nature

COMMENTARY

A handful of carbon

Locking carbon up in soil makes more sense than storing it in plants and trees that eventually decompose, argues **Johannes Lehmann**. Can this idea work on a large scale?

J. LEHMANN

Sequestering 'biochar' in soil, which makes soil darker in colour, is a robust way to store carbon.

To meet the challenges of global climate change, greenhouse-gas emissions must be reduced. Emissions from fossil fuels are the largest contributor to the anthropogenic greenhouse effect, so a reduction in fossil-energy use is a clear priority[1]. Yet, because some emissions will be unavoidable, a responsible strategy also means actively withdrawing carbon dioxide from the atmosphere[2]. Such carbon sequestration faces multi-faceted challenges: the net withdrawal of carbon dioxide must be long term and substantial, the process must be accountable and must have a low risk of rapid or large-scale leakage. One near-term technology that can meet these requirements is biochar sequestration. When combined with bioenergy production, it is a clean energy technology that reduces emissions as well as sequesters carbon[3]. In my view, it is therefore an attractive target for energy subsidies and for inclusion in the global carbon market.

An existing approach to removing carbon from the atmosphere is to grow plants that sequester carbon dioxide in their biomass or in soil organic matter[2] (see graphic, overleaf). Indeed, methods for sequestering carbon dioxide through afforestation have already been accepted as tradable 'carbon offsets' under the Kyoto Protocol. But this sequestration can be taken a step further by heating the plant biomass without oxygen (a process known as low-temperature pyrolysis). Pyrolysis converts trees, grasses or crop residues into biochar, with twofold higher carbon content than ordinary biomass. Moreover, biochar locks up rapidly decomposing carbon in plant biomass in a much more durable form[4].

No limits

The precise duration of biochar's storage time is under debate, with opinions ranging from millennial (as some dating of naturally occurring biochar suggests) to centennial timescales (as indicated by some field and laboratory trials)[5]. Whether biochar remains in soils for hundreds or thousands of years, it would be considered a long-term sink for the purposes of reducing carbon dioxide emissions. Moreover, the storage capacity of biochar is not limited in the same way as biomass sequestration through afforestation, conversion to grassland or no-tillage agriculture[2]. Agricultural lands converted to no-tillage, for example, may cease to capture additional carbon after 15–20 years, and even forests eventually mature over decadal and centennial timescales and start to release as much carbon dioxide as they take up.

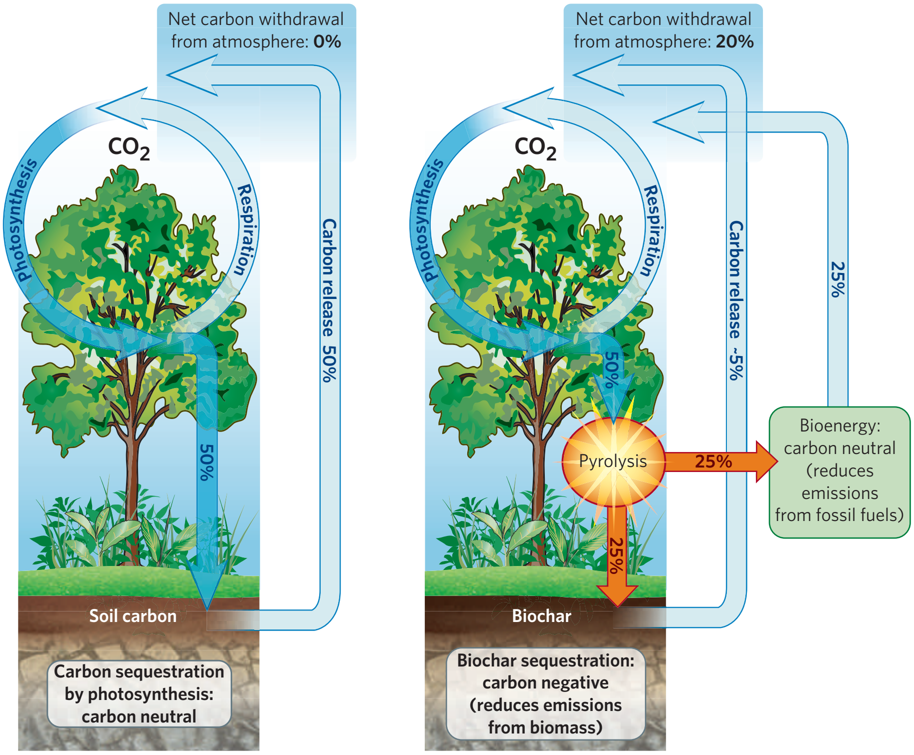
> "Biochar offers the chance to turn bioenergy into a carbon-negative industry."

Biochar is a lower-risk strategy than other sequestration options, in which stored carbon can be released, say, by forest fires, by converting no-tillage back to conventional tillage, or by leaks from geological carbon storage. Once biochar is incorporated into soil, it is difficult to imagine any incident or change in practice that would cause a sudden loss of stored carbon.

The bottom line is that plant biomass decomposes in a relatively short period of time, whereas biochar is orders of magnitudes more stable. So given a certain amount of carbon that cycles annually through plants, half of it can be taken out of its natural cycle and sequestered in a much slower biochar cycle (see graphic). By withdrawing organic carbon from the cycle of photosynthesis and decomposition, biochar sequestration directly removes carbon dioxide from the atmosphere. Pyrolysis does have costs associated with the machinery and heating (around US$4 per gigajoule) and is dependent on a supply of cheap biomass. But the bigger question is whether this approach can be scaled up to national and regional, or even global, scales.

At the local or field scale, biochar can usefully enhance existing sequestration approaches. It can be mixed with manures or fertilizers and included in no-tillage methods, without the need for additional equipment. Biochar has been shown to improve the structure and fertility of soils, thereby improving biomass production[3]. Biochar not only enhances the retention[6] and therefore efficiency of fertilizers but may, by the same mechanism, also decrease fertilizer run-off.

For biochar sequestration to work on a much larger scale, an important factor is combining low-temperature pyrolysis with simultaneous capture of the exhaust gases and converting



them to energy as heat, electricity, biofuel or hydrogen[3]. Depending on the feedstock used and bioenergy produced, low-temperature pyrolysis with gas capture (but no sequestration) can be a carbon-neutral energy source. Most companies that generate bioenergy in this way view biochar merely as a byproduct that can itself be burned to offset fossil-fuel use and reduce costs. But our calculations suggest that emissions reductions can be 12–84% greater if biochar is put back into the soil instead of being burned to offset fossil-fuel use[7]. Biochar sequestration offers the chance to turn bioenergy into a carbon-negative industry.

The million-dollar question is: can biochar sequestration and the associated bioenergy production make a real difference to national and global carbon budgets?

Promising approaches

I have calculated emissions reductions for three separate biochar approaches that can each sequester about 10% of the annual US fossil-fuel emissions (1.6 billion tonnes of carbon in 2005)[8]. First, pyrolysis of forest residues (assuming 3.5 tonnes biomass per hectare per year) from 200 million hectares of US forests that are used for timber production; second, pyrolysis of fast-growing vegetation (20 tonnes biomass per hectare per year) grown on 30 million hectares of idle US cropland for this purpose; third, pyrolysis of crop residues (5.5 tonnes biomass per hectare per year) for 120 million hectares of harvested US cropland. In each case, the biochar generated by pyrolysis is returned to the soil and not burned to offset fossil-fuel use[5]. Even greater emissions reductions are possible if pyrolysis gases are captured for bioenergy production.

Similar calculations for carbon sequestration by photosynthesis suggest that converting all US cropland to Conservation Reserve Programs — in which farmers are paid to plant their land with native grasses — or to no-tillage would sequester 3.6% of US emissions per year during the first few decades after conversion[9]; that is, just a third of what one of the above biochar approaches can theoretically achieve. Although these calculations highlight the potential of biochar, realistic projections will require rigorous economic and environmental analyses[10].

Most, if not all, approaches to bioenergy, including corn ethanol production, are costly. Pyrolysis plants that use biochar to offset fossil-fuel consumption are financially viable only when inexpensive feedstock is continuously available in sufficient quantities, for example animal wastes, clean municipal wastes or forest residues collected for fire prevention. But would returning biochar to the soil make more financial sense than burning it? There are some potential savings to be made by reduced fertilizer use and through possible gains in agricultural productivity, but the answer to this question depends largely on the value that carbon markets assign to emissions reductions.

At present, the Chicago Climate Exchange is trading carbon dioxide at US\$4 per tonne. These prices are expected to rise over the coming years to decades to US\$25–85 per tonne, assuming that societies accept the social costs of climate change[11]. We calculate that biochar sequestration in conjunction with bioenergy from pyrolysis becomes economically attractive[7], under one specific scenario, when the value of avoided carbon dioxide emissions reaches \$37 per tonne.

"Would returning biochar to the soil make more financial sense than burning it?"

This calculation does not consider the indirect benefits associated with biochar — which do not currently have a dollar value — from reduced pollution of surface or groundwaters. Subsidies to support biochar sequestration, in conjunction with bioenergy production, would be sufficient to jump-start this technology. US Senator Ken Salazar is working on comprehensive legislation, as part of the 2007 Farm Bill, that would provide significant support for biochar research and development.

Easy to monitor

When it comes to including biochar in emissions-trading schemes, accountability is more straightforward than with other soil sequestration methods. Both the conversion of biomass into biochar and its application to soil are readily monitored, without additional costs. No complex predictive models or analytical tools are required, as is the case with other soil sequestration approaches. The source of biochar additions can easily be identified by soil analyses, if desired for verification under carbon-trading schemes. Tracing the source of carbon in soil back to a change in agricultural practice, or other photosynthetic source, is much more difficult, and therefore currently not accepted under the Kyoto Protocol. Because these barriers do not exist for biochar sequestration, in my opinion there is no reason why the associated emission reductions should not be allowed into trading markets under current agreements.

The consequences of climate change are already being felt[1] and there is an urgency not only to identify but also to implement solutions. Biochar sequestration does not require a fundamental scientific advance and the underlying production technology is robust and simple, making it appropriate for many regions of the world. It does, however, require studies to optimize biochar properties and to evaluate the economic costs and benefits of large-scale deployment. ■

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1. IPCC *Climate Change 2007: The Physical Science Basis* www.ipcc.ch/SPM2feb07.pdf (2007).
2. Lackner, K. S. *Science* **300,** 1677–1678 (2003).
3. Lehmann, J. *Frontiers in Ecology and the Environment* (in the press).
4. Baldock, J. A. & Smernik, R. J. *Org. Geochem.* **33,** 1093–1109 (2002).
5. Lehmann, J., Gaunt, J. & Rondon, M. *Mitigation Adapt. Strateg. Glob. Change* **11,** 403–427 (2006).
6. Liang, B. *et al. Soil Sci. Soc. Am. J.* **70,** 1719–1730 (2006).
7. Gaunt, J. & Lehmann, J. Presentation at Power-Gen Renewable Energy and Fuels *From Plant to Power Plant* (Las Vegas, 6 March 2007).
8. EIA *Emissions of Greenhouse Gases in the United States 2005* report number DOE/EIA-0573 (2006).
9. Jackson, R. B. & Schlesinger, W. H. *Proc. Natl Acad. Sci. USA* **45,** 15827–15829 (2004).
10. McCarl, B. A. & Schneider, U. A. *Science* **294,** 2481–2482 (2001).
11. Stern, N. *The Economics of Climate Change: The Stern Review* (Cambridge Univ. Press, Cambridge, 2007).

Sequestration of carbon in tropical forests
A concept paper for PNG.

Tim Flannery and WWF

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The potential of tropical forests to contribute to climate stability

Around 20% of the carbon emitted by humanity (around 2 gigatonnes per annum) comes from destroying tropical forests, and around half of the world's tropical forests are already destroyed. These facts establish that protecting and regrowing the tropical forests are crucial aspects of any effective climate change response. While more research is needed, there seems to be no reason why 5 gigatonnes of carbon or more per year could not be sequestered by protecting tropical forests and regrowing them by 2030.

The Stern report estimates that the costs of storing carbon in existing and regrowing forests is relatively cheap – around 2-5 USD per tonne.

The purpose of this paper is to outline a practical way to establish a pilot scheme in PNG which has the potential to guide the development of a tropical forest carbon market world-wide.

Field trials are proposed that will test approaches for trading biocarbon from PNG forests and based on these experiments a more widespread mechanism will be established that will support biocarbon payments to forest owning communities across rural PNG. At least in early stages, this will not be an offset scheme but will rely on direct contributions from individuals and institutions.

The historic debt

The developed nations of the world are the beneficiaries of the Industrial Revolution. One consequence of their development and affluence has been to inflict a historic debt of 200 gigatonnes of carbon on humanity's common atmosphere. This debt is the foundation stone of the climate problem.

Investing in tropical forests represents an ideal way for the developed world to repay this debt. There are good scientific reasons for entirely separating the repayment of this historic debt from emissions based carbon trading schemes. Among them, a tonne of carbon from burning fossil fuels is not equivalent, in terms of climate impact, to a tonne of carbon sequestered in a forest.

How can the historic debt be paid by government, individuals and industry (on a voluntary basis)?

An internet-based carbon market

Advances in technology allow for identification, assessment and advertising of carbon buyers and sellers, even if separated by vast distances and circumstances. They also allow for accurate delineation of ownership of land, assessment of the amount of carbon sequestered, and provision of auction-based systems to bring buyers and sellers together. Think a scheme incorporating Google Earth and E-Bay, allowing anyone to go on line, look at the participating villages, read about their people and forests, assess their reliability as vendors, and make a purchase on-line. An individual might want to purchase protection of just one hectare of forest land as a philanthropic act, but a government or corporation such as an airline participating in a voluntary offset scheme, might want to purchase a million tones. Larger corporations might want to associate themselves with iconic species, such as birds of paradise and tree-kangaroos, in the forests they protect.

The system would work like this: with the help of an NGO or other institution, participating villages would post details of their land and what they have to offer. These could be accessed via Google Earth, then the purchaser could be referred to E-Bay, where seller history and further details could be available. A purchaser would post a bid, and if the village accepts, the funds could be put in escrow by an NGO for a 12 month period, or until the agreed carbon sequestration/ biodiversity preservation has been delivered. Deals should be honoured on a first-in basis (i.e. if villages cannot deliver the full amount they project, then late purchasers might find themselves without goods to purchase).

Two products could be identified and auctioned: forests and reaforestation. What the purchaser would actually be buying is – in the first instance - biodiversity protection, and in the second carbon sequestration (climate security). A minimum price (recommended $5.00 per tonne of carbon sequestered, or 0.1 hectare of forest protected) should be instituted.

Because the price of carbon is likely to rise, a 12 month tenure on these purchases is desirable (or a decade at most). This may result in a small price paid per tonne (1/100th of $5.00 per year) or hectare, but repeated auctioning by reliable vendors is likely to see the price rise, and acreages are so large in most of PNG relative to human populations, that the actual amount of cash received on an annual basis in the village is likely to be considerable.

Natural grasslands should be excluded from reaforestation and be considered under biodiversity payments.

Why PNG?

Papua New Guinea is uniquely suited for a trial of the scheme because clan-based land tenure places ownership of land (and thus carbon sequestered) squarely with the village. In a free market, this provides maximum incentive for communities to sequester. Where land is government owned, or overlapping tenure systems exist, incentivisation is less. Further, English is widely spoken in much of PNG, and levels of education are such that the scheme would be readily understood.

How to make it a reality?

Several basic things need to occur over the long term before such a scheme becomes a reality:

1) **50 villages** willing to participate.

2) **Education of village people** about the scheme. This could be provided by NGOs like WWF. This education should include extensive discussions about the critical nature of their reliability as vendors, distribution of payments to communities, and the need to agree tribal boundaries with neighbours. None of this will be easy, but unless it is achieved the scheme will meet formidable teething problems.

3) The provision of **internet access** in participating villages. Most villages have primary schools, where the head teacher could be charged with looking after the computer, satellite dish etc. They could also be charged with promoting the scheme, and be paid a small percentage of each sale.

4) The buy-in of Google and E-Bay to establish an **internet based system for mapping forest based carbon** and confirming that a contribution has been made. This is crucial in terms of providing market access.

5) A **sponsor** to support the setting up of the pilot scheme, and to purchase carbon and biodiversity in bulk at the beginning to kick start the scheme.

6) The establishment of a **carbon assessment tool**. This could go either of 2 ways: If purchasers are willing to deem carbon sequestration from coarse satellite images, and so to live with a certain degree of inaccuracy in the figures, existing surveillance would do. Greater resolution could be had, however, if further investments in satellite-based carbon assessment tools are made. Solid ground truthing will be necessary to confirm any analyses. The Australian government has made $200 million available under the new Global Initiative of Forests and Climate, which may go a considerable way towards alleviating the problem. The tool would need to operate in the context of a national carbon reference baseline and targets.

7) A **small regulatory body** to agree on the rules of trading and to refer disputes to. Following the example of the Forest Stewardship Council, this body might represent the interests of a range of stakeholders in forest carbon sequestration from communities to NGOs, government and business. It would oversee a set of detailed Principles and Criteria ("Green Standards") for carbon sequestration and would ensure independent audit of forest carbon trading activities to guarantee that these high standards are maintained. This institution may be based on an existing body such as a carbon credit trading company or be developed anew.

8) A "**carbon concession" system** which recognises areas where communities have committed to protect, manage or regrow forests for carbon retention. These "carbon concessions" may be established through :

- Altering forest concessions boundaries to resolve overlaps with proposed protected areas
- Establishing set aside areas within forestry concessions covering areas of low timber resource or constrained areas such as inundated land or forest on karst
- Adjusting the management of existing forestry concessions to other uses such as trekking in the Kokoda Track region or buffer zones for the gas pipeline reserve
- Replacing conversion or uncertified forestry with certified forestry
- Transforming logged over concessions into reserves where only regeneration, subsistence extraction and limited commercial activity such as community forestry are permitted[1]
- Supporting improved forest management in active concessions through certification to ensure delivery of carbon, social and environmental benefits
- Rescuing protected areas that are suffering poor management or becoming "paper parks"

It will be essential to include rules to avoid perversely rewarding past bad forest management. Grandfathering clauses will be included to avoid supporting operators for instance who are double-dipping by logging an area and then claiming reforestation credits.

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1 "Regrowing tropical forest" or reafforestation might be considered using silvicultural treatments of logged over areas to enhance regeneration. The concept of "klinim as bilong diwai" advocated by Francis Hurahura and Tom Diwai would be a preferred approach and is estimated to cost around USD 2 per hectare.

With these requirements in mind, the following strategy is proposed …

Goal

To establish a pilot scheme in PNG which has the potential to guide the development of a tropical forest carbon market world-wide

Objective

1. To establish an institution and agreed standards for managing carbon related income for forest protection, management and regrowth in PNG

2. To trial carbon payments across the forest holdings of 50 villages in PNG (approximately 500,000 hectares)

Phases

This is an entirely new way of managing the world's carbon and will need careful design, testing and adaptation before it can operate at a broader scale. Three phases of development are therefore proposed :

Phase I: Design – A small team will analyse relevant economic, social, technological and methodological issues in developing a forest based carbon protection and payment system and propose a draft design. The resulting report and project design will be reviewed by a set of shareholders and revised based on their comments. [Duration : 6 Months]

Phase II: Trial – Based on the approved design, interim agreements will be secured with approximately 50 forest owning communities to trial the proposed system. More than one approach may be tested in the agreed locations. During this period, an interim institution will be identified or established to manage forest carbon agreements and payments. A review of lessons at the end of the trial period will recommend preferred approaches and will inform the design of an implementation phase. This will also take note of emerging policy agreements such as conclusions from the December 2007 Bali COP9 [Duration : 2 years]

Phase III: Implementation – Based on lessons from phase 2, a forest carbon institution would be formalized, methodologies confirmed and village based agreements would be extended to other locations [Duration : 3 years].

Results and Activities : Phase I

Result		Activity	Indicator	Month					
				1	2	3	4	5	6
1. Coordination team	a.	Establish Enabling and Shareholder Group	ToR; Minutes of meeting						
	b.	Partnership agreement completed							
	c.	Hire Coordinator	Contract signed						
2. Design for interim framework and methodology	a.	Background study 1 : Economic analysis - options for carbon investment	Draft report						
	b.	Background study 2 : Carbon measurement protocols and monitoring systems. This would also propose an emissions reference level in the absence of a national baseline.	Draft report						
	c.	Background study 3: Land use mechanisms for long term storage of carbon (comparative review of options including PAs, certified forestry areas, dedicated carbon concessions etc). This would also propose processes for community engagement and potential sites for field trialing.	Draft report						
	d.	Background study 4 : Draft principles and criteria for carbon investments. Proposed institutional framework for managing forest carbon sequestration and trade.	Draft report						
	e.	Preparation of draft summary report and Phase 2 proposal	Draft proposal						
	f.	Report printing	Published report						
3. Internet based system for mapping and trading forest carbon	a.	Confirm partnership with Google / E-Bay and agree on parameters for system	Partnership agreement						
	b.	Design of internet based inventory and mapping system	Beta website and database						
	c.	Report on proposed system	Report						
4. Shareholder review of Phase II Design	g.	Seminar to review options and confirm methodology and institutional framework	Seminar proceedings; Comments on report						
	h.	Description of interim methodology and institutional framework							
	a.	Report printing							

Results and Activities : Phase II

Activities in Phase II will be defined by the project design but may include:

1. **Government policy endorsement -** Government approval of trial sites and methodology; Inclusion of trial in PNG national policy on carbon sequestration in forests; National policy on carbon reference baseline endorsed.

2. **Regulatory body for management of forest carbon payments -** Legal constitution or agreement; Confirmation of a Management / Shareholder group; Hiring of staff; Marketing and public relations;

3. **Initiation of trial site(s) demonstrating forest protection and sustainable management in 50 villages -** Confirmation of sites and partners; Preparation of community entry methodology and field materials; Grants to partner organisations; Training of outreach staff; Community education visits; Signing of agreement with communities to proceed with trial; Boundary mapping with Geographic Information Systems linked to website; Rules of management agreed.

4. **Carbon measurement protocols, ground truthing and monitoring systems -** Agreement on indicators of good forest management; defining rules and regulations; carbon estimates in field sites; forest quality measures

5. **Internet based mapping and trading of forest carbon** – Establishment of website and database; Funds management controls, auditing and accounting systems; Beta testing;

6. **Public awareness** – Design report launch; Publicity materials; website

Governance

- **Enabling Group** – A small team will be responsible for overseeing the management of the programme. It will meet virtually or in person on a regular basis to hire consultants and staff, confirm action plans, review progress and address policy issues. Participants might include: Tim Flannery, Government of PNG, Swire, Deloitte, FORCERT etc.

- **PNG Shareholder Group** – A forum of shareholders will be established to provide guidance on the development of activities, policy and institutional structures and will represent environmental, economic and social stakeholders. This group will include research, government, business and community interests and will coordinate with a trial project convened by the University of Twente, Netherlands[2]. Participants may include:

    - Research – Tim Flannery, UPNG, University of Twente, ANU, Smithsonian Institution, New Guinea Binatang Research Centre, SarVision
    - Industry - Swire, Deloitte, ADB, Google
    - NGO –WWF, TNC, FORCERT, FPCD, Greenpeace
    - Government - PNG Forest Authority, DEC, National Planning and Monitoring, Forest Research Institute

[2] as part of the Kyoto: Think Global Act Local "Action Research for Sustainable Forest Management"): Phase 4

Risks

1. **Scheme is used to dilute industrial obligations to meet carbon targets** -> RESPONSE: At least in the first phases, the scheme will not provide offsets for polluting industries but will be developed to allow for direct benevolent contributions to support carbon sequestration in forests. Once systems are in place and tested, offsetting will be considered. Corporate partners who are willing to demonstrate a positive carbon contribution in their footprint will be preferred.

2. **Participating villages unable to agree on boundaries or management approaches** -> RESPONSE: The programme over time will develop the capability to accurately define forest ownership. However in the short term it would be advantageous to focus on forest landscapes and communities where boundaries and management rules have already been developed or are in the process of being developed (such as in protected areas threatened with logging and Forest Management Areas with insufficient resource).

3. **Conflict between and within villages over benefit sharing** -> RESPONSE : A careful process of community engagement – such as that used by FORCERT for helping communities to establish small scale forestry businesses - will be used to ensure effective participation and equitable benefit sharing. In addition, a system of certification will independently verify that the standards have been upheld, that benefits are shared equitably and that forest carbon measures are accurately applied.

4. **Lack of government support for the scheme** -> RESPONSE: It is important that the scheme is developed in line with emerging government policy. Representation of the primary government officials developing policy on carbon sequestration and trading on the enabling and shareholder groups should address this issue and ensure government support.

5. **The pilot areas in PNG are likely to be remote, of complex terrain and often obscured by cloud, making remote sensing difficult** -> RESPONSE: The project design should allow for a range methods to be assessed (i.e. build in redundancy) to enable identification of rigorous carbon assessment method(s). This may well involve incorporation of a GIS expert model.

6. **Carbon monitoring and tracking methodologies may not be practical in PNG circumstances** -> RESPONSE: A range of remote sensing options (identified in Phase I) should be trialed if possible. These trials should be undertaken in collaboration with local experts to ensure that forest quality and cover can be identified and/or modeled effectively. For the pilot assessment phase, trials will need to involve ongoing ground-truthing of key forest and habitat types. This will require forest assessment incorporating approved carbon tracking schemes of the ground and statistically significant replication of different forest types and environments to make sure remote sensed modeling is robust.

7. **Internet is not available at the village level** -> RESPONSE: A number of initiatives are exploring internet service provision to rural and remote schools in PNG. During the pilot phase, data monitoring and carbon trading may occur via an intermediary e.g through a government station or NGO team. Feedback can then be supplied to the affected villages via ground-truthing / assessor teams. The aim however is to establish as direct a link between carbon producer and carbon buyer as soon as feasible.

8. **One partner may hijack the system and insist upon controlling the carbon trading** -> RESPONSE: Ensure that transparency is a key part of the system and that buyers have guarantees that monies are tracked and placed into an independent fund. An independent auditor and manager of the scheme will be essential.

Budget (estimate)

Item	Description	Phase 1	Cost (USD) Phase 2	Total
Salary	Coordinator	45,000	180,000	**225,000**
	PNG leader	20,000	80,000	**100,000**
	Field staff		75,000	**75,000**
	Admin staff	5,000	20,000	**25,000**
Travel		15,000	80,000	**95,000**
Meetings		10,000	60,000	**70,000**
Consultancies		80,000	160,000	**240,000**
Grants to partners			300,000	**300,000**
Office costs		5,000	50,000	**55,000**
Equipment			40,000	**40,000**
Management fees		22,500	130,625	**153,125**
Total		**202,500**	**1,175,625**	**1,378,125**