

# A PLANET AT HALF CAPACITY

*A Multi-Scale, Multi-Source Argument for Primary Productive Potential Lost — and a Path to Recovery*

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*No single study establishes this claim. Instead, converging lines of evidence — from a backyard to a watershed in Colorado, from to the cornfields of the Midwest to the open ocean — each independently support the conclusion that Earth's living systems are operating far below their primary productive potential. Together, they point to a planet running at something like half capacity. And they point toward a recovery pathway.*

**~50%**

Estimated loss of primary productive potential — not from one study, but from the aggregate weight of evidence across landscapes, agricultural systems, biodiversity, and oceans

## DOCUMENT STRUCTURE

SECTION I — The Global Evidence Base: twelve converging lines of evidence for primary productive potential lost, illustrated at three scales from the backyard to a watershed integrating many different land uses.

SECTION II — Three Scales Illustrated: the productive potential loss argument demonstrated at the property level (suburban lawn), the agricultural parcel (tallgrass prairie vs. corn belt), and the watershed level (Boulder Creek, Colorado).

SECTION III — The Recovery Pathway: a coordinated global initiative using coppice-based energy systems to simultaneously provide secure cooking fuel, restore degraded land, and increase net primary productive energy available to human communities.

## SECTION I

# The Global Evidence Base

## Why 'Primary Productive Potential' — and Why This Framing Is Defensible

This document makes a specific claim: that Earth's living systems are operating at roughly half their primary productive potential. This is not a claim about photosynthetic efficiency measured in chlorophyll absorption rates or PAR conversion percentages. Instead, this argument uses the broader and more policy-relevant concept of primary productive potential: the capacity of a landscape, watershed, or ocean region to produce life, cycle nutrients, build soil carbon, retain water, and sustain biological communities — relative to what that same area could support under intact, undegraded conditions.

This framing aligns precisely with the language used by the major international assessments — the IPBES, UNCCD, FAO, and World Atlas of Desertification — making citations direct rather than translated. It is measurable across multiple dimensions simultaneously: biomass production, soil carbon stocks, species richness, water infiltration, and trophic complexity are all expressions of primary productive potential. And it is the right question from an energy systems perspective: what is the actual biological energy capture and cycling capacity of a given area, compared to its reference potential?

The 50% figure is a *synthesis*, not a measurement. It is the aggregate conclusion that emerges when ten independent lines of evidence are assembled. Their convergence is the argument. The finding is then illustrated at three scales — from a backyard, to an agricultural parcel, to a watershed integrating many different land uses — demonstrating that the dynamic holds regardless of spatial scale.

## The Methodological Framework

No single peer-reviewed study has measured and confirmed a 50% decline in global primary productive potential. What this document argues is something more powerful: when evidence is assembled across multiple independent domains, each points in the same direction, and the aggregate picture is consistent with a planet operating at roughly half its potential. This is how complex systemic claims are properly established. Climate change was not proven by one study. The case is built from convergence.

### **01 World Atlas of Desertification — 75% of Earth's Land Already Degraded**

The World Atlas of Desertification (WAD3), published by the European Commission's Joint Research Centre using 1.8 petabytes of satellite data, finds that over 75% of the Earth's land area is already degraded, with over 90% projected to be degraded by 2050. Globally, an area half the size of the EU — 4.18 million km<sup>2</sup> — is degraded annually. Under combined degradation and climate stress, crop yields could be halved in India, China, and Sub-Saharan Africa.

*World Atlas of Desertification 3rd Edition, JRC/European Commission (2018); IPBES Land Degradation Assessment*

## 02 The Abandoned Land Accounting — More Destroyed Than Currently Farmed

Perhaps the single most striking statistic in the agricultural literature: the nearly 1.5 billion hectares of world cropland currently under cultivation are almost equal in area to the roughly 2 billion hectares that have been abandoned by humans since farming began. We have already degraded and discarded more agricultural land than we currently farm. Each year approximately 10 million additional hectares are abandoned due to soil erosion, and another 10 million critically damaged by salinization — a combined annual loss exceeding 1.3% of all remaining cropland. Soil is being lost 10 to 40 times faster than the rate of natural soil renewal.

*Pimentel & Burgess (2013), Agriculture; Pimentel et al. (1995), Science*

## 03 Global Plant Biomass — 50% Reduction Since the Dawn of Human Civilization

The Bar-On, Phillips & Milo global biomass census finds that total plant biomass has declined approximately twofold — roughly 50% — relative to its value before the start of human civilization. A parallel analysis by Vaclav Smil confirms that human activity over the last 5,000 years has reduced total global biomass by about 50%, from over 1,000 gigatons of carbon at the dawn of agriculture to approximately 545 GtC today. This is perhaps the most direct single quantification of primary productive potential lost: half of Earth's plant biomass — the foundation of all primary production — has been eliminated since human civilization began. The total biomass of all crops cultivated by humans today amounts to only approximately 2% of extant plant biomass, illustrating how narrowly replacement agriculture has captured the productive potential of what it displaced.

*Bar-On, Phillips & Milo (2018), PNAS — 'The biomass distribution on Earth'; Smil (2011), biomass census synthesis*

## 04 Global Forest Loss — One Third of All Forests Gone

Over the last 10,000 years, the world has lost one-third of its forests — approximately two billion hectares, an area twice the size of the United States. Half of that total loss occurred in the last century alone, as industrialization, agricultural expansion, and timber extraction accelerated deforestation globally. Since 1990 alone, an estimated 420 million hectares of forest have been lost, with the current annual rate running at approximately 10 million hectares per year. Primary forest — the most ecologically intact and productively complex forest type, with no visible human disturbance — has decreased by 81 million hectares since 1990. Forests currently cover only 31% of global land area, down from approximately 46% at the start of the Holocene. The significance for primary productive potential is fundamental: forests store 80% of the biosphere's above-ground biomass and more than 60% of global biomass is composed of wood. Their loss represents not just a reduction in canopy cover but a collapse of the most productive and complex terrestrial primary production systems on Earth, along with all the soil carbon, water cycling, and biodiversity they support.

*FAO Global Forest Resources Assessment 2020; Our World in Data / Williams (2003) Deforesting the Earth; Ellis et al. (2020), Land; Sasaki & Putz — global forest biomass estimates*

## 05 Biodiversity Collapse — The Living Planet Index

The WWF/ZSL Living Planet Index 2024 — tracking 34,836 wildlife populations across 5,495 species — reports an average 73% decline in monitored wildlife populations globally between 1970 and 2020. Latin America shows 95% decline; freshwater species 83% globally. Given that 57% of NPP variation correlates with biodiversity differences, this scale of wildlife collapse has direct and quantifiable implications for primary productive potential — each species lost represents not just one organism but a cascade of ecological functions many of which directly support primary production.

*WWF Living Planet Report 2024; ZSL Living Planet Index; IPBES Global Assessment (2019)*

## 06 Wild Mammal Biomass Collapse

Wild mammals today account for just 5% of total mammal biomass on Earth. Humans account for 36% and livestock 59%. In 1850, wild and domesticated mammals were roughly equal in biomass. Wild land mammal biomass is down 85% from pre-human baselines. The biomass of pigs alone nearly equals that of all wild land mammals. This is not merely a conservation statistic — it is an energy statistic, quantifying the collapse of energy flowing through natural food webs. Wild mammal biomass is the embodied energy of functioning ecosystems; its collapse reflects the degree to which primary productive energy is no longer being processed through complex biological communities.

*Greenspoon et al. (2023), PNAS; Bar-On, Phillips & Milo (2018), PNAS; Nature Communications (2025)*

## 07 Phytoplankton Decline — 40% Since 1950

Phytoplankton are responsible for approximately half of all organic matter production on Earth and form the base of the entire marine food chain — from zooplankton to fish to marine mammals. A landmark Nature study (Boyce et al., 2010) — drawing on an unprecedented compilation of ocean transparency measurements dating to 1899 and chlorophyll observations across the modern satellite era — found that global phytoplankton biomass has declined at approximately 1% of the global median per year since 1900, with declines observed in eight out of ten ocean regions. Compounded over the period since 1950, this translates to a decline of approximately 40% in global phytoplankton population. Rising sea surface temperatures — which strengthen thermal stratification and reduce nutrient upwelling — are identified as the primary driver. As lead author Daniel Boyce noted: 'Phytoplankton is the fuel on which marine ecosystems run. A decline of phytoplankton affects everything up the food chain, including humans.'

*Boyce, Lewis & Worm (2010), Nature — 'Global phytoplankton decline over the past century', doi:10.1038/nature09268*

## 08 Marine Fish Biomass — 60–80% Reduction

A comprehensive analysis of over 200 ocean ecosystem models by Christensen et al. (2014) found that in the past 100 years, 80% of the biomass of fish in the world's oceans has been lost — with 60% of that loss occurring in just the last 40 years since the onset of industrial fishing in the 1970s. Large predatory fish — tuna, grouper, sharks — experienced the most severe collapses. A parallel meta-analysis by Myers and Worm (2003, Nature) found that industrialized fisheries typically reduced community biomass by 80% within 15 years of the onset of exploitation, with large predatory fish biomass now estimated at only about 10% of pre-industrial levels. A Science Advances modeling study estimates total fish biomass has declined to 47% of pre-industrial values averaged across large marine ecosystems. Together with the phytoplankton decline, these figures indicate that the ocean's primary productive system — from the base of the food chain to its apex — is operating at a small fraction of its pre-industrial biological capacity.

*Christensen et al. (2014), AAAS Annual Meeting; Myers & Worm (2003), Nature; Guet et al., Science Advances*

## 09 Ocean Net Primary Productivity Decline — Satellite Record and CO2 Effects

A Nature Communications study using satellite remote sensing found statistically significant decreases in ocean net primary production across almost half the global ocean, concentrated in tropical and subtropical stratified regions — driven by warming that strengthens thermal stratification and cuts off nutrient supply from depth. A six-year PNAS study (2025) conducting 48 onboard experiments across the western North Pacific found an approximately 20% reduction in primary production across oligotrophic regions under elevated CO<sub>2</sub>. A Science Advances analysis found marine primary productivity in low-to-mid-latitude regions declining at 0.088% per year. The ocean is losing its greenness — chlorophyll concentrations are falling — signaling a sustained reduction in the living engine of ocean primary production.

*Kulk et al., Nature Communications (2020); Endo et al., PNAS (2025); Science Advances (2023): Declining ocean greenness in low-to-mid latitudes*

## 10 Human Appropriation of Net Primary Production (HANPP)

Studies find that humans appropriate 25–40% of all terrestrial net primary production — not just consuming it, but redirecting and suppressing it. A 9.6% reduction in NPP is directly attributable to land use change alone, with total HANPP reaching 23.8% of potential vegetation. A further 10% is estimated lost to land degradation. Together these figures mean that a third or more of all terrestrial primary production has been removed from natural biological cycling. This is a conservative floor, not a ceiling — it measures only the appropriation gap, not the structural degradation of primary productive systems, the fossil-fuel subsidy masking collapsed soil productivity, or the ocean losses described in other evidence blocks.

*Haberl et al. (2007), PNAS; Krausmann et al. (2013), PNAS; Field et al. (1998)*

## 11 Agricultural Productivity Loss — The Full Picture

The WAD3's 10% global crop yield projection for 2050 is a conservative aggregate assuming continued fossil fuel inputs masking underlying soil collapse. The actual picture: 52% of the world's soil is already degraded. Soil degradation has reduced the productivity of nearly a quarter of the global land surface, affecting 3.2 billion people and costing approximately 10% of annual global GDP in lost ecosystem services. In Sub-Saharan Africa, 65% of arable land is moderately to severely degraded, with yield losses of 30–50% already recorded. Per capita food production has been declining since 1984 — even as fossil fuel inputs have been massively scaled up.

*Pimentel & Wilson (2004); UNCCD COP15/WWF; Heinrich Böll Foundation Soil Atlas (2024); FAO SOLAW (2025)*

## 12 Biodiversity and Primary Productivity: A Quantified Relationship

Tilman et al. (PNAS 2012) showed that reducing grassland plant diversity from 16 species to 4 causes as large a drop in productivity as removing 54 kg/hectare/year of nitrogen fertilizer. A multi-scale empirical study found that 57% of variation in NPP correlates with biodiversity differences after controlling for climate. The richness-NPP relationship is log-linear — early biodiversity losses cause the steepest productivity declines.

*Tilman, Reich & Isbell, PNAS (2012); Cardinale et al. (2007), PNAS*

## The Aggregated Assessment

*No single study establishes a 50% loss of primary productive potential. But the case is made by convergence — and the finding holds at every scale of analysis.*

Begin with the most striking single fact in the entire literature: since farming began, humanity has already abandoned approximately 2 billion hectares of cropland to degradation — more land than the roughly 1.5 billion hectares currently under cultivation. The World Atlas of Desertification confirms that 75% of the Earth's land area is already degraded. On top of that: humans appropriate 25–40% of all terrestrial net primary production directly; 99% of tallgrass prairie has been converted; 50–70% of global soil carbon depleted; a third of global forest cover removed; 50% of global wetlands lost. Per capita food production has been declining since 1984 even as fossil fuel inputs have been massively scaled up to mask underlying soil collapse.

The mammal biomass data tells the story of what this has done to biological communities — but it is part of a larger biomass accounting that is even more striking. Bar-On, Phillips & Milo's global biomass census finds that total plant biomass has declined approximately 50% since the dawn of

human civilization — from over 1,000 gigatons of carbon to approximately 545 GtC today. Half of Earth's plant biomass — the foundation of all primary production — has been eliminated. Wild mammals are now 5% of total mammal biomass, down 85% from pre-human baselines. The Living Planet Index reports 73% average decline in monitored wildlife populations since 1970.

In the ocean, the story is equally severe. Phytoplankton — responsible for half of all organic matter production on Earth — have declined approximately 40% since 1950, at roughly 1% per year since 1900, declining in eight of ten ocean regions (Boyce et al., Nature 2010). Marine fish biomass has fallen 80% over the past century, with 60% of that loss occurring in just the last 40 years since industrial fishing intensified. Large predatory fish biomass now stands at approximately 10% of pre-industrial levels. The ocean's primary productive system — from phytoplankton at the base to apex predators — is operating at a fraction of its pre-industrial biological capacity.

None of these numbers, taken individually, adds up to 50%. But they are not independent losses. They compound. The losses are *structural*, not merely quantitative. And the biodiversity losses that accompany all of them further suppress the productivity of whatever living systems remain — because 57% of NPP variation is directly correlated with biodiversity. The finding is illustrated at three scales in Section II below.

### Evidence Summary — Fourteen Converging Lines

| Domain                     | Loss / Decline                                       | Key Source   |
|----------------------------|--|--|
| WAD3: Global Land          | 75% of Earth's land already degraded                 | JRC / European Commission, 2018                        |
| Abandoned Cropland         | ~2B ha abandoned — more than currently farmed        | Pimentel & Burgess, Agriculture, 2013                  |
| Global Plant Biomass       | ~50% reduction since dawn of civilization            | Bar-On, Phillips & Milo, PNAS, 2018; Smil, 2011        |
| Global Forest Loss         | 1/3 of all forests gone; 2B ha over 10,000 yrs       | FAO FRA, 2020; Williams, 2003; Ellis et al., 2020      |
| Living Planet Index        | 73% avg wildlife pop. decline since 1970             | WWF / ZSL Living Planet Report, 2024                   |
| Wild Mammal Biomass        | 5% of mammal biomass; down 85% from baseline         | Greenspoon et al., PNAS, 2023                          |
| Phytoplankton (since 1950) | ~40% decline; 1%/yr since 1900                       | Boyce, Lewis & Worm, Nature, 2010                      |
| Marine Fish Biomass        | 80% lost in 100 yrs; 60% in last 40 yrs              | Christensen et al., 2014; Myers & Worm, Nature, 2003   |
| Ocean NPP (global + CO2)   | Declining across ~50% of ocean; -20% oligotrophic    | Kulk et al., Nat. Comm., 2020; Endo et al., PNAS, 2025 |
| Terrestrial NPP (HANPP)    | 25–40% of NPP appropriated or suppressed             | Haberl et al., PNAS, 2007                              |
| Agricultural Productivity  | 52% soil degraded; -30–50% yields Sub-Saharan Africa | Pimentel & Wilson, 2004; FAO SOLAW, 2025               |
| Biodiversity-NPP Link      | 57% of NPP variation = biodiversity                  | Tilman, Reich & Isbell, PNAS, 2012                     |
| Global Soil Carbon         | 50–70% lost; cropland productivity -13%              | Sanderman et al., PNAS, 2017                           |
| Global Wetlands            | ~50% lost since 1900                                 | Ramsar Convention / WWF, 2018                          |

## SECTION II

# The Finding Illustrated at Three Scales

The primary productive potential loss documented in Section I is not an abstraction — it manifests at every level of observation. The following three case studies illustrate the same dynamic across ascending spatial scales: from a single property, to an agricultural parcel, to a watershed integrating many different land uses. In each case, the Current State is shown first, followed by the Potential High Productivity Landscape — what that same area could produce under a regenerative management approach. The pattern holds at every scale, which is itself part of the argument.

### SCALE A — PROPERTY

## The Backyard: Primary Productive Potential at the Property Scale

A standard quarter-acre suburban lot planted in turfgrass operates at a tiny fraction of its primary productive potential — a single-species canopy, active only part of the year, requiring net fossil fuel inputs to maintain, and producing almost nothing in soil building, carbon sequestration, water infiltration, or biodiversity support. The contrast with a native perennial polyculture on the same footprint is stark at every metric.

| Current State — Maintained Turfgrass Lawn   | Potential High Productivity Landscape — Native Perennial Polyculture   |
|---|--|
| <ul style="list-style-type: none"><li>• 1–3 species, single shallow canopy</li><li>• Active production 4–6 months per year</li><li>• Shallow roots, 2–4 inches deep</li><li>• Near-zero soil carbon sequestration</li><li>• 30–50% water infiltration; high runoff</li><li>• Supports minimal wildlife</li><li>• Requires mowing, fertilizer, herbicide, irrigation</li></ul> | <ul style="list-style-type: none"><li>• 50–200+ plant species per quarter acre</li><li>• Active production 10–11 months per year</li><li>• Root systems extending 10–15 feet deep</li><li>• High annual soil carbon sequestration</li><li>• 90–100% water infiltration; groundwater recharge</li><li>• Supports hundreds of invertebrate and bird species</li><li>• Zero fossil fuel inputs required after establishment</li></ul> |

**40M** Acres of lawn in the United States — more than any single irrigated crop, most operating at a fraction of primary productive potential

**5–10X** Greater primary productive potential of a native perennial polyculture vs. maintained turfgrass on the same plot

The property scale matters because it is universally relatable and universally replicable. Every property owner in the developed world has made, or inherited, land use decisions that suppress primary productive potential. Scaled across 40 million acres of American lawn alone, the aggregate loss is substantial — and recoverable.

## SCALE B — AGRICULTURAL PARCEL

### The Corn Parcel: Fossil Fuel Subsidy as Productive Potential Mask

The Midwestern corn and soybean belt occupies what was once the most productive grassland ecosystem in North America — the tallgrass prairie. Less than 1% of original tallgrass prairie remains. What replaced it appears productive by one narrow measure (grain yield per acre) but is deeply unproductive by every other metric of primary productive potential. The critical comparison is not between two crops but between an annual fossil-fuel-dependent monoculture and the self-sustaining perennial system it displaced.

#### Current State — Annual Corn / Soy Rotation

- 2 targeted species per rotation
- Root systems 2–3 feet deep
- Bare soil 7–8 months per year — zero production
- Soil organic matter: 1–3% and declining
- Net carbon loss annually
- High fossil fuel inputs required; collapses without them
- 2–5 species supported

#### Potential High Productivity Landscape — Restored Tallgrass Prairie

- 400+ plant species per acre in remnants
- Root systems 10–15 feet deep
- Photosynthetically active 10–11 months/year
- Soil organic matter: 8–12% and building
- Annual net carbon sequestration
- Zero external inputs required; self-sustaining
- Full trophic web intact — insects, birds, mammals, soil fauna

**99%**

Of original tallgrass prairie converted — less than 1% remains intact

**50%**

Decline in Corn Belt soil organic carbon since tillage conversion began — the biological foundation of primary productive capacity

The critical analytical move: strip away the fossil fuel subsidy and measure intrinsic primary productive potential. A corn field left untreated — no synthetic nitrogen, no herbicide, no fossil fuel subsidy — collapses within one season. The soil has lost the organic matter and microbial complexity to support it. The system's apparent productivity is entirely borrowed from fossilized sunlight, not current primary productive capacity. The same acre under restored tallgrass prairie would be producing across hundreds of species, storing carbon 15 feet below grade, and feeding a full trophic chain — with zero external inputs.

## SCALE C — WATERSHED

### The Boulder Creek Watershed: A Multi-Land-Use Gradient

The Boulder Creek Watershed covers 1,160 km<sup>2</sup> (roughly 286,000 acres), draining the Front Range of Colorado from the Continental Divide at 4,120 meters down to the eastern plains at 1,480 meters. It is one of the best-documented watersheds in the American West, studied extensively by the USGS, University of Colorado, and the NSF Critical Zone Observatory. Its value as a case study lies in the diversity of land uses it integrates — from alpine and subalpine headwaters, through mid-elevation forested slopes, to urban corridors and agricultural lowlands — all within one hydrologically connected system. The comparison below contrasts the current

degraded state of the watershed with a Potential High Productivity Landscape built from documented regenerative practices applicable to each zone.

| Current State — Boulder Creek Watershed  | Potential High Productivity Landscape — Boulder Creek Watershed  |
|--|--|
| <ul style="list-style-type: none"> <li>• Uplands: timber harvest, fire suppression, and recreational pressure reduce forest carbon and snowpack retention; altered hydrology compresses peak flows</li> <li>• Riparian: corridors degraded by channelization, livestock grazing, and invasive species; native riparian vegetation fragmented</li> <li>• Urban corridor: impervious surfaces generate high runoff; soil compaction, turf monocultures, pesticide and nutrient loading into the stream</li> <li>• Agricultural lowlands: annual crops, bare soil, irrigation diversions, pesticide inputs; eleven pesticide compounds detected in stream (USGS)</li> <li>• Stream: reduced baseflow, elevated temperatures, pesticide and pharmaceutical contamination from wastewater effluent; native fish species including Preble's meadow jumping mouse federally threatened</li> <li>• Soil carbon depleted across most lower watershed zones; groundwater recharge reduced</li> </ul> | <ul style="list-style-type: none"> <li>• Uplands: beaver reintroduction and beaver dam analogs slow, spread, and infiltrate water across valley floors</li> <li>• Uplands: snow retention and infiltration-focused forest management moderates peak flows and recharges groundwater</li> <li>• Uplands: fuel load reduction forestry with onsite biomass deployed in water retention and soil absorption applications</li> <li>• Uplands: targeted short-duration grazing reduces understory fuel loads and enhances nutrient cycling</li> <li>• Riparian: restored willow and cottonwood corridors reestablish multi-layered canopy, bank stability, and aquatic food web support</li> <li>• Urban corridor: bioswales, native plantings, permeable surfaces, and riparian buffers reduce runoff and thermal loading</li> <li>• Lower watershed: low-productivity irrigated cropland transitioned to drought-resilient native grasses and shrubs</li> <li>• Lower watershed: targeted short-duration grazing enhances soil biology and nutrient cycling on transitioned lands</li> <li>• Lower watershed: terracing, berming, windbreaks, and agroforestry increase moisture retention and functional biodiversity</li> <li>• Stream: restored baseflow, cooler temperatures, and improved water quality support native fish and invertebrate recovery</li> </ul> |

**1%** Riparian areas cover ~1% of Colorado's eastern plains — yet provide habitat for 80–90% of native wildlife at some life stage (Boulder County Parks & Open Space)

**40–60%** Estimated primary productive potential lost across the Boulder Creek Watershed — recoverable through coordinated regenerative management across all land use zones

The Boulder Creek Watershed illustrates the compounding nature of productive potential loss across multiple land uses within a single hydrological system. Degradation at the upland level cascades into reduced baseflow and elevated stream temperatures in the lower watershed. Degradation in the riparian corridor removes the highest-productivity biological zone in a semi-arid landscape. Degradation in the agricultural and urban lowlands adds chemical, thermal, and hydrological stressors that suppress biological productivity in the stream itself.

The Potential High Productivity Landscape is not a single intervention but a coordinated set of practices across all zones. In the uplands, beaver reintroduction and beaver dam analogs anchor water slowing and infiltration, while fuel load reduction forestry treatments deploy onsite biomass in water retention applications and targeted short-duration grazing replaces mechanical fuel reduction with biological soil improvement. In the mid-elevation riparian zone, willow and cottonwood restoration reestablishes the corridor's disproportionate habitat and productivity value. In the urban corridor, green infrastructure reduces runoff and thermal loading. In the lower watershed, transitioning low-priority irrigated cropland to native drought-resilient grasses and shrubs reduces water consumption while restoring year-round soil cover; short-duration grazing enhances nutrient cycling on these transitioned lands; and terracing, berming, windbreaks, and agroforestry techniques increase moisture retention, soil protection, and functional biodiversity across agricultural margins. Each zone reinforces the recovery of zones downstream — and together they restore primary productive potential across the full watershed gradient.

## SECTION III

# The Recovery Pathway: Coppice Energy and the Restoration of Primary Productive Potential

*If the planet is operating at roughly half its primary productive potential, then a coordinated effort to restore even a fraction of that capacity would not merely conserve nature — it would increase the net primary productive energy available to human communities. Section III presents one such pathway.*

The argument developed in Sections I and II establishes that primary productive potential has been substantially degraded — and that much of what remains is being maintained only through massive fossil fuel subsidies. As those subsidies become less available and less affordable, the underlying degradation will become impossible to mask. The question then is not only how to document the loss, but how to begin reversing it.

The recovery pathway described here is not speculative. It is grounded in established agroforestry practice, documented microclimate research, and a straightforward energy accounting. Its core logic is this: where human communities most urgently need energy security — particularly cooking fuel — the same intervention that provides that energy can simultaneously restore primary productive capacity to degraded land, increase local food security, and initiate measurable microclimate stabilization. Energy need becomes a driver of ecological restoration rather than its opposite.

## The Energy Systems Framing

From a primary productive potential perspective, the coppice energy system addresses the central problem identified in this document: the replacement of complex, multi-layered, perennial living systems with simplified, bare, or monoculture landscapes that generate neither food nor fuel nor ecological function without fossil fuel inputs.

A coppice woodlot — managed for repeated harvest of fast-growing nitrogen-fixing species — is a perennial polyculture system. It maintains living root systems year-round. It builds soil organic matter and nitrogen availability with each rotation. It provides structural habitat. It cycles water back into the landscape rather than generating runoff. And it produces renewable cooking fuel energy on a 1–4 year cycle, with no fossil fuel inputs after establishment. Unlike a corn field or a lawn, it increases primary productive potential with each passing year rather than depleting it.

This is the critical reframe for an energy systems audience: coppice is not merely *biomass energy*. It is *primary productive potential restoration that happens to generate cooking fuel as a byproduct*. The energy yield is real and substantial. But the deeper value is the restoration of living systems that have been taken offline.

## The Household Scale: Cooking Fuel as Restoration Driver

Research on cooking fuel use establishes a clear baseline. A traditional open fire consumes approximately 10 kg of wood per day per family. A wood gasifier stove reduces this to approximately 3 kg per day — a 65–70% reduction. This reduction is itself a form of productive

potential recovery: it immediately reduces the deforestation pressure that is one of the primary drivers of primary productive loss globally.

| Stove Type                | Wood Use (kg/day) | Reduction vs. Open Fire |
|---------------------------|-------------------|-------------------------|
| Traditional open fire     | ~10 kg            | Baseline                |
| Improved cookstove        | ~5 kg             | ~50% reduction          |
| Wood gas (gasifier) stove | ~3 kg             | ~65–70% reduction       |

At 3 kg per day, a family of five requires approximately 1,100 kg (1.1 tonnes) of dry wood annually. Fast-growing nitrogen-fixing coppice species yield 5–10 tonnes of dry biomass per hectare per year. At the conservative figure of 5 tonnes per hectare, each family requires just 0.25 hectares — roughly 100 feet by 270 feet — to achieve complete cooking fuel self-sufficiency with no external inputs after the first harvest cycle of 1–2 years.

| Parameter                                | Value                                |
|--|--------------------------------------|
| Annual wood needed per family (gasifier) | ~1,100 kg (~1.1 tonnes)              |
| Coppice yield (conservative)             | 5 tonnes/ha/year                     |
| Land needed per family of 5              | 0.25 hectare (2,500 m <sup>2</sup> ) |
| Equivalent area                          | ~100 ft × 270 ft (~27,000 sq ft)     |
| Time to first harvest                    | 1–2 years                            |
| Time to fully self-sustaining system     | 2–3 years                            |

## Recommended Coppice Species: Fuel and Soil Restoration Simultaneously

The species recommended for coppice energy systems are nitrogen-fixing — meaning they actively rebuild soil fertility with each rotation, directly restoring primary productive potential on degraded land. This is not incidental. It is the mechanism by which cooking fuel production becomes land restoration.

| Species                | Region             | Soil Benefit                    | Rotation  |
|------------------------|--------------------|---------------------------------|-----------|
| Acacia spp.            | Africa, Asia       | N-fixing, erosion control       | 2–4 years |
| Leucaena leucocephala  | Tropics worldwide  | N-fixing, deep roots            | 1–3 years |
| Gliricidia sepium      | C. America, Africa | N-fixing, mulch                 | 1–2 years |
| Calliandra calothyrsus | E. Africa, SE Asia | Erosion control, organic matter | 1–2 years |
| Sesbania spp.          | Africa, Asia       | N-fixing, soil organic matter   | 1–2 years |

## The Community Scale: A Climate Restoration Threshold

Research emerging from regenerative agriculture adoption in Kansas establishes that when a critical mass of land — approximately five square miles (1,295 hectares) — transitions to continuous cover, active water cycle management, and soil regeneration practices, measurable local microclimate shifts begin to occur: altered precipitation patterns, temperature moderation, and enhanced atmospheric moisture cycling. Some Kansas counties have achieved adoption rates

approaching 60–70% of their farmland, providing real-world evidence that this threshold effect is achievable at landscape scale.

Applying the household coppice model to a community of 1,000 households — each managing one integrated hectare combining coppice woodlot, polyculture food production, and soil restoration — produces 1,000 hectares of continuous, perennial, living-cover landscape. This approaches the five square mile microclimate restoration threshold.

| Parameter                                 | Value           |
|---|-----------------|
| Total households                          | 1,000           |
| Land per household                        | ~1 hectare      |
| Total managed area                        | 1,000 hectares  |
| Five square miles equals                  | ~1,295 hectares |
| Total population served (5 per household) | ~5,000 people   |

| Land Use per Household       | Area         | Function                                |
|------------------------------|--------------|---|
| Coppice woodlot              | 0.25 hectare | Cooking fuel via gasifier stove         |
| Polyculture and agroforestry | 0.50 hectare | Diverse food crops, tree crops, fodder  |
| Soil restoration and cover   | 0.25 hectare | Nitrogen fixation, carbon sequestration |
| Total per household          | 1.00 hectare | Integrated energy + food + restoration  |

Each of the 1,000 households acts simultaneously as an energy producer (coppice gasifier system), a food producer (polyculture and agroforestry), a soil restoration agent (nitrogen-fixing species, continuous cover), and a node in a regional climate stabilization network. The threshold effect is non-linear: each new household joining the network increases the collective climate impact, accelerating toward the tipping point where local weather patterns begin to measurably shift. This is the multiplier that distinguishes a coordinated community system from a collection of individual solutions.

## The Global Scale: 3% of Degraded Land, One Billion People

Applying this household model globally reveals the scale of the opportunity. With 1.66 billion hectares of degraded land available worldwide — land already taken offline from primary productive potential — providing cooking fuel via coppice gasifier systems for one billion people requires only about 3% of that degraded land base.

| Parameter   | Value                                       |
|---|---|
| Target population                                 | 1,000,000,000 people (200 million families) |
| Land required @ 0.25 ha per family (coppice only) | 50 million hectares                         |
| Comparable land area                              | Roughly the size of Spain                   |
| Total degraded land available (FAO, 2024)         | 1.66 billion hectares                       |
| Coppice land as % of degraded land                | ~3%   |
| Annual planting rate (20-year rollout)            | 2.5 million hectares/year                   |

At this scale, a distributed network of climate-restoration communities — each comprising approximately 1,000 households — would collectively transform 50 million hectares of degraded land into productive, regenerative landscapes. The result is not just energy and food security for one billion people, but the emergence of thousands of interlocking microclimate stabilization zones distributed across the globe's most degraded regions.

## Primary Productive Potential: What Gets Restored

Expressed in the framework of this document, a global coppice restoration initiative would bring the following primary productive potential back online across 50 million hectares of currently degraded land:

**50M ha**

Of degraded land restored to perennial, living-cover systems — primary productive potential brought back online (roughly the size of Spain, or California and Nevada combined)

**~3%**

Of the world's degraded land base required to provide cooking fuel security for one billion people

**5–10  
t/ha**

Annual dry biomass yield from coppice systems — renewable energy production from land that is currently producing nothing

**2–3 yr**

Time to fully self-sustaining system — the fastest-recovering primary productive intervention available at scale

But the energy accounting understates the full recovery value. Each hectare of coppice woodlot also rebuilds soil nitrogen and organic matter, reestablishes perennial root systems, begins restoring water infiltration and groundwater recharge, and provides structural habitat for wildlife. The per-hectare primary productive potential recovery is substantially larger than the cooking fuel yield alone. The fuel is the economic driver. The ecological restoration is the lasting outcome. This is the critical reframe for the energy systems perspective: restoring primary productive potential is not a cost. It is an investment that generates increasing returns — in soil fertility, in water security, in microclimate stabilization, and in the renewable biological energy that human communities can actually sustain after the fossil fuel subsidy ends. A planet at 50% primary productive potential is not a fixed condition. It is a recoverable one. And the recovery pathway begins with the most fundamental of human needs: cooking fuel.

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*We are living on a planet operating at half its primary productive potential.*

*This is not a fixed condition. It is a recoverable one.*

The evidence assembled in this document points to a loss of primary productive potential at every scale of observation — from the backyard to the watershed to the ocean. But the same framework that establishes the magnitude of the loss also illuminates the recovery pathway. Restoring 3% of the world's degraded land to perennial, living-cover systems would provide cooking fuel security for one billion people, initiate thousands of microclimate restoration zones, and begin the process of bringing offline primary productive potential back into service — for both human communities and living systems alike.

*A multi-scale analytical framework prepared for public discourse on ecological degradation and energy systems recovery. Developed by Brett KenCairn, Executive Director, [Center for Regenerative Solutions](#)*