The Ruminant Farm Systems (RuFaS) Model: An Integrated Platform for a Sustainable Dairy Future

Reimagining Dairy Sustainability with RuFaS & AI

ANIMAL & DAIRY SCIENCES
University of Wisconsin-Madison

DairyBrain
AI

RuFaS.org

DAIRY MANAGEMENT
DECISION SUPPORT TOOLS

WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON

Victor E Cabrera | MREC Conference | LaCrosse | Feb 13, 2026

Dairy farms are complex systems; our scientific tools must be too.

Interconnected Systems: Changes in one area—like feed, genetics, or manure—have cascading effects across the entire farm.

Siloed Research: Most agricultural research focuses on single components, making it difficult to predict and quantify system-wide impacts.
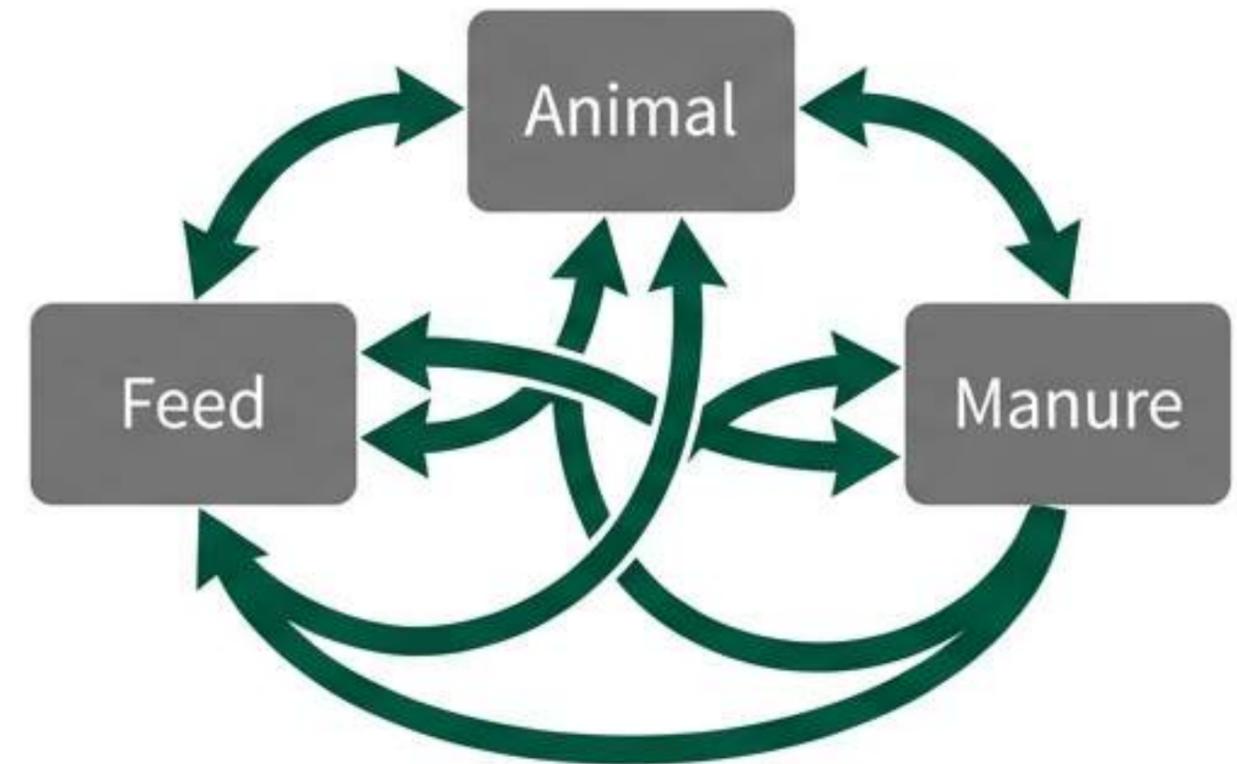
The Need: A new modeling environment is required to holistically assess management practices and support decisions for a more economically and environmentally sustainable future.
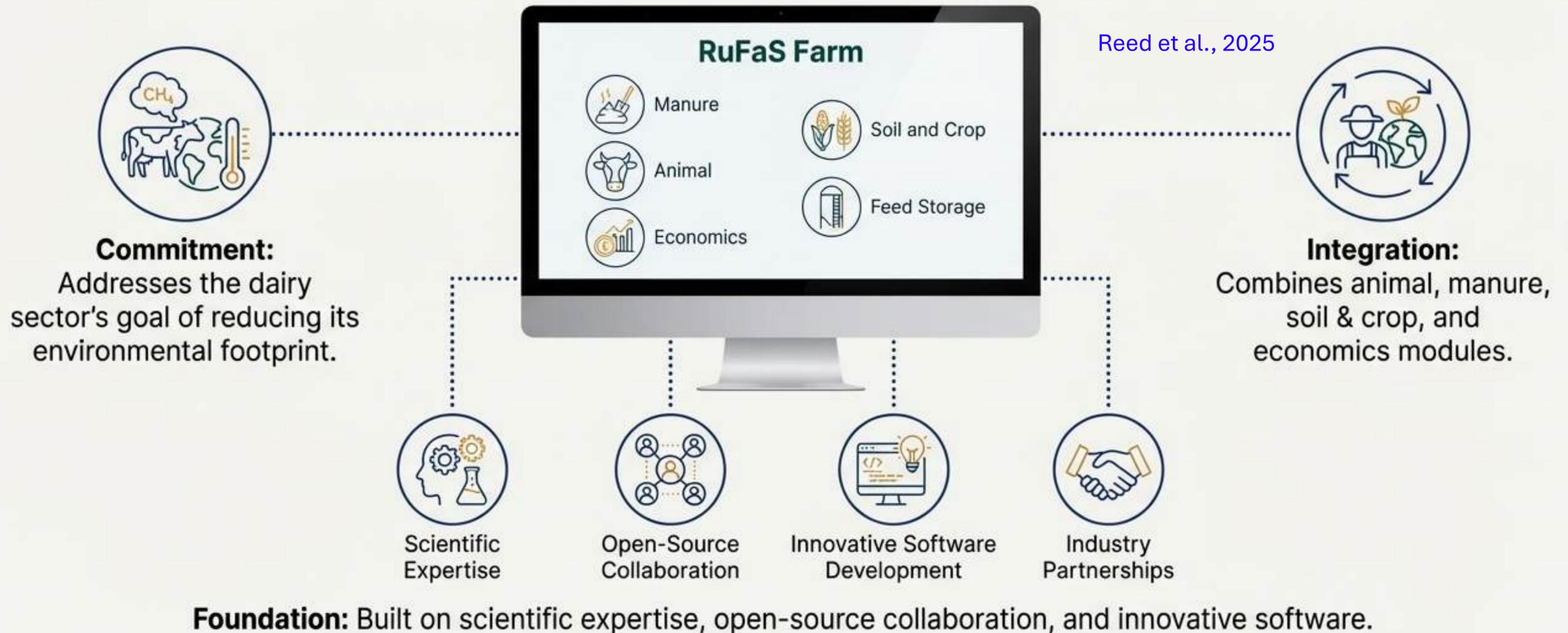
From Siloed...

Feed ➡ Animal ➡ Manure

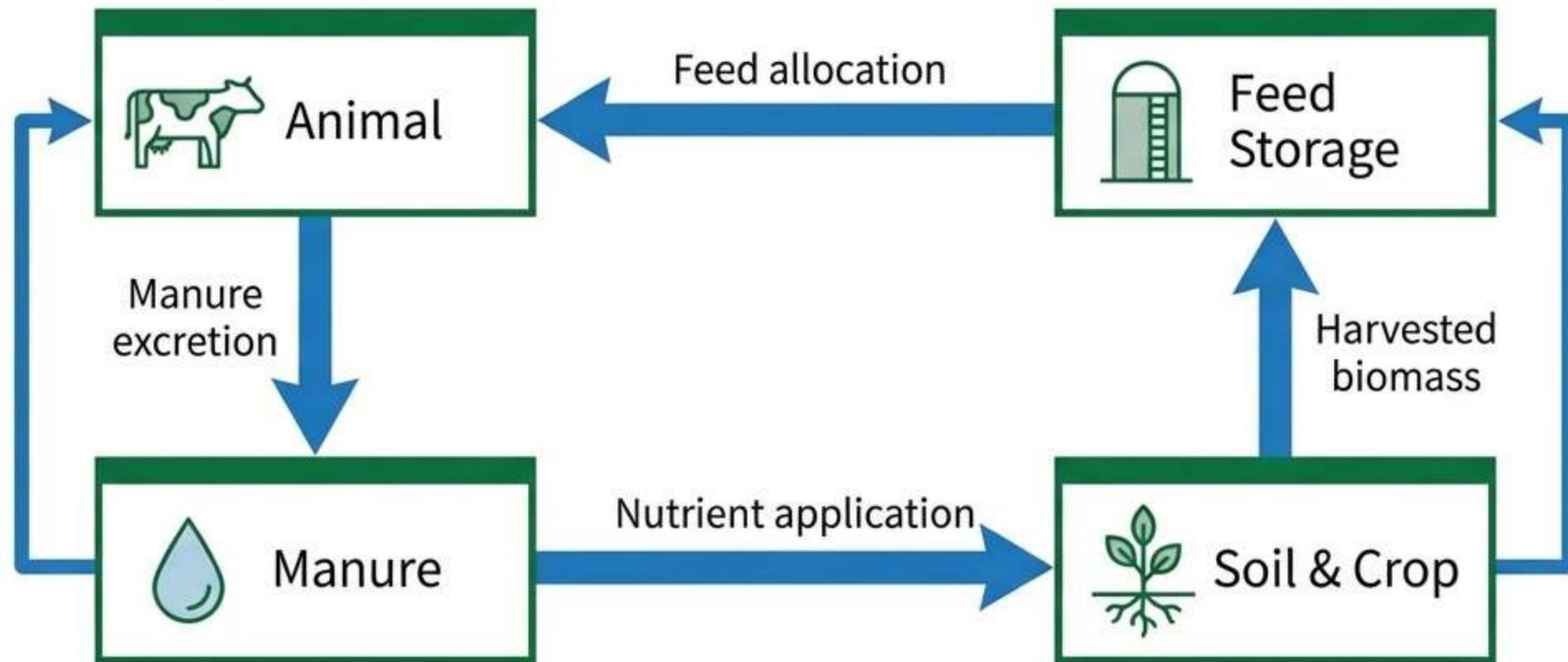## ...to Integrated

Animal
Feed
Manure

Introducing RuFaS: A Whole-Farm Simulation Platform

RuFaS is an open-source model that integrates the key functions of a dairy farm to simulate the real-world impact of management decisions.

Reed et al., 2025

RuFaS Farm
- Manure
- Animal
- Economics
- Soil and Crop
- Feed Storage

Commitment:
Addresses the dairy sector's goal of reducing its environmental footprint.

Integration:
Combines animal, manure, soil & crop, and economics modules.

Scientific Expertise

Open-Source Collaboration

Innovative Software Development

Industry Partnerships

Foundation: Built on scientific expertise, open-source collaboration, and innovative software.

The Architecture of RuFaS: A Whole-Farm System

RuFaS simulates the daily exchange of information between modules, mirroring the integrated nature of a real dairy farm.

The Four Engines of the Farm

Animal: Simulates the life cycle, reproduction, growth, and production of individual animals and the herd.

Feed Storage: Manages the farm's feed inventory, accounting for quality changes and losses from harvest to feeding.

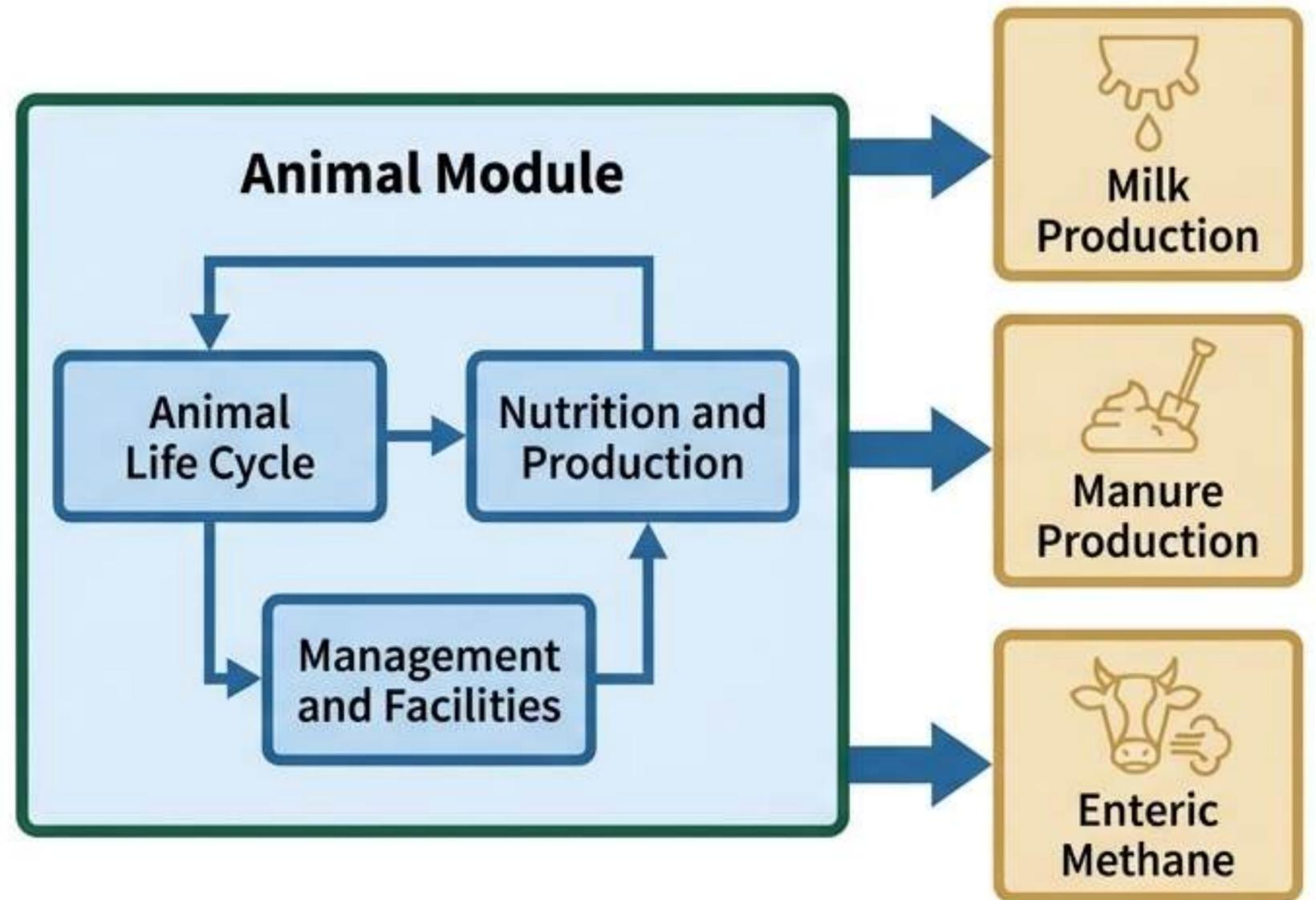**Manure:** Tracks manure through collection, storage, and treatment, predicting nutrient composition and emissions.

Soil & Crop: Models soil health, crop growth, and field management to determine yields and environmental losses.
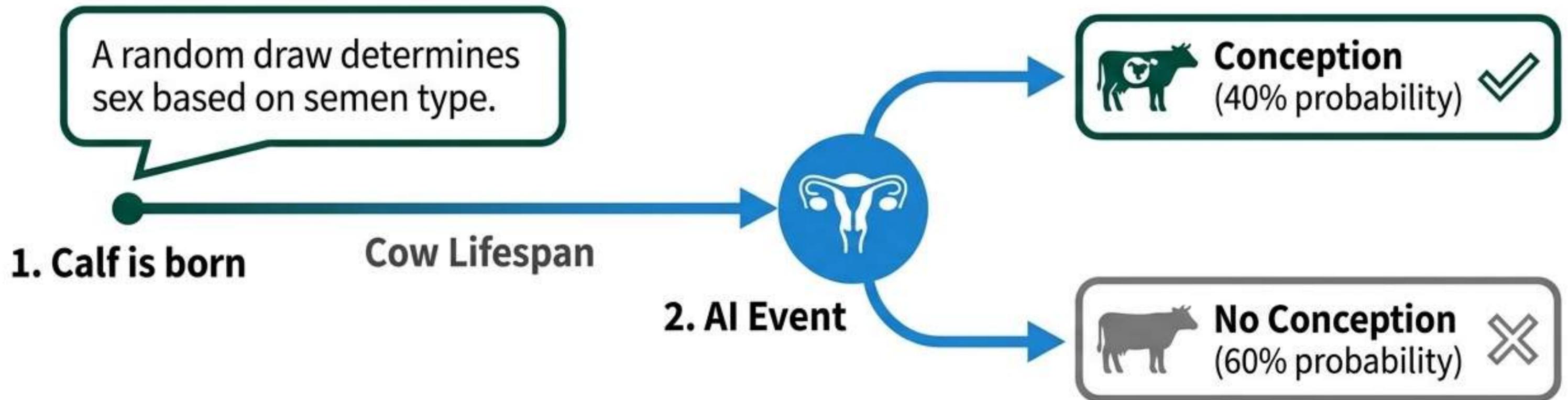
A Closer Look: The The Animal Module

The Animal Module simulates the life cycle, health, and productivity of dairy cattle at both the individual and herd level. It operates on a daily time step, capturing key events:

✓ Growth and Reproduction

✓ Lactation and Production

✓ Health and Disease

✓ Culling and Replacement

Animal Module

Animal Life Cycle → Nutrition and Production

Animal Life Cycle → Management and Facilities → Nutrition and Production

Milk Production

Manure Production

Enteric Methane

Capturing Reality: How Stochastic Simulation Works

RuFaS uses Monte Carlo processes to simulate life events for each individual animal as a series of probabilities, not fixed certainties.


A random draw determines sex based on semen type.

1. Calf is born

Cow Lifespan

2. AI Event

Conception
(40% probability) ✓

No Conception
(60% probability) ✗

3. Life events are triggered by comparing a random draw to a known scientific probability. This allows the model to represent the full range of outcomes and herd dynamics, not just an average.

A Life Story Written by Science and Chance

Each animal's life is a unique sequence of daily events, each determined by a new roll of the dice.
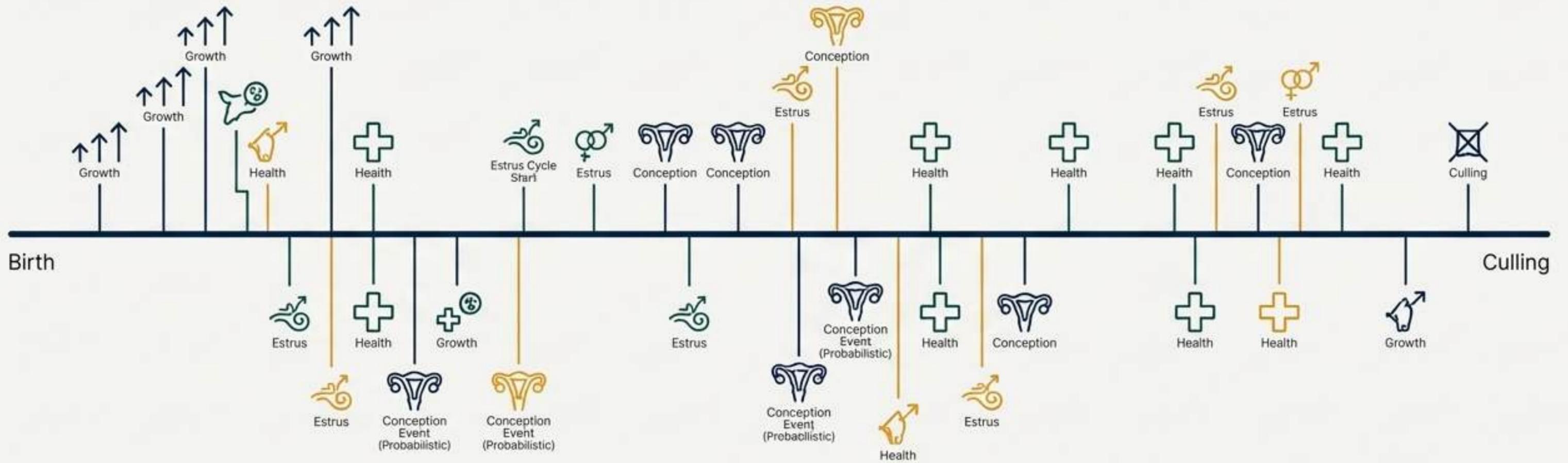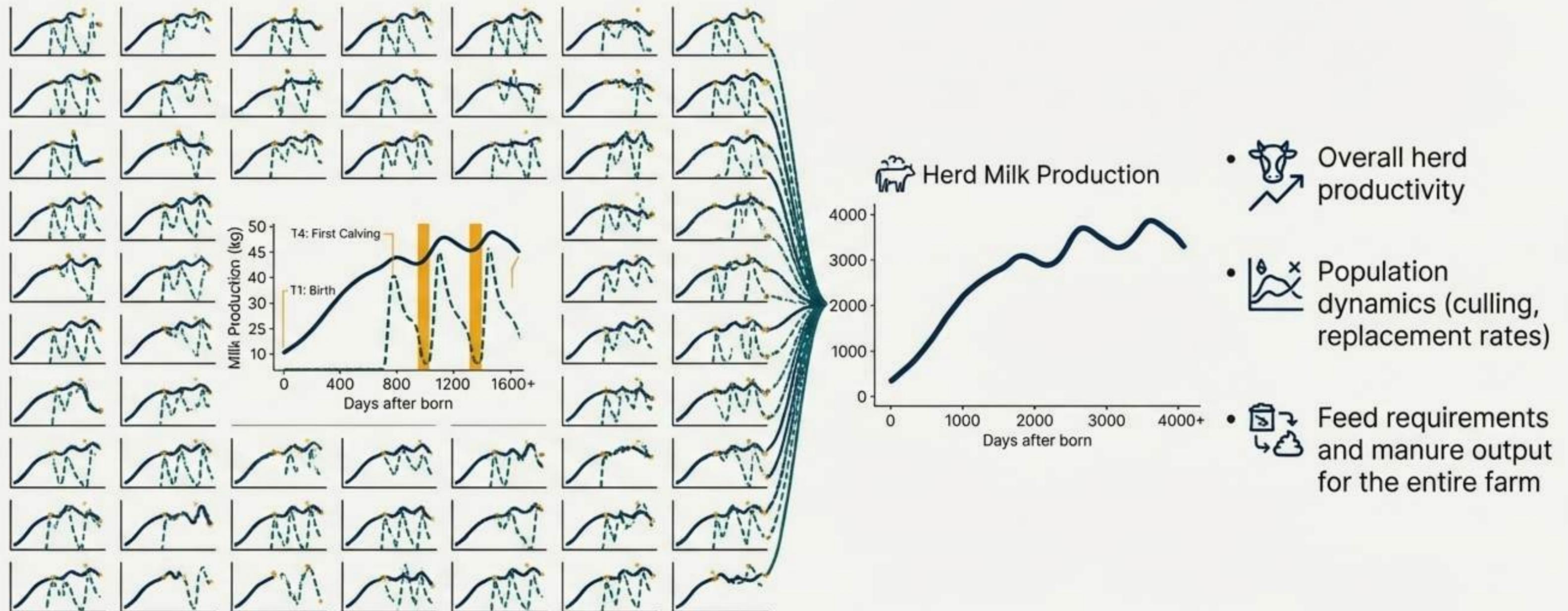
Visualizing the Life Story of a Simulated Animal
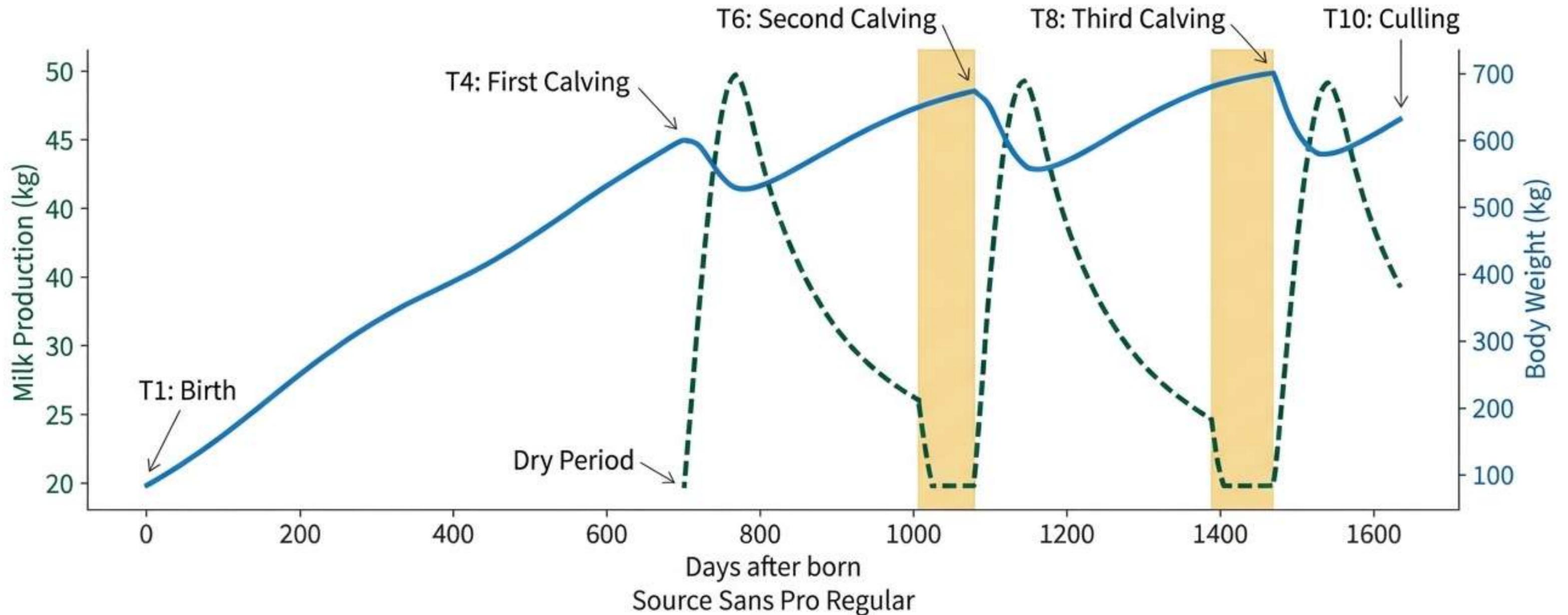
The daily time step enables the model to represent a broad range of management practices and track detailed individual animal histories.
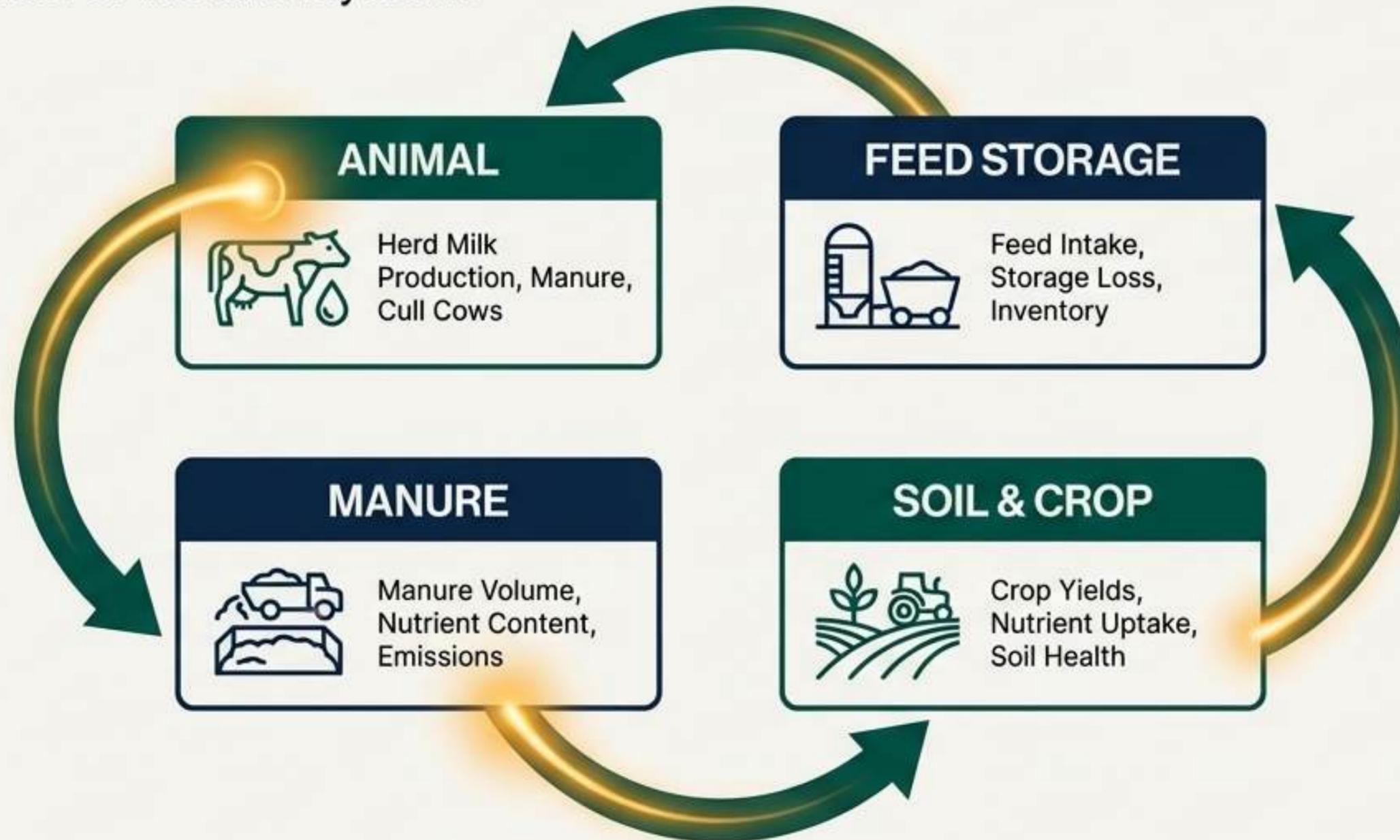
From an Animal to a Herd

By simulating thousands of individual life stories simultaneously, RuFaS creates a dynamic and realistic model of the entire herd.

Connecting the Dots Across the Farm

The herd-level outputs from the Animal Module become the daily inputs for the rest of the farm system.

ANIMAL
Herd Milk Production, Manure, Cull Cows

FEED STORAGE
Feed Intake, Storage Loss, Inventory

MANURE
Manure Volume, Nutrient Content, Emissions

SOIL & CROP
Crop Yields, Nutrient Uptake, Soil Health

RuFaS in Action: From Simulation to Solution

A Deep Dive into the Applications of an Integrated, Science-Based Model for Dairy Sustainability

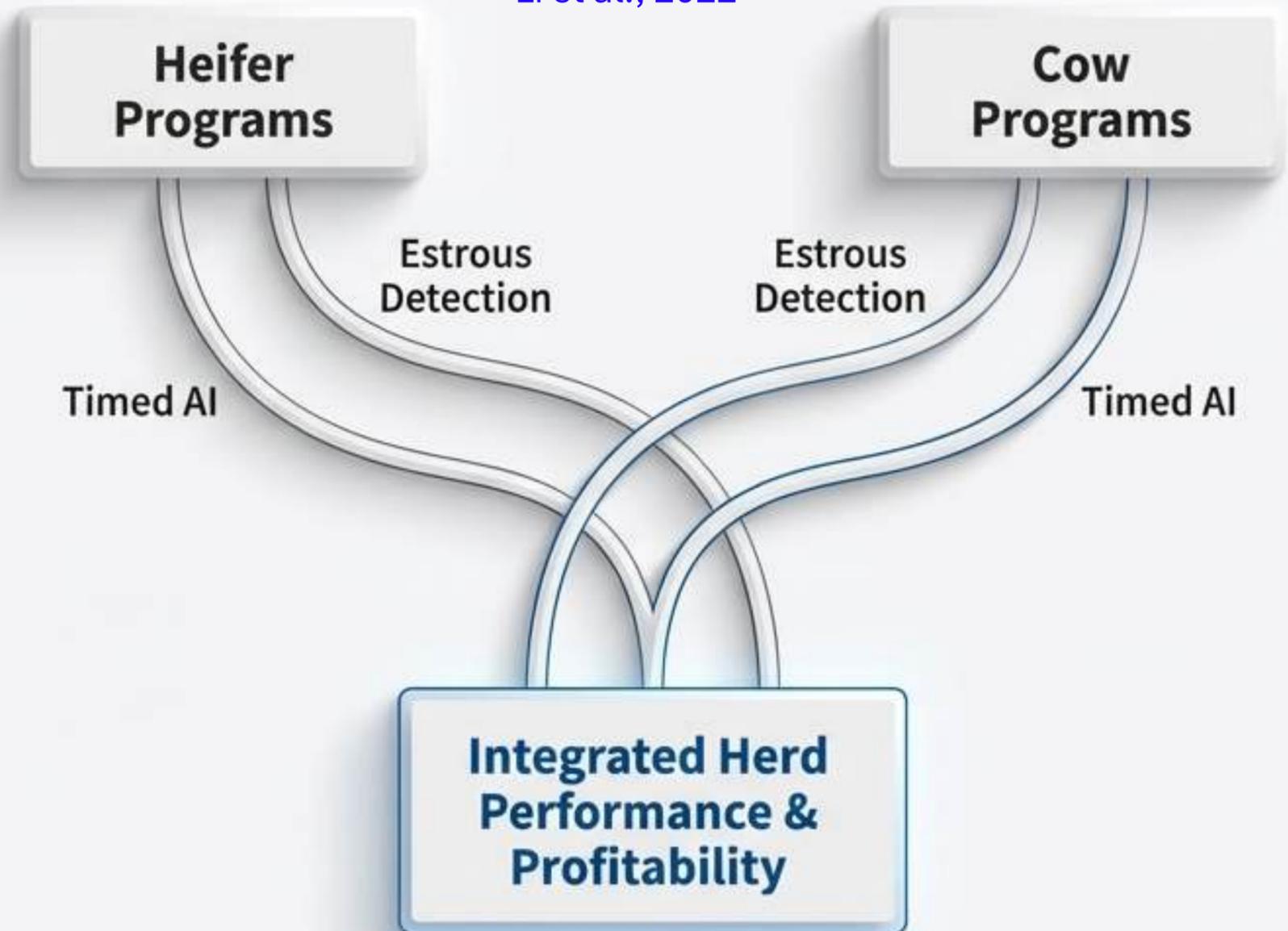# DEEP DIVE 1: The Economics of Reproductive Strategy

What is the most profitable combination of reproductive management programs for an entire dairy herd?

The Challenge: Reproductive performance is a key driver of profitability, but decisions for heifers and lactating cows are often made in isolation.

The Analysis: RuFaS simulated a 1,000-cow herd over 7 years, testing 10 different scenarios combining common programs for both heifers and cows.

The Key Insight: Heifer and cow programs have powerful, integrated effects. Analyzing them together is critical for understanding whole-farm profitability.

Li et al., 2022

Heifer Programs

Cow Programs

Estrous Detection

Estrous Detection

Timed AI

Timed AI

Integrated Herd Performance & Profitability

Modeling the Matrix of Choice

The simulation compared programs ranging from minimal intervention (Estrous Detection) to aggressive, hormone-based protocols (Timed AI).

Heifer Programs (H)

H1: Estrous Detection (ED)
Relies on observation.

H2: Synchronized ED (Synch-ED)
Hormones to group estrus, then observation.

H3: Timed AI (TAI)
Fully synchronized using a 5-d CIDR-Synch protocol.

Lactating Cow Programs (C)

C1: ED + Ovsynch
Primarily observation, with TAI for non-responders.

C2: ED-TAI (Presynch-Ovsynch)
Combination of scheduled observation and TAI.

C3/C4: TAI (Double-Ovsynch)
Aggressive, fully synchronized TAI protocols.
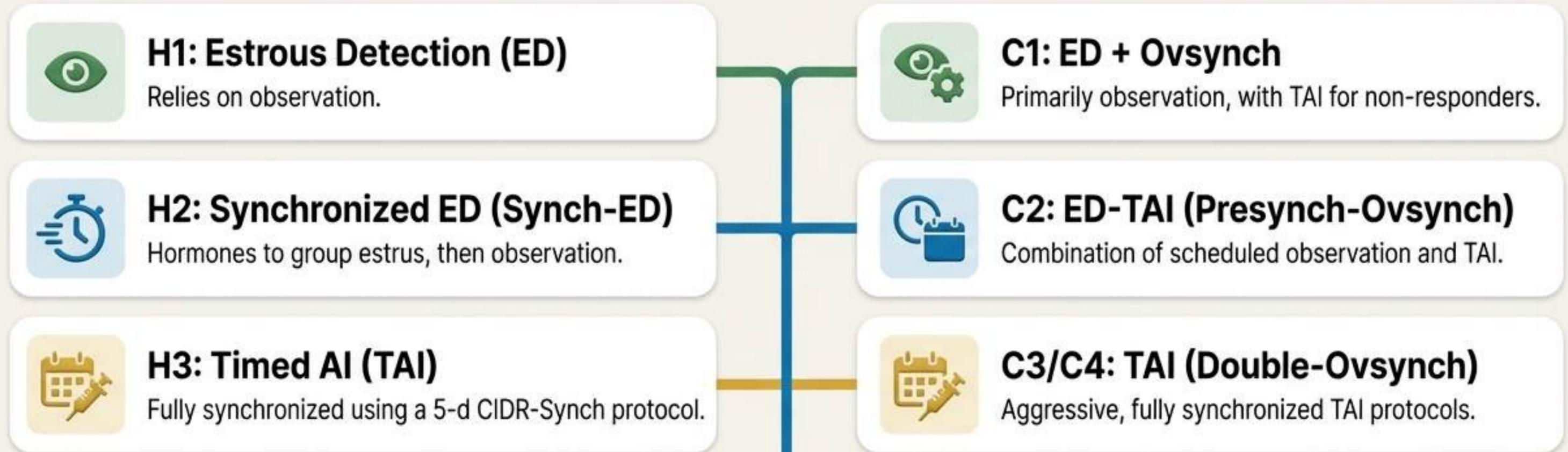
10 Scenarios Modeled: Every H x C Combination

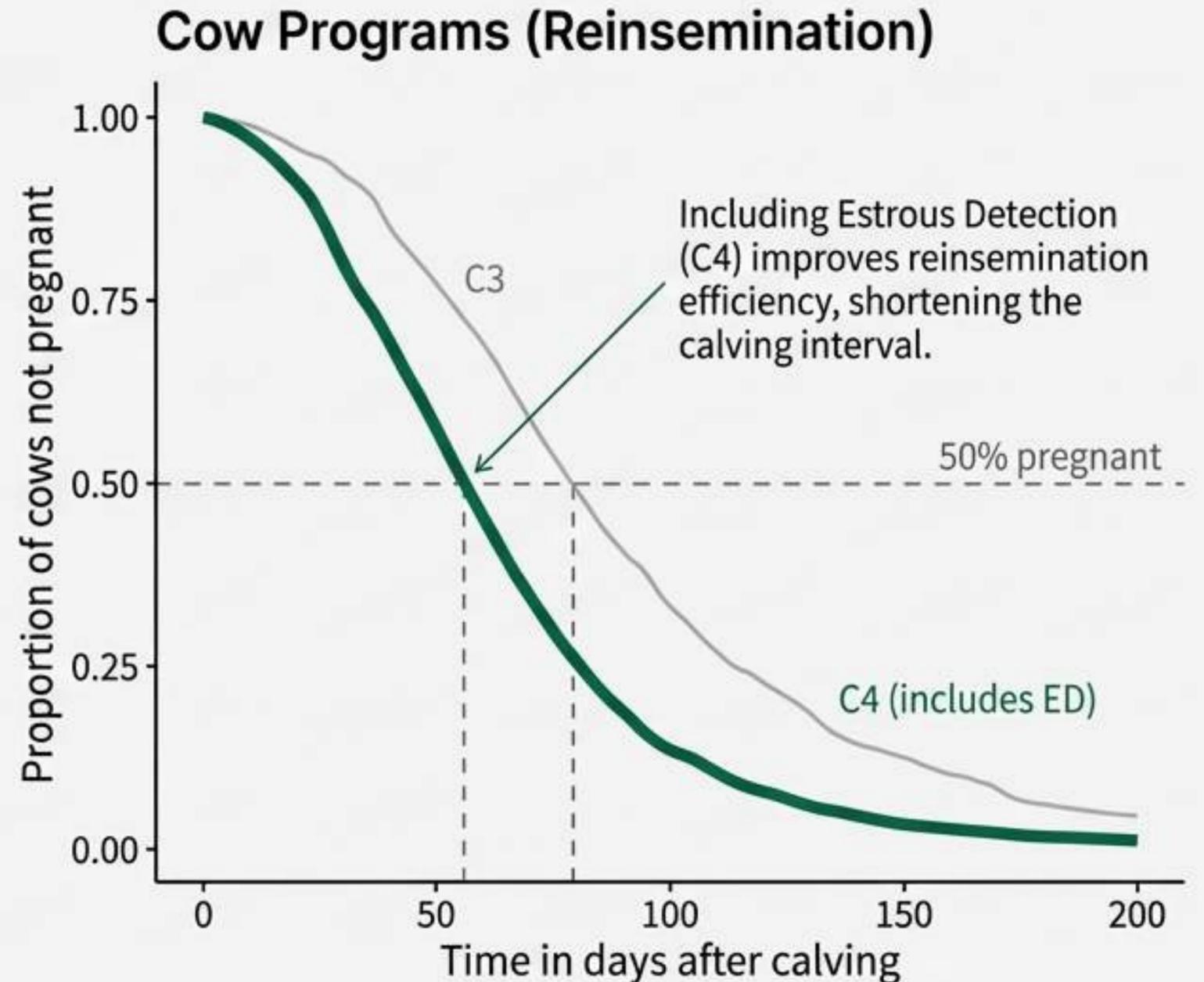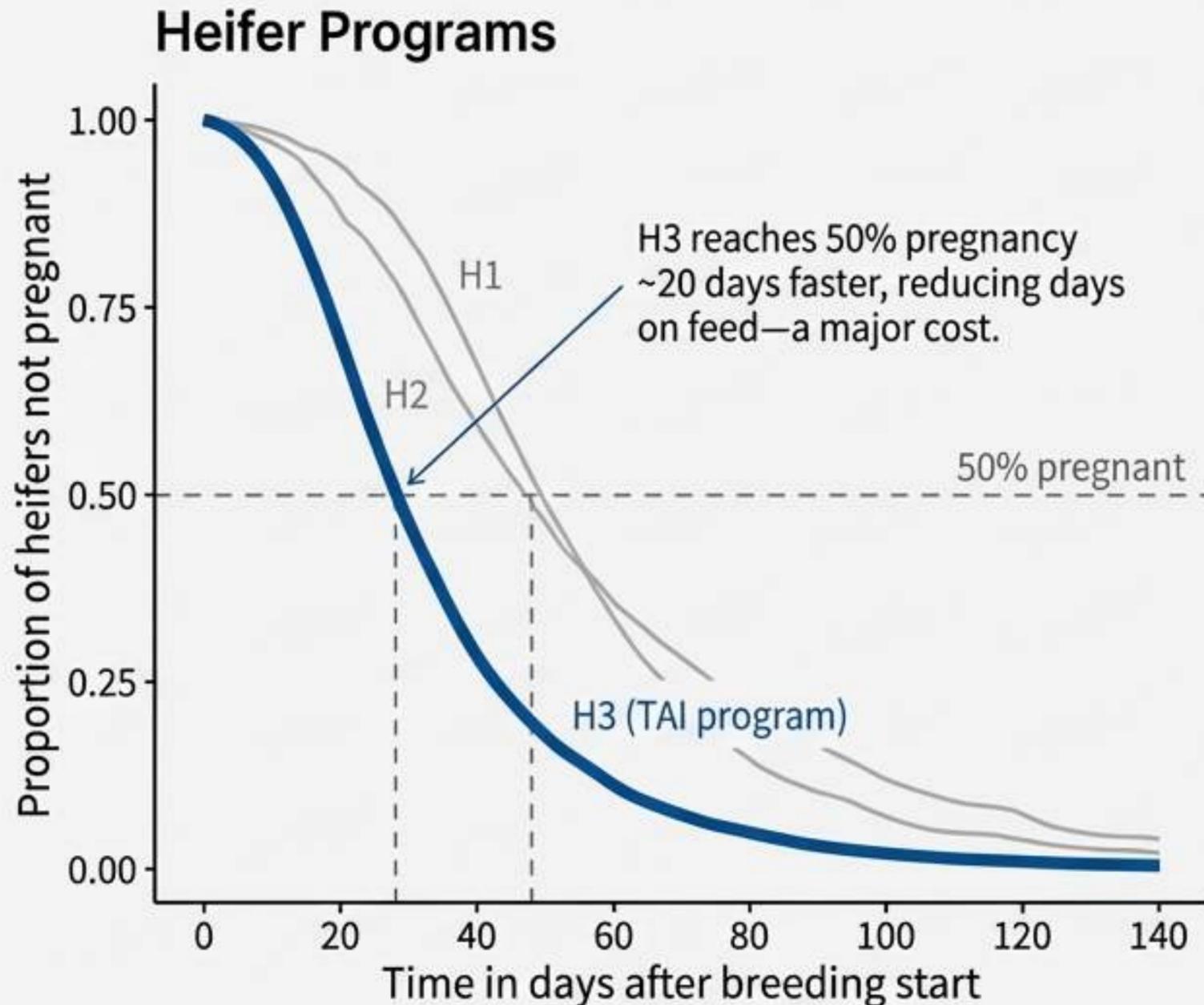# The Performance Driver: Fewer Days to Pregnancy

More aggressive programs get heifers and cows pregnant faster, directly impacting costs and productivity.

Heifer Programs

Proportion of heifers not pregnant

H1
H2
H3 reaches 50% pregnancy ~20 days faster, reducing days on feed—a major cost.
50% pregnant
H3 (TAI program)

Time in days after breeding start

Cow Programs (Reinsemination)

Proportion of cows not pregnant

C3
Including Estrous Detection (C4) improves reinsemination efficiency, shortening the calving interval.
50% pregnant
C4 (includes ED)

Time in days after calving

The Economic Verdict: Integration Drives Profit

The greatest Net Return was achieved with a fully integrated Timed AI strategy for both heifers and cows.

Highest Net Return: $2,099,035/yr
Scenario: H3-C3 (TAI Heifers + TAI Cows)

A **$39,244** annual difference between the highest and lowest performing strategies.

Lowest Net Return: $2,059,791/yr
Scenario: H2-C1 (Synch-ED Heifers + ED Cows)

A fully synchronized TAI program (H3-C3) outperformed all other combinations, demonstrating a clear financial benefit.

The System-Wide Ripple Effect

Better reproduction isn't just about speed; it reshapes the entire herd, unlocking further economic benefits.

Optimized Reproduction (H3-C3)

Lower Culling & Replacement Need
More efficient programs result in fewer reproductive culls, reducing the need to raise or buy expensive replacement heifers.

Reduced Youngstock Feed Costs
The top scenario (H3-C3) saved **$25,245/yr** in youngstock feed costs compared to the lowest (H2-C1).

More Calves to Sell
Efficient reproduction leads to more calves born, generating greater income from calf sales (**+$1,936/yr**).

RuFaS reveals the hidden value: reproductive efficiency's downstream impact on herd structure and feed costs is a massive, often overlooked, contributor to profitability.

DEEP DIVE 2: The Environmental Impact of Genetic Selection

Can we translate the benefits of selecting for healthier, more productive cows into hard environmental numbers?

Weigel et al., 2025

The Challenge:
The dairy industry increasingly selects for traits beyond production, like health and fertility, using indices like the Dairy Wellness Profit Index (DWP$). The environmental co-benefits are assumed but rarely quantified.
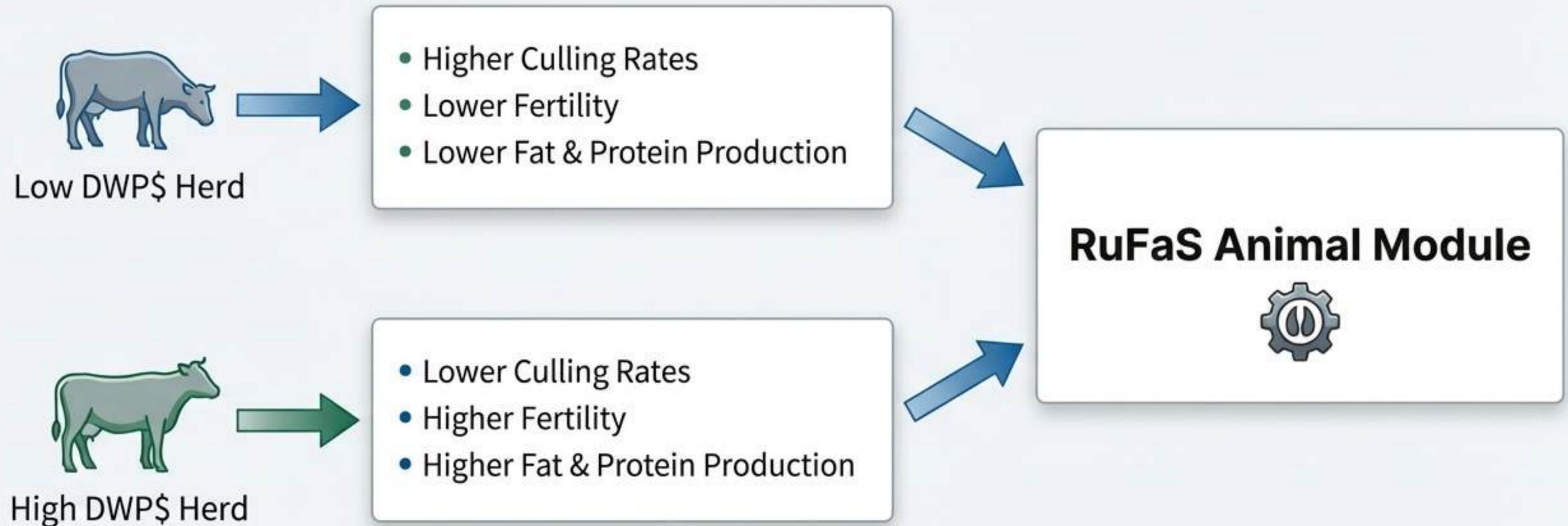
The Analysis:
RuFaS simulated herds representing the real-world productivity and health outcomes of high and low DWP$ cows.

The Key Insight:
RuFaS acts as a bridge, connecting complex genetic indices to tangible sustainability metrics, making making the benefits of advanced breeding programs visible and quantifiable.

Modeling the 'Better' Cow

The model was configured to reflect the distinct performance profiles of high- and low-ranking DWP$ animals.

Low DWP$ Herd

- Higher Culling Rates
- Lower Fertility
- Lower Fat & Protein Production

High DWP$ Herd

- Lower Culling Rates
- Higher Fertility
- Higher Fat & Protein Production

RuFaS Animal Module

The Quantified Environmental Dividend

Selecting for higher DWP$ directly translates to a lower environmental footprint per unit of milk produced.

Lower Enteric Methane Intensity

Healthier, more productive cows are more feed-efficient, producing less methane for every unit of milk.

Lower Nitrogen Excretion Intensity

Improved nutrient utilization means less excess nitrogen is excreted into the environment.

Genetic selection is a powerful environmental strategy. RuFaS provides the tool to quantify its impact and build it into sustainability planning.
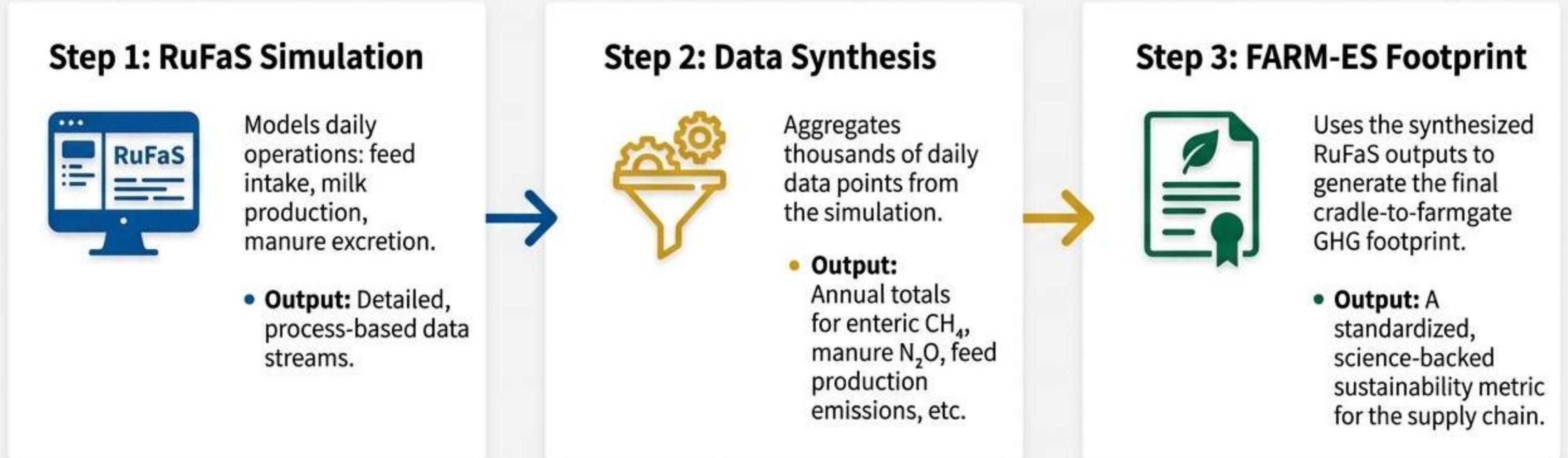
DEEP DIVE 3: The Scientific Engine of FARM-ES

RuFaS is not just a research model; it underpins the environmental stewardship program for 80% of the U.S. milk supply.

Reed et al., 2025

RuFaS

80% of the U.S. Milk Supply

FARM-ES

The Farmers Assuring Responsible Management (FARM) Environmental Stewardship program relies on RuFaS for its GHG accounting.

How It Works: From Process Model to Footprint

RuFaS provides the detailed, daily outputs that are essential for a credible and robust farm-gate emissions footprint.

Step 1: RuFaS Simulation

Models daily operations: feed intake, milk production, manure excretion.

- **Output:** Detailed, process-based data streams.

Step 2: Data Synthesis

Aggregates thousands of daily data points from the simulation.

- **Output:** Annual totals for enteric CH_4, manure N_2O, feed production emissions, etc.

Step 3: FARM-ES Footprint

Uses the synthesized RuFaS outputs to generate the final cradle-to-farmgate GHG footprint.

- **Output:** A standardized, science-backed sustainability metric for the supply chain.

DEEP DIVE 4: The Challenge: Why Generic Models Fail Specific Farms

Gong et al., 2025

- **The Problem:** Whole-farm models are powerful, but their predictions are inaccurate when relying on national averages. Each farm has a unique 'performance signature' based on genetics, feed, and management.

- **The Core Issue:** Lactation curves, the foundation of milk production, vary significantly between farms. A generic curve leads to massive prediction errors.

- **The Question:** How can we tailor the model to reflect a specific farm's reality, using data that's already on hand?

NY   TX   WI
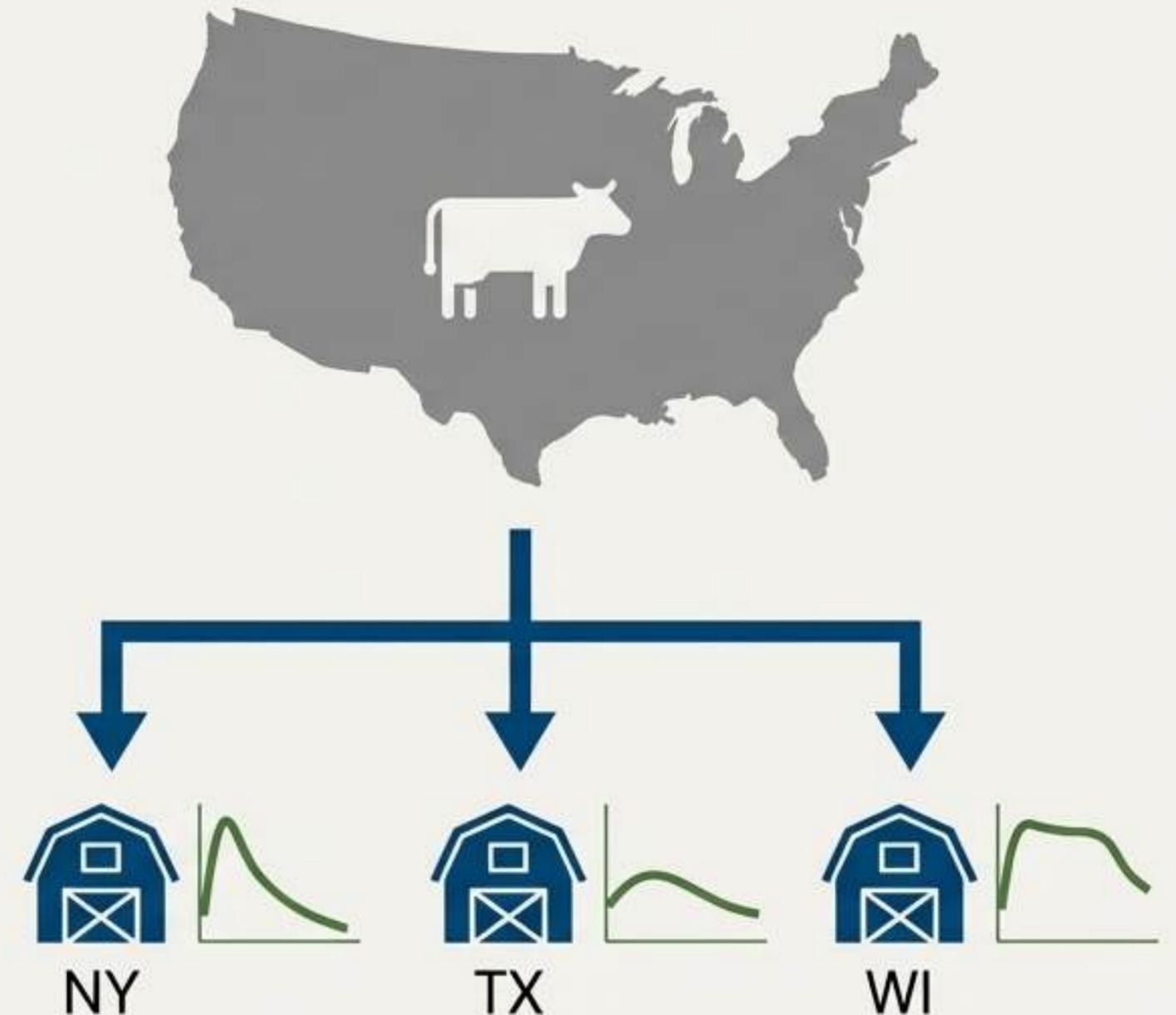
The Solution: A 2-Step Calibration Engine

From National Average to Farm-Specific

Baseline

Starts with national parameter averages (Li et al., 2022) for lactation curve parameters a, b, c.

Adjusted by:
- Parity
- Region
- Milking Frequency, etc.

Parameter a further adjusted by

Calibrated

The model's scale parameter (a) is fine-tuned using three simple, farm-level data points to match observed production.
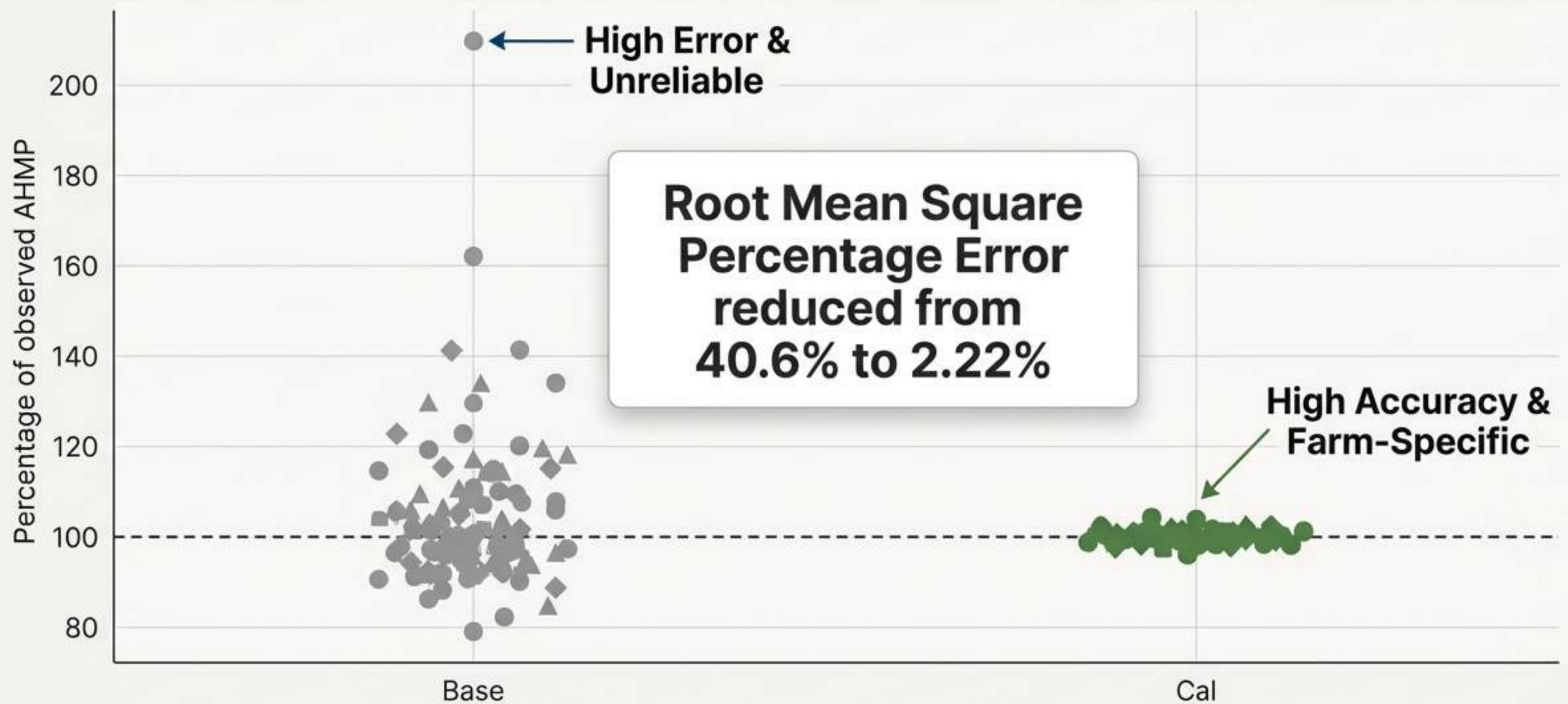
Annual Herd Milk Production (AHMP)

Number of Milking Cows

Herd Parity Composition

The Verdict: From 40.6% Error to 2.2% Precision

High Error & Unreliable

Root Mean Square Percentage Error reduced from 40.6% to 2.22%

High Accuracy & Farm-Specific

Percentage of observed AHMP

Base   Cal

The Ripple Effect of Accuracy
## Why Precision Matters: Accurate Inputs Drive Reliable Outputs

An accurate milk production forecast is the engine of the whole-farm simulation. When milk yield is right, the downstream predictions for environmental and performance metrics become reliable.

Realistic Feed Intake (DMI)

Credible Manure Excretion

Accurate Milk Production

Reliable Gross Feed Efficiency (GFE)

Trustworthy GHG Footprint (CH$_4$, N$_2$O)

DEEP DIVE 5: The Impact Question: Can We Model a 'Better' Cow?

Hansen et al., 2021

- **The Goal** The industry is increasingly breeding cows for improved feed efficiency— producing the same milk with less feed, measured by Residual Feed Intake (RFI).

- **The Challenge** While the benefits are assumed, their total system-wide environmental impact is hard to quantify. How much does improved RFI *really* reduce a farm's footprint?

- **The Application** Can we use the now-precise RuFaS Animal Module to simulate herds with different levels of feed efficiency and measure the exact environmental dividend?

Standard Efficiency
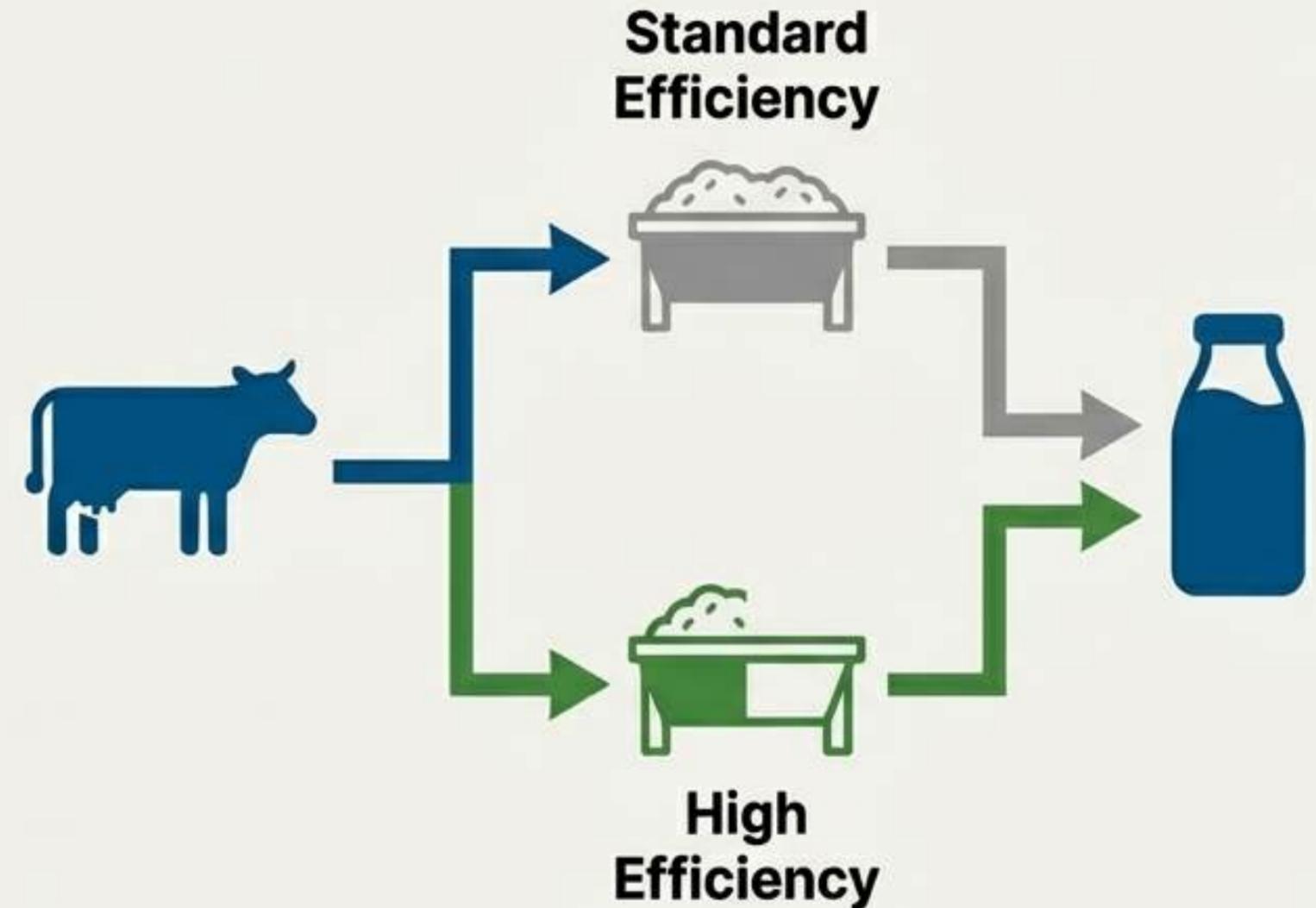
High Efficiency

The Approach: Simulating a Shift in Herd Efficiency

Modeling the Genetic Shift: Baseline vs. High-Efficiency Herds

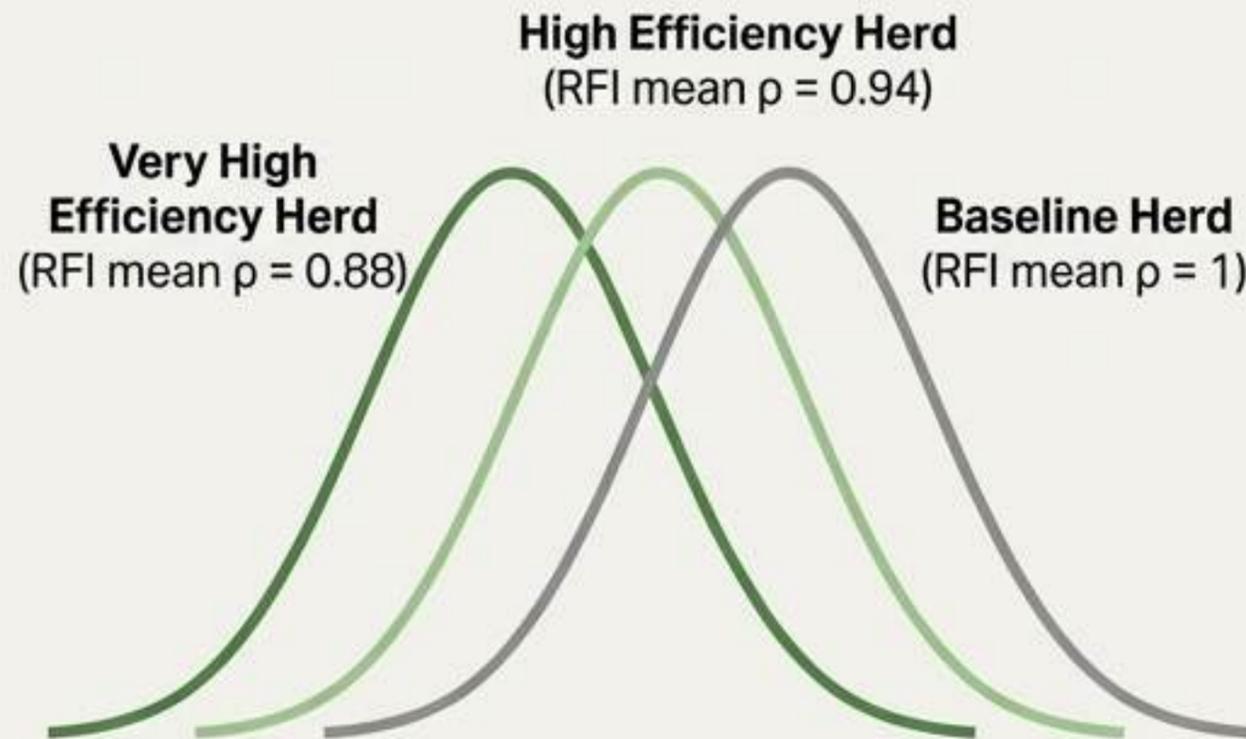**Step 1: Define Scenarios** → **Step 2: Run Simulation** → **Step 3: Measure Outcomes**

High Efficiency Herd
(RFI mean ρ = 0.94)

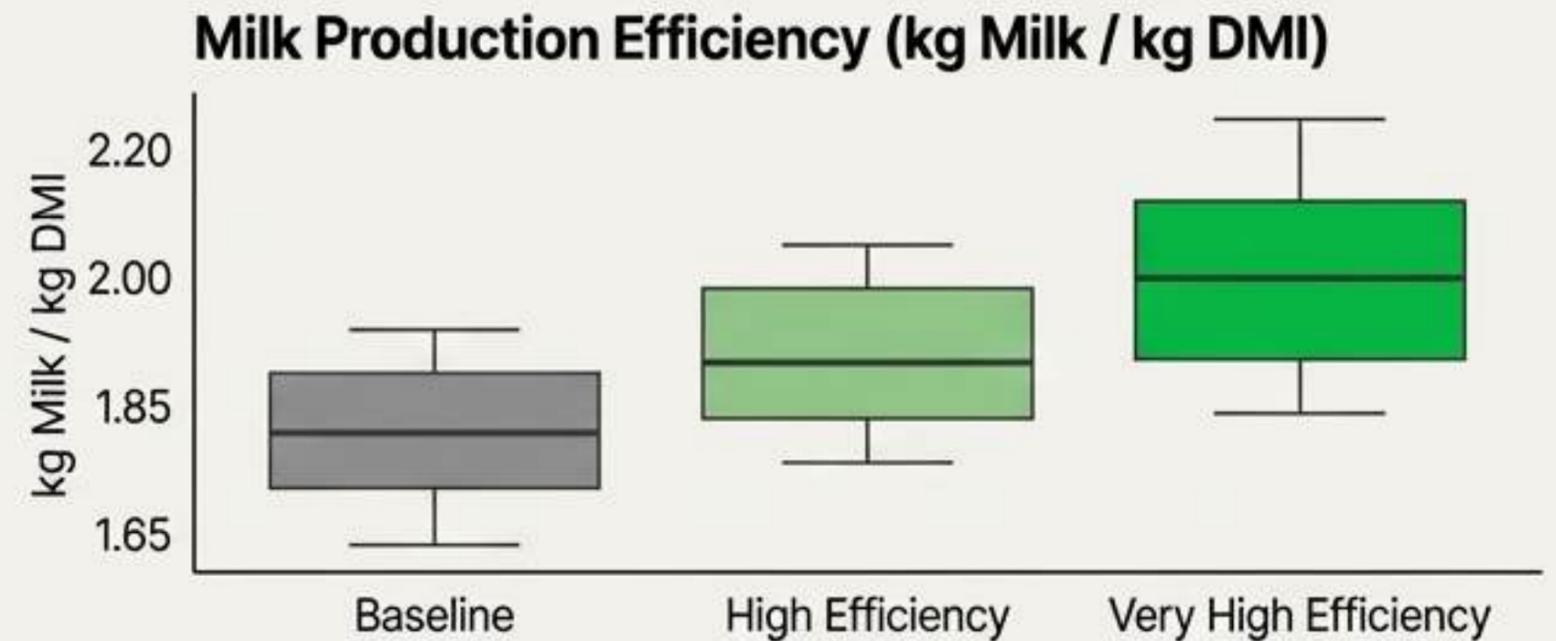Very High Efficiency Herd
(RFI mean ρ = 0.88)

Baseline Herd
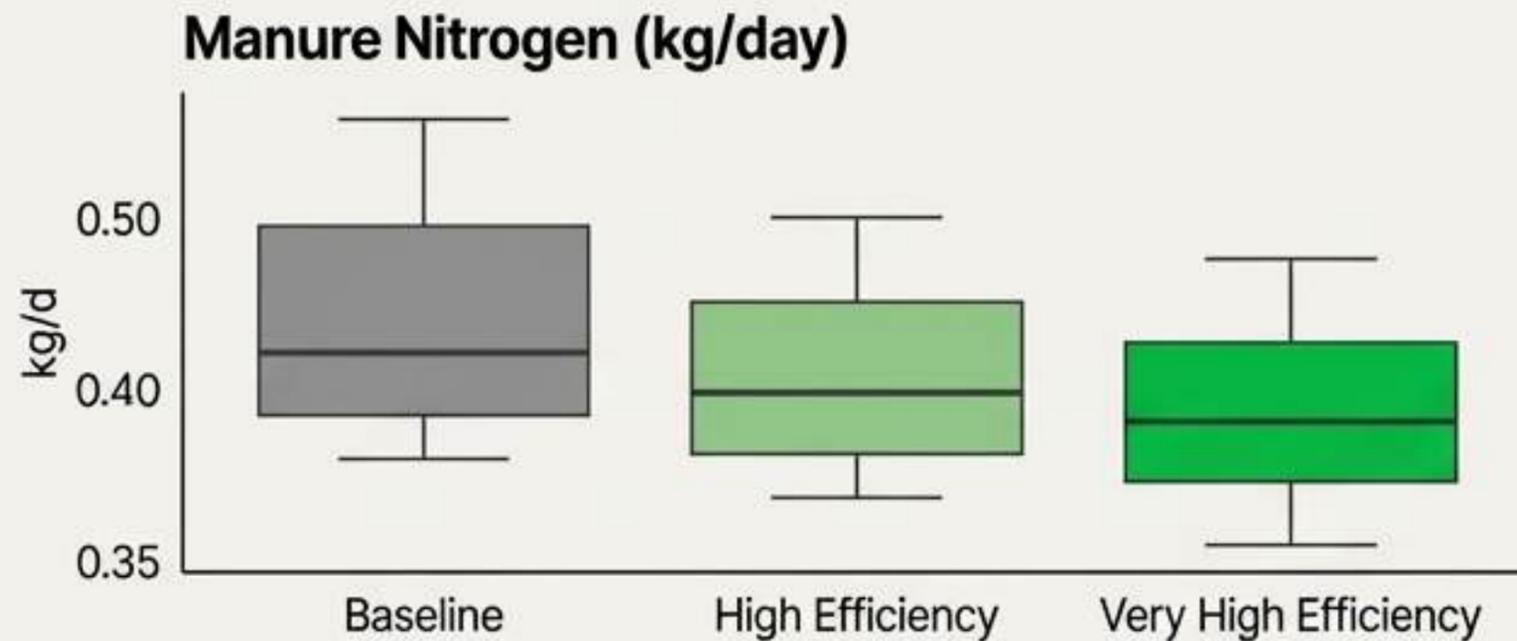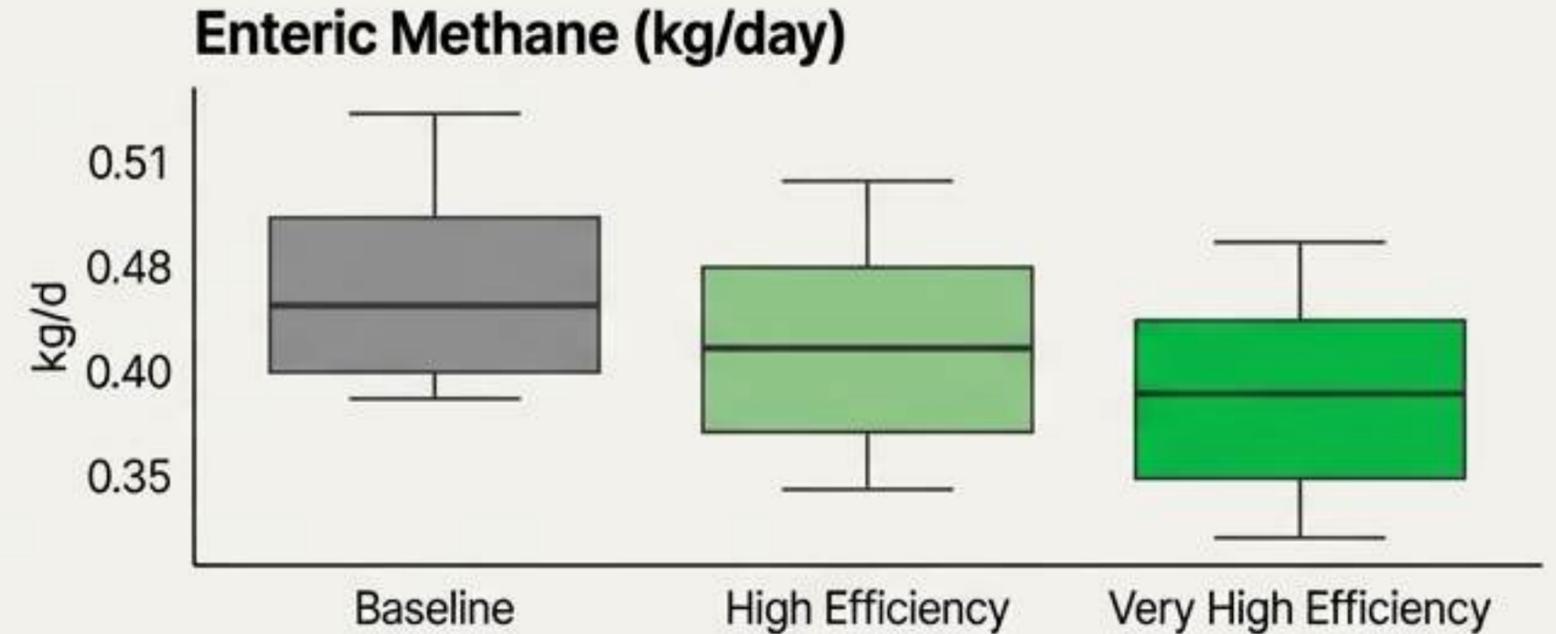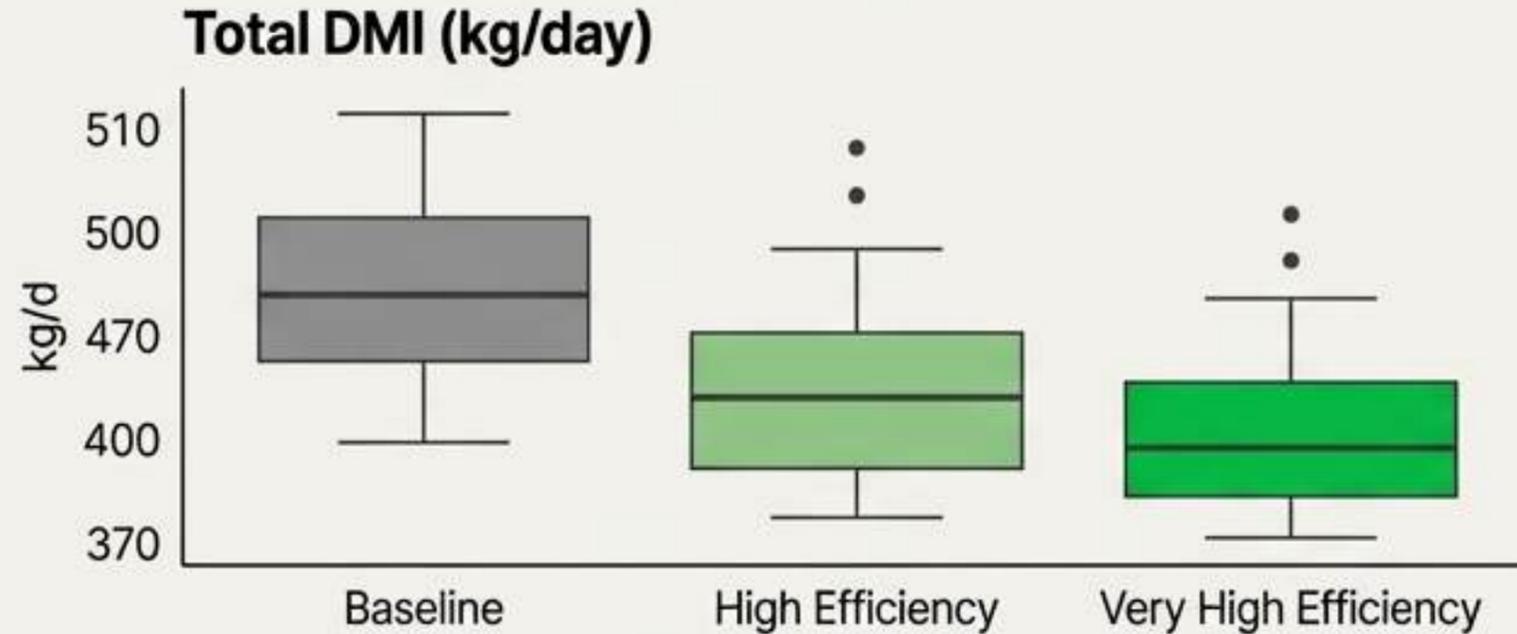(RFI mean ρ = 1)

RuFaS model

A 1000-cow herd simulated for 1 year. All other variables (reproduction, health) held constant.

Compare total feed intake, enteric methane, and manure excretion across the three scenarios.

The Result: The Environmental Dividend of Efficiency

Less Feed, Same Milk, Lower Footprint

A 9.3% Reduction in Key On-Farm Emissions

Improving herd feed efficiency from 'Baseline' to 'Very High' translates directly into a significant reduction in the farm's carbon footprint.
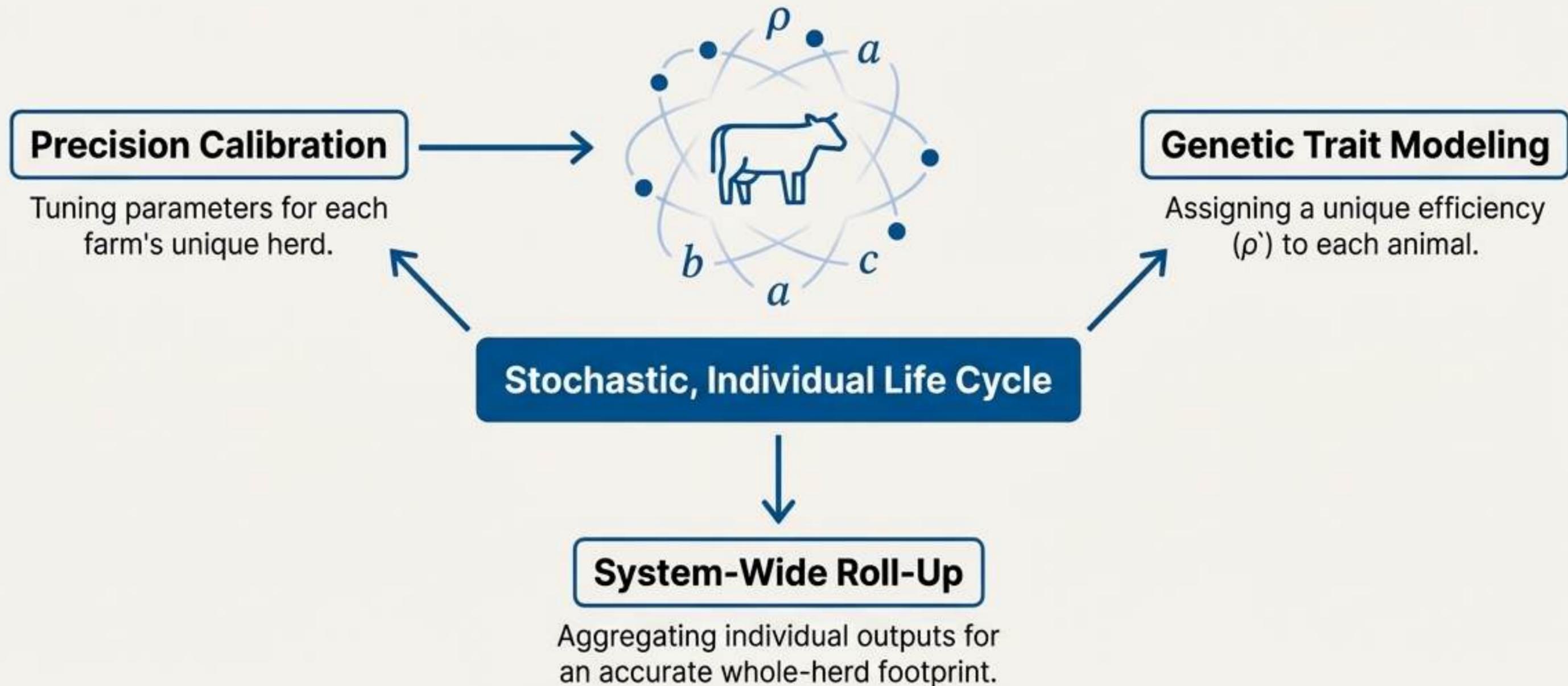
Enteric Methane CO_2-eq reduced by ~12%

-9.3%

Manure-related CO_2-eq reduced by ~9%

Total CO_2-equivalent Reduction (Enteric Methane + Manure)

The Power of an Integrated, Individual-Based Model

RuFaS succeeds where simpler tools fail because it models the entire system at the level where decisions are made: the individual animal.

Precision Calibration

Tuning parameters for each farm's unique herd.

Genetic Trait Modeling

Assigning a unique efficiency $(\rho`)$ to each animal.

Stochastic, Individual Life Cycle

System-Wide Roll-Up

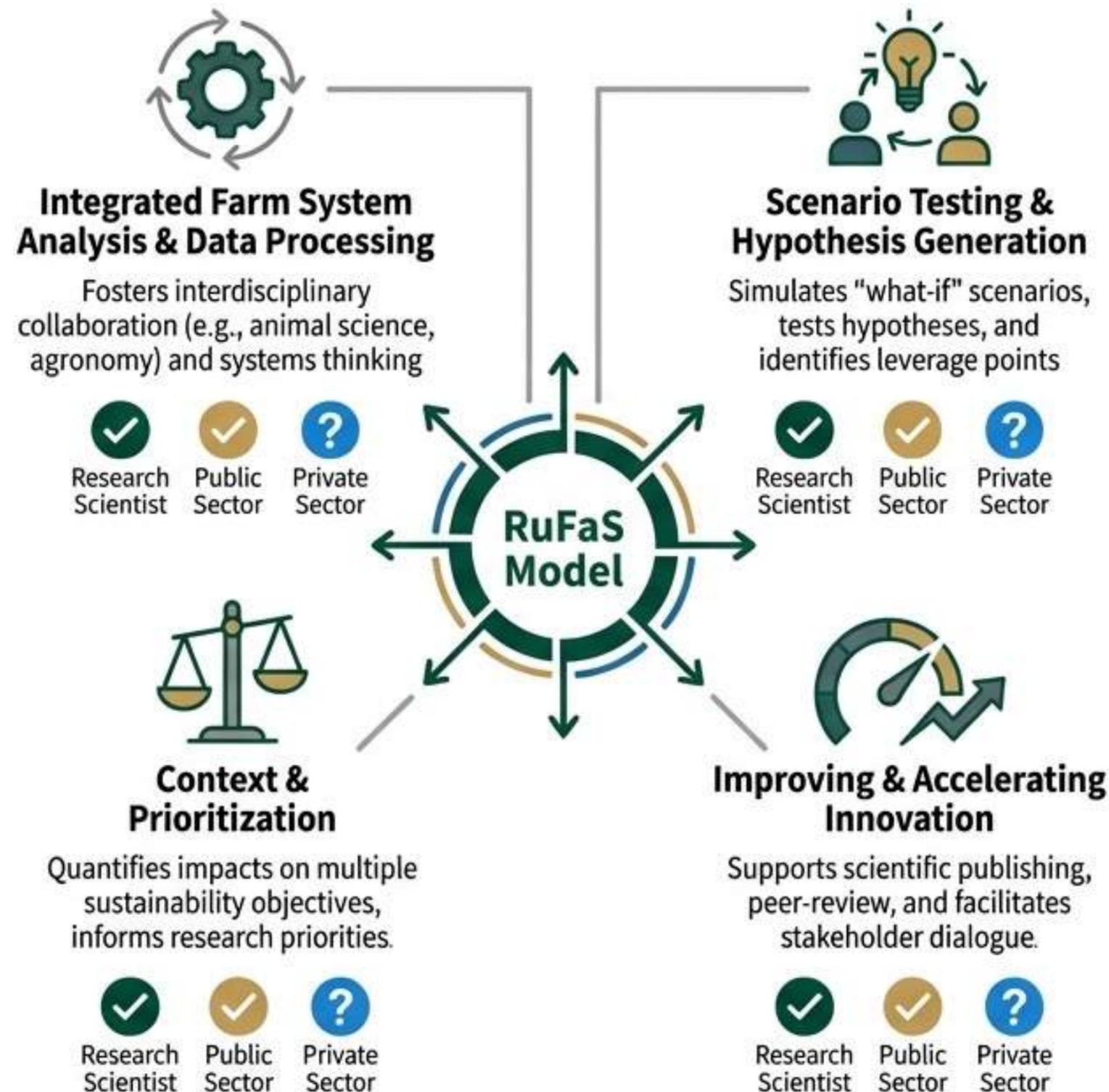Aggregating individual outputs for an accurate whole-herd footprint.

A Platform for Discovery: Identifying the Next Frontier.

A key strength of whole-farm models is their ability to **identify** research gaps by revealing downstream effects and system interactions.
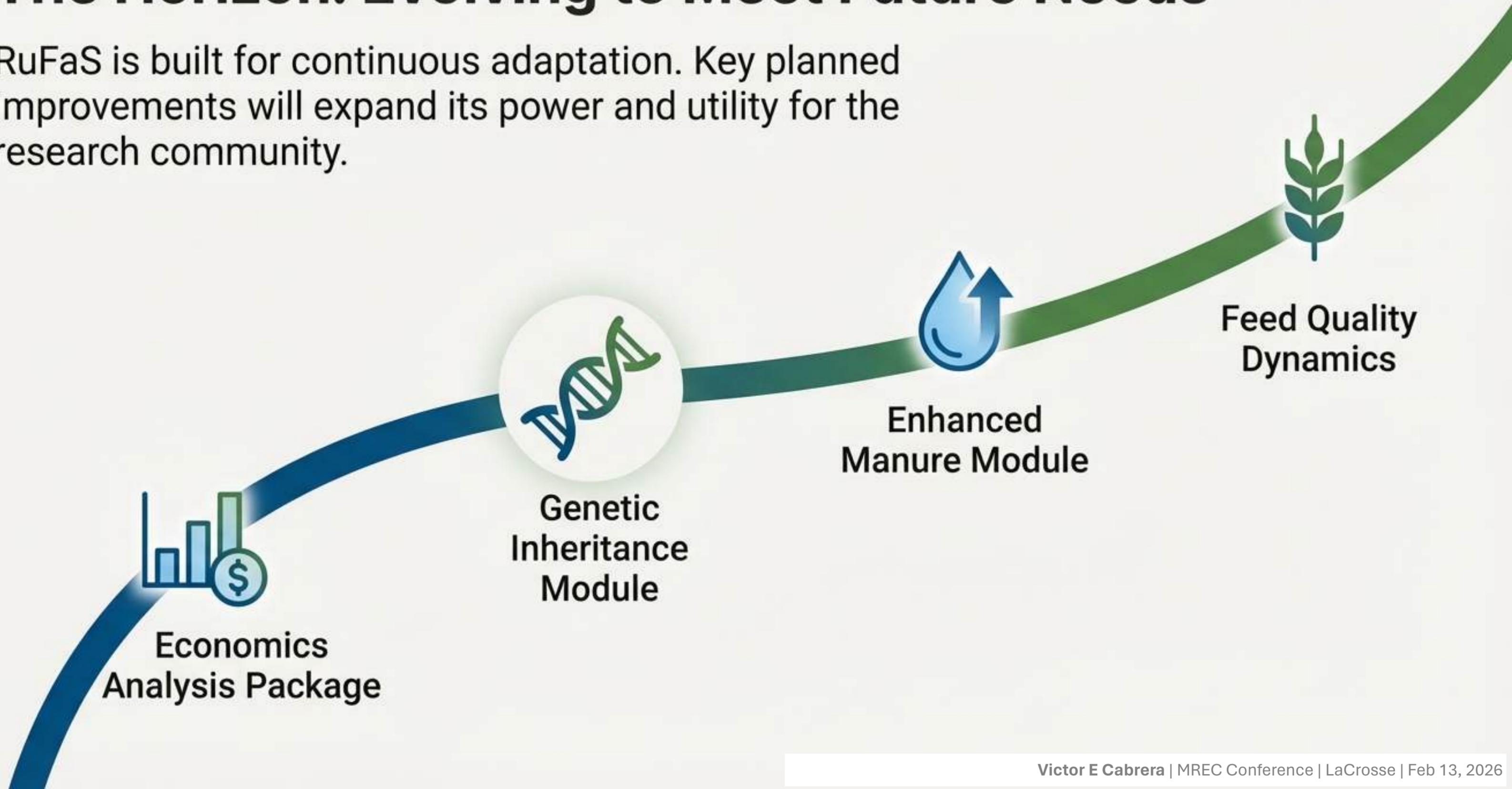
? Young Stock Emissions: Wide variation in existing manure excretion prediction methods for calves and heifers reduces confidence in downstream GHG predictions.

? Feed Additive Effects:
Feed Additive Effects: The full system impact of enteric methane inhibitors—including effects on manure composition and soil emissions—is largely unknown.

Integrated Farm System Analysis & Data Processing
Fosters interdisciplinary collaboration (e.g., animal science, agronomy) and systems thinking

Research Scientist ✓
Public Sector ✓
Private Sector ?

Scenario Testing & Hypothesis Generation
Simulates "what-if" scenarios, tests hypotheses, and identifies leverage points

Research Scientist ✓
Public Sector ✓
Private Sector ?

RuFaS Model

Context & Prioritization
Quantifies impacts on multiple sustainability objectives, informs research priorities.

Research Scientist ✓
Public Sector ✓
Private Sector ?

Improving & Accelerating Innovation
Supports scientific publishing, peer-review, and facilitates stakeholder dialogue.

Research Scientist ✓
Public Sector ✓
Private Sector ?

The Horizon: Evolving to Meet Future Needs

RuFaS is built for continuous adaptation. Key planned improvements will expand its power and utility for the research community.

Feed Quality Dynamics

Enhanced Manure Module

Genetic Inheritance Module

Economics Analysis Package

AI-Powered Climate-Smart

Challenge: simultaneously ↑ profitability and ↓ impacts

Solution: RuFaS AI-powered optimization for:
- 🐄 Herd Management
- 🌽 Feeding strategies
- 💩 Manure handling

Approach:
- 💡 AI + optimization in RuFaS
- 🌍 System Dynamics experts
- 🤝 Co-design with CIN
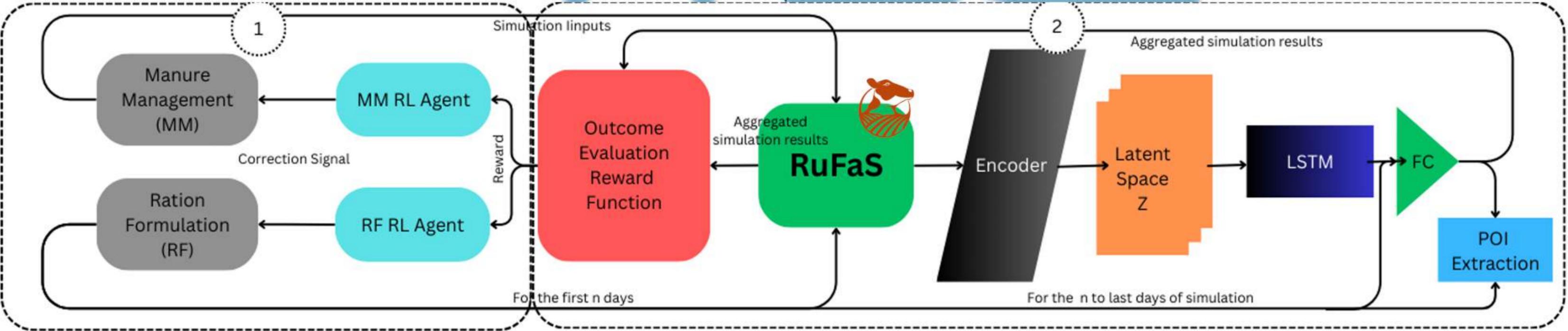- 🔗 Integrate with existing dairy software

Outcome: Site-specific, user-friendly tool that improves environmental and economic sustainability for dairy farms

RuFaS AI Pipeline

RuFaS as environment

A detailed, time-sensitive simulation of real-world farm conditions

RL agents with LSTM networks supported by autoencoders for dimension reduction, and a Fully Connected Deep Learning model to efficiently provide predictions to the RL agents.

Learning: **Simulate** → **Reward** → **Improve**

1. 🧠 RL agent proposes an action (diet/manure management)

2. 🧑‍🌾 RuFaS simulates outcomes

3. 🎯 RF assigns a reward

4. 🔁 Agent updates its policy
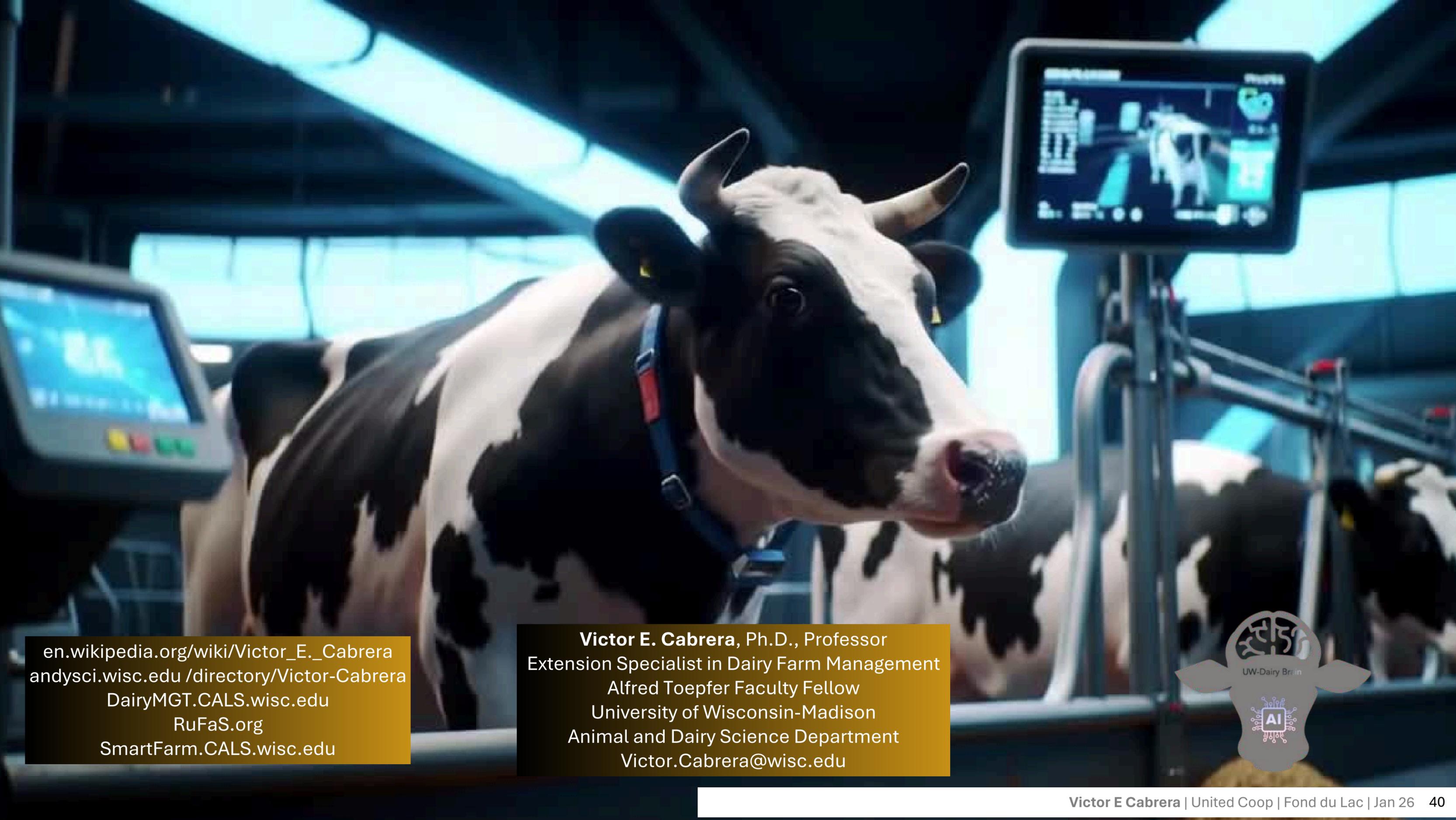
UW-Dairy Brain

AI

An Invitation to Collaborate

RuFaS is an open-source platform designed to accelerate collaborative research and shape the future of sustainable dairy.

We invite you to:

→ **Explore** RuFaS as a tool for your research.

→ **Contribute** to model development.

→ **Engage** in a shared effort to advance dairy systems science.

github.com/RuminantFarmSystems/RuFaS

en.wikipedia.org/wiki/Victor_E._Cabrera
andysci.wisc.edu /directory/Victor-Cabrera
DairyMGT.CALS.wisc.edu
RuFaS.org
SmartFarm.CALS.wisc.edu

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