Biochar: carbon sequestration potential

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Biochar Application to Soils
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Talk outline

- Introduction
  - Carbon storage and land-based options
  - Efficacy of carbon storage in soil organic matter
- Biochar (the concept)
  - Carbon sequestration
  - Bio-energy versus “carbon negative” energy
  - Definitions of biochar
- Net carbon benefits

‘Land based carbon storage’

Rationale for carbon storage strategies:

reducing use of energy will not happen soon or fast enough to decrease atmospheric CO_2

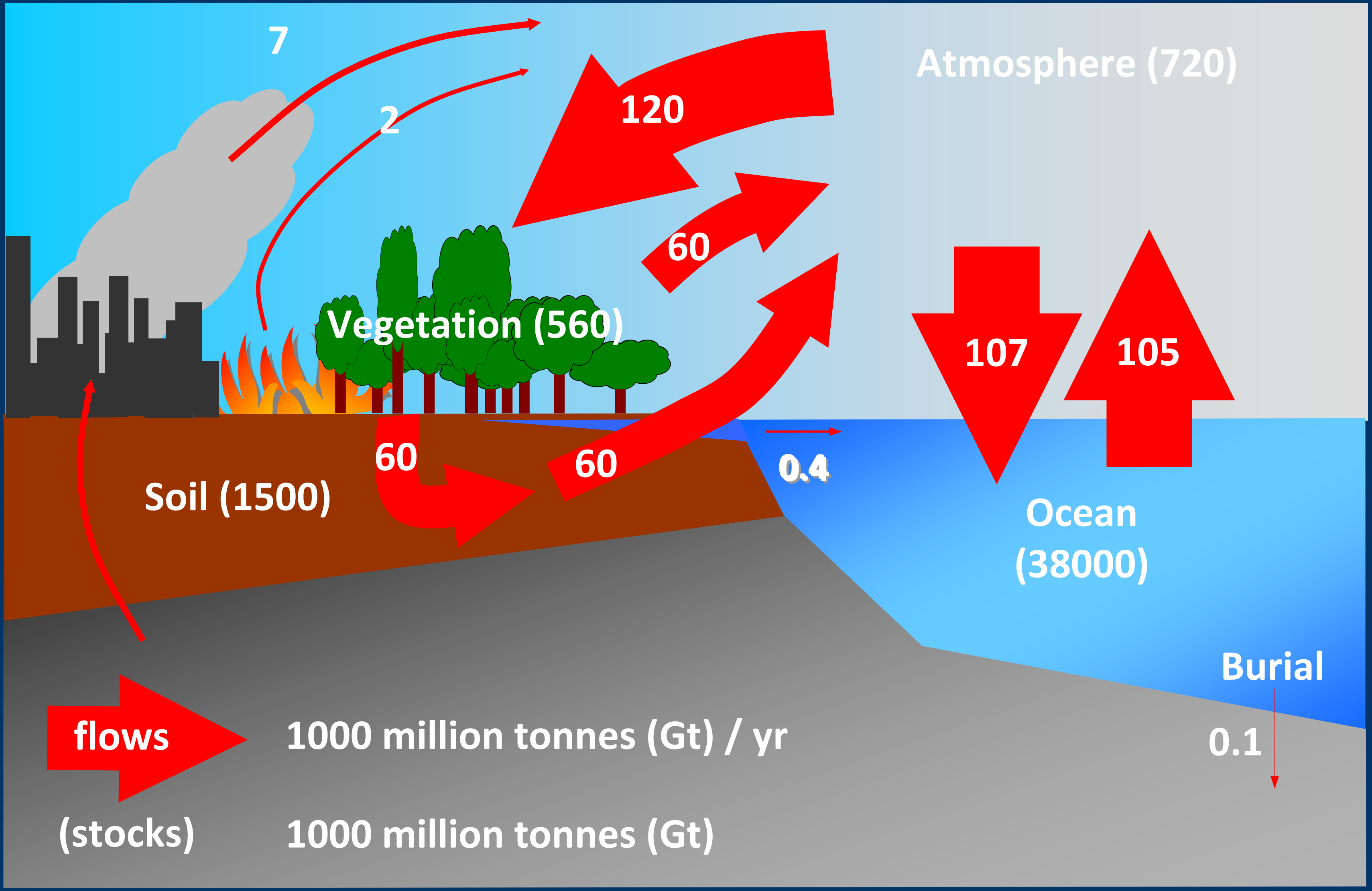
– and for storing carbon in the biosphere:

- capture undertaken by natural processes, so no “energy penalty” (c.f. flue gas capture)
- natural carbon flows large relative to fossil fuel flux, and a significant proportion already human-modified
- auxiliary benefits

Biospheric carbon cycle

Carbon is the main constituent of organic material: 45 % of plant matter, 60% of organic matter in soil

Biospheric carbon cycle - recap



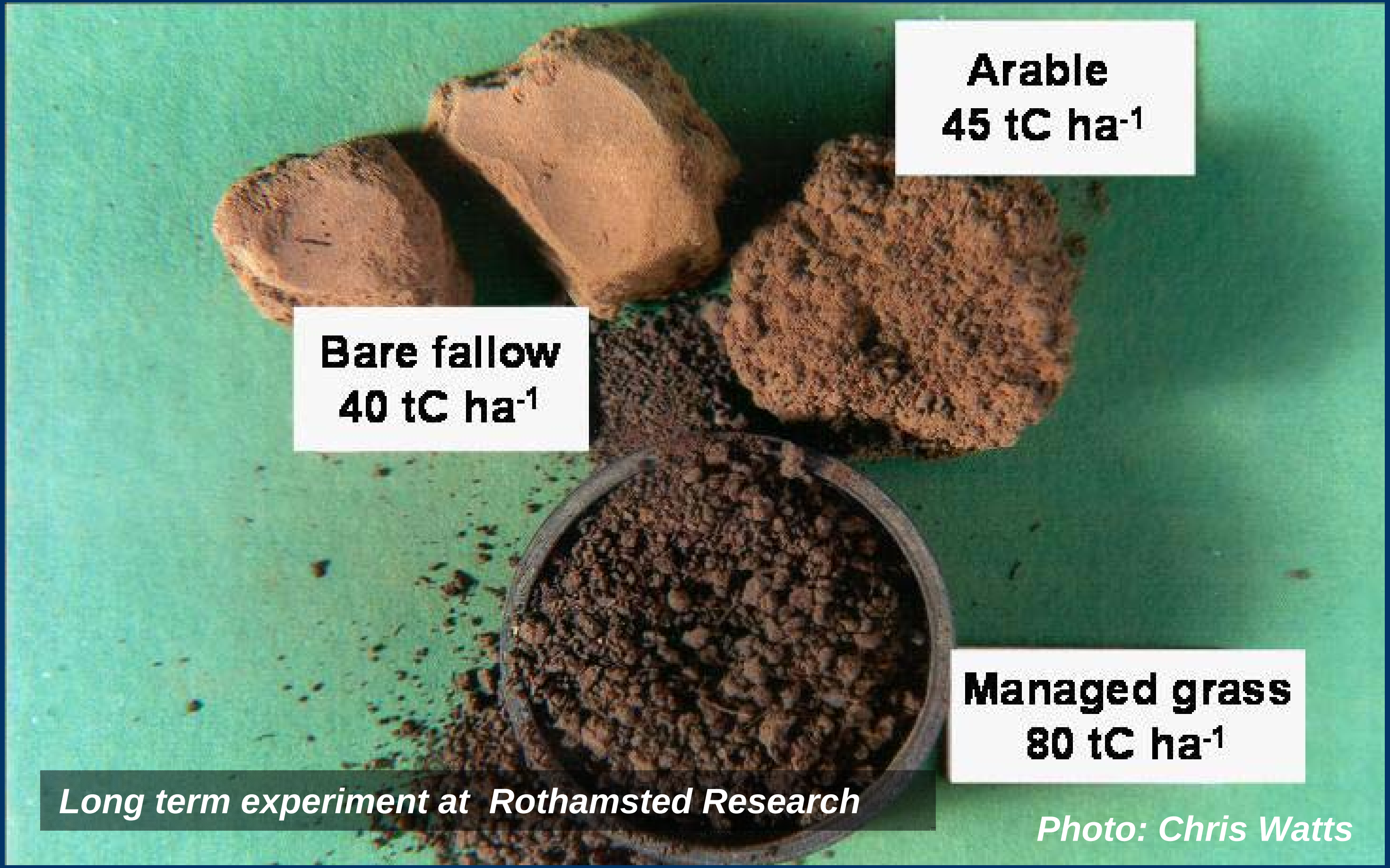
Land-based carbon storage – plants

- Increasing ‘standing carbon’ (forests, plantation)
  - trend forest cover is downward
  - annual accrual (growth) slow and finite
  - planted trees vulnerable to later fire or clearance

Land-based carbon storage – soil

- returning more crop residues, manure, compost, other organic material / waste
  - depends on availability of organic resource
- decreasing soil disturbance (reducing decomposition rate)
  - balance of evidence suggests a small effect

Soil quality driven by labile carbon



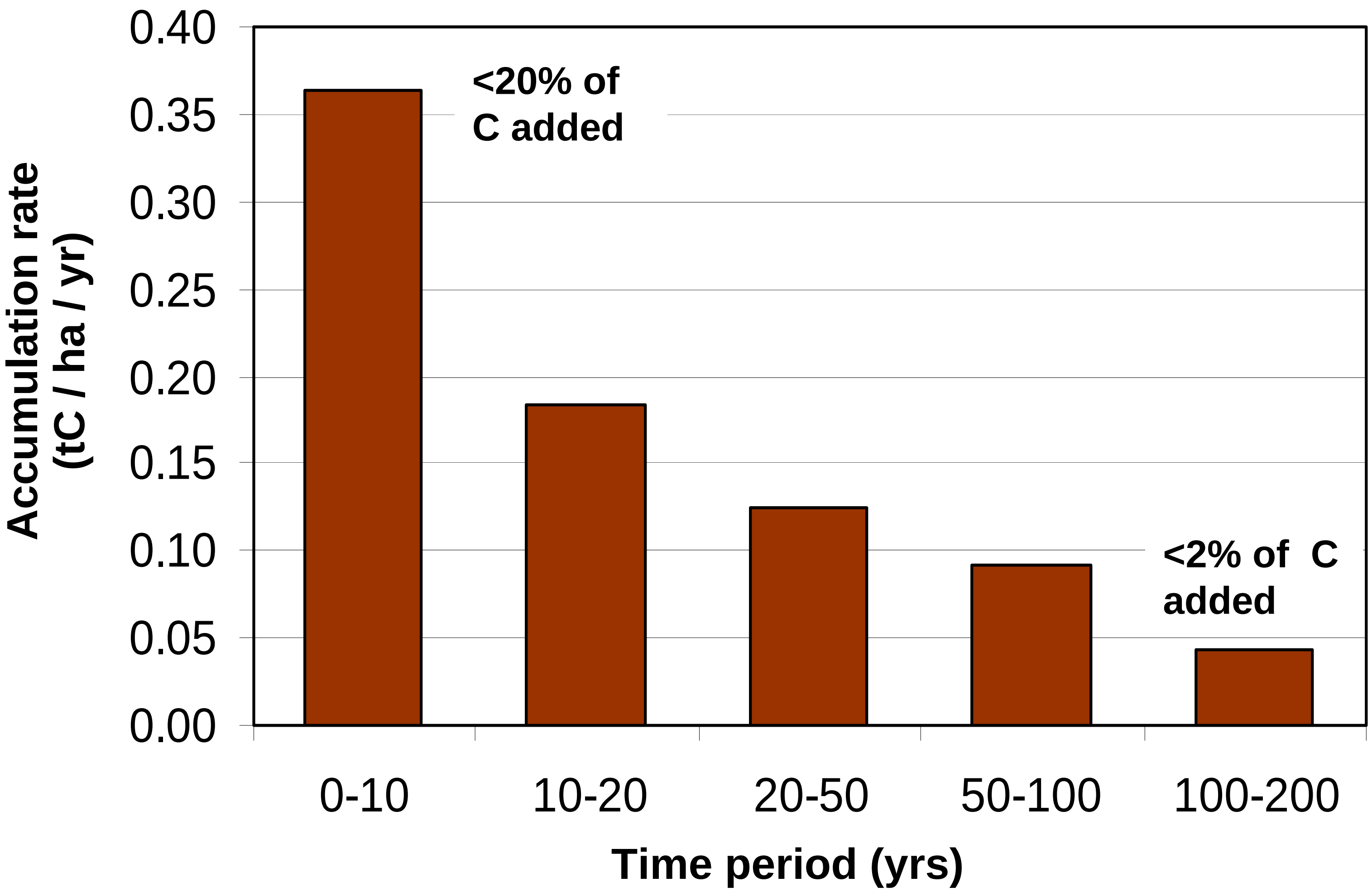
Long term experiment at Rothamsted Research

Photo: Chris Watts

Soil carbon storage – limitations

- Stock is only the balance between the input of organic matter to soil and its decomposition
  - stored rather than sequestered so harder to account
  - developing and maintaining elevated stock requires large ongoing increase in annual input of organic material (with, increasingly, other value)
  - decomposition rate may increase with climate change making soil carbon stores vulnerable to ‘feedback’
- Only a small proportion of added organic matter much stabilised, accumulation rate diminishes
  - inefficient use of organic resource after equilibration

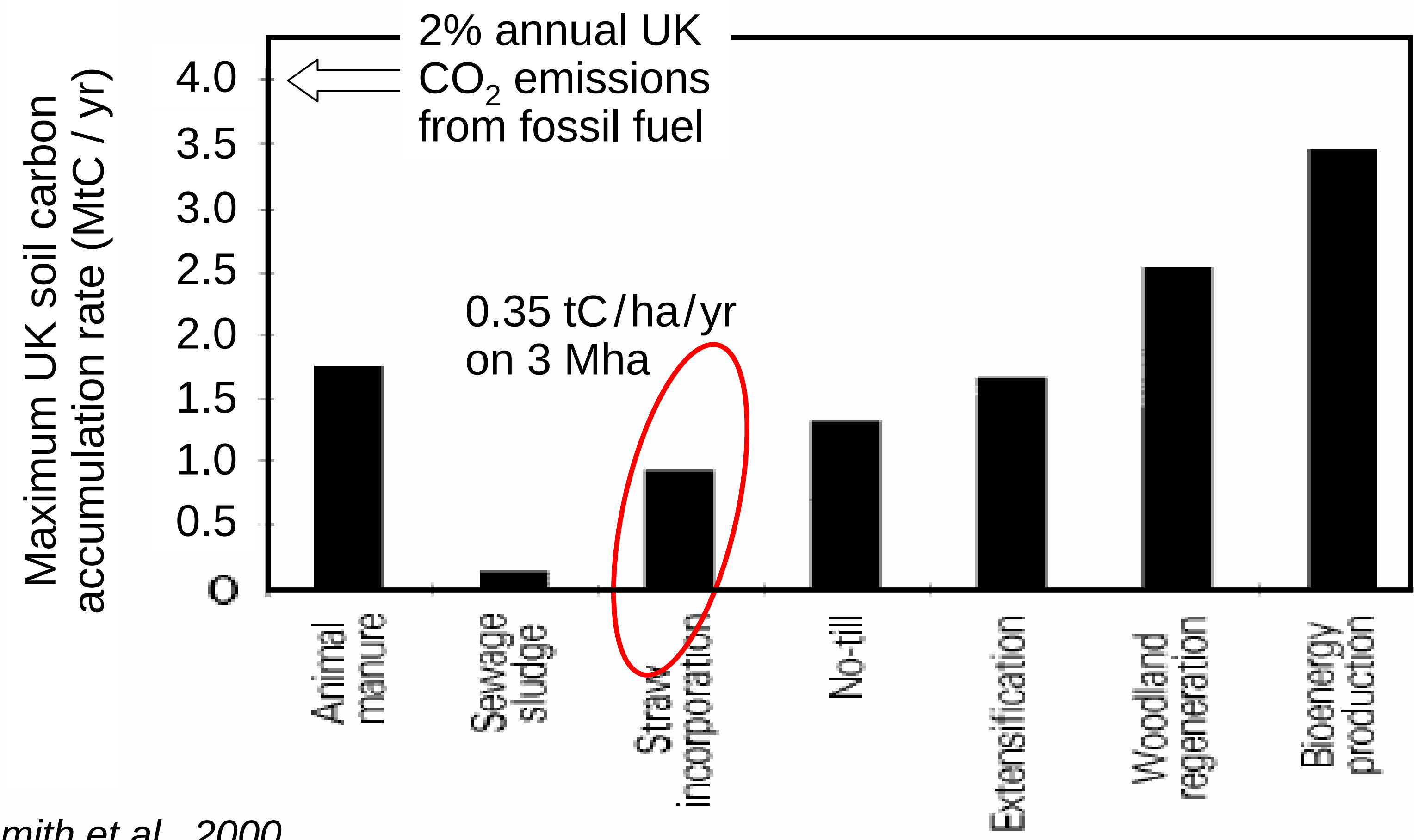
Soil carbon storage – limitations



Simulated decline* in rate of carbon accumulation after increasing organic inputs
Example: New return of 2 tC/yr (cereal straw), silty-loam soil, southern UK
(*Roth C model)

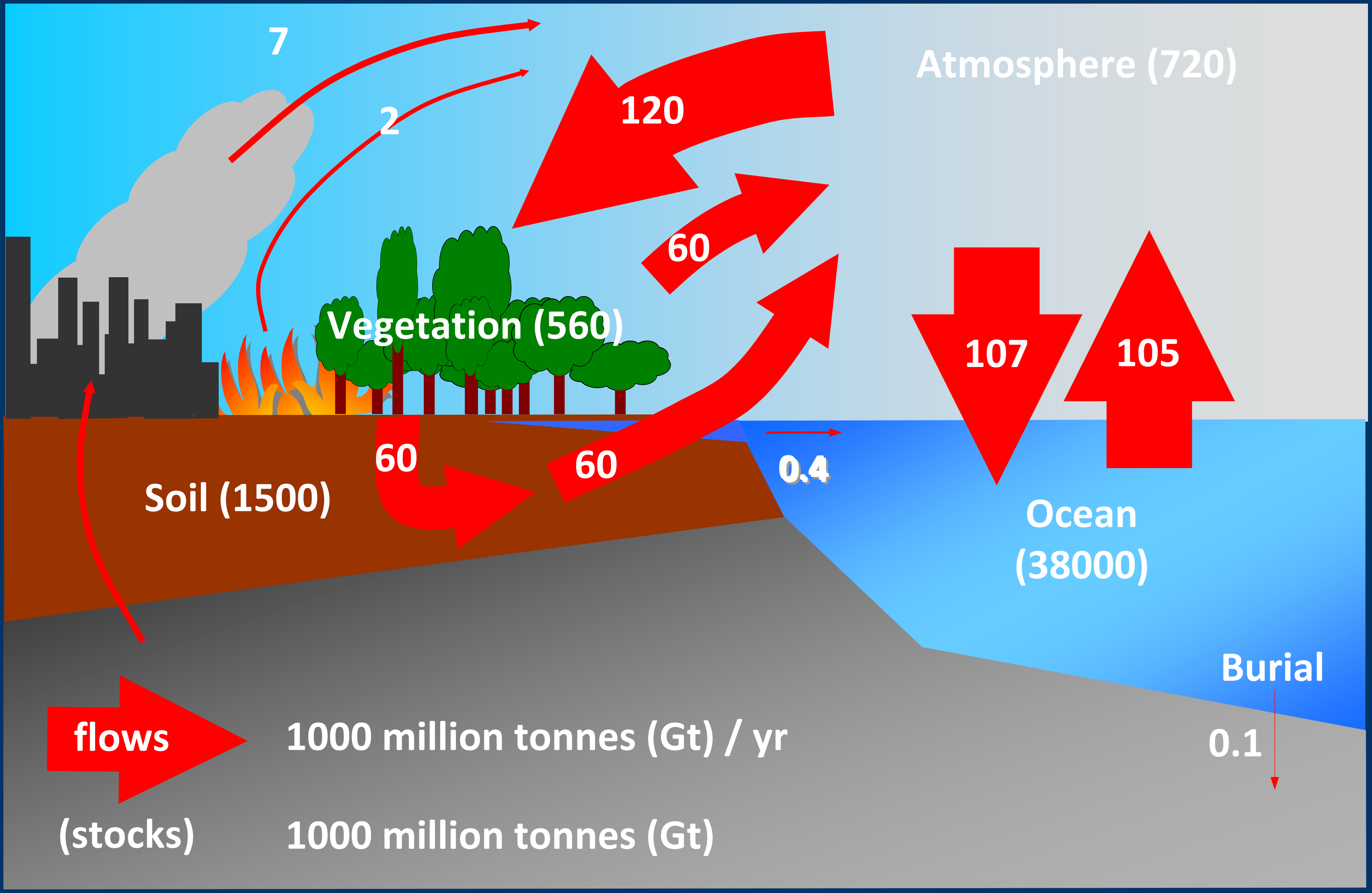
Soil carbon storage – limitations

Even ‘unconstrained’ potential is small – UK case study



Smith et al., 2000
Soil Use and Management

Biospheric carbon cycle - recap



A “new” biospheric option - biochar

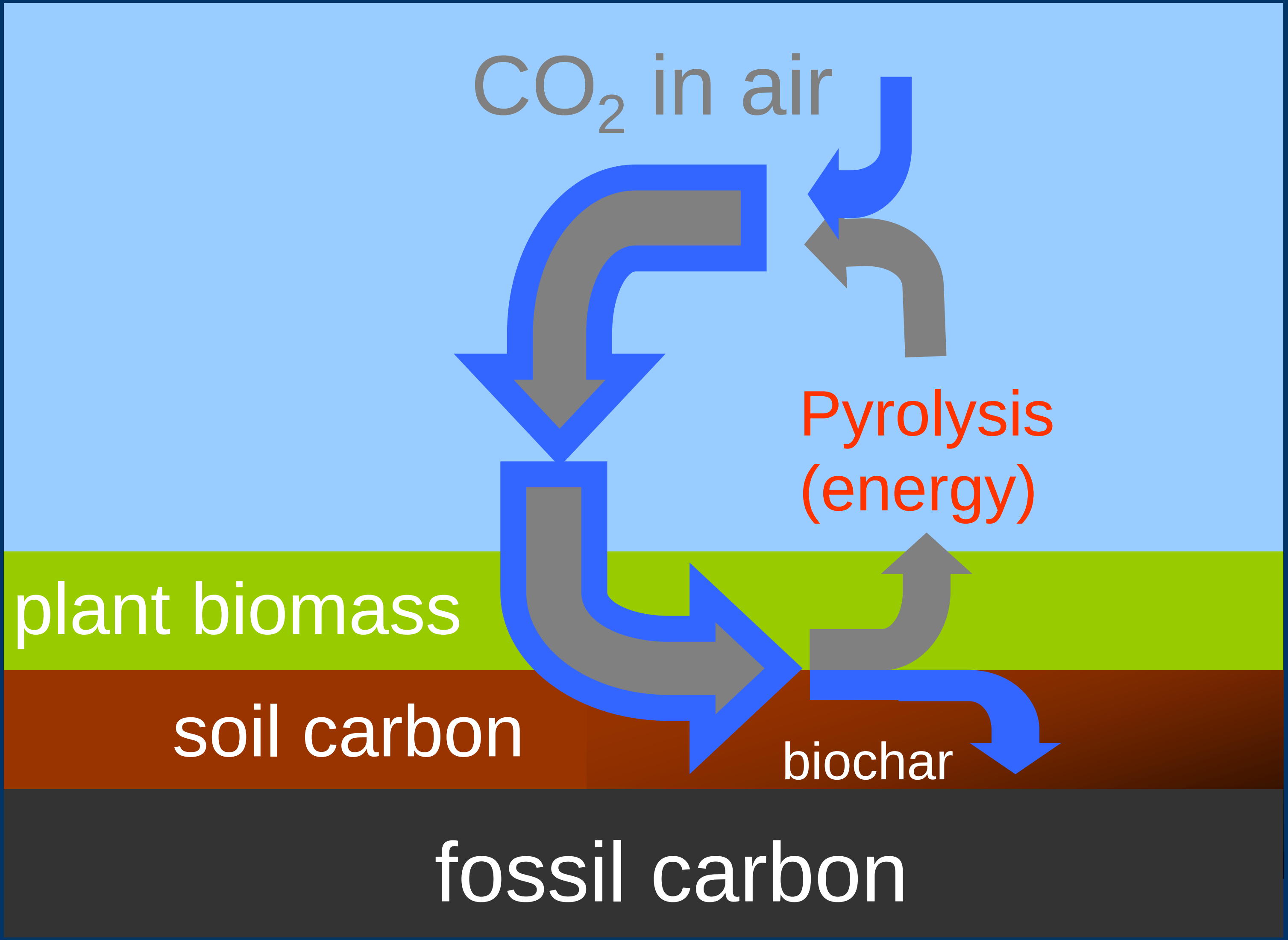
- Convert up to 1 GtC annual net primary productivity (NPP) into *chemically* stable forms
  - organised conversion is a clean process where heat and combustible gases are captured and used
- Storage in soil
  - matches diffuse feedstock and diffuse storage
  - does not depend on physical stabilisation
  - opportunity to generate feedstock through positive feedback (increasing harvestable NPP)

A natural analogue: the “black carbon cycle” (natural fire and charcoal) processes >0.1 GtC / yr

Biochar definition

- International definition (includes charcoal)
  - pyrogenic carbon from biomass
  - intended for application to soil
- Enhanced definition (analogy to charcoal)
  - zero-oxygen conversion
  - high rate of carbon conservation (e.g. >30%)
  - dominant (chemical) configuration ‘aromatic’
  - structured *or* amorphous (physically)
  - capture of synthesis gases (H_2,CH_4,CO, etc.)
    - as energy co-products
  - active matching of characteristics to situation

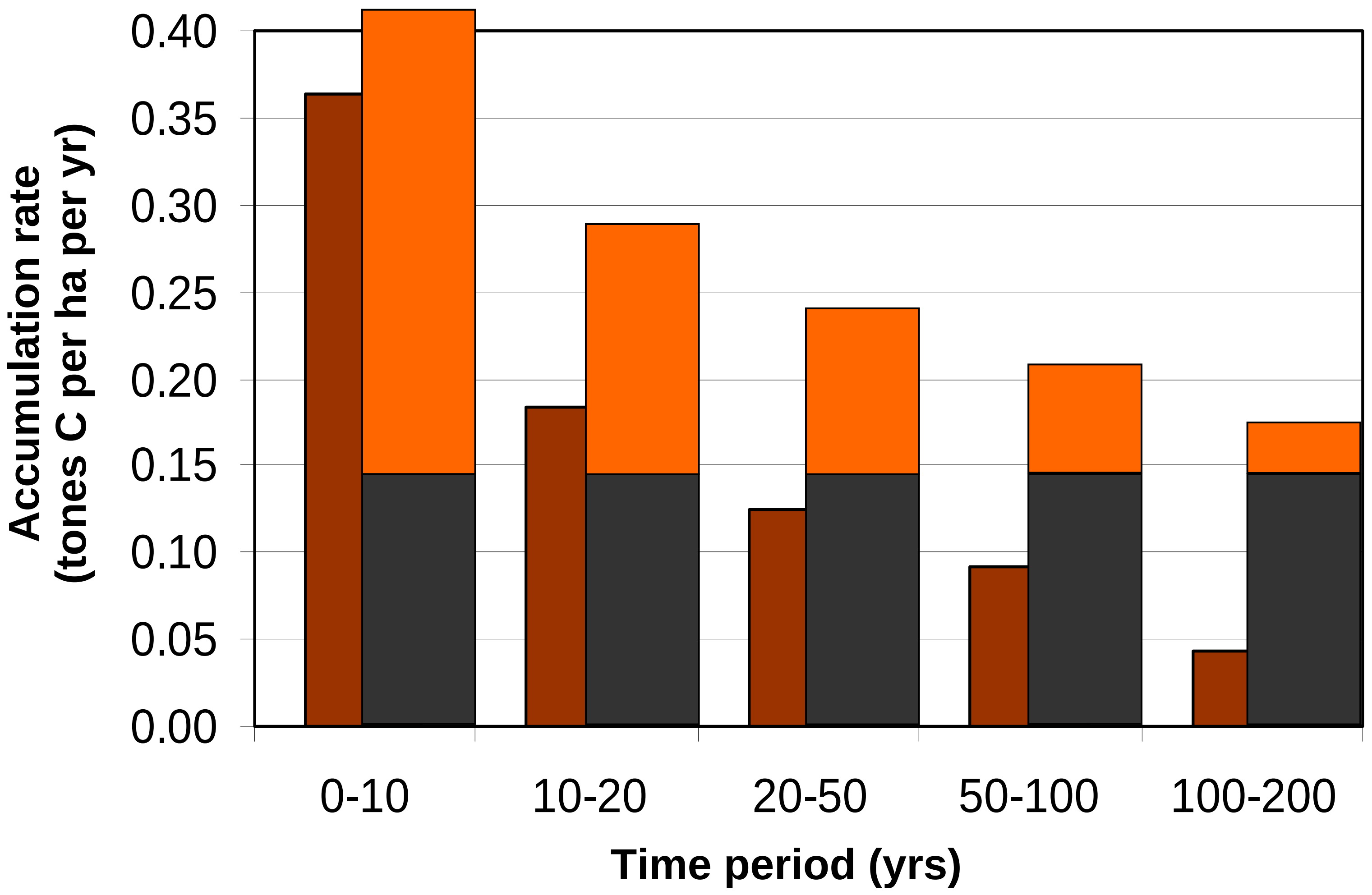
Principles of biochar sequestration



Biochar strategy – attributes

- Proportion of current organic resource converted to stabilised form, providing certain functions typical of soil organic matter, but not diminished
  - maintenance not dependent on maintenance of inputs
  - incremental enhancement
  - annual augmentation is optional or opportunistic
  - no obvious limit to storage capacity
  - secure w.r.t. future change in climate, land-use, etc.
- Can be deployed in conjunction with conventional strategies to build soil organic matter

Biochar-enhanced carbon storage



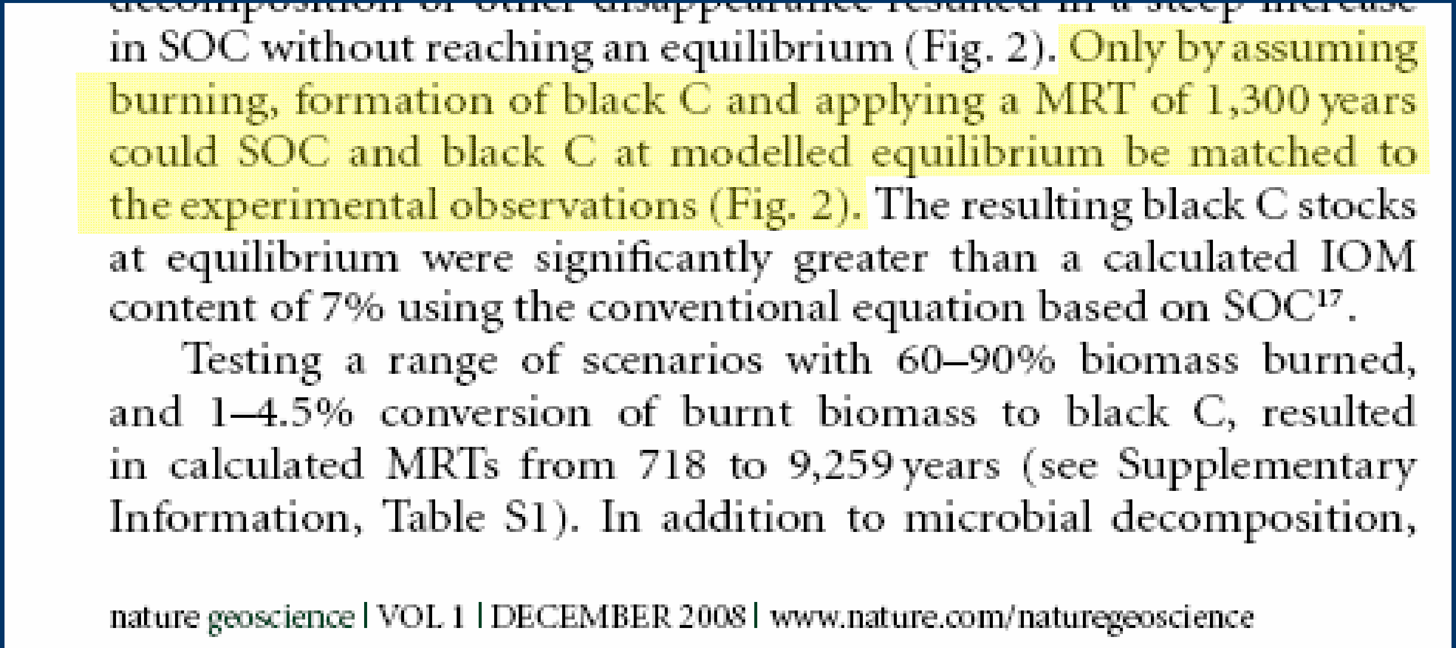
Scenario: diversion of 2 tC/yr (cereal straw) to biochar one year in four (returned to soil, 90% stable), and three years in four direct to the soil – assumes no interactions

Stability of biochar carbon

- Stability of biochar and efficiency of energy use determine net gain
- Can assume a ‘carbon stability factor’ that accounts for some short-term loss
- Sensitivity of strategy minimal for average stability exceeding 100 yr
- Extensive laboratory evidence for high stability of charcoal, millennial-scale in the field…

Stability of biochar carbon

- By analogy to charcoal in natural systems
  - Assumptions on frequency of standing biomass, burn frequency, and conversion
  - Mean residence time of 1300-2600 yrs



in SOC without reaching an equilibrium (Fig. 2). Only by assuming burning, formation of black C and applying a MRT of 1,300 years could SOC and black C at modelled equilibrium be matched to the experimental observations (Fig. 2). The resulting black C stocks at equilibrium were significantly greater than a calculated IOM content of 7% using the conventional equation based on SOC[17].

Testing a range of scenarios with 60–90% biomass burned, and 1–4.5% conversion of burnt biomass to black C, resulted in calculated MRTs from 718 to 9,259 years (see Supplementary Information, Table S1). In addition to microbial decomposition,

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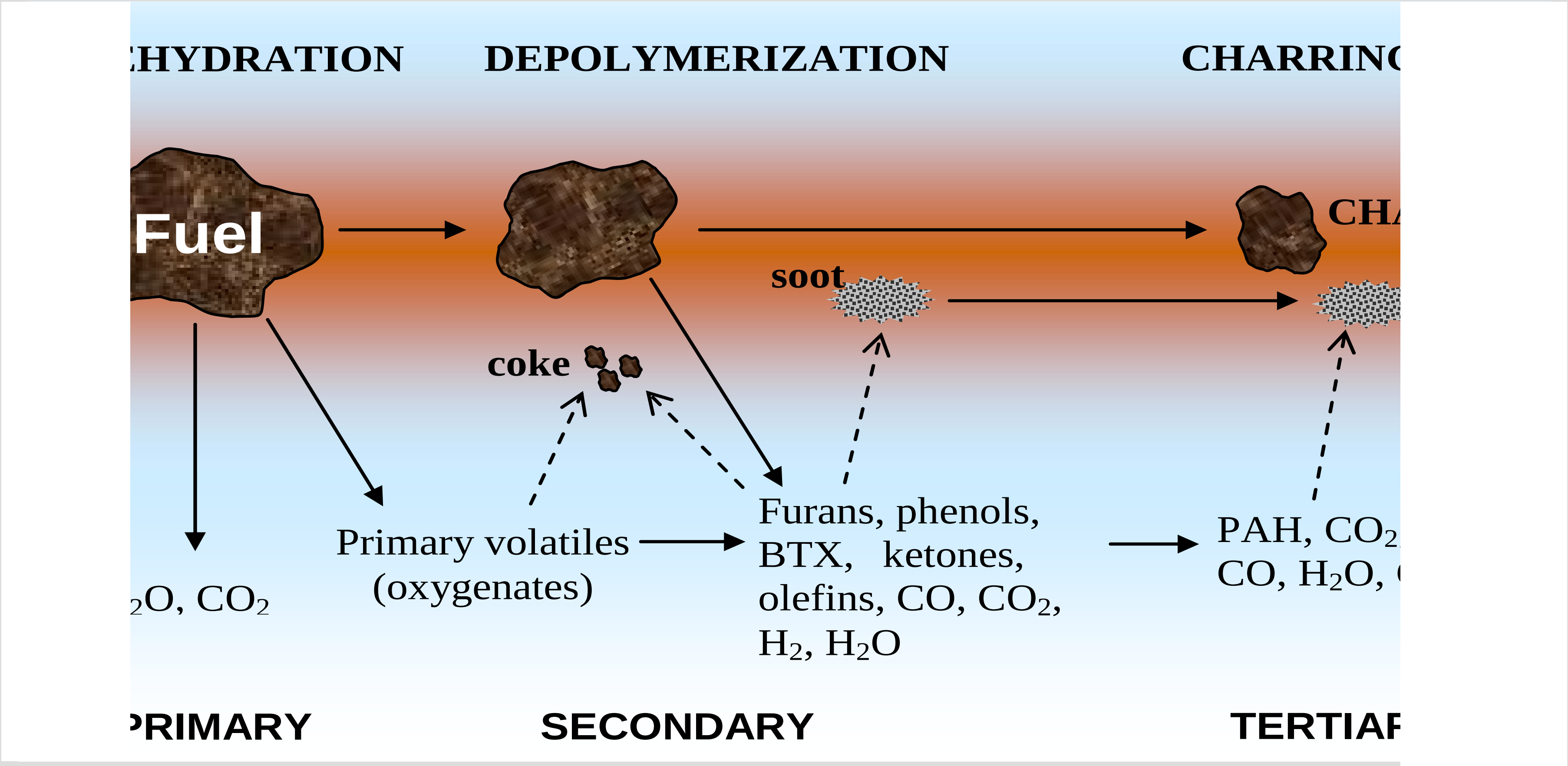
Composite nature of biochar carbon



HYDRATION DEPOLYMERIZATION CHARRIN

Fuel

CHA

soot

coke

$_2O$, CO_2

Primary volatiles (oxygenates)

Furans, phenols, BTX, ketones, olefins, CO, CO_2, H_2, H_2O

PAH, CO_2 CO, H_2O,

RIMARY SECONDARY TERTIAR

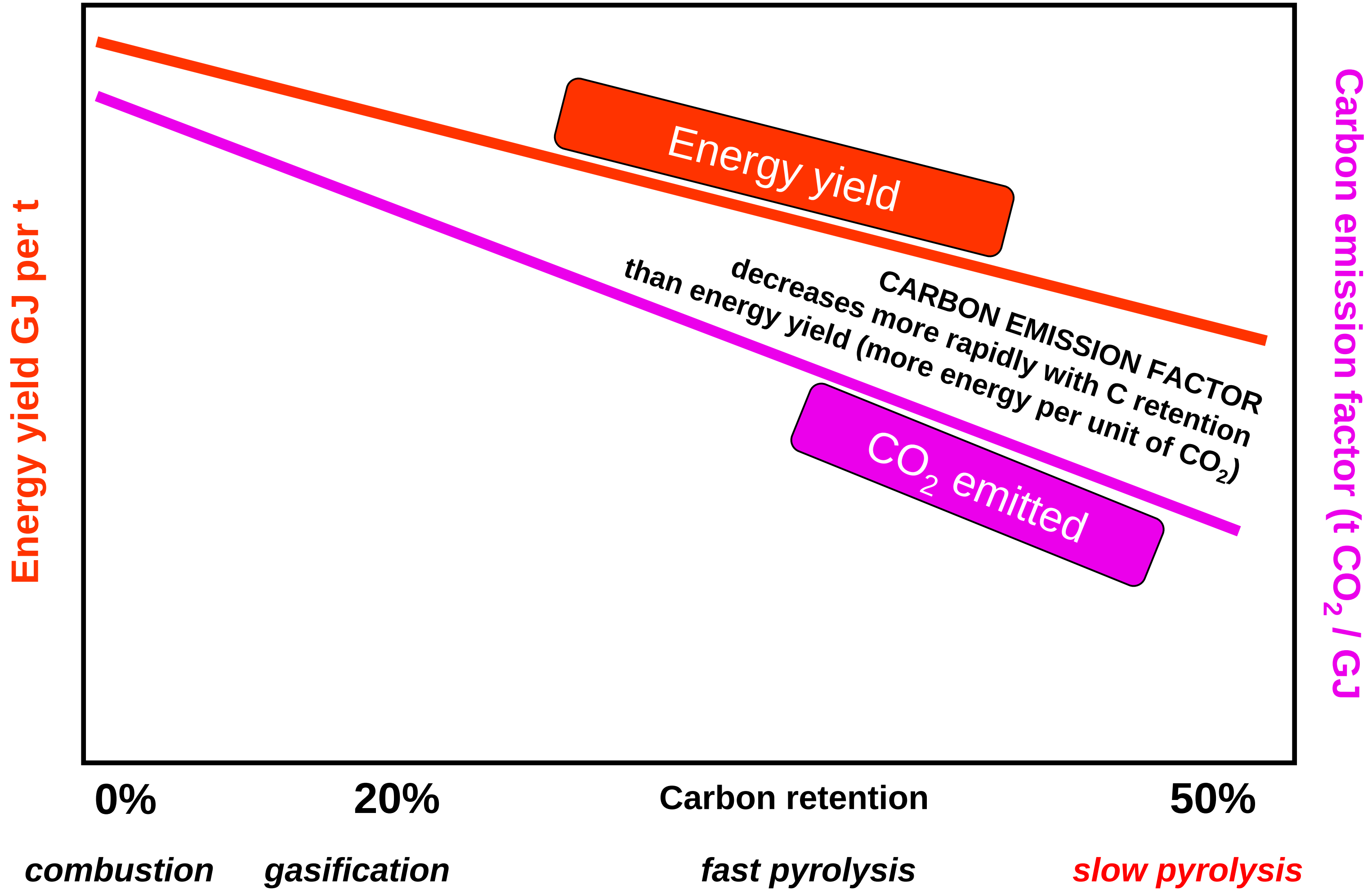
- **Less research on stability of components of carbon from pyrolysis rather than natural charcoal**

Ondrej Masek, PhD thesis

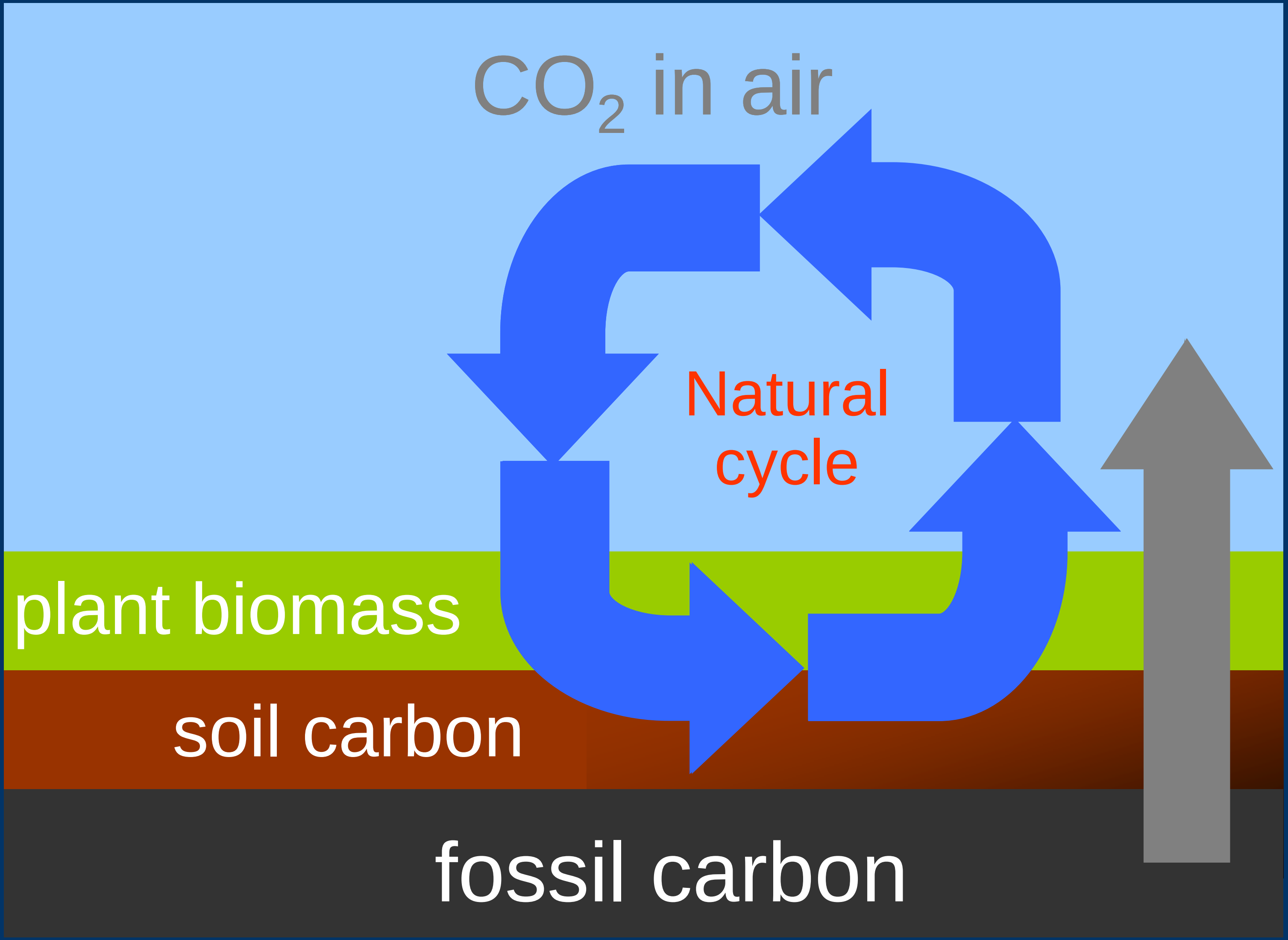
The energy angle

- To concentrate (and stabilise) carbon, hydrogen and oxygen have to be released (and some trace elements in proportion)
- Gases from slow pyrolysis may also contain about $^{2}/_{3}$ of initial carbon
- Burning gases from biomass pyrolysis constitutes bioenergy
- Gas capture prevents polluting emissions associated with traditional pyrolysis (charcoal)
- Technologies to retain more carbon during stabilisation *may* emerge

energy : CO_2 ratios in biomass conversion



“Carbon negative” bioenergy



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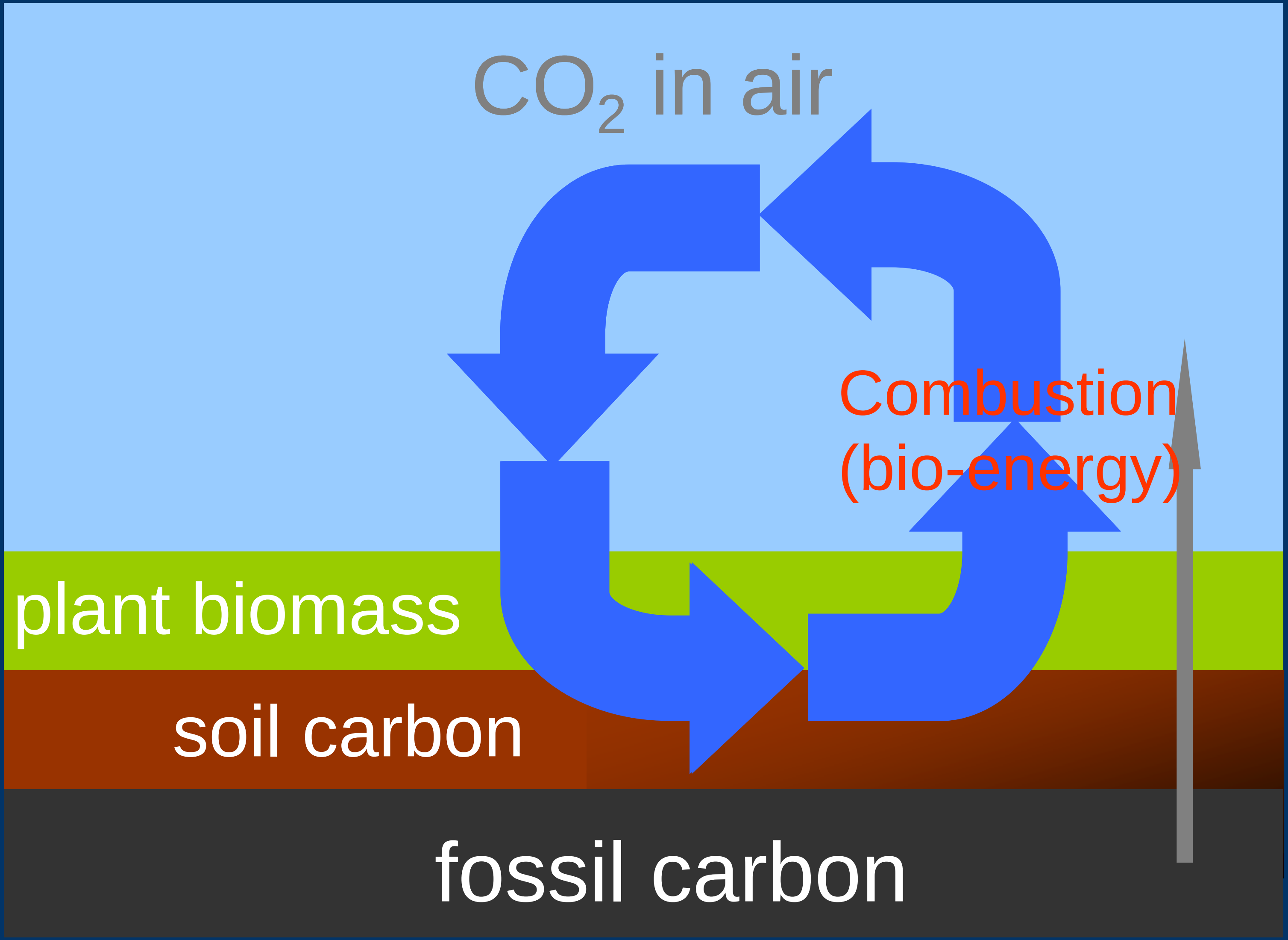


CO_2 in air

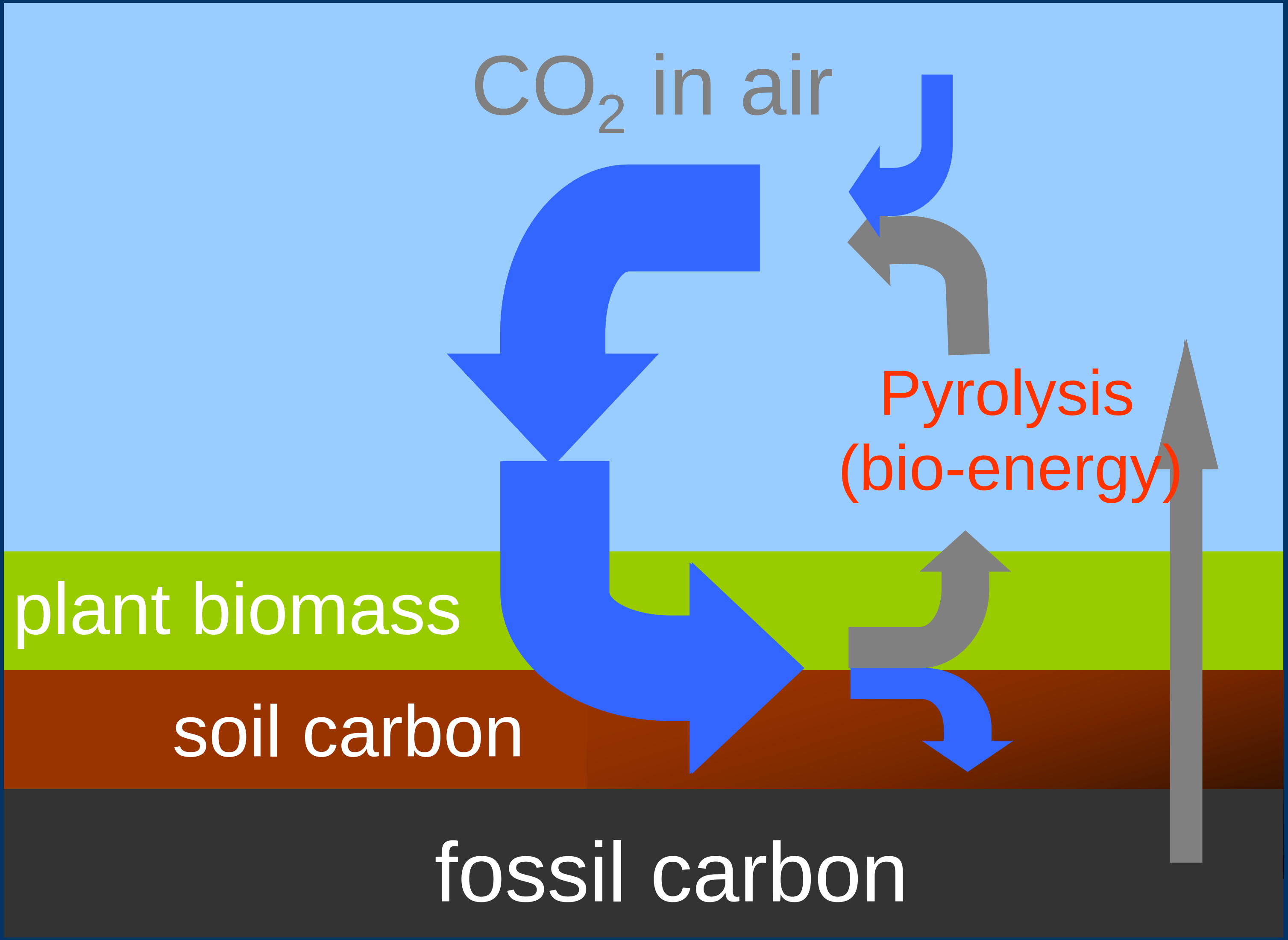
Combustion
(bio-energy)

plant biomass

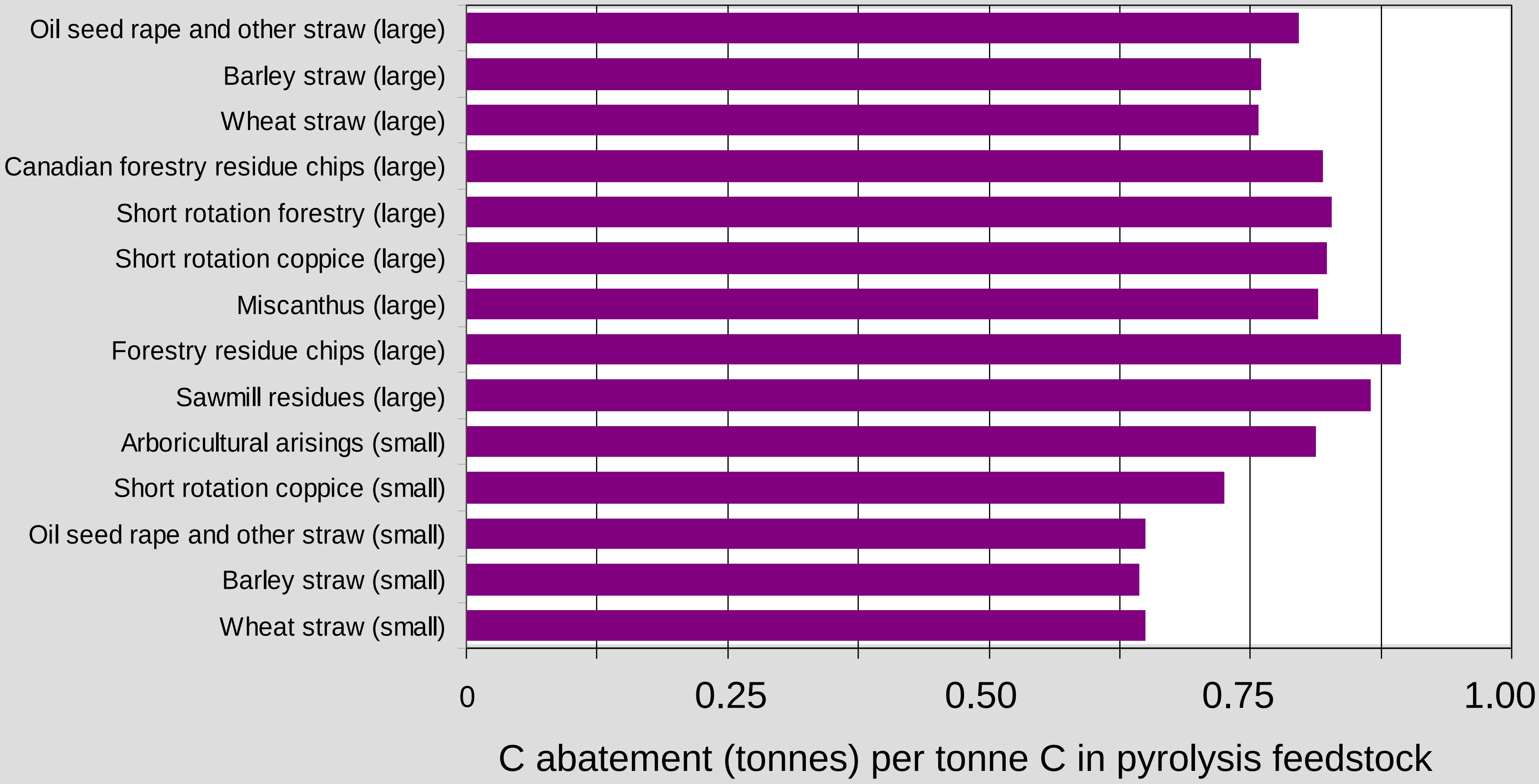
soil carbon

fossil carbon

“Carbon negative” bioenergy

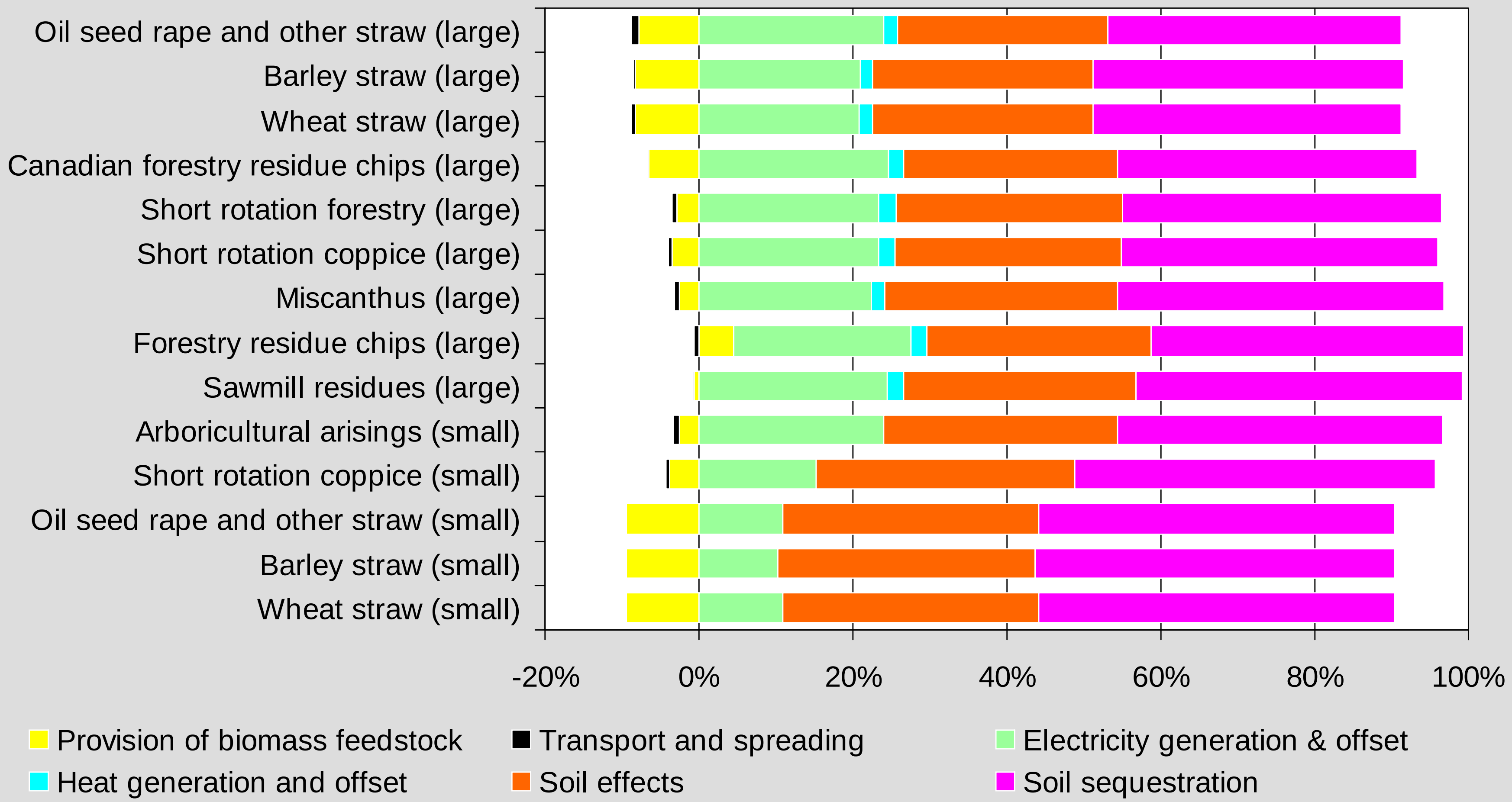


Life cycle analysis – estimates for overall gain



Hammond et al., forthcoming

Life cycle analysis – sources of gain



Hammond et al., forthcoming

Conclusions

- Biochar has the potential to sequester (rather than simply store) carbon into the biosphere
- Sequestration could be at the Gt scale using currently available feedstock, given suitable policy and economic instruments
- Pyrolysis offers bio-energy co-products with the potential to exceed the carbon gain (abatement) from combustion

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