

## ***White paper***

### ***Time accounting subgroup***

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## Introduction

The question of time accounting is in essence the question of how to combine one-time changes in carbon storage in soils and plants associated with expanded biofuel production with a carbon intensity based on continuing direct life cycle inputs. This question can be approached in several ways, with distinctions among the different approaches that are as much philosophical as technical.

The current time accounting method (annualization) used by the California Air Resources Board (CARB) estimates the land use change emissions associated with expanded production of a particular biofuel, adds 30 years of foregone sequestration, and divides the total by 30. This decision is based on an implicit forecast of the probable duration of biofuels production or perhaps the lifetime of a biorefinery. As a forecast, this timeframe is not well justified by models or other specific analysis. On the other hand, the simplicity and consistency of this approach may explain its appeal, and other regulators have adopted the same approach (US EPA) or a very similar approach (the EU adopted a 20 years timeframe).

The time accounting subgroup builds on the work of other subgroups that have responsibility for commenting on projections of land use change and how to grapple with the associated uncertainty. Taking this limitation at face value, we have developed a variety of technical means to convert a stream of emissions over time into carbon intensity metrics. Several of these methodologies convert a projected stream of emissions (from land use and direct fuel production and use) into a projection of additional carbon in the atmosphere and use this projection to develop a carbon intensity metric that could be used for LCFS compliance.

However, our group was also keenly aware that the associated carbon intensity metrics are only as good as the underlying projected emissions, and these projected emissions over time will remain uncertain and become increasingly uncertain the longer the projections reach into the future.

To develop metrics that produce meaningful results in the face of uncertain projections, a major thrust of our work has been to develop metrics that can combine long term and short term emissions without relying on long term projections of biofuel production and associated land use change.

One approach, called “baseline time accounting,” suggests that rather than consider the long-term impact of a multi-year biofuels program, one can equivalently consider the problem on a year-by-year basis. This approach models how each year of biofuels production changes the existing baseline dynamic of land use change around the world. This approach dispenses with long-term forecasts for biofuels production, but relies on detailed knowledge of land use change dynamics in different regions, and adds a data requirement to project the changes in sequestration as land

that might have otherwise reverted to (or continued in) some other use remains in production (or is brought into production) to accommodate demand for biofuels. This approach deals with time shifts by use of the global warming potential based on the rationale that this is the same methodology being used for direct emissions and ,since indirect and direct emissions are added together in the LCFS lookup tables, they should be derived based on consistent methodologies.

The final approach builds on the fundamental insight of baseline time accounting that multi-year projections can be replaced by time shifts, but approaches this insight in a highly simplified manner. In this treatment, the question of forecasting has been replaced with setting a discount rate. The discount rate decision in this context is critical, and while there are technical considerations, this discount rate decision is ultimately a policy judgment. We offer some thoughts to guide regulators in making this decision.

Finally, we briefly mention and comment on the application of the Social Cost of Carbon framework as a way to think about the consequences of carbon emissions over time.

Our group had sharply divided opinions on several key matters that influence the weight given to indirect land use emissions. However, we had many productive discussions about the technical basis of these calculations. Where we could simply explain in a neutral way the basis for the different approaches, we have done this. Where we have different perspectives, we have indicated these after the technical discussion.

### **Different Time Periods**

Key times in biofuels policy analysis: In the following discussion, repeated reference will be made to some critical characteristic times of judgment or calculation. These are defined here for consistency and the readers' convenience:

#### **Present**

We assume a decision about LCFS implementation is made “now”, on the basis of various possible projections of an ongoing future, and that fuels being compared commence production now.

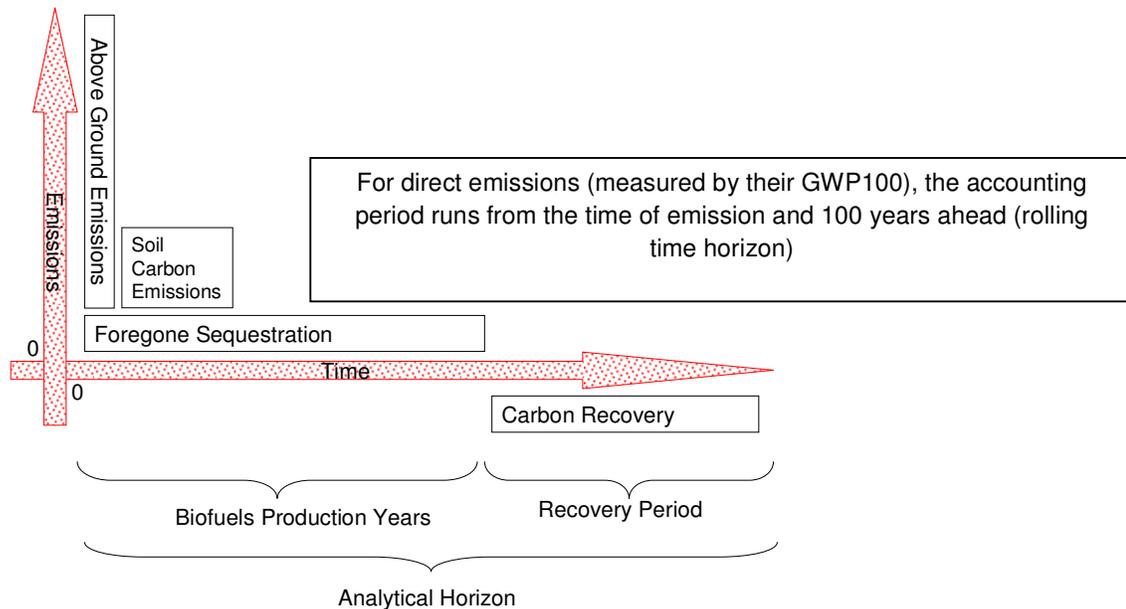
#### **ILUC emission periods**

Changes in GHG discharge from ILUC can be variously modeled as instantaneous, occurring when production of biofeedstock begins, or continuing for a few years, assuming there is burning of above-ground biomass on converted land, and then more slowly with decay of roots and possibly logs. Alternatively, changes in emissions could occur over many years when, for example, the baseline land-use involves annual burning of underutilized land (a common practice in developing

nations) and the cyclic burning is eliminated when land is brought into productive management.

### **Production period**

For most time-aware calculations of biofuels' global warming indexes (GWI), it is assumed that the biofeedstock will be grown for a certain number of years and then stop. The production period is this number of years (see Figure 1).



**Figure 1: Emissions Flows over Time**

### **Reversion period**

When biofeedstock production stops, the land no longer affected by ILUC could be retained in production for other purposes (food, feed, fiber), or revert to a prior condition, or other non-productive uses, or to a more natural state. If one assumes land reverts to a natural state, with sequestration of carbon into grass, trees, and soil carbon, the duration of this recovery is the reversion (or recovery) period (see Figure 1).

### **Analytic horizon**

Climate effects of a policy decision are counted up over a finite period from the present. This period is the analytic horizon (see Figure 1).

### **Criterion horizon**

Policies and practices are compared according to some measure of their future consequences. The future point in time when this judgment is applied, the criterion horizon, is not always obvious, and the concept is complicated by whether the judgment is instantaneous or cumulative. As illustrated in the examples in (O'Hare et al 2009), choosing different criteria and criterion horizons like "how much less aggregated warming will have occurred by X years in the future" can easily switch our judgments about how "green" one fuel is compared to another. We illustrate this with examples.

#### *Cross-sectional criterion horizon*

The LCFS directs that California vehicle fuels reduce their carbon intensity by 10% by 2022. The path by which this is attained was an implementation choice of the ARB; it could have ordered the full 10% reduction at the end of the period without reference to how quickly fuel carbon intensity approached this target. That would be a ten-year cross-sectional criterion horizon. It would not differentiate between fuel practices that reduced carbon intensity in the second year from those that only caused reductions in the ninth; as long as the target at 2022 is met, the criterion is satisfied.

#### *Integral criterion horizon*

Alternatively, society might view the LCFS as an instrument to achieve a different goal, reflecting conditions over an extended period. For example, it might seek to reduce total vehicle GHG emissions over a twenty year period below a certain level, or to minimize (within constraints) the net present value (at some discount rate) of total forcing over the next century. Those goals represent integral criterion horizons of twenty and a hundred years, respectively.

### **Method 1: Annualization**

CARB's current time accounting method (annualization or straight line amortization) assumes a 30 year biofuels production scenario and divides the emissions from above- and below-ground biomass and foregone sequestration during this biofuels production period by the volume of biofuels produced during the same period (see Figure 1).

#### **Perspective 1 (annualization)**

Spreading the emission only over the biofuels production period (and neglecting what happens to land use afterwards) and truncating it to 30 years is an arbitrary choice. From a historical perspective, the US corn ethanol program is starting to exceed 30

years with dry grind ethanol plants dating back to the early 1980s. More importantly, those early dry grind plants are still operating and have been retrofitted to match the energy efficiency of more recently constructed facilities (Mueller, 2010).<sup>1</sup> Guided by a historical perspective, a 30 year time horizon would constitute the shorter end of possible ranges.

Moreover, recent regulatory analyses such as the US EPA's analysis of the American Power Act (APA) have looked at the emissions impact and the associated costs over a longer time period: the APA analysis spans a 40 year period (ending at year 2050).<sup>2</sup> Likewise, the European Union's "World Energy Technology Outlook – 2050" includes 45 year projections and the International Energy Agencies "Energy Technology Perspective" series covers periods in excess of 40 years.<sup>3,4</sup> Finally, even CARB's Staff Report Volume I implies a longer time horizon for its policy (page IS-3): "To achieve Governor Schwarzenegger's long-term goal or [sic] reducing GHG emissions by 80 percent by 2050." Again, this suggests that we should analyze the emissions impact over a longer period of time. This perspective recommends that we consider land use after a minimum 30 year biofuels production scenario and add an analytical horizon to the time accounting methodology.

CARB, in its Staff Report, Volume I, Appendix C attempts to recognize a land reversion potential after biofuels production and states:

*"If corn ethanol production declines when producers no longer receive LCFS credits, pressure on food crops will be reduced. This will result in a "reversed" land use change in which land somewhere in the world may be allowed to revert to native vegetation (e.g. forest or grassland). [...] We note however that annualizing emissions that occur over 50 years is problematic given the large variation of emissions flows (highly positive to negative) occurring over such a long time period [...] Therefore, staff does not recommend using the annualized method if land reversion is to be included."*

We recommend that CARB reconsider the exclusion of land reversion emissions on the basis that they are occurring "over such a long time period." Many studies project future land use with great care and validated models.<sup>5,6</sup>

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<sup>1</sup> Mueller, S. "2008 National Dry Mill Corn Ethanol Survey"; Biotechnology Letters, 2010

<sup>2</sup> <http://www.epa.gov/climatechange/economics/apa.html>

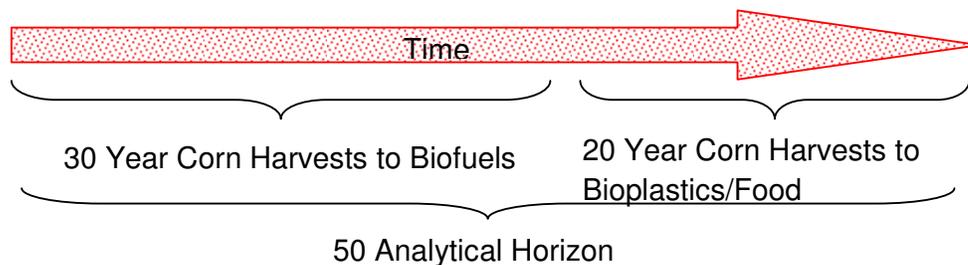
<sup>3</sup> International Energy Agency, "International Technology Perspectives, Scenarios and Strategies to 2050" published in 2008 and 2010, <http://www.iea.org/techno/etp/index.asp>

<sup>4</sup> EUROPEAN COMMISSION, 2006, Directorate-General for Research, Directorate Energy, [http://ec.europa.eu/research/energy/pdf/weto-h2\\_en.pdf](http://ec.europa.eu/research/energy/pdf/weto-h2_en.pdf)

<sup>5</sup> Fischer (2009): World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability? FAO Expert meeting on how to feed the world in 2050, 24-26 June 2009.

Furthermore, while CARB recognizes the land reversion potential, it omits other possible uses for the land. Applying current ILUC theory, any land released from biofuels production relieves land-use pressure globally, making it available in areas where there is demand to clear new land, and thereby reducing or eliminating that demand. It is most likely that biofuels land will continue in production for food and other products.

Similarly, in many developed nations including the U.S., the only significant net change in land use over the past twenty years has been the expansion of “developed land” at the expense of cropland. Therefore, while land use after biofuels could include reversion to a natural state in some parts of the world, this does not appear likely given current trends. More probable scenarios would assume that land released from biofuels either continues producing food or is converted to non-productive use such as urbanization; both scenarios have consequences for GHG emission estimates. In the case of continued production, the bio-products could provide life cycle greenhouse gas benefits over petroleum based products (see Figure 2). This includes corn-derived bioplastics, lignin-based fibers, and biobased solvents (such as ethyl lactate substituting for petroleum based solvents, see Mueller, 2010 b).<sup>7</sup>



**Figure 2: Time after Biofuels Production**

Thus, one logical scenario for areas with arable land expansion, and taking into account current US corn-ethanol production and a 50-year time horizon, would assume a 30 year biofuels production period followed by a 20 year period of other products. The emissions from land use change will be prorated by the 30 years going into biofuels production and the 20 corn harvests going into other corn products. In this case the accounting does not incur the “highly positive and negative” emissions flows estimated by other approaches.

<sup>6</sup> Bruinsma J (2009): The resource Outlook to 2050. By how much do land, water and crop yields need to increase by 2050?, FAO Expert meeting on how to feed the world in 2050, 24-26 June 2009.

<sup>7</sup> Mueller, S. “Life Cycle Analysis of Ethyl Lactate Production and Controlled Flow Cavitation at Corn Ethanol Plants”; 2010 b.

## **Perspective 2 (annualization)**

What has been called annualization or straight-line amortization has been criticized as being arbitrary or relying on flawed assumptions. My own perspective after our extensive discussion of alternatives is that the simple averaging is not itself a problem, but the decision does need to be justified more clearly. In particular, the current approach of dividing one-time land use emissions by 30 seems to me better explained as a policy judgment of time preference, than as a prediction about the duration of any particular timeframe related to facility lifetime, corn cultivation or etc. The use of a 30 year timeframe for indirect land use reflects a policy judgment that current annual direct lifecycle changes in emissions are weighted 30 times more heavily than the one time changes in carbon stores associated with expanding production of these fuels. This is approximately equivalent (in terms of the resulting ILUC estimates) to choosing a discount rate of 3.4%. The choice of a discount rate depends upon a number of factors, and should be chosen with an eye to the specific goals of the policy. My own judgment is that in this instance the 30 year timeframe is too long, and that a more appropriate timeframe would be between 15 and 20 years, reflecting discount rates of 5-7%. This reflects the policy judgement about the importance of supporting low carbon biofuel production while at the same time preserving carbon stored in forests and soils. For a more complete discussion of discount rates see the section on discount rates below.

## **Perspective 3 (annualization)**

There are infinite potential scenarios for land-use and land-use changes associated with bioenergy production, leading to equally diverse opinions about appropriate time-frames and discount rates. If the U.S. achieves EISA targets, bioenergy cropland could begin “release” within the next 10-15 years as the ethanol industry transitions toward cellulosic feedstocks. Similar land release scenarios have been documented based on double-cropping and other management approaches to integrate bioenergy feedstock production with increasing output of food, feed and other products, while reducing demand for land (Dale et al. 2010). Such scenarios are consistent with US production trends which for fifty years have persistently increased outputs using less and less land (USDA-NASS historic agricultural production and land use data).

Given the inherent uncertainty surrounding the long-term predictions and time accounting, and given the wide range of opinions on key parameters such as discount rates, recommendations include: (a) use the most transparent tools available to estimate effects; (b) avoid complications that do not add value to the analysis; (c) clearly define near-term goals – e.g. how does the ILUC regulation hope to influence land-use effects; and (d) carefully review the actual effects of policies on land-use on a regular basis using a multi-disciplinary approach. The key to success is to determine whether the regulations and policy are effectively supporting your goals or not. To make that determination, models must be supplemented with more

current knowledge and data and policies should be planned with goals and assessments measurable on manageable time horizons (4-6 years).

#### **Perspective 4 (annualization)**

The annualization method applies a simple and static approach. It is assumed that the 'biofuels shock' leads to an instantaneous increase in world cropland (modeled with the GTAP Model) and that this increase remains constant over 30 years. It is thereby implicitly assumed that crop yields will stay constant over the next 30 years. This is obviously a questionable assumption as crop yields have historically been increasing continuously (FAOSTAT 2010) and must be expected to continue to do so, especially with new genetically modified crops. Even if CARB updates the ILUC analysis in the LCFS on a regular basis to take yield changes (and other changes) into account, the 'ILUC factor' of today will still be affected (in an upward direction) due to the implicit 'constant yield assumption' currently applied in the annualization method. One way to improve the current use of the annualization method (if this will still be CARB's preferred time accounting method in the future) would be to assume that, in each year of the production period, part of the land indirectly affected by biofuels production would go out of production and start reversion. The amount of land going out of production could be estimated based on a reasonable estimate of future crop yield increases. This approach would not remedy some of the implicit problems with the annualization method (especially the production period assumption) but it would however make its use slightly more sophisticated.

## **Subject 1: Reversion**

In instances in which the analytical horizon exceeds the assumed or expected production time frame, some analysts recommend that the carbon intensity be estimated over the full analytical time period, accounting for what happens when land comes out of production for biofuels. Some aspects of this can be illustrated in CCLUB and is also a possible parameter choice that can be implemented in BTIME, the simple spreadsheet used to illustrate the application of FWP.

### **Perspective 1 (reversion)**

It has been discussed whether land (indirectly brought into production due to biofuels) should be assumed to “revert” when biofuels production stops. Some claim the land will go into food production (e.g. three of the reviewers of the US EPA ILUC methodology). If biofuel production stops or transitions to cellulosic residues and wastes within the next 10-20 years, then the assumption that land will not revert but instead go into another use is supported by several projections of future land use. Bruinsma (2009), FAO and others expect that global agricultural land use will continue to increase up to and possibly beyond 2050. If that is the case, there is reason to believe that any land brought into production (as an indirect result of biofuels production) would have come into production anyway. However, the biofuels production may accelerate this land conversion. To estimate the climate impact of the temporal shift in the time of conversion, the baseline time accounting concept (see chapter later in this white paper) can be applied.

If the current assumption in the LCFS ILUC analysis of a ‘static land use baseline’ is applied (global agricultural land use is fixed before and after the biofuels shock), the only consistent thing to assume about reversion is that land will revert after biofuels production stops.

This offers two scenario options: 1) Land can revert to its prior state after biofuels production stops or 2) Land can go into other uses when biofuels production stops. Therefore, if the analytical time horizon is longer than the assumed biofuels production period (only relevant for the annualization and the FWP method), one of the two options mentioned above must be considered. Assuming neither would be methodologically inconsistent.

### **Perspective 2 (reversion)**

The key consideration required to decide on whether to account for post-production land uses (e.g. reversion) is not what happens to land following biofuels production, but rather whether it is appropriate to credit these changes to the lifecycle of the biofuel. In a simple lifecycle accounting methodology, like the direct averaging CARB is doing now over a 30 year timeframe, carbon sequestration that may occur on the

land after biofuel production ends is irrelevant, since it is not caused by or associated with the biofuel. If a subsequent land use sequestered carbon, that subsequent land use should receive credit for this carbon storage. If it had already been included in the lifecycle assessment of the previous crop, it would be double counting to give the subsequent land user the credit. Thus to ensure that changes in carbon storage are charged to the appropriate party, the accounting should cease no later than when the biofuel production ceases. If a person rents a property and then damages it, the person is responsible for the damage. If a subsequent tenant repairs the damage, the original tenant is not entitled to claim the damage has been mitigated and therefore their responsibility is diminished. This is analogous to giving credit for post-production reversion to the original land use.

There are circumstances in which it may be appropriate to consider post-production land uses. For example, in a sensitivity analysis it would be appropriate to test the robustness of results by modeling a variety of possible land use scenarios over a fixed time horizon. In this case it may be sensible to include scenarios with shorter production periods followed by reversion to cases with longer production periods to assess the range of possible outcomes and provide a more concrete assessment of uncertainty.

This issue of accounting for post production reversion was addressed by the EPA as part of their peer review of time accounting. The context of the EPA peer review was a little different from the present LCFS regulation, since EPA had proposed to model a 100-year period and discount emissions. In this context there was a significant probability that they would be modeling a time period over which a particular biofuel production might terminate. Of the five peer reviewers, three opposed the consideration of reversion, and one suggested consideration only in the context of evaluating multiple scenarios to test the sensitivity of the analysis to different assumptions.

Rather than re-summarize, I will quote the summary from the RFS peer review here:

***Charge Question 2: Should sequestration from land reversion be considered in this analysis? If so, what is the best way to estimate the impacts of land reversion?***

Two peer reviewers gave conditional support, while three did not support considering sequestration from land reversion in EPA's analysis.

Mr. Heimlich and Dr. Richards offered conditional support. Mr. Heimlich advised EPA to consider land reversion impacts only if it had reason to believe that croplands dedicated to biofuels would be reverted. He emphasized that sequestration from abandoned croplands could be greater or less than foregone sequestration from the original land clearing because sequestration depended on the location and character of the vegetative cover. He indicated that, in general, sequestration is greater for newly planted vegetation than mature vegetation. Dr. Richards stated that land reversion could be included if EPA finds the impacts from land reversion to be

significant. He suggested trying different scenarios to test if land reversion has a significant effect on the GHG lifecycle analysis.

Drs. Fargione, Marshall, and Martin responded that land reversion should not be counted because there is no reason to assume that the land would revert. Instead, it is more likely that land would be kept in crop production for food or that the land would be developed. In addition, Dr. Marshall recommended that EPA consider post-project salvaged carbon as part of a second independent land use change that occurs once the biofuel project terminates. Dr. Fargione noted that even if land were reverted, the benefits of sequestration would be attributable to the grazing, forestry, or conservation payment activities associated with the new land use, not to biofuel production.

Dr. Fargione expanded on the reasons for his lack of support (see Appendix B). He interpreted EISA to mandate reduced emissions during the project time frame, and therefore concluded that emission reduction calculations should be based only on land use change and foregone sequestration that occur during the project time frame. He stated that the only policy-appropriate way to implement a lifecycle analysis was to consider GHG emissions independent of any speculated changes in land use after the end of the project time frame, and to account for emissions that were already released during the project time frame. According to Dr. Fargione, one potential exception to this would be if EPA were in to include long-lived forest products, as these emissions are not dependent on assumptions about future land use change.

Dr. Marshall introduced other issues to consider with land use and land reversion. She asserted that in cases where the initial conversion significantly affects the carbon potential of land on or off the site producing biofuels, then the biofuels driving that conversion should be credited or penalized with that change in carbon potential. She provided examples of deforestation and rehabilitation to illustrate the concept (see Appendix D). Dr. Marshall also suggested that land-use activity in the forest “increases risk of forest fire, causing additional carbon losses in neighboring forests, and that such fires increase the forest’s susceptibility to further burning” and cited research by Nepstad et al. (2008) on the issue. She added that such land-use changes also could fragment existing natural habitat, expand degraded “edge” habitat, and lose native species and biodiversity. Dr. Marshall concluded, “the potential for irreversible change along other social and environmental dimensions highlights the need for a more comprehensive definition of the sustainability of biofuel production than that captured by the GHG requirements alone.”

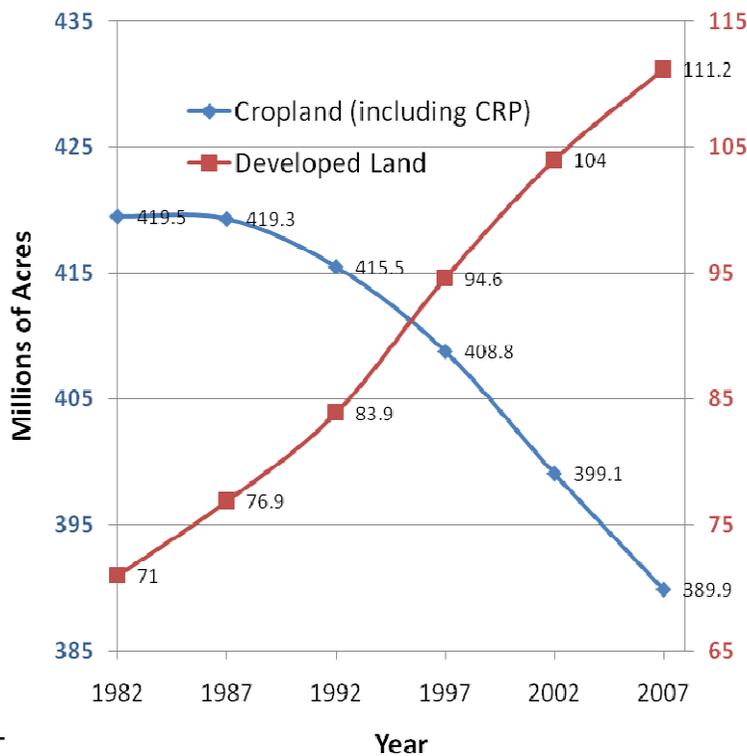
### **Perspective 3 (reversion)**

One question is whether it is appropriate to include consideration of post-production land use change in the lifecycle of the biofuel. This underscores the need to clearly define LCA boundaries and apply them consistently. If it is appropriate to consider estimates of indirect land-use change in a given analytical time period for the purpose of emission accounting, then the LCA must also consider all other indirect effects that have significant emission consequences occurring in the same time period. If the analytical boundaries include indirect effects as currently proposed by CARB, then the emission consequences of all indirect effects during the analytical

time frame should be included. Recommendation: clearly define and consistently apply the analytical boundaries for LCA.

A second question that affects the time accounting relates to the assumption in the LCFS ILUC analysis of a ‘static land use baseline’ (global agricultural land use is fixed before and after an assumed “biofuels shock” in demand. This assumes that U.S. farmland is fully utilized and that biofuels displace food crops (or forests and pasture). It also assumes that we can view and interpret global land use change dynamics through the lens of cropland. These underlying assumptions are critical in determining ILUC effects. Are the assumptions valid?

**Change in U.S. Land Use** (Source: USDA 2009, NRI)



**Figure 3: Change in Land Use**

Figure 3, based on data in the most recent National Resources Inventory (NRI 2009), shows how total US cropland has fallen while developed land increased in the past 25 years – a trend that has continued even as US biofuel production grew by 500% since 2001. The illustrated loss of cropland would be much larger if it included CRP set-asides as reductions in cropland (the NRI definition broadly defined cropland to include CRP). The NRI report also illustrates that total area of forests and rangelands in the US have been relatively stable over the past twenty years and that the only significant net changes were a loss of farms and cropland and an increase in developed land. Additionally, the NRI states that from 1982-2007, 14 million acres of “prime farmland” was lost and “most of this loss was due to development.” Given these empirical data, the effects of LCFS on US land use might more accurately be

represented in models as delayed conversion of cropland to other development. The GHG emission implications and ILUC effects of delayed conversion of US cropland to “developed” uses should be considered within the LCFS analysis.

Separate but equally important is to verify that pre-production land-use trends and drivers in other nations are understood. Dr. Marshall (quoted earlier in comments on RFS2) stated, “in cases where the initial conversion significantly affects the carbon potential of land on or off the site producing biofuels, then the biofuels driving that conversion should be credited or penalized with that change in carbon potential.” Whether to credit or penalize biofuels depends on what the true effects of biofuel policies are over time with respect to other drivers of land-use change. For example, in a baseline where forest clearing accelerates with poverty, insecurity, and local policy incentives (clearing is often the only recognized way to “claim” new land), where more land is cleared than is utilized for crops, and where land is “maintained” with repeated burning (e.g. much of the developing world where “agricultural expansion” is occurring), the indirect effects of LCFS and other external biofuel policies can be complex but can support increased incomes, improved land management, reduced pressure for deforestation and reduced emissions from repeated fire on unmanaged lands (Kline et al. 2009).

## **Subject 2: Cumulative Radiative Forcing (CRF)**

Several carbon intensity metrics have been proposed that are based on cumulative radiative forcing (CRF), which is, in more colloquial language, a measure of the total additional warming the earth has experienced in a particular time interval. Some of these metrics are described in detail in a paper published by O’Hare et al<sup>8</sup>. The baseline time accounting described in a later chapter also uses CRF as part of the metric, although it is approached in a different way. These methods construct a carbon intensity metric by application of or analogy to the widely used Global Warming Potential (GWP), which is used to compare different GHGs on a consistent basis.

The GWP is the ratio of the total cumulative radiative forcing (CRF) over a fixed time horizon caused by emissions at some initial time of one unit of a particular GHG, for example methane (CH<sub>4</sub>), compared to an emission of a unit of carbon dioxide (CO<sub>2</sub>) at the same initial time. Thus

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<sup>8</sup> O’Hare, M., Plevin, R. J., Martin, J., Hopson, E., Jones, A. D., & Kendall, A. (2009), Proper accounting for time increases crop-based biofuels’ greenhouse gas deficit versus petroleum. Environ. Res. Lett. 4(024001).

$$GWP_{CH_4} \equiv \frac{CRF_{CH_4}}{CRF_{CO_2}} = \frac{\int_0^{t_a} RF_{CH_4}(t) dt}{\int_0^{t_a} RF_{CO_2}(t) dt} = \frac{\int_0^{t_a} a_{CH_4} \cdot [CH_4(t)] dt}{\int_0^{t_a} a_{CO_2} \cdot [CO_2(t)] dt}$$

Where  $a_{CH_4}$  is the radiative efficiency of CH<sub>4</sub>;  $[CH_4(t)]$  is the time dependent concentration profile of CH<sub>4</sub> in the atmosphere dictated by its atmospheric persistence;  $RF_{CH_4}(t)$  is the radiative forcing at time  $t$  caused by the additional methane in the atmosphere;  $t_a$  is the analytical timeframe, and likewise for CO<sub>2</sub>.

The analytical timeframe is a critical decision when comparing gasses with very different residence time in the atmosphere. Since CH<sub>4</sub> remains in the atmosphere a much shorter time than CO<sub>2</sub>, the relative impact is larger over shorter timeframes. Thus over a 20 year analytical horizon,  $GWP_{CH_4}^{20} = 72$ , while over 100 years,  $GWP_{CH_4}^{100} = 25$  (IPCC 2007).

The appropriate timeframe for a particular analysis depends upon the circumstances and the policy goals, and reflects a policy judgment about time preference that is analogous to a decision of a discount rate. Discounting continuously reduces the weight of future consequences while the GWP, by contrast, treats all future warming within the timeframe with equal weight, and then truncates warming beyond the analytical timeframe. The GWP is a quasi-physical metric in that it avoids the direct consideration of economic discount rates, relying only on physical science for the calculation. However, the decision about the timeframe remains a policy choice, and thus the metric implicitly includes the same basic judgment about time preference as a more explicitly economic analysis.

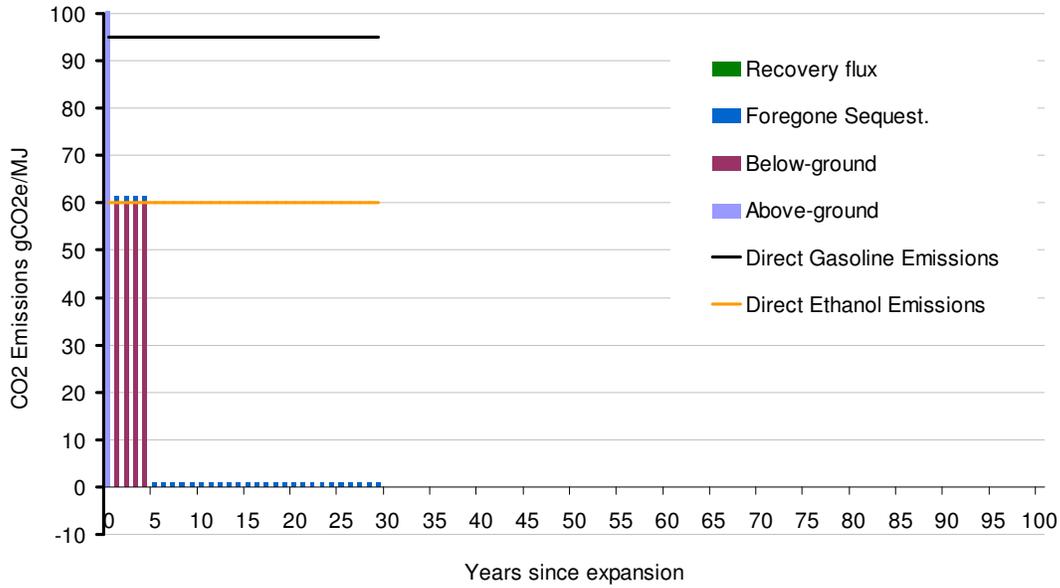
## Method 2: Physical Fuel Warming Potential (FWP<sub>p</sub>)

The Physical Fuel Warming Potential ( $FWP_p$ ) is the ratio of the CRF associated with a biofuels scenario ( $CRF_b$ ) and a gasoline reference scenario ( $CRF_g$ ).

$$FWP_p \equiv \frac{CRF_b}{CRF_g}$$

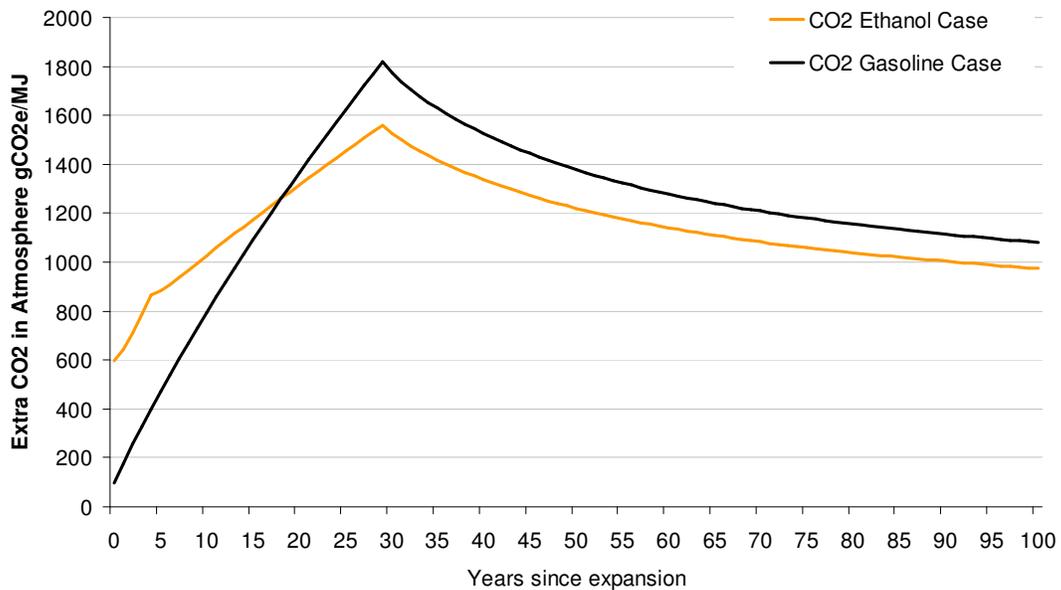
This is closely analogous to the GWP except that rather than comparing two gasses emitted at the same time, we consider two fuel production scenarios, a biofuel case and a gasoline reference case, that produce the same quantity of fuel over the same time period.

Illustrated graphically using the Hertel 2010 data (777 g CO<sub>2</sub>e/MJ fuel production, + 0.8 g/MJ per year foregone sequestration over a 30 year production period with direct ethanol emissions of 60 g/MJ and direct gasoline emissions of 95 g/MJ) the stream of emissions is as shown in Figure 4 below

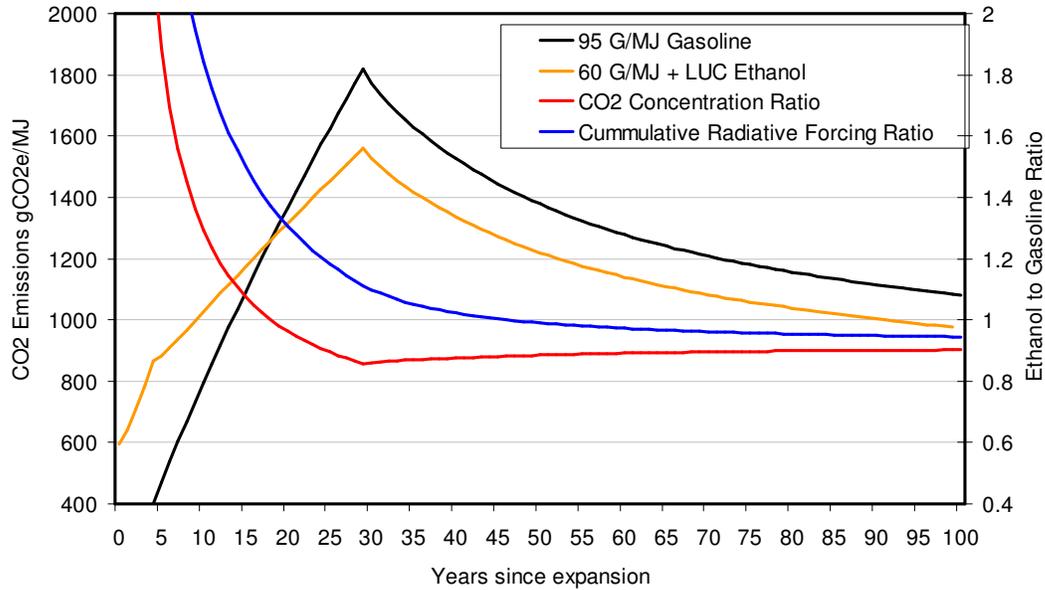


**Figure 4: CO<sub>2</sub> equivalent flows from Hertel 2010 with direct emissions of 60 g/MJ for ethanol and 95g/MJ for gasoline. For illustrative purposes only.**

The emissions stream is converted using the Bern model (IPCC 2007) into additional CO<sub>2</sub> in the atmosphere, shown in Figure 5 below:



**Figure 5: Extra CO<sub>2</sub> in atmosphere for flows from Figure 4. For illustrative purposes only.** The ratio of the CO<sub>2</sub> in the atmosphere is shown in Figure 6 below with the red line and the ratio of the CRF is shown in the blue line.



**Figure 6: Physical carbon intensity metrics for flows from Figure 4. For illustrative purposes only.**

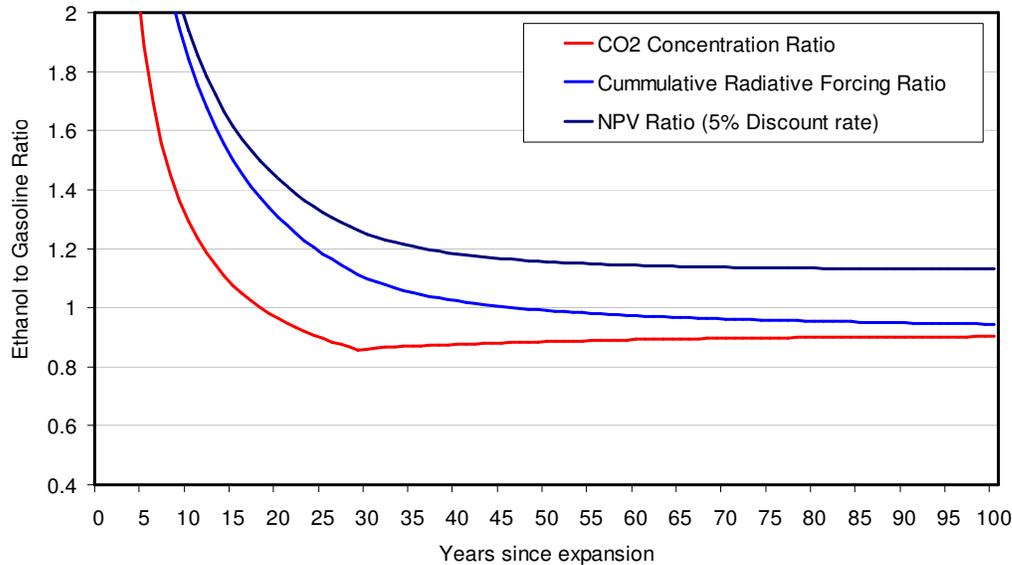
After year 30 in the scenarios above, no further carbon is being released into the atmosphere in either the ethanol or gasoline scenarios. The CRF is always higher for the ethanol case because the emissions are earlier, and so they act to warm the planet for a larger portion of the analytical timeframe. The effect of the later emissions is truncated, and thus they have less weight in the final value. This introduces an element of time preference, and the magnitude of the time preference depends upon the analytical timeframe. Thus at 30 years the CRF is 28% higher than the CO<sub>2</sub> concentration ratio, while after 100 years the CRF is just 4% higher and after 500 years the difference is less than 1%.

**Method 3: Economic Fuel Warming Potential (FWP<sub>e</sub>)**

In addition to the indirect measure of time preference embedded in the FWP<sub>p</sub>, it is also possible to add a direct measure of time preference by adding an explicit discount rate to the calculation. In the simple treatment presented in O’Hare et al., the radiative forcing is discounted (based on the assumption that the damage per unit of extra heat was constant over time). In this case the performance metric is the ratio of the net present value of the biofuel scenario to the gasoline scenario.

$$FWP_e \equiv \frac{NPV_b}{NPV_g}$$

The results for the example dataset below are shown with a 5% discount rate.



**Figure 7: Physical and economic carbon intensity metrics for flows from Figure 4. For illustrative purposes only.**

### Perspective 1 (FWP)

The use of a discount rate is an alternative to the use of truncation as a way to add a measure of time preference into the carbon intensity metric. For comparison, the  $FWP_p$  with a 30 analytical timeframe has the same result as a  $FWP_e$  with a discount rate of just over 4% and an arbitrarily long analytical timeframe (100 years or more). The use of a discount rate is a more visible means of including a measure of time preference that one implemented by truncation within the  $FWP_p$  timeframe.

The  $FWP_e$  as implemented above makes a highly simplified assumption that the damage associated with an extra unit of warming is constant over the timeframe of the analysis. This makes the analysis more tractable, but is a major step short of taking the analysis of emissions to an estimate of economic damages, discounting these appropriately and etc. This more explicitly monetized approach is the subject of discussion under the heading of Social Cost of Carbon discussed later in this white-paper and in the associated references.

In my judgment, there is an advantage to the intermediate point represented by the  $FWP_e$  since it represents the rate of time preference in a visible manner that is more straightforward than the truncation in the  $FWP_p$ . However the  $FWP_e$  does not introduce all of the uncertainty and controversy associated with the economic damage functions that are required to do the full social cost of carbon analysis.

### Perspective 2 (FWP):

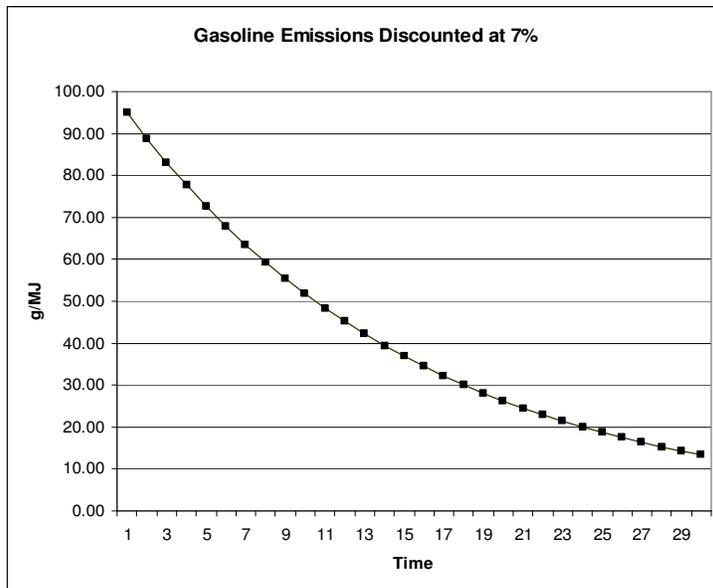
Given the uncertainty associated with unknown damage functions for future climate change and the climate change effects of biofuel policy, and the inherent uncertainty

in the ILUC numbers currently being modeled (as documented by other EWG sub-groups), moving toward more detailed and complicated systems to address issues of time preference and time-accounting appears unwarranted at this time.

### **Perspective 3 (FWP)**

Discounting introduces particular anomalies when applied to concepts such as the economic Fuel Warming Potential, where the emissions streams from land use change combined with the direct pathway emissions (refinery emissions etc.) are plotted and discounted for both fuel types (biofuels and gasoline). To illustrate, if we assume a 7% discount rate, then current gasoline emissions of 95 gCO<sub>2</sub>/MJ are discounted to one seventh or 13.35 gCO<sub>2</sub>/MJ at the end of 30 years (see figure below). Biofuels do not get this large discounting benefit because most emissions occur upfront. Furthermore, we are neglecting the following:

- a) High gasoline emissions are incurred in the future with certainty. In fact, the 95 gCO<sub>2</sub>/MJ only constitute a floor with higher gasoline emissions likely from Canadian tar sand contributions. Discounting decreases the weight from gasoline's increasing direct carbon intensity.
- b) Low direct biofuels emissions are incurred in the future with a high likelihood for further reduction. In fact, on the direct emissions side we have seen dramatic reductions due to efficiency improvements in corn agriculture and at the biorefinery level indicating that these emissions streams constitute a ceiling. Discounting reduces the weight from future technology improvements in the biofuels sector.
- c) The higher initial indirect biofuels emissions are potentially mitigated in the future. For example, a host of possibilities exist including emissions mitigation from corn stover removal, double cropping, and production of high value animal feeds (which in turn reduce land demand). Discounting reduces the weight of mitigating measures in the future.



**Figure 8: Discounted Gasoline Emissions**

### **Perspective 4 (FWP)**

The FWP methods take the different residence times of CO<sub>2</sub> emissions from fuel discharge patterns into account. However, the FWP method also requires an estimation of the biofuels production period resulting in the same concerns mentioned earlier for current CARB methodology: the selection of a production period and assumed land-use after biofuel production represent arbitrary choices that do not necessarily align with baseline projections and land-use trends over the past decade. We recommend that the arbitrary nature of these choices be mitigated by applying a method that operates independently of a biofuels production period. The only method examined in this work group that achieves this goal is “Baseline Time Accounting.” Baseline Time Accounting operates on the premise that the indirect effects of land used for a biofuels program can be accounted for by considering it as a temporal shift in ongoing land-use change dynamics. This could include acceleration of land expansion in areas where arable land is already increasing, delayed reversion in areas where arable land is decreasing (Kløverpris and Mueller, 2010; Kløverpris and Mueller, submitted), or other changes in baseline dynamics. Based on this concept the ILUC factor is a function of land use change and the change of arable land expansion (or reversion) but not dependent on the production period. The acceleration or delay can be converted into an ILUC factor independently of a production period assumption (see supporting Perspectives below).

### **Perspective 5 (FWP)**

As the FWP methods have been applied so far (see previous description and illustrations), it is implicitly assumed that crop yields remain constant during the biofuels production period, assumed to be 30 years (just as in CARB’s use of the

annualization method). Furthermore, the use of the FWP methods (as previously demonstrated) builds on the following assumptions:

- The average carbon intensity of gasoline will remain constant over the biofuels production period (assumed to be 30 years)
- Efficiency in biofuels production will remain constant over the biofuels production period (assumed to be 30 years)

Both of these assumptions are highly questionable (as well as the 'constant crop yield assumption'). This is not a methodological problem (as the biofuels production period assumption), but a data problem. If CARB should choose to use one of the the FWP methods for time accounting, it is recommended to apply more realistic assumptions for crop yields, gasoline carbon intensity, and efficiency in biofuels production during the assumed biofuels production period.

### **Subject 3: Discounting**

*Discounting* denotes a convention by which the same event occurring at different times is 'counted' in decisionmaking as having different values. The mathematical formulation most generally used, though often to represent very different theories of value change, is that delaying an event by one year makes it worth less by a percentage called the discount rate,  $r$ . Discounting is encountered in its simplest form in financial transactions in which a payment of  $X$  is worth  $(1 - r)X$  if paid a year from now. In other words, individuals are indifferent between receiving  $X$  now and  $(1 - r)X$  in a year's time, and by extension  $(1 - r)^n X$   $n$  years from now. Directly,  $[1/(1 - r)]X$  now is equivalent to  $X$  in a year. The behavioral justification for this kind of discounting is the universal willingness of individuals and firms to deposit or lend  $[1/(1 - r)]X$  for a promise of a payment  $X$  from a bank or borrower in a year's time.  $(1 - r)$  is the price at which dollars a year apart trade against each other. Of course,  $r$  may vary for different kinds of deals. A good overview of the theory and practice of discounting is presented in Boardman, A. et al, *Cost-Benefit Analysis: Concepts and Practice* (3<sup>rd</sup> Ed.) Prentice Hall 2005.

Financial discounting of this kind is generalized in benefit-cost analysis to discounting the value of events to which a price or value can be attached even when they are not actually traded in markets (except in the sense that choosing one policy or program over another is in effect a trade). In this context, the same mathematical structure represents one or more of several time-relevant considerations in addition to market prices of debts.

#### **Inflation**

The value of money usually declines slowly over time, so a dollar is expected to buy less real economic goods in the future, and for transactions denoted in so-called current dollars, future values will be discounted according to an assumed inflation rate. This is the least interesting dimension of discounting, and usually avoided by using so-called "real" dollars, representing constant amounts of economic value over time.

#### **Risk**

Nothing in the future is certain; a debtor may default or become bankrupt, crops can fail, and a project may become infeasible before its projected lifespan. The further into the future a benefit is projected to occur, the more things can go wrong, so it is conventional to discount future costs and benefits to reflect the possibility that they may not happen. This is one reason a government pays less to borrow money than a firm and, usually, a firm than an individual: the risk of default is higher respectively for each of these parties.

#### **Pure time preference**

Independently of the ability of economic actors to actually invest or borrow funds at a financial discount rate, individuals exhibit a “pure time preference” for receiving most goods sooner rather than later and bads later rather than sooner. Benefits received in the future are worth less, other things being equal and whether or not a market exists to trade them across time. Accordingly, a discount rate is used to devalue delayed benefits.

### **Discount rates**

Appropriate discount rates to reflect the foregoing preferences and valuations are the subject of lively discussion, for example in the Stern-Nordhaus-Weitzman<sup>9</sup> dialogue regarding the rate at which societies should invest now in climate stabilization. When analysis extends over especially long periods, especially across generations and especially into the lives of persons not now alive, it may be appropriate to use a discount rate that varies across the analytic period. Cost-benefit analysis over periods of a few decades universally recognizes a discount rate between 2 and 7 percent per year. Within this range, different values of  $r$  can switch our preference between policies and projects.

### **Social cost of phenomena**

In general, conventional discounting applies to the economic value of goods, but not necessarily to events and consequences described in physical terms. A unit of GHG discharged  $n$  years from now may do more or less actual damage than the same unit discharged now. In a section below we discuss the idea of a variable *social cost of carbon* (SCC) reflecting (for example) the possibility that a discharge in the future inflicts the same percentage injury to a larger world economy, experienced by more people, and thus has a higher social cost at that time. A variable SCC might also reflect emission into an atmosphere with a different ambient level of GHG, where forcing is not linear with concentration.

While SCC has been described with the same mathematical form (though usually with a negative effective  $r$ , meaning that future discharges are more damaging than present ones rather than less, it reflects a fundamentally different set of concepts than ordinary discounting, more related to benefit-cost estimation than to time preferences about benefits and costs, or exchanges thereof across time.

### **Perspective 1 (discounting)**

ILUC is different from “direct” GHG discharges from fuel manufacture and use because, as discussed above, it follows a different time profile. CARB’s current practice of summing discharges over (for example) thirty years with no discounting and dividing by an amount of fuel *treats a gram of GHG discharge today as being*

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<sup>9</sup> See, for example, Weitzman, M. “Risk-Adjusted Gamma Discounting” 2009  
<http://www.economics.harvard.edu/faculty/weitzman/files/GammaRiskAdjustedF.pdf>

*equivalent to a gram discharged three decades from now.* This is indefensible, because such an equivalence means society is indifferent between of a gram of carbon discharged now and the same gram discharged in thirty years—but because it will be cheaper to avoid the discharge then owing to technological advance, the later discharge is always preferred. Generalized, this implication means *no GHG reduction should ever be undertaken as it will be equally valuable, and cheaper, if we put it off.* We emphasize the identity between the italicized phrases above; the first implies the second.

There is no intellectually supportable escape from the universally demonstrated judgment of society that consequences occurring at different times must be valued with reference to the time of occurrence. Discounting the economic value of events like atmospheric forcing, or at least, and imperfectly, GHG discharges in GWP units, is the conventional and widely accepted method of recognizing this judgment. IPCC 2007/II/2.10.1 recognizes the liability of GWP accounting to error resulting from not discounting forcing calculated over long periods, but GWP comparisons are at least made (typically) between discharges occurring at the same time.

### **Perspective 2 (discounting)**

Discounting is “icing on a cake” that we have yet to bake. Are the costs of complicating estimates and compounding uncertainty by using a subjective discount rate worth any added benefit at this time? It is better to resolve bigger issues first and perhaps, in the future, there will be greater consensus on damage functions and appropriate discount rates.

### **Perspective 3 (discounting)**

Using carbon emissions as a proxy for damages caused by these emissions, some literature would suggest assigning a time-varying social cost of carbon (SCC) to the emissions streams, and possibly a social discount rate (SDR) to the stream of SCC-valued emissions. . The SDR reflects a society’s relative valuation of today’s well-being versus well-being in the future (Zhuang et al., 2007).<sup>10</sup> In other words, a tenth of a degree of average temperature increase avoided today is preferred to the same temperature increase avoided tomorrow resulting in the assignment of lower relative weights to emissions incurred in the future. In contrast, the SCC, as currently implemented, finds an increasing cost of carbon in the future in undiscounted dollars and therefore higher weights to future emissions as damages get more severe over time (Pearce, 2002). The effective discount rate applied to emissions then will generally be the difference between the SDR and the SCC.

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<sup>10</sup> Zhuang et al., “Theory and Practice in the Choice of Social Discount Rate for Cost Benefit Analysis: A Survey”; Asian Development Bank; May 2007.

Discount rate estimates for the SDR further differ by the time duration and distinguish between the intragenerational and the intergenerational discount rate. Estimates for the intragenerational SDR are cited in EPA's Guidelines for Preparing Economic Analyses (page 48):<sup>11</sup>

*"OMB's own guidance on discounting currently recommends discounting using a rate of seven percent, an estimate of the average real pre-tax rate of return generated by private sector investments."*

With respect to intergenerational SDR, the same EPA report recommends a "no-discounting" scenario, as well as scenarios with 2-3% and 7% discount rates (page 52).

Estimates for the SCR are summarized in Pearce et al., who states (page 12):<sup>12</sup>

*"The Nordhaus –Boyer, Tol (1999), Roughgarden and Schneider, and Tol and Downing studies all produce near-term estimates in the bracket \$4-9 per ton of C for a discount rate of 3 per cent, and \$7 to +\$15 for a discount rate of 5 per cent."*

The wide range of documented discount rates and the offsetting effects of different rate types (SDR vs. SCC) introduce another significant layer of arbitrariness to time accounting. In May, 2010, the World Resources Institute held an expert workshop to discuss the applicability of discounting concepts to biofuels time accounting. It is this author's distinct impression that most experts attending the workshop were very critical of this concept.

In summary, choosing a biofuels production period is fairly arbitrary: several scenarios are equally plausible. There is significant policy precedence to look at longer analytical horizons such as 40 to 50 years. Within a 40 to 50 year analytical horizon there is reason to assume that the biofuels production period is at least 30 years or even longer (if the historic US biofuels program is a measure). With longer analytical horizons land use after biofuels production needs to be taken into account whether it is used for biofuels production, other corn products, or reverting to native state. A possible approach is to prorate emissions between the biofuels production and subsequent crops and products. The current CARB biofuels production period of 30 years is too short and CARB's argument for not considering subsequent land use is inconsistent.

Another way around these arbitrary analytical/biofuels periods is the baseline time accounting concept. Therefore, we recommend that CARB either (a) switch to the baseline time accounting concept, or (b) improve the current time account method by

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<sup>11</sup> US EPA, "Guidelines for Preparing Economic Analyses", September 2000.

<sup>12</sup> Pearce, David; "The Social Cost of Carbon and Its Policy Implications"; University College of London, 2002.

applying consistent system boundaries to all aspects of the LCA, considering longer biofuels production periods and incorporating emission effects of land use changes over the entire period, including land use after bioenergy production ends.

Regardless, we recommend that discounting not be incorporated into the selected accounting method. Discounting applied to biofuels introduces another layer of arbitrariness to time accounting.

#### **Perspective 4 (discounting)**

Discounting (artificially) reduces the weight of future benefits and future problems. With a high enough discount rate, any cost of transition from current practice to a practice with future benefits will not be worthwhile because future benefits disappear when discounted. Furthermore, discounting takes the perspective of the present and asks the question: How can we, today, optimize our actions to achieve the highest benefit for ourselves? Discounting thereby gives less weight to the wellbeing of future generations. It is worthwhile to ask the question whether this is in line with the Brundtland definition of sustainable development, which states that sustainable development is *'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'* (UN 1987). This has also given rise to the discussion of intergenerational equity.

A more prudent approach to apply when considering time preference would be to ask the following hypothetical question: If we step 100 years into the future and look back, which decision would then appear to be the right one? Such an approach would acknowledge the wellbeing of future generations and thereby be more consistent with the Brundtland definition of sustainable development.

In fact, this approach would also be more consistent with the GWP100 (see previous description). It is worth noting that the GWP values published by the IPCC and applied for direct emissions in basically all LCAs do not rely on discounting. Had discounting been applied in the GWP methodology, a greenhouse gas like methane, for instance, would have had a much higher GWP because methane causes most of its warming during the early stage of its atmospheric residence time before it is oxidized to CO<sub>2</sub> (see previous discussion).

Based on the considerations above, it is recommended not to apply discounting in CARB's ILUC analysis.

#### **Perspective 5 (discounting)**

The central fact is that CARB must make a policy judgment about time preference. The narrow technical question of what mathematical form the expression of this judgment takes is much less important. The simplified time shift accounting described in a subsequent section below illustrates that a averaging over a fixed

timeframe (i.e. dividing ILUC by 30 years) or discounting a simplified one year time shift of ILUC emissions (i.e. multiplying by a discount rate) are mathematically equivalent; these are two different ways of explaining the same decision about time preference. The language of discount rates is familiar to economists while a simple timeframe is clearer to a general audience. If the land modeling of land use change produced a detailed time sequence of emissions over a long timeframe, then discounting would produce a more continuous weighting than truncating after a fixed timeframe. But however it is implemented, a policy decision about time preference must be made.

It is clear that there is not one technically correct discount rate or timeframe, so CARB will need to make a decision based on the particular policy context. Therefore, the question becomes, what is the context, and are there particular justifications for adopting an especially long or short timeframe.

One of my colleagues has invoked the Brundtland definition of sustainable development. This context of intergenerational equity is often used to justify much lower long-term discount rates than are typically used in cost benefit analysis, and in his argument he is trying to justify the use of a 100 year timeframe for lifecycle analysis in the time shift approach. This argument is compelling in the context of a cost benefit analysis that balances money against the preservation of an irreplaceable natural system, in particular the climate of the whole planet, which may not be replaceable with money.

However, in the context of the LCFS ILUC metric, we are not weighing money against the environment or deciding how to value reduced GHG emissions. Instead, we are balancing the preservation of carbon stored in forests and other natural ecosystems against more rapid development of biofuels made from corn, soybeans, sugarcane and other crops. These crops, the technology used to convert them to fuel, and the vehicles and infrastructure needed to use this fuel are mature technologies. So marginally higher incentives for these fuels will not serve a technology-forcing role within the transportation sector. On the other hand, the expansion of agriculture will damage fragile ecosystems that will never be replaced.

In this context, there is no compelling reason to adopt an especially low discount rate (or long timeframe). While there are disagreements about mechanisms, there is broad agreement that biofuels development should seek to minimize emissions from land use change. To support this goal, the discount rate (or timeframe) should provide an effective market signal that supports efficient use of land, especially land that is currently producing food or storing large quantities of biological carbon. A discount rate of 5-7% (or timeframe of 15-20 years) would provide an appropriate market signal while still providing efficient crop based biofuels the opportunity to contribute to LCFS compliance. A discount rate in this range would also be consistent with other types of cost benefit analysis.

#### **Method 4: Baseline Time Accounting**

The baseline time accounting concept considers the interplay between indirect land use change caused by a given subject of study (in this case biofuels consumption in California) and ongoing changes in global land use driven by other factors (baseline changes). By taking the dynamics of international land use into account, each year of biofuels production can be viewed separately and the production period assumption (on which annualization and the FWP method rely) can thereby be avoided.

The baseline time accounting concept takes its methodological point of departure in a paper published by Kløverpris et al. (2010). In this paper (Fig. 3), it is shown how changes in land use quality caused by ILUC can be assessed independently of the duration of the activity causing the ILUC. The question of how to relate changes in land quality to a given activity – and potentially how to allocate changes in land quality to different consecutive activities – have been the subject of debate in the LCA community for more than a decade, see e.g. Lindeijer (2000) and Milà i Canals et al. (2007). This question is very similar to the question of how to perform time accounting for indirect land use emissions from biofuels production.

The first early considerations on the baseline time accounting concept were presented at a DOE-sponsored workshop in Tennessee in May 2009 (ORNL 2009) and a more mature version (Kløverpris and Mueller 2010) was presented at an IEA workshop in March 2010<sup>13</sup>. Based on discussions in the time accounting subgroup, the concept has been further refined and a paper giving a full description of the methodology (Kløverpris and Mueller in prep.) has been submitted for peer-review. To make sure publication rules are not violated, this white paper only contains a short synopsis of the overall principles of the baseline time accounting concept. For further information, please see the presentations given by the time accounting subgroup at the 4<sup>th</sup> and 7<sup>th</sup> meeting in the expert workgroup (15 July and 14 October, respectively).

#### **Synopsis**

The agricultural area in the developing world is increasing while it is decreasing in the developed world. Under these conditions, indirect land use change from biofuels may cause land in the developing world to come into production sooner than it otherwise would while it may cause land to stay in production longer than it otherwise would in the developed world. This means that indirect land use change from biofuels can cause temporal changes in land use emissions. In the developing world, greenhouse gas emissions from land conversion could occur sooner than in the baseline and thereby cause more warming. In the developed world, land kept in production will

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<sup>13</sup> Information about the conference is available at <http://ieabioenergy-task38.org/workshops/brussels2010/>

likely have a distinct emission profile compared to other uses (the most accurate comparison would consider what uses are most prevalent as current cropland areas are released, and then compare the corresponding emission profiles). For the purpose of this illustration, we assume that the land reverts back to an unmanaged state and that the emission flux of managed cropland is greater than that of unmanaged land. In that case, delayed reversion would cause more greenhouse gases to be present in the atmosphere and thereby cause more warming. By use of the global warming potential methodology, it is possible to estimate the amount of CO<sub>2</sub>, which would cause the same warming effect as these temporal shifts in emissions within the next 100 years. It is thereby possible to calculate an ILUC factor, which is not only independent of production period assumptions but also consistent with the methodology used for direct emissions, i.e. the global warming potential with an accounting period of 100 years (GWP100).

Preliminary results for the baseline time accounting concept are available in the time accounting subgroup presentation from the 7<sup>th</sup> EWG meeting (14 October 2010) where the concept was applied using the estimated ILUC results from Hertel et al. (2010).

### **Perspective 1 (baseline time accounting)**

The baseline time accounting proposal presented by Kløverpris and Mueller has some intriguing insights but also some serious deficiencies that disqualify it from serious consideration for regulatory purposes at the present time.

First, the method has not been presented in detail and has not been reviewed by all members of this sub-team or an external peer review process.

Second, the scoring of accelerated deforestation is seriously flawed. The baseline accounting methodology converts a prediction problem into a time shift problem. The question of how to compare deforestation today from deforestation next year is essentially the definition of time preference, and yet the authors have proposed no explicit consideration of time preference. Instead they use the GWP100 as a measure of time preference, which obscures the implicit use of a very low value for time preference, equivalent to a discount rate of less than 1%.

The Kløverpris and Mueller proposal uses the use of mathematics of the GWP100 in an inappropriate manner. GWP is defined as the ratio of CRF for two a reference case and a baseline over identical timeframes. In the Kløverpris and Mueller proposal, the quantity in the numerator is not an actual emission that contributes to CRF for the 100 year timeframe, but a difference between emissions made in year one, and emissions avoided in year two. Since these profiles are subtracted, it is the CRF associated with 1 year of emissions. The denominator -- which in the spirit of the GWP should be a reference case using the same metric and timeframe as the numerator -- instead is a cumulative radiative forcing of a unit of CO<sub>2</sub> over 100 years.

No justification is given for dividing one year of warming by 100 years in the denominator except for consistency with GWP. However, the GWP compares 100 years of warming in both the modeled case and the reference. For all practical purposes, this misapplication of GWP serves merely to obscure in technical complexity the choice of an extremely low rate of time preference. It would be highly improper for CARB to disguise such an important decision in this way.

This rate of time preference is an important policy choice, and should be made in plain sight. The treatment of accelerated expansion in Kløverpris and Mueller is equivalent to a timeframe of more than 100 years. I do not think there would be broad support for biofuels that induce emissions from deforestation more than 100 times as large as their annual reduction in emissions, so CARB would be ill advised to adopt a metric that would support such an outcome.

There is no reason the methodology proposed by Kløverpris and Mueller could not be revised to include a more reasonable measure of time preference, such as by applying a discount rate of 5% on radiative forcing as done in the FWP<sub>e</sub>. Changed in this manner, the methodology may provide useful insight.

The Kløverpris and Mueller methodology rests on a flawed assumption that agricultural expansion will follow the same path regardless of when it occurs. If, for example, effective measures limiting deforestation are gradually put in place over time, then delayed agricultural expansion will result in lower deforestation than immediate agricultural expansion. So accelerated agricultural expansion could lead to larger carbon emissions than later expansion, even before a measure of time preference is considered. The method should be amended to include this dynamic.

The treatment of delayed reversion also requires more work to account for the complex rates of carbon uptake by different land types as they leave agriculture for subsequent uses.

## **Perspective 2 (baseline time accounting)**

The baseline time accounting approach is elegant in its simplicity and transparency. It would facilitate future adjustments to accommodate new data, or more accurately reflect analysis of local land-use change dynamics and improved understanding of the land-use effects of biofuel policies. All generic ILUC models are resting on highly uncertain aggregated data and flawed assumptions about agricultural expansion and the drivers that determine forest loss or recovery – and they all equally merit further review by applying multi-disciplinary assessments and analyzing empirical evidence of the effects of policy.

### **Perspective 3 (baseline time accounting)**

The baseline time accounting concept represents an attempt to model as closely as possible the actual consequences of indirect land use change with respect to the boundary conditions in which ILUC occurs (the dynamics of the global agricultural area) and to represent the results in a manner, which is as consistent with direct emissions as possible to allow for the consistent summation of direct and indirect emissions. The baseline time accounting concept simply ask the question: Which CO<sub>2</sub> emission would cause the same amount of warming over a 100 year period as the temporal shift in land use emissions potentially caused by biofuels.

Under Perspective 1, one of our colleagues finds that we are using the GWP methodology 'in an inappropriate matter'. We would therefore like to re-iterate that we are comparing a change in cumulative radiative forcing (CRF) over a GWP accounting period of 100 years (same accounting period applied for all direct emissions) to the CRF of one unit of CO<sub>2</sub> over the same period of time. We would also like to emphasize that we *are* looking at the same accounting period for both the modeled case and the reference case (in contrast to what our colleague claims). It is however correct (as our colleague states) that the change in CRF derives from a temporal shift in land use emissions (which could potentially be *more* than one year depending on the land use baseline). This is the whole point. We cannot think of a better and more consistent way of applying the GWP concept to indirect emissions (and have not been presented with such). We therefore do not think that our approach is a 'misapplication' of the GWP concept. A similar application has been used for changes in albedo (Muñoz et al. 2010).

Our colleague also states that our approach is equivalent to a time frame of more than 100 years. It is not clear what the basis for this statement is but we would like to emphasize that we use a GWP accounting period of exactly 100 years (as applied for direct GHG emissions).

Furthermore, our colleague states that our methodology relies 'on a flawed assumption that agricultural expansion will follow the same path regardless of when it occurs'. We acknowledge that our colleague (despite his harsh choice of words) has a point here. We have not been able to counter in such dynamics. However, our approach is still consistent with the 'supply/demand logic' embedded in the economic models, which produce the land use change results that are modified in time accounting. It is however true that land use change is governed by many factors, not just economic factors. This is also discussed under the subject of 'land use transition theory'. We believe that our methodology could potentially be cross-fertilized with the land use transition theory in the future. For now, however, it solves some serious methodological problems inherent to the existing time accounting methods but it does not solve all problems at once. We still consider it a step forward.

Finally, we agree with our colleague that more scientific work is required to better understand long-term carbon sequestration on abandoned agricultural land. This is

however work to be carried out by soil scientists and other experts in this field. We also agree that our methodology could theoretically incorporate a discount rate but we did not do that because it would be inconsistent with the GWP methodology.

#### **Subject 4: ILUC and GWP time horizons**

Following the 7<sup>th</sup> EWG meeting, the time accounting subgroup was asked to include a *'Discussion of whether chosen time horizon for LUC emissions must be consistent with GWP time horizon used for direct emissions'*.

#### **Perspective 1 (ILUC and GWP time horizons)**

Indirect emissions are added to direct emissions in the LCFS lookup tables. This addition requires that the values be computed in a consistent manner. It is therefore important to ensure that indirect emissions are evaluated on the same basis as direct emissions. You cannot add apples and pears. In the LCFS, direct emissions are measured by their GWP100, i.e. the amount of CO<sub>2</sub> that would cause the same cumulative radiative forcing over a 100 year accounting period as a given GHG emissions (Ramaswamy et al. 2001). The long-term perspective in the GWP100 is the common measure for global warming in basically all LCA methodologies (see e.g. Wenzel et al. 1997) and also the measure recommended by the UNFCCC for national GHG inventories.

In principle, CARB could choose another GWP accounting period for direct emissions and a consistent accounting period for indirect emissions. However, this would be in contradiction with common LCA practice. Furthermore, CARB would run the risk of overlooking long-term benefits that do not appear within a short-term accounting period. The recommendation is to use a consistent approach for the values of emissions from land-use change that are being summed. This issue is distinct from other issues related to the use of variable time frames for economic modeling.

#### **Perspective 2 (ILUC and GWP time horizons)**

The timeframe used for ILUC accounting is not directly related to the GWP100 timeframe, and there is no particular reason that these should both be the same.

The use of the 100 year timeframe for GWP is applied very narrowly to one question about simultaneous emissions of different GHGs. The question of time accounting for ILUC emissions is a distinct question that requires separate consideration. For the sake of consistency, all comparisons of different GHGs should use the same set of GWP equivalences, presumably the GWP100 equivalencies, but this does not require that other elements of the analysis adopt a 100 year timeframe.

In fact, there are many elements of the ILUC analysis that have different timescales associated with them, including the economic models. The economic models are certainly not calibrated to predict changes on a 100 year timescale. Nor is the policy itself conceived of on a 100 year basis. The choice of an Armington model of trade within GTAP is another decision that is based on changes over a timeframe shorter than 100 years. While it might seem tidier if all models and analysis used in the

regulation had precisely the same timeframe, this is not practical given the available analysis and data.

The benefit of using the GWP100 as a convention is to simplify a technical matter (the weight of different GHGs) that is not of central importance to many policy discussions. The comparison of deforestation and the annual lifecycle emissions of biofuels is the central question of land use accounting, and the use of a 100 year timeframe simply on the basis of convention is unjustifiable. While it would be technically feasible to adopt a GWP30 (changing the weights of different GHGs) to match the timeframe considered most appropriate for ILUC accounting, this would introduce confusion and problems with other data sources calculated on the basis of a 100 year GWP. The use of different timeframes for GWP and other parts of the analysis is at the most a minor matter, and should not overrule or mask important policy judgments about the time preference.

## Method 5: Simplified Time Accounting

Because the time profiles of biofuel and fossil fuel GHG releases are different, a central problem in ILUC accounting within a regulatory structure like the LCFS is to combine the estimates of early, intense ILUC discharge associated with increasing *capacity* to produce biofuel with the continuing “direct” discharge that is proportional to fuel volume. This combination is analogous to combining a capital investment in a factory that might produce few or many widgets with the variable cost (parts, labor, etc.) of widgets to come up with a total per-widget cost.

This section presents an alternative method of combining ILUC with proportional discharges that avoids assumptions about production period (total fuel produced) and does not require analysis of atmospheric residence, forcing, and the other physical modeling used in the Fuel Warming Potential method described above. To illustrate with a simple example, consider a unit of fuel produced during a single year, with ILUC “capital” discharge of  $G_c$  in  $\text{gCO}_2\text{eMJ}^{-1}\text{y}^{-1}$ , that is, grams of  $\text{CO}_2$ -equivalent ILUC associated with increasing production capacity by one MJ per year, and a variable discharge of  $G_v$ , in  $\text{gMJ}^{-1}$ . Note, importantly, that these values are all actually releases during a single year<sup>14</sup>, for a single year’s worth of biofuel production, and can be compared reasonably to grams of discharge in the same categories from a fossil fuel. All the  $G$  values represent gases for which IPCC  $\text{CO}_2$  equivalence values can be used, again because all the discharges occur in the same year not only for the biofuel whose total  $G$  is being calculated but also for the other fuels to which it is being compared. Incorporation of atmospheric decay, warming effect, and the like is done the same way for all of them for all fuels, and for fuel comparison purposes, so these values can be considered proportional to social cost at least to a first, practical, approximation.

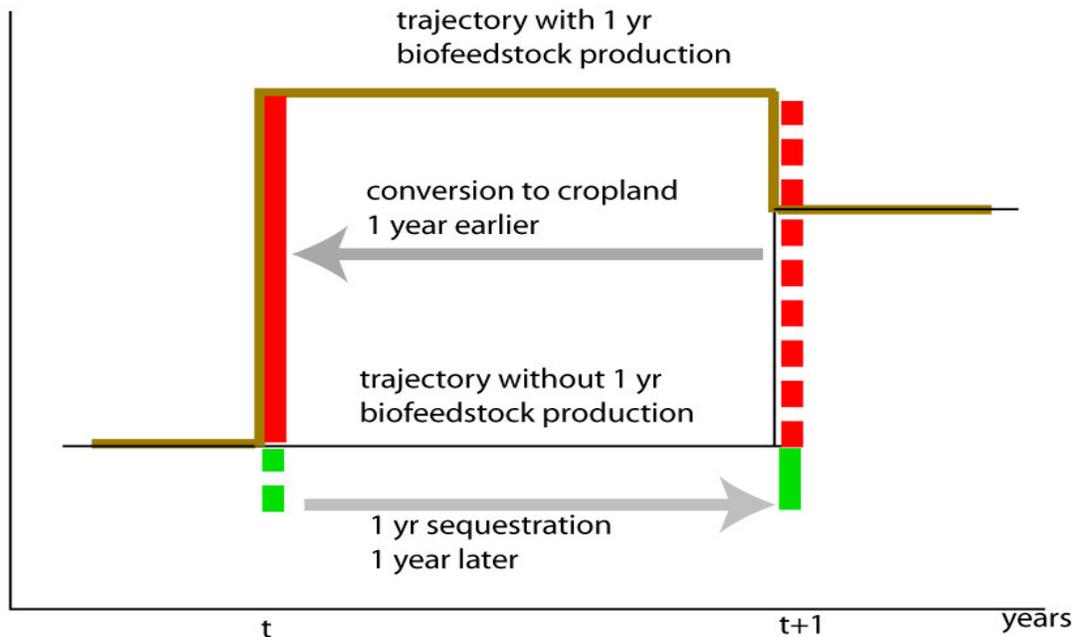
The key to this simplified calculation is the insight of Kløverpris and Mueller (see above, Baseline Time Accounting) that if annual land conversion to crops for reasons unrelated to a given biofuel is greater than the land required for the biofuel in question, the effect of any year’s production is to accelerate conversion owing to the biofuel by a year, and delay the start of reversion (where land is reverting to natural conditions or other uses for exogenous reasons) by a year.

Figure 9 illustrates the effect schematically.

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<sup>14</sup> Actually releases from, for example, forest conversion are not instantaneous, but if the delayed release from decay as compared to burning is important, it can be captured in the carbon stock releases for different kinds of land incorporated in the model that estimates ILUC. As tropical forest comprises a very large fraction of land conversion to cultivation {Gibbs, 2010 #2663}, and this conversion involves rapid decay and burning, the correction is probably small.

GHG release



**Figure 9:** the trajectory of GHG release with and without a year of biofeedstock production, omitting direct (variable) discharge. The heavy red bar represents GHG release from land clearing accelerated by one year, and the green bar represents a year of resequstration delayed a year where it would have occurred without the biofuel. The figure is not to scale: Hertel et al estimate a year’s resequstration worldwide from US corn ethanol as only about 0.01% of the discharge from clearing.

What is the social cost of these displaced discharges? For discharges occurring approximately simultaneously, cost can be considered proportional to gCO<sub>2</sub>e. Ignoring the tiny delayed resequstration (only about .01% of land clearing discharge for US corn ethanol, according to Hertel et al), with a discount rate of  $r$ , the present value, or “variable equivalent ILUC discharge”  $G_c^v$  that can be added to the direct discharge of the unit of fuel is simply

$$G_c^v = G_c - (1 - r)G_c$$

$$= rG_c$$

Using our example numbers, and a discount rate of 5%, corn ethanol would have a GWI of  $(.05 \times 776) + 60 = 98g$ ; at 3%, 83g.

Notice that this analysis applies to any year of production as long as exogenous land clearing exceeds the requirements of the biofuel program, so it combines capacity-building discharge with variable discharge in an intellectually defensible and realistic way without the necessity to predict a production period or to model atmospheric persistence or forcing beyond what is captured in GWP equivalence for non-CO<sub>2</sub> gases. Notice also that like any defensible combination of a “capital” with a “variable”

cost, it requires a choice of discount rate. If the GWI of, say, gasoline is 96g, and corn ethanol is judged about equivalent at a discount rate of 5%, it is entirely reasonable to also think that if we were to value events in the future more nearly equally with events now—a lower discount rate—we would judge ethanol to be “greener”.

### **Perspective 1 (simplified time accounting)**

This approach offers several advantages similar to the baseline time accounting approach, but adds the complication of subjective choice (and appropriateness) of discount rates for emissions over time. Given that other uncertainties have a larger effect on the ILUC estimates, it might be preferable to keep things simple and avoid adding another controversial dimension to the regulatory framework.

### **Perspective 2 (simplified time accounting)**

The simple time shift accounting method described above demonstrates that the overall ILUC emissions values can be converted to an annual figure to add to the annual lifecycle emissions by the straightforward application of a discount rate. This converts the policy decision regarding the timeframe (how many years to divide ILUC by) to an expression of time preference (what discount rate to multiply ILUC by). The two are mathematically interchangeable, but the language of discount rates presents CARB an opportunity to anchor the decision in existing California policies regarding the choice of a discount rate in cost benefit analyses.

## Subject 5: Land Use Transition Theory and Time Accounting Implications

Choice of temporal scale influences all aspects of ILUC analysis. Understanding how biofuel policy interacts with LUC drivers over time is essential to reduce risks of unintended policy consequences. And understanding the dynamics of initial land-use change is critical when implementing any of the proposed improvements in time accounting that interact with baselines.

The hypothesis of a land-use or forest transition was first presented by Mather in 1992 and has since been the subject of significant analysis and research (See multiple citations on transition theory from Mather, Grainger, Lambin and others, and on biomass transition in Kauppi et al.). The land-use transition studies suggest that details of time accounting of indirect effects from the California LCFS may not be significant compared to other factors governing the amount of forest converted in a given nation, which is determined by many other, primarily local, driving forces. The transition theory and related multi-disciplinary analyses of empirical data related to forest conversion and recovery dynamics around the world, suggest that a state-level policy in the U.S. is unlikely to significantly change the downward sloping loss of forest in the transition curve (see black line in Figure 10) for nations in the forest conversion or “land use transition” stage, nor change the ultimate low point of forest cover at the bottom of the curve.

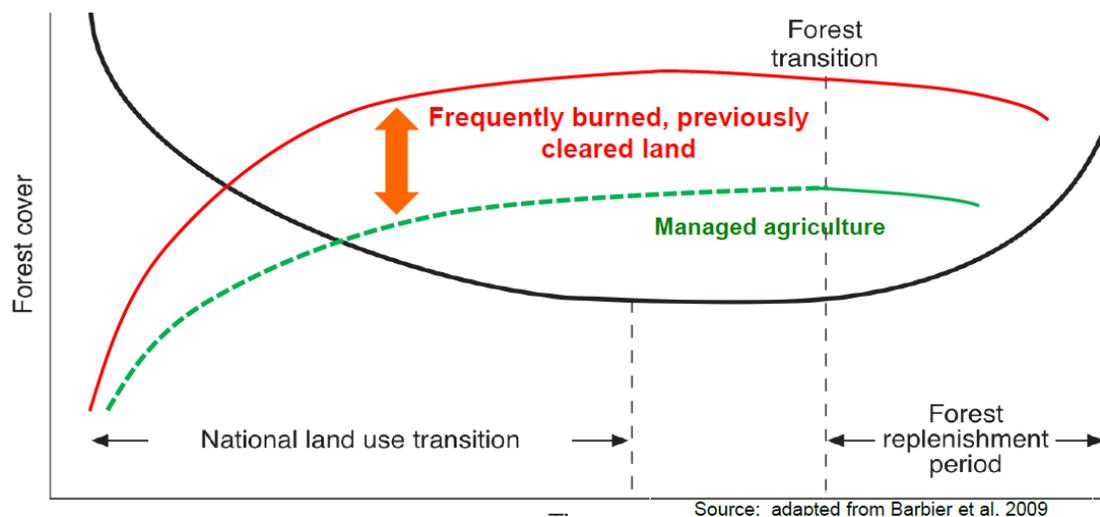
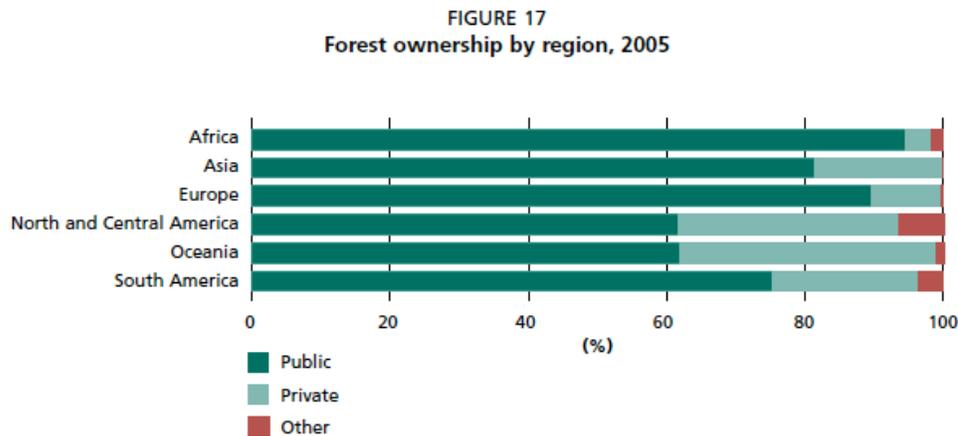


Figure 10: Land Use Transition Theory

As forests are converted, some of the new land comes into managed production (illustrated by the green line) but in many nations, a large portion of cleared land remains underutilized for long periods after clearing begins (illustrated by the red line). Fire is a common, low-cost tool used to maintain claims on previously cleared

but under-utilized lands. Between 330 and 430 million hectares of land burned each year around the globe, from 1997 to 2008 (Giglio et al. 2010) – with significant GHG emissions. Much of this land was in the tropical areas of Africa and Latin America, in and along the “agricultural frontier.” Bringing land into managed production offers incentives to reduce burning and run-away fires along the forest frontiers.

There are many reasons why biofuel policy as proposed in California is unlikely to have significant effects on first time conversion in other nations. First time forest conversion is a process that is set in motion by a dynamic interaction among local conditions and policies including those related to land tenure, development and infrastructure. Also, the first-time conversion process often begins in isolated frontiers, on public lands far removed from market influences. The vast majority of the world’s remaining forests subject to conversion are on public lands Figure 11.



**Figure 11: FAO 2010 Figure 17**

Where the baseline shows that remaining forests (and potential deforestation) are predominantly in the public domain, analytical tools need to be amplified to capture non-market policy effects that are omitted from economic trade model assumptions (all land is privately held, managed to maximize profit by owners, and all LUC is price-driven).

Biofuel policies could affect land-use change dynamics if local plans, policies, or enforcement change explicitly in response to US (or CARB) biofuel policies and, in so doing, directly affect local drivers of first-time conversion or forest replenishment. In Brazil, potential examples of this sort of indirect effect might be the government’s redoubled efforts to control deforestation – which could be partially attributed to international attention accentuated around biofuels – and similarly, increased compliance by the sugarcane industry with long-standing environmental regulations, leading to increasing protection of riparian areas and increasing forest cover in Sao Paulo State (forest replenishment stage).

Some research suggests that there may be a higher probability of an indirect effect from an external bioenergy policy during forest replenishment stages, when exogenous factors may be more influential than in the initial transition (forest conversion) stage – the latter being more associated with endogenous factors (Lambin and Meyfroidt, 2010).

Another way to simplify this concept follows: The drivers of first time conversion of forests are complex, highly varied, site specific and largely endogenous. What determines whether a parcel of forest will be degraded and eventually cleared is distinct from the factors that later determine what may or may not be planted on the land over subsequent years. The latter land management decisions – which may not begin to play a role until years or decades after initial conversion is set in motion – are more susceptible to influence by global markets and prices. This distinction was highlighted in the international workshop on Land-Use Change and Bioenergy as shown in Figure 12 (CBES 2009).

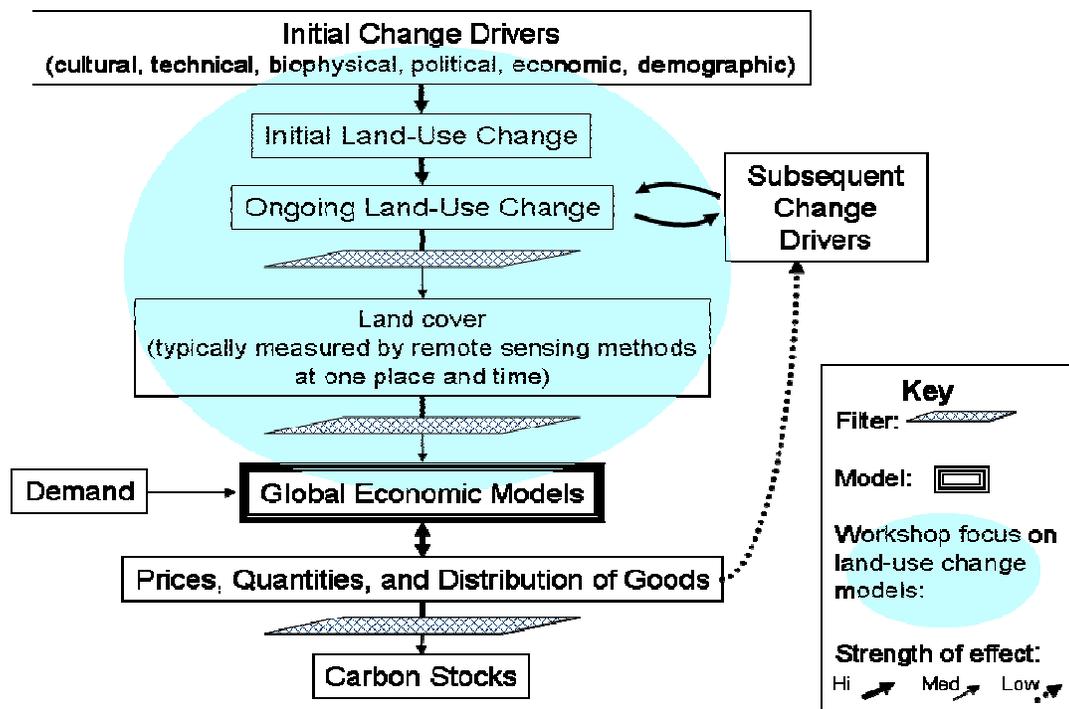


Figure 12: Drivers of Land Use Change

### Perspective 1 (Land Use Transition)

This perspective on drivers of land-use change suggests that the amount of land that is converted around the world in the coming decade is unlikely to change significantly due to California’s LCFS. But how land is managed after it was cleared, e.g. land that

was previously converted and remains underutilized, could more likely be influenced by such external policies. Thus, how policy is structured and communicated can be important. The multi-disciplinary research being conducted around the world by individuals and organizations associated with the Global Land Project could make valuable contributions to improving the representation of dynamic baseline scenarios and for understanding and assessing the effects of biofuel policies on land use around the world.

In summary:

- The interaction of policy with baseline land-use dynamics determines ILUC and related emissions; therefore the board should collect and apply more accurate representations of key baseline dynamics (using analyses of recent historic data and empirical data available from the global land use scientific community)
- Baseline dynamics vary greatly by country. Therefore, it is recommended that any approach used for ILUC emission accounting should be adaptable to transparently accommodate different baseline scenarios.
- A more accurate representation of the interactions of LCFS policy with baseline LUC dynamics will have much greater influence on the ILUC emission accounting over time than other factors considered by the sub-group (e.g. discount rates) and therefore, this issue should receive priority.

Recommendations: consider additional scientific approaches to assess policy impacts and complement economic modeling; conduct iterative analyses to improve baselines for applied use in time accounting and other modeling; consider the implications of LUC research based upon empirical evidence; design policy goals aimed at measurable improvements in land management over time; and don't let "scoring" and time accounting distract from the true policy goals to reduce actual emissions, today and tomorrow. A long-term monitoring plan is recommended to develop more accurate emission profiles for land use and LUC over time.

### **Subject 6: Social Cost of Carbon and Time Accounting Implications**

Elizabeth Marshall from USDA ERS made a presentation of some work she did while at World Resources Institute, and a workshop held at WRI exploring how a Social Cost of Carbon (SCC) framework could be applied to the question of the time value of carbon and carbon storage. The materials she presented are available on the CARB expert work group web site.

One of the most salient conclusions of Dr. Marshall's work was that if one tried to infer the equivalent physical carbon discount rate implied by the SCC work published

by the Federal Government (SCC 2010), the discount rate would be extremely low (1% or less).

### **Perspective 1 (social cost of carbon)**

...See prior comments on the meeting and conclusion of most participants (and several members of this sub-group) that at this point in time, SCC should not be considered.

### **Perspective 2 (social cost of carbon)**

If CARB should choose to apply discounting in its ILUC analysis (despite the discouragement from several members of the time accounting subgroup), CARB would also have to take the social cost of carbon into account in order to ensure a balanced and consistent approach.

### **Perspective 3 (social cost of carbon)**

The central purpose of the social cost of carbon (SCC) methodology is to assign an economic cost to carbon emissions in the broadest possible context. The Low Carbon Fuel Standard, on the other hand, is a transportation sector specific initiative that provides a technology forcing mechanism to ensure that this sector develops low carbon technology in a timely fashion. In the context of the special urgency the LCFS places on technology transformation of the transportation sector, reducing the LCFS metrics to absolute equivalence with the broad context of the SCC is counterproductive. Instead the metrics for implementation of the LCFS should consider the specific context of the LCFS, as discussed previously in Perspective 5 to the discounting section above.

Moreover, the SCC is far from a settled matter. The SCC calculations depend upon models far more complex and controversial than those involved in ILUC, which include profound value judgments about the economic value of everything affected by climate over several hundred years (Ackerman 2010). Thus while it may be mathematically possible to draw inferences about the time value of carbon from the SCC methodology (Marshall 2010), to use these inferences in the administration of the LCFS would add a great deal of uncertainty, controversy and opacity to the regulation. It is my strong recommendation that CARB not adopt a time accounting methodology based on the SCC.

## Consensus Statements

- The production period is an especially uncertain parameter and time accounting methodologies that can ignore it are attractive
- Any time accounting methodology is only as good as the modeling results that go into it.
- Choice of discount rate in a regulation is a policy choice that combines value judgments and inferences with technical factors
- It is possible to consider the impact of a biofuels policy as a temporal shift of the complex dynamics which drive land use change and vary widely at local scales:
  - In regions with an expanding agricultural area (typical for the developing world) , ILUC could cause land to come into production sooner than it otherwise would.
  - In regions with a contracting agricultural area (typical for the developed world) , ILUC could cause land to stay in production longer than it otherwise would.
- The timing of emissions are important and, as a general goal, policy should differentiate based on timing where possible

## **Recommendations**

In the near term, the panel recommends that CARB apply consistent time horizon boundaries for computing GHG emissions associated with LUC under the LCFS. In that vein, CARB should clarify and justify the choice of a 30-year simple averaging approach that is now applied, or adjust it based on contributions from the EWG and other new information.

In the future CARB should compare alternative methodologies for time accounting as research results become available in the peer-reviewed literature. We recommend that CARB evaluate new methodologies based on their ability to improve the accuracy, transparency and flexibility of an approach for emission accounting over time. CARB should also seek to clarify the assumptions about time scales and time preferences that are embedded within the LCFS accounting structure and justify these decisions.

Our panel did not reach consensus on other recommendations for changes to the time accounting methodology used by CARB in the LCFS.

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