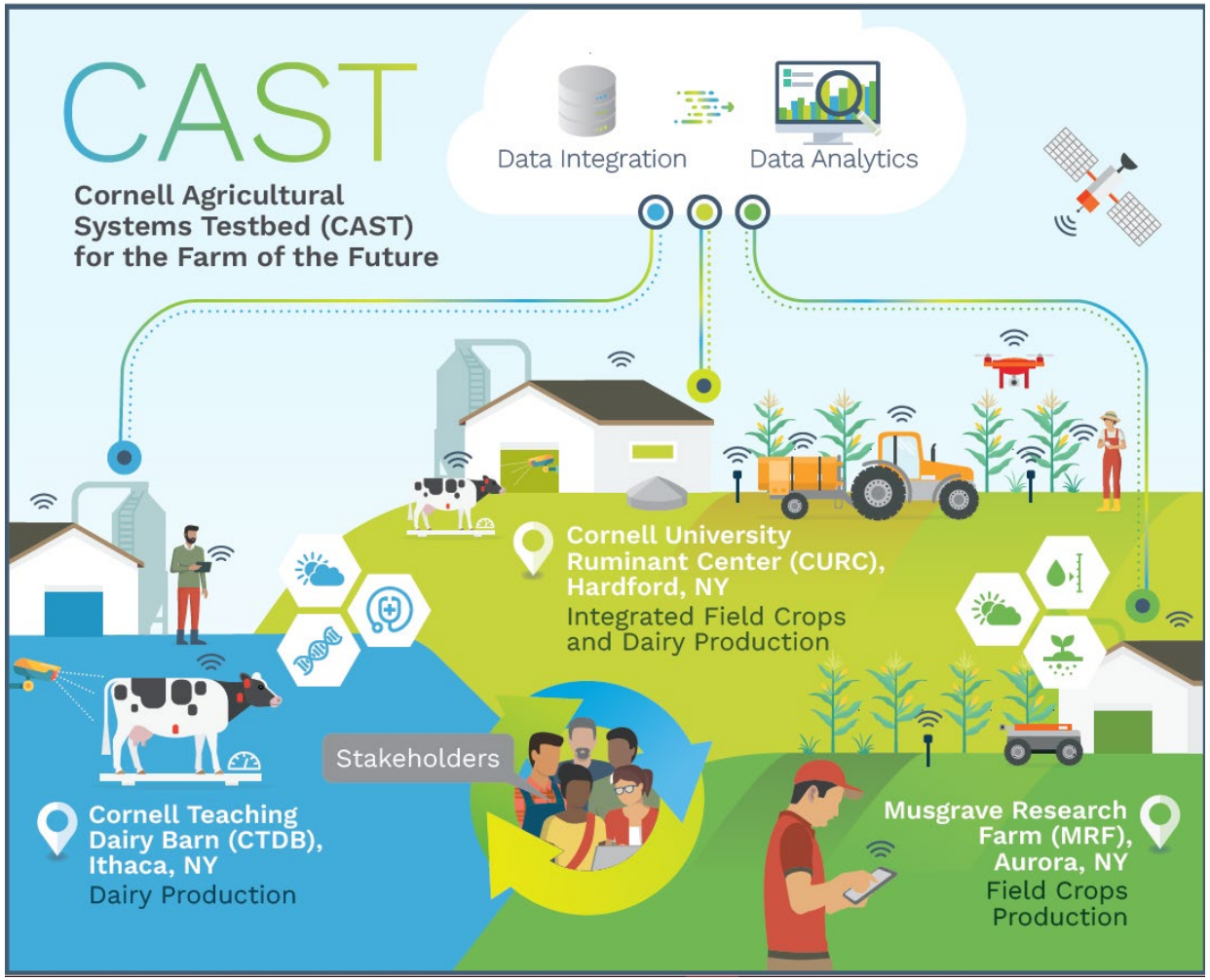
Integrating the Cornell Agricultural Systems Testbed and the Ruminant Farm Systems Model

cida Cornell Institute *for* Digital Agriculture

Cornell CALS
College of Agriculture and Life Sciences

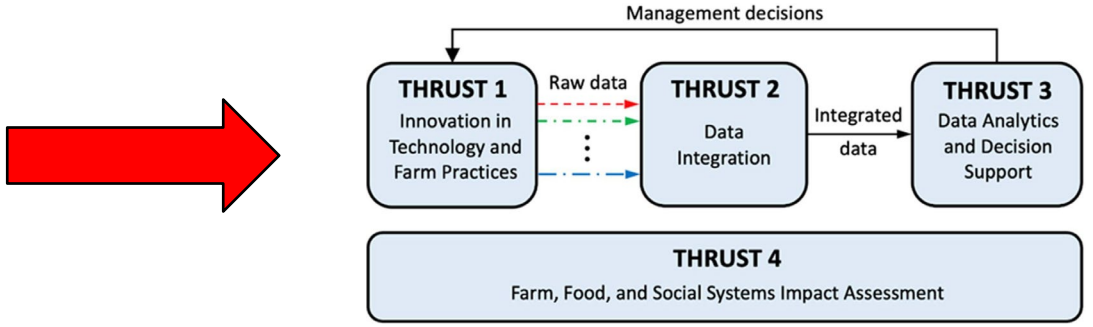
Cornell Agricultural Systems Testbed and Demonstration Site for the Farm of the Future

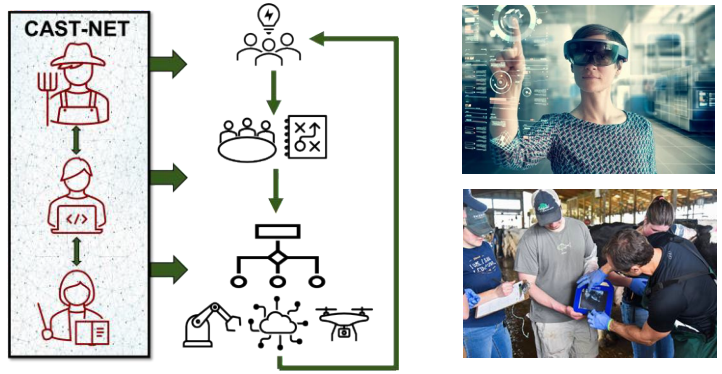
- Grant from USDA-NIFA. One of two FotF sites in the US
- A cluster of 3 farms in NY will host ***data-driven research***, ***extension***, and ***education*** under the aegis of CIDA
- CAST will focus on ***field crops*** and ***dairy production*** as models of the US ag economy
  - Cornell University Ruminant Center
  - Cornell Teaching Dairy Barn
  - Musgrave Research Farm



Integrated project

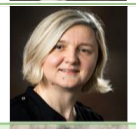
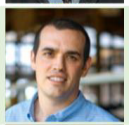
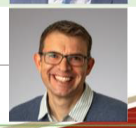
1. Research
2. Extension
3. Education





The team

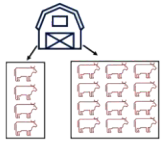
- ***Interdisciplinary*** group of researchers, extension, and teaching faculty from CALS, COE, CS, CVM, Dyson, and A&S
- Partnership with University of Arkansas at Pine Bluff (UAPB)

	**Julio Giordano** Associate Professor, Department of Animal Science	**Abdul Momin** Assistant Professor, Department of Agriculture, University of Arkansas at Pine Bluff	
	**Louis Longchamps** Assistant Professor, School of Integrative Plant Science Soil and Crop Sciences Section	**Kristan Reed** Assistant Professor, Animal Science	
	**Quirine Ketterings** Professor, Department of Animal Science	**Diane Bailey** Director of the Cornell Institute for Digital Agriculture (CIDA) and Geri Gay Professor of Communication, Department of Communication	
	**Hakim Weatherspoon** Professor, Computer Science	**Christopher De Sa** Assistant Professor, Computer Science	
	**Chris Wolf** E. V. Baker Professor of Agricultural Economics Director of Land Grant Affairs	**David Erickson** S.C. Thomas Sze Director of the Sibley School of Mechanical and Aerospace Engineering Professor, Mechanical Engineering	
	**Laurie Drinkwater** Professor, School of Integrative Plant Science Horticulture Section	**Ying Sun** Assistant Professor, School of Integrative Plant Science Soil and Crop Sciences Section	
	**Fengqi You** Roxanne E. and Michael J. Zak Professor in Energy Systems Engineering; Smith School of Chemical and Biomolecular Engineering	**Renata Ivanek** Department of Population Medicine and Diagnostic Sciences Professor	
	**Malte Ziewitz** Associate Professor; Director, Digital Due Process Clinic, Department of Science and Technology Studies College of Arts and Sciences	**Sharon Sassler** Professor; Director of Undergraduate Studies	
	**Mike Van Amburgh** Professor, Animal Science	**Thomas Overton** Department Chair, Professor, Animal Science Program Director, PRO-DAIRY	
	**Joseph McFadden** Associate Professor of Dairy Cattle Biology, Animal Science Northeast Agribusiness and Feed Alliance Sesquicentennial Faculty Fellow, PRO-DAIRY	**Benjamin Houlton** Ronald P. Lynch Dean, Office of the Dean Professor, Ecology and Evolutionary Biology Professor, Department of Global Development	
	**Johannes Lehman** Liberty Hyde Professor, School of Integrative Plant Science Soil and Crop Sciences Section	**Matthias Wieland** Department of Population Medicine and Diagnostic Sciences Assistant Professor	

Cornell Agricultural Systems Testbed and Demonstration Site for the Farm of the Future

Rationale and overarching goals

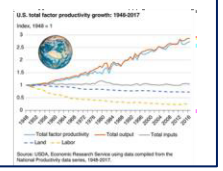
- Larger land base or more animals to work with



- Scarcity of qualified labor and higher labor cost

- Improve farmer/worker (and animals) quality of life

- Increase efficiencies, profitability, and sustainability



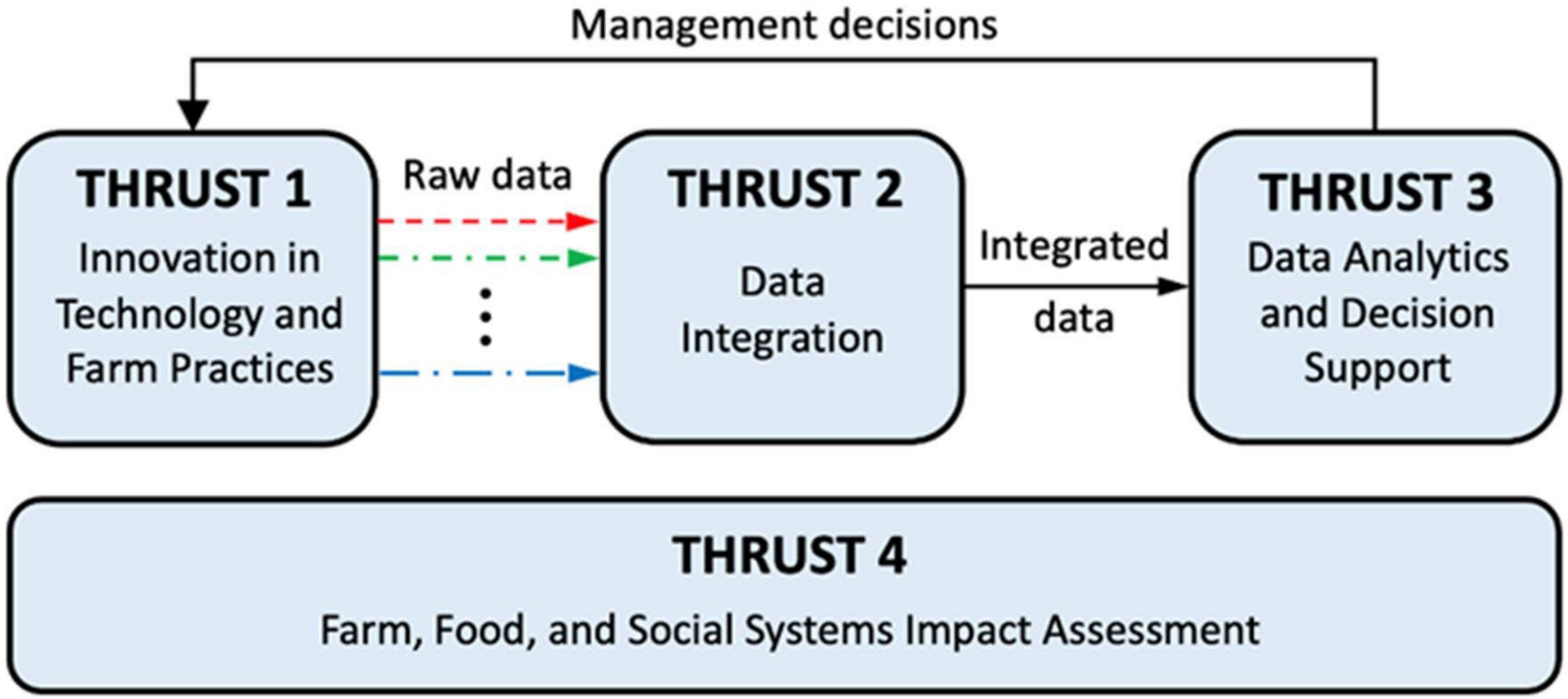
Leverage integrated data-driven tools and management practices to:

1. Improve *efficiency* to increase productivity while reducing costs and environmental impacts
2. Reduce agriculture's *environmental impacts*
3. Examine *social, socioeconomic, and farm-level financial impacts*

Research at the CAST for the FotF

CAST's primary research goals

1. Support ***development***, ***deployment***, and ***evaluation*** of technological and data-driven breakthroughs
2. ***Test*** and ***demonstrate*** existing and emerging technologies and practices under commercial-farm-like conditions



Research at the CAST for the FotF

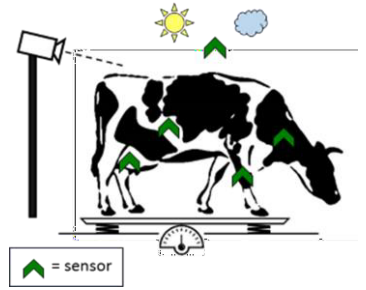
THRUST 1
Innovation in Technology and Farm Practices

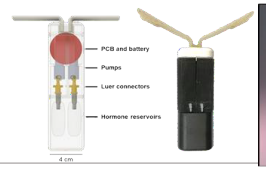
Technology-enhanced field crop production

- Precision management of crop inputs
- Cover cropping
- Soil amendments (rock dust) and biochar

Smart automation and data-driven precision animal management

- Feeding and nutritional management
- Health management
- Reproductive monitoring and management





e-Synch device
Automated ovulation synchronization

Repro-Phone device
Point-of-care pregnancy testing

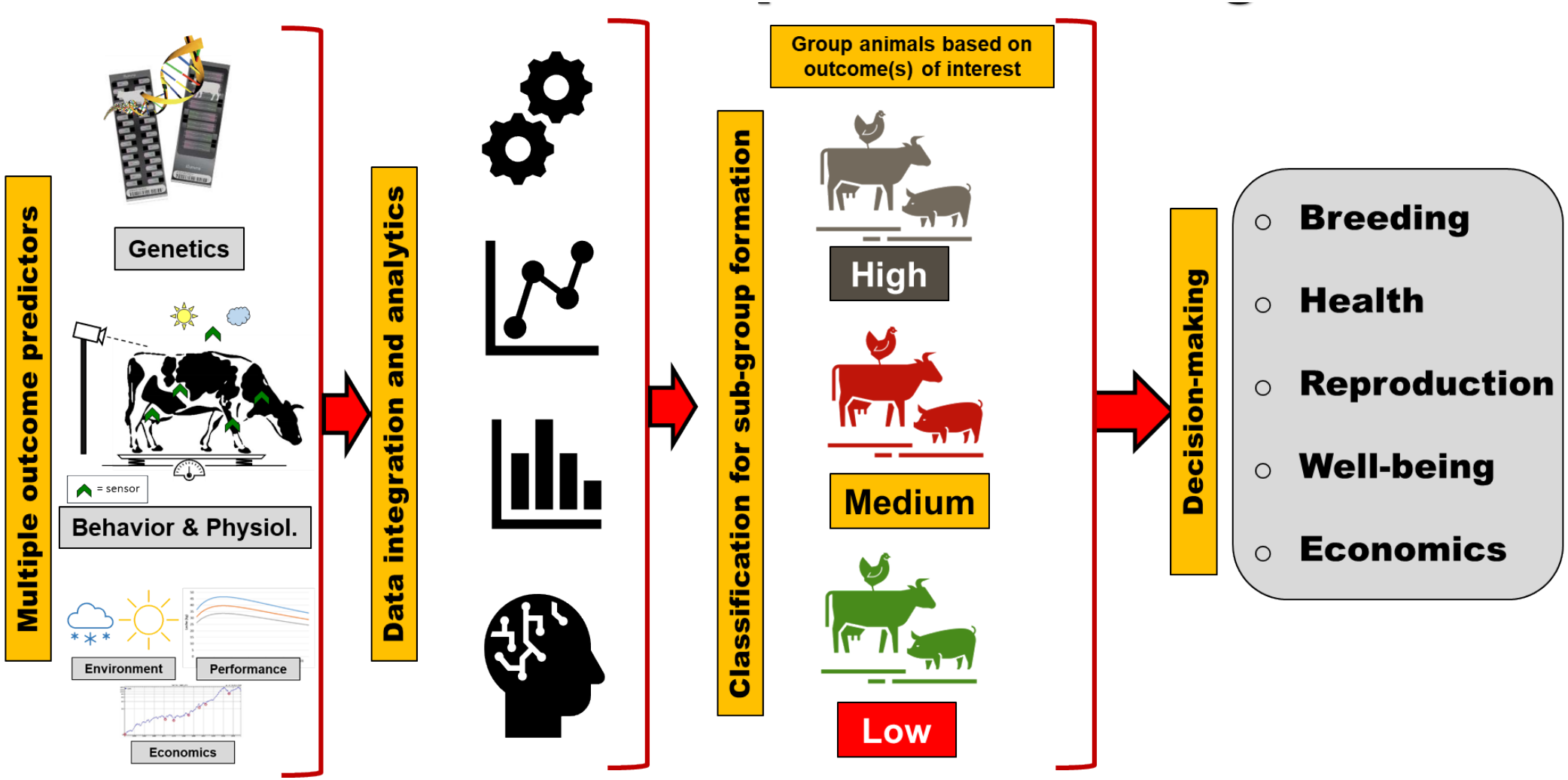
Computer vision system
Udder and teat end tissue health

Field Crop Research at the CAST

Precision management of crop inputs	
Data & tools	Multi-year yield maps (grain and biomass), soil maps (soil properties, elevation, and electrical conductivity), remote sensing data (satellite and/or drone imagery)
Testing	Evaluate potential of AI analytics to understand main driving factors of soil productivity potential across management zones.
Demo	Yield stability management zones delineation and single strip evaluation approach (SSEA) to determine the right rate and location for seeds, manure, and N fertilizer.
Benefits	Improve crop input use efficiency thus increasing profitability and environmental stewardship.
Cover cropping	
Data & tools	Agronomy literature on cover crops (SARE publications), past and on-going research data (from commercial scale CURC and small plots Musgrave Farm), multi-year yield maps, soil maps, remote sensing data, and environmental data (weather station).
Testing	Develop decision support system w. AI analytics to provide farmers site-specific solutions.
Demo	Cover cropping at scale of production using decision support and autonomous seeder.
Benefits	Help farmers obtain best return for cover cropping investments, which will increase the acreage under cover crops, and provide multiple benefits to farmers and society including restoration of soil health, increases in soil organic matter reserves while reducing erosion and nutrient losses.
Soil amendments - rock dust by enhanced rock weathering (ERW) and biochar	
Data & tools	Multi-year yield maps (grain and biomass), soil maps (soil properties, elevation, and electrical conductivity), remote sensing data (satellite and/or drone imagery), on-farm treatments of rock dusts and biochar of variable composition and amount, soil health, sequestered carbon (belowground water samples and soil carbon), GHG emissions.
Testing	Assess the environmental (carbon sequestration) and agronomic (improved soil health and productivity) impact of ERW rock dust and biochar in agricultural fields.
Demo	Spread and till rock dust and monitor carbon dynamics using Cornell support system.
Benefits	Soil amendment with ERW rock dust and biochar can mitigate climate change by removing CO_2 from the atmosphere and reducing emissions of other gasses such as N_2O, while also increasing crop yield, improving soil structure, and increasing soil nutrient content and retention,

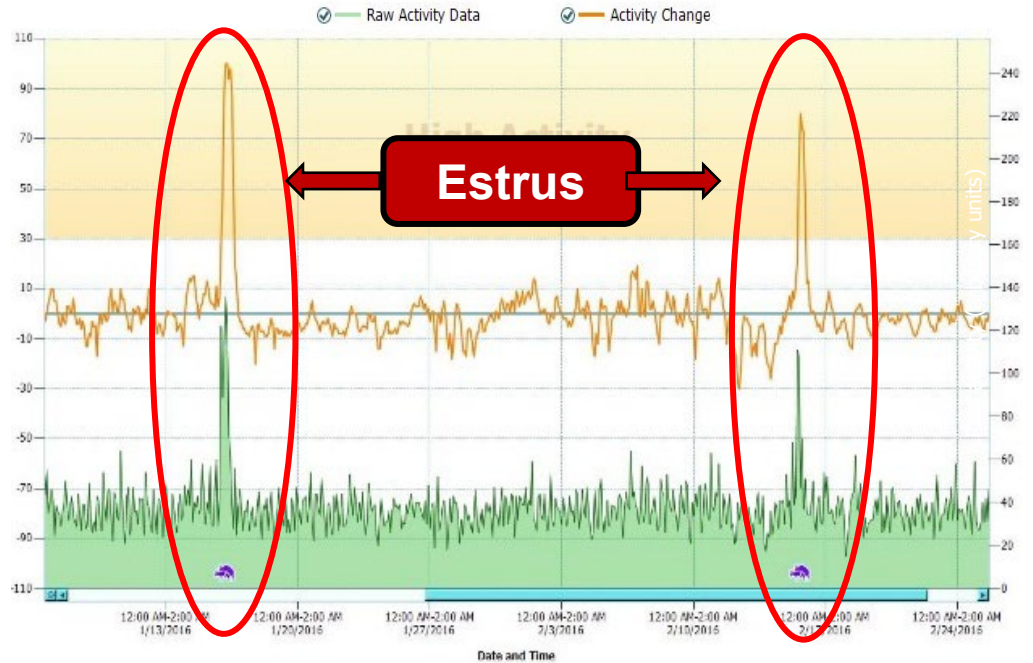
Dairy Cattle Research at the CAST

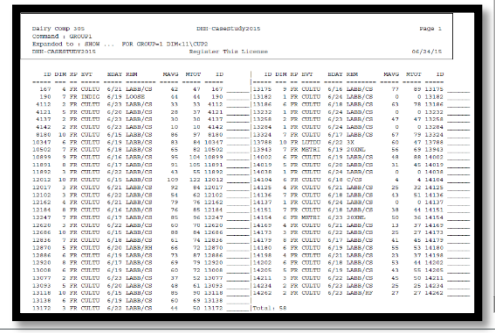
Framework for targeted/precision/selective animal management



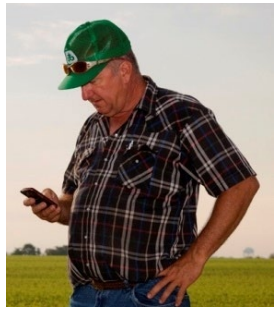
Automated monitoring systems

Wearable or non-wearable sensor

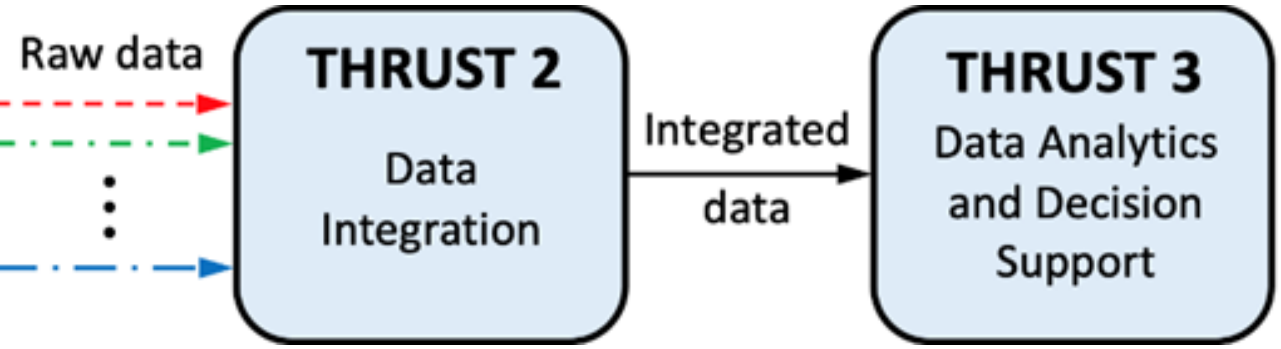


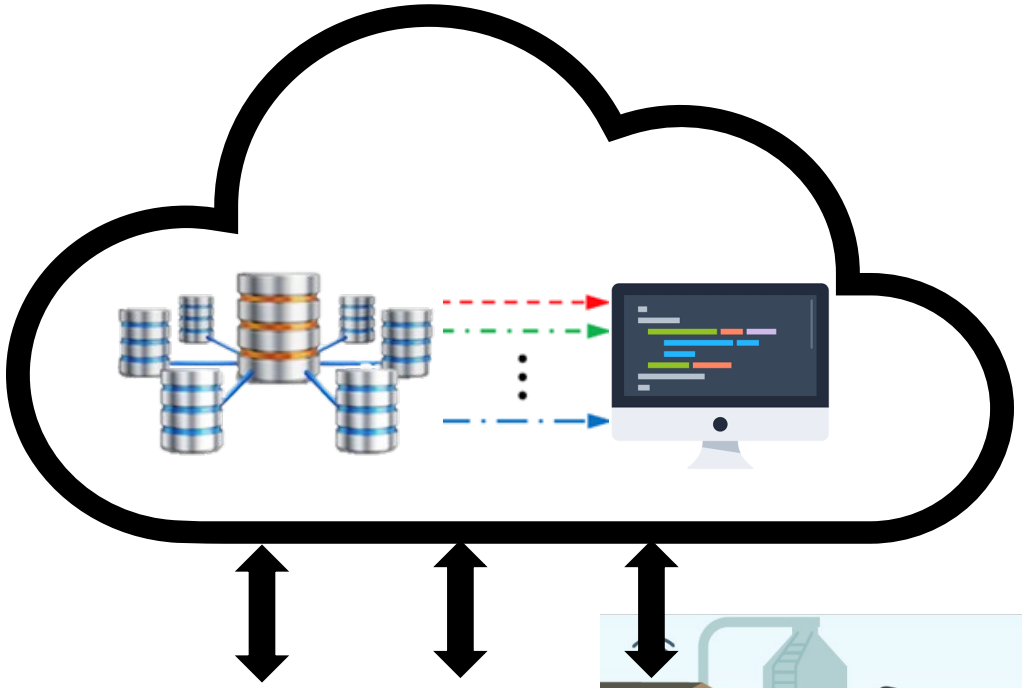


	Cow Number	Group	Lactation Status	Days in Lactation	Days from Last Breeding	Activity Peak	Ruminati on Peak	Daily Ruminati on	Amount Of Evaluatio	Health Index for Non
1	20600	7	Before	6		-15	-40	0	-132	20.00
2	10856	7	Before	5		-40	-44	13	-464	32.60
3	9473	7	Before	44		-75	-100	38	-561	55.00
4	11558	11	No Heat	85		-39	-40	0	-462	66.30
5	9362	7	Colostrum	3		-37	-98	86	-136	67.20
6	12451	1	Before	8		-7	11	310	-1	72.00
7	12645	9	Before	27		-25	-40	0	0	73.00
8	4980200	7	Colostrum	3		-22	-27	145	-290	79.00
9	2152200	1	No Heat	91		-13	-23	133	-23	81.50
10	950600	7	Ready	80		8	-40	2	2	82.00
11	8662200	1	Before	43		-15	-20	181	-35	83.00
12	8062200	1	Before	57		-7	-21	135	15	83.70
13	508600	1	Ready	68		-29	-52	328	-206	83.80
14	9251200	1	Ready	72		-17	-34	318	-133	84.70
15	12561	1	Before	46		-5	-15	186	5	85.50
	15									



Research at the CAST for the FotF

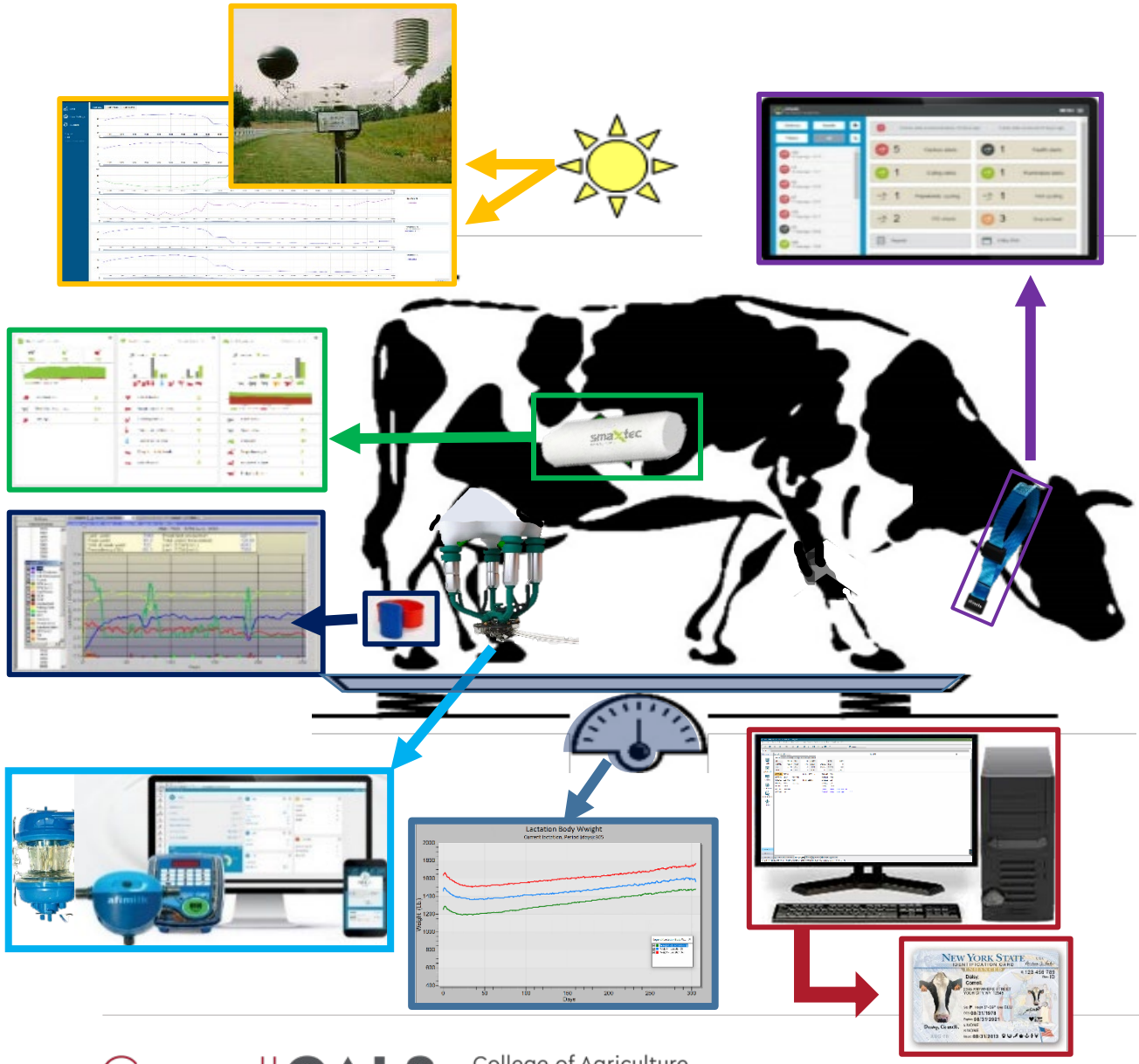




Field Data integration at the CAST

Soil Maps				
Parameter	**Sensor or monitoring tool**	**Spatial resolution**	**Frequency**	**Units**
Organic matter	Manual	Sub-field (5/ha)	One time	%
Cation exch. cap.	Manual	Sub-field (5/ha)	One time	meq/100g
pH	Manual	Sub-field (5/ha)	One time	Unitless
Macronutrients (N,P,K)	Manual	Sub-field (5/ha)	One time	ppm
Ca ppm	Manual	Sub-field (5/ha)	One time	ppm
Secondary nutrients (Ca,Mg,S)	Manual	Sub-field (5/ha)	One time	ppm
Micronutrients (Fe, Cu, Mn, Mo, Zn)	Manual	Sub-field (5/ha)	One time	ppm
Electrical cond'y	Sensor data	Sub-field (1000/ha)	One time	mS/m
Elevation	Sensor data	Sub-field (1000/ha)	One time	m
Yield maps				
Parameter	**Sensor or monitoring tool**	**Spatial resolution**	**Frequency**	**Units**
Grain Yield	Yield monitoring sensor	Sub-field (1000/ha)	Once a year	Mg/Ha
Biomass yield	Yield monitoring sensor	Sub-field (1000/ha)	Once a year	Mg/Ha
Remote sensing data				
Source	**Sensor or monitoring tool**	**Spatial resolution**	**Frequency**	**Units**
Landsat 8-9	Multispectral cam (8 band)	30 m/pixel	Every 16 days	Reflectance (a.u.)
Sentinel 2	Multispectral cam (10 bd)	20 m/pixel	Every 10 days	Reflectance (a.u.)
Rapid Eye	Multispectral cam (5 band)	5 m/pixel	Every 5.5 days	Reflectance (a.u.)
Planet	Multispectral cam (4 band)	3 m/pixel	Every day	Reflectance (a.u.)
Environmental data				
Parameter	**Sensor or monitoring tool**	**Spatial resolution**	**Frequency**	**Units**
Temperature	Thermometer	Farm	Hourly	Celcius
Rainfall	Pluviometer	Farm	Hourly	mm
Light intensity	PAR sensor	Farm	Hourly	$\mu mol/m^2/sec$
Rel. humidity	Hygrometer	Farm	Hourly	%
Wind speed	Anemometer	Farm	Hourly	m/sec
Wind direction	Wind vane	Farm	Hourly	degrees
Barometric pr.	Barometer	Farm	Hourly	mb

Animal Data integration at the CAST

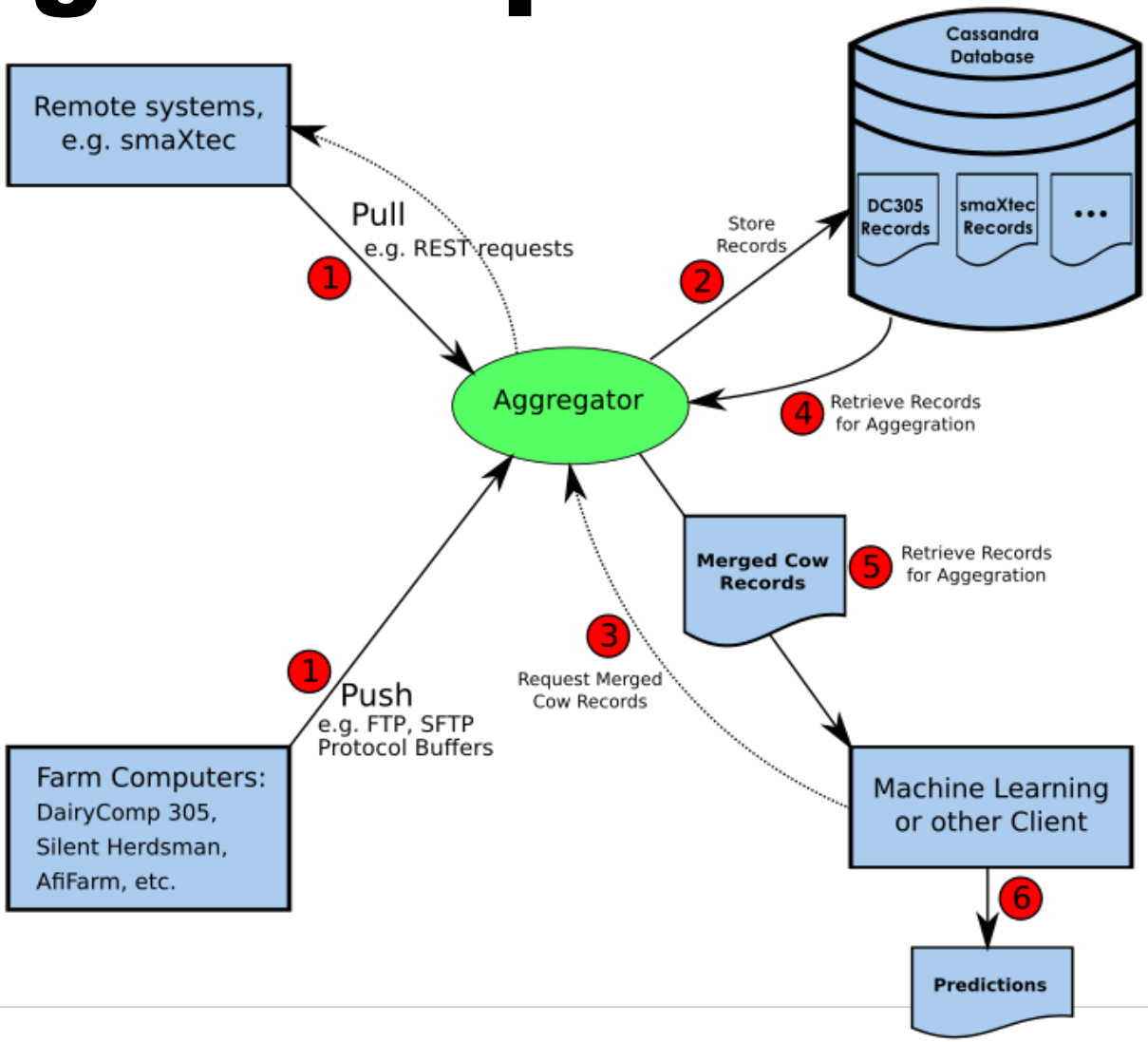


Cow Behavioral, Physiological, and Productivity Parameters			
Parameter	**Sensor or monitoring tool**	**Recording**	**Units**
Rumination time	Accelerometer (neck tag)	continuous	min/h
Eating behavior	Accelerometer (neck tag)	continuous	min/h
Physical activity	Accelerometer (leg tag, rumen bolus)	continuous	Arbitr. units/h
Lying behavior	Accelerometer (leg tag)	continuous	# and min/bout
Core body temperature	Thermometer (ruminal bolus)	continuous	°C
Drinking cycles	Electronic thermometer (rumen bolus)	continuous	number
Milk yield & production rate	Milk meter	3X/day	gr, gr/h
Milk conductivity	Milk meter	3X/day	mS/cm
Milking time	Milk meter	3X/day	seconds
Milk fat, protein, & lactose yield	Infrared spectroscopy	1/month	%, gr
Milk fat-to-protein ratio	Infrared spectroscopy	1/month	ratio number
Body weight[1]	Walk-in scale	2X/day	Kg
Body condition score[2]	3D camera	2X/day	units (1 to 5)

Cow features and parameters of performance [Tool: dairy herd management software]		
Parameter	**Recording**	**Units**
Age and parity number	once/lactation	days & number
Previous lact. milk & compon't yield	once/lactation	Kg
Health events (curr. & prev. lact)	once/lactation	type & number
Repro. events (curr. & prev. lact)	once/lactation	type & number
Calving season (curr. & prev. lact)	once/lactation	cool vs warm
Genomic predictions[3]	once per lifetime	units

Environmental and management factors			
Parameter	**Sensor or monitoring tool**	**Recording**	**Units**
Barn & outside THI[3]	Thermometer	continuous	THI[2] units
Barn and outside temperature	Thermometer	continuous	°C
Barn and outside black globe temp.	Thermometer	continuous	°C
Barn and outside relative humidity	Hygrometer	continuous	%
Feeding time	Feed management software	daily	time of day
Dry matter intake (group)	Feed management software	daily	Kg
Stocking density	Dairy herd management software	daily	cows/stall

Deploy, refine, and expand existing data integration platform at the CAST



Current dairy data aggregator

SmaxTec
Temperature, Activity

DairyComp305
Hist, Pred, Fresh, Pen

AfiFarm
Milk yield, protein, fat

SilentHerdsman
Eating time, rumination time

Dairy Management Software

API

Protobuf's

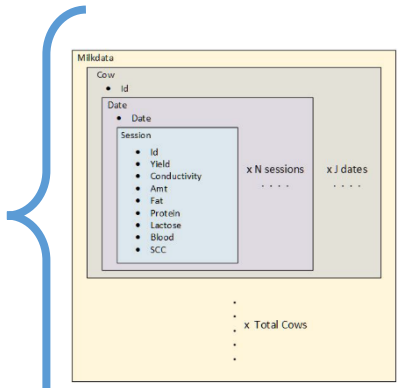
Message

Message

Message

Message

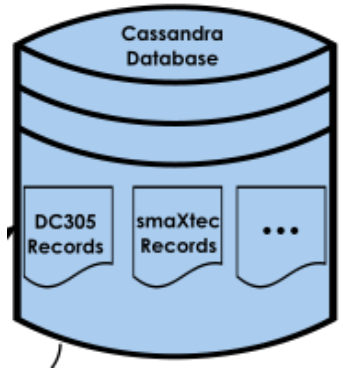
AGGREGATOR

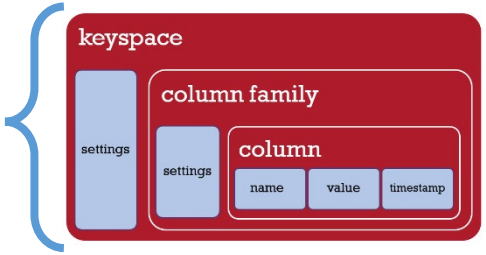


ID	Date	SICK	M&D	MET	MAST	OTHER
134	1/1	N	10	05	10	00
343	1/1	Y	85	15	10	05
405	1/1	Y	20	05	75	10
546	1/1	N	05	10	10	05
575	1/1	N	15	05	15	10

POST-PROC

MLA





Implementation and refinement

Post-process query data from aggregator, edit formats and fix to feed **MLA**

MLA analyze the integrated data from last 24 h and predicts cow health status and possible disorders

ID	Date	SICK	M&D	MET	MAST	OTHER
134	1/1	N	10	05	10	00
343	1/1	Y	85	15	10	05
405	1/1	Y	20	05	75	10
546	1/1	N	05	10	10	05
575	1/1	N	15	05	15	10

Wrong classifications used to **re-train** models

ID	Date	SICK	Check
134	1/1	N	✗
343	1/1	Y	✓
405	1/1	Y	?
546	1/1	N	✓
575	1/1	N	✓

Cows Flagged sick without evident clinical signs would be followed over time.

Researchers perform **clinical examination** and asses the health status of cows to corroborate **MLA** performance

Perez and Giordano, unpublished
Dairy Cattle Biology and Management Lab

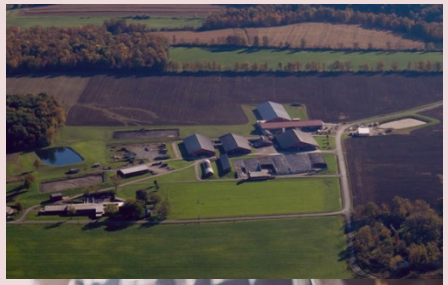
Research at the CAST for the FotF

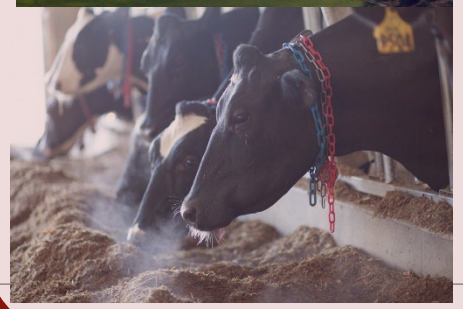
THRUST 4

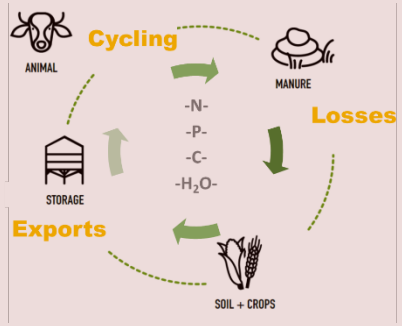
Farm, Food, and Social Systems Impact Assessment

Farm Financial Feasibility

Whole Farm Animal and Environmental Health

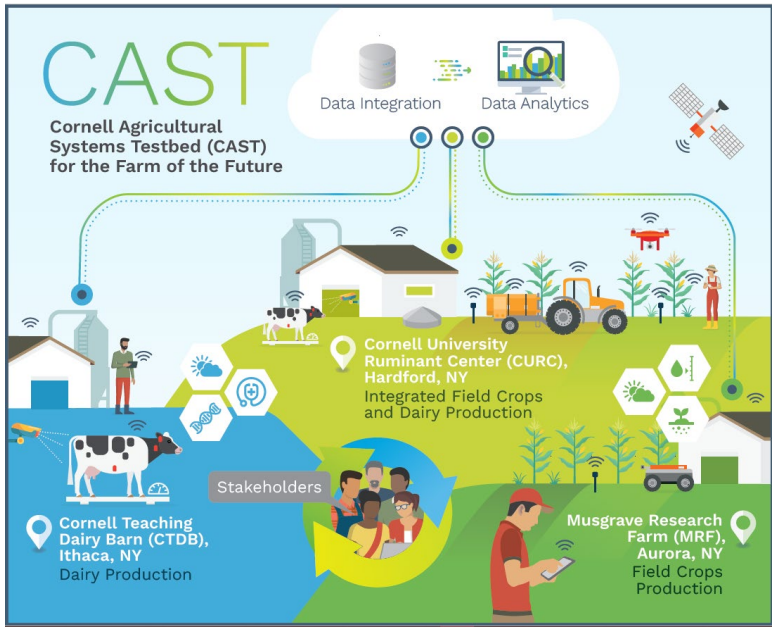






Social and Socioeconomic Impacts

Integration and Application of RuFaS in CAST

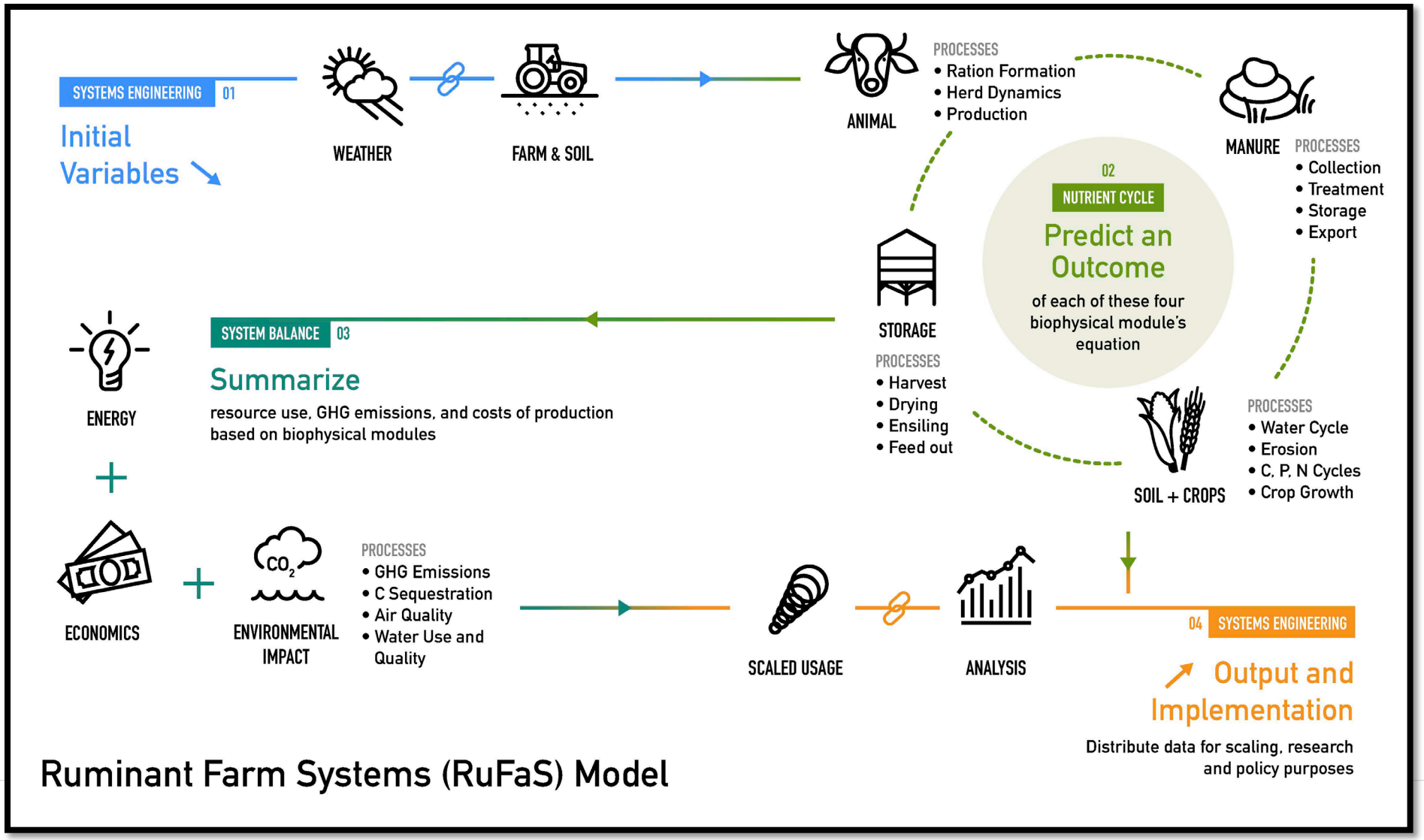


What is RuFaS?

A Next-Generation, Whole-Farm, Dairy Sustainability Simulation Model

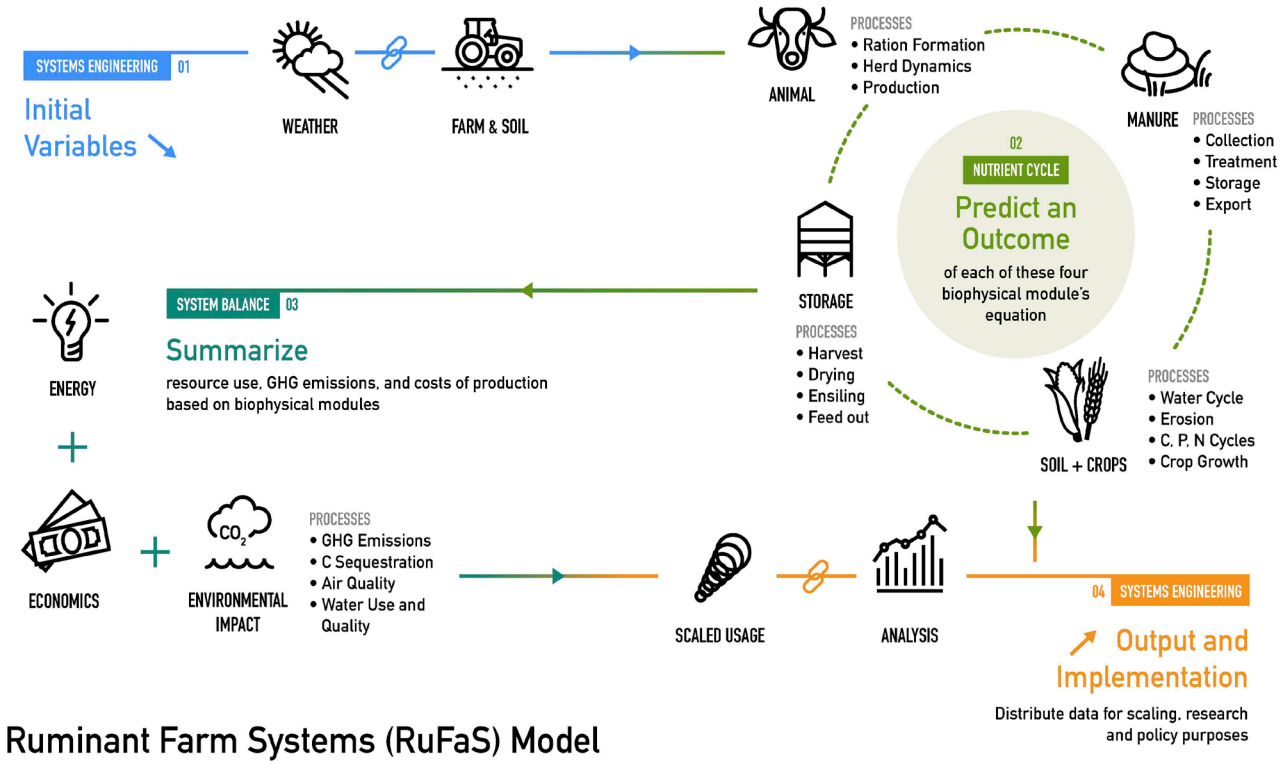
- Process based simulation model of dairy farm production and environmental impact
- Identifies ways to improve efficiency and sustainability
- Has a range of applications, from a research tool for scientists to a decision-aid tool for the dairy industry
- Coding emphasizes transparency and accessibility to ensure model flexibility, clarity, adaptability, and persistence

What is RuFaS?



The RuFaS Vision

To ***support research and sustainable decision-making*** in ruminant animal production through ***a state-of-art, open-source modeling environment*** that is continuously adapting as technology and scientific knowledge advance.



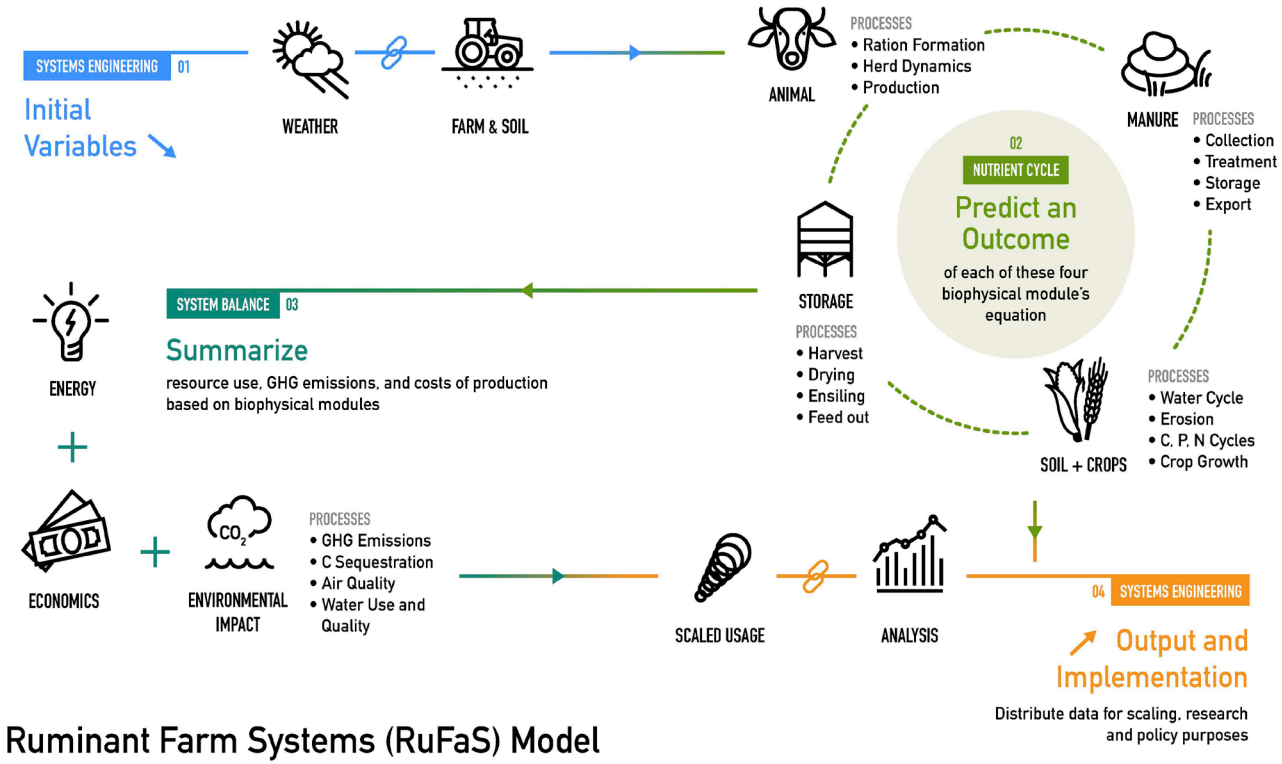
Ruminant Farm Systems (RuFaS) Model

The RuFaS Mission

To ***build an integrated, whole-farm model*** that simulates milk, meat, and crop production, greenhouse gas emissions, water quality impacts, soil health, and other ***sustainability outcomes*** of ruminant farms.

We strive to achieve the ***highest standards for prediction accuracy***, ***code structure*** and clarity, ***documentation***, and ***accessibility***.

Through ***continuous learning*** and improvement of our methods and algorithms, we are ***creating an open and inclusive platform*** for scientific collaboration.



Ruminant Farm Systems (RuFaS) Model

RuFaS Goals

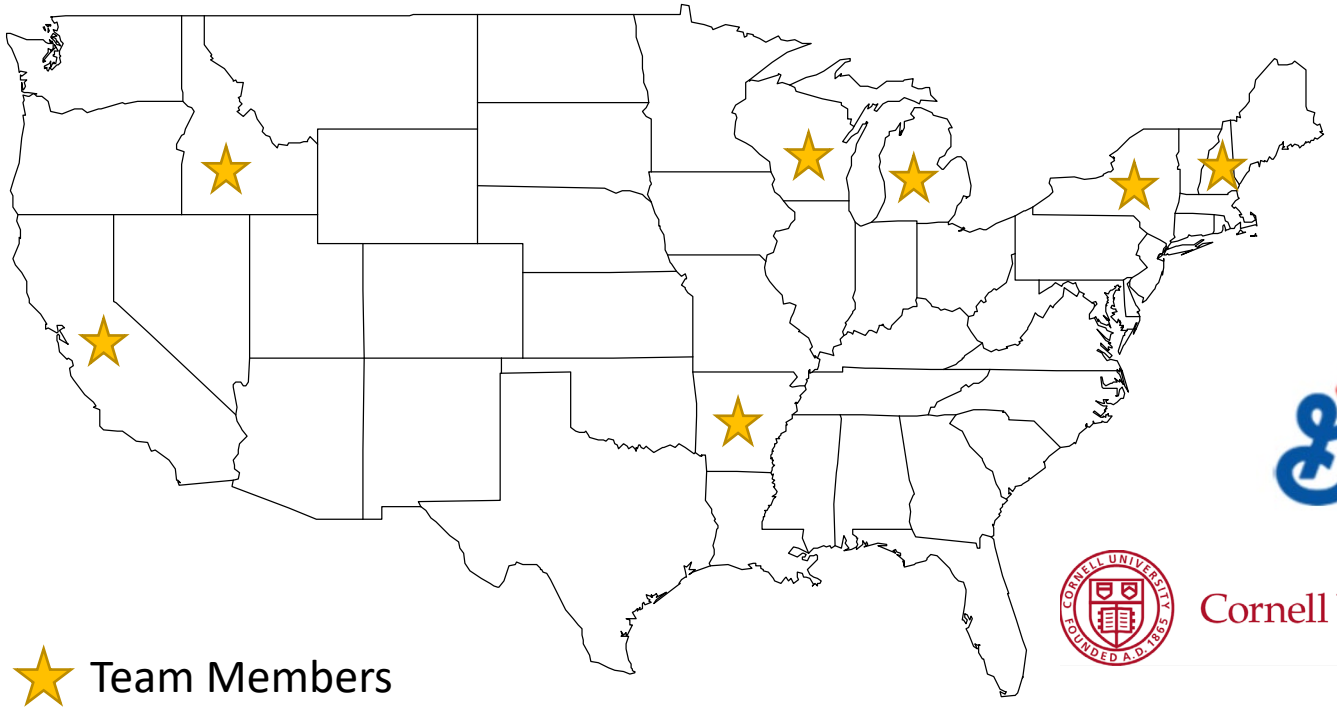
Interoperable

Documented

Open Source

Sustainable

RuFaS Team



★ Team Members

ANIMAL

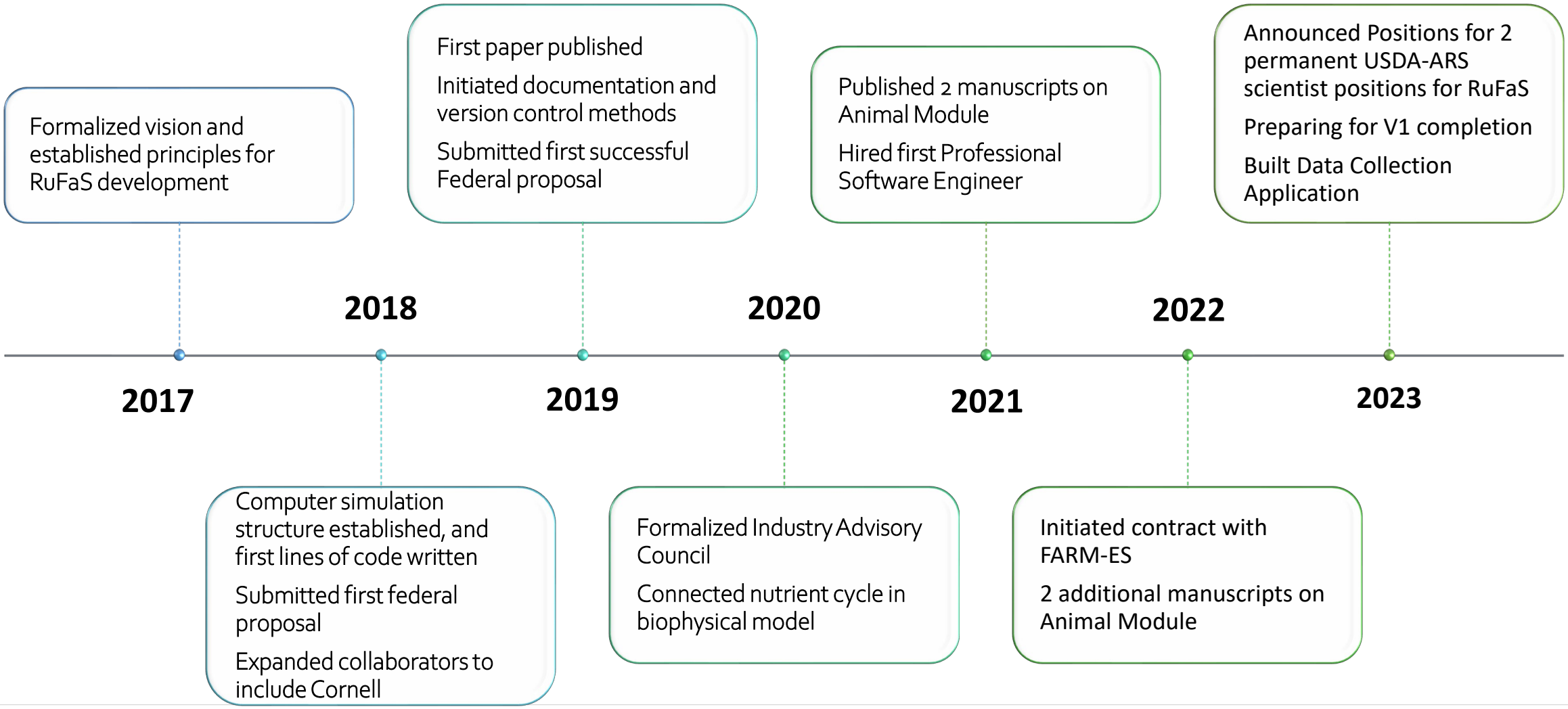
MANURE

SOIL + CROPS

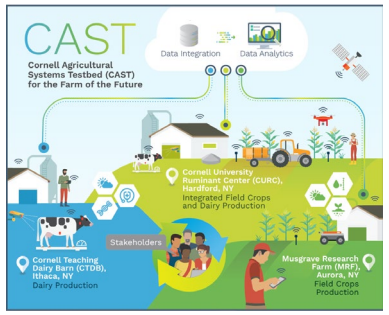
ENERGY

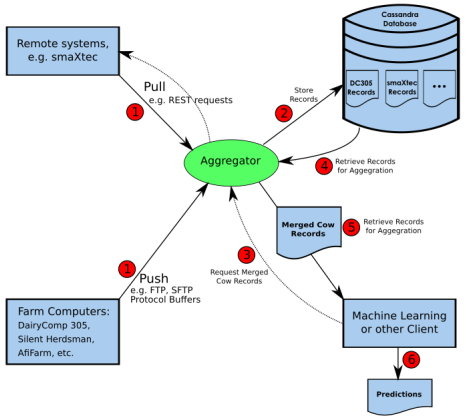
ECONOMICS

RuFaS Evolution



Objectives RuFaS- CAST integration





Environmental Impacts to inform:

- Reporting efforts
- Benefits/impacts of technologies tested at CAST
- Farm decision-making

Frequency increases with increased automation of data exchange

Cleaned, aggregated data for:

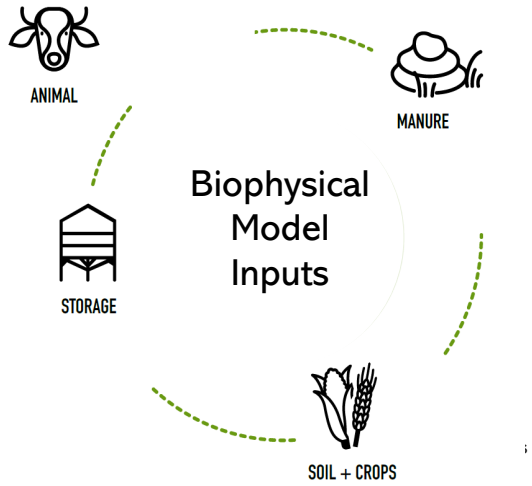
- Model Initialization
- Model Evaluation
- Replacing Modeled Outputs

RUFAS I/O STRUCTURE

INPUT MANAGER

Single Source of Truth

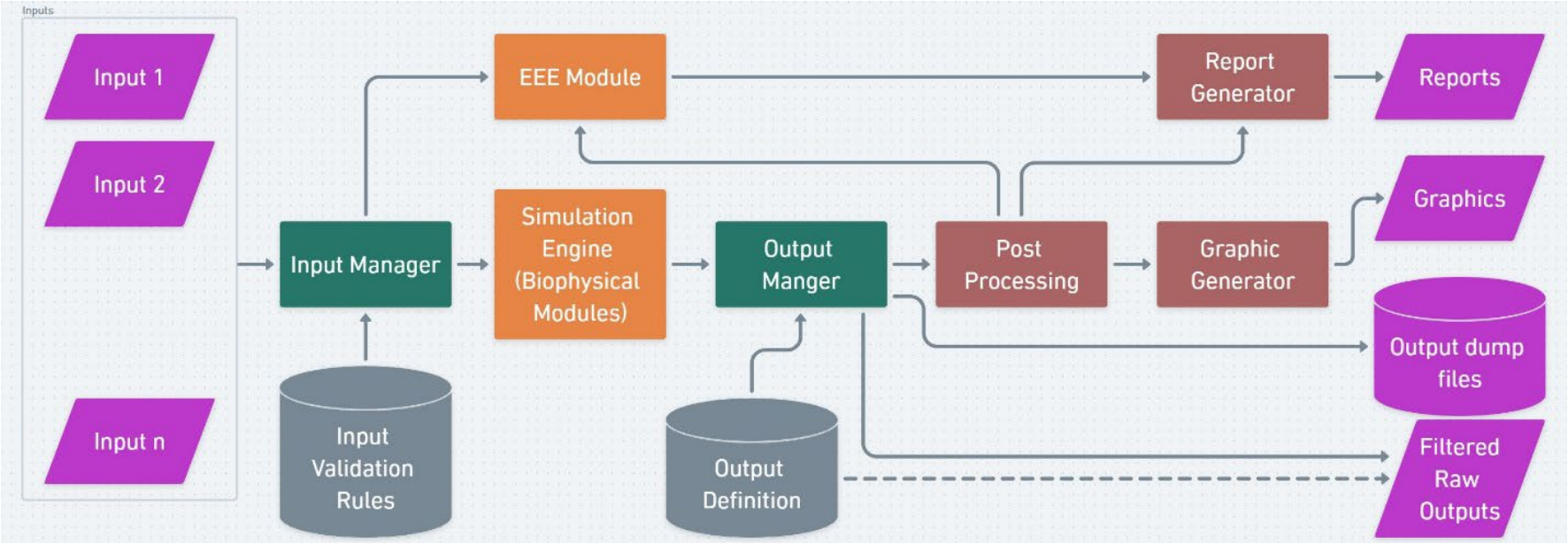
All inputs flow through Input Manager. Checks and corrects inputs if needed.



OUTPUT MANAGER

Complete Overhaul

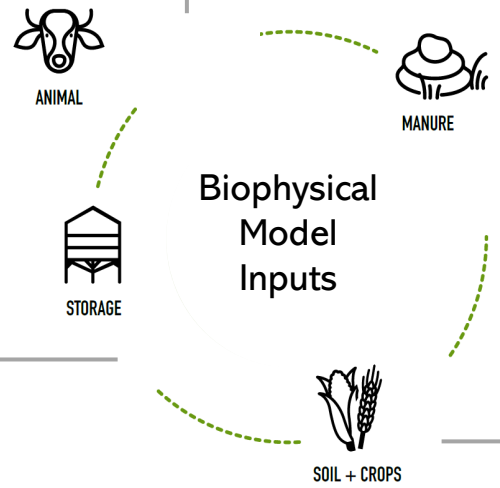
New methods are flexible, testable, and **scalable**



RuFaS Inputs

Farm Level Inputs
- Simulation length
- Weather
- Lat & Long
- Feed Composition Library

- Herd demographics
- Milk production
- Calf management
- Reproductive Program Management
- Avg. Birth weight and Mature Bodyweight
- Feeding Groups and Feeds or Diets

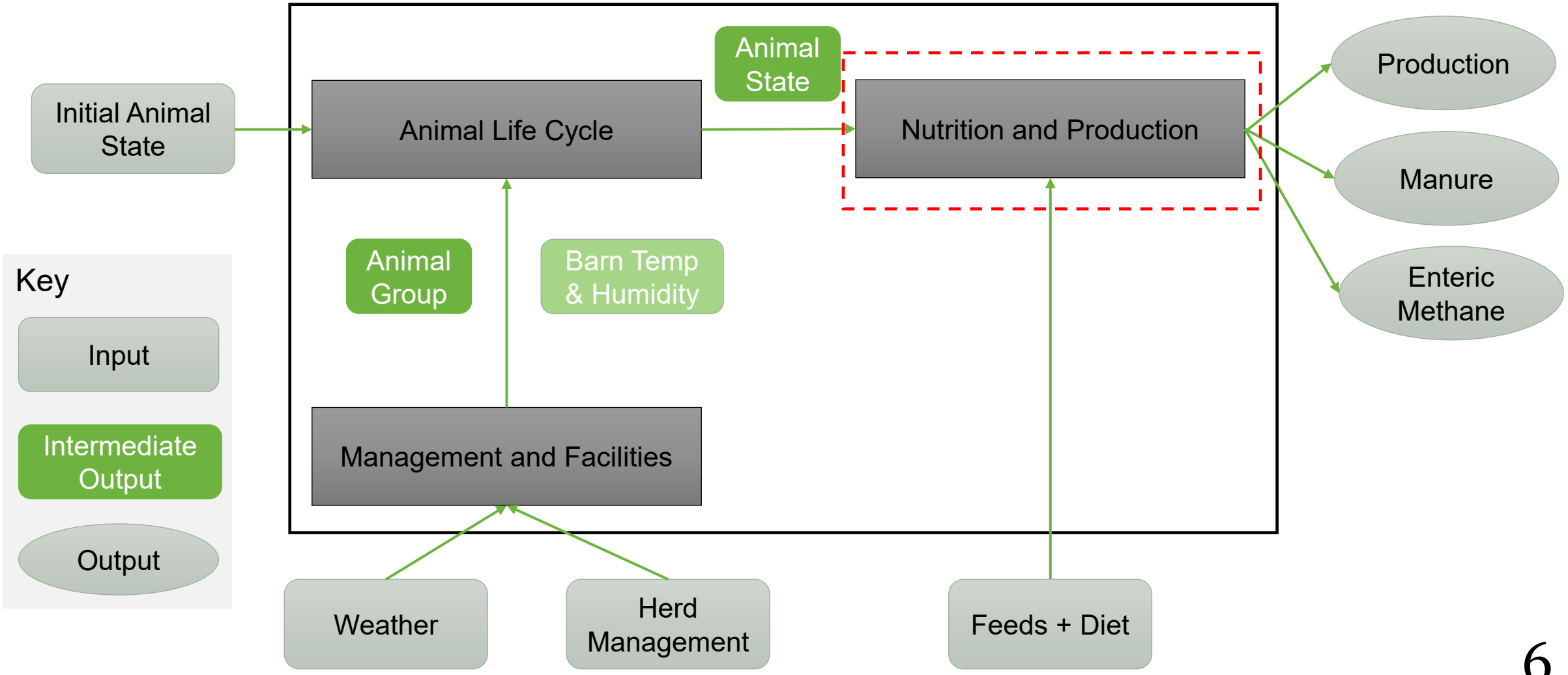


- Manure cleaning methods
- Bedding type
- Manure storage methods
  - Separation Methods
  - Treatment process
  - Long term storage methods
- Scenarios assigned to each pen separately

- Feeds used for different animal groups
- Feeds grown on farm
- Storage options used
- Purchased feeds

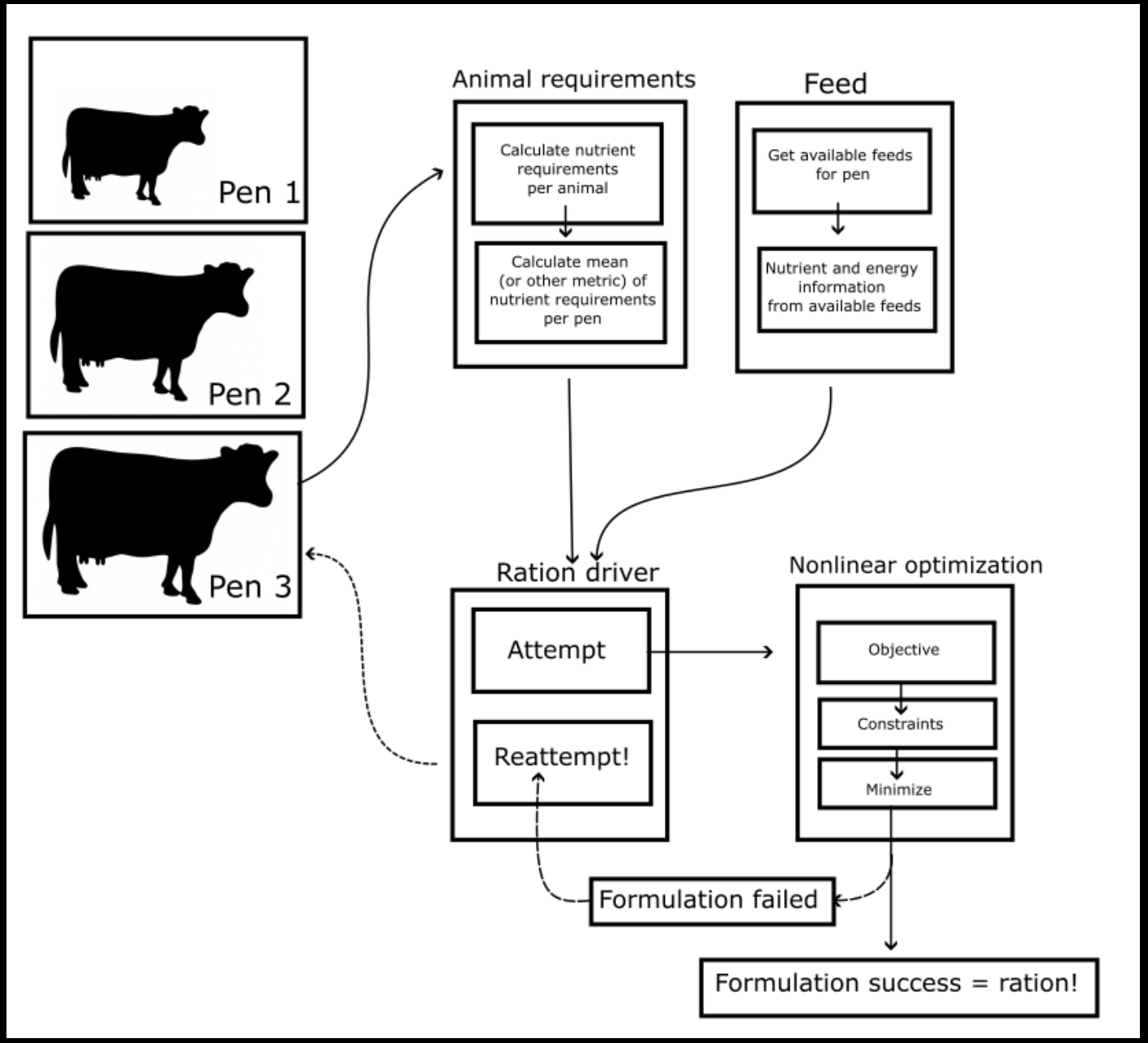
- Field Management
- Crops (and crop rotations)
- Field Fertilizer Practices
- Field Manure Practices
- Field Tillage Practices
- Field Soil Profiles

The Animal Module

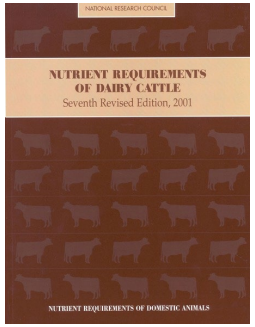


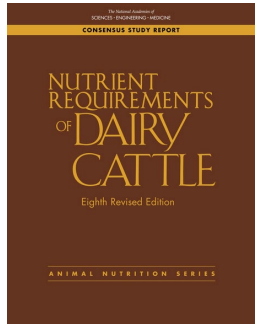
Ration formulation in RuFaS

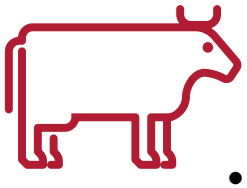
- Formulation occurs at a user-defined interval (e.g. weekly or monthly)
- Total amounts delivered updated daily based on animal numbers



Automated Diet Formulation uses National Standards for Nutrient Requirements







Inputs

- Body weight
- Days in pregnancy
- Parity
- Calving interval
- Milk components
- Milk yield
- Days in milk
- Body condition score
- ...

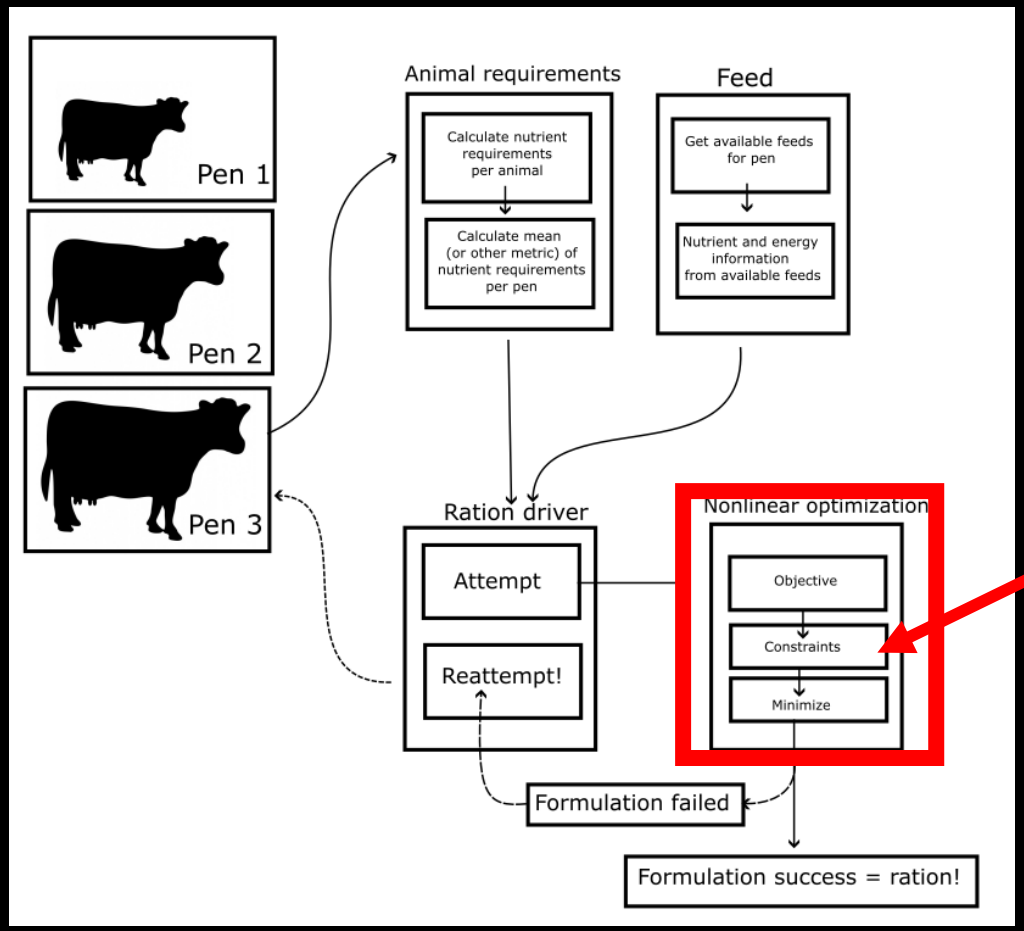
calc_rqmts

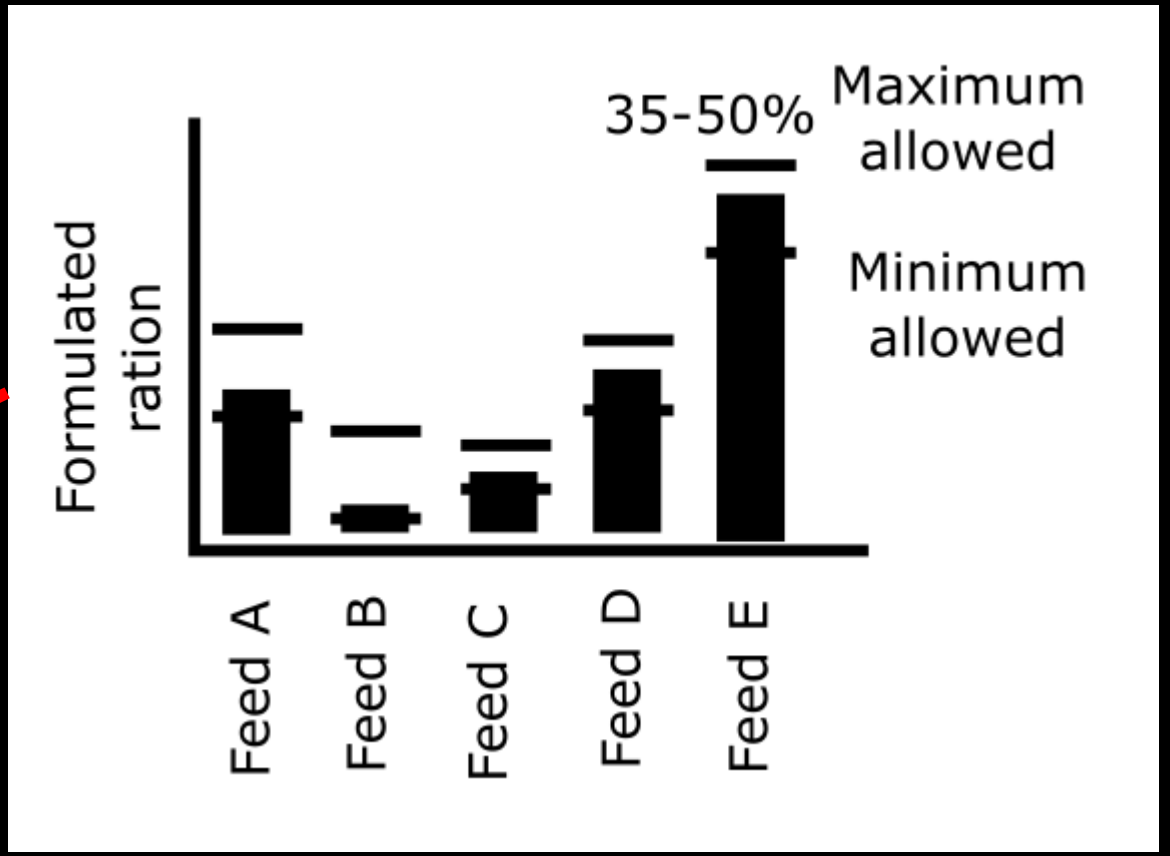
Outputs

- Net energy for maintenance
- Net energy for growth
- Net energy for pregnancy
- Net energy for lactation
- Metabolizable protein
- Calcium
- Phosphorus
- Dry matter intake estimate
- …

Adapted from Hansen, 2021

User-Defined Ration Option adds Target inclusion rates and acceptable bounds to the constraints

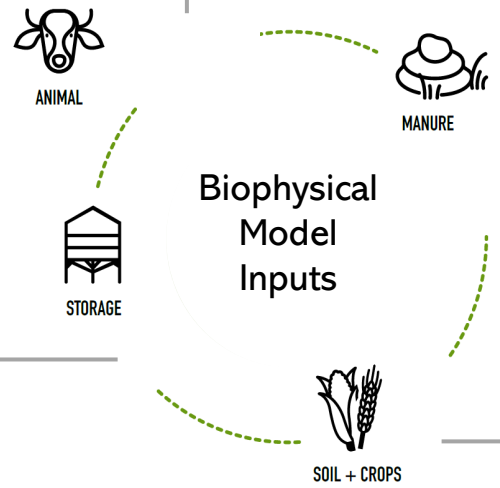




RuFaS Inputs

- Herd demographics
- Milk production
- Calf management
- Reproductive Program Management
- Avg. Birth weight and Mature Bodyweight
- Feeding Groups and Feeds or Diets

Farm Level Inputs
- Simulation length
- Weather
- Lat & Long
- Feed Composition Library



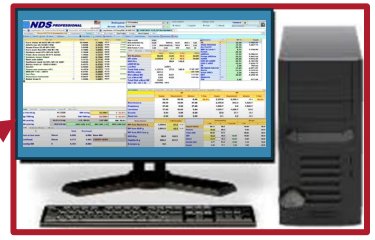
- Manure cleaning methods
- Bedding type
- Manure storage methods
  - Separation Methods
  - Treatment process
  - Long term storage methods
- Scenarios assigned to each pen separately

- Feeds used for different animal groups
- Feeds grown on farm
- Storage options used
- Purchased feeds

- Field Management
- Crops (and crop rotations)
- Field Fertilizer Practices
- Field Manure Practices
- Field Tillage Practices
- Field Soil Profiles

Dairy Cattle Feeding Process

Diet Formulation Software



Diet Recipe
(kg DM feed/cow)

Feed Mixing + Delivery Software

Pen Diet Recipe
(kg As-Fed feed /pen)

Feed Mixers

Feed Delivery

Refusals

Number of cows / pen

Herd Management Software

Animal Production Info

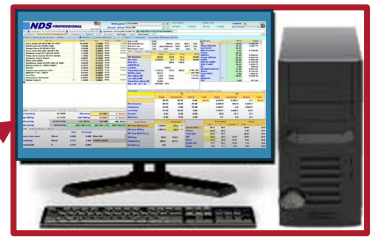
Feed Analysis Report

Feed DM Content
(% DM)

Feed Nutrient Content

Initiating CAST Data Integration with RuFaS

Diet Formulation Software



Diet Recipe
(kg DM feed/cow)

Feed Mixing + Delivery Software

Pen Diet Recipe
(kg As-Fed feed /pen)

Feed Mixers

Feed Delivery

Refusals

Feed Nutrient Content

Feed Analysis Report

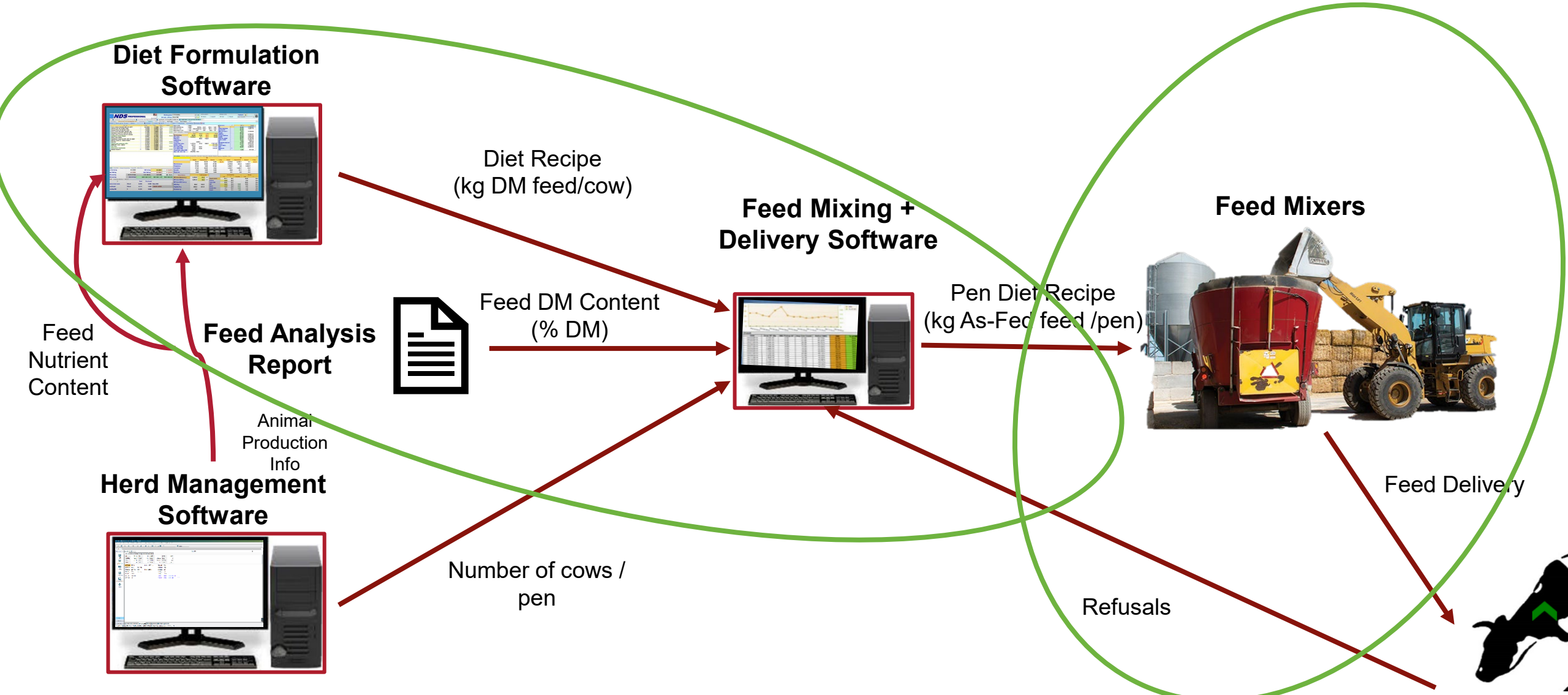
Feed DM Content
(% DM)

Animal Production Info

Herd Management Software

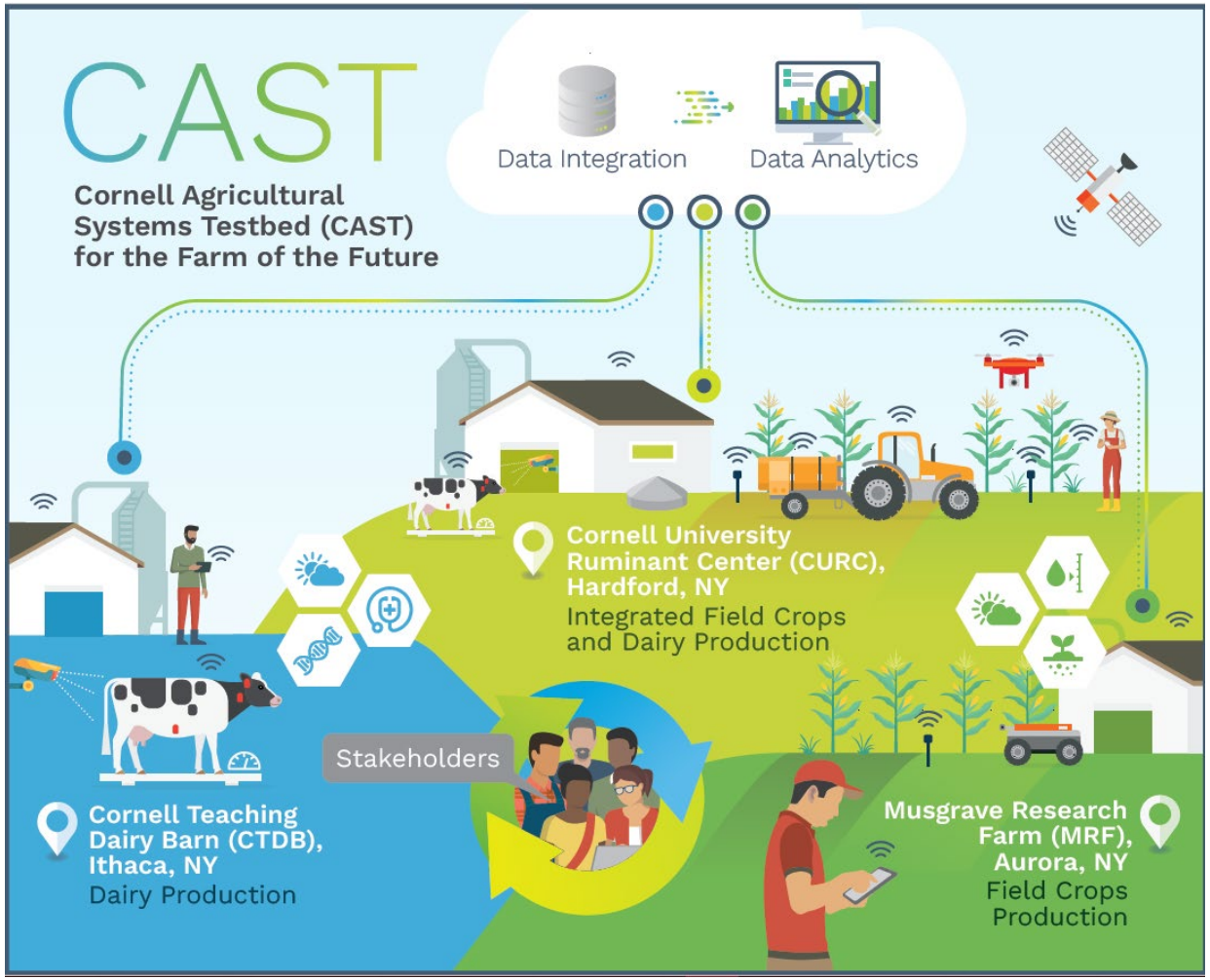
Number of cows / pen

Next Steps…


Diet Formulation Software
Diet Recipe (kg DM feed/cow)
Feed Mixing + Delivery Software
Feed Mixers
Feed Nutrient Content
Feed Analysis Report
Feed DM Content (% DM)
Pen Diet Recipe (kg As-Fed feed /pen)
Animal Production Info
Herd Management Software
Number of cows / pen
Feed Delivery
Refusals

Ag Data Use Case: Integration of CAST & RuFaS for Sustainable Decision making

- CAST is a research and education site to promote advances and education in digital agriculture
- RuFaS is a whole farm simulation model that provides holistic estimates of environmental footprints
- By integrating these digital platforms we will increase understanding of short- and long-term benefits of digital technologies and management
- Immediate focus will address barriers to data interoperability in the dairy feeding process



Thank you for tuning in!

We rely on stakeholder participation!

- Participatory development involves stakeholders in all parts project: from conceptualization to implementation and reporting
  - Creates a shared understanding of the system, the problem and the solutions
  - Increases stakeholder ownership of the research outcomes

- **Contact Kristan (kfr3@cornell.edu) if interested in joining RuFaS or CAST advisory councils**