A Life Cycle Assessment of Greenhouse Gas Emissions for Almond Production in California

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Research Objectives

- **Quantify** net greenhouse gas (GHG) **emissions** and **energy** use in California almond production, based on an accounting of all **material** and **energy inputs, biomass accumulation,** and **carbon sequestration**.
- **Generate** a **modeling tool** that will help identify "**hotspots**" (operations and inputs contributing most to total system emissions and energy use).
- **Address** the following **questions:**

How much do off-farm inputs contribute to an orchard GHG footprint, compared to on-farm operations?

To reduce the GHG footprint, is it more important to reduce tractor passes or to reduce pruning?

How will changing from flood to micro-sprinkler irrigation affect an orchard's GHG footprint?

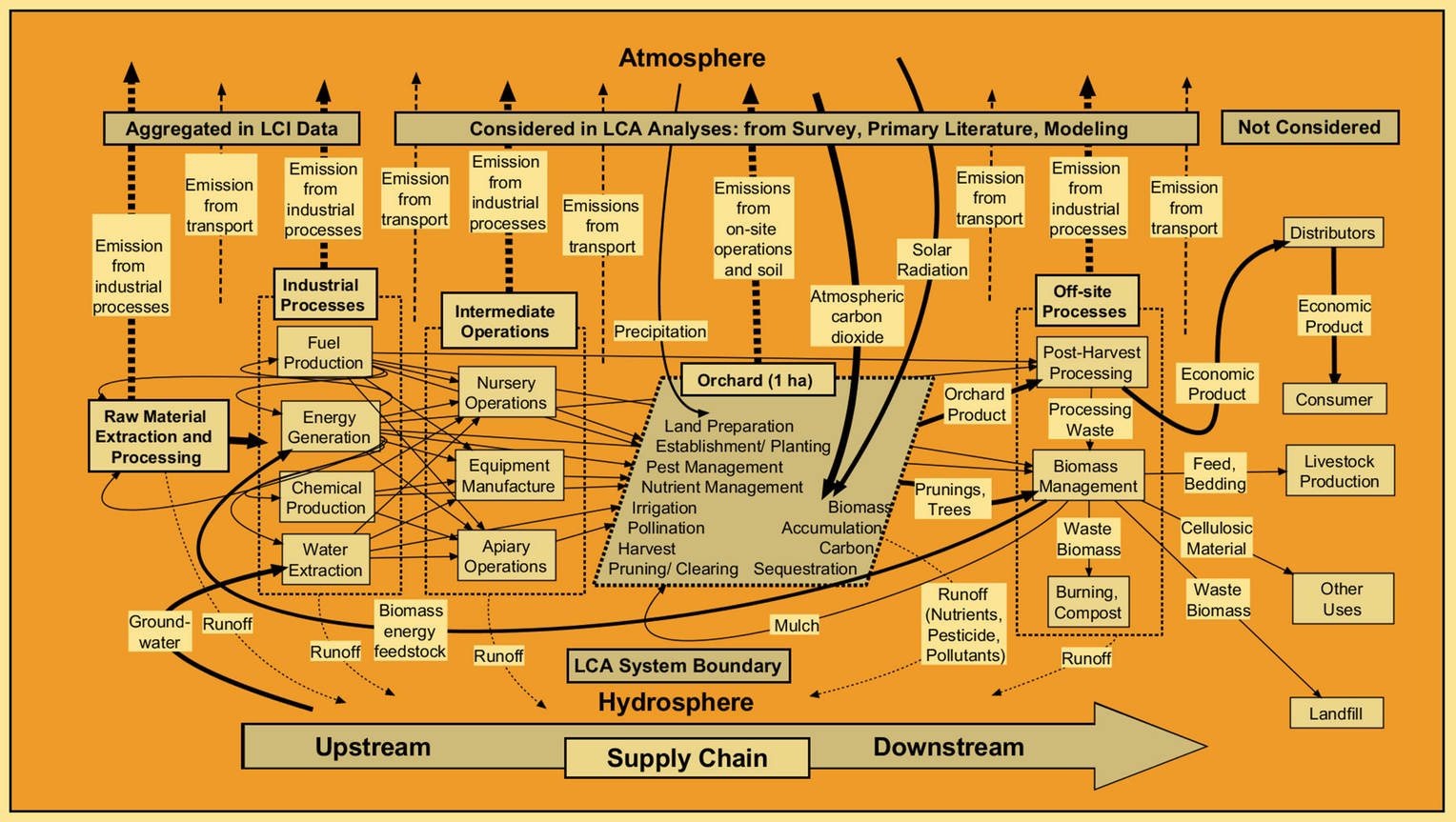


Figure 1. Life cycle inputs and outputs in the almond production system and relationship to environmental pools.

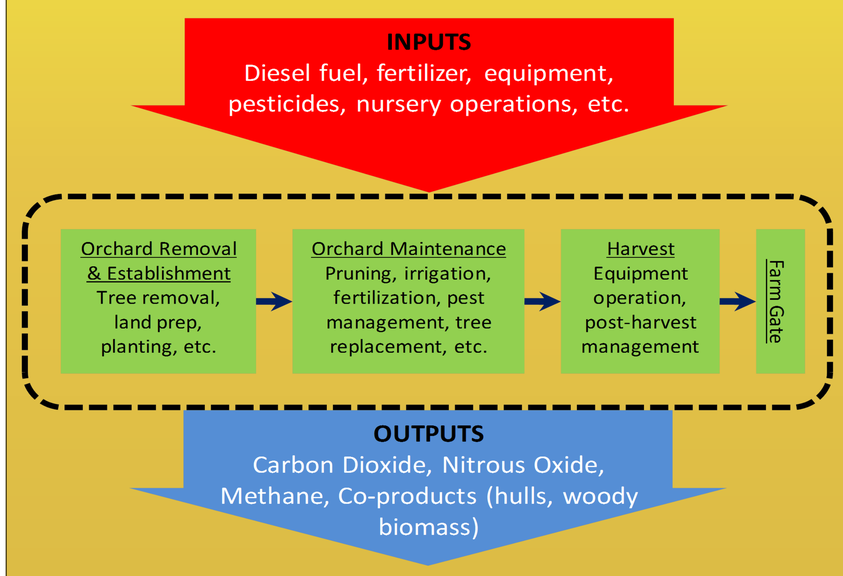


Figure 2. Simplified LCA model for almond production.

Life Cycle Assessment Approach

• **Life Cycle Assessment** (LCA) evaluates the energy and material **inputs** and **outputs** (product) over a system life cycle (in this study, the life cycle of almond production is measured from **nursery** to **farm gate**).

•Raw material extraction, manufacturing, transportation, in field fuel combustion, and ecological processes are accounted for. This allows a robust assessment of the **environmental sustainability** of a given process.

Methods

•**Input**, **yield**, and **operations** data were gathered from UC Davis Department of Agriculture and Resource Economics cost/return studies, farmer and operator survey, literature review, and collaboration with other researchers.

•**Emissions** and **energy** use data for industrial processes were collected from Life Cycle Inventory (LCI) databases provided by GaBi 4, Ecoinvent, and USLCI.

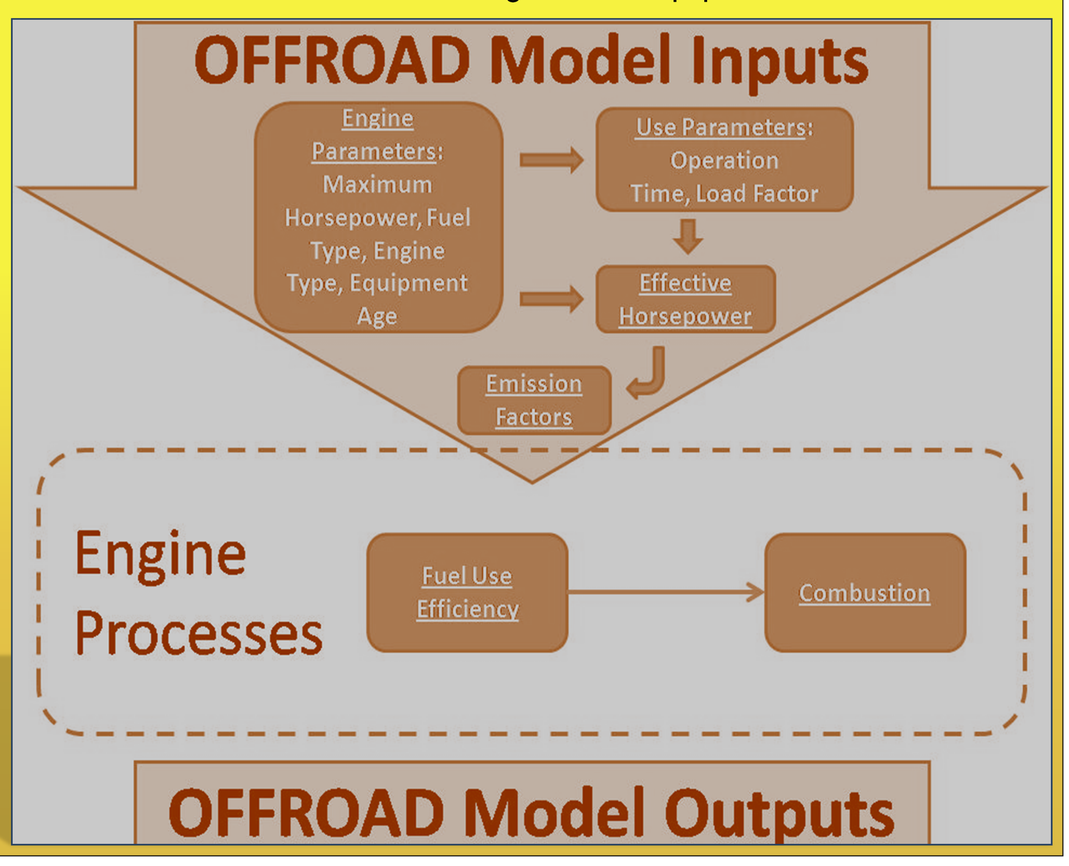
•Greenhouse gas emissions are expressed as **100-year Global Warming Potential (GWP)**, calculated according to Intergovernmental Panel on Climate Change (IPCC) guidelines.

•**Cogeneration potential** was calculated from tree mass at orchard clearing and pruning mass, based on a logarithmic growth model and assuming 95% biomass removed directed to cogeneration (G&F Ag Services LTD, personal communication).

•**Fuel combustion** emissions are calculated using the California Air Resources Board (CARB) OFFROAD modeling tool.

•**Soil emissions** in response to management and nutrient inputs are estimated using IPCC Tier 2 calculations.

Figure 3. General OFFROAD model structure for calculation of engine emissions from agricultural equipment



Results and Future Research Directions

• **Potential** greenhouse gas **offsets** represent a significant proportion of total almond production emissions (excluding processing and distribution).

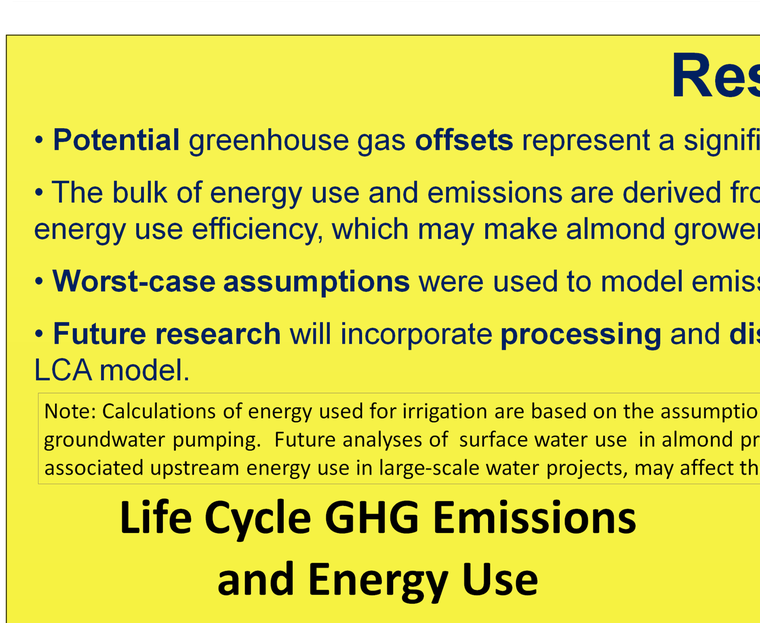
• The bulk of energy use and emissions are derived from **nutrient management** – particularly from **production** of **nitrogen fertilizers**. This is a **hotspot** for improvements in energy use efficiency, which may make almond growers eligible for carbon payments under potential future California Air Resources Board emissions offset programs.

• **Worst-case assumptions** were used to model emissions and energy use, so many individual orchards in California may have substantially **lower emissions** and **energy use**.

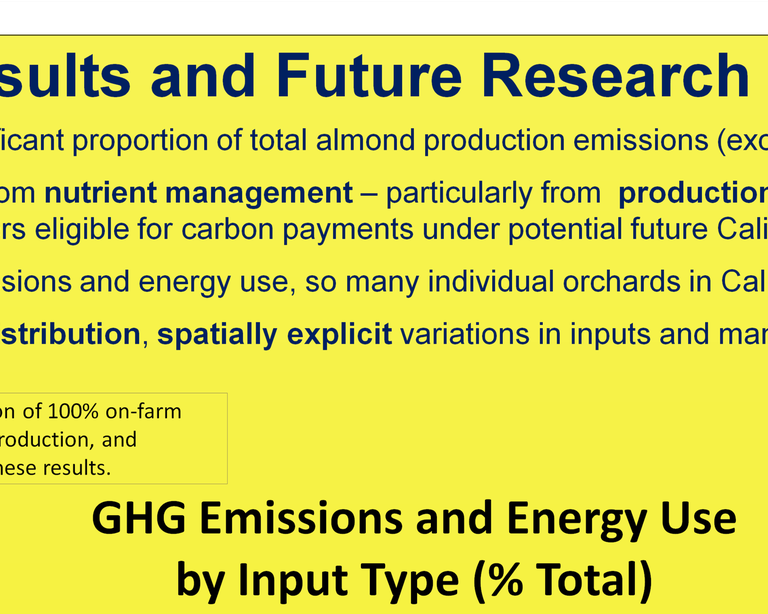
• **Future research** will incorporate **processing** and **distribution**, **spatially explicit** variations in inputs and management, and **IPCC Tier 3** field emissions models into the system LCA model.

Note: Calculations of energy used for irrigation are based on the assumption of 100% on-farm groundwater pumping. Future analyses of surface water use in almond production, and associated upstream energy use in large-scale water projects, may affect these results.

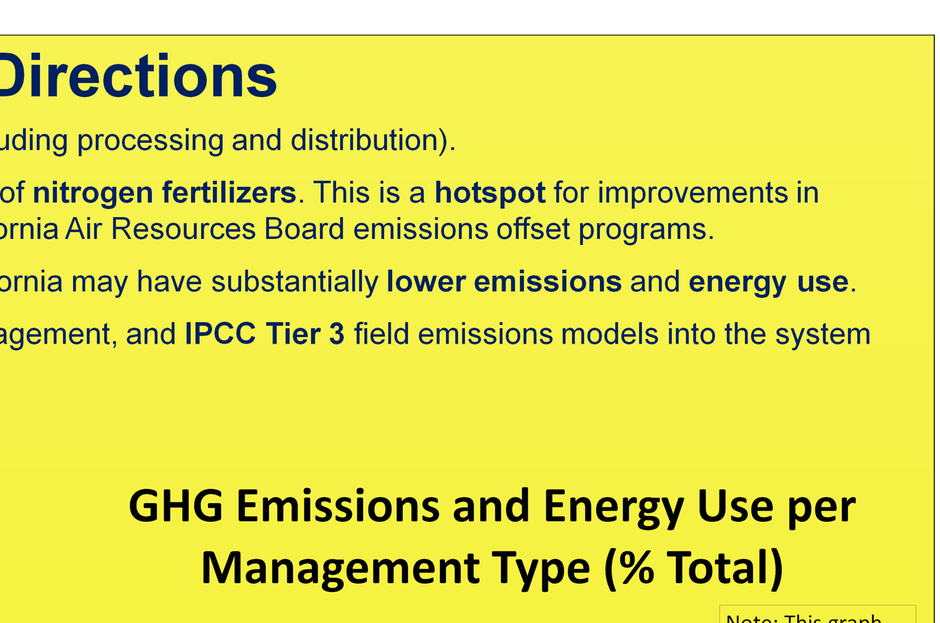
Life Cycle GHG Emissions and Energy Use



GHG Emissions and Energy Use by Input Type (% Total)



GHG Emissions and Energy Use per Management Type (% Total)



Note: This graph includes both energy and fuel as well as material inputs.