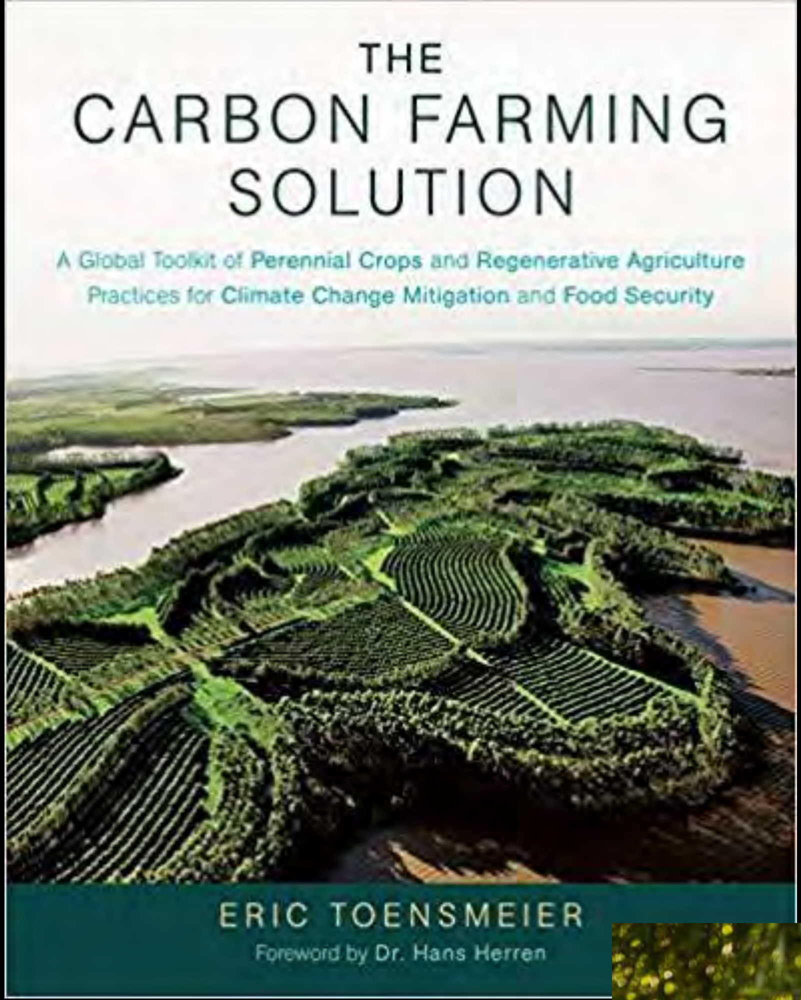


Carbon Farming

Inspired by

The Carbon Farming Solution

By

Eric Toensmeier

Eric Toensmeier

- Eric Toensmeier is the award-winning author of *Paradise Lot* and *Perennial Vegetables*, and the co-author of *Edible Forest Gardens*. He is an appointed lecturer at Yale University, a Senior Biosequestration Fellow with Project Drawdown, and an international trainer. He has studied useful perennial plants and their roles in agroforestry systems for over two decades.
- He is the author of ***The Carbon Farming Solution***: A Global Toolkit of Perennial Crops and Regenerative Agricultural Practices for Climate Change Mitigation and Food Security.

Why Attention to Farming Practices are Critical in the coming decades

- Food security
- Human Need

Food Security

- i. Agriculture is the single largest employer in the world, providing livelihoods for 40 per cent of today's global population. It is the largest source of income and jobs for poor rural households.

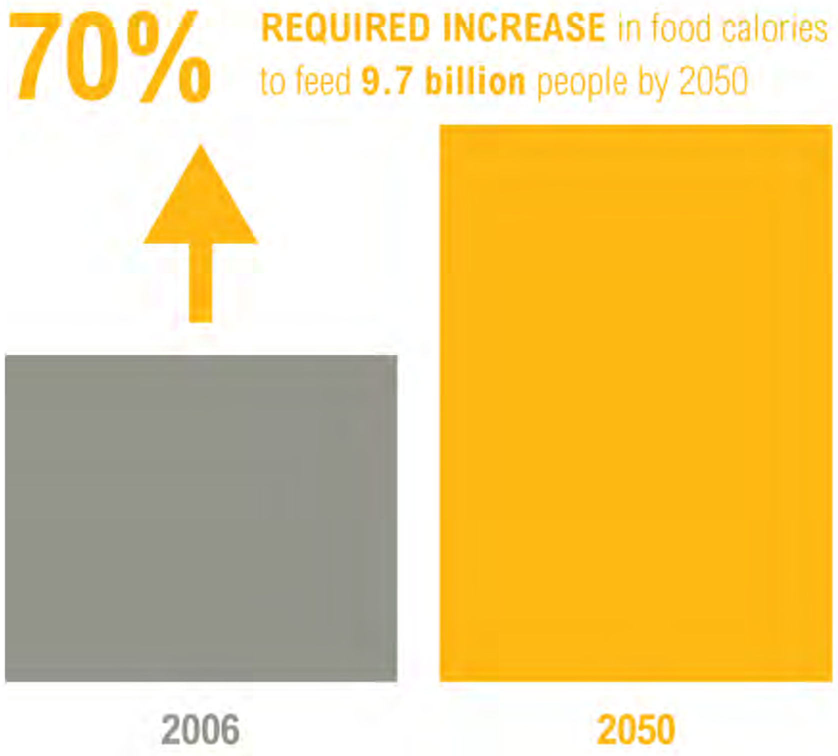
- ii. 500 million small farms worldwide, most still rain fed, provide up to 80 per cent of food consumed in a large part of the developing world. Investing in smallholder women and men is an important way to increase food security and nutrition for the poorest, as well as food production for local and global markets.

Human need

- i. Figure Food Gap: By 2050, only 31 years from now, the world will need 70% more calories than it did in 2006. This is a whopping increase in demand.

- ii. Not only are there more people, people are consuming more calories per capita than ever before. Fig food consumption by nation

The World Needs to Close a 70% Food Gap



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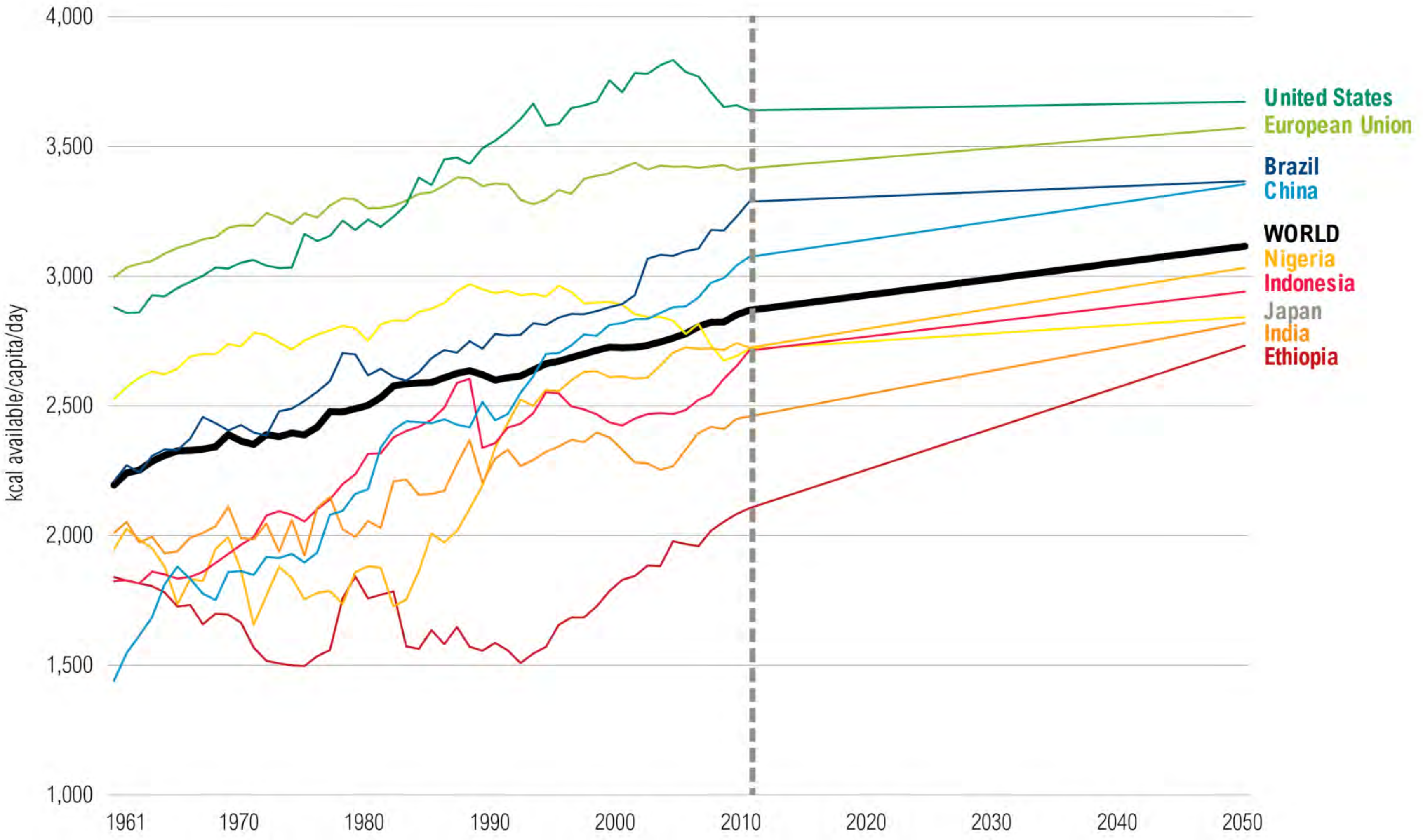
People Are Consuming More Calories



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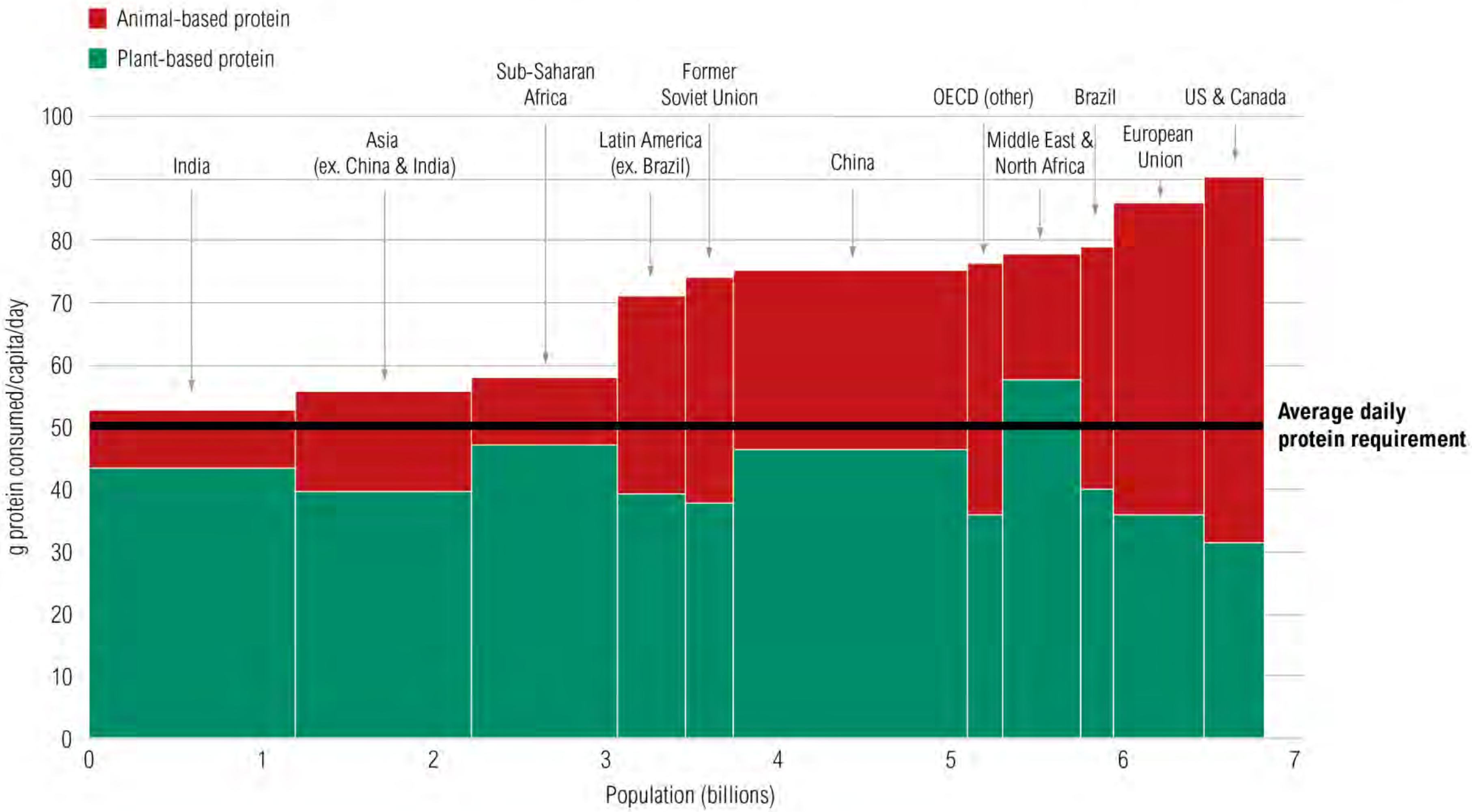
Human need

- iii. People are increasing demand for protein and are consuming more protein than needed for daily requirements
- iv. Much of this increase in demand is in the form of animal protein
- v. Animal Protein is much more resource intensive than plant protein. Some animal protein sources are significantly worse than others.

People Are Eating More Protein than They Need—Especially in Wealthy Regions



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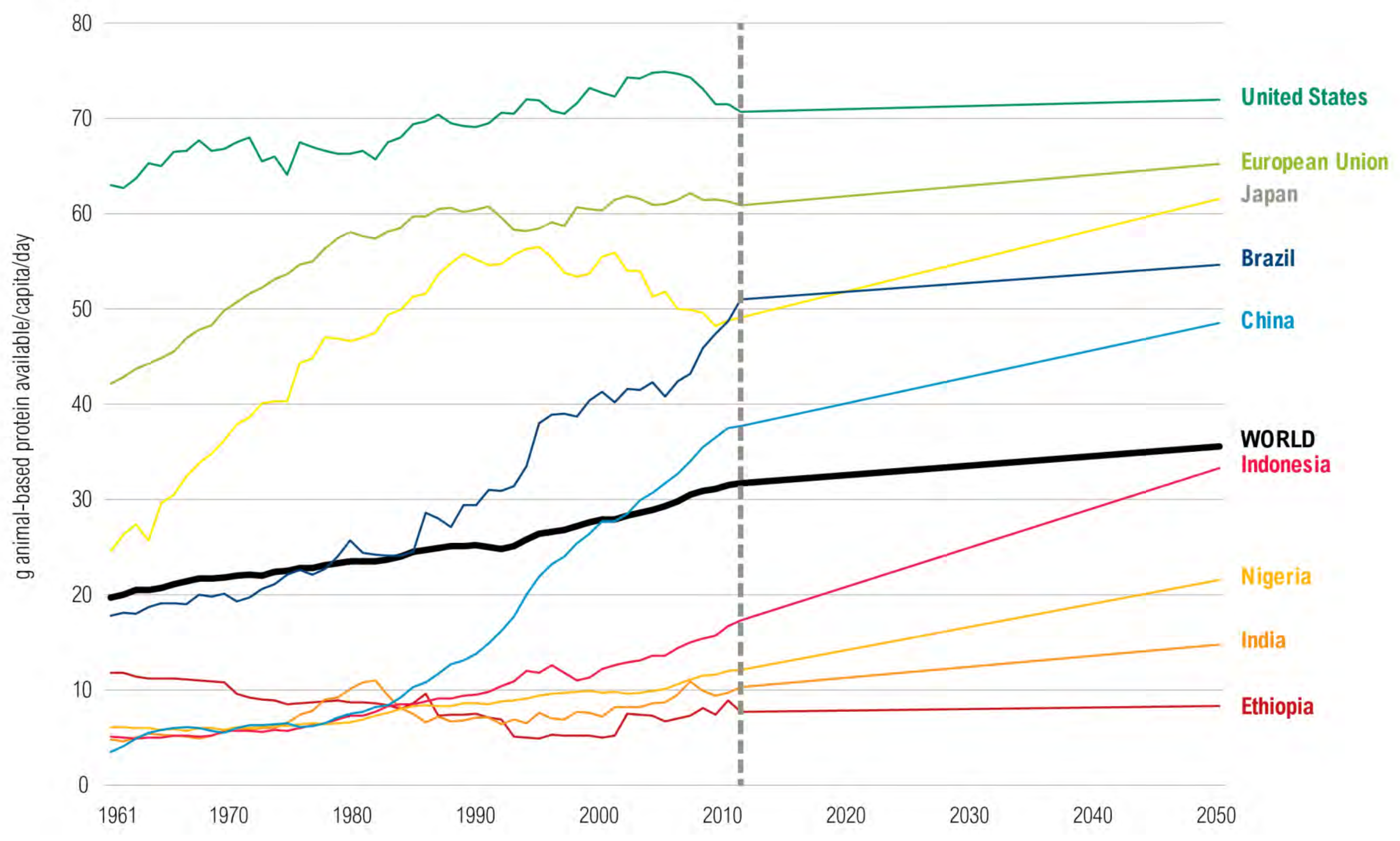
People Are Consuming More Animal-Based Protein



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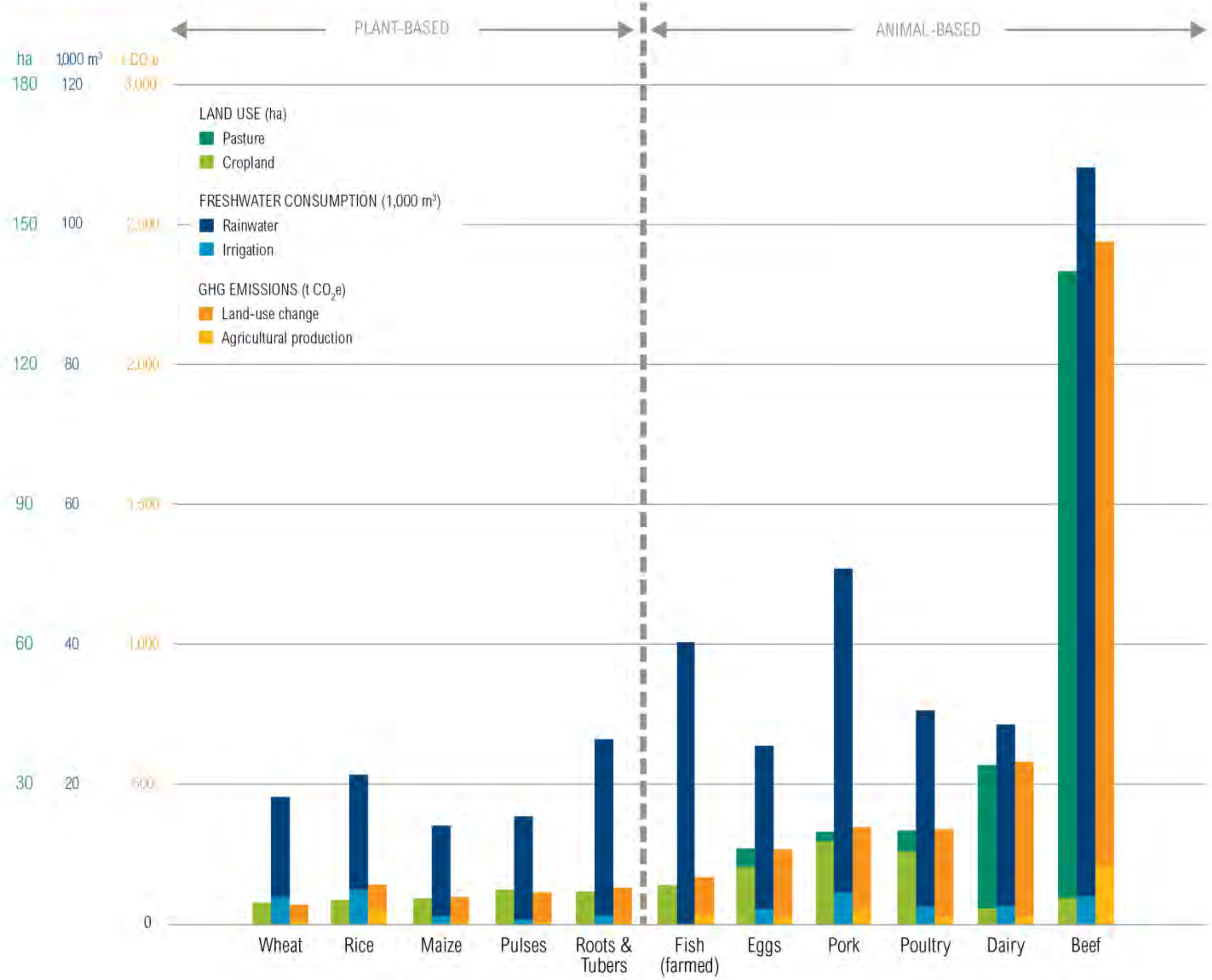
Animal-Based Foods Are More Resource-Intensive than Plant-Based Foods

PER TON PROTEIN CONSUMED



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Protein Scorecard

	FOOD	IMPACT (GHG emissions per gram of protein)	COST (Retail price per gram of protein)
LOW	Wheat		$
	Corn		$
	Beans, chickpeas, lentils		$
	Rice		$
	Fish		$$$
	Soy		$
	Nuts		$$$
	Eggs		$$
MEDIUM	Poultry		$$
	Pork		$$
	Dairy (milk, cheese)		$$
HIGH	Beef		$$$
	Lamb & goat		$$$

Lighter shade shows emissions from agricultural production, darker shade shows emissions from land-use change.

Sources: GlobAgri-WRR model developed by CIRAD, Princeton University, INRA, and WRI (GHG data); USDA and BLS (2016) (US retail price data).

www.wri.org/proteinscorecard

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Human need

- vi. Beef Foot print is huge world wide. If cattle were a nation, it would be the world's third largest GHG emitter behind China and USA. Demand for beef by 2050 is expected to grow by 95%.

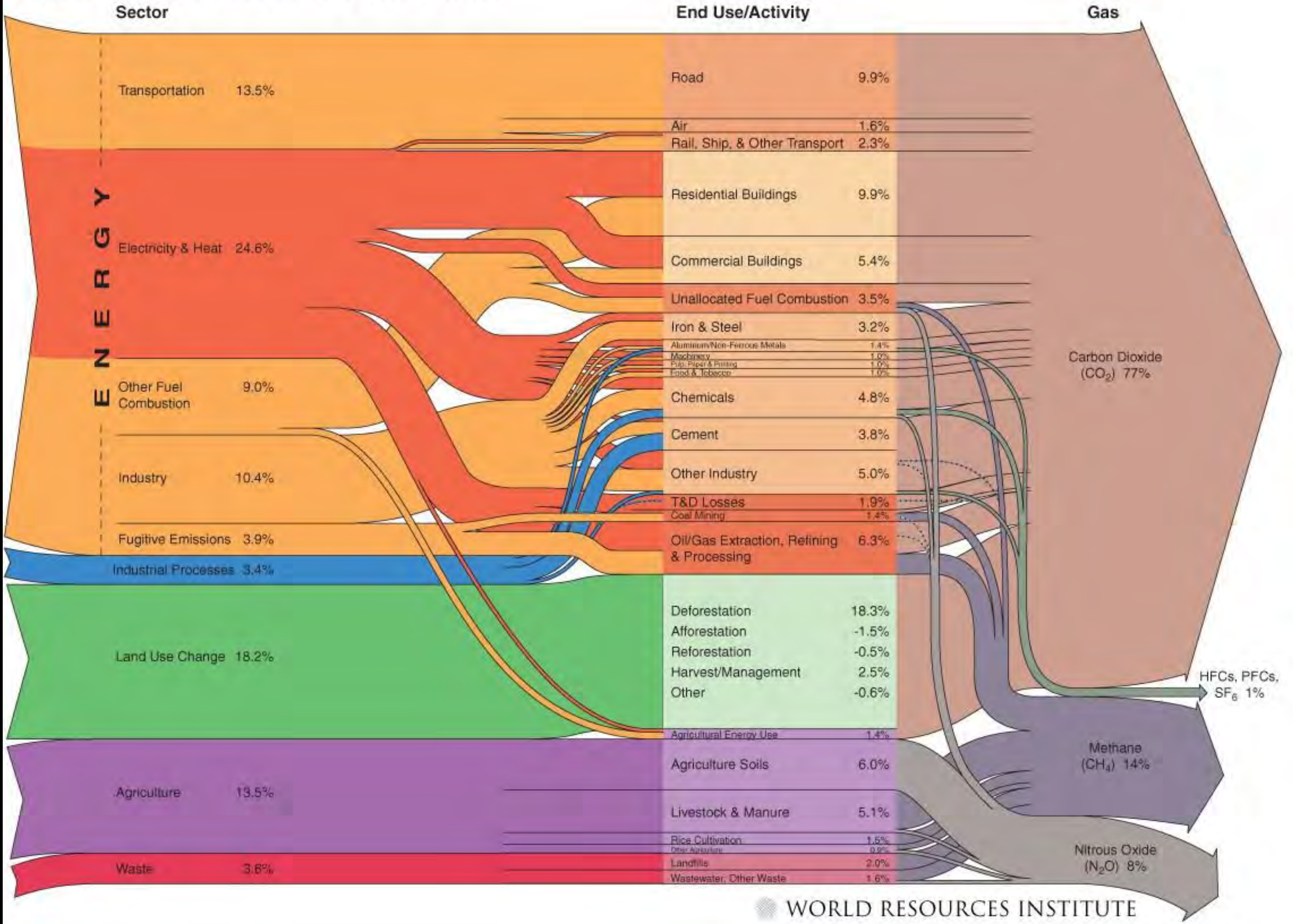
- vii. Alteration of dietary habits, without any special farming techniques can alter GHG emissions. Dietary changes are compared with a standard US diet. Reduction of beef consumption by 70% is equal to a vegetarian diet in terms of land use efficiency and GHC emissions.

- viii. Even a 40% reduction in consumption of beef and dairy has huge savings in both land use and GHG emissions: twice the land mass area of India would be saved and would avoid 168 billion tons of future GHG emissions (time period?)

World GHG Emissions Flow Chart

- Globally one third to one half of all agricultural GHG emissions are related to livestock and manure

World GHG Emissions Flow Chart



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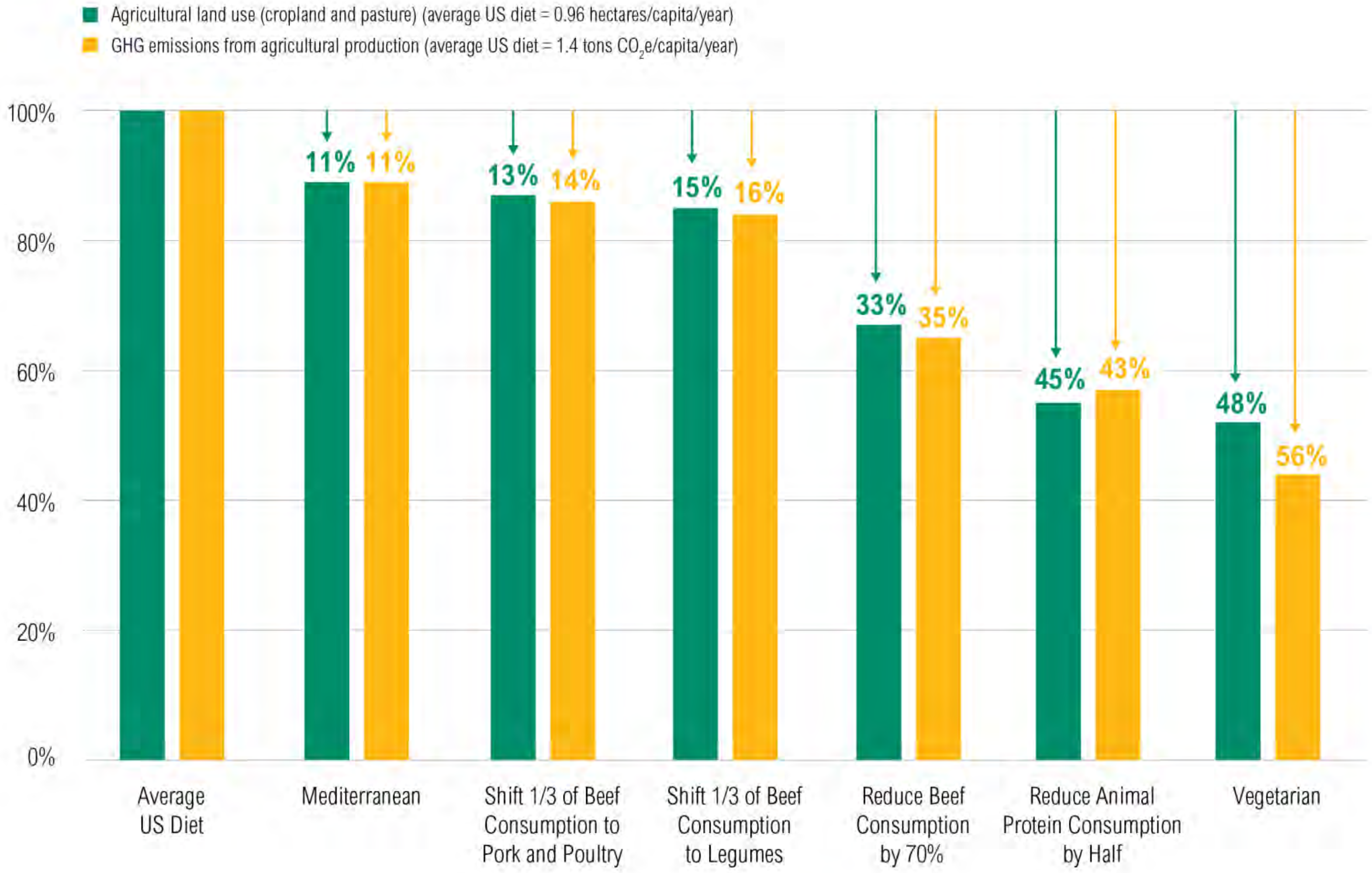
Shifting High Consumers' Diets Can Greatly Reduce Per Person Land Use and GHG Emissions



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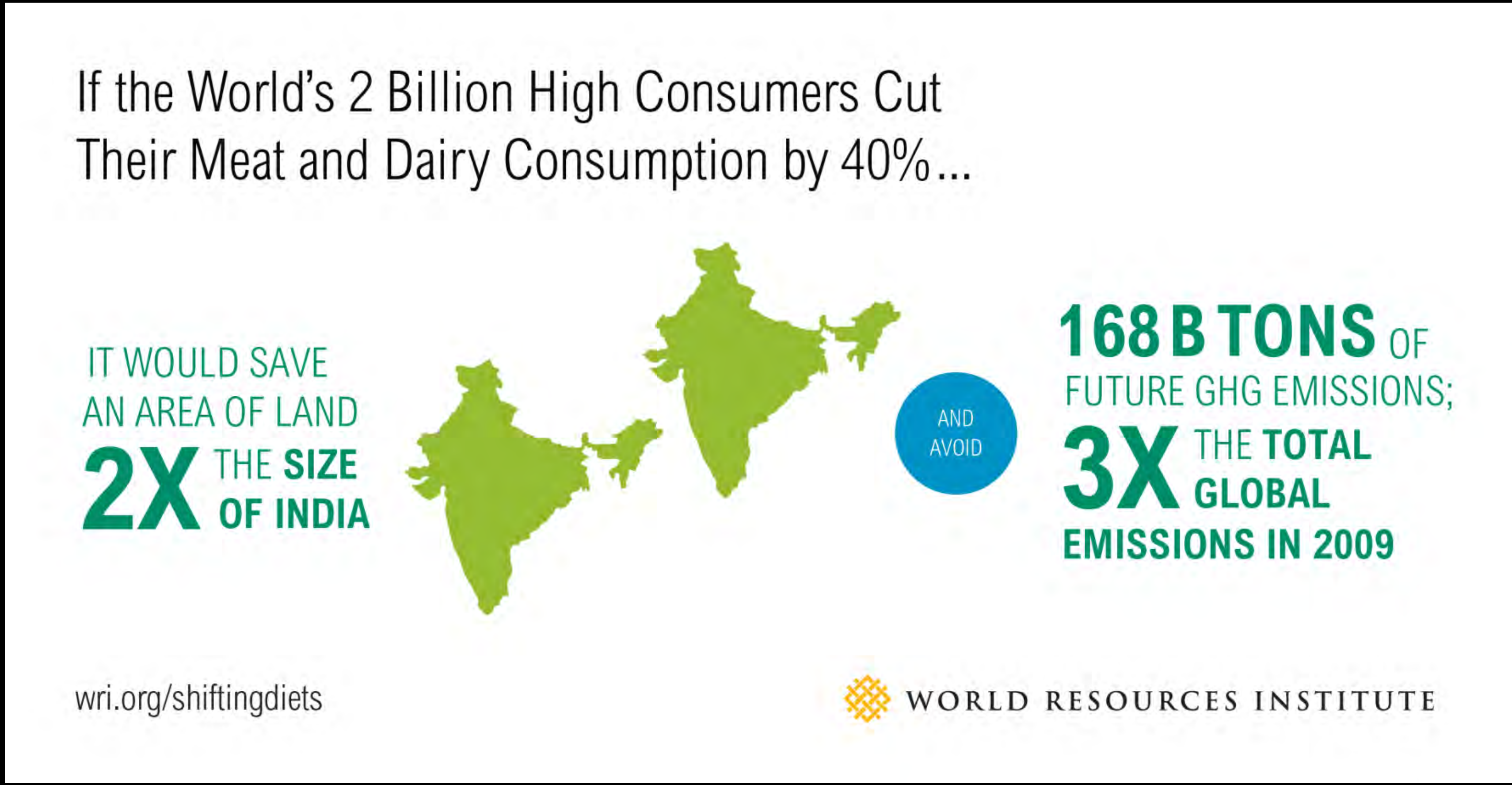
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Their Meat and Dairy Consumption by 40%...
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GLOBAL
EMISSIONS IN 2009
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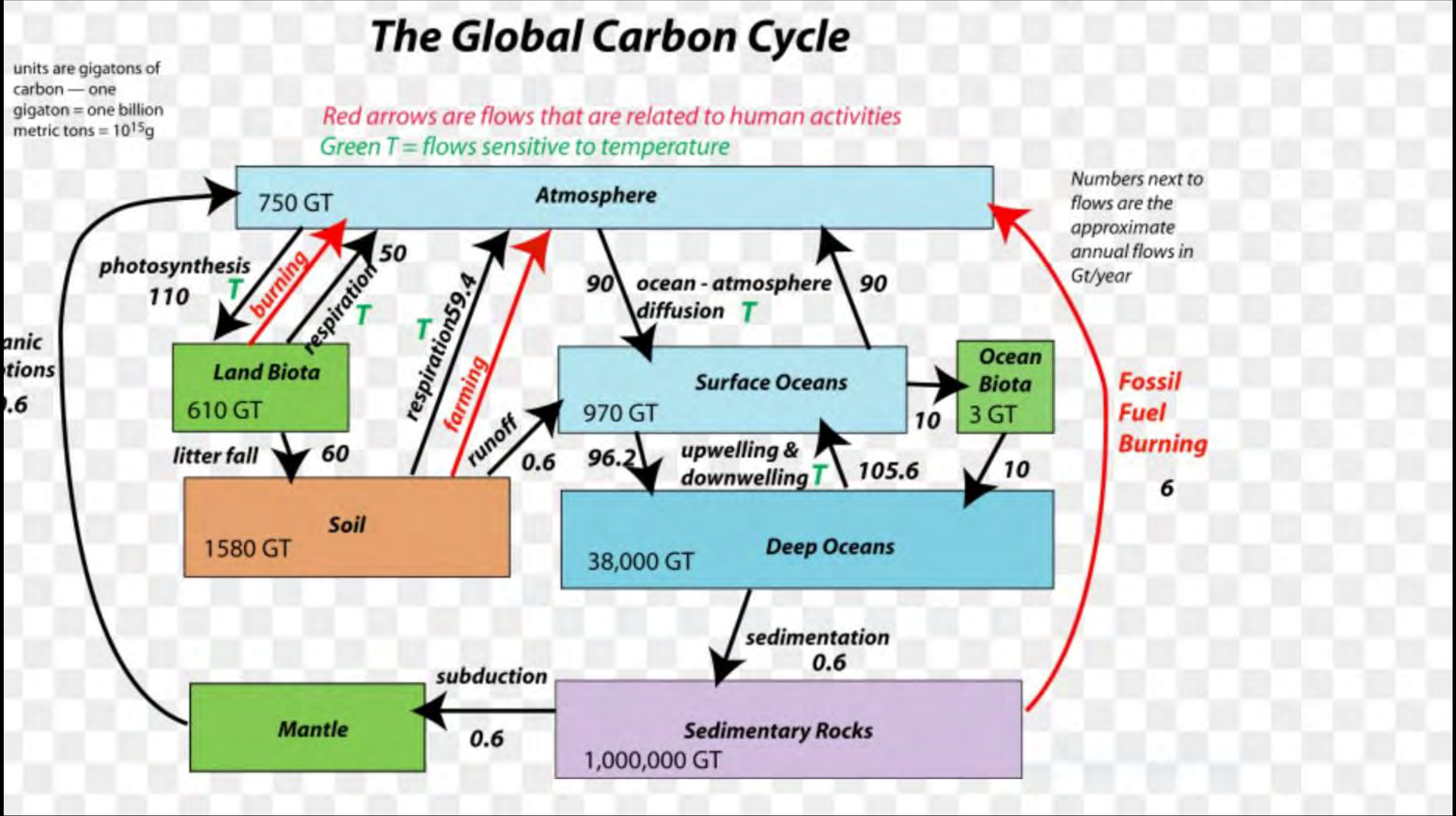
Solutions for Meeting Increasing Need and Demand for Agriculture While Mitigating Climate Change and Global Warming

- The Carbon Farming Solution

The Planetary Carbon Cycle

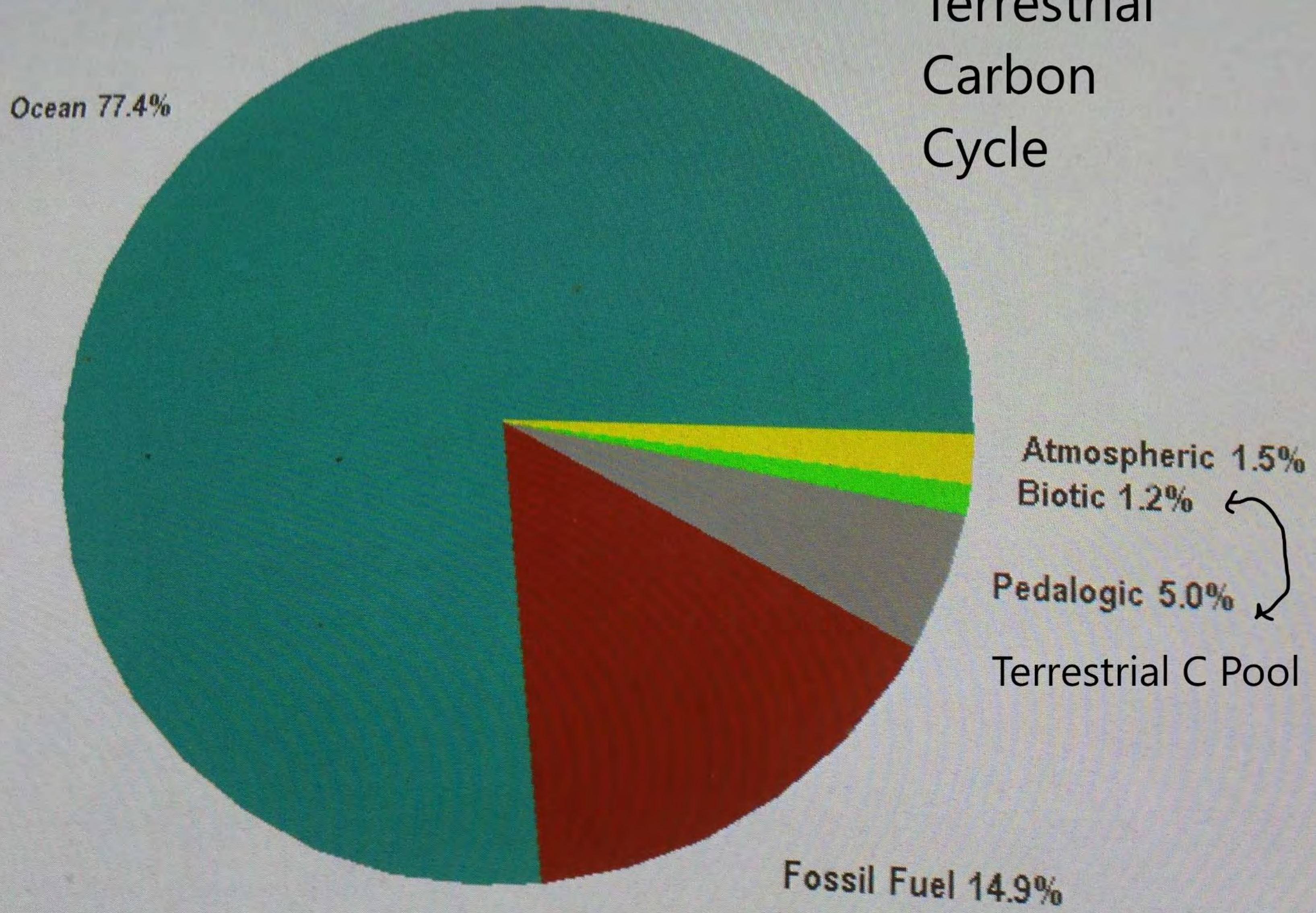
- A natural cycle that has moved carbon back and forth among 5 major pools for billions of years.

- Burning fossil fuels and farming have moved carbon from the fossil and terrestrial pools to the atmospheric pool.



The Global Carbon Cycle
units are gigatons of carbon — one gigaton = one billion metric tons = 10^{15}g
Red arrows are flows that are related to human activities
Green T = flows sensitive to temperature
Numbers next to flows are the approximate annual flows in Gt/year
Atmosphere
750 GT
photosynthesis
110
T
burning
respiration
T
50
respiration59.4
T
farming
runoff
0.6
90
ocean - atmosphere diffusion
T
90
Land Biota
610 GT
litter fall
60
Soil
1580 GT
Surface Oceans
970 GT
Ocean Biota
3 GT
10
96.2
upwelling & downwelling
T
105.6
10
Deep Oceans
38,000 GT
Fossil Fuel Burning
6
anic
tions
.6
sedimentation
0.6
subduction
0.6
Mantle
Sedimentary Rocks
1,000,000 GT

Terrestrial Carbon Cycle

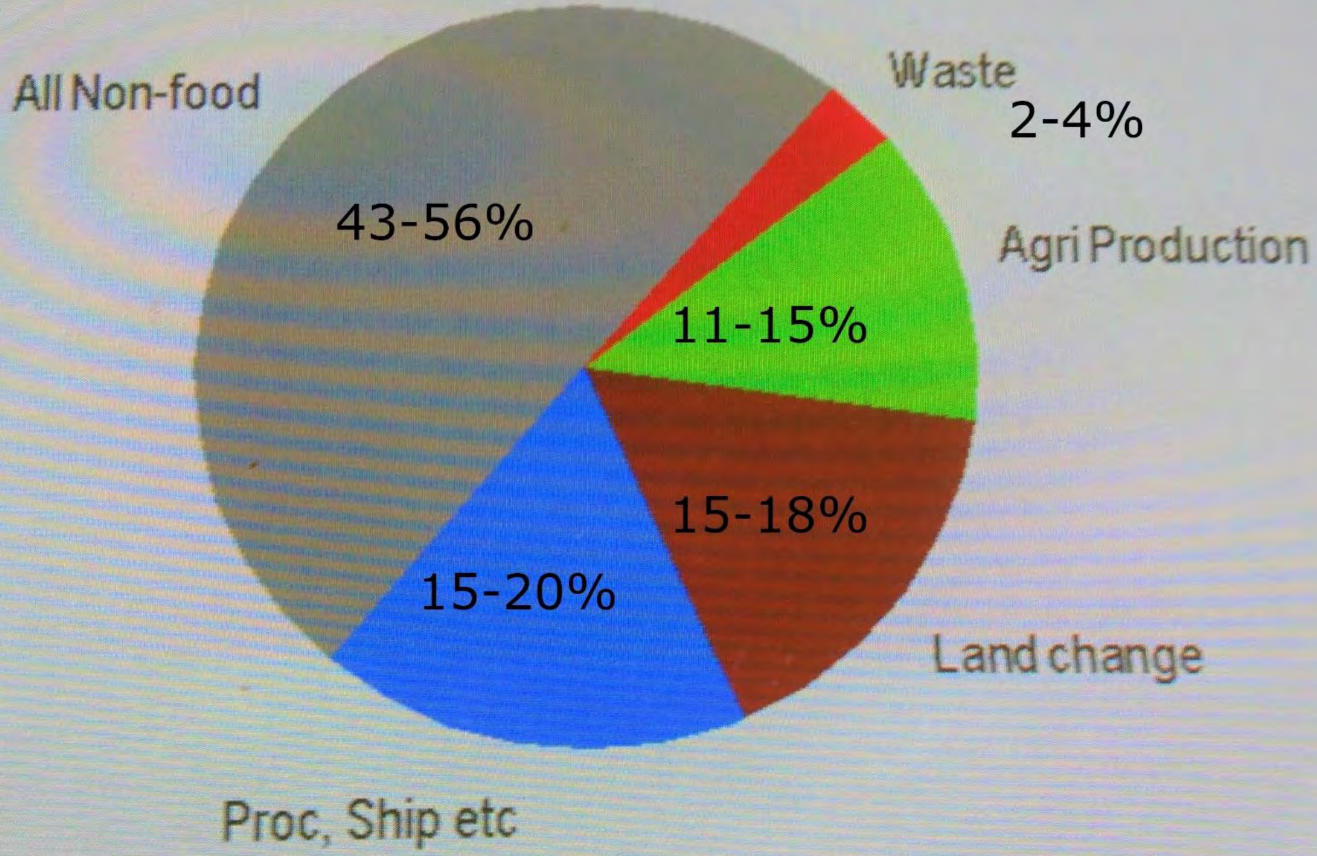


Why do we care about carbon farming?

- Agriculture is a major contributor to greenhouse gases globally. Toensmeier lists a high percentage due to agriculture 44-57 % including deforestation, processing and distribution, and waste in the tally. Other estimates are between 18 and 25% globally, 10% in USA.

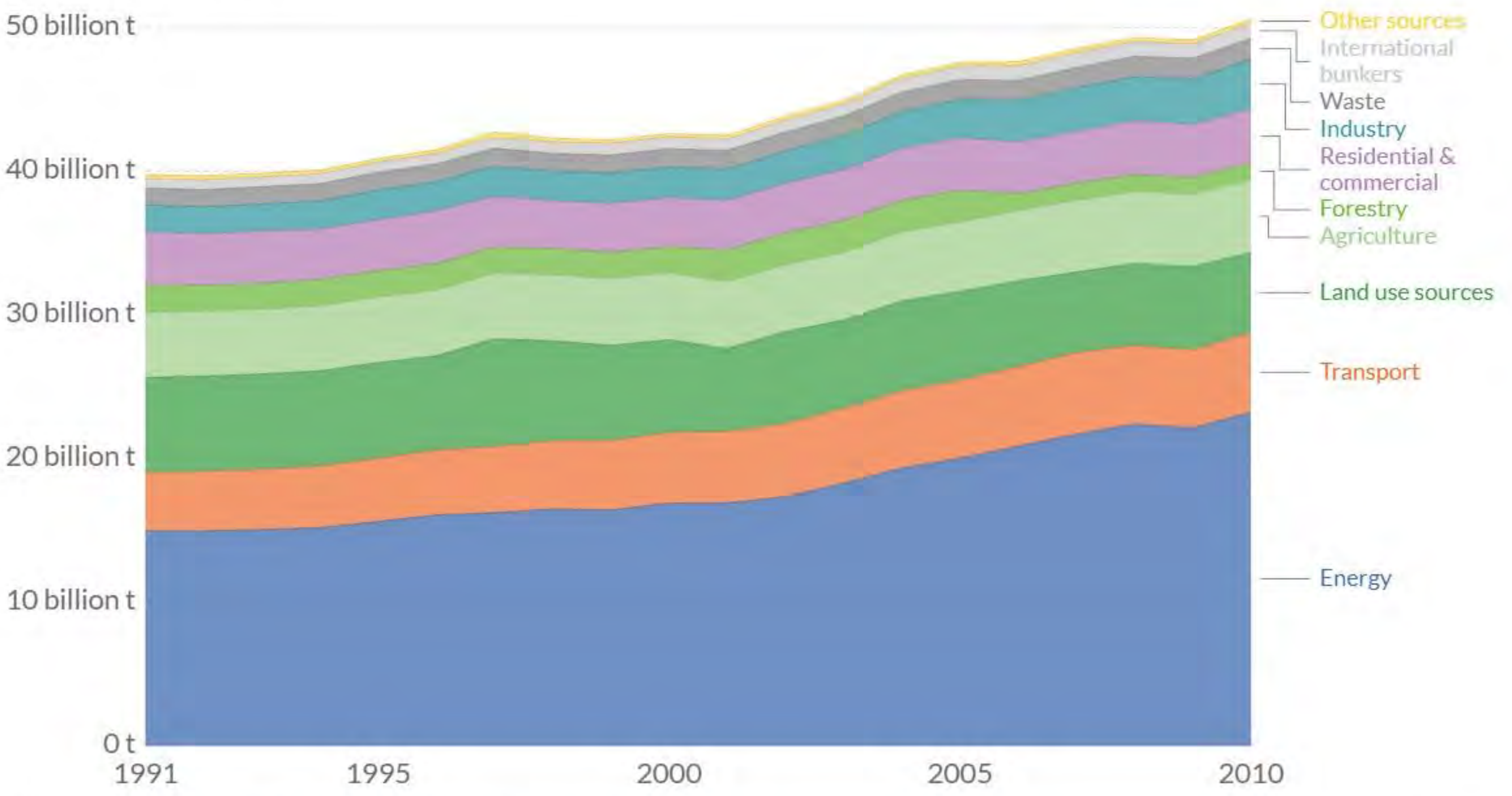
- The Great Irony is that agriculture can move from being a large contributor to GHG to being a carbon sink.

Agriculture: a Leading Cause of Climate Change Emissions



Greenhouse gas emissions (CO_2e) by sector

Breakdown of total greenhouse gas emissions by sector, measured in tonnes of carbon-dioxide equivalents (CO_2e). Carbon dioxide equivalents measures the total greenhouse gas potential of the full combination of gases, weighted by their relative warming impacts.



Source: UN Food and Agricultural Organization (FAO)

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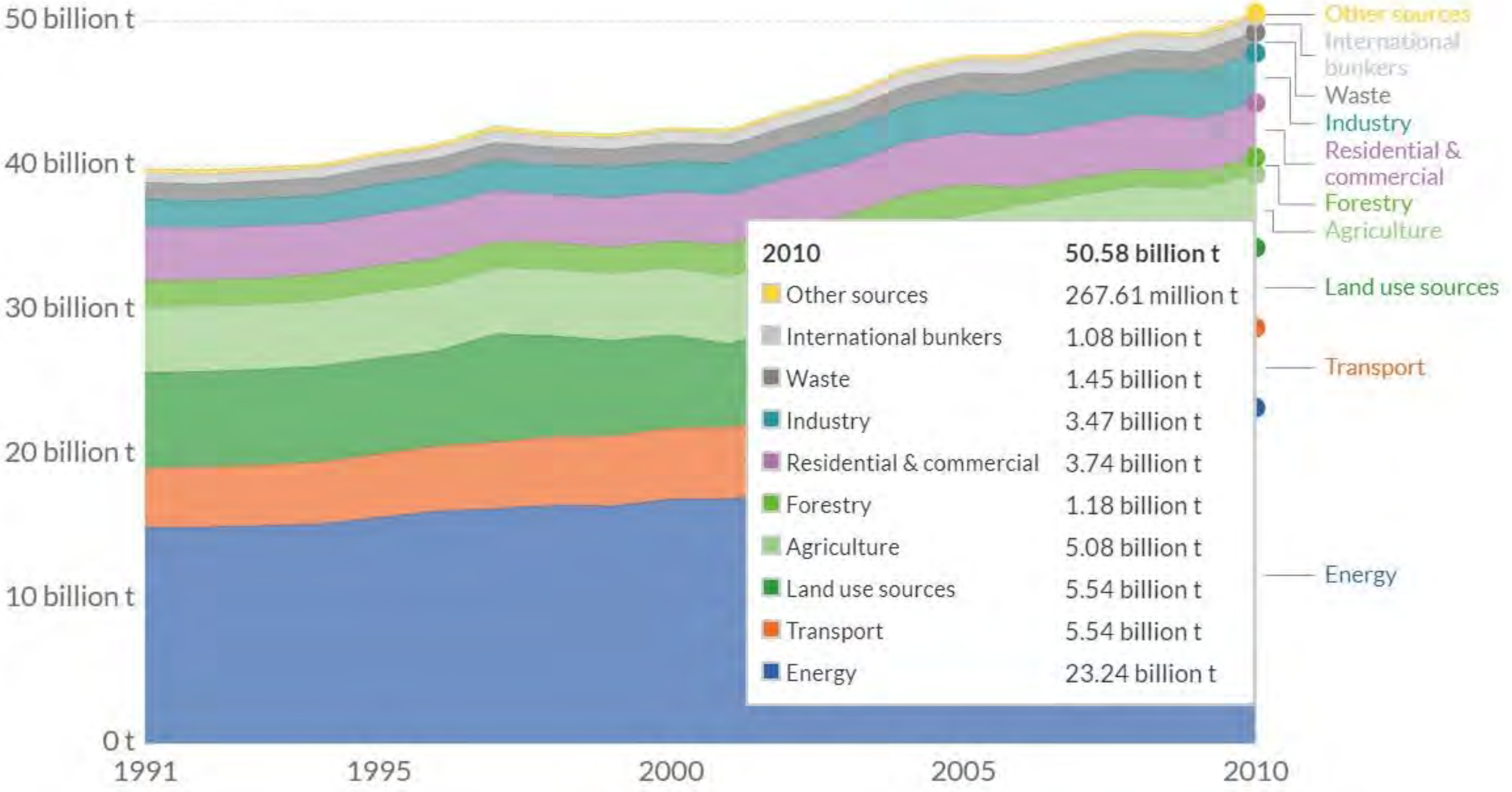


Source: UN Food and Agricultural Organization (FAO)

Carbon Farming: Regenerative Agriculture for Climate Stabilization

Connor Stedman, M.S.

Omega Institute - Ecological Literacy Immersion Program
University of Vermont - Leadership for Sustainability Program

AppleSeed
Permaculture LLC

Connor Stedman – Agroforestry, Ecology Specialist

- Connor is a field ecologist, agroforestry specialist, and educator based in western New England and the Hudson Valley.
- He holds an M.S. in Ecological Planning from the University of Vermont and is a lead organizer of the internationally recognized Carbon Farming Course.
- Connor offers consulting and design for multi-productive forest management at AppleSeed Permaculture, including silvopasture, forest understory crops, productive buffers, and wildlife habitat.

Agriculture & Climate Change

- Agriculture contributes ~10% of US GHG emissions (~25% globally due to tropical deforestation)
- Agriculture is highly vulnerable to climate disruption:
  - Drought
  - Heat waves
  - Flooding
  - Pollination disruption
  - New pests & diseases
- Agriculture CAN become a carbon sink through transitioning to carbon farming practices!

Reviewing the Climate Math

- Current CO2 levels in atmosphere: ~407 ppm.
- CO2 levels needed for maximum 2C average global warming: 350ppm
- To get below 350ppm, 130+ billion tons C will need to be removed from the atmosphere, plus ZERO net additional emissions.

Reviewing the Climate Math

- Current CO_2 levels in atmosphere: ~407 ppm.
- CO_2 levels needed for maximum 2C average global warming: 350ppm
- To get below 350ppm, 130+ billion tons C will need to be removed from the atmosphere, plus ZERO net additional emissions.
- Currently ~5 billion net tons C emitted globally per year.

Responses to the Climate Crisis

1. Emissions reduction
2. Carbon sequestration
3. Adaptation to disrupted climate

And an additional agricultural priority:

4. Food production intensification without further tropical forest loss.

Carbon Farming Definitions

1.*A suite of crops and agricultural practices that sequester carbon in the soil

2. A system of increasing carbon in terrestrial ecosystems for adaptation and mitigation of climate change, to enhance ecosystem goods and services, and trade carbon credits for economic gains. (Dr Rattan Lao, Ohio State University, Direc. Carbon Management and Sequestration Center)

3. A working definition: a suite of agricultural practices that increase Soil Organic Carbon by increasing the total mass of perennial plants and amending the quality of soils.

20 USDA Natural Resources Conservation Service Approved Practices

Forests, Trees & Shrubs
Tree/Shrub Establishment
Silvopasture Establishment on Grazed Grasslands
Windbreak/Shelterbelt Establishment
Hedgerow Planting

Grasslands, Pastures & Rangelands
Range Planting
Restoring Degraded Rangeland w/ Compost
Prescribed Grazing
Forage Biomass Planting
Conservation Cover
Improved Nutrient Management
No Till
Field Border

Streams & Wetlands
Riparian Restoration
Riparian Herbaceous Cover
Riparian Forest Buffer
Critical area Planting
Wetland Restoration
Filter Strip / Grassed Waterway

Ranch Facility & Operations
Anaerobic Digester
Combustion System Improvement (for Farm Equipment)

Biological Carbon Sequestration Pathways

- Decomposition -> Soil
- Photosynthesis -> Soil
- Photosynthesis -> Perennial Plants



The Math of Carbon Farming

- Carbon sequestration (storage)
  - 1% increase in topsoil organic matter = ~10 tons belowground C stored per acre.
  - Converting treeless farmland to tree-based farming (agroforestry) will store 50-150 tons aboveground C per acre in most regions of the US.
  - Out of 2.3 billion acres total US land, 880 million acres farmland:
    - 420 million acres pasture & rangeland
    - 380 million acres tillage (annual cropland)
    - 75 million acres forested land on farms
    - 5 million acres orchards & vineyards

Lifetime Soil Carbon Stocks of Carbon Farming Systems Compared

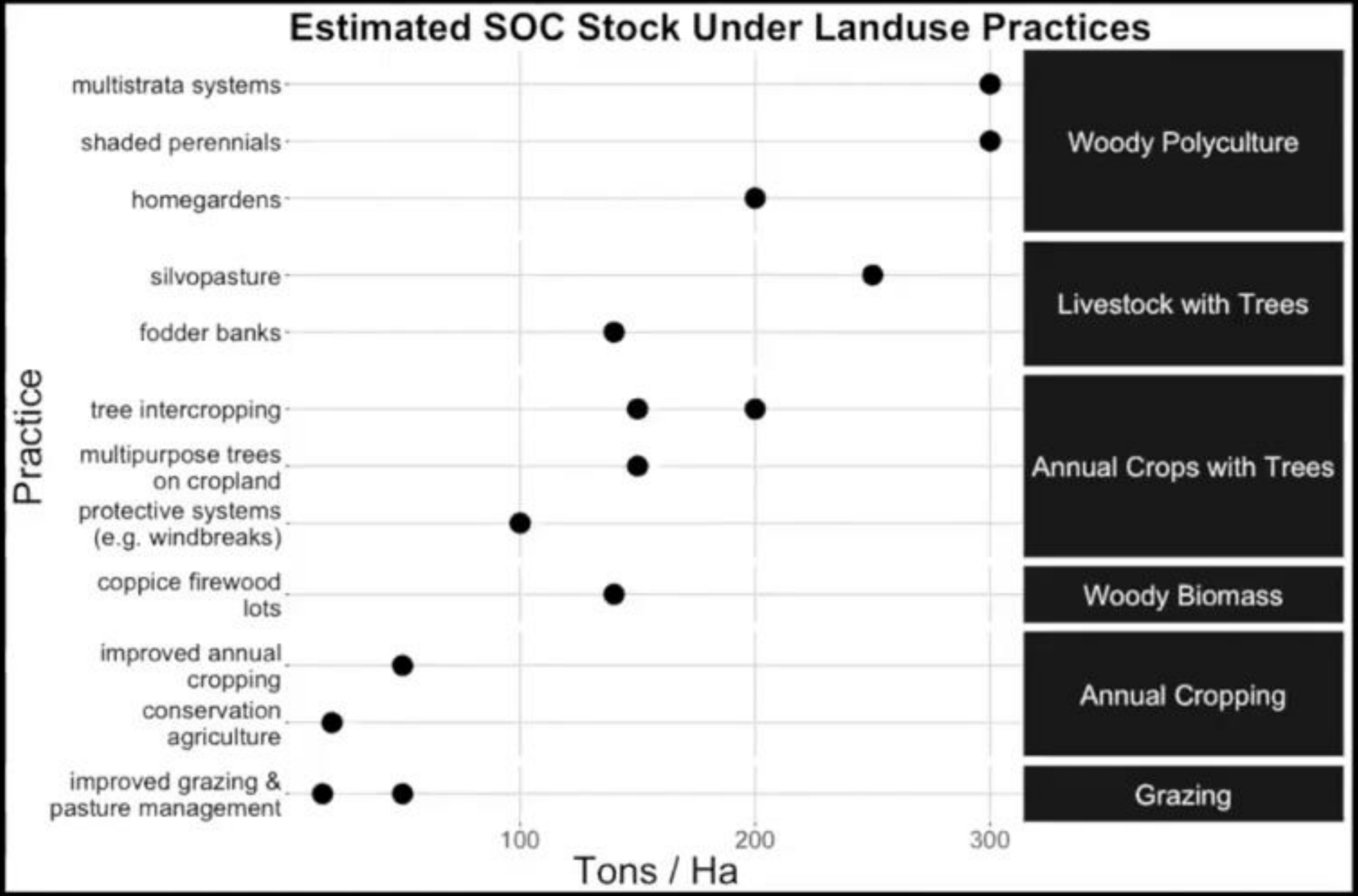
Category	Practice	Location	Lifetime Soil Organic Carbon Gains per Hectare
Annual cropping	Conservation agriculture	USA. India	-4 to +20
	Improved annual cropping	Global	30-50
Silvoarable agroforestry	Tree intercropping	Tropical humid	“very low”-150
	Tree intercropping	Temperate	Up to 200
	Protective systems (e.g., windbreaks)	Arid and semi-arid	Up to 100
Grazing systems	Improved grazing and Pasture management	Global	30-50 (Expert est.) Up to 16 (Review)
Livestock with trees	Silvopasture	Global	Up to 250
	Fodder banks	Tropical	Up to 140
Woody biomass	Coppiced firewood lots	Tropical	Up to 140
Woody polyculture	Multistrata agroforestry	Humid tropics	Up to 300

Comparing CF Systems for the US

SYSTEM	SEQUESTRATION POTENTIAL/ACRE	READINESS/ ADOPTABILITY	EXAMPLE(S)
Improved Annuals	Very Low to Low	High	Compost, cover cropping
Improved Grazing	Very Low to Medium	High	Managed rotational grazing
Perennial Grains & Legumes	Low to Medium	Low, in development, some production	Kernza perennial wheat
Tree-Annual Alley Cropping	Medium to High	High	Alleys of timber or nut trees between strips of annual crops
Silvopasture	Medium to Very High	High	Trees added to pastures in alley or savanna arrangement
Staple Food Tree Crops	Medium to Very High	Regionally variable	Chestnut, mesquite, breadfruit
Multi-Strata Agroforestry	Medium to Extremely High	Low except in HI & PR	Shade-grown coffee & cacao
Perennial Industrial Crops	Low to Extremely High	Low, in development, some production	Rubber, bamboo, milkweed, experimental crops

Adapted from Eric Toensmeier

Comparing CF Systems for the US



Data adapted from Eric Toensmeier
Data visualization by Rafter Ferguson

Co-Benefits

- Carbon farming practices offer significant co-benefits to farmers:
  - Increased climate change resilience
  - Increased soil & water conservation
  - Diversified production
  - Many systems offer greater profitability long term

Risks & Challenges

- Transition to new practices has costs and risks for farmers. Often years before breaking even on investment.
- Industry, philanthropy & governments all need to make $ available to farmers for transition to carbon farming.
- No incentive for land insecure farmers to invest in perennial crops & land improvements.
- Land access, tenure, & reform is a major part of carbon farming work.
- NOT a silver bullet!

Conservation Agriculture: Improved Annual Farming

- Practices:
  - –Minimal tillage
  - –Extensive cover cropping
  - –Compost/manure application
  - –Minimal to no herbicides/pesticides or synthetic fertilizer
  - –Crop rotation & fallow/ grass buffer strips

Management-Intensive Grazing

- Principles:
  - –High animal density
  - –Frequent rotations: short grazing time, long recovery time
  - –Animals, forages, soils all managed together

Systems In Development

Compost on Rangelands

Pasture Cropping

Biochar

Perennial Grains

Tree-Based Systems: Agroforestry

Windbreaks & Shelterbelts

Riparian Buffers

Coppice Biomass

Alley Cropping

Silvopasture

Multi-Strata Agroforestry & Forest Gardens

Carbon Farming

In

California

Dr. Jeffrey Chreque, PhD

Nicasio Native Grass Ranch, Marin CA

The Beginning

- John and Peggy bought the 540 acre former dairy ranch in 1998 as a hobby farm
- To initiate its return to a “pristine” state, they barred neighbors’ cows from the land
- The land began to change within months, but not in the direction expected

Beginnings cont.

- Brush encroached on the meadow
- Dried-out grass blocked growth of new grass
- Disease struck the oak trees
- Woolly distaff thistle, an invasive weed, took over the pasture and was immune to attempts to eradicate it

What Now?

- The land was losing its vitality
- Wick concluded, “Our vision of wilderness was failing. Our naïve idea was not working out so well.”
- Then range ecologist, Jeff Creque, came into the project

Creque’s Action Plans

- Squeeze out weeds with conditions favorable to grasses
- Bring back the cows

Rationale

- Grasslands and grazing animals co-evolved.
- Grasses rely on animals for defoliation and the recycling of nutrients since they don’t shed their leaves.
- The manure and urine from grazing animals fuels healthy growth. Done right, grazing could be restorative.

Isn’t Grazing turning the World into a Desert?

- How you graze makes all the difference.

- Animal herds should feed at high density for short periods before being moved to new pasture (like wild buffalo herds): intensive rotation pulse grazing benefits the land.

- If the animals are let loose and rounded up a few months later — the “Columbus method” — the land is likely to end up hard-packed and barren.

Cows Return to the Ranch

- Wick borrowed a herd of cattle for the summer
- Cows beat back the brush
- New and different grasses grew
- Perennial plants began to return
- The herd gained 50,000 pounds by fall
- The land was richer and the grass lusher
- Meadow larks and other animals were more abundant

How Creque Accounted for the Extra Cattle Weight

- Grasses were like straws sipping carbon from the air, bringing it back to earth.
- Carbon, the building block of life, was constantly flowing from atmosphere to plants into animals and then back into the atmosphere.
- Plants could be deliberately used to <u>pull carbon out of the sky</u>.

Further Preliminary Findings

- A thin layer of <u>compost</u>, spread half an inch over 3 acres, resulted in increased soil carbon.
- Grazing alone did not lead to carbon sequestration. Soil in untreated control plots lost carbon. The compost treated plots absorbed carbon equivalent to 1.5 tons of CO2 (0.41 tons of carbon) per acre per year.
-
- This was the inspiration for the Marin Carbon Farming Project.

Marin Carbon Farming Project

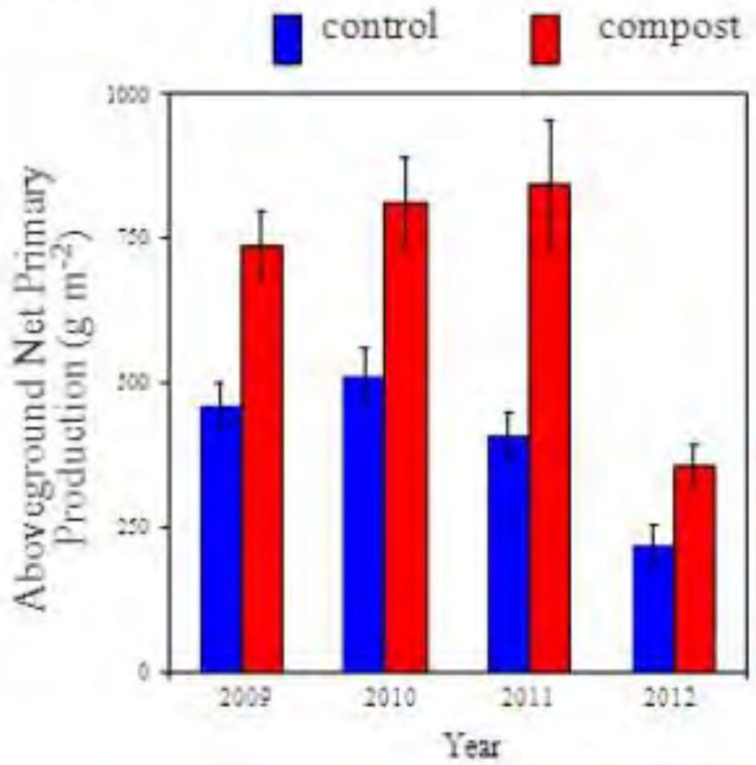
- Founded in 2008 by Jeff Creque and John Wick
- Initiated more than $15 million in field, laboratory research, and demonstration projects
- Led to adoption of a statewide California Healthy Soils Initiative in 2015 with collaborators and stakeholders throughout the state.

Key Findings

- Restorative land management practices increase durable soil carbon
- Compost addition was of particular importance
- Organic matter amendments increased soil carbon by 50 MT C ha-1 in the top meter of soil. 30 years later, approximately half that carbon remained in the soil
- Each year for 4 years after adding compost, the soil carbon increased.
- The initial treatment jump-started the soil's microbial community and energized the plants.

Compost Results – Forage

Plant production (aka forage) has increased every year following a one time compost application



Ryals and Silver 2012, Ryals and Silver in prep.

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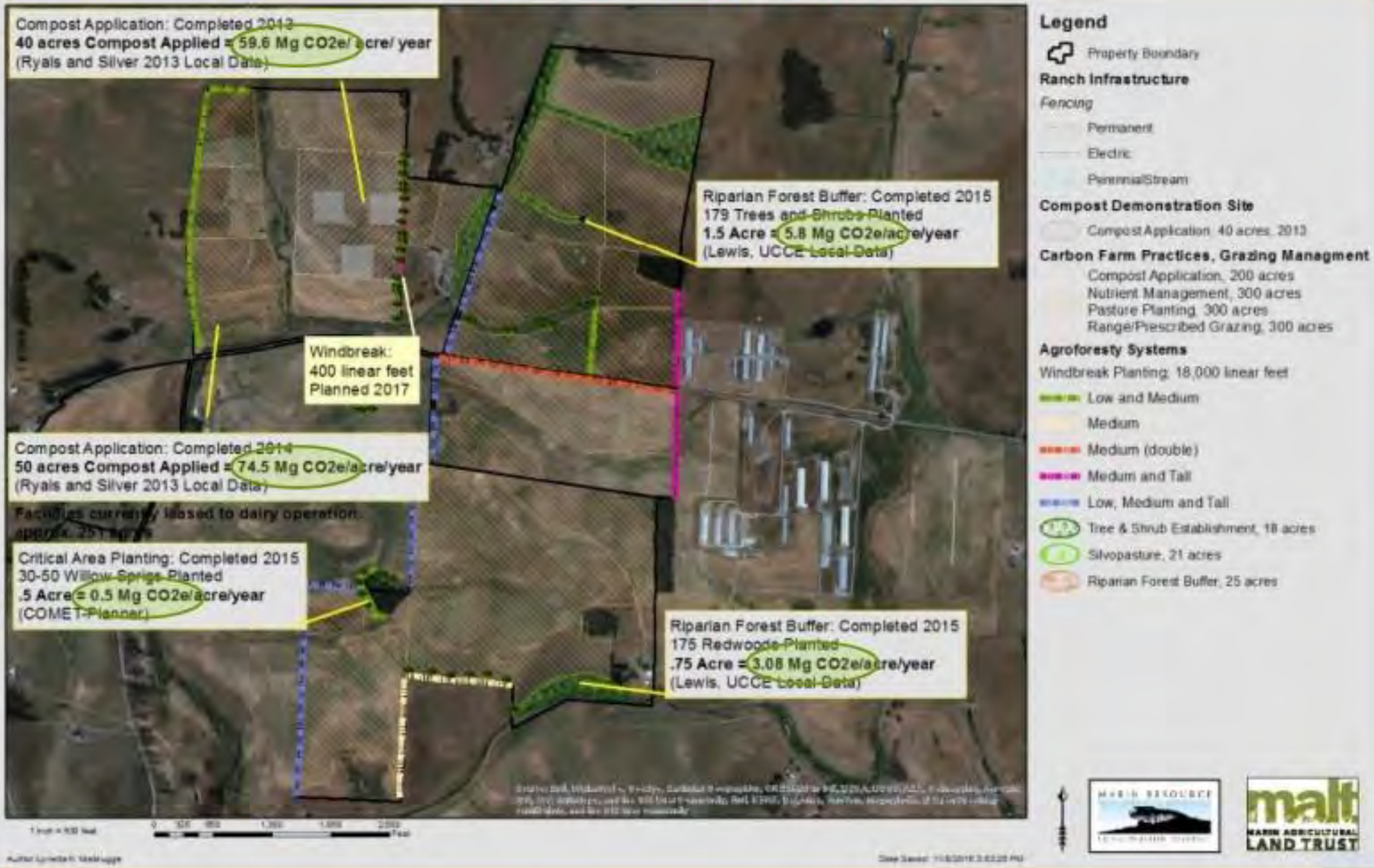
Ranch Facility & Operations
Anaerobic Digester
Combustion System Improvement (for Farm Equipment)

Loren Poncia's Stemple Creek Ranch was one of the nine demonstration projects

Marin Carbon Project - Carbon Farm Plan
STEMPLE CREEK RANCH



$MTCO_2e$ Reduction-Sequestration for one ranch

Year	Conservation Practice Implemented	Acres	Approximate Carbon Sequestration and Greenhouse Gas Emission Reductions ($MTCO_2$ e per acre per year)			Calculation References
			Annual	20 Year	40 Year	
2013	Compost	39	59.6	1192	2384	Ryals and Silver 2013, DeLonge et al, 2014; Ryals et al 2015.
2014	Compost	50	74.5	1490	2980	
2015	Compost	65	96.58	1931.6	3863.2	
2015	Riparian Forest Buffer	1.5	5.8	116	232	COMET -Planner
2015	Riparian Forest Buffer (Redwood Planting)	0.76	3.08	61.6	123.2	
2015	Critical Area Planting (willows around pond)	0.5	0.5	10	20	COMET -Planner
2017/18	Windbreak	0	0	0	0	
2014	Prescribed Grazing	300	54	1080	2160	
2013	Range/Pasture Planting	200	68	1360	2720	
TOTAL		**657**	**362**	**7,241**	**14,482**	

Mg= 1 Megagram or 1 Metric Tonne

Stemple Creek Plan

- Compost and manure were used as fertilizer
- Trees were planted and riparian forest buffers added to areas near the creek
- *An intensive grazing practice, rotation pulse grazing, was used. Cattle were confined to graze intensively for a short duration before they were moved to a new pasture.

Poncia’s Observations

- Land had been grazed for over 200 years
- In past 15 years due to new practices, he has doubled the herd carrying capacity because of the amount of grass he can grow
- He continues to add more perennial plants that keep living roots in the ground year round even with 6mo/ year drought. Their deep roots reach moisture that annuals can’t, bring micronutrients to the surface, and decompact the soil.

Comparison of good and poor soil

Soil after using SOC practices

Poncia’s Observations

- “We’re reaping the benefits of storing more carbon and water in the soil. Carbon in the soil is like a sponge”.

- Carbon fosters a cycle: with more carbon,
  - the soil will store more water, and more perennial plants can grow;
  - the more perennial plants, the more carbon stored in their roots.
  - When perennials decay in the soil, more organic material is added to the earth.

Poncia’s Observations

- Carbon farming has not directly made his operation more profitable.
- To subsidize up to half of those costs, he participates in federal and state cost-sharing programs.
- He also sold his development rights to a local land trust, adding to his bottom line and preventing the land from ever being developed.

Cost for 1 Ranch

			Total Costs		Total Returns			
USDA NRCS Practices	Size	Size Unit	Cost	USDA Funding	CO_2e (Mg/20 yrs)	SOM (Mg/20 yrs)	WHC (AF/20 yrs)	Forage Benefit ($)
999 - Compost Application	3,808	Cubic Yd	$91,392	$0	31,826	17,344	159	
382 - Fence		Feet	$0	$0				
380 - Windbreak Establishment	40,040	Feet	$16,384	$8,192	404	98	1	
391 - Riparian Forest Buffer	32	Acre	$45,882	$34,412	7,353	1,048		
342 - Critical Area Planting	32	Acre	$24,488	$12,244				
390 - Riparian Herbaceous Cover	32	Acre	$69,418	$56,099				
528 - Prescribed Grazing	4,411	Acre	$16,946	$8,473	15,800	8,610	79	$26,667
516 - Livestock Pipeline		Foot	$0	$0				
614 - Watering Facility		Gallon	$0	$0				
345 - Reduced Till	537	Acre	$19,364	$9,682	2,080	1,134	10	
381 - Silvopasture	134	Acre	$62,209	$46,657	1,880	270	2	
Total Plan Costs and Returns			**$346,083**	**$175,759**	**59,343**	**28,504**	**251**	**$26,667**

GHG sequestration/reduction for 9 Marin County Ranches

Practice	Acres	Annual $MTCO_2e$	20 Year $MTCO_2e$
Improved Nutrient Management	1,433	99	1,972
Filter Strip / Grassed Waterway	2	14	282
Tree/Shrub Establishment	151	131	2,624
Silvopasture Establishment on Grazed Grasslands	384	265	5,308
Windbreak/Shelterbelt Establishment	33	62	1,240
Hedgerow Planting	4	16	311
Range Planting	1,218	340	6,810
Restoring Degraded Rangeland w/ Compost	1,929	1,170	40,886
Prescribed Grazing	3,135	567	14,370
Riparian Restoration	40	207	4,140
Riparian Herbaceous Cover	76	117	2,155
Riparian Forest Buffer	147	185	6,191
Critical area Planting	58	57	1,131
Conservation Cover	1	1	20
Forage Biomass Planting	351	128	2,554
Wetland Restoration	9	10	57
Anaerobic Digester	2	1,645	32,900
Field Border	10	12	240
No Till	70	25	490
	9,054	**5,049**	**123,679**

- **The voluntary Marin CAP goal for emission reduction through methane capture technologies on dairies is estimated at 4,638 ($MTCO_2e$).**

20-year Averages of $MTCO_2e$ Sequestered Per Practice for 9 Marin County Ranches

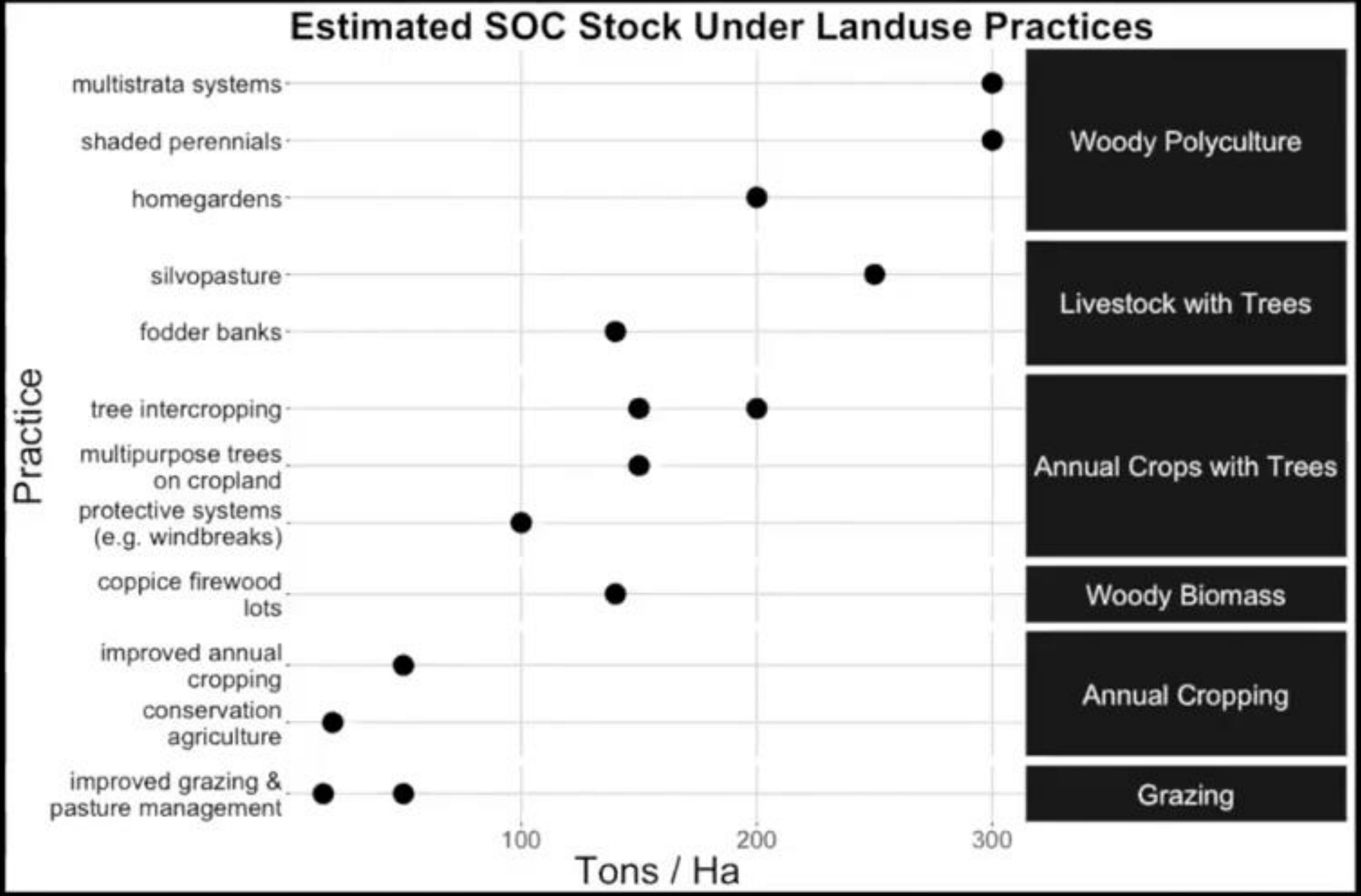
Conclusions

- For the Marine Carbon Farming Project the three practices that have sequestered the most carbon on the nine original ranches are:
  - Compost addition to degraded rangeland
  - Construction of an anerobic manure digester to handle animal waste
  - Use of prescribed, pulse rotation, grazing

Lifetime Soil Carbon Stocks of Carbon Farming Systems Compared

Category	Practice	Location	Lifetime Soil Organic Carbon Gains per Hectare
Annual cropping	Conservation agriculture	USA. India	-4 to +20
	Improved annual cropping	Global	30-50
Silvoarable agroforestry	Tree intercropping	Tropical humid	“very low”-150
	Tree intercropping	Temperate	Up to 200
	Protective systems (e.g., windbreaks)	Arid and semi-arid	Up to 100
Grazing systems	Improved grazing and Pasture management	Global	30-50 (Expert est.) Up to 16 (Review)
Livestock with trees	Silvopasture	Global	Up to 250
	Fodder banks	Tropical	Up to 140
Woody biomass	Coppiced firewood lots	Tropical	Up to 140
Woody polyculture	Multistrata agroforestry	Humid tropics	Up to 300

Comparing CF Systems for the US



Data adapted from Eric Toensmeier
Data visualization by Rafter Ferguson

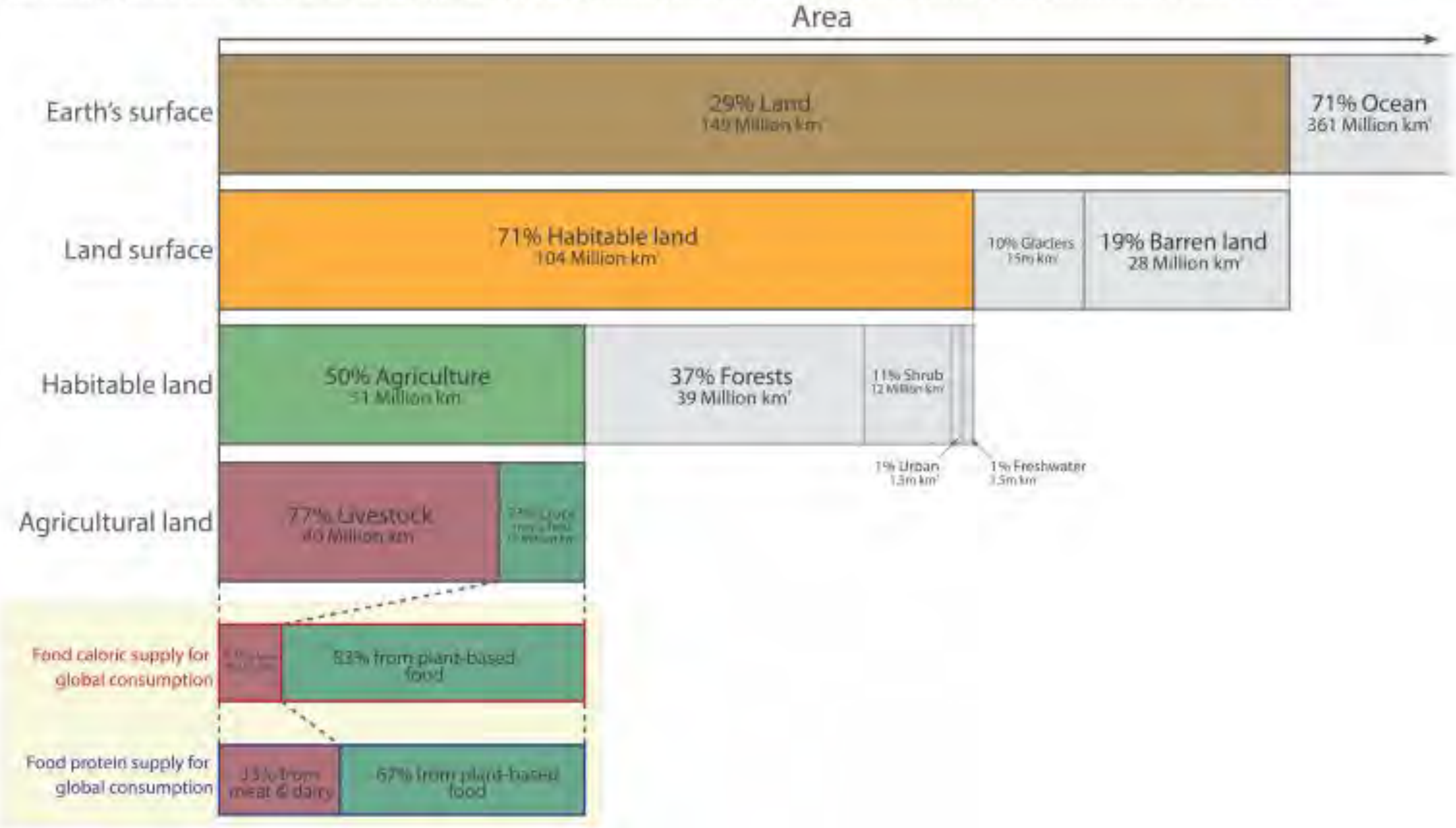
Conclusions

- Toesmeier emphasized Agroforestry based CF solutions well suited to the tropics and subtropics. These tree based CF practices have the greatest SOC sequestration potential per hectare. I did not use his examples to quantify CF in this lecture.
- The Marin Carbon Farming Project and separate lecture by Connor Stedman prominently featured regenerative practices suitable for temperate climates, annual cropping, and grazing. I used these examples since they apply to the USA and had quantitative data. Expected SOC/hectare is lower but the applicable acreage is many fold greater.

Global surface area allocation for food production

Our World in Data

The breakdown of Earth surface area by functional and allocated uses, down to agricultural land allocation for livestock and food crop production, measured in millions of square kilometres. Area for livestock farming includes grazing land for animals, and arable land used for animal feed production. The relative production of food calories and protein for final consumption from livestock versus plant-based commodities is also shown.



Data source: based on UN Food and Agricultural Organization (FAO) Statistics.
The data visualization is available at OurWorldinData.org. There you find research and more visualizations on this topic.

Additional References

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