Carbon Footprint and Ecosystem Services During the Life Cycle of Landscape Plants

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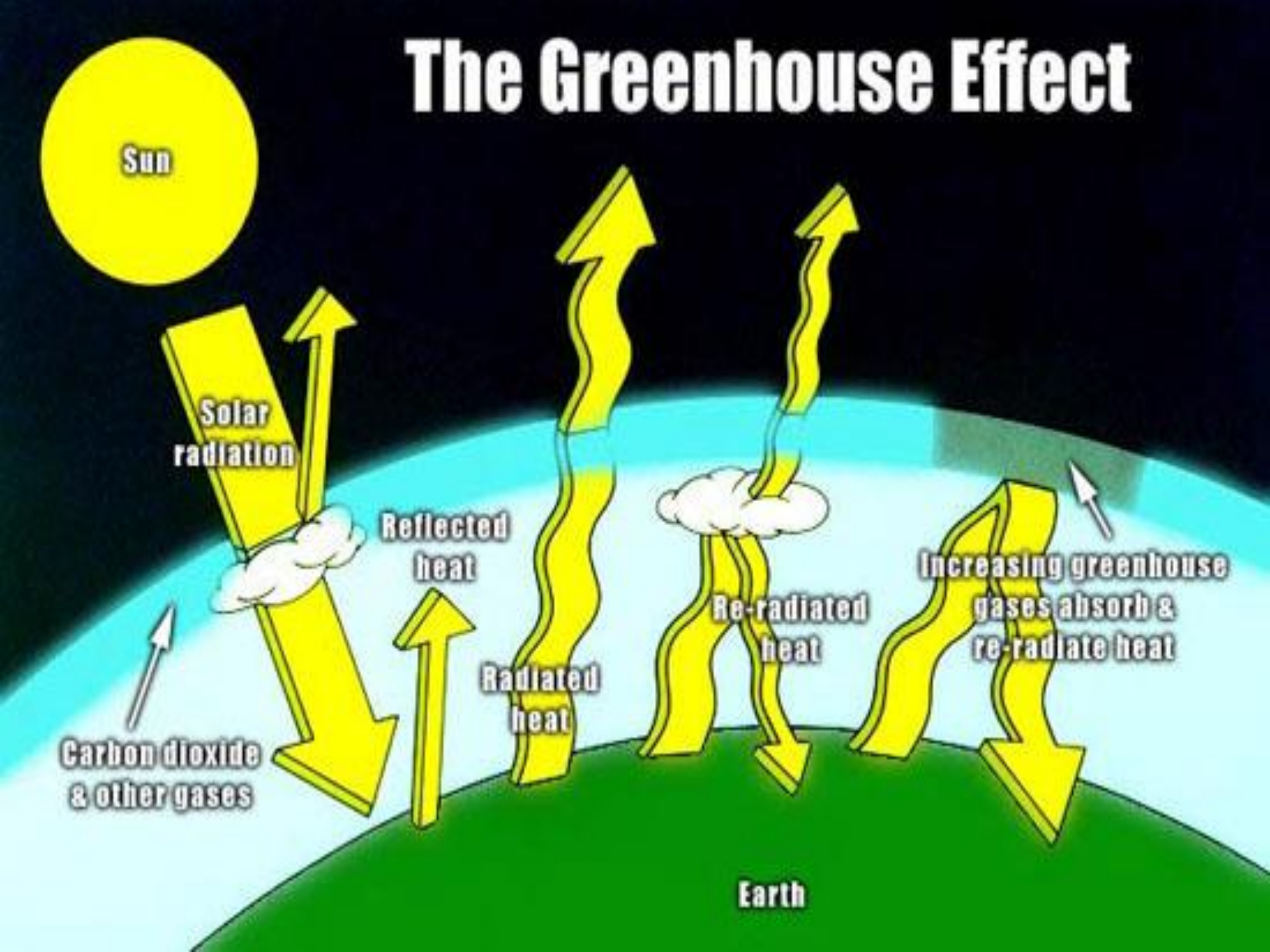
Nursery Crop Production
http://ncer.ca.uky.edu

Summary of scientific basis for role of CO_2 in global warming

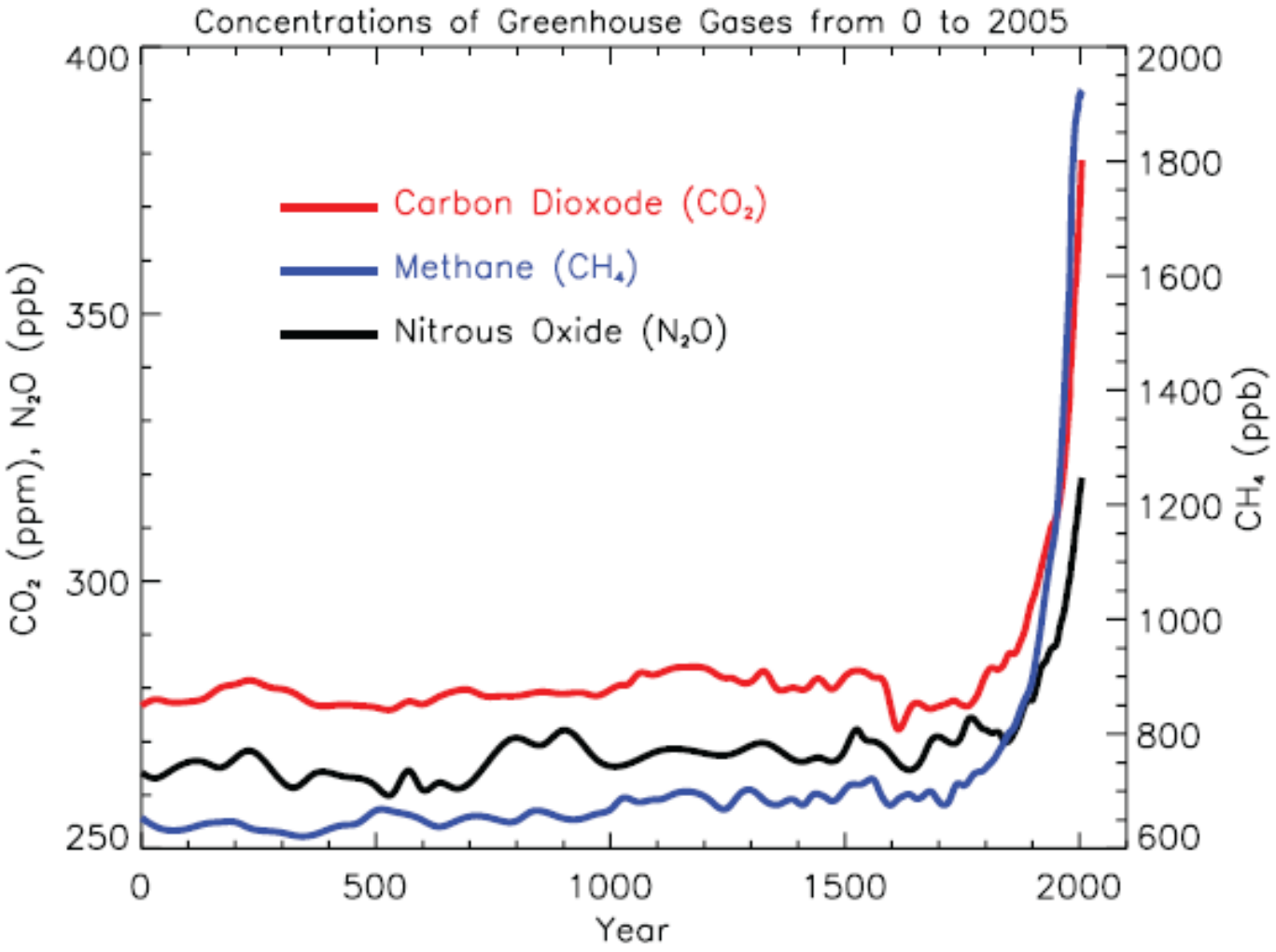
- Human activity is emitting large amounts of CO_2
- CO_2 concentration in atmosphere is increasing
- CO_2 and other greenhouse gases traps thermal radiation


The Greenhouse Effect
Sun
Solar radiation
Reflected heat
Radiated heat
Re-radiated heat
Increasing greenhouse gases absorb & re-radiate heat
Carbon dioxide & other gases
Earth

Greenhouse Gas Emissions have Global Warming Potentials, GWP

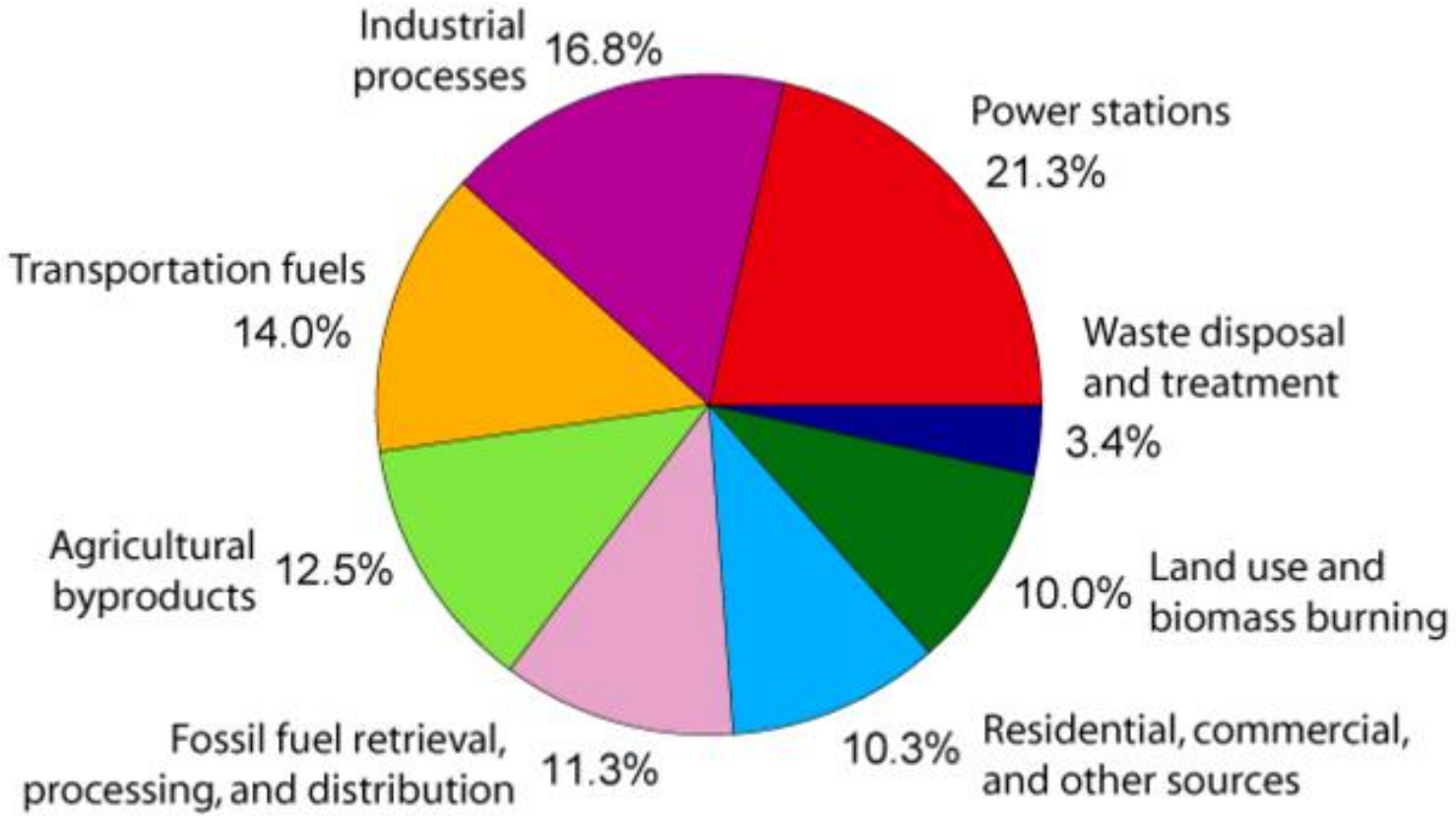
- The GWP of CO_2 is set at 1
- The GWP of N_2O is 296
- The GWP of CH_4 is 23

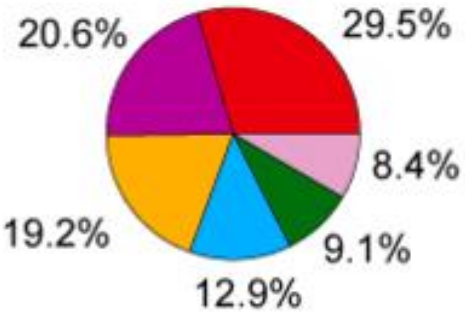
Atmospheric concentrations of important greenhouse gases



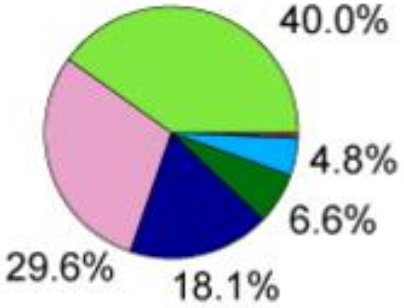
IPCC. FAQ

Annual Greenhouse Gas Emissions by Sector

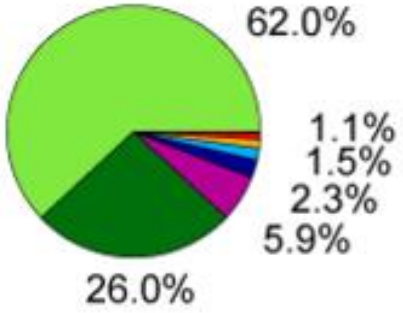




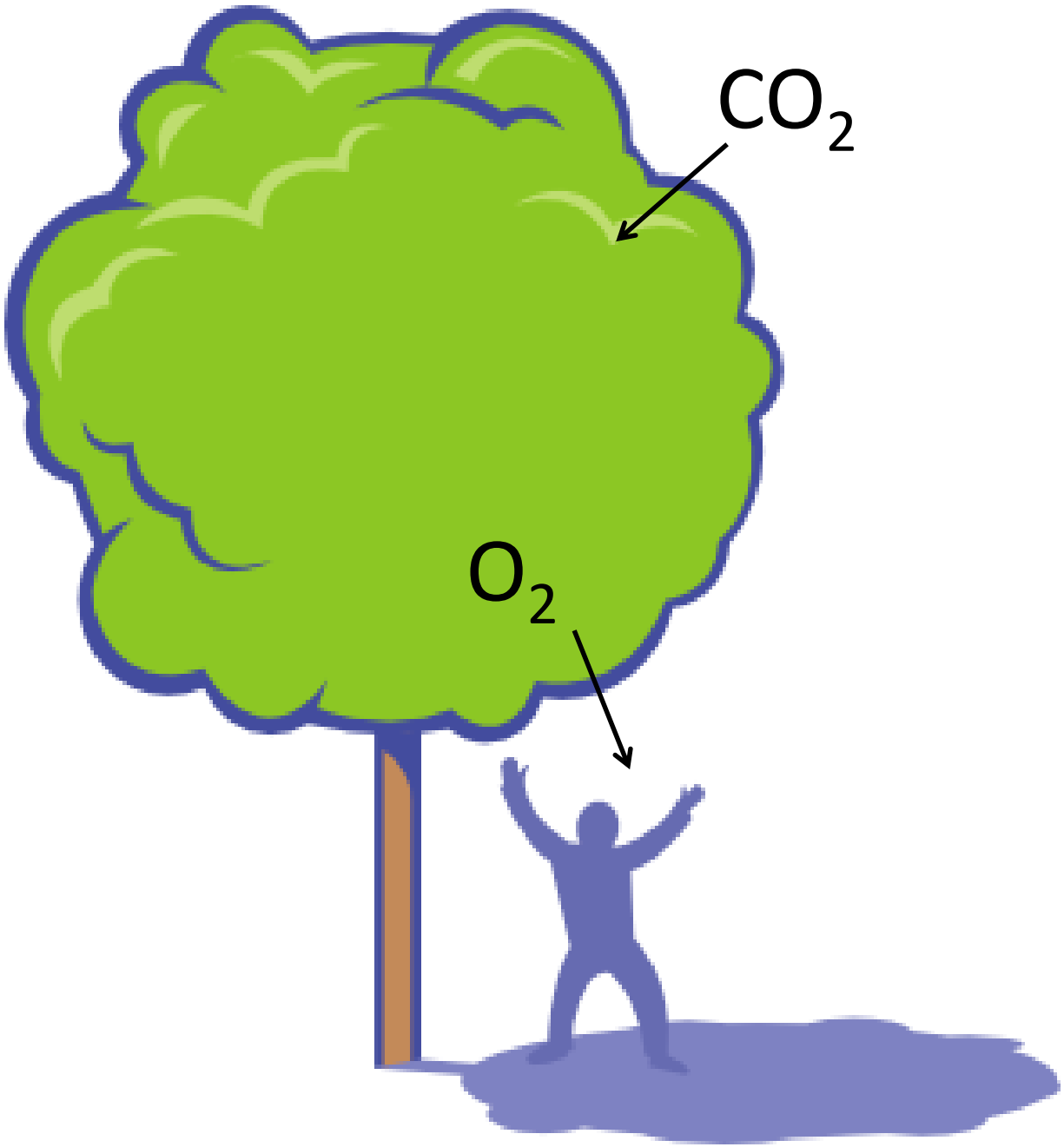
Carbon Dioxide
(72% of total)



Methane
(18% of total)



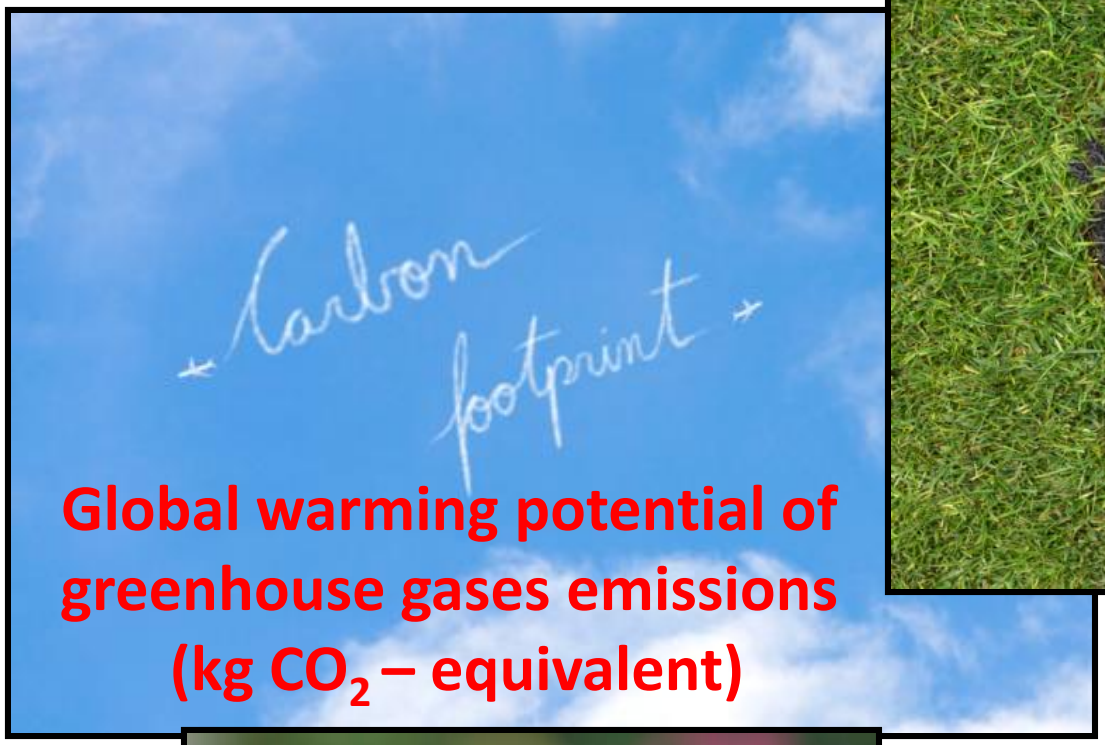
Nitrous Oxide
(9% of total)


CO_2
O_2

Life Cycle Assessment:

A research tool to determine environmental impact of products and processes


carbon
footprint



Global warming potential of greenhouse gases emissions (kg CO_2 – equivalent)

…a few reported carbon footprints

…complete life cycle

- Six-pack of beer…….. 3.7 kg CO_2e
- Gallon jug of milk…….. 3.4 kg CO_2e
- Timberland winter boots…….. 54.0 kg CO_2e
- 2-Liter bottle of Coca Cola…….. 0.5 kg CO_2e
- ½-gallon carton of orange juice… 1.7 kg CO_2e

Production of Trees and Shrubs

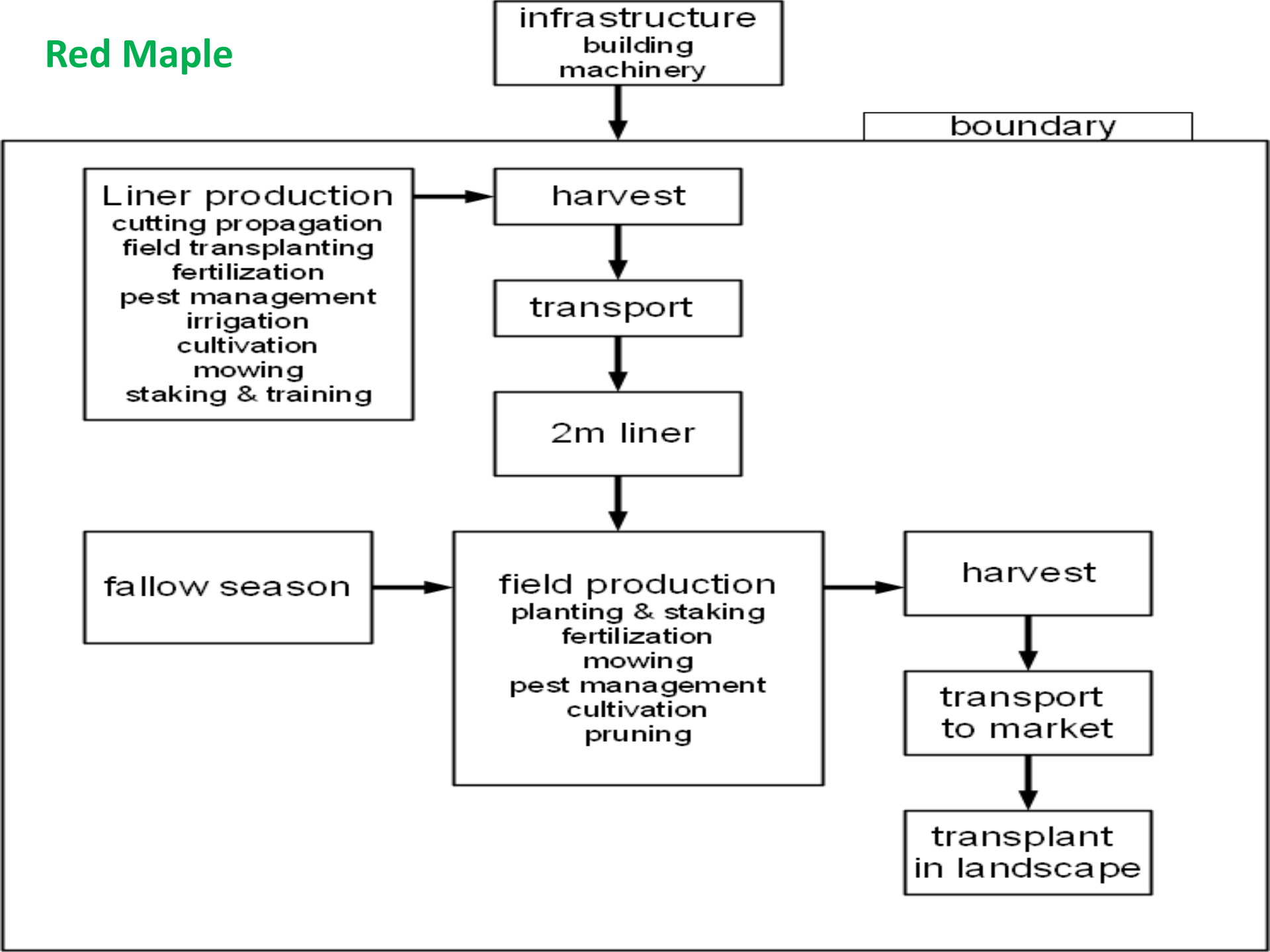
- 2011… Red Maple
- 2012… Colorado Blue Spruce
- 2012-13… Redbud
- 2014-15… Field-grown shrubs
- 2015… Pot-in-pot
- 2016… Container-grown shrubs

Inventory the System

Life Cycle Inventory

- Every material used
- Every chemical used
- Each equipment use
- Energy inputs
- Labor inputs

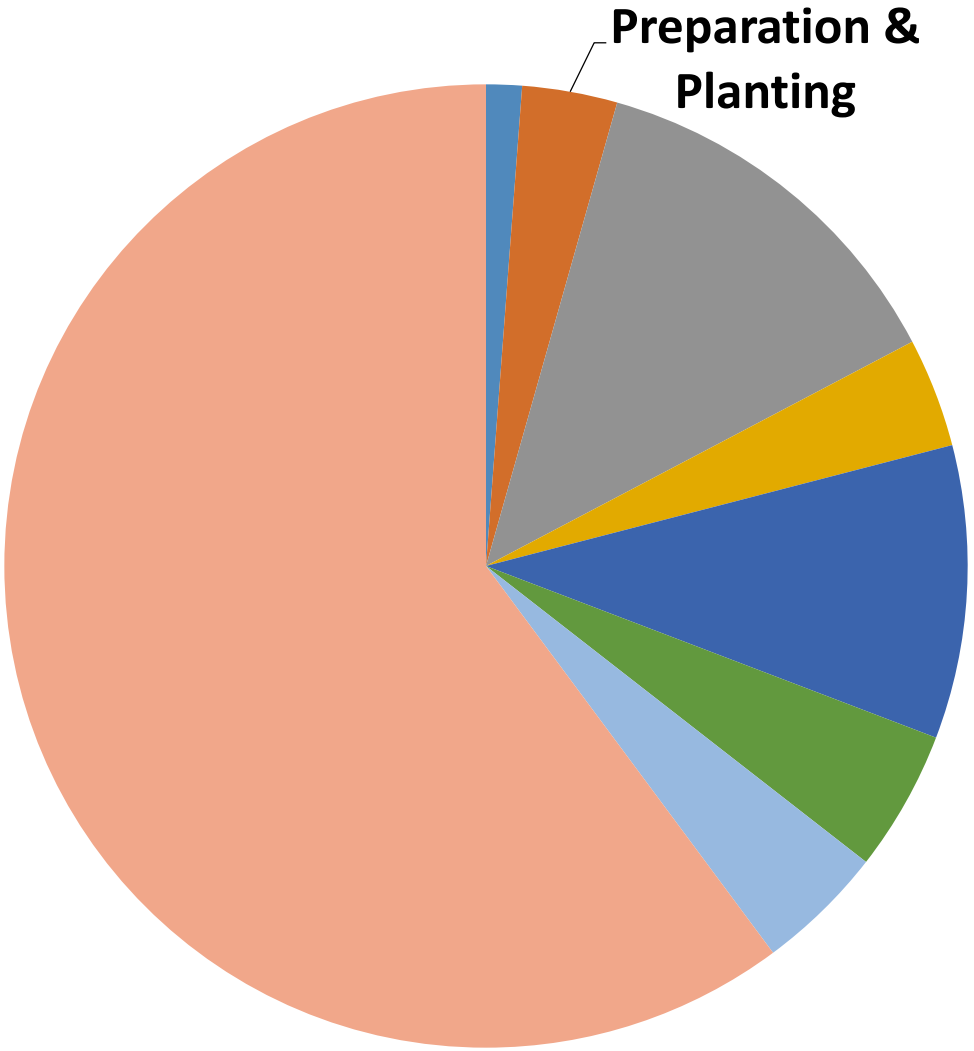
Red Maple


infrastructure
building
machinery
boundary
Liner production
cutting propagation
field transplanting
fertilization
pest management
irrigation
cultivation
mowing
staking & training
harvest
transport
2m liner
fallow season
field production
planting & staking
fertilization
mowing
pest management
cultivation
pruning
harvest
transport
to market
transplant
in landscape

Field Production Phase

Relative GWP of input materials and equipment use during 2-in caliper, red maple field production phase

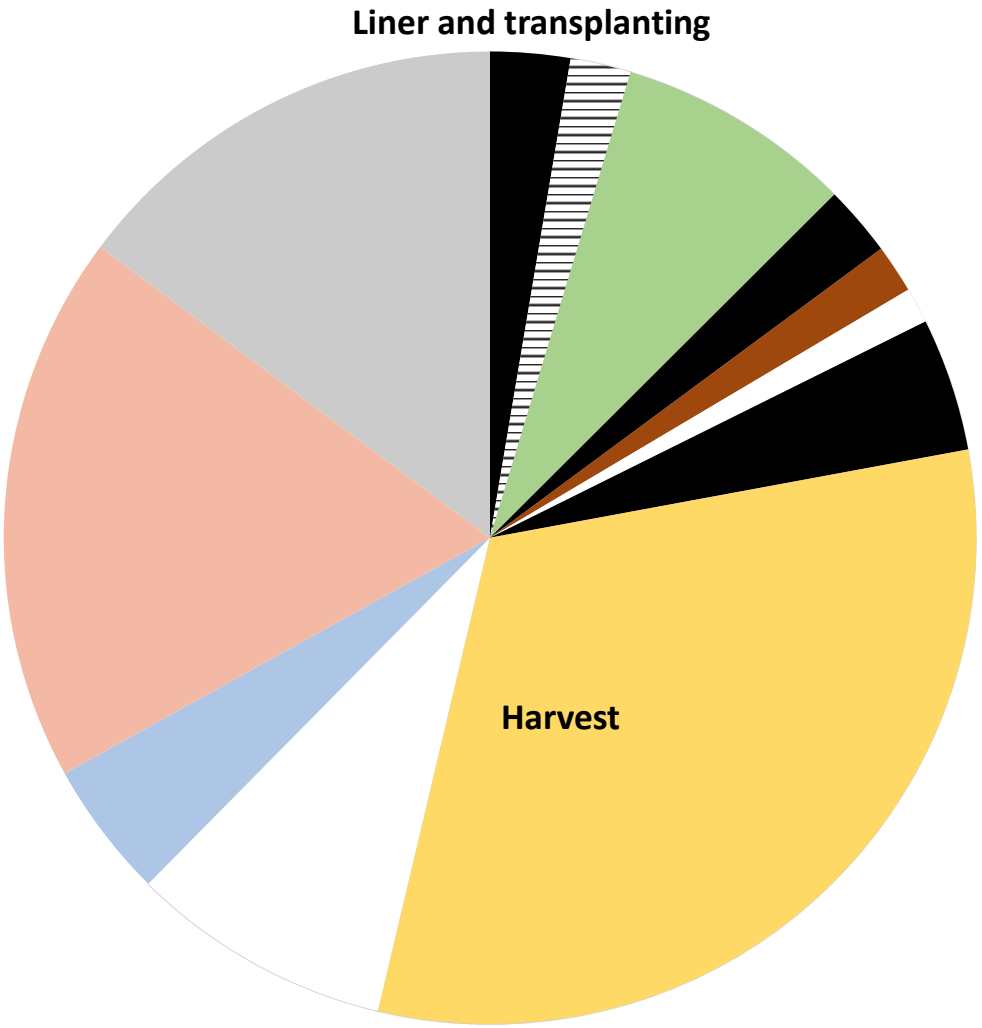
(kg CO_2e / tree)



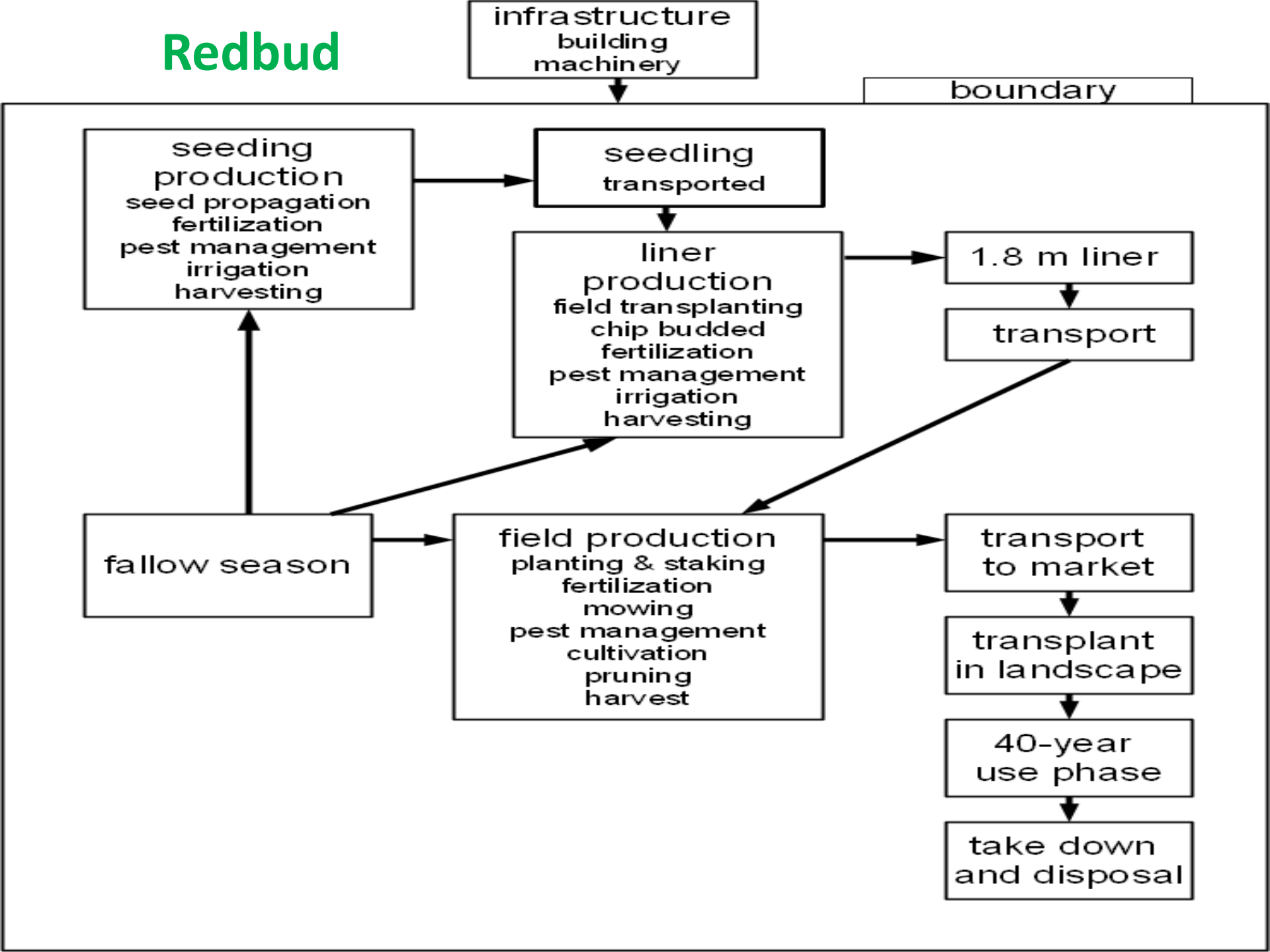
Transport and Transplanting of Tree

- Transport 240 miles to customer, 100 trees/load
- Transport another 20 miles to the landscape site (10% of load)
- Tractor with boom positioned the tree for transplanting

Red Maple, 2” caliper, B&B
Cutting to landscape



Redbud


infrastructure
building
machinery
boundary
seeding production
seed propagation
fertilization
pest management
irrigation
harvesting
seedling transported
liner production
field transplanting
chip budded
fertilization
pest management
irrigation
harvesting
1.8 m liner
transport
fallow season
field production
planting & staking
fertilization
mowing
pest management
cultivation
pruning
harvest
transport to market
transplant in landscape
40-year use phase
take down and disposal

Redbud Field Production

Input Material	Product/A	Product per marketable tree (kg)	GWP (kg CO_2e / kg)	GWP per marketable tree (kg CO_2e)
Sudex seed	40	0.025199	4.0670	0.1024861
Pre-plant Ag lime	2000	1.259972	0.5862	0.7386461
Fertilizer (15-15-15)	1300	0.818982	1.4325	1.1731916
Bambo stake	800	0.244444	0.1818	0.0444400
Fescue in middles	11.25	0.007087	4.0670	0.0288242
Wire basket (cnt)	720	0.652000	1.2927	0.8428541
Trunk protector (cnt)	720	0.011352	0.4700	0.0053353
Transplant (cnt)	800	1.111111	0.6073	0.6747600

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Redbud Field Production

	Product/A	Active ingredient per marketable tree (kg)	GWP (kg CO_2e / kg a.i.)	GWP per martketable tree (kgCO_2e)
Surflan	115.2	0.002291	23.0832	0.0528751
Goal	57.6	0.001145	23.0832	0.0264375
Roundup (glyphosate)	86.4	0.001465	33.3424	0.0488309
Bifendrin	87	0.000507	18.6864	0.0063211
Discus	15	0.000738	18.6864	0.0000966

Redbud Field Production

Equipment Use	hrs/A	hrs per marketable tree	fuel per marketable tree (Gal)	GWP (kg CO_2) per marketable tree
Chisel plow	2	0.002778	0.011499	0.1314622
Disk (2 times)	2	0.002778	0.011499	0.1314622
Apply Ag lime	0.5	0.000694	0.002875	0.0328655
Seed sudex	1.3	0.001806	0.007474	0.0854504
Plow	1	0.001389	0.005749	0.0657311
Rototill	0.75	0.001042	0.004312	0.0492983
Transport liners to field	0.25	0.000347	0.000229	0.0026362
Transplant liners	1	0.001389	0.005749	0.0657311
Sow fescue in middles	0.5	0.000694	0.001437	0.0164597
Stakes to field	0.5	0.000694	0.000457	0.0052723
Irrigation	9.6	0.013333	0.059616	0.6814912
Apply fertilizer (3 yr)	1.5	0.002083	0.001372	0.0158169
Cultivate (4 times in 3 yr)	4	0.005556	0.011499	0.1316776
Apply herbicide (3 yr)	3	0.005556	0.003658	0.0421784
Apply Glyphosate (3yr)	3	0.004167	0.002743	0.0316338
Apply insecticides (3 yr)	1.5	0.000694	0.001437	0.0493791
Mow (3 yr)	6	0.000769	0.001592	0.0182323
Digging with tree spade	48	0.066700	0.279590	3.1964104
Loading in field	36	0.050000	0.194041	2.2186659
Hauling from the field	36	0.050000	0.206977	2.3663185
Unloading and loading	36	0.050000	0.194041	2.2186659
Removal of culls	6.7	0.009259	0.035934	0.4108641
Haul culls from field	3.3	0.004630	0.005080	0.0583418

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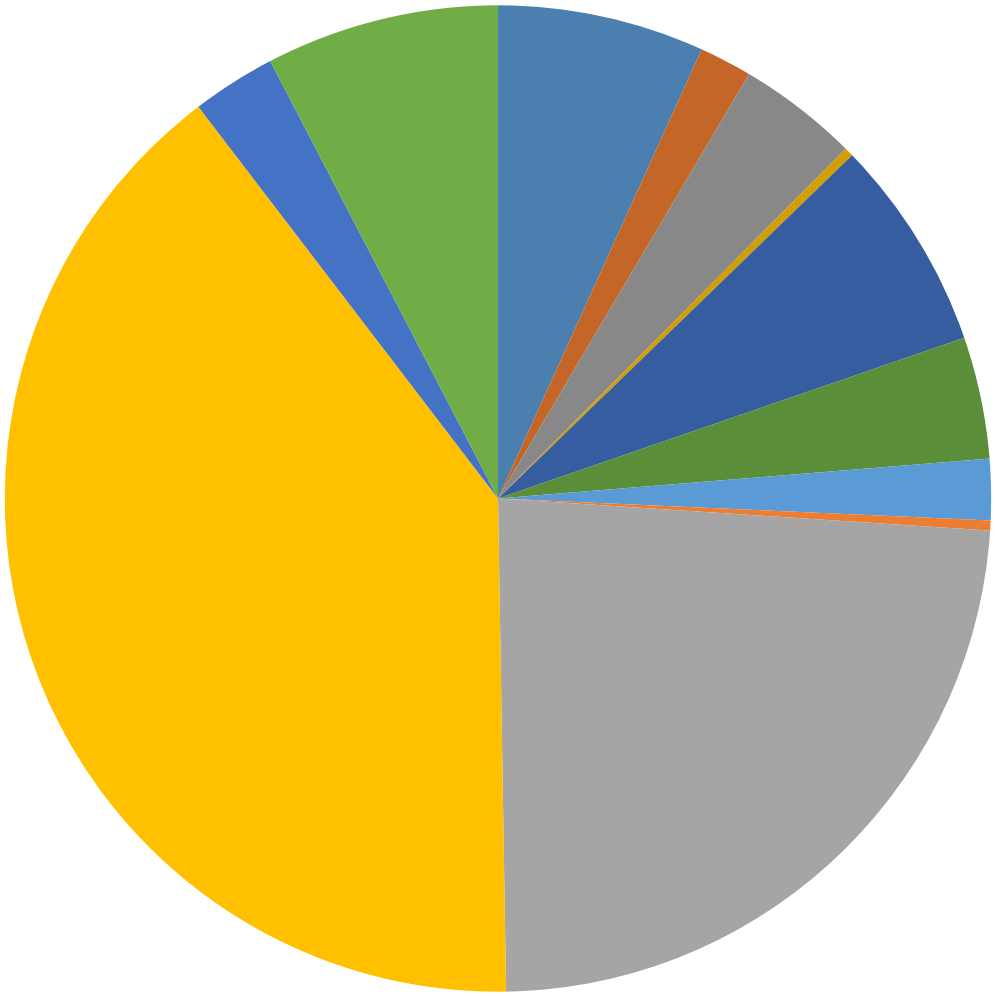
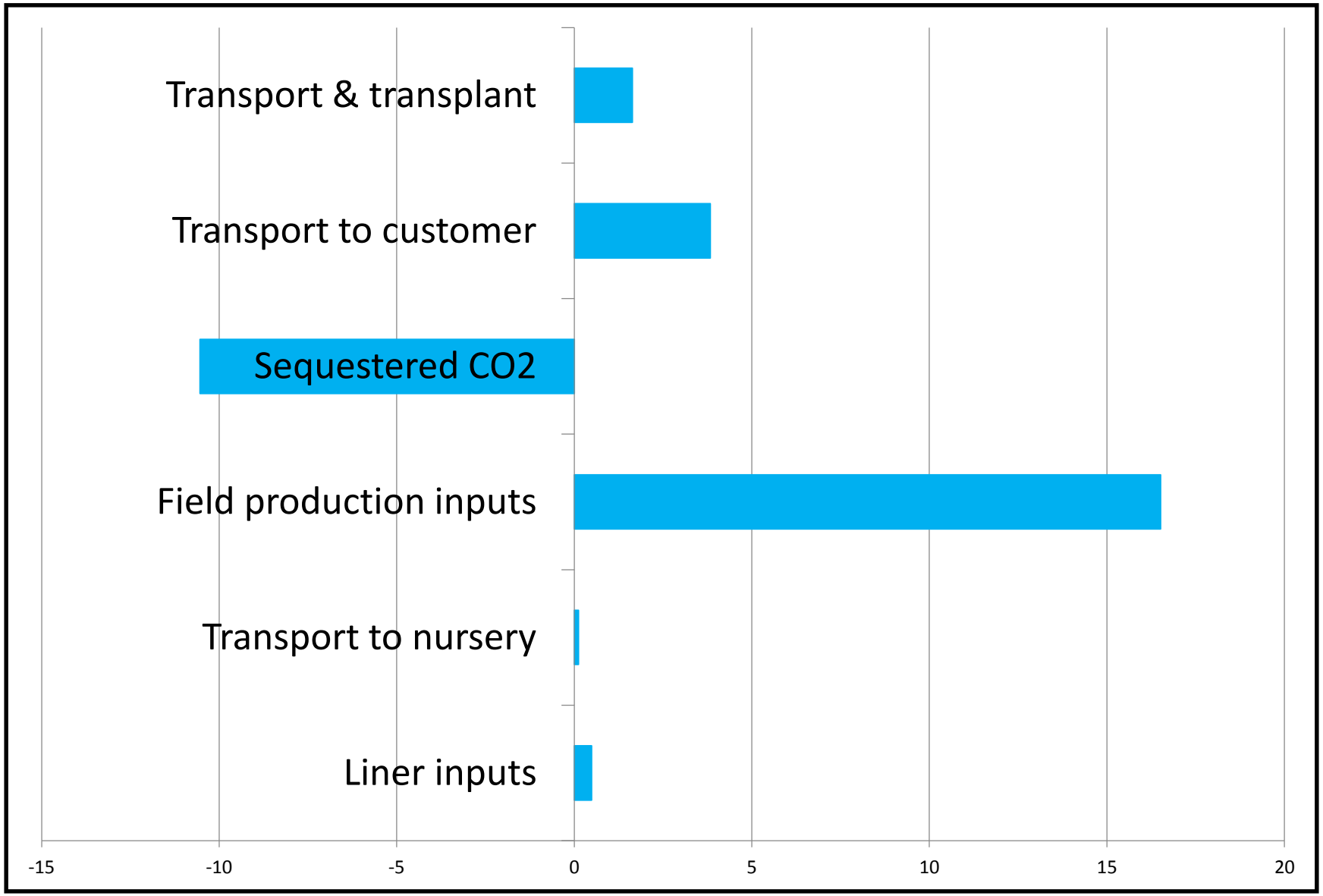
Relative GWP of input materials and equipment use during redbud field production phase (seed-to-gate)

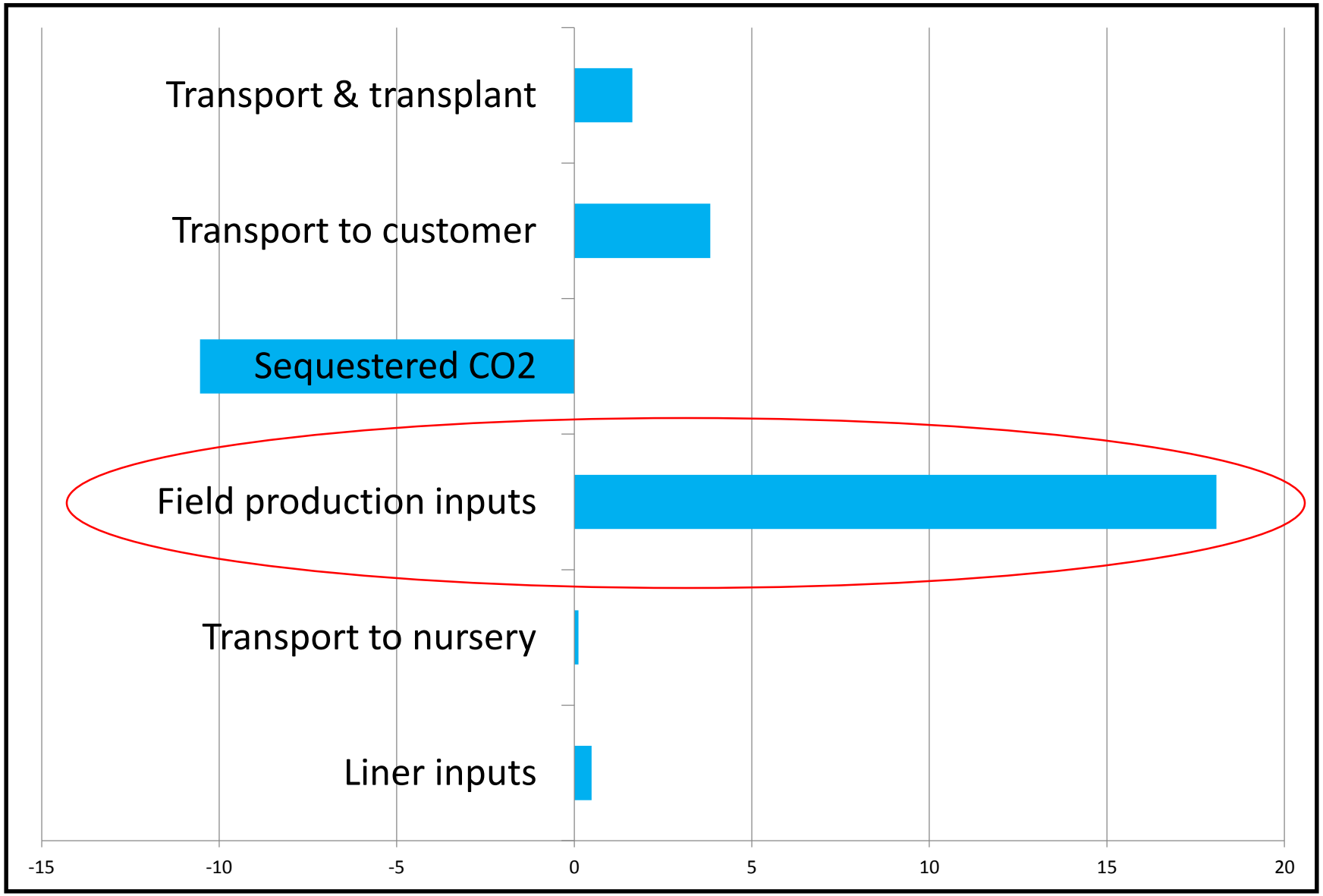
(kg CO_2e / tree)



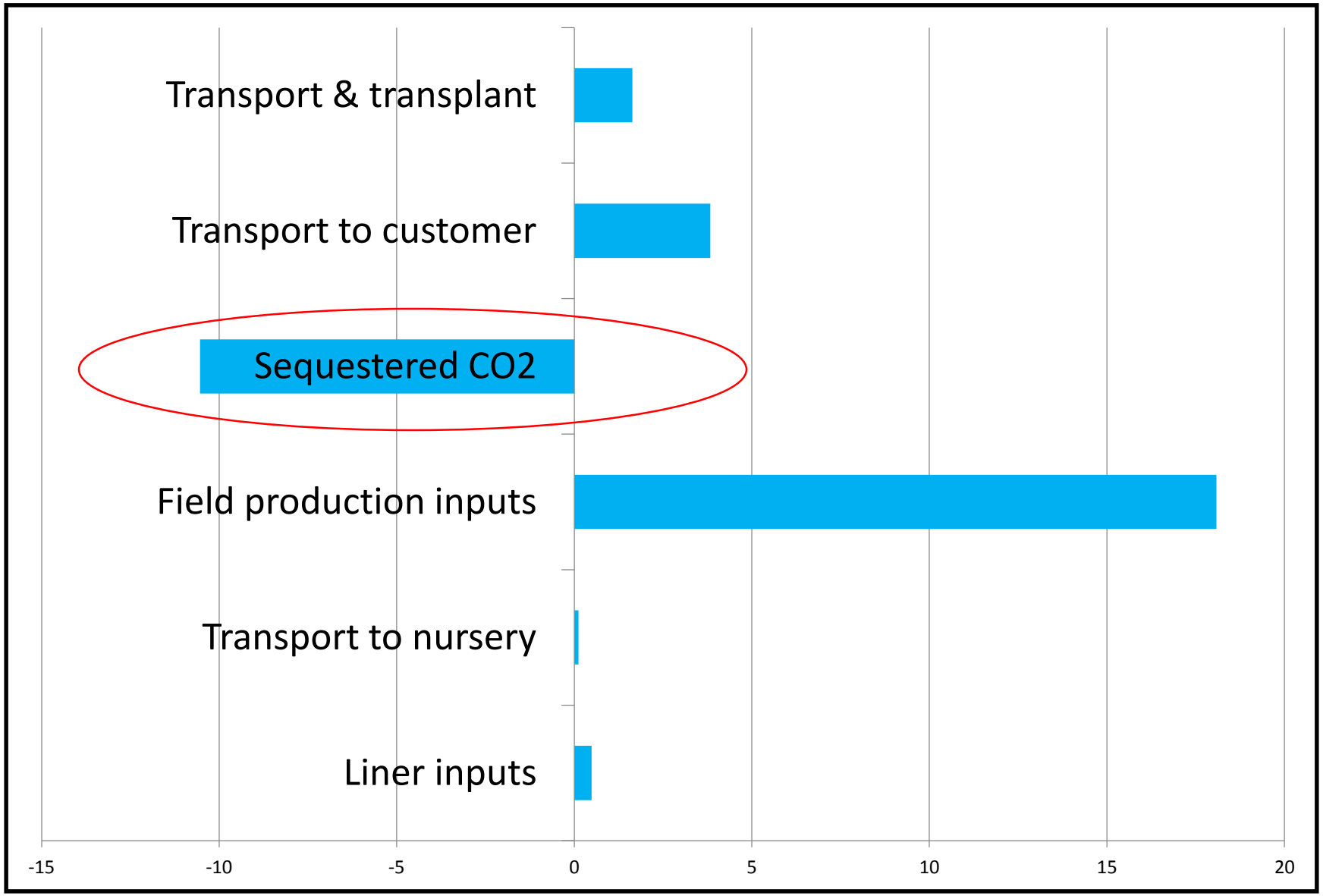
Redbud


Transport & transplant
Transport to customer
Sequestered CO2
Field production inputs
Transport to nursery
Liner inputs
-15
-10
-5
0
5
10
15
20

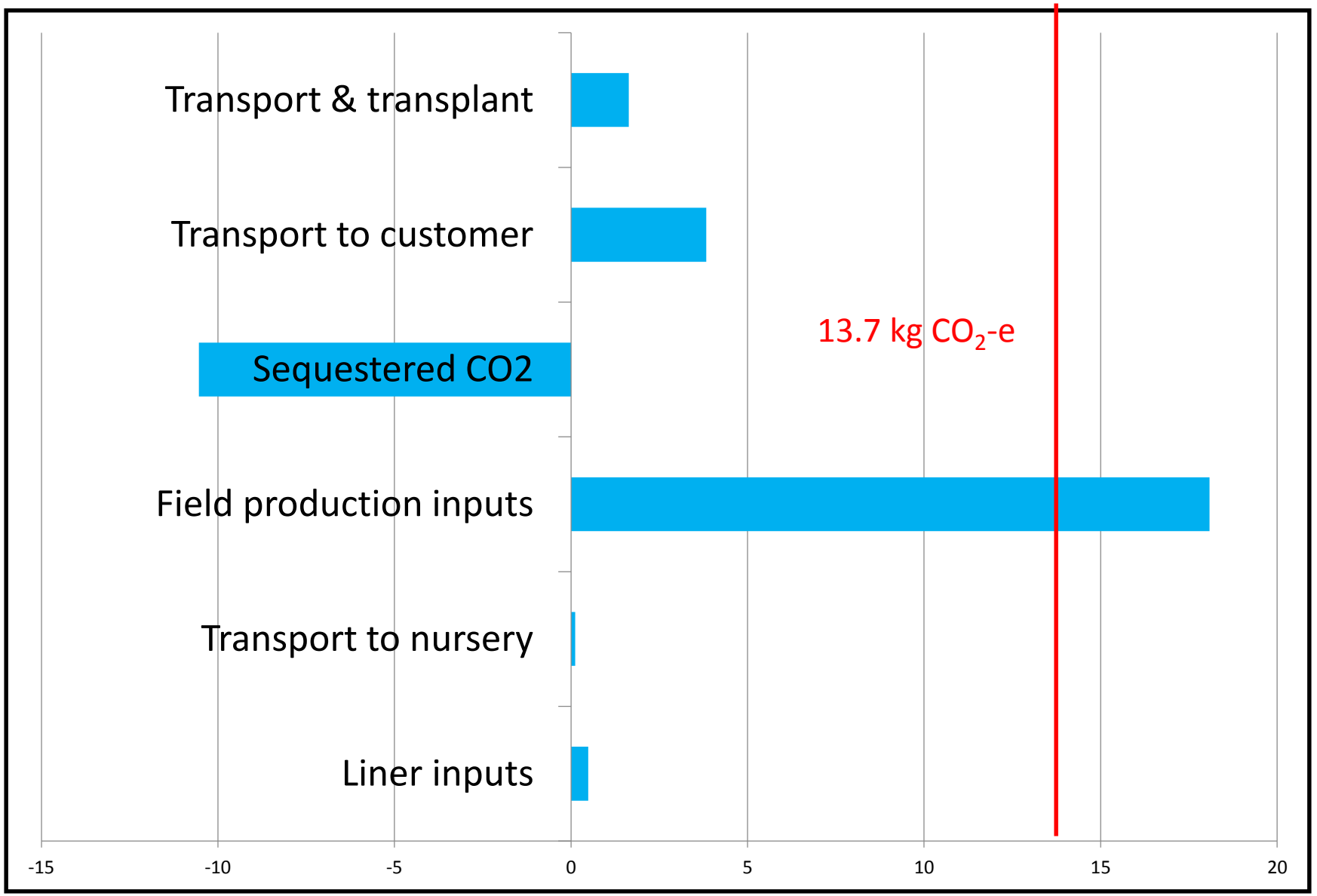
Redbud


Transport & transplant
Transport to customer
Sequestered CO2
Field production inputs
Transport to nursery
Liner inputs
-15
-10
-5
0
5
10
15
20

Redbud


Transport & transplant
Transport to customer
Sequestered CO2
Field production inputs
Transport to nursery
Liner inputs
-15
-10
-5
0
5
10
15
20

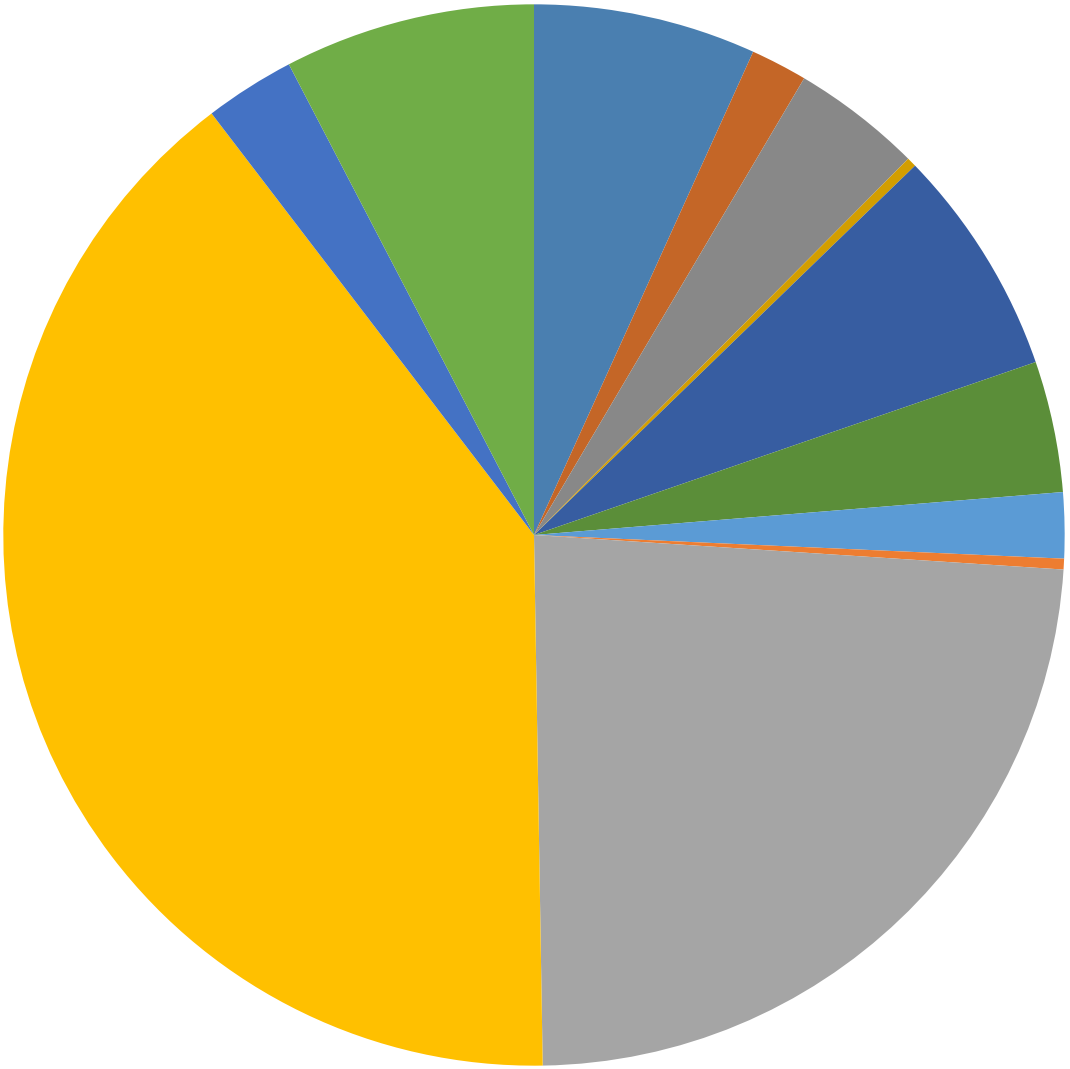
Redbud


Transport & transplant
Transport to customer
Sequestered CO2
Field production inputs
Transport to nursery
Liner inputs
13.7 kg CO_2-e
-15
-10
-5
0
5
10
15
20

Collaboration with Dr. Charlie Hall

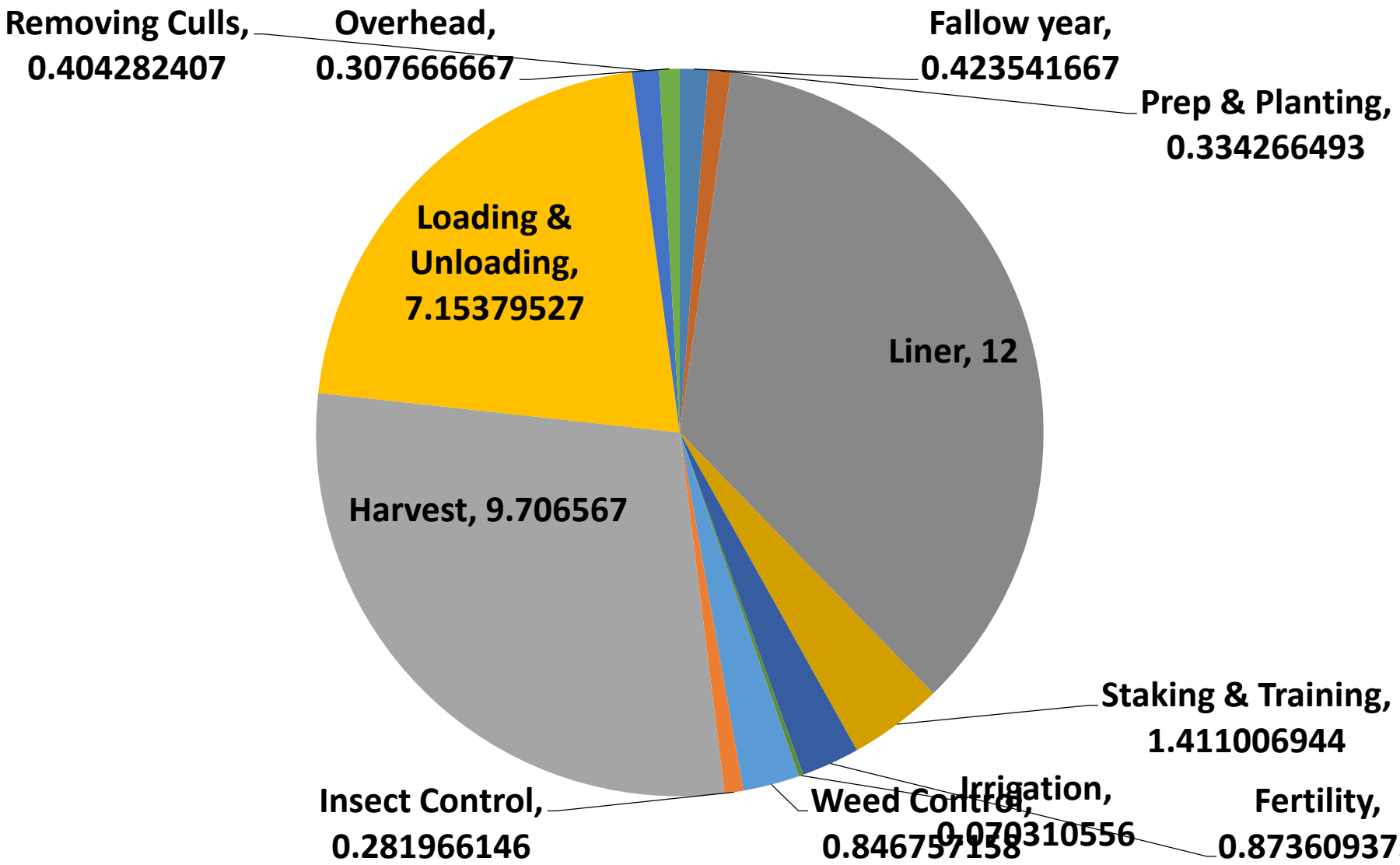
Relative GWP of input materials and equipment use during redbud field production phase (seed-to-gate)

(kg CO_2e / tree)



Relative cost of materials, labor and equipment use during redbud field production

($)



Farm-Gate GWP and Variable Costs of field-grown trees are closely related…

Primarily due to equipment use

“so what”
can be addressed by
“what if”
using the models

What if…. for redbud

it took 4 years in the field vs 3 years

Increase cutting-to-landscape carbon footprint by

4% to 14.1 kg CO_2e

Add $0.77 to the cost of each tree

What if…. for redbud

the cull rate was 15% instead of 10%

Increase seed-to-gate carbon footprint by

9% or 0.619 kg CO_2e

Add $1.42 to the cost of each tree

What if…. for redbud

reduce fertilizer by 1/3

Decrease cutting-to-landscape carbon footprint by

0.396 kg CO_2e

Reduce cost $0.28

Transport and Transplanting of Tree

- Transport 240 miles to customer, 120 trees/load
- Transport another 20 miles to the landscape site
- Tractor with boom positioned the tree for transplanting

What if…. for redbud

Product shipping distance was reduced by 1/3 to 160 miles

Decrease

cutting-to-landscape carbon footprint by

16% to 11.4 kg CO_2e

Save $2.60 per tree

What if…. for redbud

Transported tree to landscape 40 miles instead of 20 miles

Increase

cutting-to-landscape carbon footprint by

17% to 16 kg CO_2e

Cost by $1.87 per tree

What if…. for redbud

Transported 100 trees / load to landscaper instead of 120

Increase

cutting-to-landscape carbon footprint by

5% to 14.5 kg CO_2e

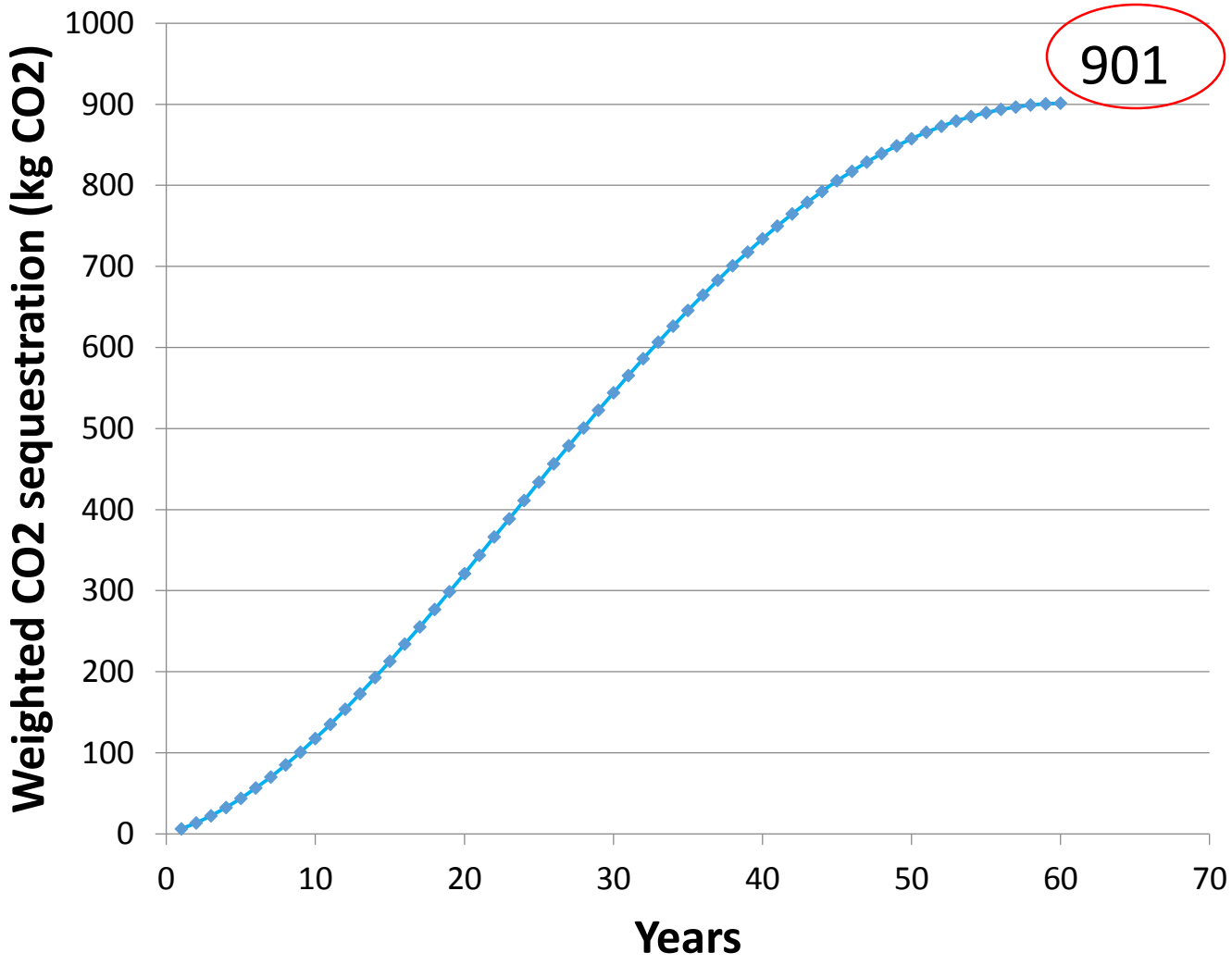
Cost by $1 per tree

Model System Assumptions:
Use Phase

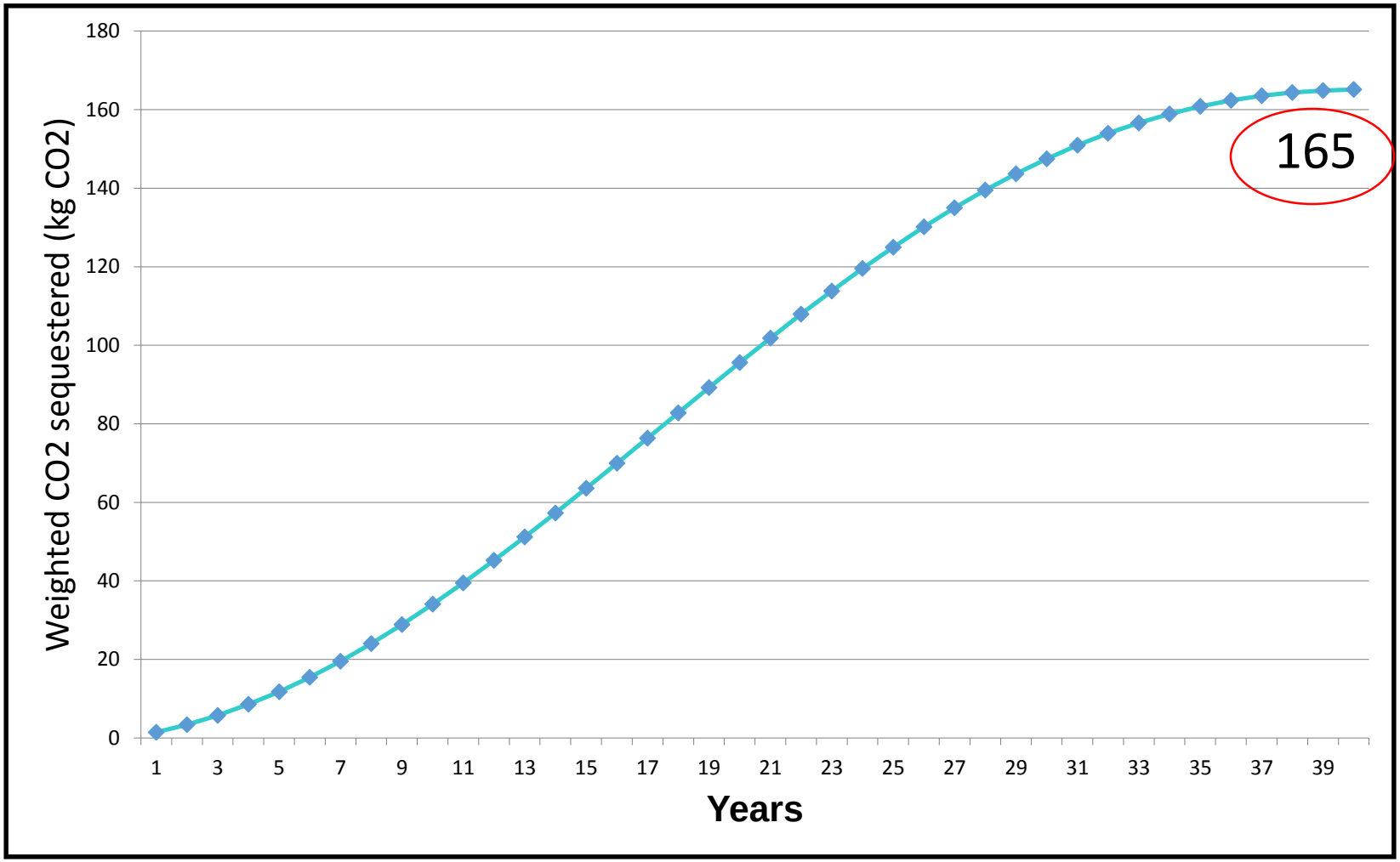
- Transplanted to a favorable suburban site
- 60 years of useful life for Red Maple
- 40 years of useful life for Redbud
- Will take-up CO_2 and store C as wood
  - CUFR Tree Carbon Calculator

It was assumed there was no specific investment of Greenhouse Gas Emissions during the maintenance of the tree in a suburban residence

Red Maple
CO_2 sequestration during use phase



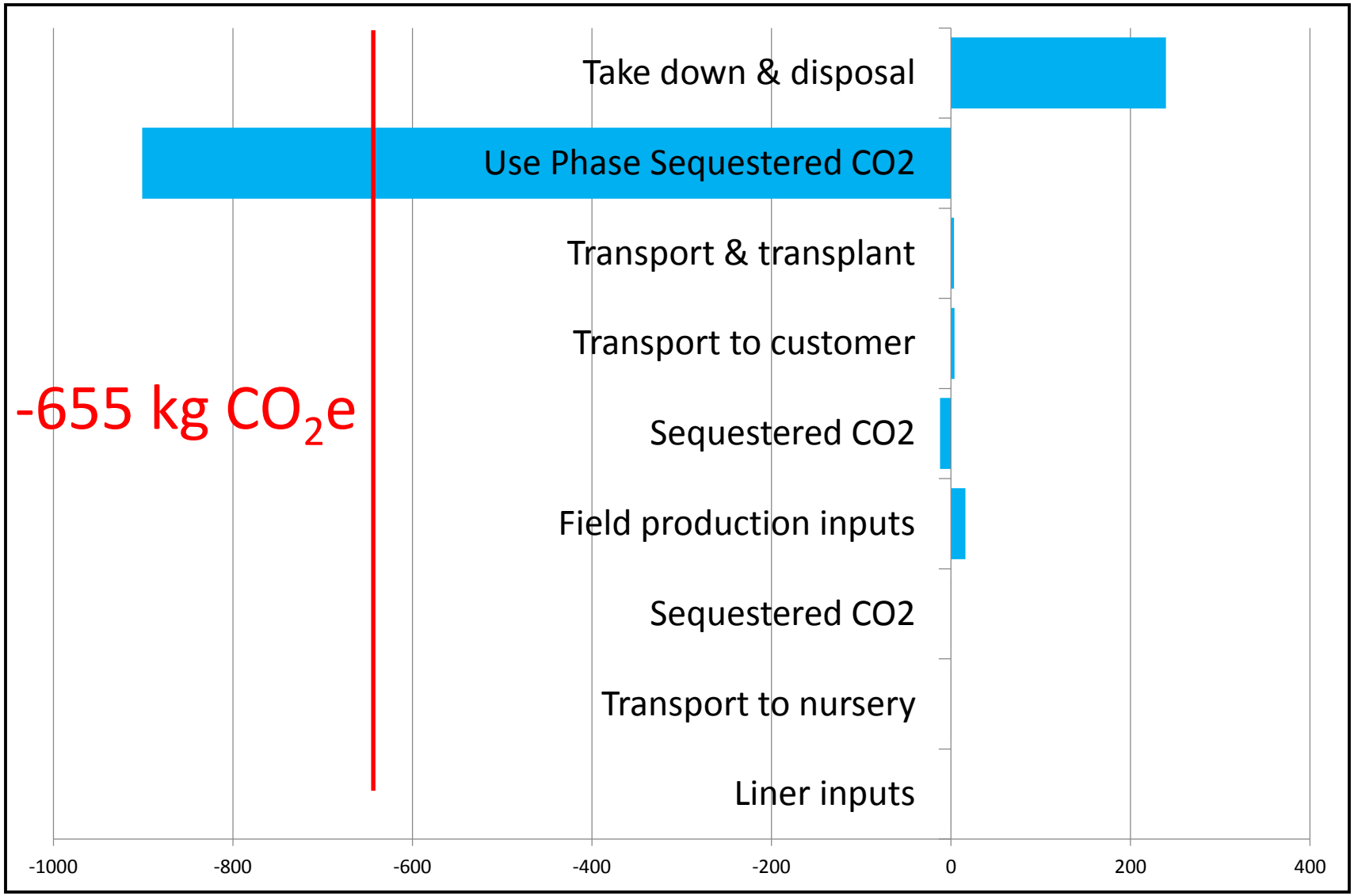
Redbud
CO_2 sequestration during use phase



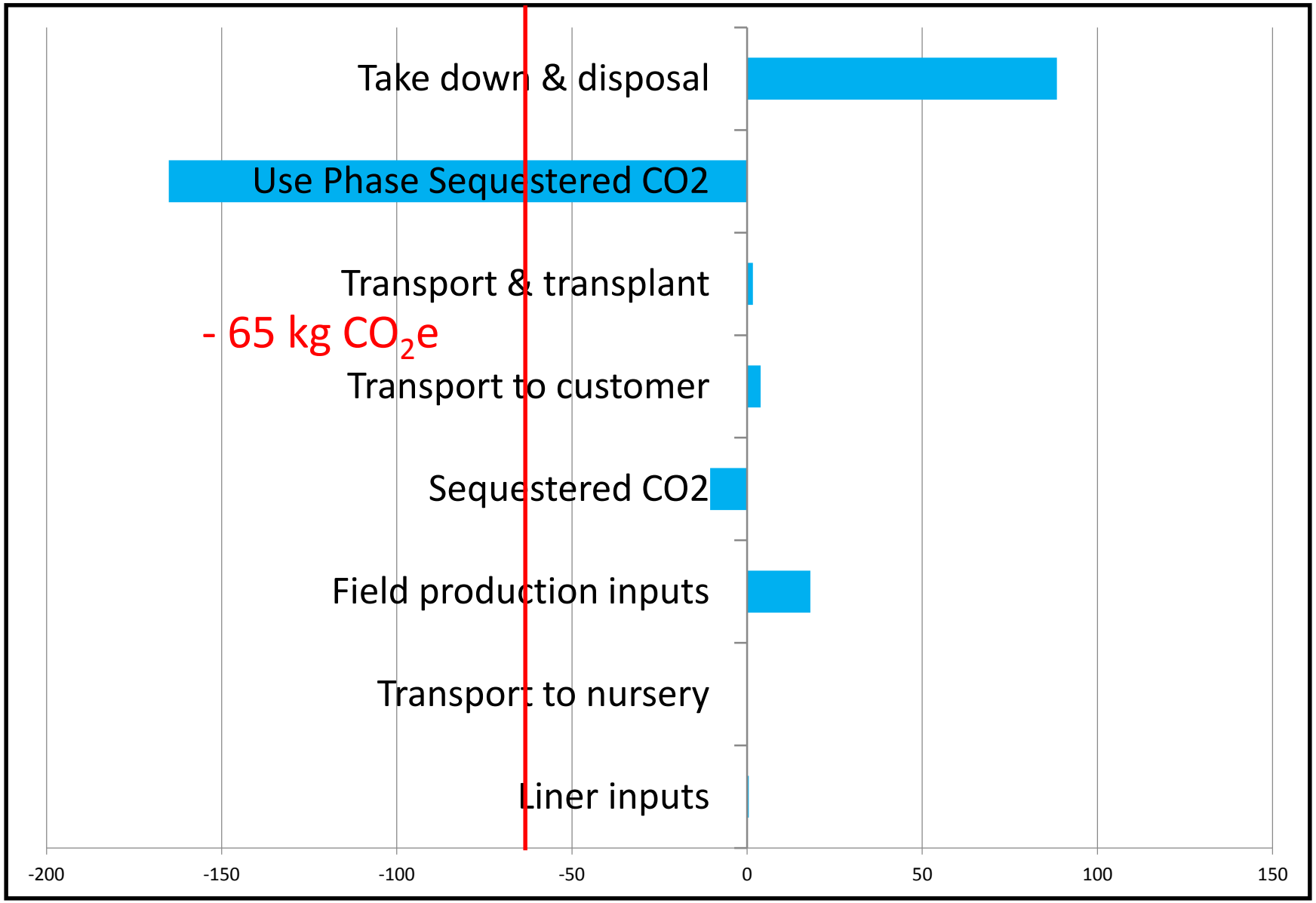
Model System Assumptions:
Take down and disposal

- Travel 24 miles in heavy truck
- Use chain saw 3.5 hours for Red Maple
  and
  1 hour for Redbud
- Use 140 hp chipper 2 hours for Red Maple
  and
  0.5 hours for Redbud… 120 hp chipper
- Chips hauled to site for municipal use as mulch
- Data based on interviews with certified arborists

Red Maple


Take down & disposal
Use Phase Sequestered CO2
Transport & transplant
Transport to customer
Sequestered CO2
Field production inputs
Sequestered CO2
Transport to nursery
Liner inputs
-655 kg CO_2e
-1000
-800
-600
-400
-200
0
200
400

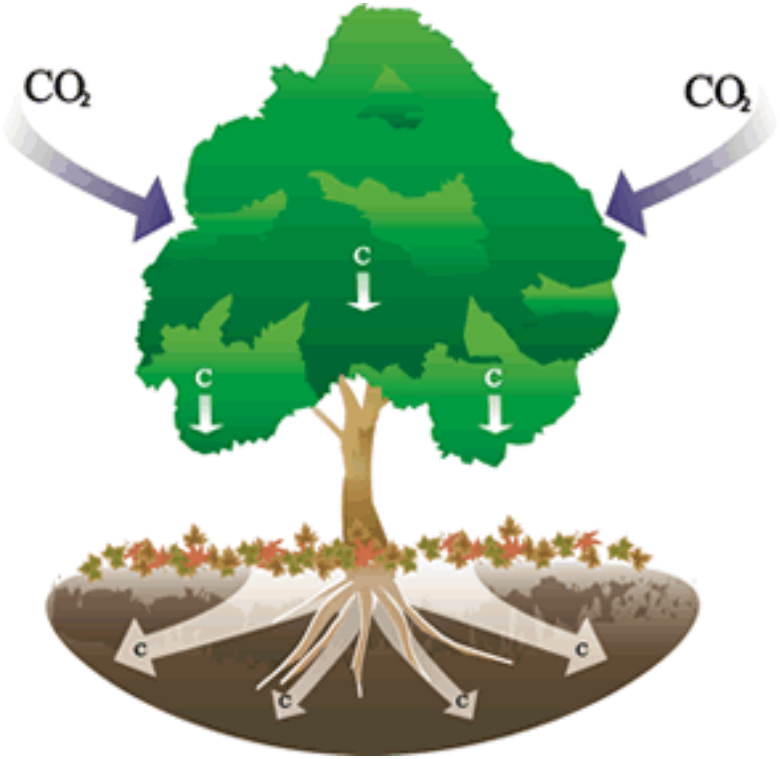
Redbud


Take down & disposal
Use Phase Sequestered CO2
Transport & transplant
- 65 kg CO_2e
Transport to customer
Sequestered CO2
Field production inputs
Transport to nursery
Liner inputs
-200
-150
-100
-50
0
50
100
150

Tree Species and Field Production "System" Comparisons

	Red Maple	Redbud
Liner - inputs	0.115	0.153
Liner - equipment use	0.311	0.169
Liner transport	0.105	0.123
Liner nursery overhead	0.005	0.157
Field Production - inputs	2.878	3.649
Field Production - equipment use	10.146	12.016
Field nursery overhead	1.083	1.304
Sequestered C in production	-12.100	-10.539
Transport to landscaper	4.565	3.831
Transport to site & transplant	3.766	1.633
Use phase sequestered C	-901.355	-165.111
Take down & disposal	239.546	88.444
Net Positive Life Cycle Impact	**-655.261**	**-64.769**

All units: Global Warming Potential (GWP) in kg CO_2 equivalents



50% of an individual tree or shrub's dry biomass is carbon, sequestered from the atmosphere via photosynthesis.

_____

Below ground, long term sequestration in soil not quantified at this time, but may be substantial for some plants.

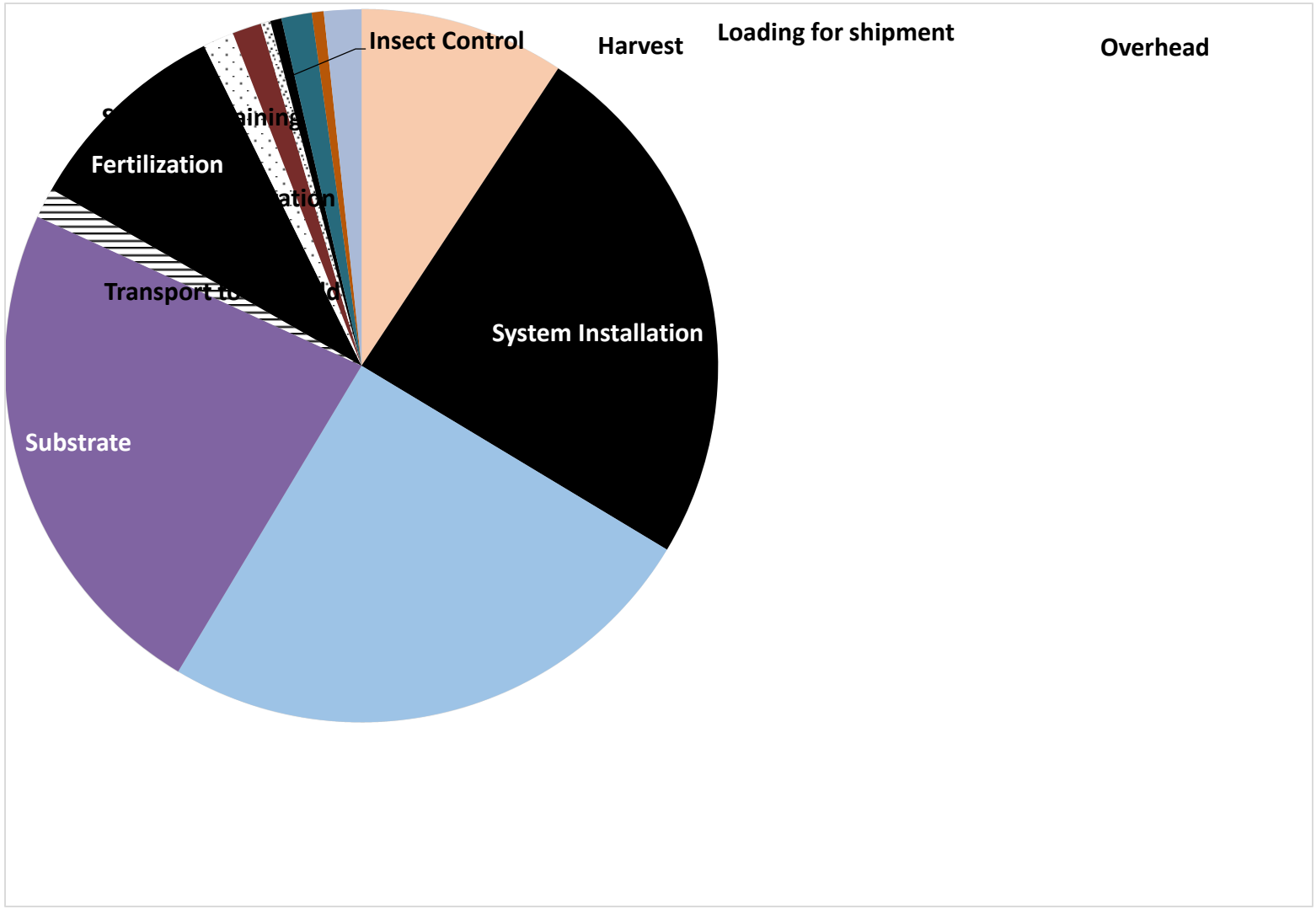
Landscape Plant	kg CO2
Red maple tree – *Acer rubrum*	655
Evergreen tree – *Picea pungens*	430
Flowering deciduous tree – *Cercis canadensis*	63
Deciduous shrub – *Viburnum spp.*	11
Evergreen shrub – *Taxus spp.*	9

Reduced global warming impact of above ground growth plant's life expectancy, after accounting for emissions during production and take down at end of life.

Image: US Forest Service

Relative GWP of red maple PIP production components in a #25 container (cutting-to-gate)

(kg CO_2e / tree)



2-inch caliper red maple tree

Pot-in-Pot Production

Component	GWP (kg CO_2e)	Variable Cost ($)
Rooted cutting stage	**0.0814**	**$0.3511**
Liner stage	**1.2784**	**$5.3856**
PIP nursery stage	**15.3171**	**$55.4877**
TOTAL - farm gate GWP & Cost	**10.7421**	**$55.4877**
Postharvest stage		
Transport tree to customer	2.6268	$3.4667
Transport tree to landscape	2.2837	$1.9023
Planting in the landscape	0.0000	$21.2010
Subtotal - postharvest stage	**4.9105**	**$26.5700**
TOTAL cutting to landscape	**15.6527**	**$82.0576**

Field Production

Component	GWP (kg CO_2e)	Variable Cost ($)
Rooted cutting stage	**0.0128**	**$0.0986**
Liner stage	**0.4885**	**$2.6421**
Field Production stage	**17.0730**	**$36.6583**
TOTAL - farm gate GWP & Cost	**12.4980**	**$36.6583**
Postharvest stage		
Transport tree to customer	4.6560	$6.2400
Transport tree to landscape	2.8544	$2.3777
Planting in the landscape	0.9194	$22.1499
Subtotal - postharvest stage	**8.4298**	**$30.7676**
TOTAL cutting to landscape	**20.9278**	**$67.4260**

Potential environmental impacts that can be modeled using LCA

- **Global warming potential** kg CO_2 eq
- **Ozone depletion** kg CFC-11 eq
- **Smog** kg O_3 eq
- **Acidification** kg SO_2 eq
- **Eutrophication** kg N eq
- **Carcinogenic human toxicity** CTUh
- **Non-carcinogenic human toxicity** CTUh
- **Respiratory effects** kg PM2.5 eq
- **Ecotoxicity** CTUe
- **Fossil fuel depletion** MJ surplus

What are Ecosystem Services?

- ecosystem services = benefits provided to human from ecosystems.
- Landscapes / built environment primarily concerned with "regulating" and "cultural" services provided by plants in landscape.

Thanks to Josh Knight, Extension Associate

Regulating services

Air Quality

Human Health

Biodiversity Potential / Wildlife Habitat

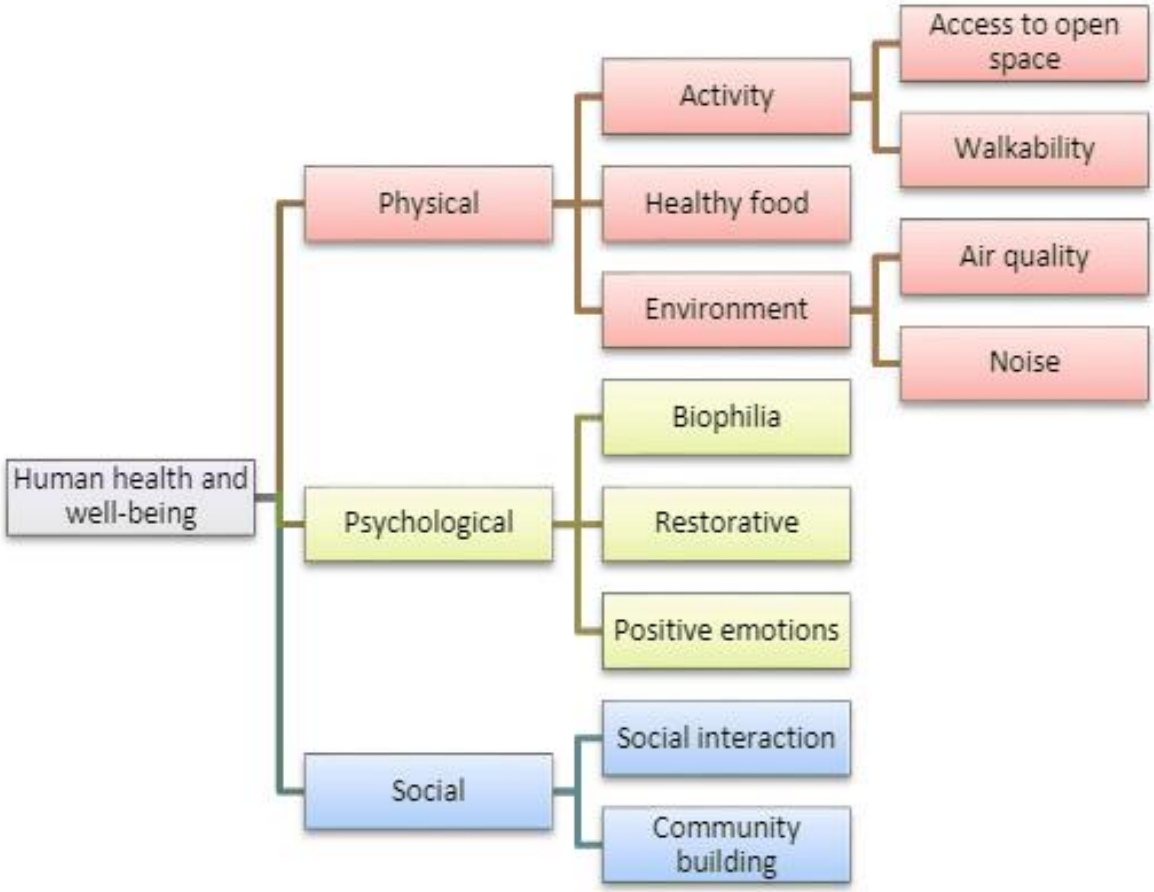
Carbon Sequestration

Energy Conservation and Microclimate Regulation

Noise Reduction

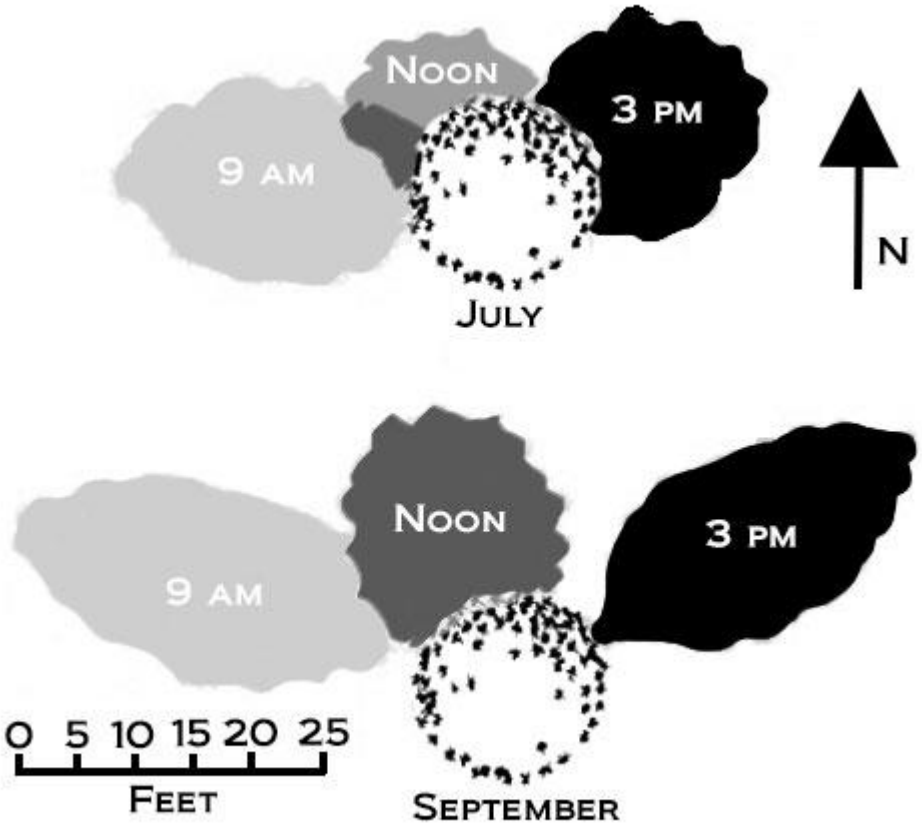
Stormwater management

Summary of human health and well-being benefits of Green Infrastructure



Source: M. Ely and S. Pitman 2014

Microclimates and Energy Conservation



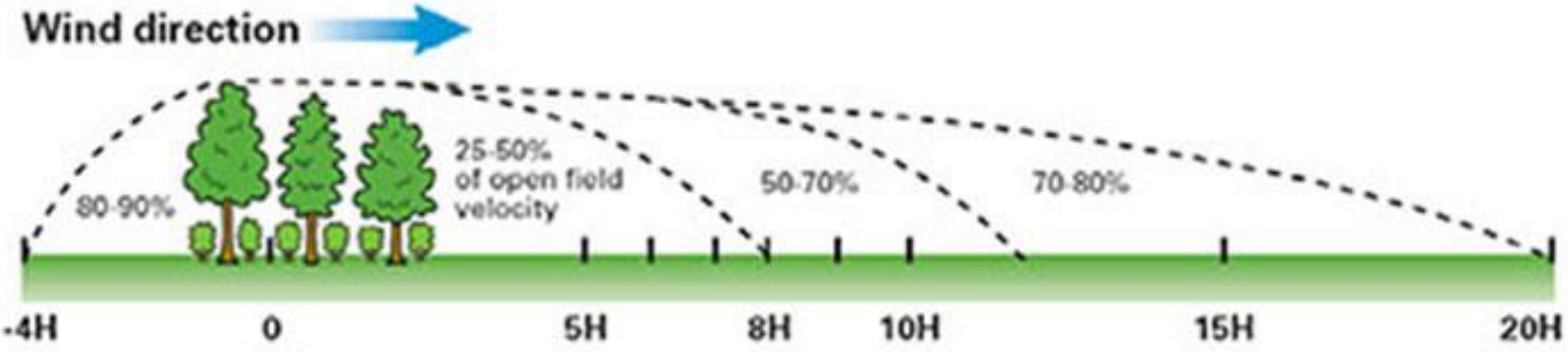
Shade patterns shift **daily and seasonally**

Suburbs with trees:
Air 4-6 degrees cooler

Schoolyards with trees:
Air 20 degrees cooler

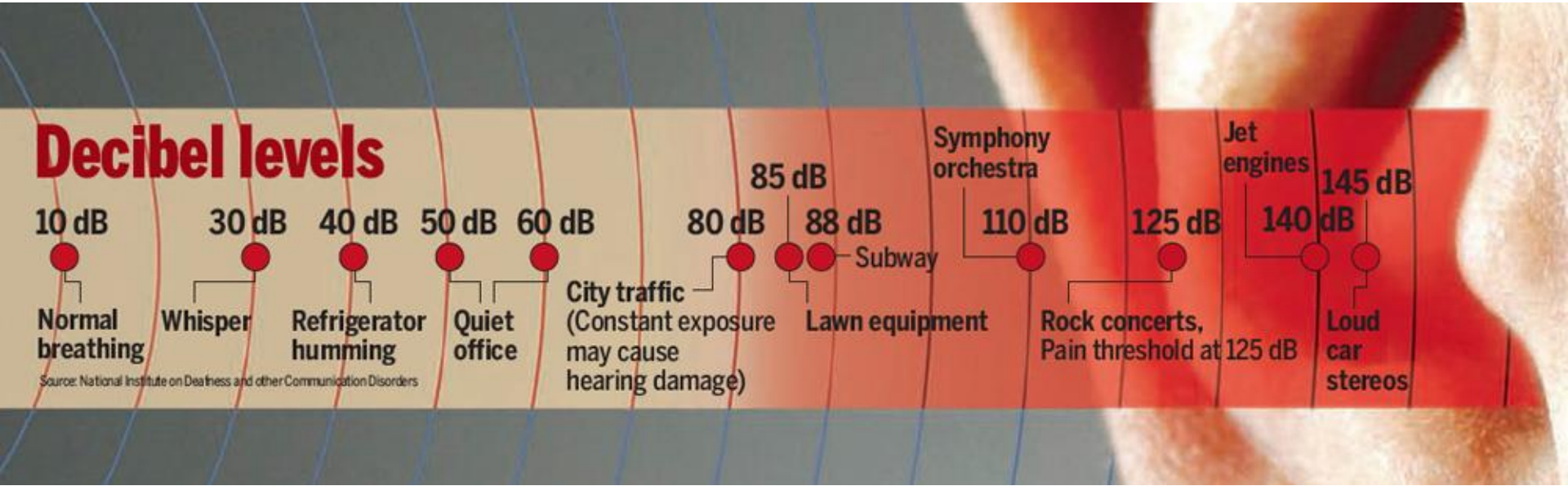
1 Properly watered tree can evaporate-transpire
40 gallons of water each day:
offsetting heat equivalent from
100x 100 watt lamps burning for 8 hours.

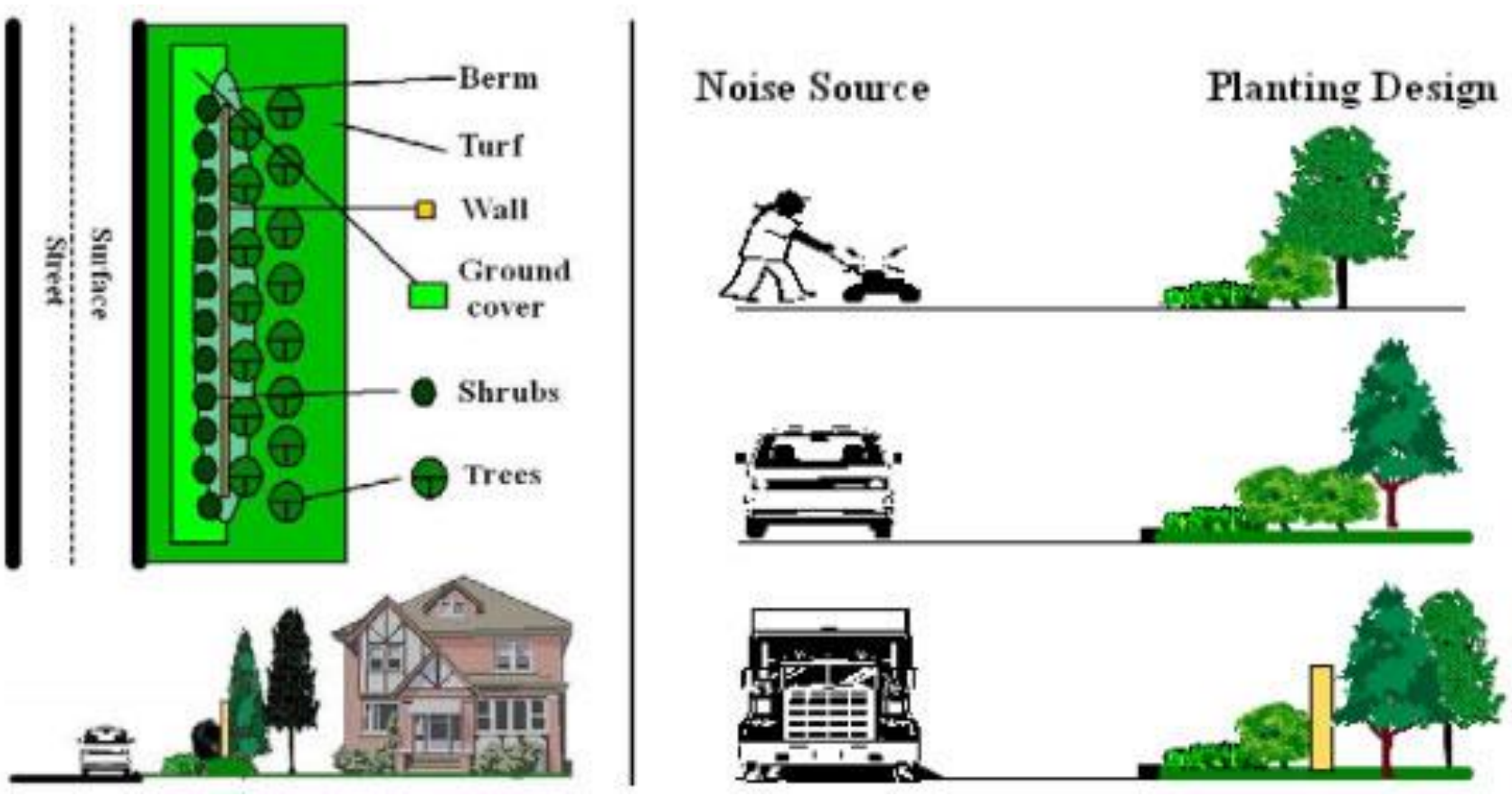
Height vs. Distance



Noise Reduction

- Cities are loud
- Constant exposure to city traffic sounds can cause hearing damage!
- Decibel is a logarithmic unit: "small" unit increases or decreases are more noticeable at higher levels





More layers reduce louder noises.

Source: Georgia Forestry Commission

GEORGIA FORESTRY COMMISSION

Green Buffers for Screening and Noise Reduction

"Plant materials help attenuate sound and 'calm' the noise. Some types of plants are better at performing this function than others. **Efficient trees and shrubs have thick, waxy leaves, dense evergreen foliage, and branches that extend to the ground.**"

- Georgia Forestry Commission

Stormwater Management

Impervious Surfaces cause Stormwater Runoff

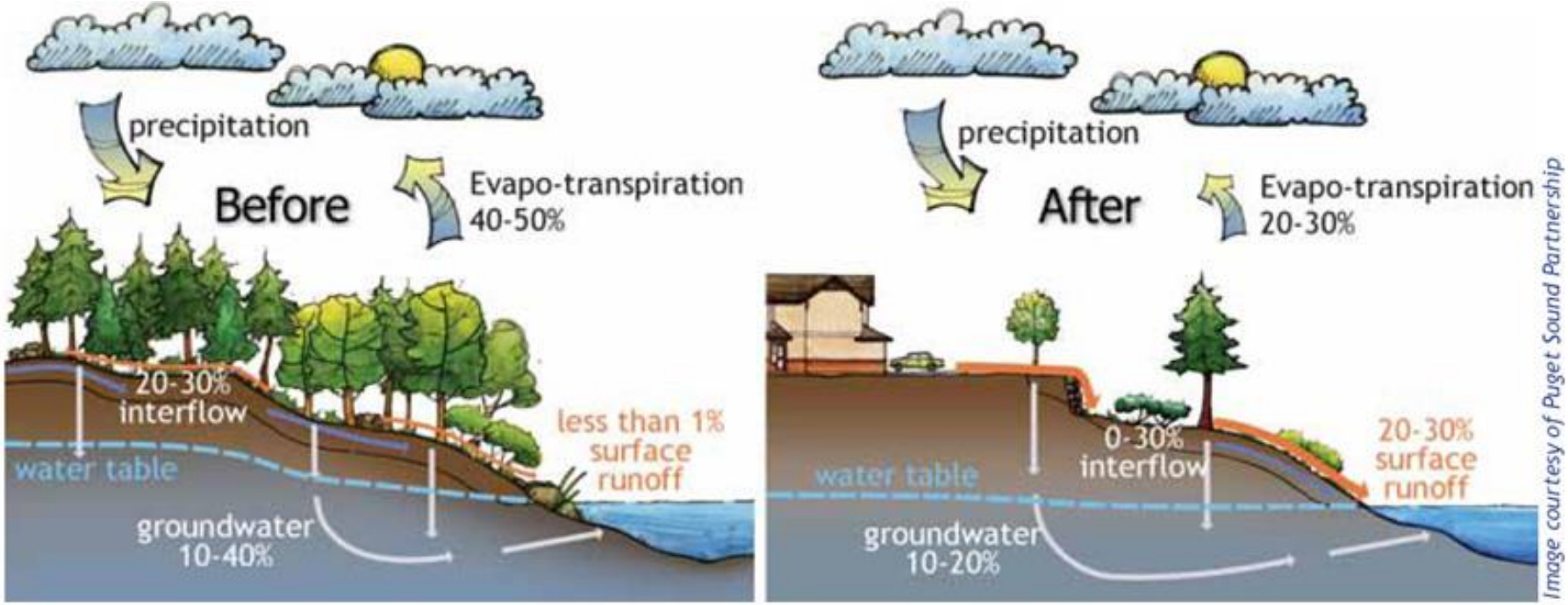


Image courtesy of Puget Sound Partnership

Before *development almost all rainfall is taken up by plants, evaporates or infiltrates through the ground.*
After *conventional development, surface runoff increases significantly while evaporation and infiltration into the ground decrease.*

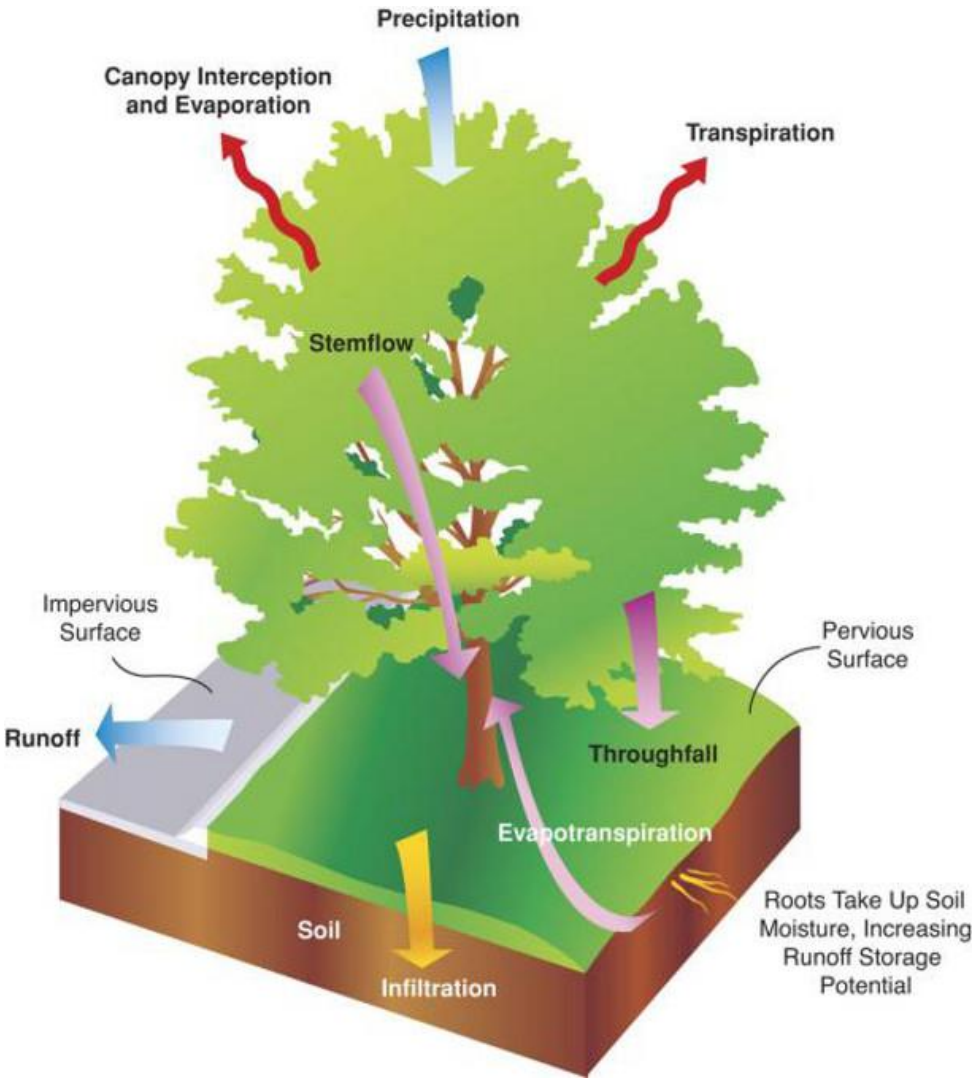
Problems with runoff:

- Toxic! Metals, animal waste, pathogens.
- Gravelly/Sandy soils allow rapid infiltration of stormwater, can contaminate ground water.
- Leading cause of water pollution in urban creeks/waterways.
- Impaired habitat for fish / wildlife.

Grey infrastructure is at risk during peak events.

Green infrastructure flattens these peaks by slowing runoff during and after rainfall events.

Green infrastructure improves the capacity of existing grey infrastructure, saving public funds.



Cultural Services

- Aesthetic, Recreation and Cultural values difficult to quantify, though Property Values representative

- "150% return on investment of 8-10% of the value of the property is **conservative**" – John Gidding, HGTV's "Curb Appeal"

Monetary credit for carbon sequestration… in our future

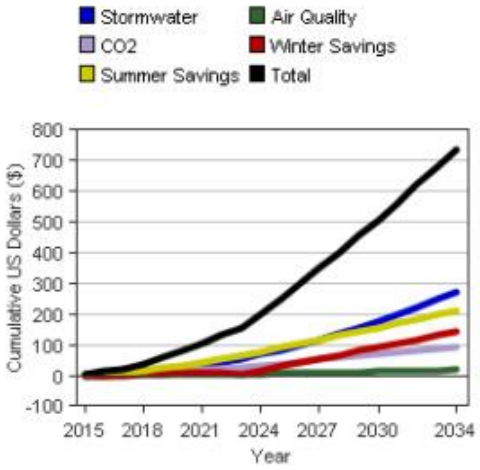
- Sequestered carbon has monetary “credits” in a carbon “market.”
- According to a Bloomberg Business Report, the August, 2015 value for off-setting carbon dioxide equivalents was $662 per ton.
- The “weighted” 655 kg CO_2 (0.7 tons) sequestered by a red maple tree during its life cycle would have a value of $463.
- We don’t have a functioning market yet for carbon credits!

Summary
i-Tree Lexington

Over 20 years, a single red maple planted in 2015 located ~25' from the southwest corner of a climate controlled structure in Lexington, KY will…

- Save **$143** in winter heating costs
- Save **$210** in summer cooling costs
- Intercept 44,028 gallons of water
  - Saving the community **$273** in stormwater reduction costs
- Save **$18** in air quality improvement upgrades
- Reduce contributions to atmospheric carbon by 9,766 lbs through sequestration and decreased energy production needs.

- Total Value Added: **>$700**



Cumulative tree benefit forecast for a properly sited red maple planted in 2015. (Lexington, KY)

Source: i-Tree Design itreetools.org

Summary
i-Tree Gainesville

Over 20 years, a single red maple planted in 2016 located ~25' from the western face of a climate controlled structure in Gainesville, FL will…

- Save $20 in winter heating costs
- Save $511 in summer cooling costs
- Intercept 39,271 gallons of water
  - Saving the community $238 in stormwater reduction costs
- Save $26 in air quality improvement upgrades
- Reduce contributions to atmospheric carbon by 11,191 lbs through sequestration and decreased energy production need.

- Total Value Added: >$900

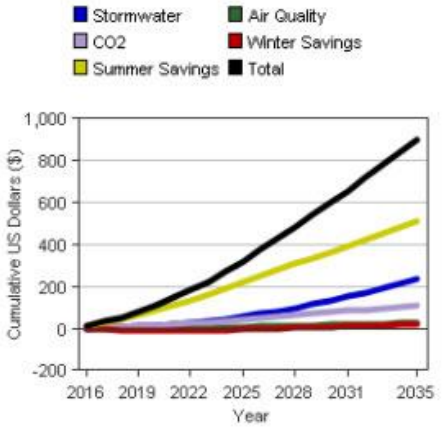


Figure 1. Tree benefit forecast for 20 years

Cumulative tree benefit forecast for a properly sited red maple planted in 2016. (Gainesville, FL)

Source: i-Tree Design itreetools.org