2026. 5. 6.

K-Climate Technology

Data-Driven Methane Prediction in Dairy Systems

From emission factors to animal-level precision monitoring

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Presented at Korea Green Innovation Days (KGID) Symposium

Why Methane Matters in Livestock ?

Global Emission Structure: Agriculture and Livestock

Livestock plays a major role within agriculture and is a critical target for climate action.

1 Global Greenhouse Gas Emissions

Total Global Emissions
= 100%

2 Agriculture Contribution

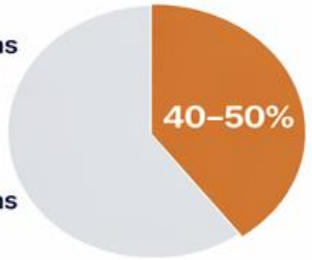
~10 – 12%
from Agriculture
(on-farm activities)

~20 – 24%
including Land Use (AFOLU)

3 Livestock Contribution

~40 – 50%
of Agricultural Emissions

Equivalent to
~14 – 15%
of Total Global Emissions
(FAO, full supply chain)



KEY TAKEAWAY

Livestock represents one of the largest emission sources within agriculture and accounts for nearly 15% of total global emissions.

Source: IPCC (2019), FAO (Gerber et al., 2013)

How Methane is Produced in Cattle?

1 Feed Intake & Rumen Fermentation

Feed enters the rumen, where microbes break down carbohydrates under anaerobic (oxygen-free) conditions.

2 Hydrogen Production

Fermentation produces hydrogen (H_2), carbon dioxide (CO_2), and volatile fatty acids (VFAs).

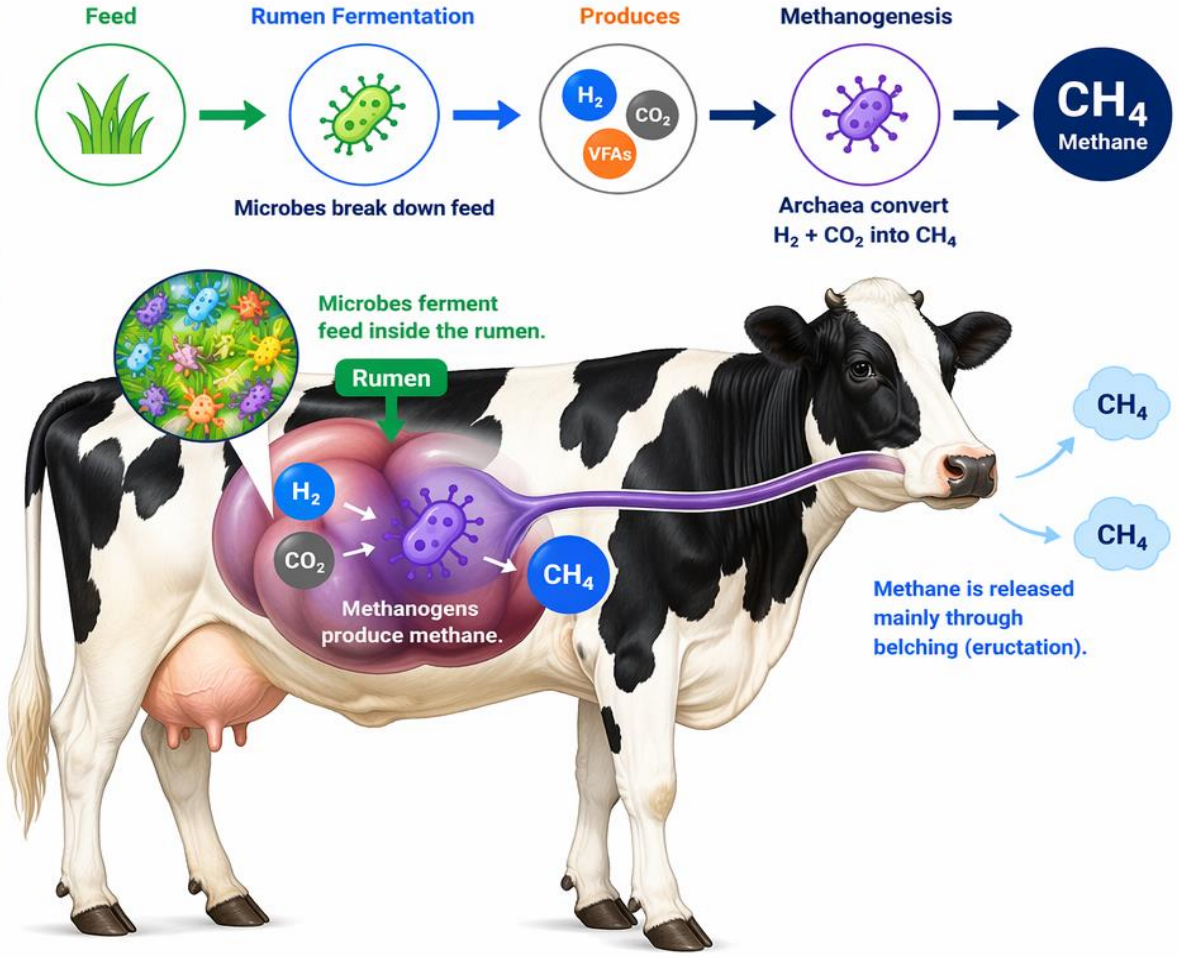
3 Methanogenesis

Methanogenic archaea use hydrogen and carbon dioxide to produce methane.

$$4H_2 + CO_2 \rightarrow CH_4$$

Emission Pathway

Methane accumulates in the rumen and is released mainly through eructation (belching). CH_4



Source: Hristov et al. (2013); IPCC (2019)

Transitioning to Data-Driven Precision Migration in Dairy Systems

National Methane Emission Factor: Tier 1, 2, 3

IPCC Guidelines for National Greenhouse Gas Inventories

Tier 1 — Default Approach

The simplest method using default emission factors provided by the IPCC.

Data Used

- IPCC Default Emission Factor (applicable globally)
- Livestock Population Statistics

Calculation Example

CH_4 Emissions = Livestock Population × IPCC Default EF (kg CH_4/head/year)

1,000,000 head × 39 kg (IPCC Default) = 39,000 tons CH_4/year

Simple and conservative, but least accurate.

Tier 2 — Improved Approach (Country-Specific)

Reflects national characteristics by adjusting the emission factor to be more country-specific.

Data Used

- Country-Specific Emission Factor (reflecting feed, management, productivity, etc.)
- Livestock Population Statistics

Calculation Example

CH_4 Emissions = Livestock Population × Country-Specific EF (kg CH_4/head/year)

1,000,000 head × 33 kg (National Survey) = 33,000 tons CH_4/year

More accurate than Tier 1 by reflecting national conditions.

Tier 3 — Advanced / Activity-based Approach

Uses actual activity data or models to estimate emissions with the highest accuracy.

Data Used

- Individual Animal Measurements (e.g., MRC, NIRS, sensors)
- Feed Intake, Body Weight, Productivity and Other Activity Data
- Country-Specific Models

Calculation Example

CH_4 Emissions = ∑ (Measured Emissions per Animal) or Model-based Estimation

28 kg (Animal 1) · 31 kg (Animal 2) · 25 kg (Animal 3) · … → Average / Sum 28.0 tons CH_4/year

Most accurate and internationally credible.

Simple / Conservative → Accurate / Robust / Data-driven

"Accurate, individual-level methane data is essential for next-generation climate policy and livestock sustainability."

Source: IPCC (2006, 2019); 2019 Refinement to the 2006 IPCC Guidelines

Global Status of AI-driven Methane Prediction

AI and machine learning enable accurate, scalable methane prediction

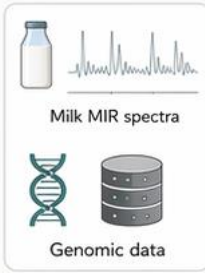
Integration of multi-source data improves prediction performance

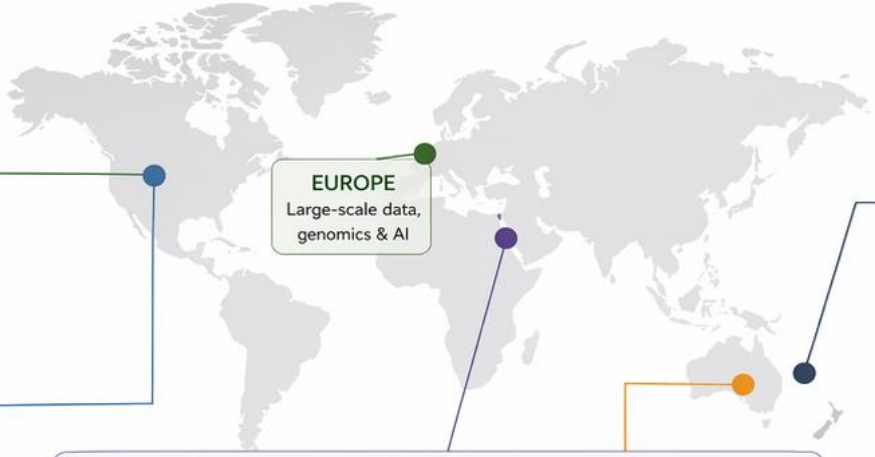
Genomic information allows selection for low-emission animals

Countries are advancing toward national breeding programs

EUROPE (Netherlands & Denmark)
Genomics + MIR + AI

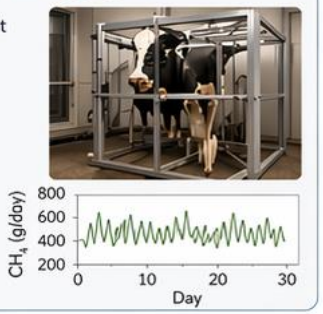
- Large-scale milk MIR spectra combined with genomic data
- Machine learning models predict methane traits (CH_4, intensity)
- Projects: Breed4Green, CH_4COW, Micro-HUB
- Moving toward genomic evaluation and national implementation





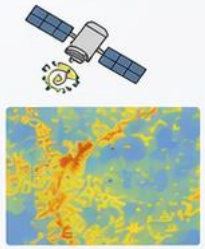
NEW ZEALAND
World-leading methane breeding program

- Long-term methane measurement using respiration chambers and SF_6 tracer
- Development of genomic breeding values (GEBV) for methane
- Methane included in national breeding index (e.g., NZLM)



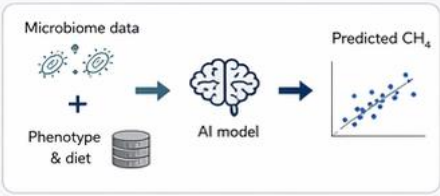
CANADA
AI + Sensor + Satellite

- Integration of on-farm sensor data and management information
- AI models estimate methane at herd and regional scale
- Satellite data (Sentinel-5P) + ML for regional methane monitoring and inventory



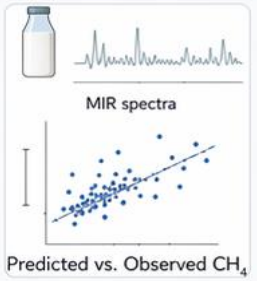
ISRAEL (Research Example)
AI + Microbiome

- Rumen microbiome profiles combined with phenotypes
- Machine learning models predict methane emission and feed additive responses
- Up to 27% reduction in methane with targeted interventions



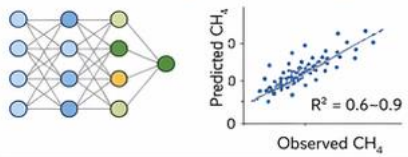
AUSTRALIA
MIR + Machine Learning

- Milk MIR spectra and herd data used for methane prediction
- ML models provide accurate predictions at large scale
- Supporting national breeding and carbon-neutral strategies

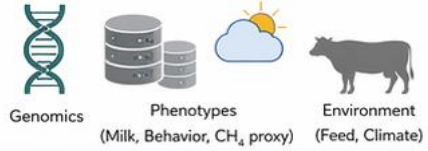


1. Measurement
Chamber / Sniffer / MIR

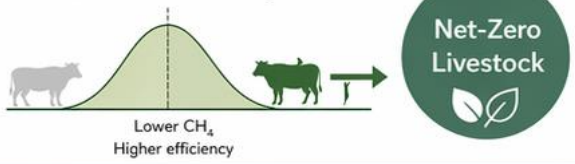
2. AI Prediction
Machine Learning / Deep Learning



3. Data Integration
Genomics + Phenotypes + Environment



4. Genomic Selection
Low-emission breeding



Abbreviations: CH_4 = Methane, MIR = Mid-infrared spectroscopy, SF_6 = Sulfur hexafluoride, ML = Machine Learning, AI = Artificial Intelligence, GEBV = Genomic Estimated Breeding Value, NZLM = New Zealand Livestock Improvement

Bottlenecks in AI-based Methane prediction in livestock

Limited Ground Truth Data

Methane data is sparse and unevenly distributed globally.

- Small sample sizes for robust training
- Insufficient coverage of biological variability

Data Integration Complexity

Merging heterogeneous data (MIR, Genomic, Env) is demanding.

- Time lag between MIR sampling and CH_4 measurements
- Requires high-precision preprocessing and syncing

Model Generalization Issues

Predictive models lack robustness across different farm environments.

- Variation in breeds, feeding, and management
- Local models rarely transfer well without massive validation

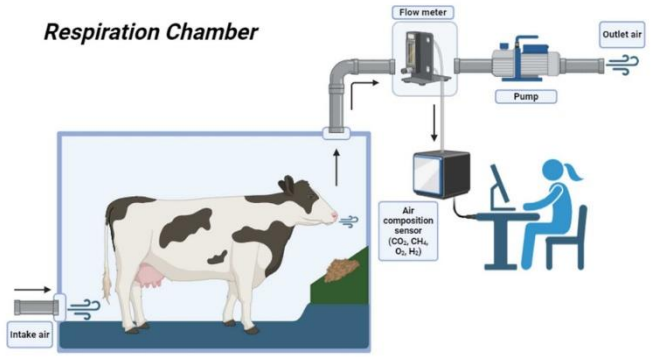
Biological Trust & Interpretation

Deep Learning models lack transparency for policymakers.

- Limited explainability of MIR spectral features
- Farmers require "Why" before technological adoption

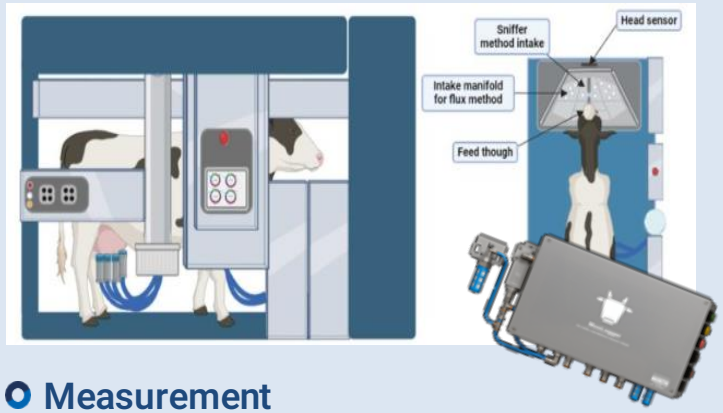
Methane Measurement Efficiency Comparison

Respiration Chambers



- **Measurement :** Difference in CH_4 Concentration between incoming and outgoing air and the ventilation rate
- **Accuracy:** High
- **Daily Capacity:** 1~2 cows
- **System Cost:** Very High
- **Stress level :** Very High
- **Policy Scalability:** Low

Sniffer



- **Measurement**
  Methane and CO_2 concentrations (ppm) are measured around the animal's nose and mouth
- **Accuracy:** Correlation (0.77 ± 0.18) with Chambers
- **Daily Capacity:** more than 100 cows
- **System Cost:** Zero Extra cost
- **Stress level:** Zero (Non-Invasive)
- **Policy Scalability:** Extremely High

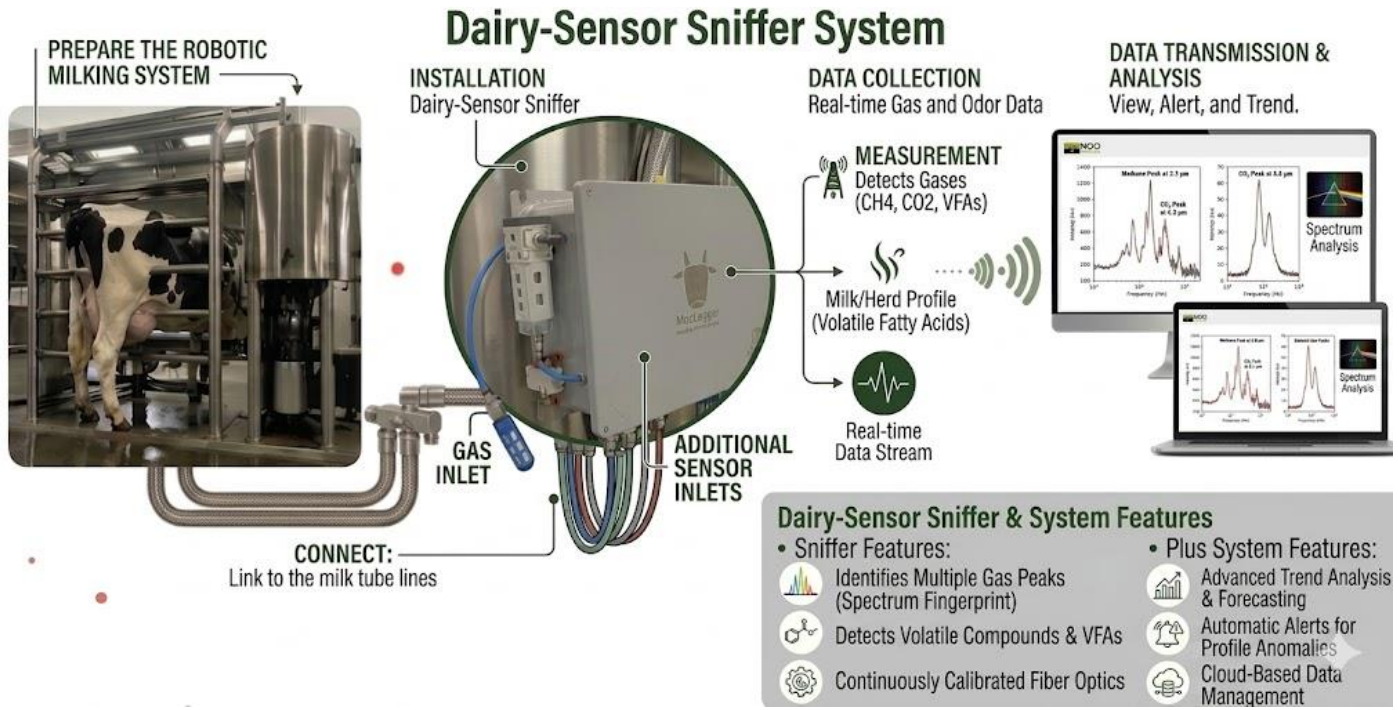
GreenFeed

- **Measurement**
  Measured during feeding visits using gas concentration and airflow sensors.
- Accuracy:
- **Daily Capacity:** 15~25 Cows
- **System Cost:** ~$150K
- **Stress level :** Moderate
- **Policy Scalability:** Moderate

Auto Milking System (AMS) + Sniffer device

Monitoring CH4 and CO2 emissions from ruminants' breath.

New diets, nutrition additives, genetic profiling, and husbandry practices can be validated through accurate measurement of CH_4 and CO_2 emissions.



https://www.youtube.com/watch?v=P6APywH6x-o

Genetic Selection using Bio-data in Dairy system

Using “genetics to select naturally low-methane cattle” for a greener planet.

The Permanent Solution

Unlike feed changes that need to happen every day, genetics are built-in. When we select cows that **naturally produce less methane**, that trait stays with them for life.

$$\text{Phenotype} = \text{Genotype} + \text{Environment}$$

Result = Nature (Genetics) + Care (Farm Management)

Strategic Advantages

- Permanence No recurring daily costs or labor required.
- Passes Down The next generation inherits these eco-friendly genes.
- Verifiability DNA markers provide clear, auditable proof for carbon credits.

AI-Driven Methane Prediction for Smarter Dairy Breeding

Integrating Sniffer, Milk MIR, and Genomic Data to Select Low-Methane Cattle

Goal: Develop accurate methane prediction models to accelerate genetic selection for low-methane and sustainable dairy cattle.

1 Data Collection

Collect multi-source data from the same animals.

Key Output Raw datasets (CH_4, MIR, SNP, yield)

2 Synchronization

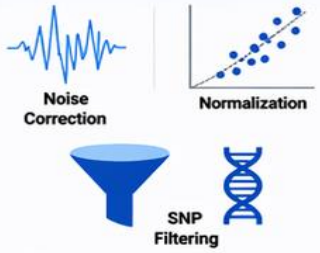
Match records by animal ID, date, and lactation stage.

Animal ID	Date	DIM
001	2024-03-12	150
001	2024-03-12	150
001	2024-03-12	150

Key Output Unified animal-level dataset

3 Preprocessing

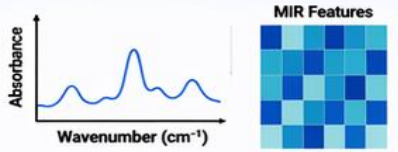
Clean and standardize data for reliable analysis.



Key Output High-quality analytical dataset

4 Feature Extraction

Transform MIR spectra into informative features.

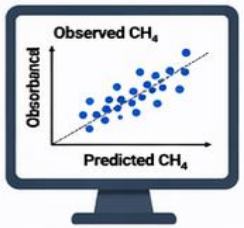


- Spectral preprocessing
- Feature selection (e.g., PLS, PCA)
- Combine with SNP & performance

Key Output Optimized feature set

5 Model Training

Train AI/ML models to predict methane from combined data.



- PLS
- Random Forest
- Neural Network

Key Output Trained prediction model

6 Model Integration

Combine MIR, genomic, and environmental informations.

Key Output Integrated multi-modal framework

7 Validation

Evaluate accuracy and robustness across herds and lactations.

$R^2 = 0.62$

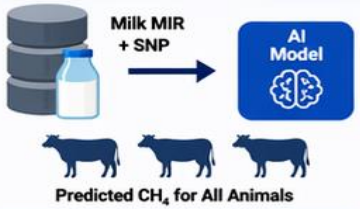
RMSE = 6.8 g/day

- Cross-validation
- Across-herd testing
- Across-lactation validation

Key Output Validated and reliable model

8 Scale Prediction

Predict methane for large populations, even without sniffer.



Key Output Herd-scale methane prediction

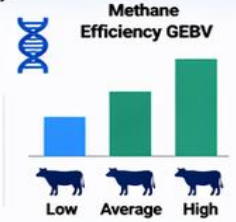
9 Genomic Evaluation

Estimate breeding values for methane efficiency.

$y = \mu + g + e$

$g \sim GBLUP$

- GEBV for Methane
- Genetic Correlation with Production



Key Output Methane GEBV for selection

10 Elite Selection

Select and breed low-methane, high-performance cattle.

Selection Candidate List

Rank	GEBV	Milk Yield
1	-0.23	High
2	-0.18	High
3	-0.15	Very High

Key Output Accelerated genetic gain for a low-carbon dairy future

Data-Driven
Leverages sniffer, milk MIR, genomics, and production data.

Accurate & Scalable
Delivers reliable predictions for individuals and entire herds.

Smarter Breeding
Enables selection of elite low-methane cattle for a sustainable dairy industry.

AI Methane Prediction Platform

Technical Architecture: Converting Livestock Data into Climate-Smart Economic Value

Milk MIR Data
Non-invasive spectroscopy info

Genomic Info
Genotypes & Pedigree records

Feed Intake
Nutritional composition data

Environment
IoT-based barn climate logs

Integrated AI Analytics
- Advanced bio-prediction algorithms
- Low-methane cattle selection logic
- Real-time precision feed optimization

Market Value
Carbon credits & incentives

Policy Ready
NDC reporting & verification

Dynamic Updates
Continuous feedback loops

Capturing Digital Fingerprints from routine dairy data to generate verifiable carbon credits.

From Methane Data to Market Value

Data-Driven Certification

Automated methane monitoring using milk MIR spectroscopy data.

- Monthly individual cow & farm reports
- Zero additional labor requirement

Low-Carbon Certification

Continuous verification through MRV-compliant data streams.

- Transparent carbon footprint tracking
- Fully auditable and reliable data logs

"Transforming routine farm data into verified climate and economic value"

Carbon Market Integration

Linking verified emission reductions directly to market credits.

- Voluntary and compliance market access
- High-integrity monetization pathways

Digital Platform System

One-stop management of genetics, milk recording, and emissions.

- Precision decision-making support
- Integrated real-time farmer feedback

Core Value Proposition

By automating biological data capture and verifying it through a digital-first MRV framework, we transform routine farming metrics into bankable carbon assets and certified low-carbon premiums.

Strategy 1：National Genetic Evaluation system

Genetic Trait & Index Integration

Adopt Residual Methane (RMeP) and Methane Efficiency

- Reflect in proven sire selection index
- Establish evaluation standards for genetic potential

NACF System Integration

Collaborate with the NACF Dairy Cattle Improvement Center for data collection.

- Leverage MIR analysis from national milk recording
- Provide individual methane reports to farms

Data Feedback & Monitoring

Incentivize Low-Carbon Management through real-time data circulation.

- Add methane stats to milk recording reports
- Provide customized feed efficiency analytics

National Evaluation Framework

Consolidate a unified database for national genetic evaluation of methane traits.

- Integrate nationwide data repositories
- Finalize the infrastructure for genetic evaluation

Strategy 2: Advancing National Methane Emission Factor

"Leading the Global Standard in Scientific Livestock Carbon Accounting"

Precision Statistical Transition

Upgrading from Tier 2 (Regional Averages) to Tier 3 (Individual Real-time Measurement) is essential for scientific carbon accounting.

Statistical Precision Goal

Tier 2 → Tier 3

- IPCC Reporting Excellence: Provides high-resolution primary data for the National Greenhouse Gas Inventory Report (NIR).
- Customized Emission Factors: Establishment of Country-Specific Emission Factors that accurately reflect domestic feeding environments.
- 2050 Net-Zero Support: Provides the scientific backbone for a "Low-Carbon Dairy Certification" system to incentivize farm-level reduction.

MRV Optimization Roadmap

1. National Reference DB Establishment Standardizing enteric methane data across diverse domestic environments using high-resolution Sniffer and Milk MIR synchronization.
2. AI-Driven Emission Profiling Developing AI algorithms to convert spectral milk data into precise individual emission profiles with >70% reliability.
3. Country-Specific Factor Optimization Defining and validating high-precision national emission factors to replace default values in the IPCC inventory framework.
4. Policy Integration & Certification Launching a real-time MRV system to support the 2050 Carbon Neutrality roadmap and voluntary carbon market participation.
   Compliance with IPCC 2006/2019 Refinement Guidelines

Global Technology transfer & Scaling Strategy

Optimized AI Management Package

Our solution bridges the "Digital Divide" in the livestock sector by combining Korean AI expertise with existing milk testing infrastructure. It allows for immediate methane monitoring and productivity gains without the need for expensive new hardware, providing the most economical and rapid scaling model for developing countries.

Scalable Technology

Rapid Deployment Framework

- AI-based methane prediction using existing milk MIR data
- No additional equipment required (Leveraging current infrastructure)
- Capable of rapid deployment at a national scale

Integrated Development

Economic & Environmental Synergy

- Improved livestock productivity and smallholder farm income
- Simultaneous reduction of absolute methane emissions
- Foundation for Climate-Smart Livestock (CSL) systems

Policy & Global Alignment

Global Market Interoperability

- Compatibility with Carbon Markets and Climate Finance
- MRV-ready data for national NDC (Climate Goal) reporting
- Integration into National Dairy Development Programs

Building a Sustainable Future for Global Dairy with Data

Thank you for your attention.

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