typical maximum mature heights become overshadowed by the taller species and die due to lack of sunlight. Even within a forest with a single major species slower growing trees are overshadowed and die. The result of these die-offs is that the number-density of individual trees begins decreasing. The forest canopy is high and dense; however, at ground-level the forest becomes more open.

Keep in mind that the Pacific Northwest, West forests has the highest growth during the first 100 years of any other region in the lower 48 states of the USA. This is because the major species in these forests have, due to both genetics and environment, both larger maximum sizes and lifespans.

The next slide shows growth rates of forests in the Pacific Northwest, West region. Carbon density of a forest is a measure of both individual tree mass and number-density.

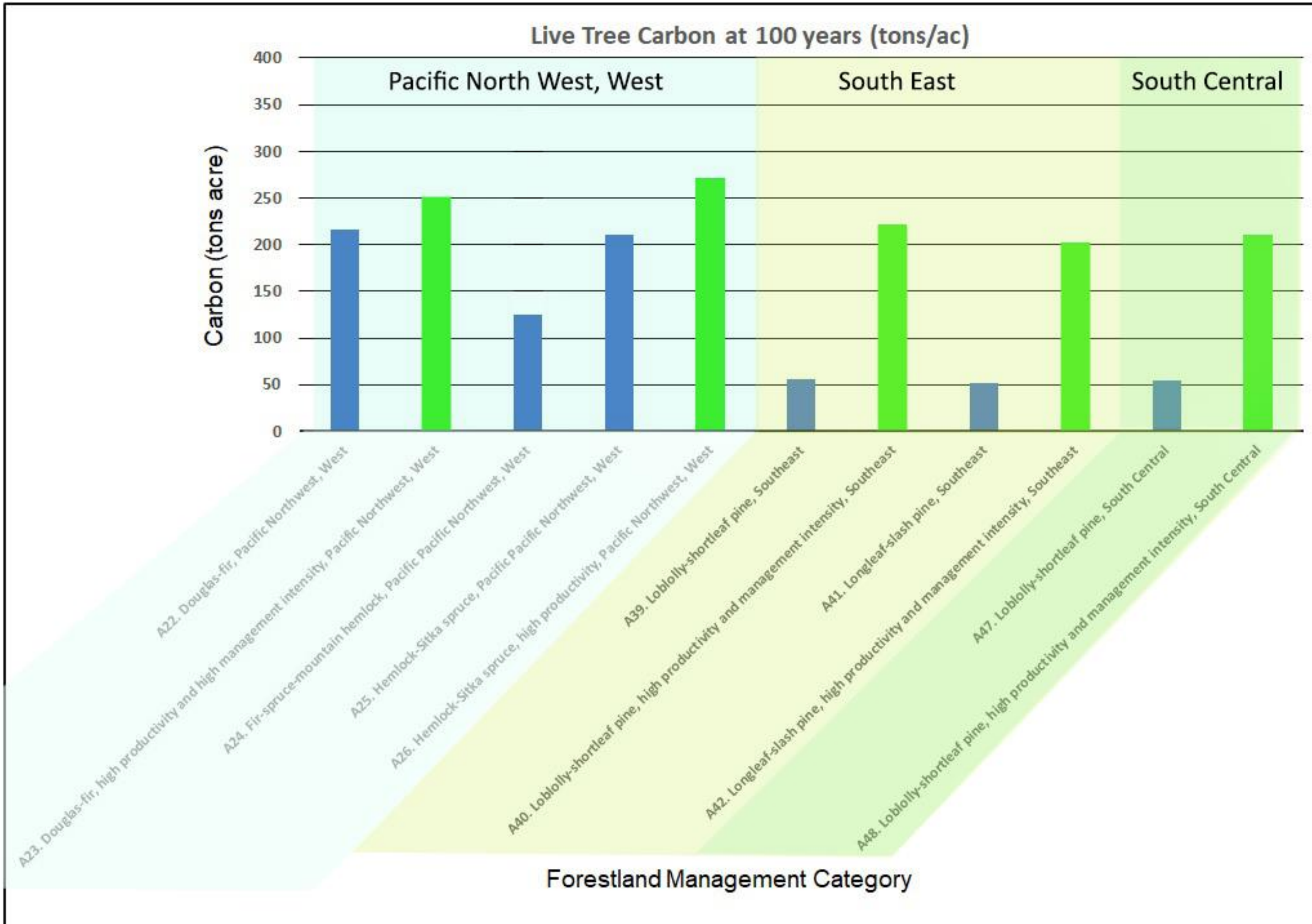
For each of the forests shown, it is clear that if the forests are to be harvested for their carbon mass, an optimum forest age can be determined.



Annual Carbon Uptake Averaged Every Ten Years
Douglas Fir (A22)
Hemlock-Sitka Spruce (A25)
Fir-Spruce-Mountain Hemlock (A24)
Tonnes Carbon / Acre / Year
Growth Year
0
0.5
1
1.5
2
2.5
3
3.5
0 10 20 30 40 50 60 70 80 90 100 110 120 130

There are many compelling reasons why forests of the Pacific Northwest, West region should not be harvested. To harvest or not to harvest is a value judgment which must be made. However, for the forests in the rest of the lower 48 states of the USA, the answer to this value judgment may be very different.

The next slide shows the results of the five alternative scenarios that were evaluated. Alternatives were evaluated for three forest regions: the Pacific Northwest West, the South East, and the South Central regions. This slide also shows the natural growth scenario for each alternative.



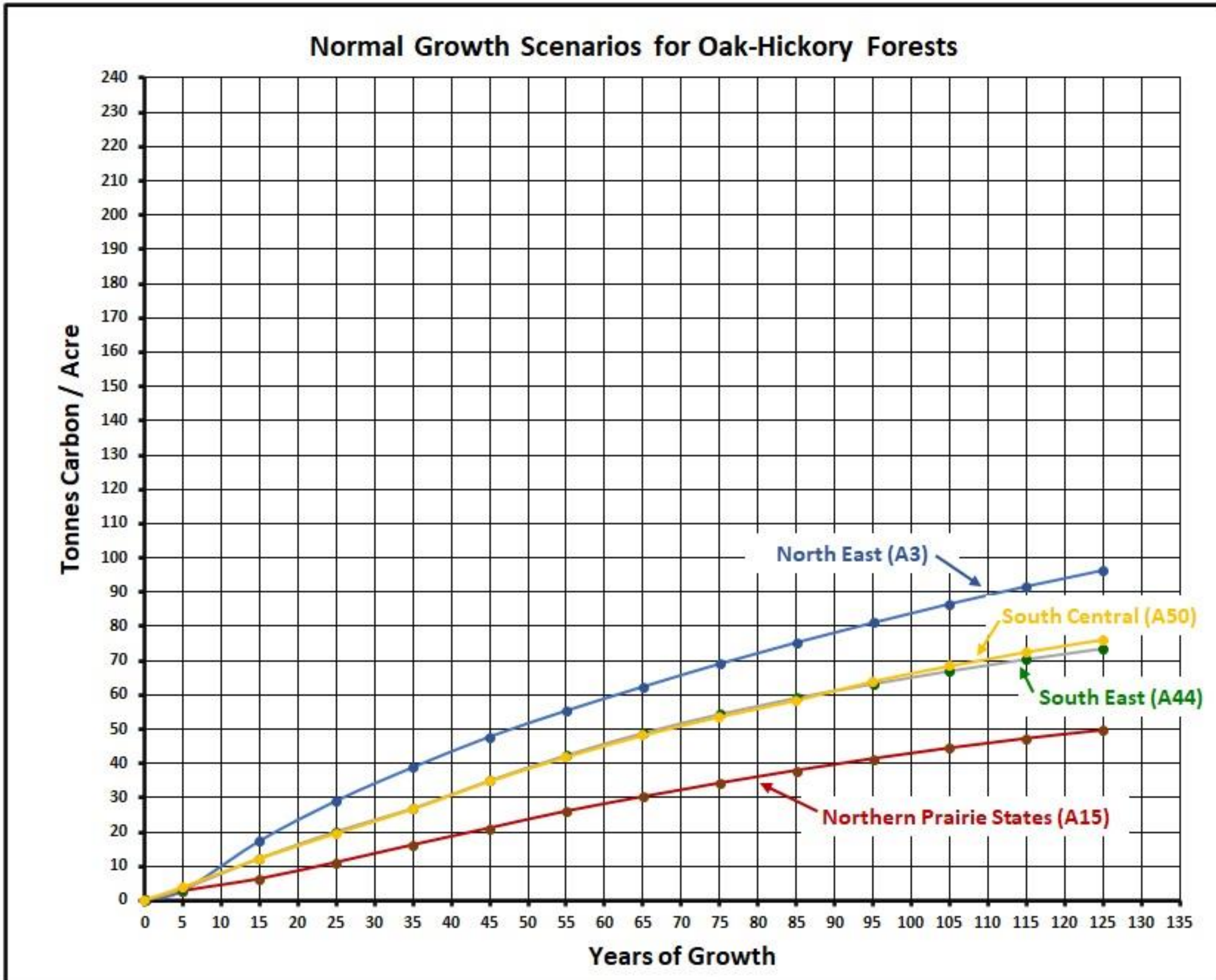
Live Tree Carbon at 100 years (tons/ac)
Carbon (tons acre)
400
350
300
250
200
150
100
50
0
Pacific North West, West
South East
South Central
A22. Douglas-fir, Pacific Northwest, West
A23. Douglas-fir, high productivity and high management intensity, Pacific Northwest, West
A24. Fir-spruce-mountain hemlock, Pacific Pacific Northwest, West
A25. Hemlock-Sitka spruce, Pacific Pacific Northwest, West
A26. Hemlock-Sitka spruce, high productivity, Pacific Northwest, West
A39. Loblolly-shortleaf pine, Southeast
A40. Loblolly-shortleaf pine, high productivity and management intensity, Southeast
A41. Longleaf-slash pine, Southeast
A42. Longleaf-slash pine, high productivity and management intensity, Southeast
A47. Loblolly-shortleaf pine, South Central
A48. Loblolly-shortleaf pine, high productivity and management intensity, South Central
Forestland Management Category

The major take away from this slide is that alternative scenarios were only marginally successful in the Pacific Northwest West but were phenomenally successful in the two southern USA regions.

Using the alternative scenarios in the southern forests yields carbon sequestration potential essentially equal to the Pacific Northwest West natural scenarios.

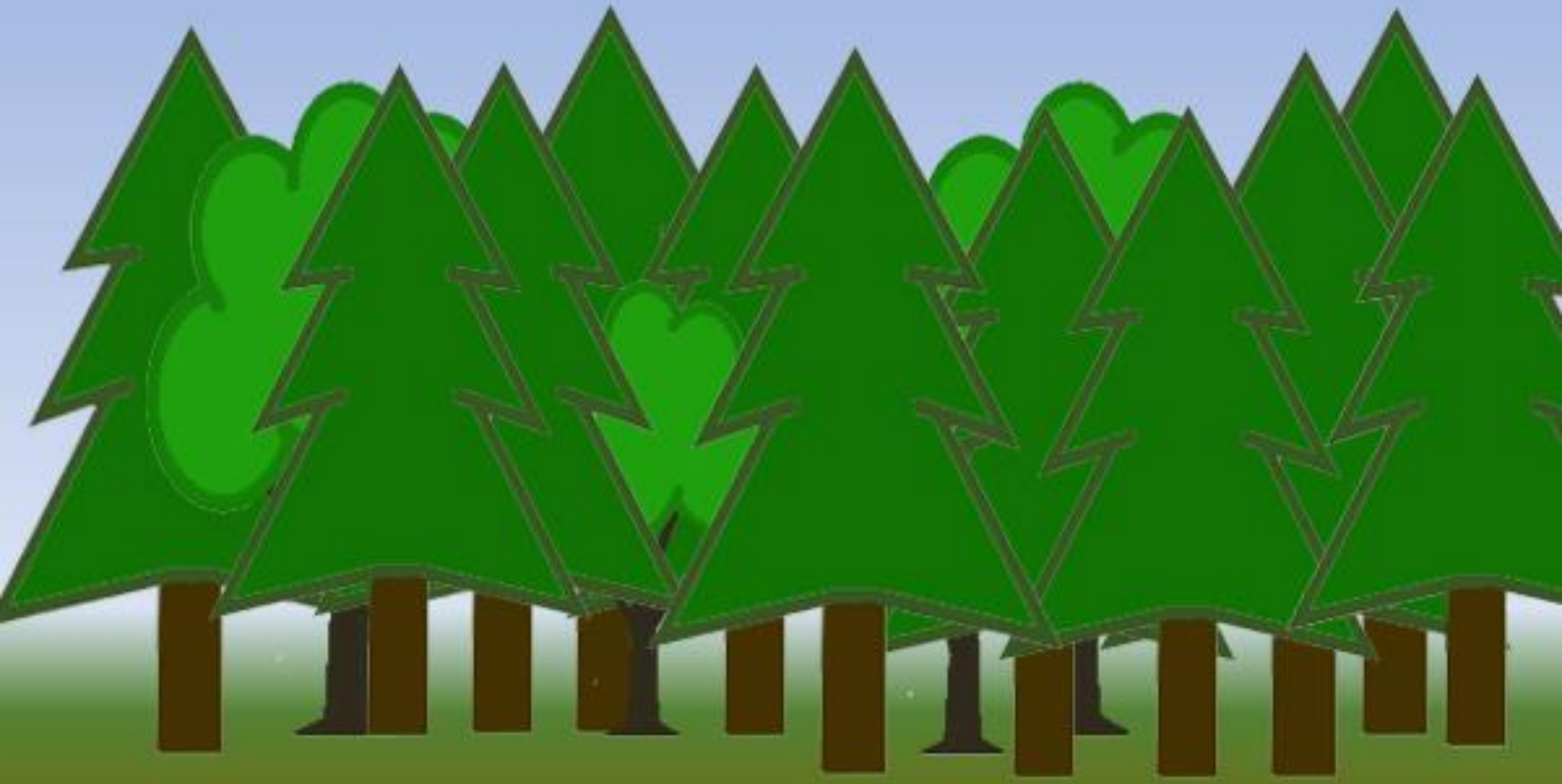
In fact, the southern alternative scenarios are already being used in many forests. These alternatives use genetically improved trees, forest fertilization, multiple harvestings, and more frequent clear cutting. Each of these alternatives involve planting pine tree species. Natural and manmade “pine plantations” have existed throughout the history of the southern USA.

Natural forests in other regions and of other tree species grow more slowly. The following slide shows the natural growth Oak-Hickory forests. The growths are slower, but all have potential harvest cycles which can optimize harvestable wood.



Normal Growth Scenarios for Oak-Hickory Forests
Tonnes Carbon / Acre
Years of Growth
North East (A3)
South Central (A50)
South East (A44)
Northern Prairie States (A15)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135

HARVESTING METHODS



SELECTIVE CUTTING is used when specific trees are cut or a category of trees is cut. For example, dead, damaged, and diseased trees may be cut and harvested. Or perhaps there is a partial harvest of trees for the purpose of thinning the forest in order that the remaining trees will continue to grow larger.

CLEARCUTTING is the most used method of harvesting large tracts of forests.

Clearcutting is harvesting of wood from forests. Clearcutting may range from cutting all the trees with marketable wood to cutting all the trees. Clearcutting may be carried out on small plots of a few acres to tracts with hundreds of acres or larger. The objective of clearcutting is to allow the forest to regenerate either naturally or with planting of seedlings.


Note that a few mature trees have been left to provide reseeding.
Note that stumps and dead wood have been left in place.

Clearcutting a forest and land clearing are different operations and have very different objectives.

Clearcutting does significantly alter the nature of the forest. Although the clearcut area may appear to be like a ruin following a fire or hurricane damage, the land still provides home for many wildlife species. Even as natural forests age, there are always species that move away and new species that come in.

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Land Clearing is removing all, or most all trees, including stumps and deadwood from a tract of forestland to convert it into another use, such as agriculture, pasture, housing, or industrial uses. The trees usually are harvested, and the stumps and deadwood burned.


The few remaining live trees
were probably left because
they are growing in ravines.
Heavy equipment is being
used to remove stumps and
pile with dead wood.
Stumps and dead wood
have been stacked for burning.
The foreground area
has been completed.


Regrettably, sometimes
the entire tree cover is burned
by pushing up the
whole trees
and piling with the
stumps and deadwood.

SEQUESTRATION

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SEQUESTRATION is the removing of a substance from the active biosphere. Sequestration of carbon removed from the atmosphere is the objective for minimizing climatic changes resulting from excessive carbon emissions. Sequestration of carbon for any time period shorter than a century is of questionable value.

SEQUESTRATION within living trees can be used for long-lived tree species. Living trees are subject to disease, storm damage, and fire which could negate long-term sequestration.

The temperate rainforests of the Pacific Northwest, especially in the states of Oregon and Washington, are viable means of carbon sequestration.

SEQUESTRATION within long-lived wood products is a means of carbon sequestration. Wooden homes and buildings can be maintained for centuries, although they do slowly decay and release the stored carbon. Wooden structures are also subject to disease, storm damage, and fire which could negate long-term sequestration. In our economy of constant growth, the size of this sequestration alternative seems to be greatly limited.

SEQUESTRATION through landfilling of trees and wood is possible. In anaerobic conditions, the rate of decay of wood is low. Such conditions exist in deep landfills and lakes. Landfilling of regular tree trunks is feasible. However, trees and wood consist of more than just carbon, such as oils, resins, and volatile organic compounds. Anaerobic decay releases methane, which is a strong greenhouse gas.

SEQUESTRATION through conversion of wood into charcoal is the best way to sequester tree carbon. Mature stems of trees contain from 46 to 55 percent carbon.* Softwoods generally contain higher mass concentrations of carbon. Humans have made charcoal from wood for many thousands of years. Charcoal contains from 50 to 95 percent carbon. Charcoal is highly combustible. However, in anaerobic conditions such as found in landfills charcoal is extremely stable and long-lasting. Landfilling of charcoal for carbon sequestration is the human equivalent to reversing the extraction of coal as a fossil fuel.

* Lamlom, S. H. and Savidge R. A., "A reassessment of carbon content in wood: variation within and between 41 North American species," University of New Brunswick, Faculty of Forestry and Environmental Management Fredericton, N.B., E3B 6C2 Canada.

WHAT WE CAN DO NOW?

South Carolina is the smallest state within the southern USA, that is, the South East and South Central regions. It has a population of about 5.1 million persons.

South Carolina has a total land area of about 19.3 million acres. Approximately 12.9 million acres (67%) are forestland. Private individuals and families own about 6.7 million acres (52%) of the forestland. These private forestlands are spread among 237,000 owners. About 30,000 of these own forest tracts of 50 to 500 acres comprising a total of about 3.7 million acres (or 55 percent of the private landholdings).

In 2017, the average Carbon Footprint for the USA was about 20 metric tons CO2e/capita. Each metric ton of carbon is equal to 3.7 metric tons equivalent of CO2 (that is, CO2e). Each acre of forest could enable the permanent sequestration of 0.37 Carbon Footprints per year.

Using the Loblolly-Shortleaf Pine high-intensive strategy on 41 percent of the privately owned forest land could provide permanent sequestration for 20% of the Carbon Footprint for the State of South Carolina. What other actions that we can take will produce this level of reduction in Carbon Footprint?

During the past one hundred years (1920 to 2020) burning of fossil fuels added an estimated 1,200 billion metric tons of CO2 into the atmosphere.* Some of the CO2 emitted into the atmosphere does not stay there.

During this same period, the amount of CO2 retained in the atmosphere was about 870 billion metric tons,** meaning that over 330 billion metric tons went into other natural sinks. Some of the sinks for the CO2 are equilibrium reactions in which case the captured CO2 will be released into the atmosphere as the atmospheric CO2 concentration decreases. Other sinks, such as deposits into the ground or seabed, may be more permanent.

* Hannah Ritchie and Max Roser (2020) - "CO_2 and Greenhouse Gas Emissions". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions' [Online Resource], accessed 20212027.

** Based upon increase of atmospheric CO2 concentration (ppmv) increase from 303 to 414.

Each year that we continue to burn fossil fuels increases total CO_2 in the atmosphere. On a simple linear basis, each year 0.5 billion metric tons of CO_2 have been released into the atmosphere each year since 1960. Even if we optimistically begin reducing carbon emissions from fossil fuels on a course that is inverse of the increase in the past century, by 2120 the atmosphere would contain about 1,740 billion metric tons of CO_2 that should never have been emitted. Without significant carbon removal and sequestration, the atmospheric CO_2 content would peak at about 525 ppmv (that is, parts per million by volume). This estimate does not include increases resulting from continued population growth.

The removal of CO_2 from the atmosphere using "trees to charcoal sequestration" is a long-term, but certain, process which we can implement. Until we get the human Carbon Footprint to zero, removing CO_2 using "trees to charcoal sequestration" will only lessen the rate of increase in atmospheric CO_2 concentration. We must not give in to the temptation to stop at the point where our Carbon Footprint equals zero. We must continue carbon removal in order to actually begin decreasing the CO_2 concentration in the atmosphere. Based upon the preceding scenario, if we continue "trees to charcoal sequestration" for another century, by the mid-2200s the atmospheric CO_2 concentration could be restored to a little less than the level existing today.*

* Hopefully, the decrease in CO_2 concentration will not only decrease the detrimental climate effects, but if we are lucky, will also remove detrimental effects in the oceans.

Using “trees to charcoal sequestration” is the simplest, most straightforward major action which we can do to reduce climate change impacts. To start the process requires only that we, through our governments, commit to pay for each ton of carbon sequestered by this method. Let our economy sort out all the other details. No new environmental regulations are required. In fact, we much guard against over regulation that now manifests itself in the carbon-offset approaches. Let “trees to charcoal sequestration” function in much the same manner as the current “trees to wood products” industry operates. We just need to create a new valuable wood product, that is, charcoal made from trees that is not burned.

Increasing the economic value of trees will protect forests, protect and restore the environment, and preserve life on Earth!

Otherwise…

The End

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