Brazilian bio-ethanol and other biofuels: Their impact on the mitigation of greenhouse gas emissions

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Sugarcane in Brazil 2008 - 2009

- Harvested area 2009 – 8.7 million ha (Mha)
- Planted area 2009 – 9.8 Mha
- Total cane production 2009 = 690 million tonnes.
- Mean cane yield – 79.5 ton./ha
- Ethanol production (2008) - 27 billion litres (5.4 bi exported)
- Ethanol production per ha - 6500 litres

The Contribution of Fossil Energy

In all stages of sugarcane production and its processing to produce ethanol there are inputs of conventional (fossil) energy

For example:

1. **Diesel oil for sub-soiling, ploughing, spraying.**
2. **Fertilizer manufacture (natural gas) and pesticides and their transport and application (diesel oil).**
3. **Harvest and transport of cane to factory (diesel oil).**
4. **Construction of factories/distilleries (cement, steel etc.) and manufacture of field machinery (tractors, ploughs, harvesting machines) and factory equipment.**

Energy balance for ethanol production from sugarcane*

Operation		MJ/ha/ano
A. Agriculture		
Diesel oil		1589
Machinery		1384
Fertilizers/pesticides etc		5865
Transport of cane to factory		2058
Application of vinasse		656
Harvest (60% burned, 40% green)		778
	Total	12330
B. Factory/distillery		
Chemicals, lubricants		488
Constructions and machinery		2123
	Total	2611
	Total Fossil energy	14941
Total energy produced in 1 ha of sugarcane (79.5 ton. cane, 6,500 Litres ethanol)		139640
	ENERGY BALANCE	9.35

*Source: Boddey et al., 2008. Bio-ethanol production in Brazil. Chapter 13. *In*: Pimentel. D.. (ed.). Biofuels. Solar and Wind as Renewable Energy Systems: Benefits and Risks. Springer. New York pp 321-356.

Emissions of other greenhouse gases

Apart from CO_2 there are two other gases which which also absorb infra-red radiation (heat):

Nitrous oxide (N_2O) and methane (CH_4)

- **Nitrous oxide is emitted when nitrogen (in fertilizers and residues) is applied to the soil; the emissions being higher when the soil is at high moisture content.**
- **The quantities are small (typically 1% or less of the added N) but N_2O is approximately 300 times more active than CO_2 in absorption of infra-red radiation.**
- **Methane is liberated when the cane trash is burned or when vinasse (distillery waste) is added to the soil.**
- **Methane is approximately 24 times more active than CO_2 in the absorption of infra-red radiation.**

Emissions of GHGs (CO_2, N_2O e CH_4) during all stages of the production of bio-ethanol

Production step	Greenhouse gas emitted (per ha)			
	CH_4	N_2O	CO_2	CO_2 eq.[a]
	g of CH_4 or N_2O ha^{-1} ano^{-1}		kg ha^{-1} ano^{-1}	
Planting of cane	+ 9	+ 2	+ 718	+ 719
Agric. activities	+ 3	1,363♣	+ 87	+ 510
Harvest	+ 17,017*	631	+ 315	+ 841
Ethanol production	+ 3,413[Ψ]	---	+ 108	+ 305
Ethanol distribution				+ 217
Emissão total de GEE fóssil				+ 2,592

* Methane produced from burning cane (today 60 % of the área)

Ψ Methane produced from vinasse

♣ N_2O from N fertilizer and crop residues

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Greenhouse Gas Emissions

Emission of GHGs during a journey of 100 km run by the same vehicle using three different fuels

Model	Motor	Fuel	Consumption km/L	Maximum power	GHGs kg CO_2	Avoided emission (%)
S10* single cabin	2.8 turbo	Diesel	13.5	140 CV	29.69	--
S10 single cabin	2.4 flexpower	Pure gasoline	10.4	141 CV	35.10	0
S10 single cabin	2.4 flexpower	Brazilian gasoline (24% etanol)	9.5	141 CV	27.6	21
S10 single cabin	2.4 flexpower	Ethanol (sugarcane, Brazil)	7.2	147 CV	5.54	84

The vehicle running ethanol from sugarcane emits only 16 % of the GHGs which it would emit using pure gasoline OR

The use of Brazilian bioethanol promotes a mitigation of 84 % of the GHGs emitted when the same distance is covered using pure gasoline

*S10 Chevrolet pickup

Impact of GHG emissions of biological nitrogen fixation

Field N budget for a typical cane variety growing in São Paulo State

- **Yield 84 tonnes/ha**
- **Total N (kg N /ha/yr) in:**
- **Cane stems ……………………… 42 kg**
- **Trash/senescent leaves*………. 52 kg**
- **Flag leaves (left in field) ………. 62 kg**
- **Total aerial tissue ………………156 kg**

- **Removed by burning and exported to mill … 94 kg**
- **Added as N fertilizer 65 kg N/ha**
- **Balance = minus 29 kg N ha *(not counting leaching. volatilization and erosion losses)***
- **Rainfall and dry deposition inputs estimated for Piracicaba as <9 kg N/ha***

* Krusche et al.. 2003. Environ. Pollution 121: 389-399

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Impact of GHG emissions of biological nitrogen fixation

Today a mean of approximately 60 kg N fertilizer per year are applied per ha of sugarcane. The manufacture. transport and application of this quantity of N fertilizer emits 270 kg CO_2eq*.

On application to the soil IPCC estimates 1 % of the N (600 g) is emitted as N_2O. equivalent to an emission of 292 kg CO_2.

Thus the total GHG emission = 562 CO_2eq.

Nearly all other countries in the world use between 150 and 200 kg N fertilizer per ha. So BNF saves Brazil an emission from ~120 kg N (1100 kg CO_2eq) which would increase total GHG emission by 33 %.

If further advances in BNF research results in the complete elimination of N fertilizer then present GHG emissions will be reduced by 17 %.

* Manufacture. transport and application of 1kg N fertilizer emits 4.5 kg CO_2eq of GHGs (IPCC. 2006)

Impact of the change from manual harvesting of burned cane to mechanical harvesting of green cane

Less soot and smoke – less health problems.

Soil surface protected – less erosion and evaporation.

64 % decrease in harvest GHG emissions (~~methane~~).

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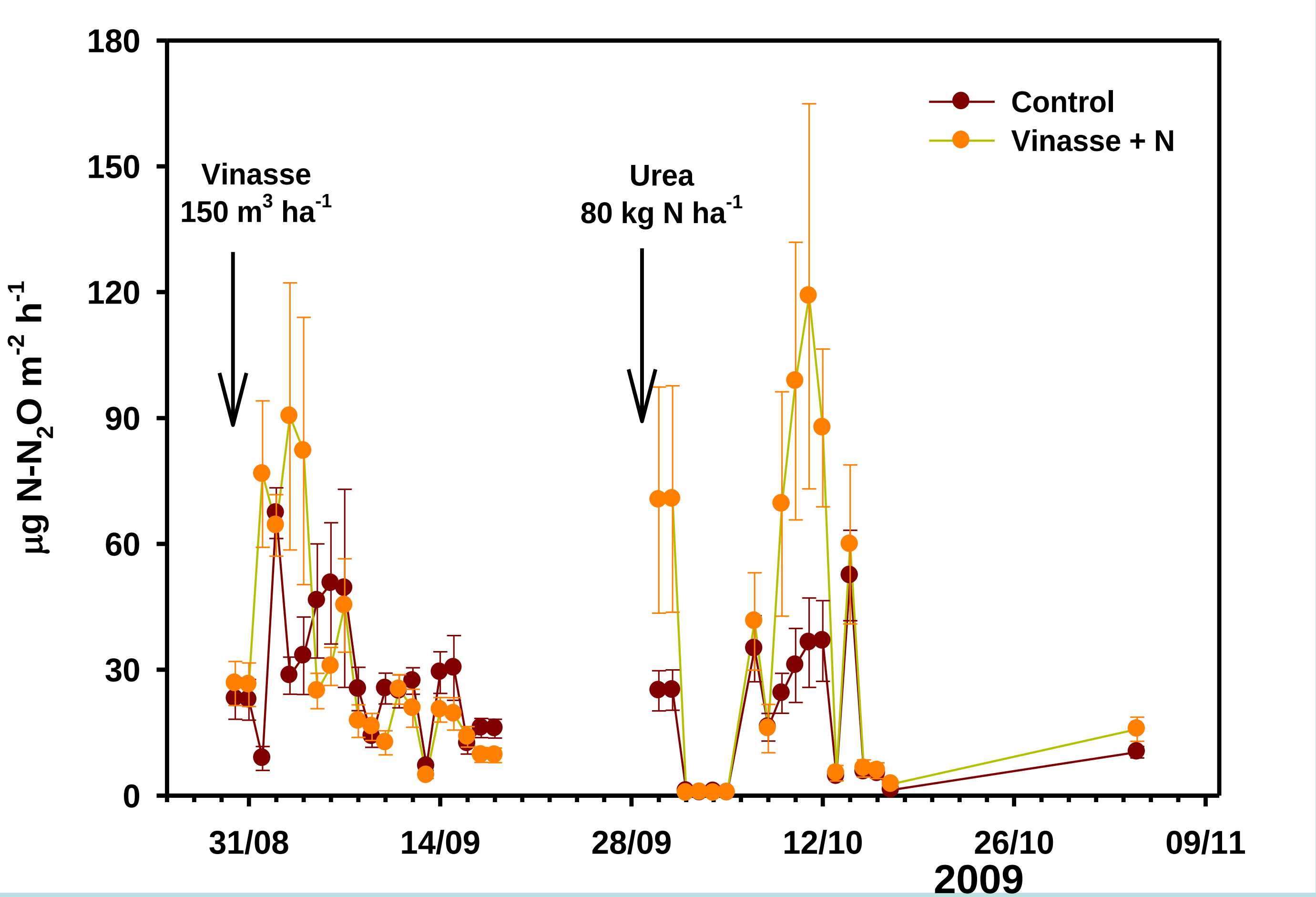
Emissions of nitrous oxide are principally associated with applications of vinasse and nitrogen fertilizer

Methodology
Closed static chambers

Soil N_2O-N fluxes after vinasse and urea application on sugarcane crop growing on a Cambisol of Campos dos Goytacazes (RJ)



Direct N_2O emission factor

Vinasse – 0.06 %

Urea – 0.14 %

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Impact of GHG emissions on conversion of land to sugarcane production

1 ha of sugarcane produces today ~6,500 Litres of ethanol which will fuel a journey by a pickup fuelled by 2.4 L flexfuel motor approximately 46,800 km. This distance requires 4,500 L if pure gasoline is used.

The total emission of GHGs (N_2O, CH_4 & fossil CO_2) by the 6,500 L of ethanol = 2,594 kg CO_2eq.

The total emission of GHGs by 4,500 L of pure gasoline = 16,427 kg CO_2eq

Thus the total avoided emissions ("Carbon sequestration") of 1 ha of sugarcane used for bioethanol production =

13,830 kg CO_2 ha^{-1} (5.5 Mg C ha^{-1}) $year^{-1}$.

So should we worry about soil C stock changes (LUC) which rarely exceed 0.5 Mg C ha^{-1} $year^{-1}$?

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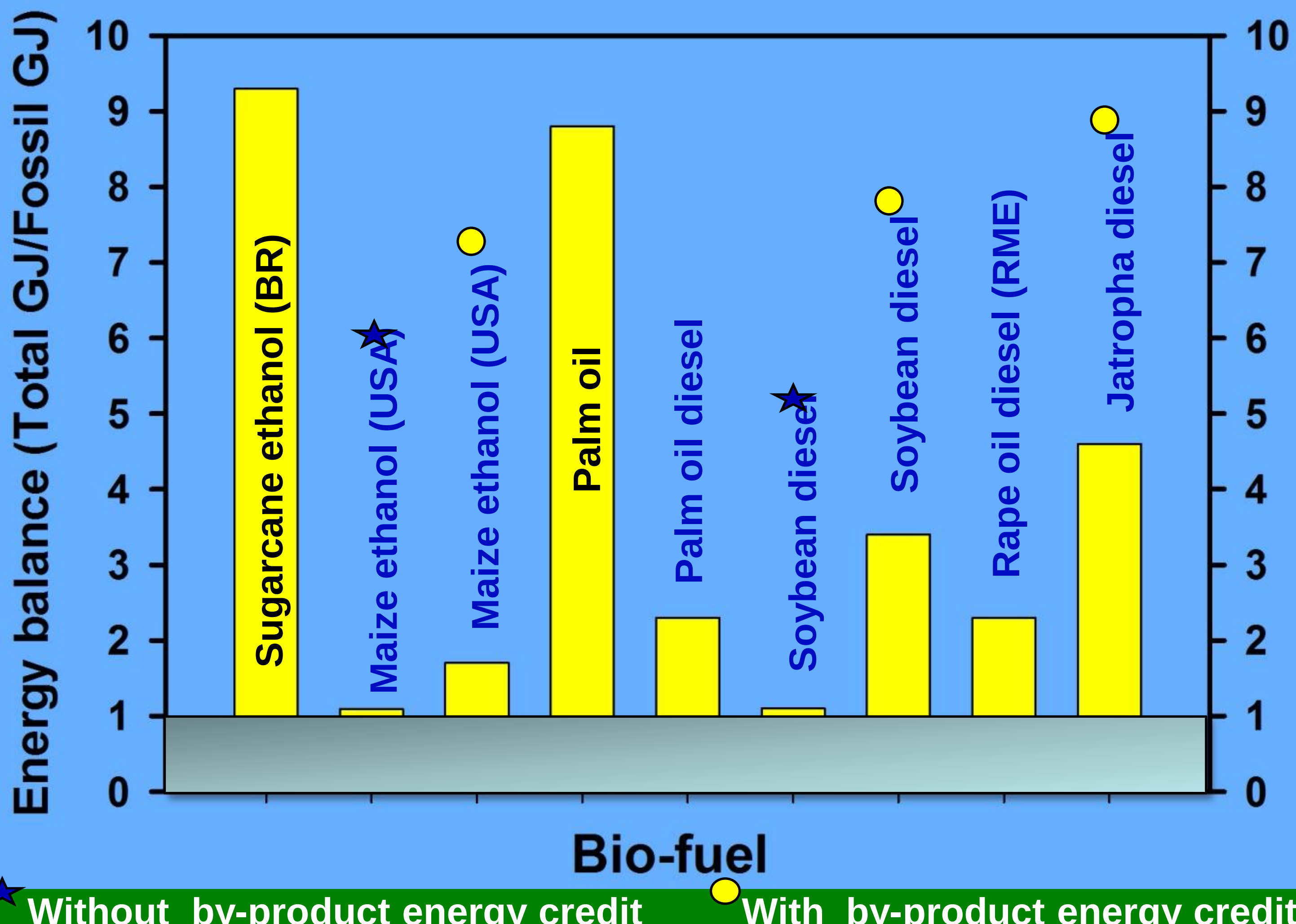
Energy balance of potential bio-fuels with or without by-product energy credits



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One hectare of sugarcane in Brazil will fuel a Flexfuel pickup a distance of 46,800 km = one circumnavigation of planet earth plus 6,700 km.

As the GHG mitigation amounts to 84 %, the circumnavigation of the globe has a zero GHG cost.

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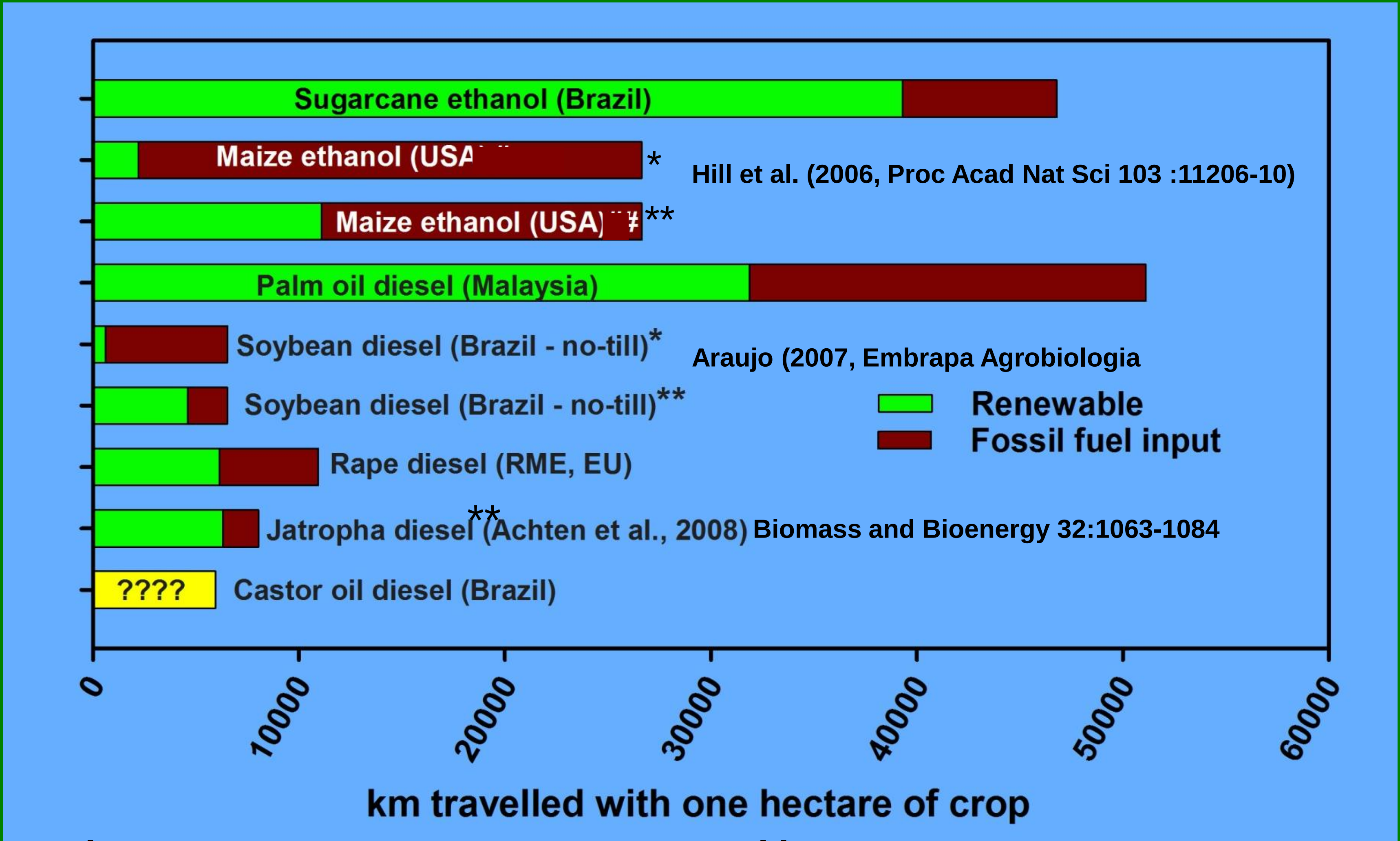
Distance travelled by a S10 pickup with biofuel produced on one hectare of land in one year



*Without by-product energy credit **With by-product energy credit

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This is what more than 60 million ha of the coastal Atlantic forest region looks like today

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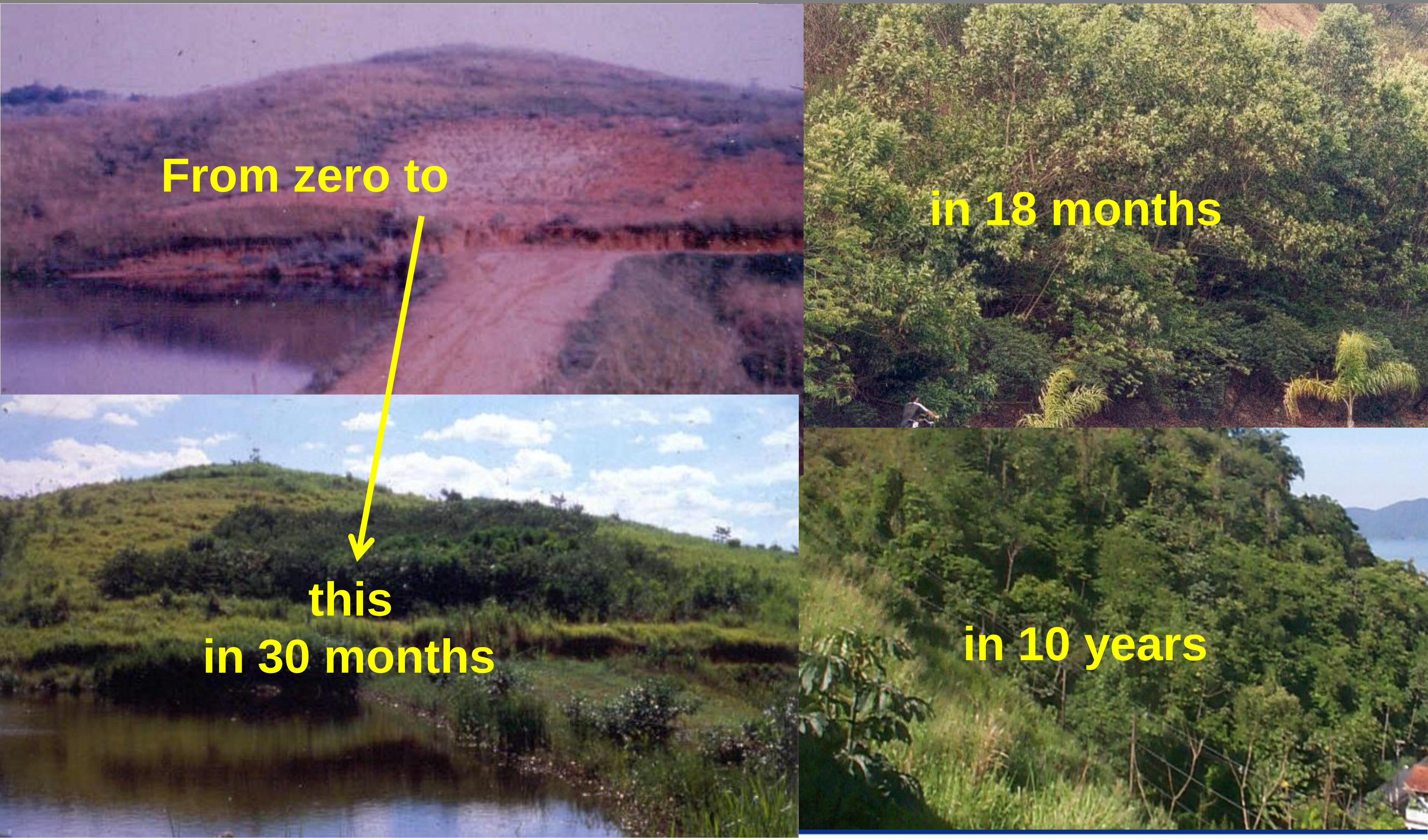
But with fast-growing legume trees inoculated with rhizobium and arbuscular mycorrhizal fungi this is what we can do



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Conclusions

1. There may be important justifications to invest in bio-fuel crops, such as alleviation of rural poverty or national energy security but if the principal objective to reduce greenhouse gas (GHG) emissions, then the GHG balance and the effective renewable energy yield per hectare must be of paramount importance.

2. In Brazil alone, in areas of abundant rainfall there are over 100 Mha of degraded land, much of it on sloping land. Fast-growing N_2-fixing legume trees can accumulate biomass C at over 4 Mg ha^{-1} yr^{-1} and soil C at over 1.5 Mg ha^{-1} yr^{-1} for at least 13 years**.

Boddey et al. American Society of Agronomy Monograph 52, Chapter 14, pp 387-413, and
Macedo et al. (2008, Forest Ecology and Management 255: 1516-1524)

The team: Luis Henrique Soares, Ednaldo Araújo, Bruno Alves, Segundo Urquiaga, Bob Boddey et al:

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