California Environmental Protection Agency

Air Resources Board

iLUC Analysis for the Low Carbon Fuel Standard (Update)

March 11, 2014

Agenda

- Background on iLUC analysis in the Low Carbon Fuel Standard (LCFS) regulation
- Expert Working Group (EWG) – Recommendations
- GTAP and Carbon Emissions Integration
- Details of Agro-Ecological Zone-Emissions Factor (AEZ-EF) Model
- Updates to GTAP model
- Draft Results
- Evaluation of Uncertainty
- Next Steps

iLUC Analysis: 2009-2014

- Approved by the Board in 2009/2010
  - 30 g/MJ for corn ethanol
  - 46 g/MJ for sugarcane ethanol
  - 62 g/MJ for soy biodiesel
- Expert Working Group
  - Recommendations provided to Board in 2010
- Current Analysis <u>March 2014</u>
  - Draft updates for iLUC values for corn ethanol, sugarcane ethanol and soy biodiesel
  - Draft iLUC values for canola biodiesel and sorghum ethanol

Expert Working Group (EWG)

EWG Recommendations

- Use TEM model for productivity of new land
- Re-evaluate the soy biodiesel work completed in 2009
- Consistency in co-product treatment between CA-GREET and GTAP
- Improve carbon emission factors (include peat emissions and emissions from forest products)
- Conduct systematic analysis of uncertainties and develop probability distributions
- Calibrate GTAP to real-world data
- Refine CET approach to land transformation

EWG Recommendations (cont.)

- Account for indirect effects from all fuels
- Account for changes in fertilizer and livestock emissions
- Compare alternative methodologies for time accounting
- Update and improve the land pools within GTAP to include “inaccessible” forests; unmanaged shrub land, grassland, and savanna; idle/fallow/abandoned cropland; and other marginal (low productivity) lands

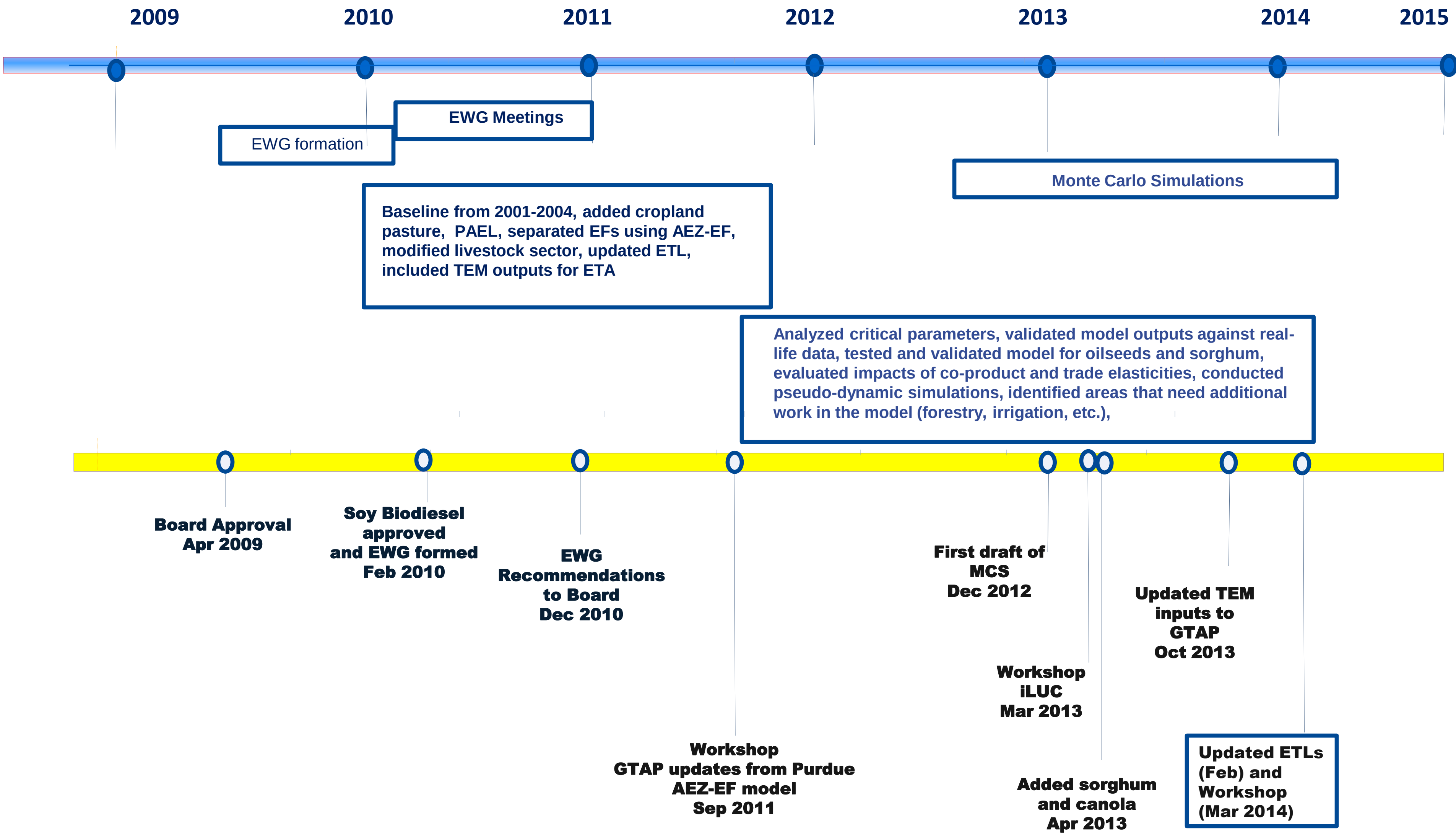
EWG Recommendations (cont.)

- Evaluate alternatives to estimating yields of marginal land
- Evaluate alternative approaches to calculating yields on new agricultural lands based on statistical analysis of climate and management factors using updated datasets
- Modify the Armington approach, update cropland pasture yield, include pasture intensification
- Estimate land conversion by mapping model outputs with land conversion probabilities

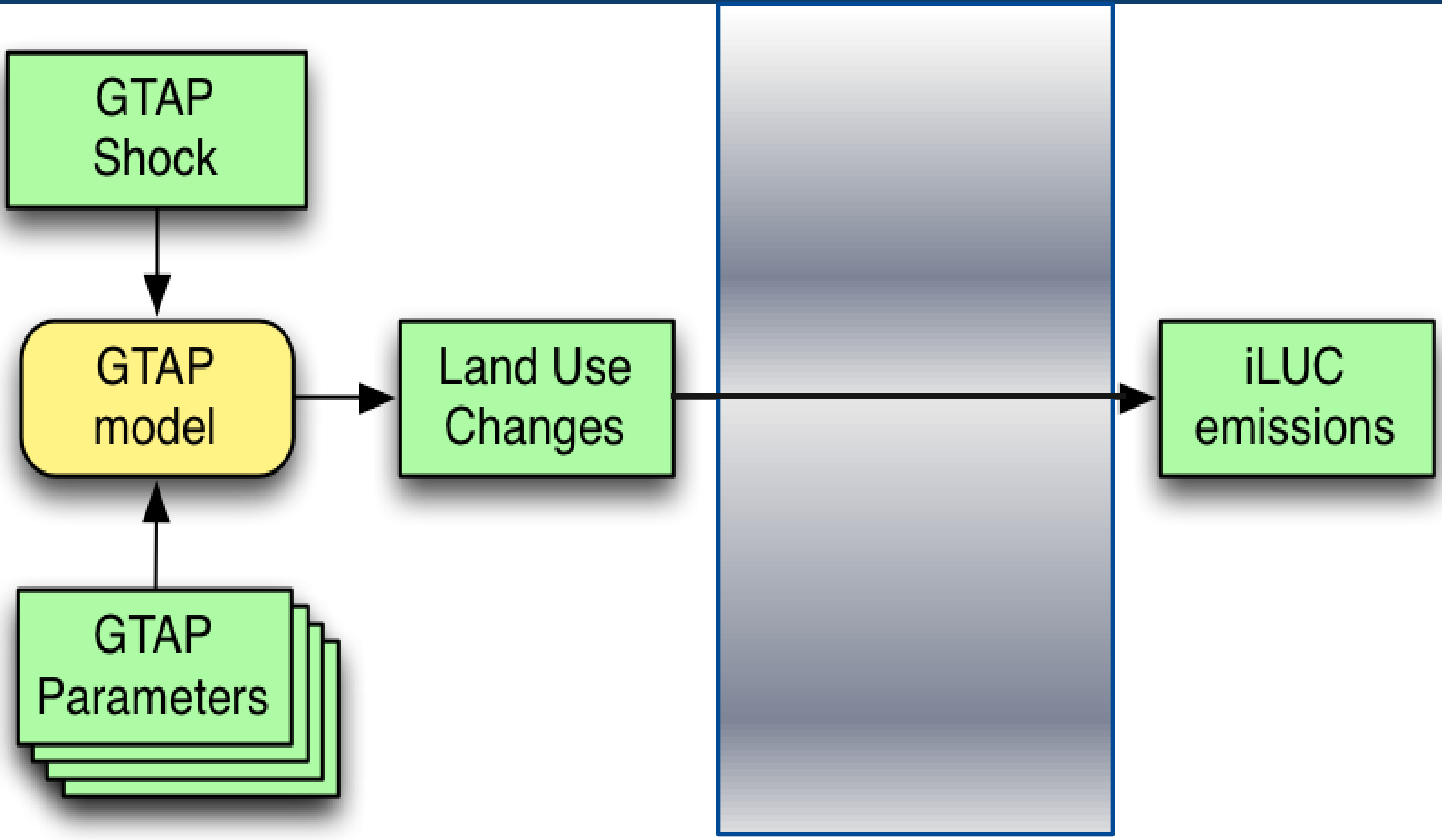
EWG Recommendations (cont.)

- Adopt a framework that that can incorporate time dependent changes such as technology driven yield improvements. This will likely involve switching to a dynamic version of GTAP
- Account for non-Kyoto emissions (e. g., black carbon)

Chronology of iLUC Analysis beyond 2009



GTAP Integration with Carbon Emissions
(iLUC Estimation Methodology)

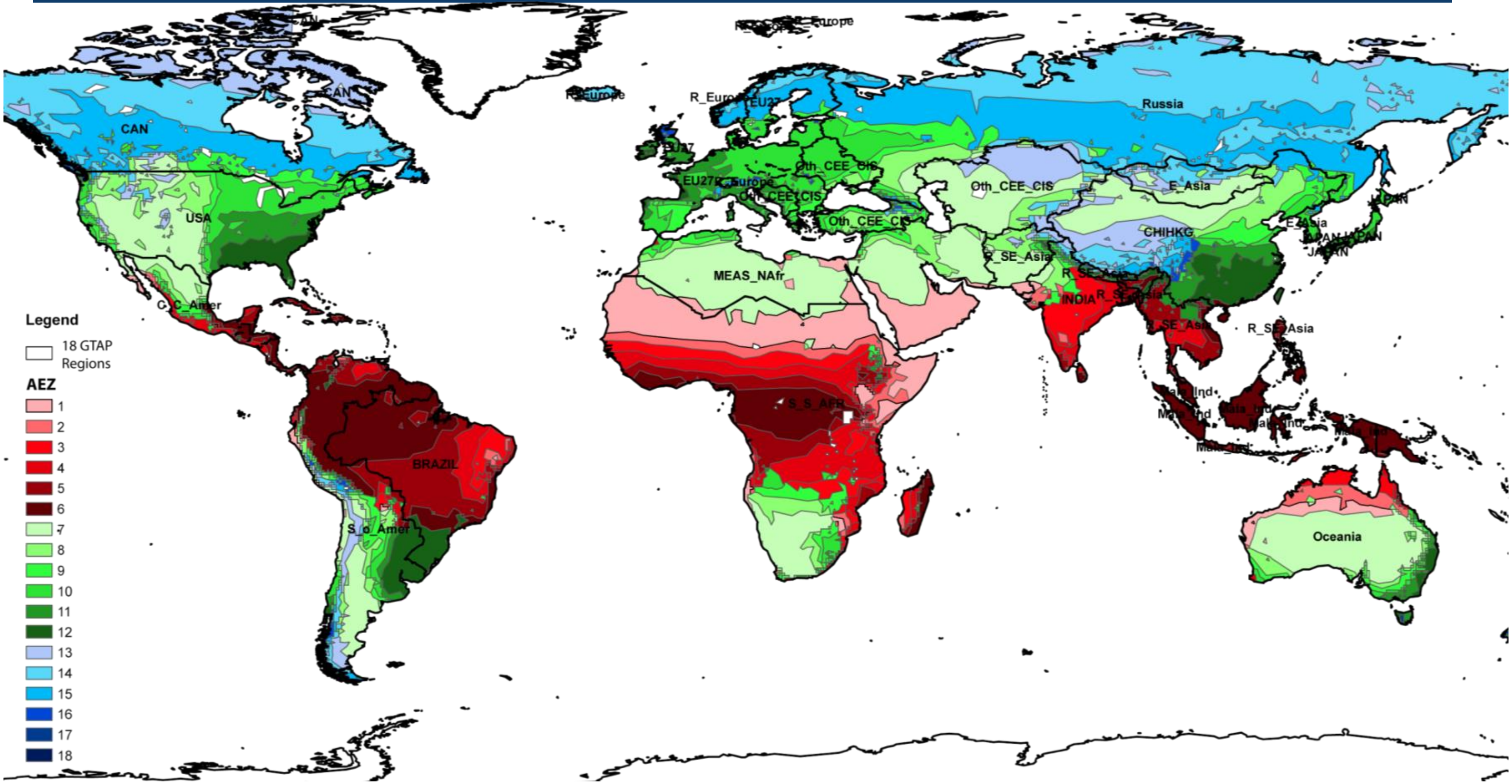


Agro-Ecological Zone - Emissions Factor (AEZ-EF) Model

AEZ-EF: Motivation

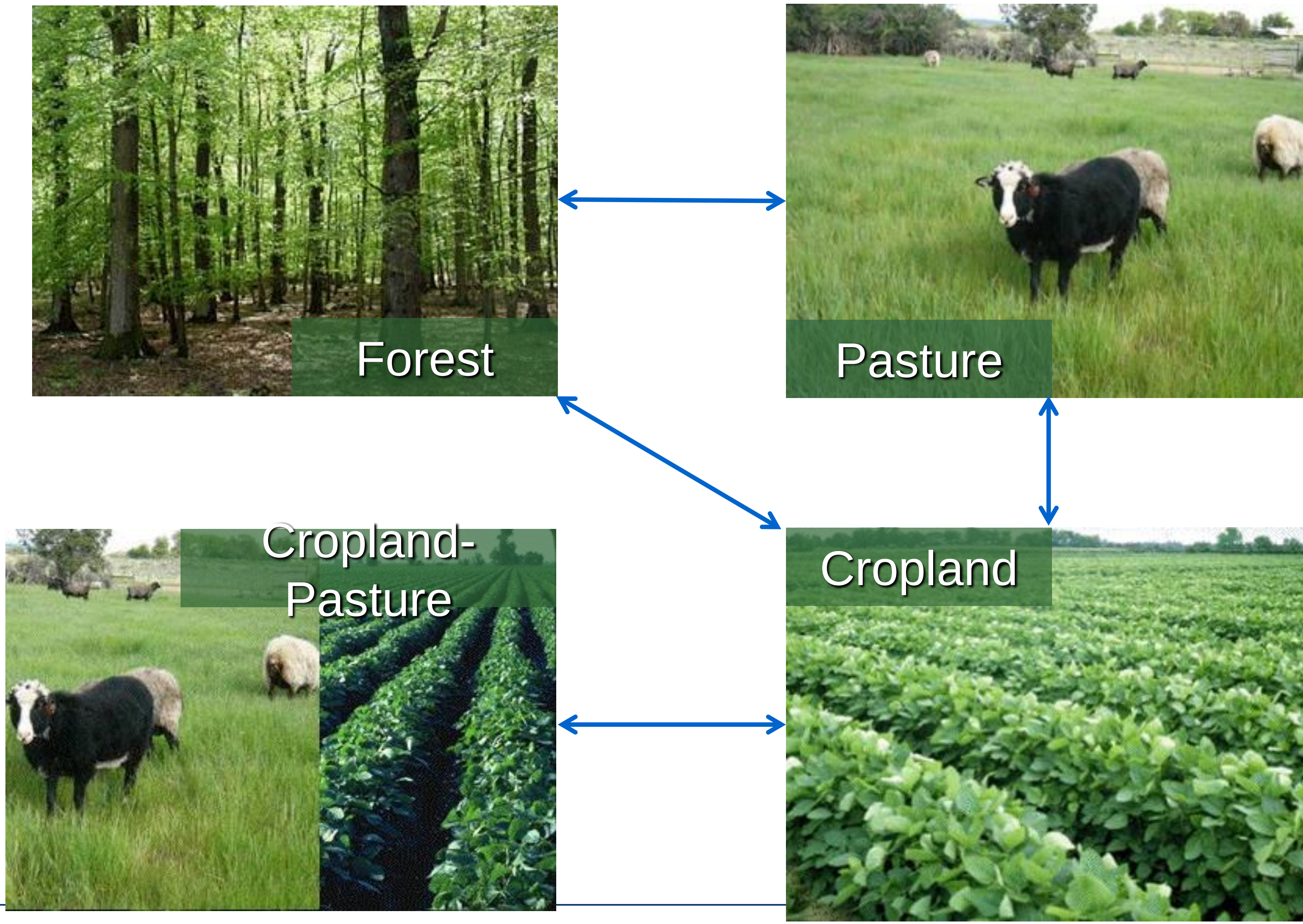
- 2009 analysis used carbon data from Woods Hole
- Limited disaggregation of regions
- GTAP AEZ/Regions not a good match with Woods Hole disaggregation
- No detailed breakdown of all potential sources of carbon emissions

AEZ-EF: GTAP Regions and AEZs

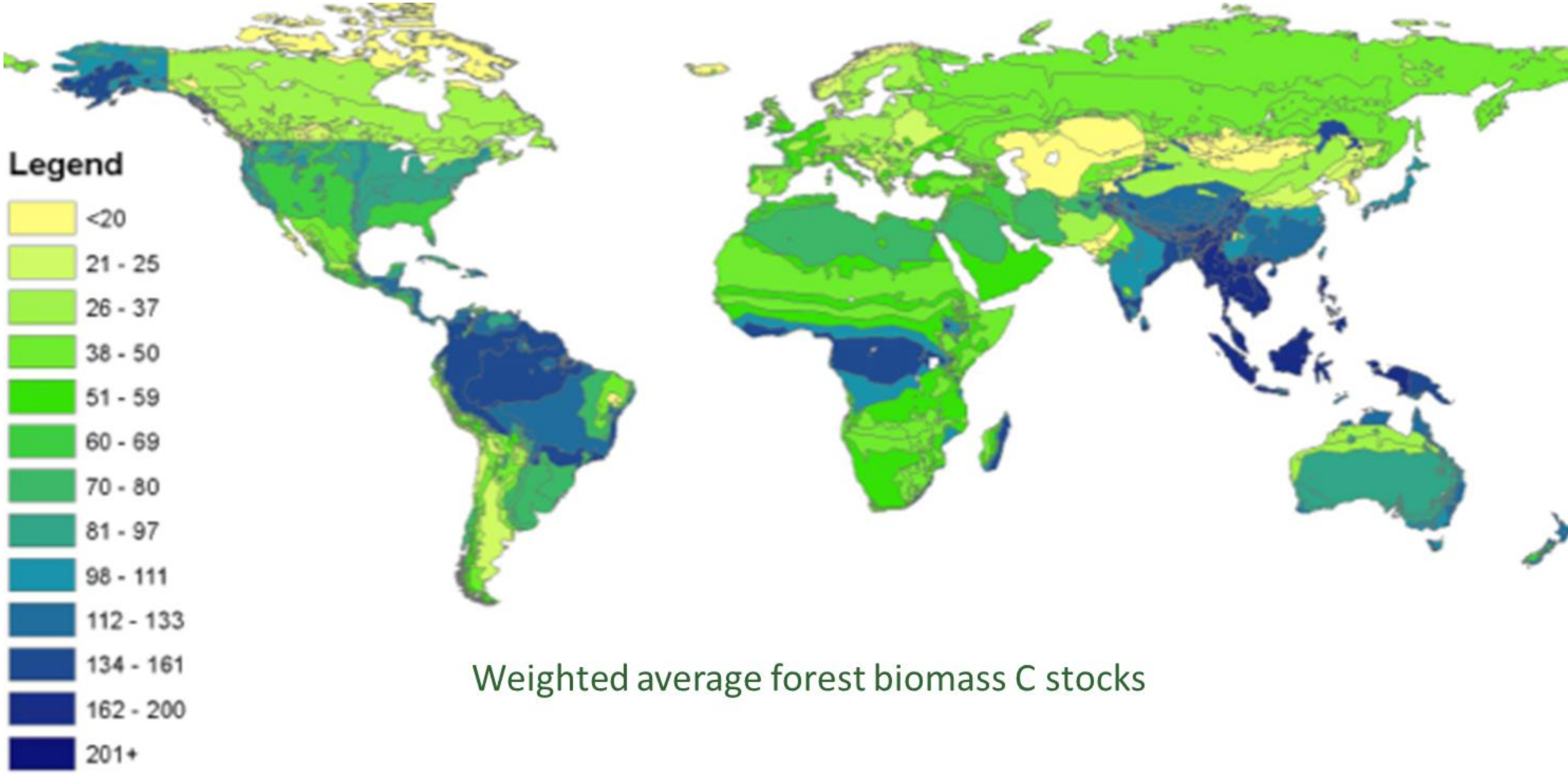


AEZ-EF: Carbon pools

AEZ-EF: 8 conversion sequences

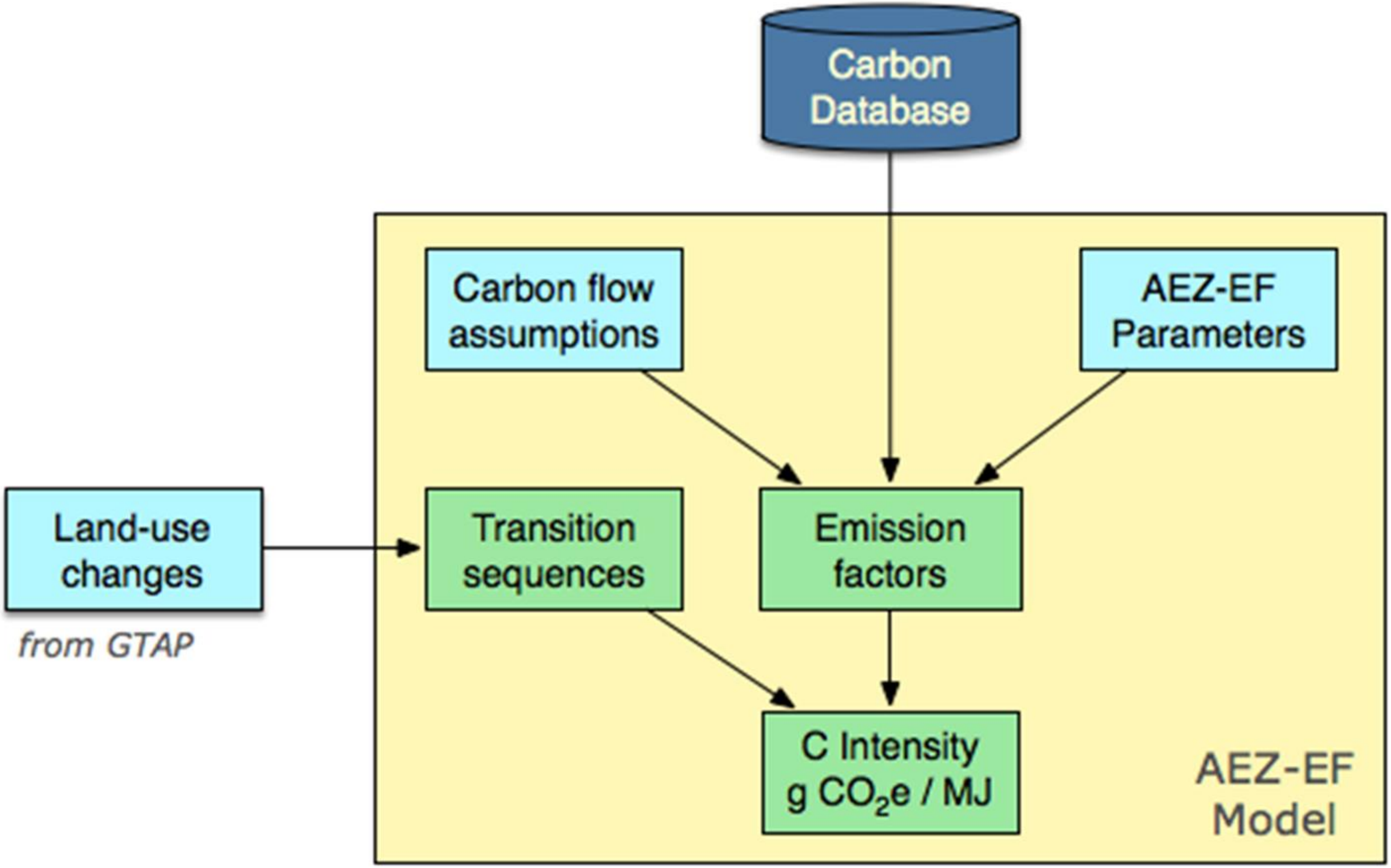


AEZ-EF: Spatial Carbon Data



Spatial C data aggregated to 19 regions × 18 AEZs

AEZ-EF: Schematic



AEZ-EF: Updates since 2011

- Contributions to carbon emissions from Harvested Wood Products (HWP) was updated
- Peat emission factor updated using ICCT data
- C data updated for 246 countries × 18 AEZs, aggregated to 19 GTAP regions
- Added oil palm carbon stock based on Winrock update to RFS2 analysis
- Post-conversion crop biomass C is now estimated from GTAP's predicted yields
- Fully documented in updated report

AEZ-EF: Comparison with GTAP Carbon Emissions

	2009 GTAP	AEZ-EF
Carbon stocks	Woods Hole data for 10 regions	Gibbs & Yui (2014) data for 246 countries and 18 AEZ combinations
Soil emissions	25% of top 100 cm	Variable by region; mostly IPCC method
Carbon Pools	Above and below ground live biomass, and soil carbon	All these plus understory, litter, deadwood, and HWP
Conversion sequences	Forest and pastureland to cropland	8 transitions among forest, pasture, cropland, C-P
Other	None	Peatland in Indonesia/Malaysia.

GTAP: Current Work

GTAP: Staff Efforts

- Model
  - Evaluated trade issues related to marginal vegetable oils and evaluated several versions of the model
  - Evaluated model outputs using real FAO, USDA and other data, assisted Purdue on data checks for new feedstocks, evaluated pseudo-dynamic approach, concurrent shocks, etc.
- Parameters
  - Evaluated importance of parameters, parameter values, and parameter distributions
- Structure
  - Evaluated ‘share-preserving’ aspect of the model
  - Conducted tests with model versions that included structural refinements (for land transformation)

GTAP: Review of Parameters

- Yield price elasticity (YPE)
- Armington elasticity
- Land transformation elasticities (ETL)
- ETA elasticity using TEM
- DDGS
- Irrigation impacts
- Forestry sector issues
- Fertilizer, livestock, and paddy rice emissions

GTAP: Yield Price Elasticity (YPE)

GTAP: YPE and its Significance

- Yield Price Elasticity (YPE) measures sensitivity of yield with respect to a change in crop prices
- Significance of YPE in the GTAP model
  - When crop prices increase due to increased demand for a biofuel feedstock, this parameter exogenously increases cropland productivity which in turn eases higher demand for land
  - Land conversion estimates are very sensitive to this parameter
- Two effects of YPE within the model:
  - Endogenous and exogenous

GTAP: Exogenous YPE

Estimated value for exogenous YPE

- Recent estimates of YPE varies from zero to 0.30
- The estimates vary because of differences in
  - Data (times series versus cross section, region)
  - Methodology (using instrumental variable or not)
- Estimates are generally based on US data but the results are applied to all regions worldwide
- There is no agreement in the scientific community on an appropriate value

GTAP: Endogenous YPE

- GTAP includes an endogenous YPE

- Effective YPE = Endogenous + Exogenous

  i.e., if input (exogenous)YPE is 0.25, effective YPE in GTAP is around 0.39

- Our approach to this problem: We do use not a single value for exogenous YPE but a range of values between 0.05 and 0.30

GTAP: Empirical Studies for YPE (Corn)

Authors	Period	Elasticity	Data, Location, Method
Houck & Gallagher	1951-1971	**0.76**	TS with log trends, US, OLS
Houck & Gallagher	1951-1971	**0.69**	TS with log trends & AC, US, OLS
Houck & Gallagher	1951-1971	**0.28**	TS with linear trends, US, OLS
Houck & Gallagher	1951-1971	**0.24**	TS with linear trends & AC, OLS
Menz & Pardey	1951-1971	**0.61**	TS with log trends & AC, US, OLS
Menz & Pardey	1972-1980	**0**	Replication of Houck & Gallagher
Lyons & Thompson	1961-1973	**0.22**	TS, 14 countries, US, OLS
Choi & Helmberger	1964-1988	**0-0.27**	TS, US, OLS
Kaufman & Schnell	1969-1987	**~0**	TS, US, OLS
Huang & Khanna	1977-2007	**0.15**	County level data, US, IV
Smith & Sumner	1961-2005	**Neg. & Sig**	County level data, US, OLS
Berry & Schlenker	1961-2009	**0**	Country-level data, US, IV (Crops)
Goodwin, et al.	1996-2010	**0.008 SR** **0.19-0.27 LR**	3 US States, OLS
Pérez	1960-2004	**0.29**	Panel data. Iowa, Duality-Bayesian

Note: The estimates are for corn unless specified; TS=Time Series; OLS= Ordinary Least Square; AC: Acreage Control; IV: Instrumental Variable

GTAP: Armington

GTAP: Armington Treatment

- Armington is an approach in the model about the formation and persistence of patterns of bilateral trade between various countries
  - It assumes goods are differentiated by the country of origin. e.g., corn produced in U.S. is different from corn produced in Canada, Brazil, etc.
  - Tends to maintain status quo in trade patterns
  - This assumption makes the results path dependent. This creates an issue when trade happens beyond historical patterns
- Armington treatment is based on two factors:
  - trade elasticities - can be changed
  - trade shares – these are fixed at the base year. They are built in the model and cannot be changed

GTAP: Armington (cont.)

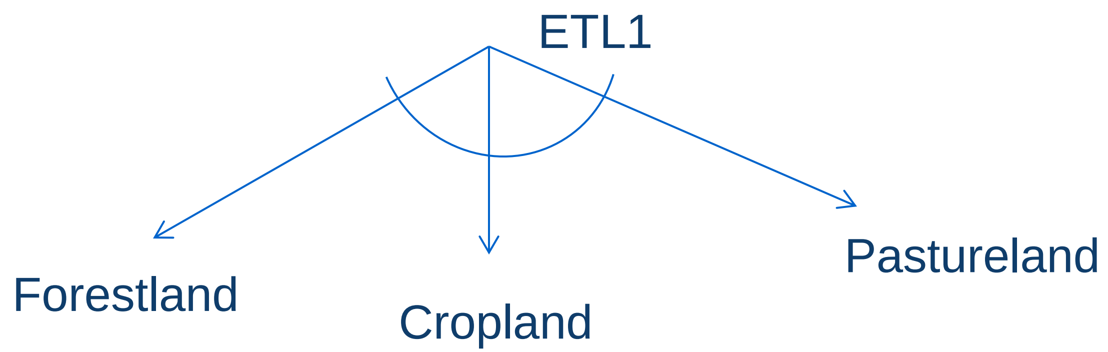
- Staff evaluated model by changing trade elasticities and found that they do not significantly impact results because:
  - With Armington, trade patterns remain close to the baseline and price changes do not have measurable impacts on trade. This is not observed in the real world
- There is no easy solution because changing shares is not possible under the current model structure
- Possible long-term solutions
  - Drop the Armington assumption at least for commodities and adopt an Integrated World market approach
  - Make the model dynamic
- No changes related to Armington in the current model

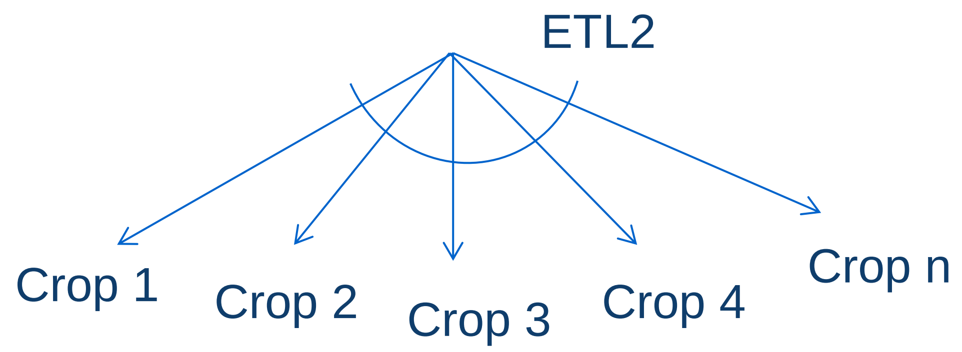
GTAP: Land Transformation Elasticities (ETL)

GTAP: ETL

- GTAP predicts land conversion from one type of land cover to another (e.g., forest-crop, pasture-crop, etc.)
- GTAP uses Land Transformation Elasticity (ETL) to model land conversion
- The value of the ETL parameter governs the ease (or difficulty) of land conversion
- The elasticity of land transformation is intended to reflect:
  - Biophysical land heterogeneity within AEZ, region-specific infrastructure, socioeconomic factors, ownership of land, costs of conversion, managerial inertia, unmeasured benefits from crop rotation
- These elasticities are difficult to directly estimate using econometric methods due to lack of sufficient data

GTAP: ETL (cont.)





GTAP: ETL (cont.)

GTAP Region	ETL1	ETL2		GTAP Region	ETL1	ETL2
USA	-0.02	-0.75		R_SE_Asia	-0.3	-0.5
EU27	-0.02	-0.75		R_S_Asia	-0.1	-0.75
BRAZIL	-0.2	-0.75		Russia	-0.02	-0.75
CANADA	-0.02	-0.25		Oth_CEE_CIS	-0.02	-0.75
JAPAN	-0.2	-0.5		Oth_Europe	-0.02	-0.25
CHIHK	-0.2	-0.25		MEAS_NAfr	-0.02	-0.25
INDIA	-0.1	-0.25		S_S_AFR	-0.3	-0.25
C_C_Amer	-0.02	-0.25		Oceania	-0.02	-0.25
S_o_Amer	-0.1	-0.5				
E_Asia	-0.2	-0.5				
Mala_Indo	-0.3	-0.25				

Staff has utilized these values in the preliminary analysis presented here

GTAP: Elasticity of Crops Yields w.r.t. Area Expansion (ETA)

GTAP: ETA

- ETA parameter is used to determine the productivity of newly converted cropland relative to productivity of existing cropland
- For 2009: Purdue assumed that ETA parameter is equal to 0.66 all across the world based on empirical evidence from U. S. land use and expert judgment on the productivity of the new cropland
- The Terrestrial Ecosystem Model (TEM) estimates net primary productivity (NPP), a measure of maximum biomass productivity
- Purdue updated the GTAP model in 2010 using the NPP of new land and existing cropland in a given region/AEZ to calculate ETA

GTAP: ETA (cont.)

- The use of biophysical models such as the TEM may be a weak substitute for measuring yield potential in GTAP
- TEM estimates net primary productivity, which is quite different from yield for a specific crop under local management conditions
- Additional work is required to refine the current assessment of the extensive margin of crop yields
- Current GTAP model uses the TEM approach until new research information is available

GTAP: Dried Distiller's Grains with Solubles (DDGS)

GTAP: DDGS Analysis

GTAP results compared with USDA data on DDGS use and exports

- GTAP model for US corn ethanol shock predicts DDGS domestic demand to increase by 336%, while exports increase by 84%
- Reports from USDA show an increase in US DDGS exports by 2,135% for approximately the same time period
- Elasticity of substitution between DDGS and coarse grains for use in feed of dairy, ruminants, and non-ruminants in the domestic markets is an important factor that governs DDGS exports
- To reduce differences between GTAP results and USDA, staff considered adjustments to DDGS-related elasticities

GTAP: DDGS Analysis (cont.)

- Change in elasticity values did not significantly impact results because:
  - GTAP analysis is constrained by base export values. If the base exports for any region such as China or Canada is initially small, the model is not able to predict large changes
- Conducted simulations by exogenously shocking the model to fit real-data for DDGS exports
  - Small differences in land conversions across the world
  - No significant impacts related to DDGS export constraints
- Long term model updates (e.g., Dynamic model) could address the DDGS export constraint
- Current model did not change DDGS treatment

GTAP: Irrigation

GTAP: Irrigation Impacts

- Current version of GTAP model
  - No differentiation between irrigated and rain-fed land
  - Irrigated land has higher productivity compared to rain-fed
  - Assumes no restrictions on water for new land that comes into production
- However…
  - Availability of water for irrigation is limited
  - Use of water costs $$
  - Crop expansion and crop switching decisions will require availability of water resource and may change model predictions

GTAP: Irrigation Impacts (cont.)

Approach to address this issue and timeframe

- Data for water availability, productivity differences, and land elasticity will be collected and integrated into the model

- Anticipate a revised GTAP model within the next few months

GTAP: Forestry

GTAP: Forestry Sector Issue

- GTAP does not make distinction between managed and unmanaged forest
- In the absence of different forest categories, GTAP creates unrealistic deficit from wood products in the forestry sector
- Current version of model includes adjustments in ETL values which may be a temporary solution to this issue
- We are working with Purdue and plan to complete this work by April 2014

GTAP: Fertilizer, Livestock, and Paddy Rice Emissions

GTAP: Effects of Fertilizer, Livestock and Paddy Rice Emissions

- GTAP simulations predict changes in paddy rice, livestock quantity, crop intensification, new crop production etc., but the current analysis does not account for corresponding changes in GHG emissions
- What are the net impacts by including these changes in emissions?
  - CH_4 from paddy rice cultivation (potential credits)
  - CH_4 and N_2O from livestock enteric fermentation and manure (potential credits)
  - N_2O from fertilizer use for crop intensification (potential deficits)
  - N_2O from new crop production (potential deficits)

GTAP: Fertilizer, etc. Emissions (cont.)

- Current challenges
  - Potential double counting between CA-GREET and GTAP
  - Methodological inconsistency
- Timeframe to address these emissions
  - Requires update to emissions database
  - Resolve potential double counting issue
  - May not be able to complete in 2014

GTAP: Summary of Updates

GTAP: Updates since 2009

- Updated oilseeds sector to account for vegetable oils and co-products
- Updated GTAP database from v.6 (2001) to v.7 (2004)
- Introduced cropland pasture into the model
- Re-estimated energy sector demand and supply elasticities
- Updated co-product treatment
- Modified livestock sector
- TEM model to update yields of new cropland
- Adoption of a consistent model version and set of model inputs for all biofuel pathways

GTAP: Updates (cont.)

- Incorporation of an endogenous yield adjustment for cropland pasture
- Disaggregated coarse grains to add sorghum
- Disaggregated other oilseeds to add canola
- Developed regionalized ETL1 and ETL2 values

iLUC: Preliminary Results

iLUC: Scenario analysis

- 2009/2010 iLUC analysis
  - Average of 5 to 7 scenarios for each biofuel
- Current analysis:
  - 1440 scenario runs for each biofuel
  - Used variations of input values for YDEL, ETL1, ETL2, ETA, and PAEL that include the complete range of literature values or best estimates
  - Includes draft iLUC analysis for corn ethanol, sugarcane ethanol, soy biodiesel, canola biodiesel and sorghum ethanol

iLUC: Cropland Pasture Yield Elasticity (PAEL)

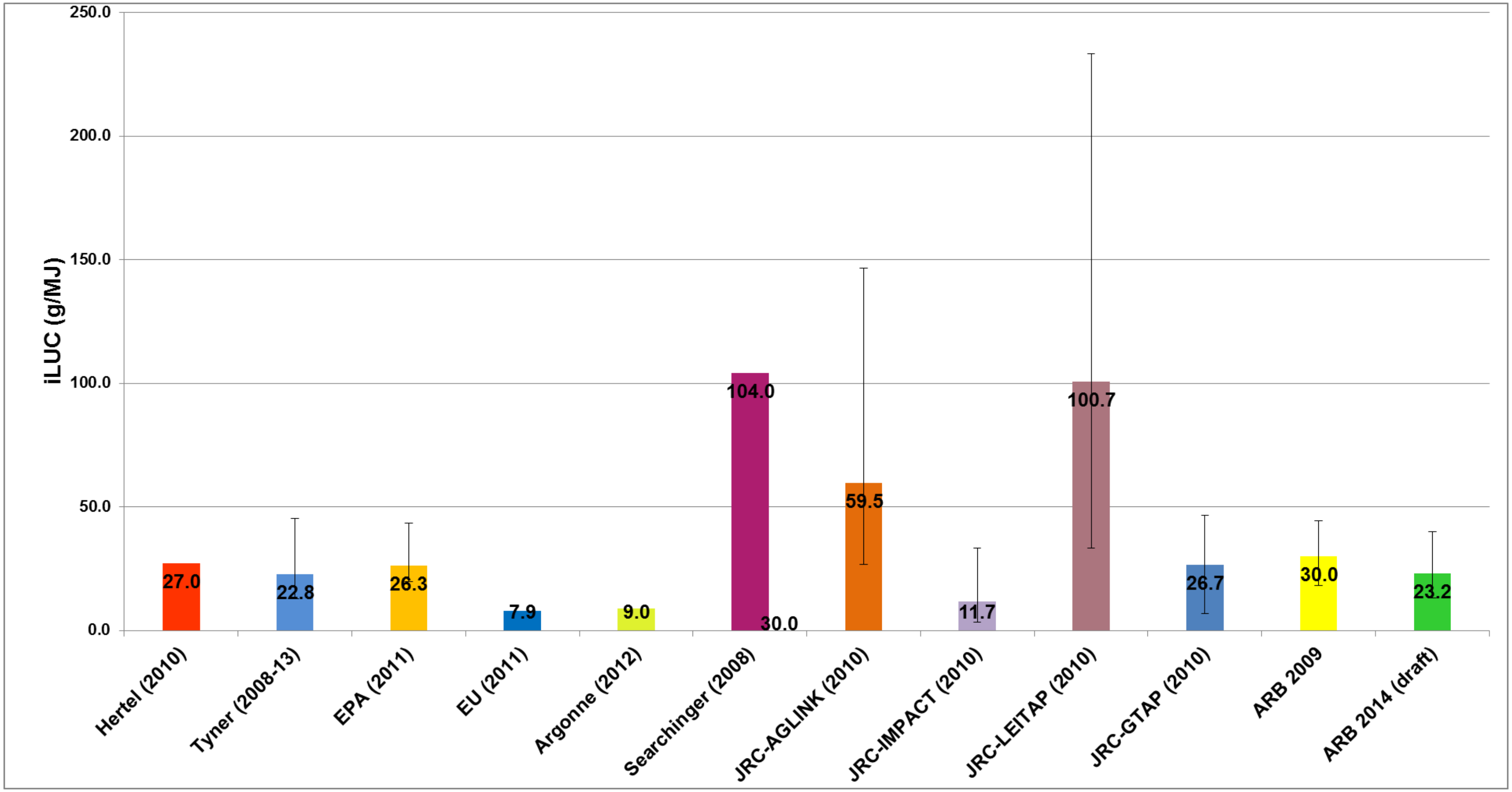
Cropland-Pasture

- Land category introduced into GTAP after 2009
- Includes land cultivated in the past but currently used as feed lot (but can return to crop production)
- PAEL is an elasticity parameter which accounts for increases in productivity of cropland pasture directly resulting from increase in land rents

iLUC: Values Used in Scenario Analysis
(1440 runs)

Parameter/ Scenario	Description	Values
YPE	Yield Price elasticity	0.05 to 0.3
PAEL	Cropland pasture elasticity	0.1 to 0.6 U. S. 0.1 to 0.2 Brazil
ETL2	Land transformation elasticity that distributes available cropland between crops	Baseline, 80%, 90%, 110% and 120% of baseline
ETL1	Land transformation elasticity that governs land conversion between forest, cropland, and pasture land	Baseline, 80%, 90%, 110% and 120% of baseline
ETA	Elasticity of crop yields with respect to area expansion	Baseline, 80%, and 120% of baseline

iLUC: Comparison of Results for Corn Ethanol



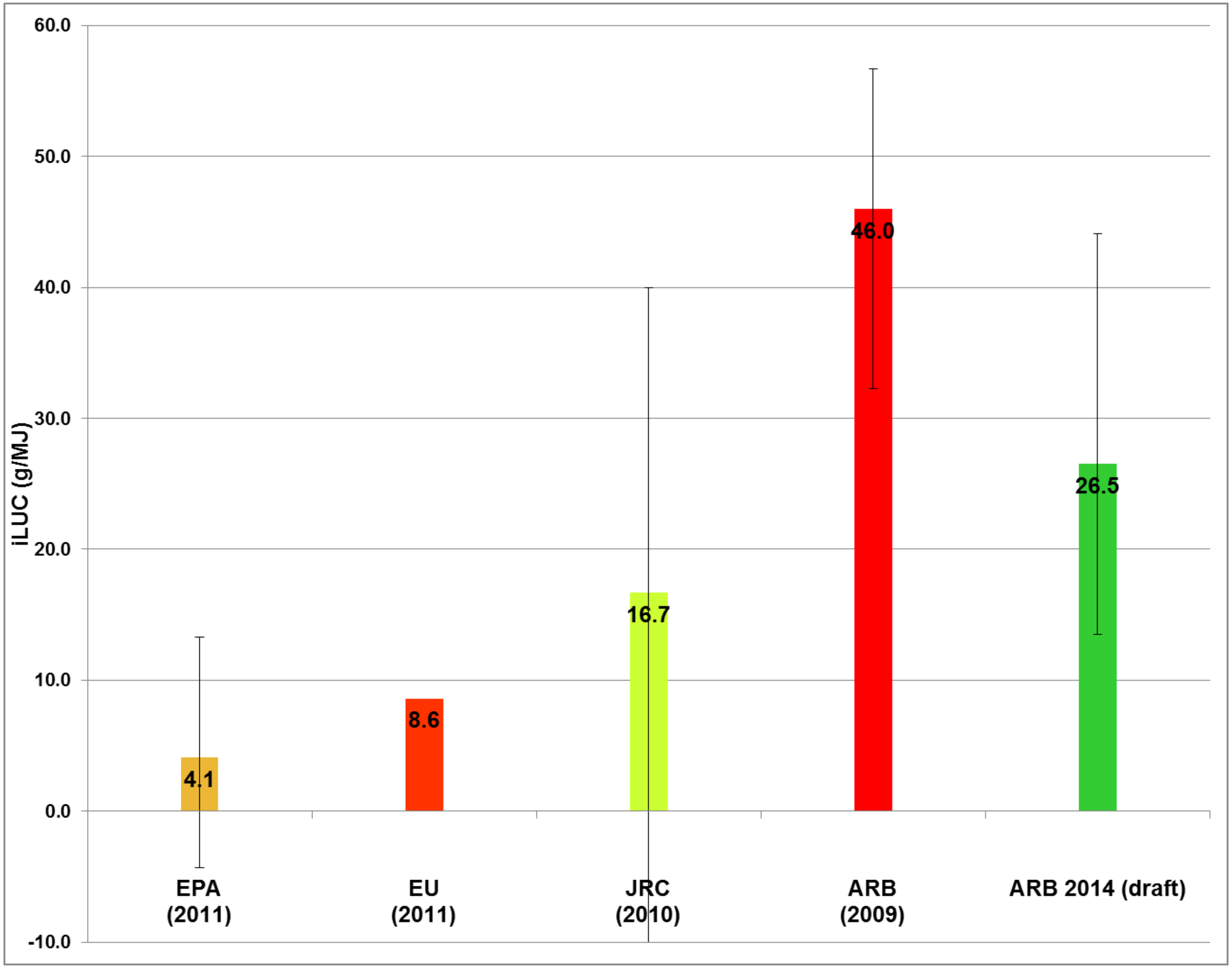
iLUC: Why Results Vary between Studies?

Source	Model	Type	Timeframe	Scope	Emission Factor
ARB	GTAP	CGE	Current	Global	AEZ-EF
EPA	FAPRI/ FASOM	PE	2022	Regional/global	Winrock/ Daycent/IPCC
Searchinger	FAPRI	PE	Not specified	Regional	Woods Hole
Tyner (Purdue)	GTAP	CGE	Current	Global	Woods Hole/ AEZ-EF
Hertel (Purdue)	GTAP	CGE	Current	Global	Woods Hole
EU	MIRAGE	CGE	2020	Global	IPCC
Argonne	GTAP	CGE	Current	Global	Woods Hole, CENTURY, COLE
JRC	IMPACT	PE	2020	Global	FAO/IPCC/Others
JRC	AGLINK-COSIMO	PE	2020	AGLINK-OECD COSIMO-Developing	FAO/IPCC/Others
JRC	LEITAP	CGE	2020	Global	FAO/IPCC/Others

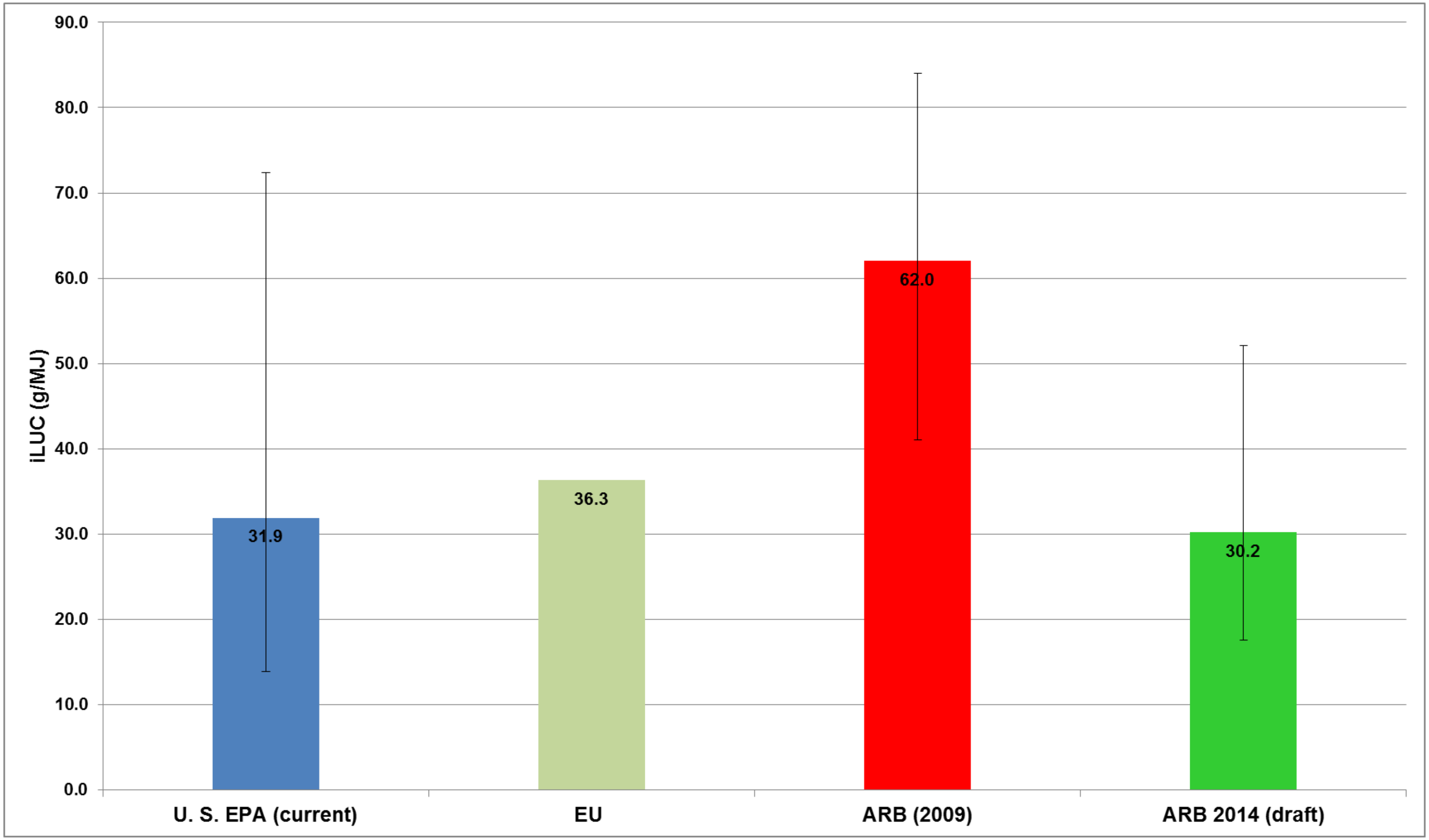
iLUC: Why Results Vary between Studies? (cont.)

Modeling Aspect	Others	ARB
Number of runs	Mostly single run with parameter specified values	1440 runs
Yield price elasticity	Yield increase related to price increase based on one study	Range of values between 0.05 to 0.3
Land conversion mapping	Land converted predicted by model mapped to historical conversion	Predicted by GTAP
Productivity of new land	Typically 75-100%	45-90%
Target year	Typically 2022 or 2020	Current
Scope of biofuel shock	Some studies only limit impacts to region of interest	Shock applied globally
Emission factors	Mostly IPCC or aggregated sources	Detailed emission factors based on latest data using AEZ-EF model

iLUC: Comparison of Results for Sugarcane Ethanol



iLUC: Comparison of Results for Soy Biodiesel



iLUC: Preliminary Results (1440 scenario runs for current results)

Biofuel	2009 (g/MJ)	2014 Ave. (g/MJ)	Range (g/MJ)
Corn Ethanol	**30.0**	23.2	13.1 – 40.0
Sugarcane Ethanol	**46.0**	26.5	13.5 – 44.1
Soy Biodiesel	**62.0**	30.2	17.6 – 52.1
Canola Biodiesel	n/a	41.6	24.8 – 70.2
Sorghum Ethanol	n/a	17.5*	10.9 – 28.4*

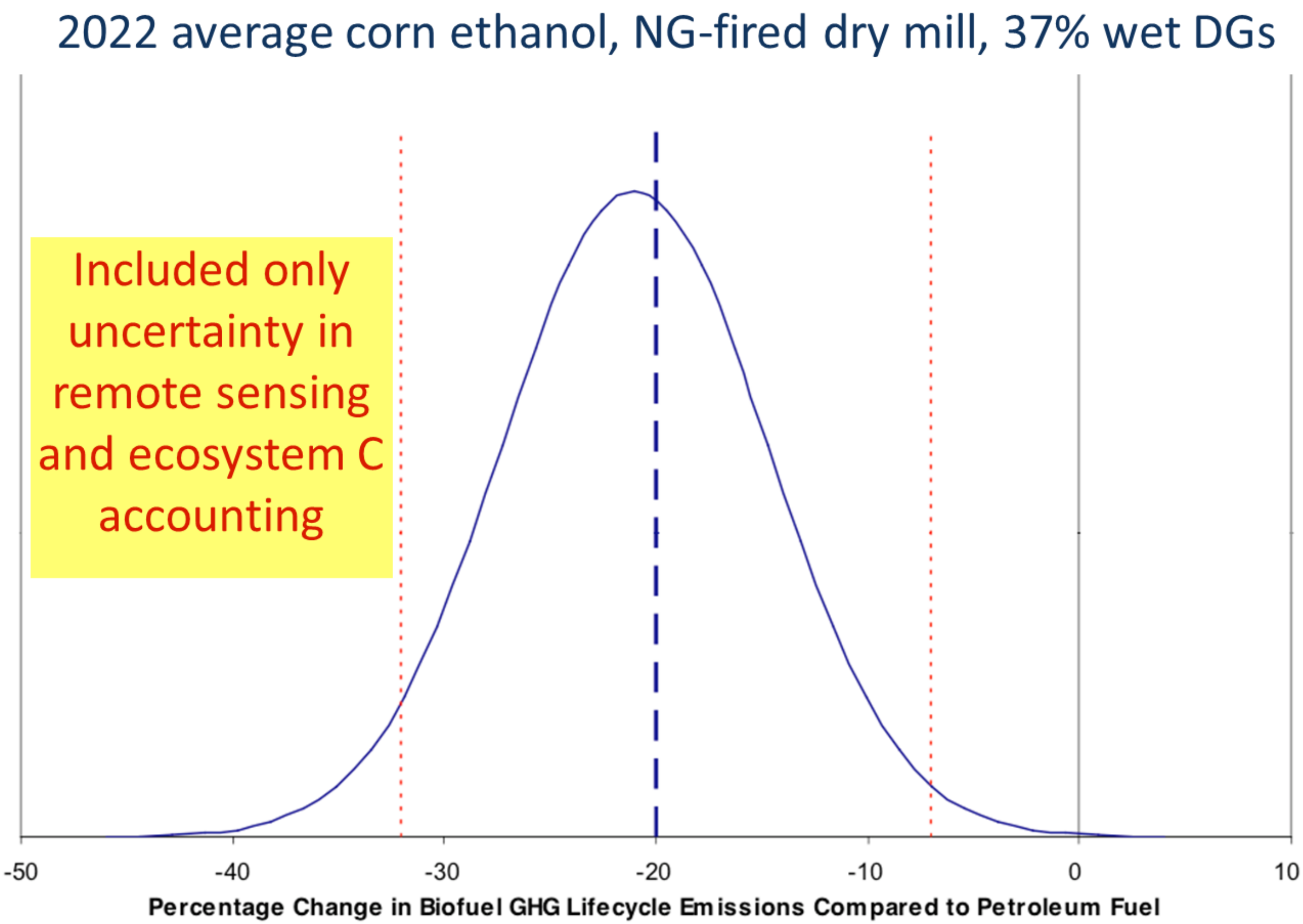
*** Only around 1200 runs completed**

Evaluation of Uncertainty

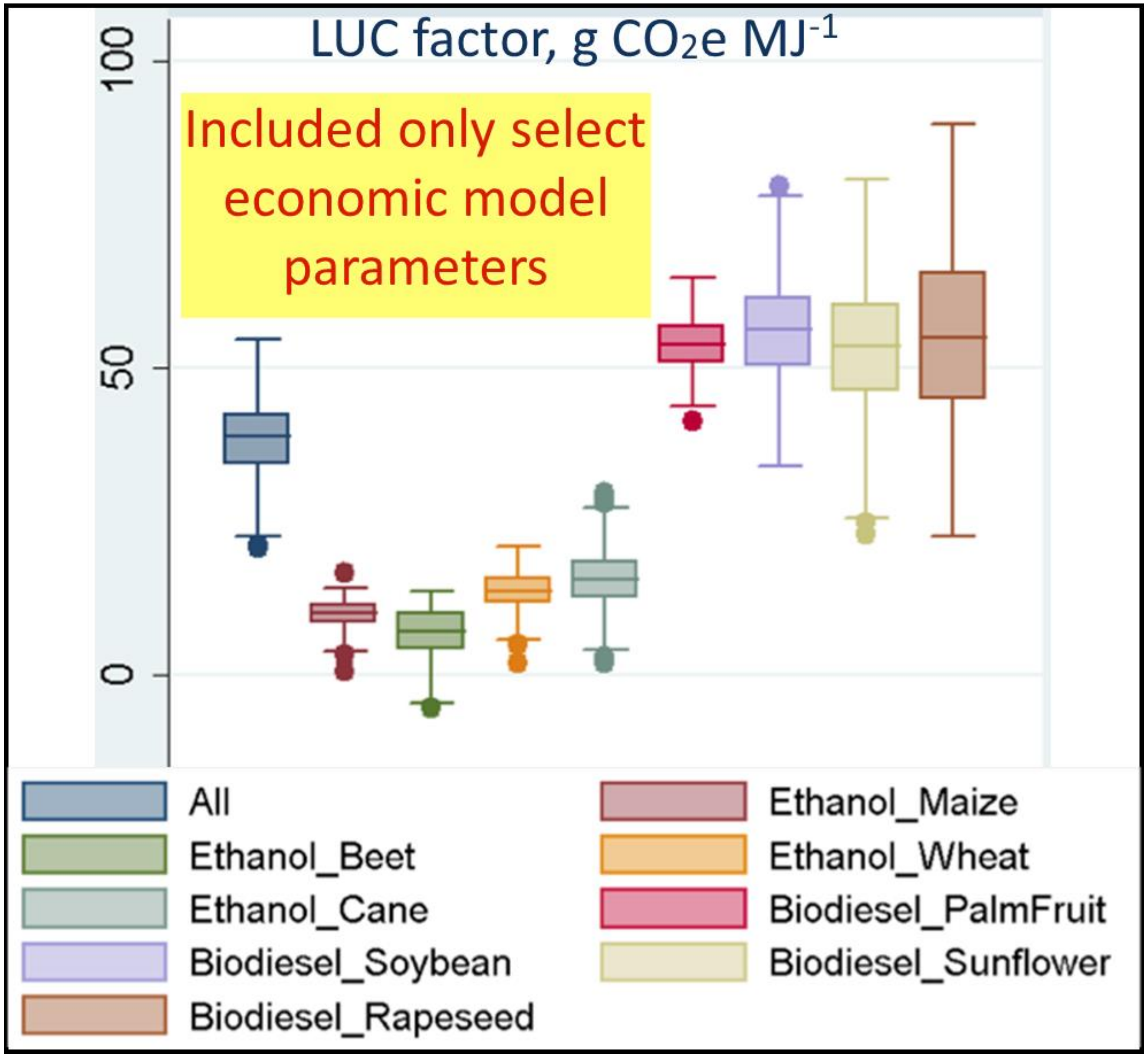
Uncertainty: Overview

- Monte Carlo (MC) framework
- Systematic approach to uncertainty analysis
- Identifies most sensitive parameters and model components; guides further research
- Provides an estimate of expected value
- Joint model comprising GTAP and AEZ-EF

Uncertainty: EPA Analysis for RFS2



Uncertainty: IFPRI's Analysis for the EU

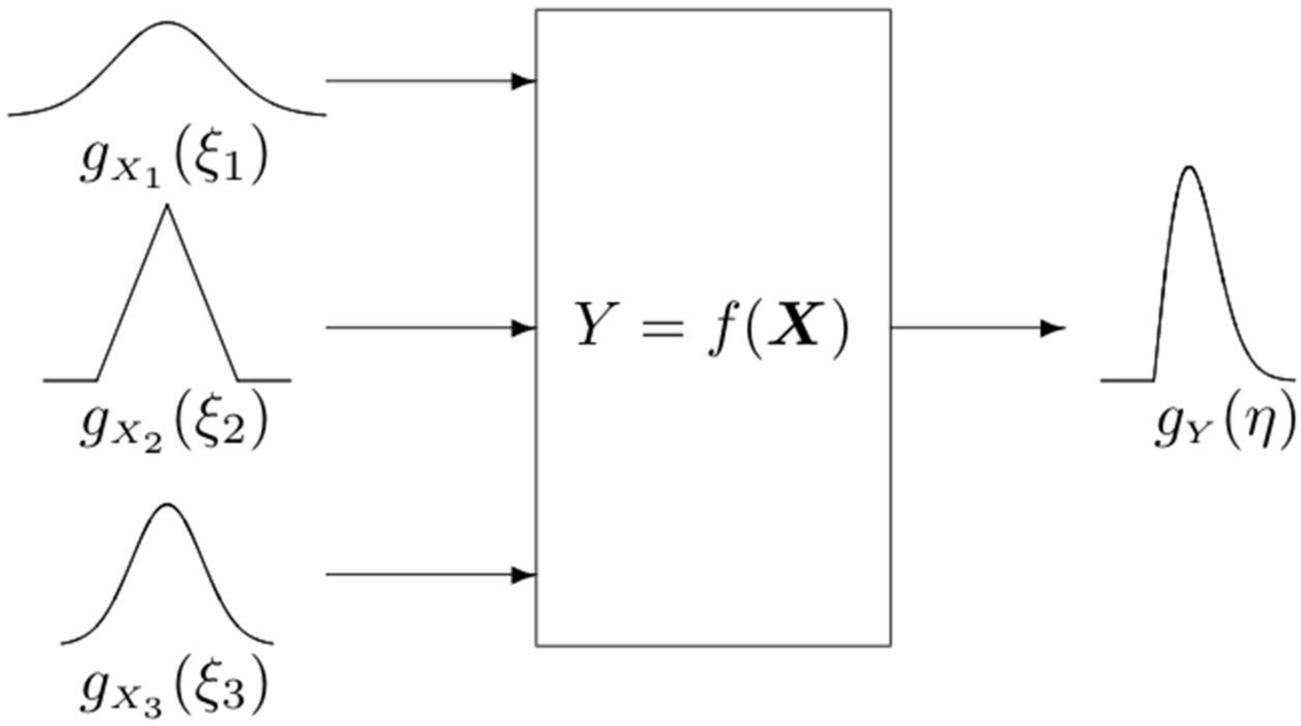


Uncertainty: Parameters in GTAP/AEZ-EF

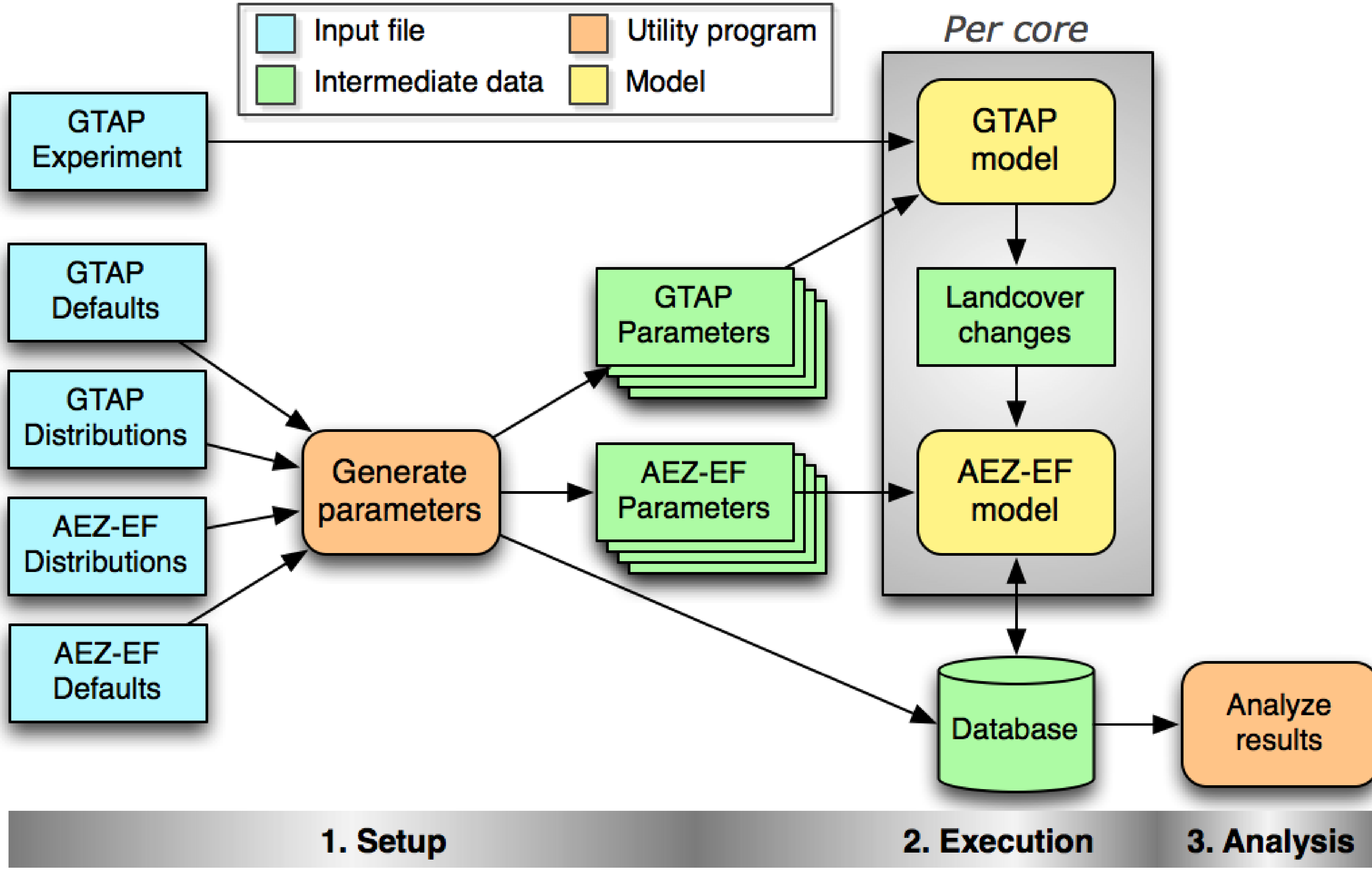
- AEZ-EF model has 45 parameters
  - Many are matrices of 18 AEZs by 19 regions
  - Carbon stocks, growth rates, change factors
- GTAP model has 53 behavioral parameters
  - Many are matrices of 19 regions by 35 sectors
  - Most are elasticities of substitution

Uncertainty: Details of MC Inputs

Parameters used distributions and ranges developed in consultations with experts and from review of published literature



Uncertainty: MC System Schematic

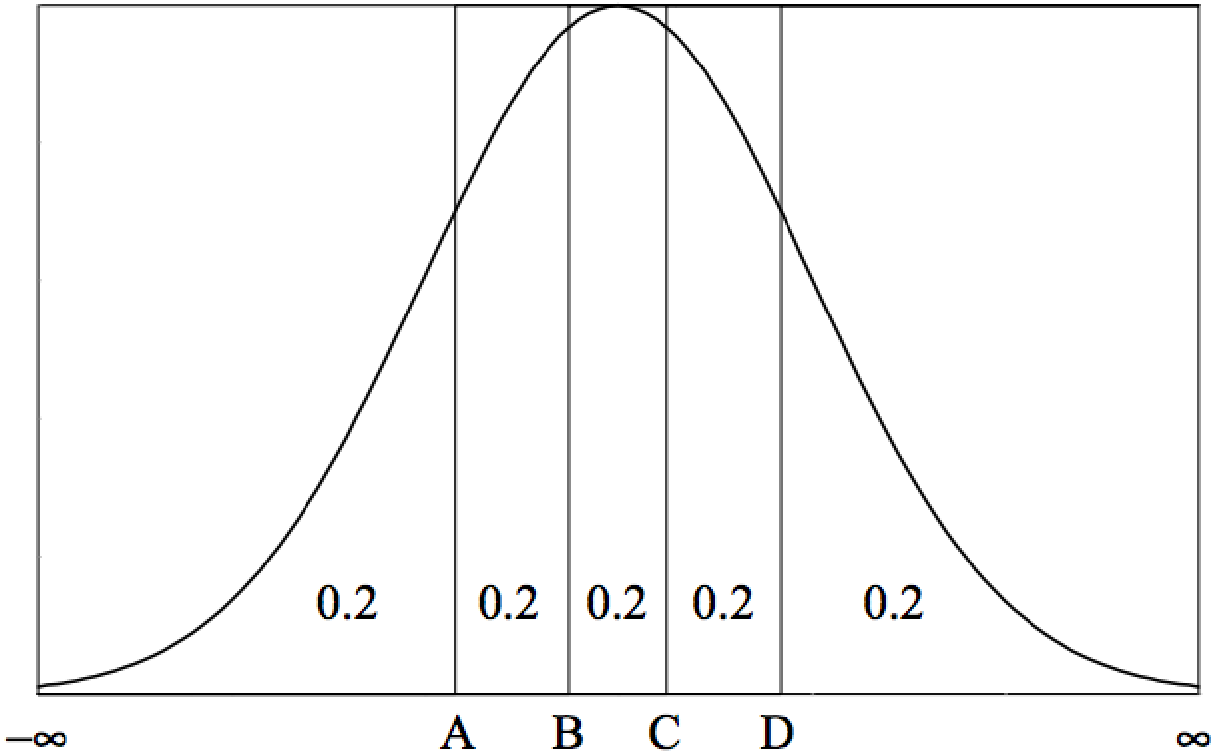


Uncertainty: MC Framework

- Latin hypercube sampling
- Parameter covariance
- Generates input files
- Collects results
- Generates output frequency distributions

Uncertainty: Latin Hypercube Sampling

- Stratified sampling technique
- Divides distribution into equiprobable intervals and samples from these; ensures even sampling over distribution
- Reduces number of trials in a Monte Carlo simulation



Uncertainty: Computation for MC

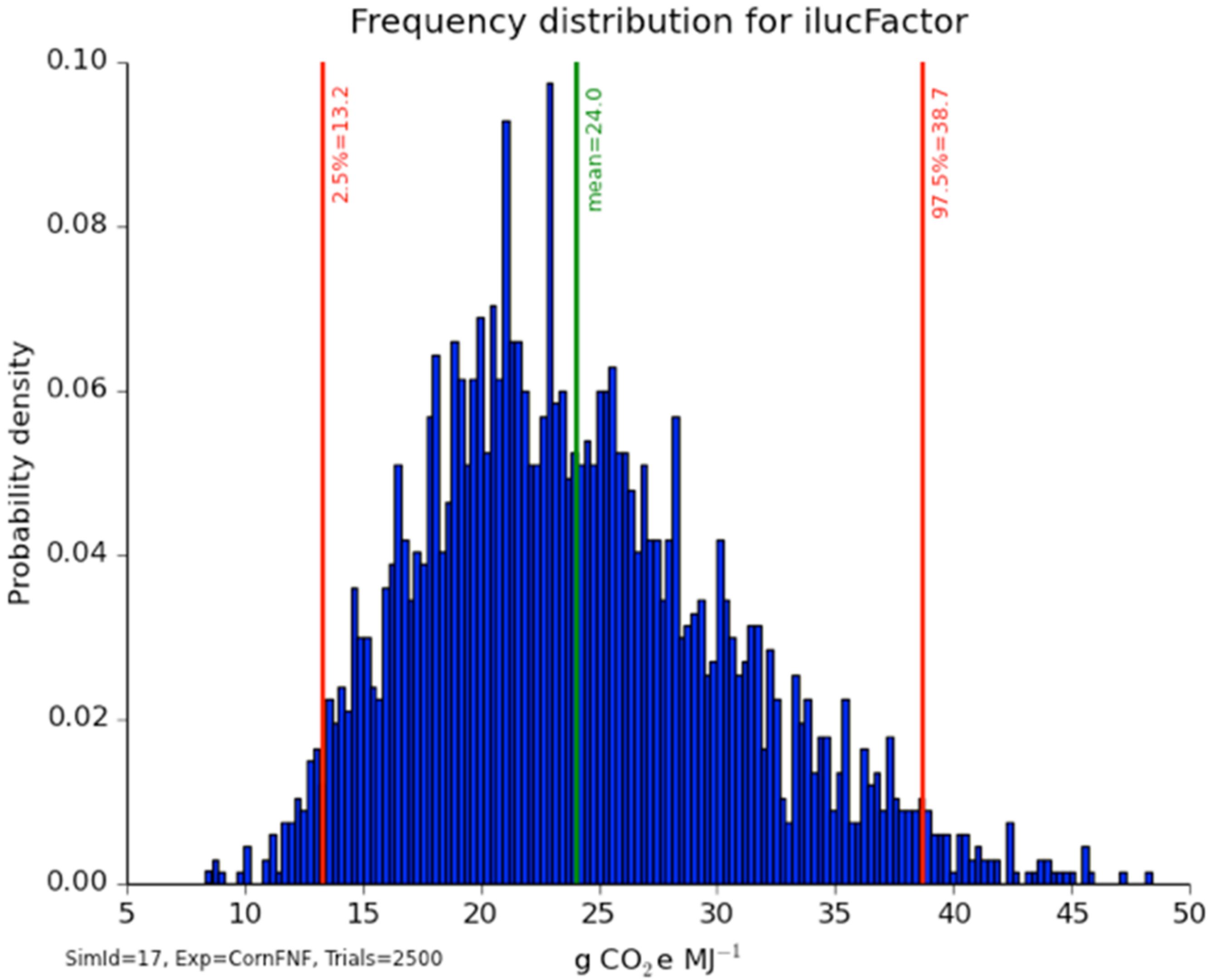
- National Energy Research Scientific Computing system
- Carver: liquid-cooled IBM iDataPlex system
  - 10,000 processor cores
  - Linux operating system
  - Runs ~10 GTAP trials per minute
  - 2,500 trials in 2-6 hours

Uncertainty: Details of MC simulations

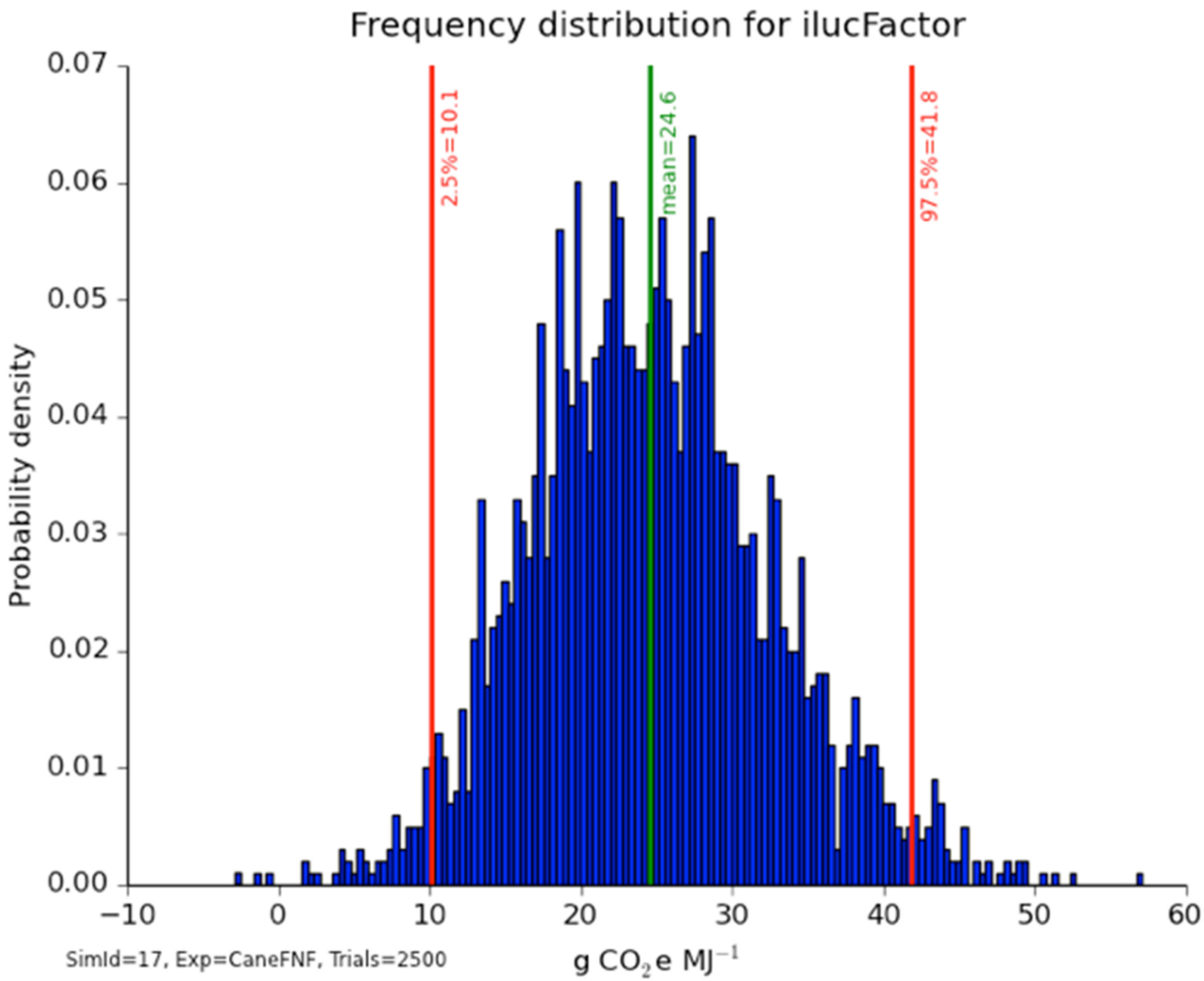
- Conducted simulations 1000s of times and saved results
- For each simulation, values are selected from input distribution
- Accumulated outputs describe a frequency distribution

Uncertainty: Simulation Results

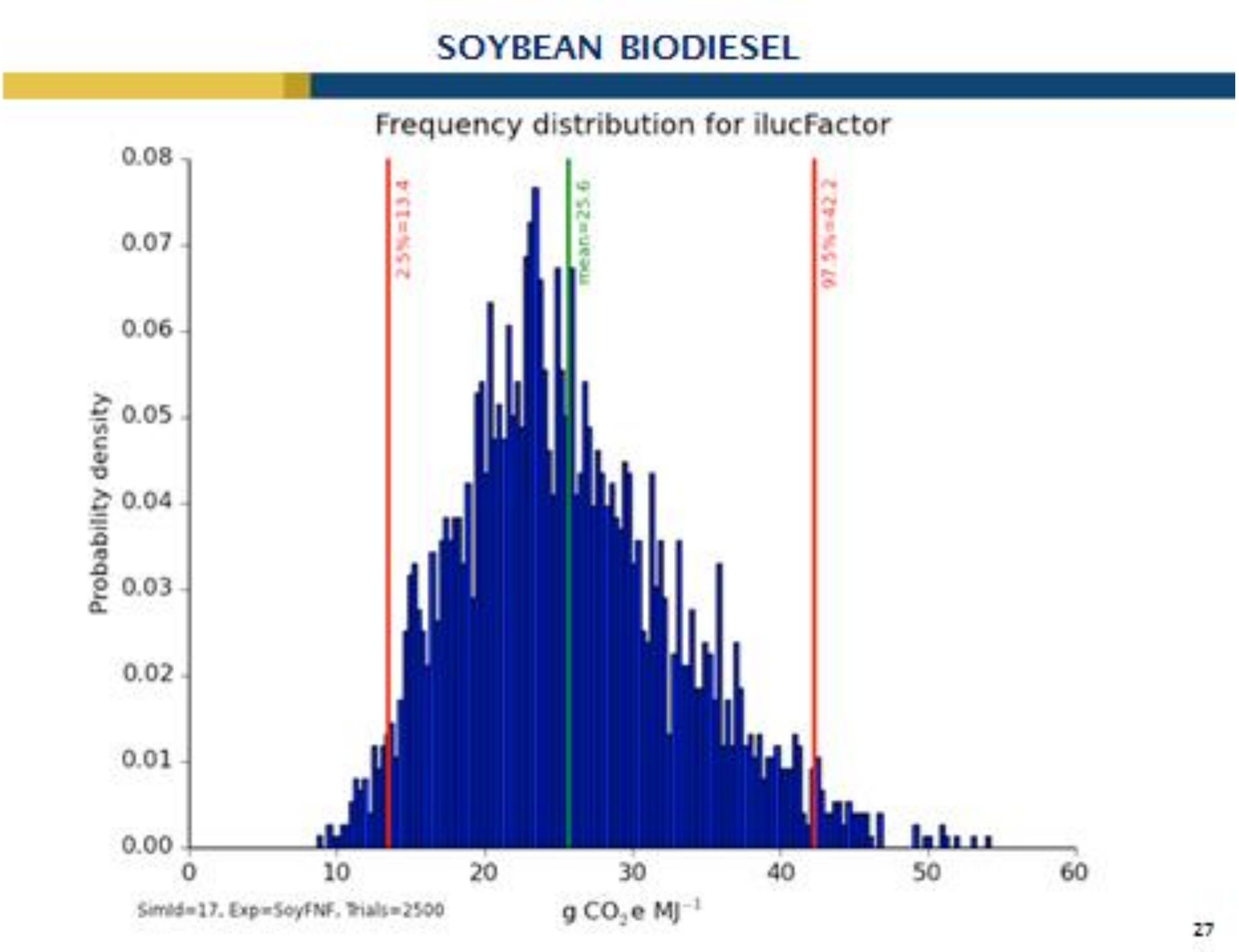
iLUC: Probability Distributions (Corn Ethanol)



iLUC: Probability Distributions (Sugarcane Ethanol)



iLUC: Probability Distributions (Soy Biodiesel)



iLUC: Comparison of Monte Carlo versus Scenario (Preliminary)

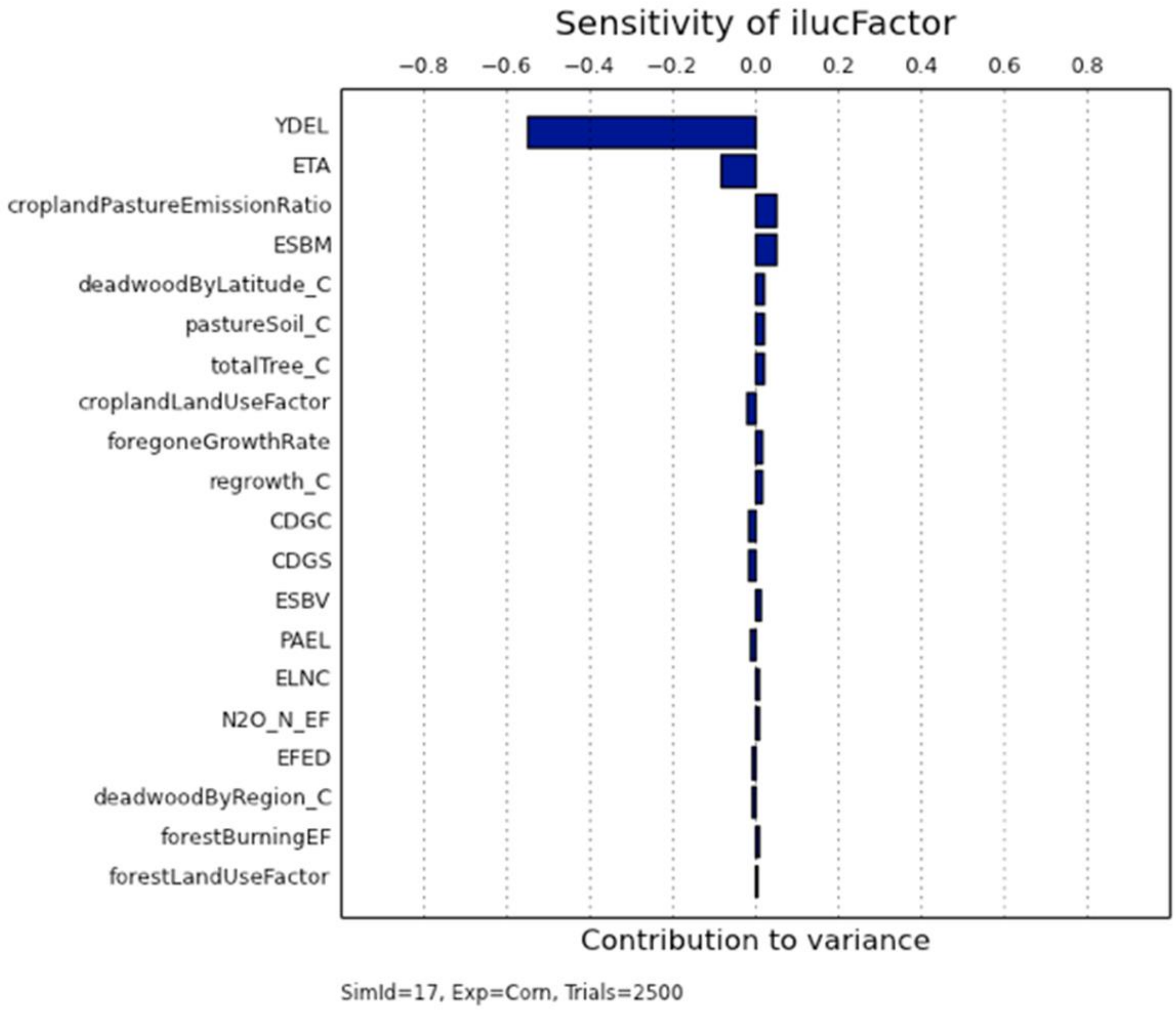
Biofuel	Monte Carlo (g/MJ)	Scenario (g/MJ)
Corn Ethanol	24.0	23.2
Sugarcane Ethanol	24.6	26.5
Soy Biodiesel	25.6	30.2
Canola Biodiesel	**	41.6
Sorghum Ethanol	**	17.5*

*** Only around 1200 runs completed, ** in progress**

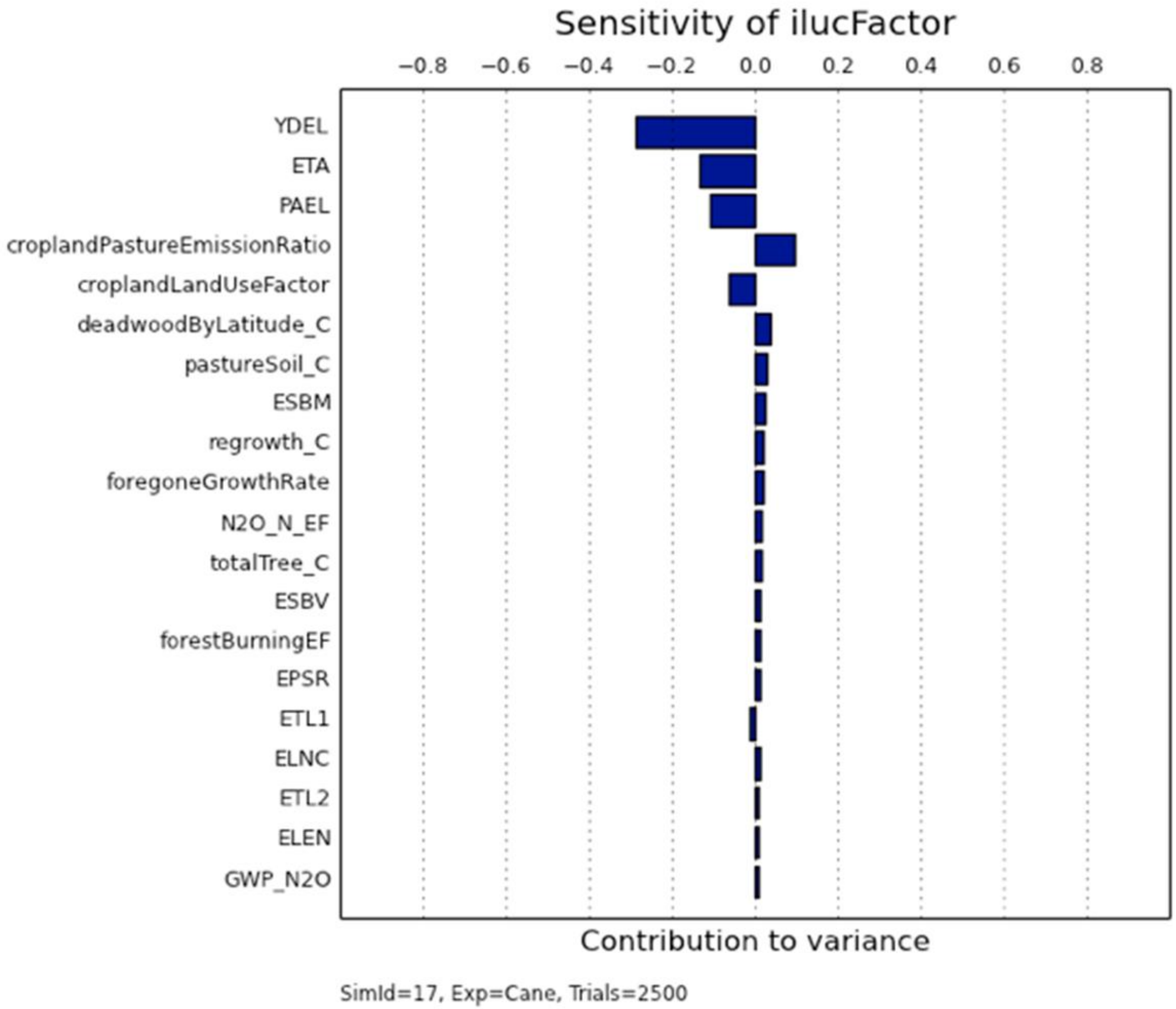
iLUC: Correlation / Covariance

- Accounts for dependencies between input variables
- Can simulate rank correlation fairly easily
- Irrelevant on unimportant/weakly correlated parameters

Uncertainty: Contribution to Variance in iLUC (Corn Ethanol)



Uncertainty: Contribution to Variance in ILUC (Sugarcane Ethanol)



Schedule for iLUC Analysis in 2014

iLUC: Schedule for 2014

- Present preliminary results (March 2014)
- Feedback requested by end of March 2014
- Evaluate and respond to feedback from workshop, and modify model and approach, if necessary
- Complete structural changes to the model to include irrigation and forestry
- Schedule one or two additional workshops to present new model and results to solicit feedback
- Evaluate, respond, and modify model if necessary

iLUC: Schedule for 2014 (cont.)

- Initiate and complete Independent Academic Review (IAR) (process to establish review panel has been initiated)
- Board Hearing in fall 2014 to consider updated iLUC values as part of considering the re-adoption of LCFS

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