



Biochar: Examination of an Emerging Concept to Sequester Carbon

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Summary

Biochar is a charcoal produced under high temperatures using crop residues, animal manure, or any type of organic waste material. Depending on the feedstock, biochar may look similar to potting soil or to a charred substance. The combined production and use of biochar is considered a carbon-negative process, meaning that it removes carbon from the atmosphere.

Biochar has multiple potential environmental benefits, foremost the potential to sequester carbon in the soil for hundreds to thousands of years at an estimate. Studies suggest that crop yields can increase as a result of applying biochar as a soil amendment. Some contend that biochar has value as an immediate climate change mitigation strategy. Scientific experiments suggest that greenhouse gas emissions are reduced significantly with biochar application to crop fields.

Obstacles that may stall rapid adoption of biochar production systems include technology costs, system operation and maintenance, feedstock availability, and biochar handling. Biochar research and development is in its infancy. Nevertheless, interest in biochar as a multifaceted solution to agricultural and natural resource issues is growing at a rapid pace both nationally and internationally.

Past Congresses have proposed numerous climate change bills, many of which do not directly address mitigation and adaptation technologies at developmental stages, such as biochar. However, biochar may equip agricultural and forestry producers with numerous revenue-generating products: carbon offsets, soil amendments, and energy.

This report briefly describes biochar, some of its potential advantages and disadvantages, legislative support, and research and development activities underway in the United States.

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Introduction

Biochar—a charcoal produced under high temperatures using crop residues, animal manure, or other organic material—has the potential to offer multiple environmental benefits. Some contend that biochar can meet pressing environmental demands by sequestering large amounts of carbon in soil. It is of interest to those seeking to sell or purchase carbon offsets, increase soil conservation efforts, improve crop yield, and produce renewable energy. However, little is known about how biochar production systems could successfully be implemented and what the effect would be on long-term operations in the U.S. agriculture and forestry sectors. Some contend that it will be a considerable amount of time before this technology reaches its full potential. Studies underway at federal government research institutions and in academia are focused on ensuring that biochar production systems are a practical and reliable technology for producers to adopt.

Biochar

Biochar is a soil supplement that sequesters carbon in the soil and thus may help to mitigate global climate change.¹ It has the potential to curtail greenhouse gas emissions and other environmental hazards in the near term and to benefit agricultural producers as a soil amendment and source of renewable energy. Thus far, biochar use in the United States has been confined to small-scale applications reflective of the limited but growing number of researchers in this area over the last few years.

Biochar is similar in appearance to potting soil or to a charred substance, depending on the feedstock (**Figure 1**). Modern biochar production is based on an ancient Amazon technique for creating a nutrient-rich soil, *terra preta*. As a charcoal containing high levels of organic matter, biochar is formed from plant and crop residues or animal manure under pyrolysis conditions. Pyrolysis is the chemical breakdown of a substance under extremely high temperatures in the absence of oxygen. The quantity and quality of biochar production depends on the feedstock, pyrolysis temperature, and pyrolysis processing time. A “fast” pyrolysis (~500°C) produces biochar in a matter of seconds, while a “slow” pyrolysis produces considerably more biochar but in a matter of hours.²

Biochar production via pyrolysis is considered a carbon-negative process because the biochar sequesters carbon while simultaneously enhancing the fertility of the soil on which the feedstock used to produce the bioenergy grows (**Figure 2**). The biochar production system is operated using energy produced by the system. The three main outputs of a biochar production system are syngas, bio-oil, and biochar (**Figure 3**).³

¹ A series of presentations delivered at the 2008 United Nations Climate Change Conference elevated interest in biochar as an immediate response to mitigate climate change, given its carbon sequestration ability. “Dangerous Sea Level Rise Imminent without Large Reductions of Black Carbon and Implementation of Other Fast-Action Mitigation Strategies,” *Environmental Research Web*, December 12, 2008.

² Institute for Governance & Sustainable Development and IGDS/INECE Climate Briefing Note, “Significant Climate Mitigation Is Available from Biochar,” December 8, 2008.

³ Syngas, or synthesis gas, consists of varying concentrations of carbon monoxide and hydrogen and can be used as a replacement to natural gas or liquid fuel. Bio-oil is a liquid fuel that can be used, once upgraded, as a motor fuel.

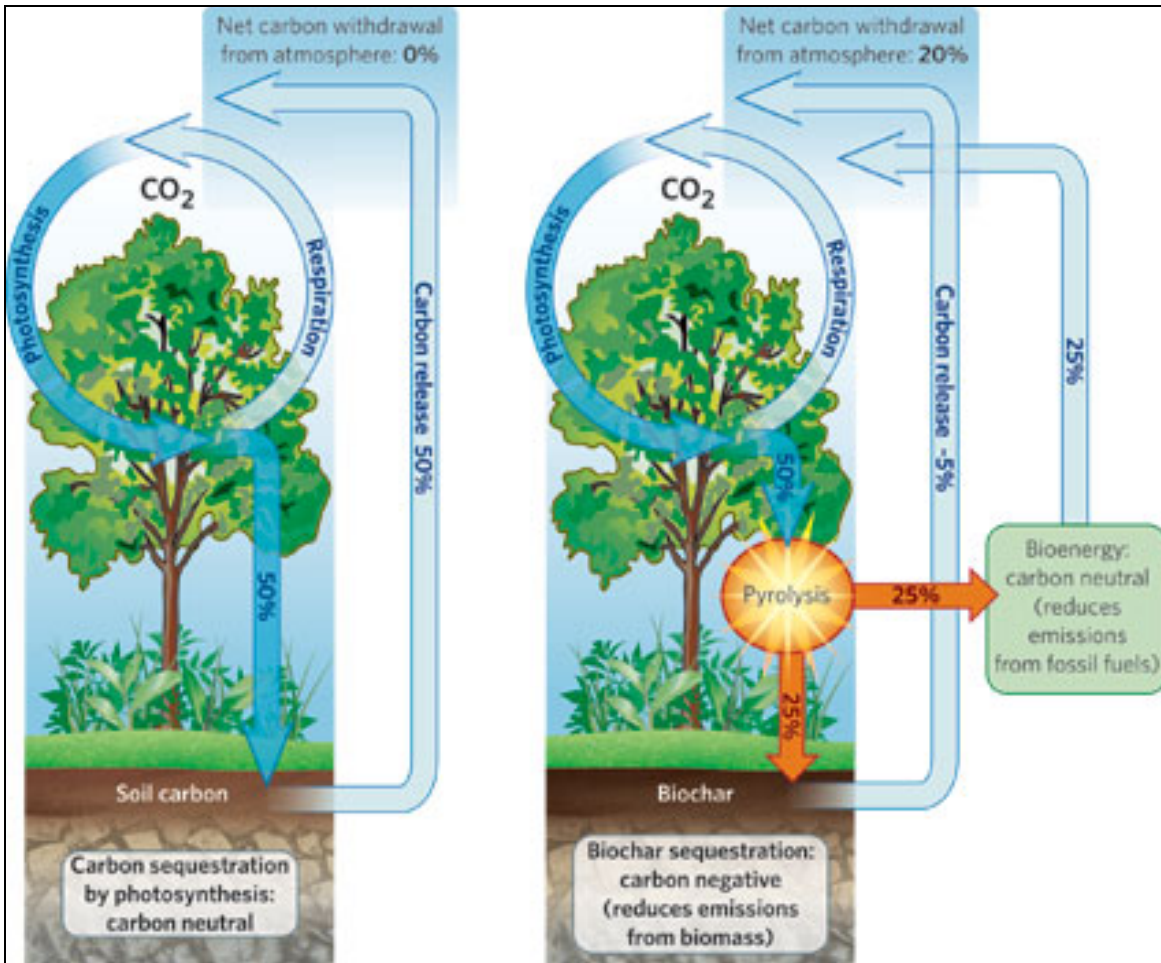
Figure 1. Biochar



Source: Biochar Engineering (BEC Inc.; <http://www.biocharengineering.com>).

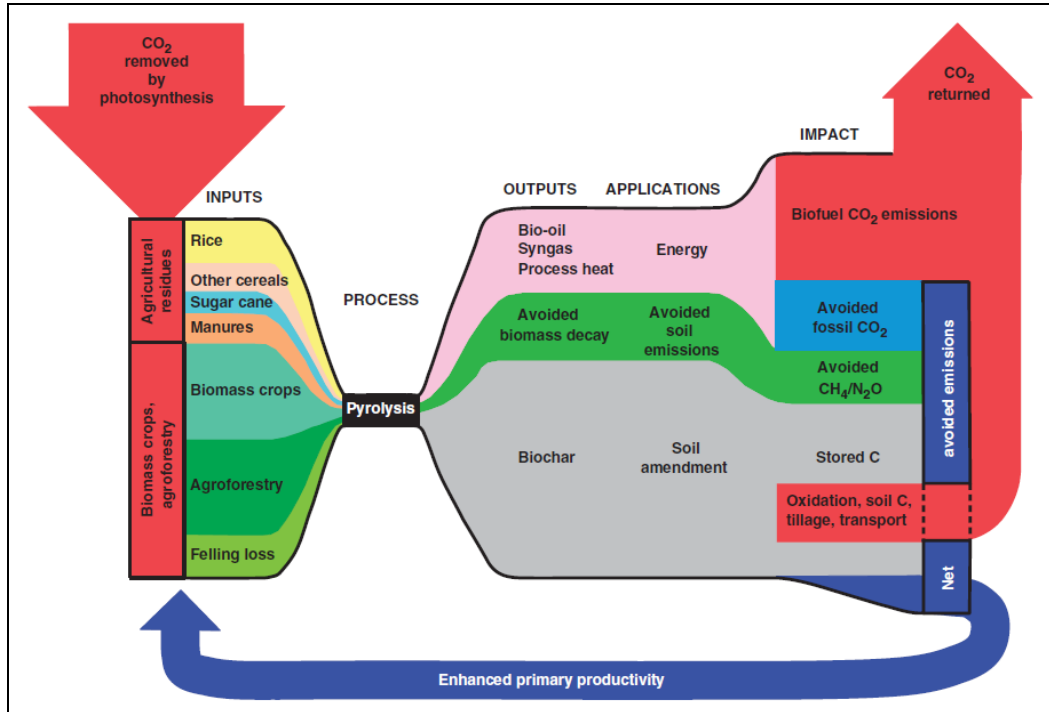
Notes: Wood chips on the right and in barrel were processed through a biochar production system.

Figure 2. Carbon Cycle for Soil Carbon and Biochar



Source: J. Lehmann, "A Handful of Carbon," 2007. *Nature* 447, pp. 143-144.

Figure 3. Biochar Inputs, Process, Outputs, Applications, and Global Climate Impact



Source: Dominic Woolf, James E. Antonette, and F. Alayne Street-Perrott, et al., “Sustainable Biochar to Mitigate Global Climate Change,” *Nature Communications*, August 10, 2010.

Notes: Within each category (inputs, process, outputs, applications and impacts on global climate), the relative proportions of the components are approximated by the height and width of the colored fields.

Potential Advantages

Whether used as a soil amendment⁴ or burned as an energy source (e.g., for cooking and heating), biochar provides numerous potential environmental benefits, some of which are not quantifiable. The three primary potential benefits are carbon sequestration, greenhouse gas emission reduction, and soil fertility.

Carbon Sequestration

Carbon sequestration is the capture and storage of carbon to prevent it from being released to the atmosphere. Studies suggest that biochar sequesters approximately 50% of the carbon available within the biomass feedstock being pyrolyzed, depending upon the feedstock type.⁵ The remaining carbon is released during pyrolysis and may be captured for energy production. Large amounts of carbon may be sequestered in the soil for long time periods (hundreds to thousands of years at an estimate),⁶ but precise estimates of carbon amounts sequestered as a result of biochar

⁴ A soil amendment improves the physical properties of soil (e.g., moisture-holding capacity, nutrient retention ability).

⁵ Johannes Lehmann, John Gaunt, and Marco Rondon, “Bio-char Sequestration in Terrestrial Ecosystems—A Review,” *Mitigation and Adaptation Strategies for Global Change*, vol. 11 (2006), pp. 403-427.

⁶ Bruno Glaser, Johannes Lehmann, and Wolfgang Zech, “Ameliorating Physical and Chemical Properties of Highly Weathered Soils in the Tropics with Charcoal—A Review,” *Biology and Fertility of Soils*, vol. 35 (2002), pp. 219-230.

application are scarce. One scientist suggests that a 250-hectare farm could sequester 1,900 tons of CO₂ a year.⁷

Greenhouse Gas Emission Reduction

Primary greenhouse gases associated with the agriculture sector are nitrous oxide (N₂O) and methane (CH₄). Cropland soils and grazing lands are an agricultural source of nitrous oxide emissions.⁸ Livestock manure management and enteric fermentation are leading agricultural sources of methane emissions.⁹ When applied to the soil, biochar can lower greenhouse gas emissions by substantially reducing the release of nitrous oxide.¹⁰ One report showed a 40% reduction in emissions of this greenhouse gas, which is approximately 310 times stronger than carbon dioxide in terms of global warming potential.¹¹ Laboratory studies suggest that nitrous oxide emission reductions from biochar-treated soil are dependent on soil moisture and soil aeration.¹² Greenhouse gas emission reductions may be 12%-84% greater if biochar is land-applied instead of combusted for energy purposes.¹³

Soil Fertility

Biochar retains nutrients for plant uptake and soil fertility. The infiltration of harmful quantities of nutrients and pesticides into groundwater and soil erosion runoff into surface waters can be limited with the use of biochar.¹⁴ If used for soil fertility, biochar may have a positive impact on those in developing countries. Impoverished tropical and subtropical locales with abundant plant material feedstock, inexpensive cooking fuel needs, and agricultural soil replenishment needs could see an increase in crop yields.¹⁵

Potential Disadvantages

Recognizing that biochar technology is in its early stages of development, there are many concerns about the applicability of the technology in the United States. Three issues are feedstock availability, biochar handling, and biochar system deployment. Successful implementation of biochar technology depends on the ability of the agricultural community to afford and operate a system that is complementary to current farming and forestry practices.

⁷ Emma Marris, "Black Is the New Green," *Nature*, vol. 442, no. 10 (August 2006), pp. 624-626.

⁸ For more information on nitrous oxide emissions, see CRS Report R40874, *Nitrous Oxide from Agricultural Sources: Potential Role in Greenhouse Gas Emission Reduction and Ozone Recovery*, by Kelsi Bracmort.

⁹ For more information on methane emissions from agricultural sources, see CRS Report R40813, *Methane Capture: Options for Greenhouse Gas Emission Reduction*, by Kelsi Bracmort et al.

¹⁰ Johannes Lehmann, "Bio-energy in the Black," *Frontiers in Ecology and the Environment*, vol. 5, no. 7 (2007), pp. 381-387.

¹¹ Tyler Hamilton, "The Case for Burying Charcoal," *Technology Review*, April 26, 2007.

¹² Yosuke Yanai, Koki Toyota, and Masanori Okazaki, "Effects of Charcoal Addition on N₂O Emissions from Soil Resulting from Rewetting Air-Dried Soil in Short-Term Laboratory Experiments," *Japanese Society of Soil Science and Plant Nutrition*, vol. 53 (2007), pp. 181-188.

¹³ Johannes Lehmann, "A Handful of Carbon," *Nature*, vol. 447 (May 10, 2007), pp. 143-144.

¹⁴ Johannes Lehmann, "Bio-energy in the Black," *Frontiers in Ecology and the Environment*, vol. 5, no. 7 (2007), pp. 381-387.

¹⁵ Stephan M. Haefele, "Black Soil, Green Rice," *Rice Today*, April-June 2007, p. 27.

Feedstock Availability

The availability of a plentiful feed supply for biochar production is an area for further study. To date, feedstock for biochar has consisted mostly of plant and crop residues, a primary domain of the agricultural community. There may be a role for the forestry community to be involved, as woody biomass is deemed a cost-effective, readily available, feasible feedstock. Little is known about the advantages of using manure as a biomass feedstock. According to a group of researchers in Australia, manure-based biochar “has advantages over typically used plant-derived material because it is a by-product of another industry and in some regions is considered a waste material with little or no value. It can therefore provide a lower cost base and alleviate sustainability concerns related to using purpose-grown biomass for the process.”¹⁶

Biochar Handling

The spreading of biochar as a soil amendment is ripe for further exploration. Specific questions concern the ideal time to apply biochar and how to ensure that it remains in place once applied and does not cause a risk to human health or degrade air quality.¹⁷ Particulate matter, in the form of dust that is hard for the human body to filter, may be distributed in abnormal quantities if the biochar is mishandled. There are potential public safety concerns for the handling of biochar, as it is a flammable substance. Additionally, the amount of land available for biochar application requires further investigation.

Biochar System Deployment

Biochar systems are designed based on the feedstock to be decomposed and the energy needs of an operation. It would be ambitious to expect a “one size fits all” standard biochar system. According to proponents, a series of mass-produced biochar systems designed for the needs of a segment of the agriculture or forestry communities might prove to be feasible (e.g., forestry community in the southeastern region, corn grower community in the midwestern region, poultry producer community in the mid-Atlantic region). Extensive deployment of biochar systems would depend on system costs, operation time, collaboration with utility providers for the sale of bio-oil, and availability of information about technology reliability.

Policy Context

Climate Change Debate

Carbon offsets were a prominent factor in the climate change debate in the 111th Congress. A carbon offset is defined as “a measurable avoidance, reduction, or sequestration of carbon dioxide (CO₂) or other greenhouse gas (GHG) emissions.”¹⁸ Carbon sequestration projects are one type of

¹⁶ K. Y. Chan, L. Van Zwieten, and I. Meszaros et al., “Using Poultry Litter Biochars as Soil Amendments,” *Australian Journal of Soil Research*, vol. 46 (2008), pp. 437-444.

¹⁷ David A. Laird, “The Charcoal Vision: A Win-Win-Win Scenario for Simultaneously Producing Bioenergy, Permanently Sequestering Carbon, While Improving Soil and Water Quality,” *Agronomy Journal*, vol. 100, no. 1 (2008), pp. 178-181.

¹⁸ For more information on carbon offsets, see CRS Report RL34241, *Voluntary Carbon Offsets: Overview and* (continued...)

carbon offset. In addition to direct carbon capture and sequestration activities, Congress may consider the role of biological (indirect) sequestration—such as biochar production technology—that can be implemented by agricultural producers at the field level.¹⁹ The establishment of an offset program, identification of eligible project types, carbon offset ownership, and offset verification may be pertinent to the adoption of biochar production technology.²⁰

Congress may examine the use of biochar as an indirect carbon sequestration technology that could be used to offset carbon emissions from major emitters. In 2008, 6% of total U.S. greenhouse gas emissions were attributed to the agricultural sector.²¹ While not as large as the amounts produced by some other sectors, agricultural emissions come from a large number of decentralized sources, leading many to conclude that controlling such emissions would be difficult. On the other hand, some argue that soil carbon sequestered as a result of biochar application is easily quantifiable and transparent, which may be ideal for carbon trading requirements. Others contend that ancillary benefits could include additional revenue earned by agricultural producers through the sale of carbon credits earned from biochar application or the sale of biochar as a soil amendment. Energy costs for a producer's operation may be reduced by using the energy generated from the biochar production system. Additionally, some assert that the use of biochar results in higher crop yields. This could be a criterion to consider within the larger land use debate.

Legislation Introduced During the 111th Congress

The Water Efficiency via Carbon Harvesting and Restoration (WECHAR) Act of 2009,²² introduced during the 111th Congress, sought, among other things, to establish loan guarantee programs that would develop biochar technology to use excess plant biomass and establish biochar demonstration projects on public lands. The legislation was primarily focused on woody biomass as the feedstock. Some asserted that the legislation addressed research and development needs for biochar production. Others argued that the legislation lacked specific actions regarding technology transfer or commercial development of biochar production systems.

The discussion draft of the American Power Act offered during the 111th Congress contained three provisions relevant to biochar.²³ The first provision identified projects for biochar production and use as an eligible project type under the domestic offsets program.²⁴ The second provision instructed the U.S. Environmental Protection Agency (EPA) to submit to Congress a report on the sources and effects of black carbon emissions, and strategies to reduce black carbon emissions,

(...continued)

Assessment, by Jonathan L. Ramseur.

¹⁹ For more information on carbon capture and sequestration, see CRS Report RL33801, *Carbon Capture and Sequestration (CCS)*, by Peter Folger; and CRS Report RL33898, *Climate Change: The Role of the U.S. Agriculture Sector*, by Renée Johnson.

²⁰ For more information on the role of offsets in current greenhouse gas legislation, see CRS Report R40643, *Greenhouse Gas Legislation: Summary and Analysis of H.R. 2454 as Passed by the House of Representatives*, coordinated by Mark Holt and Gene Whitney.

²¹ U.S. Environmental Protection Agency, *2010 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-10-006, April 2010, <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>.

²² S. 1713.

²³ Discussion draft available at <http://kerry.senate.gov/americanpoweract/pdf/APAbill.pdf>.

²⁴ American Power Act (discussion draft), Title VII, Part D, Sec. 734.

including “research and development activities needed to better characterize the feasibility of biochar techniques to decrease emissions, increase carbon soil sequestration, and improve agricultural production, and if appropriate, encourage broader application of those techniques.”²⁵ The third provision directed the Secretary of Agriculture to provide grants for up to 60 facilities to “conduct research, develop, demonstrate and deploy biochar production technology for the purpose of sequestering carbon.”²⁶

Farm Bill

The 110th Congress promoted biochar development through the 2008 farm bill (P.L. 110-246), which listed it under grants for High Priority Research and Extension Areas. Noted research areas include biochar production and use, co-production with bioenergy, soil enhancements, and soil carbon sequestration. Listing biochar development as a high-priority research area in the 2008 farm bill did not authorize a specific appropriations amount. Funding for biochar development research would be determined in future appropriation bills and by the U.S. Department of Agriculture. Farm managers facing needs with respect to soil fertility, residue and manure management, energy efficiency, and additional revenue generation may benefit from a policy that further supports biochar production and use (e.g., technology practice standard, cost-share).

Long-Term Prospects

Biochar’s fate as a viable component of the long-term solution to mitigate climate change by way of carbon sequestration depends upon further development by the scientific and technology transfer communities. In particular, biochar’s practical application at various locations and scales using multiple feedstocks throughout the United States is an area for additional study. Policy that encourages academia and other institutions to conduct in-depth research and development could quicken the pace of technology deployment. One study hypothesizes that a U.S. research program (technical demonstrations and a coordinated national field trial program), funded at \$100 million-\$150 million for eight years, could support the research, development, and deployment of commercial-scale biochar production and use.²⁷

An assessment of external factors (e.g., feedstock transportation costs and disposal fees) associated with the economic growth of biochar production systems, similar to studies conducted for the biofuels industry, could provide guidance on the types of federal financial and technical incentives necessary to spur development (e.g., regulatory requirements, technical standards). The definition of biomass used in climate change and energy legislation will directly affect the eventual impact of biochar in limiting GHG emissions.²⁸ Indeed, the biomass definition would determine what sources of material are deemed acceptable and which lands would be eligible lands for biomass removal.

²⁵ American Power Act (discussion draft), Title VII, Subtitle C, Part II, Sec. 2211.

²⁶ American Power Act (discussion draft), Title VII, Subtitle C, Part II, Sec. 2214.

²⁷ Stephen Brick and Sasha Lyutse, *Biochar: Assessing the Promise and Risks to Guide U.S. Policy*, Natural Resources Defense Council, November 2010, http://www.nrdc.org/energy/files/biochar_paper.pdf.

²⁸ For more information on biomass definitions, see CRS Report R40529, *Biomass: Comparison of Definitions in Legislation Through the 111th Congress*, by Kelsi Bracmort and Ross W. Gorte

U.S. Department of Agriculture Activities

According to a U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) official, an estimated \$2.6 million was spent in 2010 on in-house biochar research by ARS.²⁹ ARS has multiple projects underway to ascertain biochar's value as a soil amendment given varying soil, climate, and cropping system conditions. Additionally, ARS is examining feedstock types and pyrolysis conditions for biochar production. ARS estimates that the United States could use biochar to sequester 139 Tg of carbon on an annual basis if it were to harvest and pyrolyze 1.3 billion tons of biomass.³⁰

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²⁹ Correspondence with USDA ARS official, January 2011.

³⁰ Correspondence with USDA ARS official, January 2009. A teragram (Tg) is equivalent to 1 trillion grams. A Tg C (teragram of carbon) is a unit of measurement used to compare greenhouse gases emitted from different sources on the same basis.