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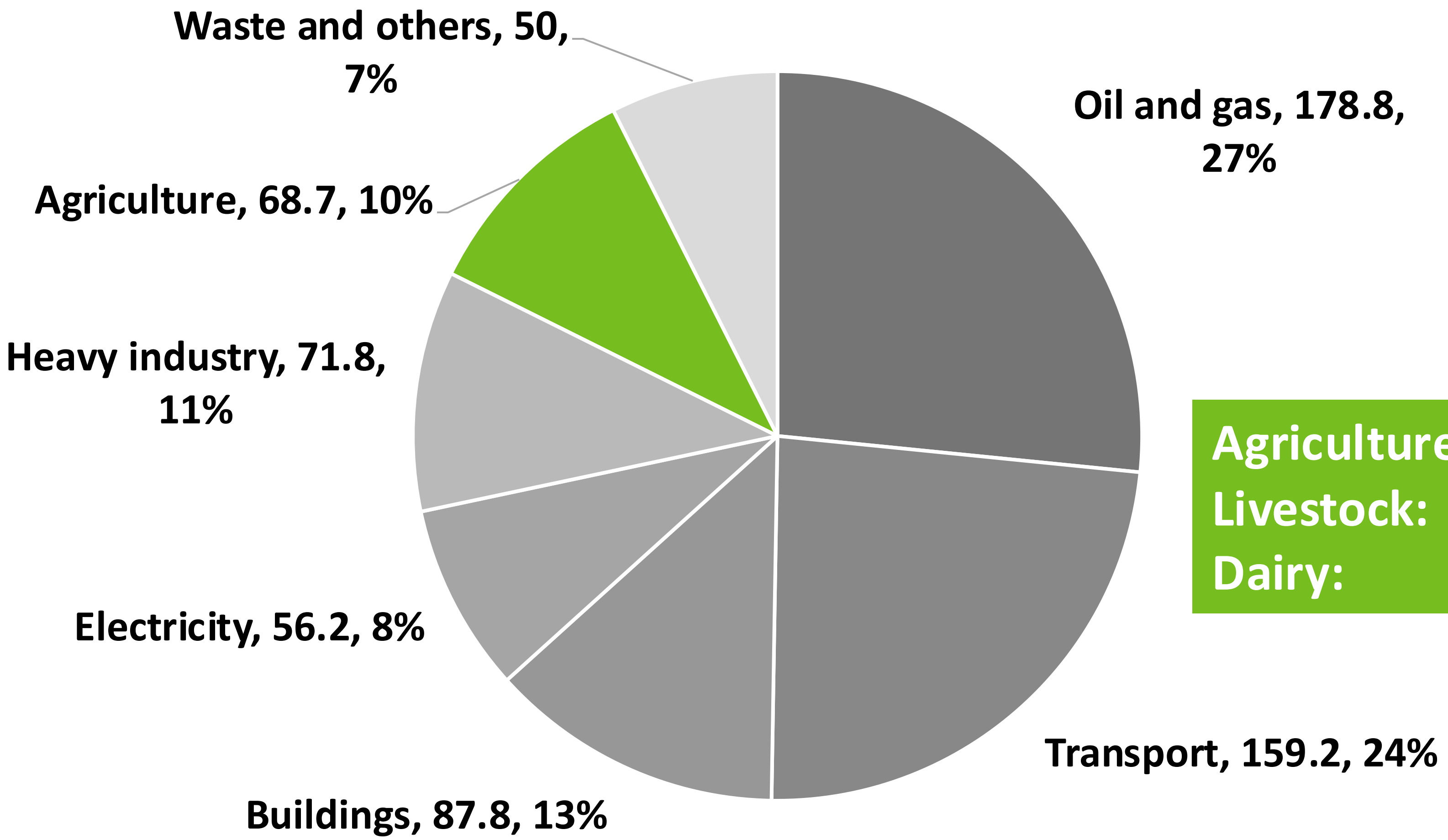
Have your cake and eat it too: Breeding cows for Fertility, Disease Tolerance, and Efficiency

Christine Baes
Full professor & Canada Research Chair in Livestock Genomics
Chair of Department of Animal Biosciences, University of Guelph

GHG by Canadian Economic Sector

Megatonnes of carbon dioxide equivalents



Agriculture:	68.7 Mt CO_2-eq
Livestock:	34.2 Mt CO_2-eq
Dairy:	12.4 Mt CO_2-eq

1.2%

Adapted from: www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions

Dairy Cattle Enteric Methane

492 g

CH_4 is produced per day by the average Holstein cow

±30%

Variation exists between cows within a herd

4-7%

Loss in gross energy intake for the animal

Achieving “Dairy Net Zero”

- Canada has endorsed the Global Methane Pledge
- Dairy Farmers of Canada (DFC) targeting net-zero GHG emissions from farm-level sources by 2050
- Many pathways to achieve this significant industry goal
- All possible strategies and tools will need to be used
- One major tool is **genetic selection – a permanent and cumulative approach**

Building Environmental Traits Capacity Over Time

2012

Milk Spectral Data

- Milk MIR pipeline and storage since 2013
  90% of milk recorded cows since 2018

2014

Efficient Dairy Genome Project

- Feed Efficiency & Methane Emission DB
  4,500 cows with FE and 1,500 with ME

2018

Resilient Dairy Genome Project

- Additional international partners
  15,000 cows with FE and 4,500 with ME

2022

New regional initiatives

- Lactanet investing in FE and ME collection
  CH_4 sniffers in Canadian commercial farms

2023

Dairy$_{Zero}$ Genome Project

- New Genome Canada program
  Roadmap for GHG mitigation

Since 2013, multiple projects to genotype cows with medium-high density chips -> over 45,000 cows

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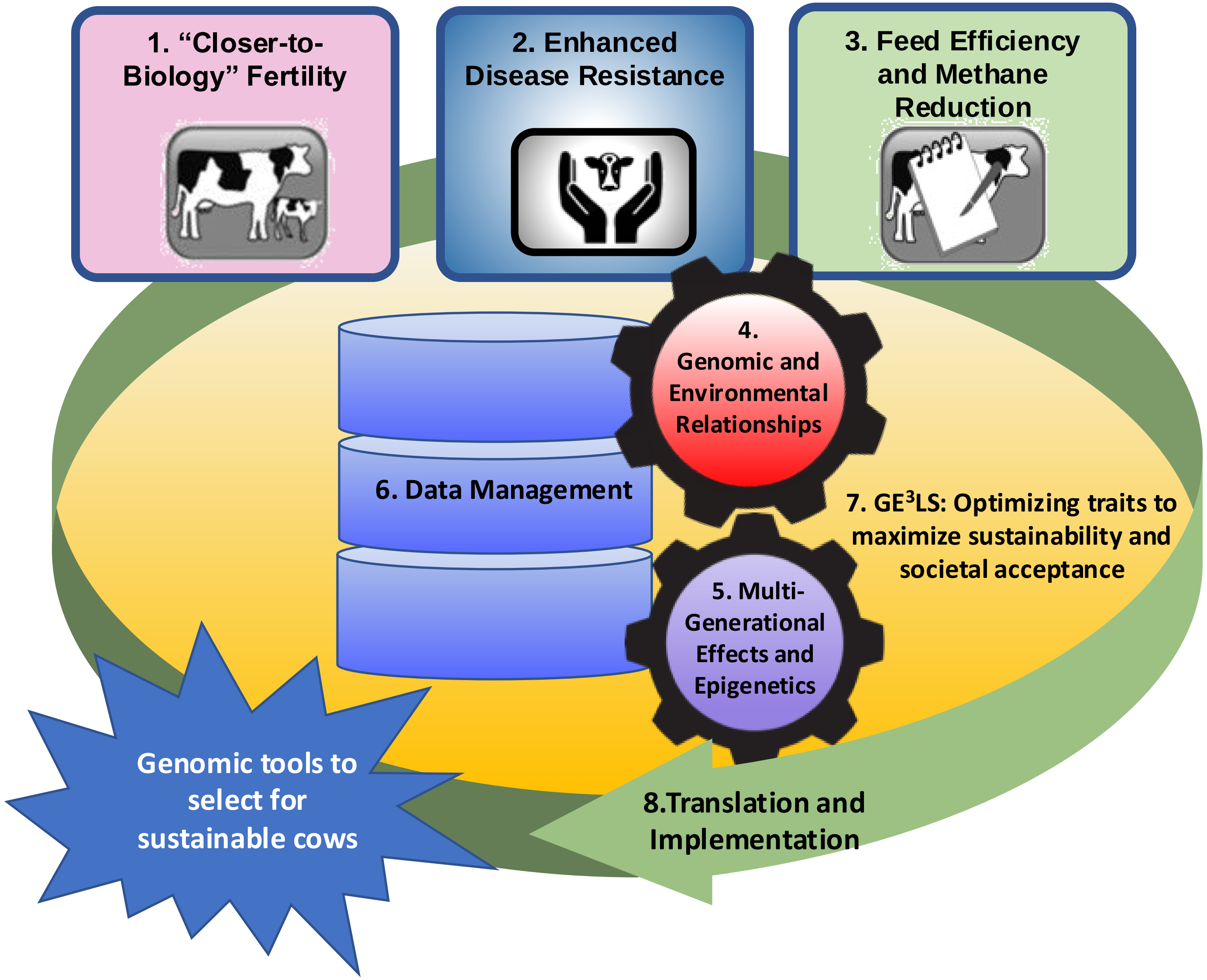
Dairy Resiliency Research

What is a resilient animal?

An animal able to adapt rapidly to changing conditions,
without compromising its productivity, health or fertility,
while becoming more resource-efficient,
and reducing its environmental burden.

The Resilient Dairy Genome Project

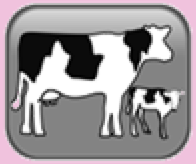


1. ‘Closer-to-biology’ fertility

THE UNIVERSITY OF BRITISH COLUMBIA

Dr. Ronaldo Cerri

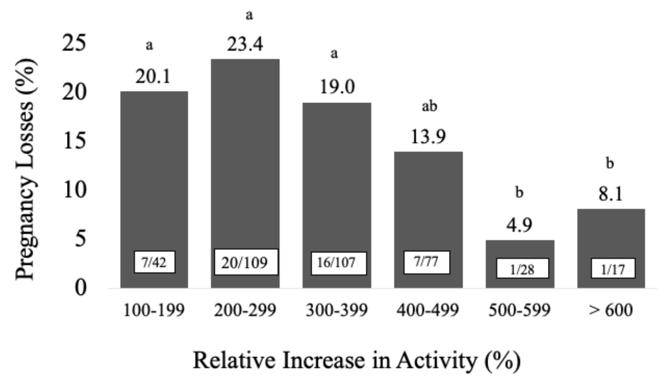
1. “Closer-to-Biology” Fertility



- Standardized phenotypes based on automated sensors
- Physiological factors affecting estrous expression and embryo survival
- Genomic markers of estrus expression and fertility
- Other new fertility phenotypes (Audrey Martin, Ella Dodd)

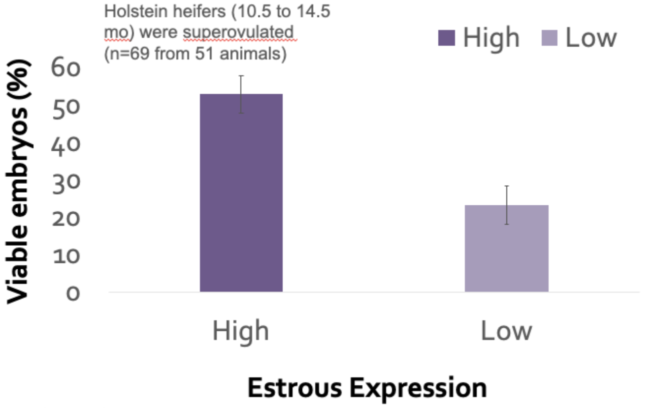
Repro. Biology: Madureira et al., 2022; 2021;
Size and Position Score: Martin et al., 2022a & b;
CNVs & Fertility: Oliveira et al., 2022;
Hormone Use: Lynch et al., 2022; Oliveira et al., 2021

Distribution of pregnancy losses (%) according to relative increase in activity during estrus



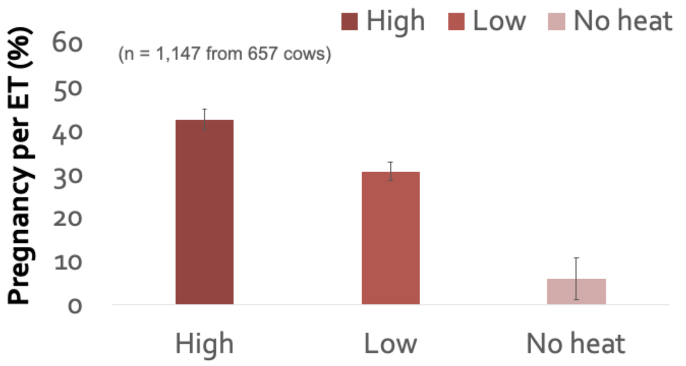
Madureira et al., 2019. J. Dairy Sci. 102:3598-3608

Increased Percent Viable Embryos



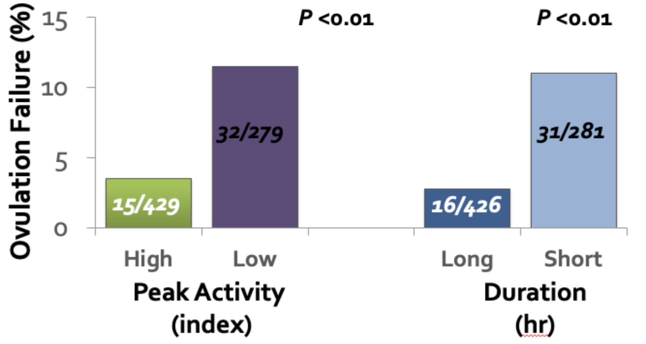
Madureira et al., 2020. J Dairy Sci. 103:5641-5646

Increased Pregnancy per Embryo Transfer



Madureira et al., 2020. J Dairy Sci. 103:5641-5646

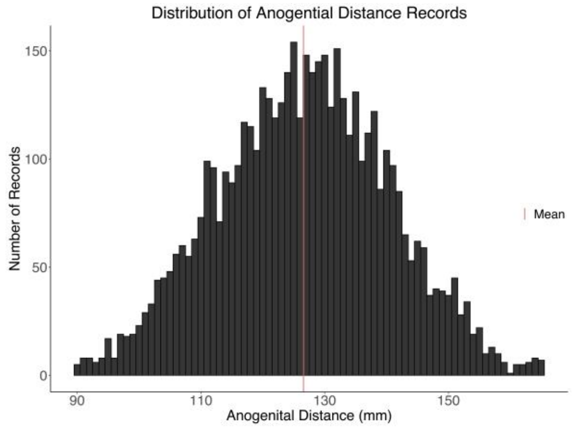
Reduced estrous expression resulted in more failed ovulations



Burnett et al., 2018. J. Dairy Sci. 101:11310-11320.

New Fertility Trait, Hot off the Press!

- Shorter Ano-genital distance (AGD) has favorable correlations with positive reproduction outcomes:
  - + Pregnancy / insemination
  - - follicular recruitment
  - - age at first conception
  - - Androgenous concentration
- Quick and simple phenotype, now being collected by Holstein Canada



Heritability: 0.39 ± 0.04
Reliability: 0.5
Sires with >10 Daughters: 0.7
Sires with >30 Daughters: 0.83

2. Enhanced disease resistance

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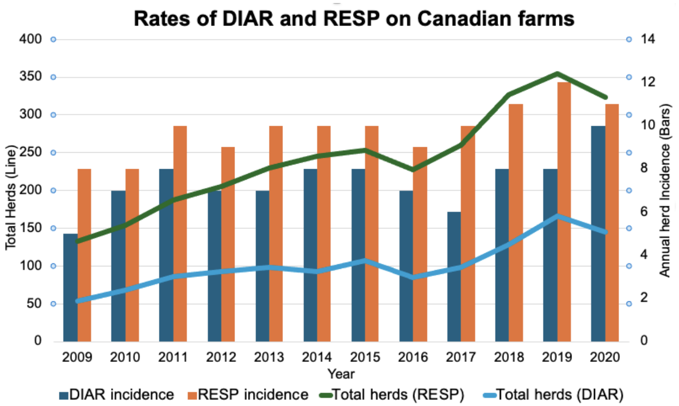
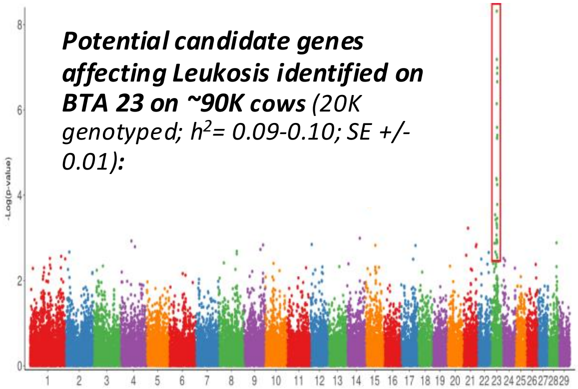
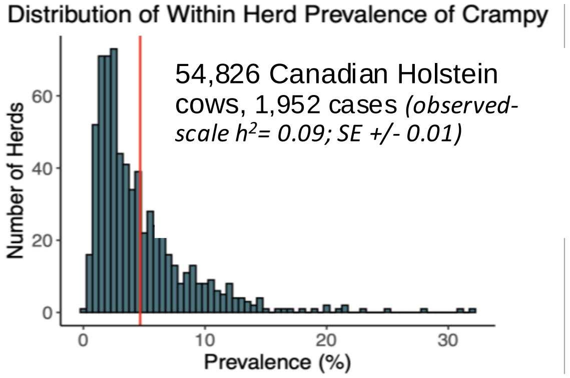
Dr. Christine Baes

- Fertility disorders in routine genomic analyses (Lactanet, 2020)
- Develop methods for routine phenotyping of
  - Calf health (Colin Lynch)
  - Calf feed efficiency (Kyle Hoeksema)
  - Leukosis (Renee Bongers)
  - Crampy (Gabby Condello)





Parameters	First month RMEI	Second month RMEI
Genetic variance	82.28 (41.98)	227.71 (116.77)
Residual variance	171.46 (22.80)	487.02 (64.42)
Heritability of Metabolizable Energy Intake in Calves	0.32 (0.14)	0.32 (0.13)



Lynch et al, 2024, Hoeksema et al., sub., Bongers et al., in prep., Condello et al., in prep

3. Feed efficiency and methane emissions

Lactanet

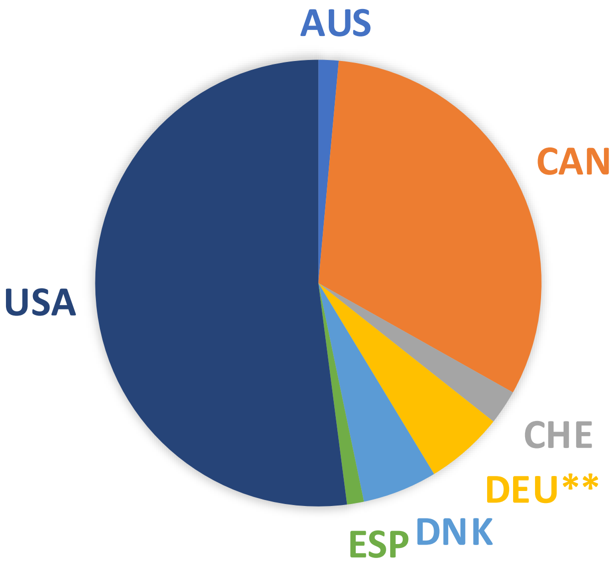
Dr. Gerrit Kistemaker

UNIVERSITY of GUELPH

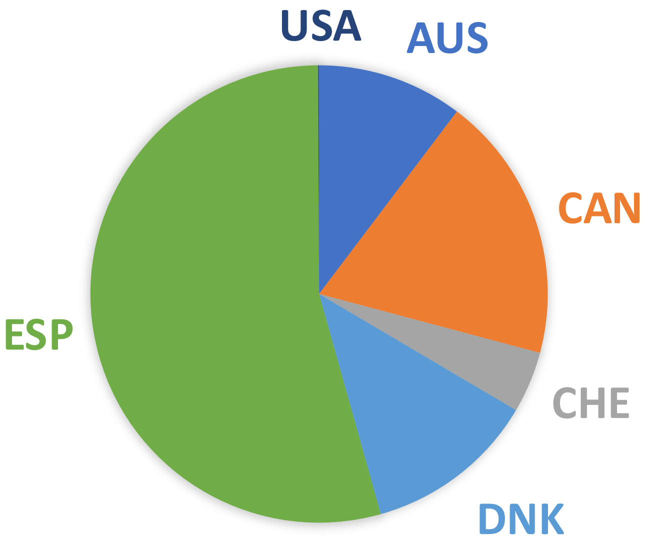
Dr. Christine Baes

3. Feed Efficiency & Methane Reduction

FEED EFFICIENCY (N=15,782)



METHANE EMISSIONS (N=4,504)



Enlarging the reference population for

- **Feed efficiency** (*n=17,000*)
- **Methane emissions** (*n=7,800*)

Many challenges, but even more opportunities

Rumination Time (Lucas Lopes)

4. Genomic and environmental relationships

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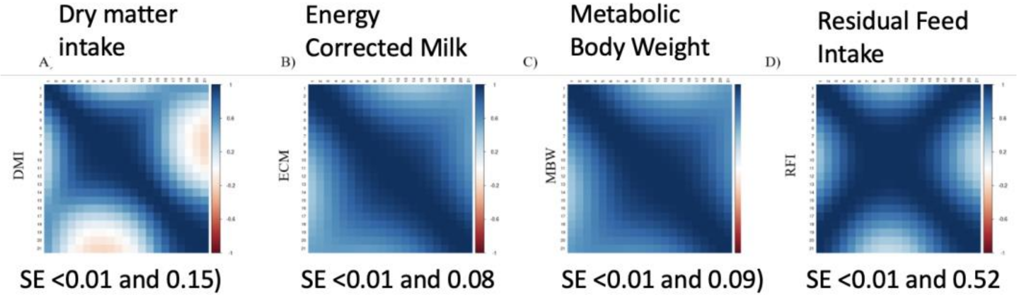
Dr. Flavio Schenkel

Genetic parameters and prediction of EBVs of resilience traits

- Multi-trait GWAS and meta-analysis to identify genomic regions with pleiotropic effects on resilience traits
- Genomic predictions for resilience indicator traits using copy number variants
- Investigate the effects of heat stress on important traits



Houlahan et al., 2022

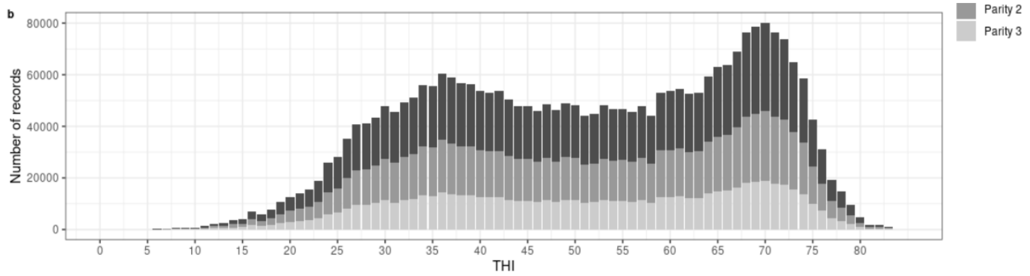
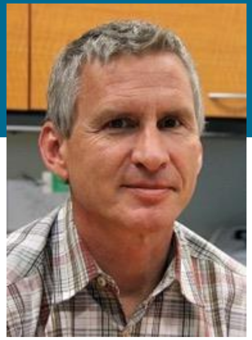


Figure 1. Number of test-day (TD) records per temperature-humidity index (THI) calculated using maximum temperature and minimum relative humidity by parity, in Ontario (**a**) and Quebec (**b**).

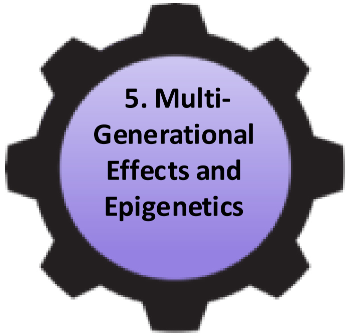
Campos et al., 2022

5. Multi-generational effects and epigenetics

UNIVERSITÉ LAVAL



Dr. Marc-André Sirard



- Quantify effect of early environment (i.e., cow's production) on resilience of daughters
- Survey for epigenetic signature on precisely phenotyped animals

Preliminary Results:

- 1.3 kg Energy-Corrected Milk gain per daughter lactation for every 1 day increase in dam Days In Milk at conception *(Cue et al., 2022)*

- 48 animals with Whole Genome Bisulfite Sequence:
  - 24 healthy
  - 24 with mastitis, poor performance, infertility, or lameness

6. Data management

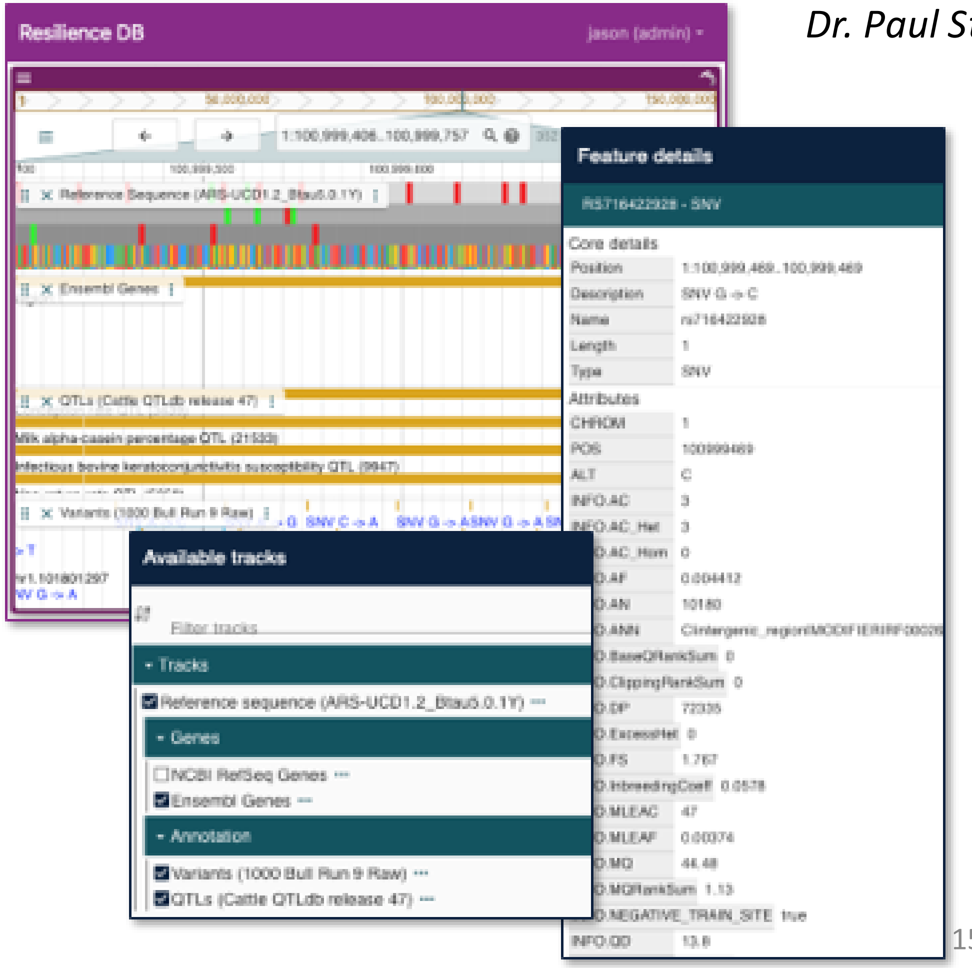
UNIVERSITY OF ALBERTA

Dr. Paul Stothard

6. Data Management

Management of project database

- Whole-genome sequence data analysis for variants, genotypes, functional annotations
- Genome browser integration of GWAS findings, epigenetic signatures, & annotated sequence variation



7. GE3Ls: sustainability and social acceptance

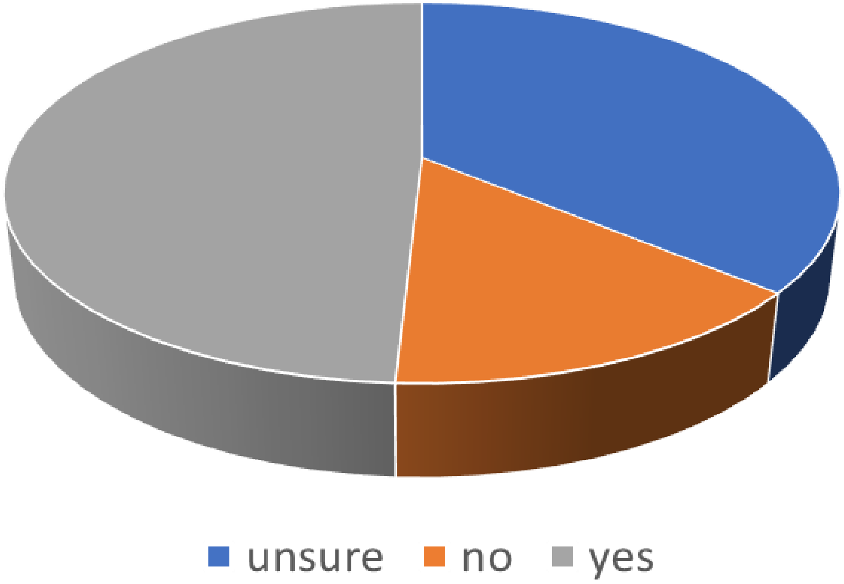
Dr. Getu Hailu

Dr. Ellen Goddard

7. GE³LS: Optimizing traits to maximize sustainability and societal acceptance

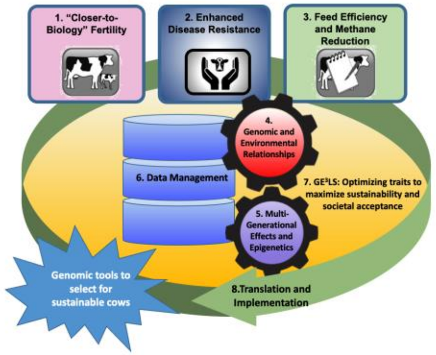
- Farm level decisions about trade-offs between traits
- Farm/Market level outcomes from selection of resilience traits
- Public acceptance of dairy under different breeding strategies

If selective breeding could be used to solve the environmental impacts of the dairy industry in Canada, do you think that you would be happy?



Goddard et al., 2022

8. Translation and Implementation



Lactanet

Dr. Filippo Miglior

Dr. Gerrit Kistemaker

Implementation of evaluations:

- Fertility Disorders (2020)
- Feed Efficiency (2021)
- Methane Efficiency (2023)
- Body Maintenance Req. (2023)

Develop resiliency index → integrated into modernized LPI/Pro$

Data Source (Activity)	Trait	Stage of Implementation
1.3	Estrous Activity	Study
1.3	Estrous Intensity	Study
1.3	Estrous Interval	Study
1.3	Size and Position Score	Study
1.3	Ano-Genital distance	Study
2.1	Retained Placenta	Implemented
2.1	Metritis	Implemented
2.1	Cystic Ovaries	Implemented
2.2	Johne's Disease	Study
2.2	Leukosis	Under review
2.3	Calf Respiratory Disease	Under development
2.3	Calf Diarrhea	Under development
2.3	Metabolizable Energy Intake (Calves)	Study
3.1	Dry Matter Intake	Implemented
3.2	Methane Emissions	Implemented
3.2	Body Maintenance Requirements	Implemented

Scientific Deliverables

- 27 peer-reviewed publications
- 75 invited presentations
- 155 seminars, conference presentations, abstracts and posters
- 73 undergraduate students
- 8 MSc Theses completed
    - 1 in progress
- 5 PhD Theses completed
    - 4 in progress
- 9 postdoctoral researchers
- 2 research technicians
- 2.25 project managers
- 44 TV, radio and media contributions

Economic Deliverables

Population size: 0.9 M Lag time* for Benefits: 3.33 yrs 10-Year Horizon	Genetic progress (Pro$)	Benefit per cow per year ($)	Cumulative benefits per year of selection ($M)
Before Genomics (2004-2009)	104	54	302
Introduction of Genomics (2010-2015)	204	106	593
Adoption of Genomics (2016-Today)	248	129	721
Addition of GHG Mitigation	**283**	**148**	**823**

*number of years between the selection investment and the first year of benefits

From research to implementation: Genomic Selection for Methane

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Mid-Infrared Spectroscopy (MIR) Data Processing

Individual milk samples processed by FOSS Milkoscan FTIR spectrophotometers

Predicting Methane

- 241 MIR spectral datapoints used as input predictors
- Collected average daily methane from 496 cows from two herds between 5-305 DIM

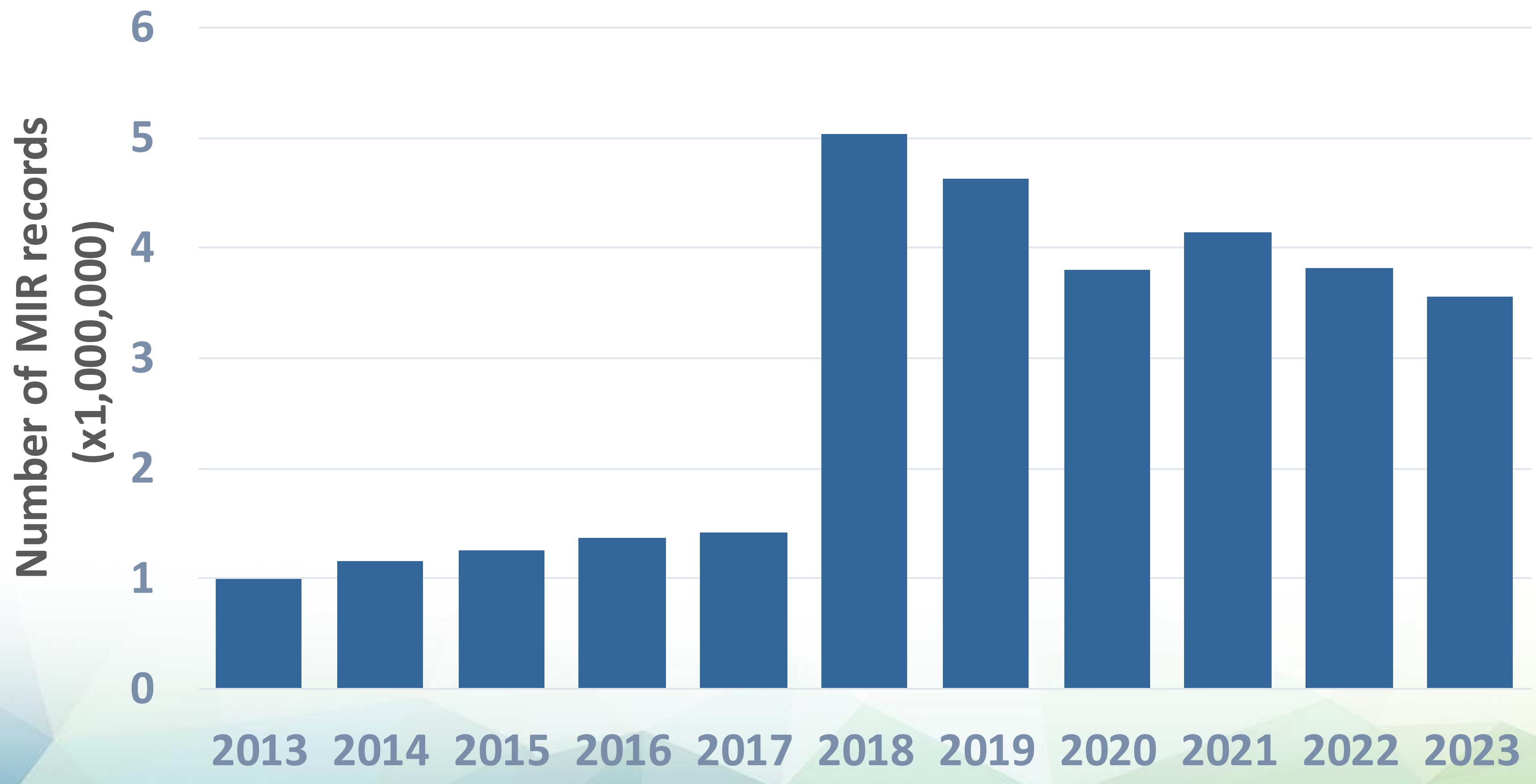
Prediction accuracy of 0.70

Genetic Correlation 0.92 (0.22)

Shadpour et al., 2022; Oliveira et al., 2024

Apply prediction to MIR population

- Over **19M** records collected since 2018
- Milk MIR data on **90% of milk recorded cows** since 2018

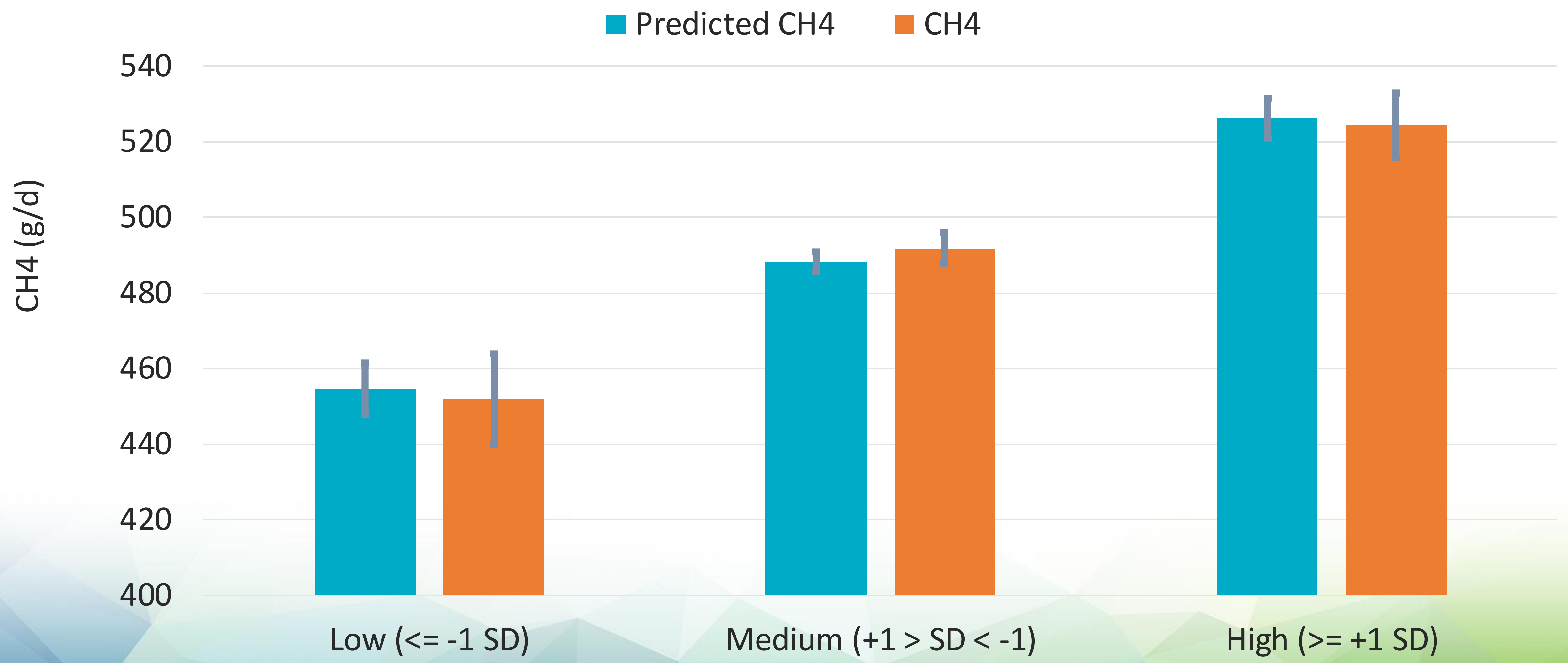


≈6.1M records from ~7,000 herds

≈2M cows

≈150,000 genotyped cows

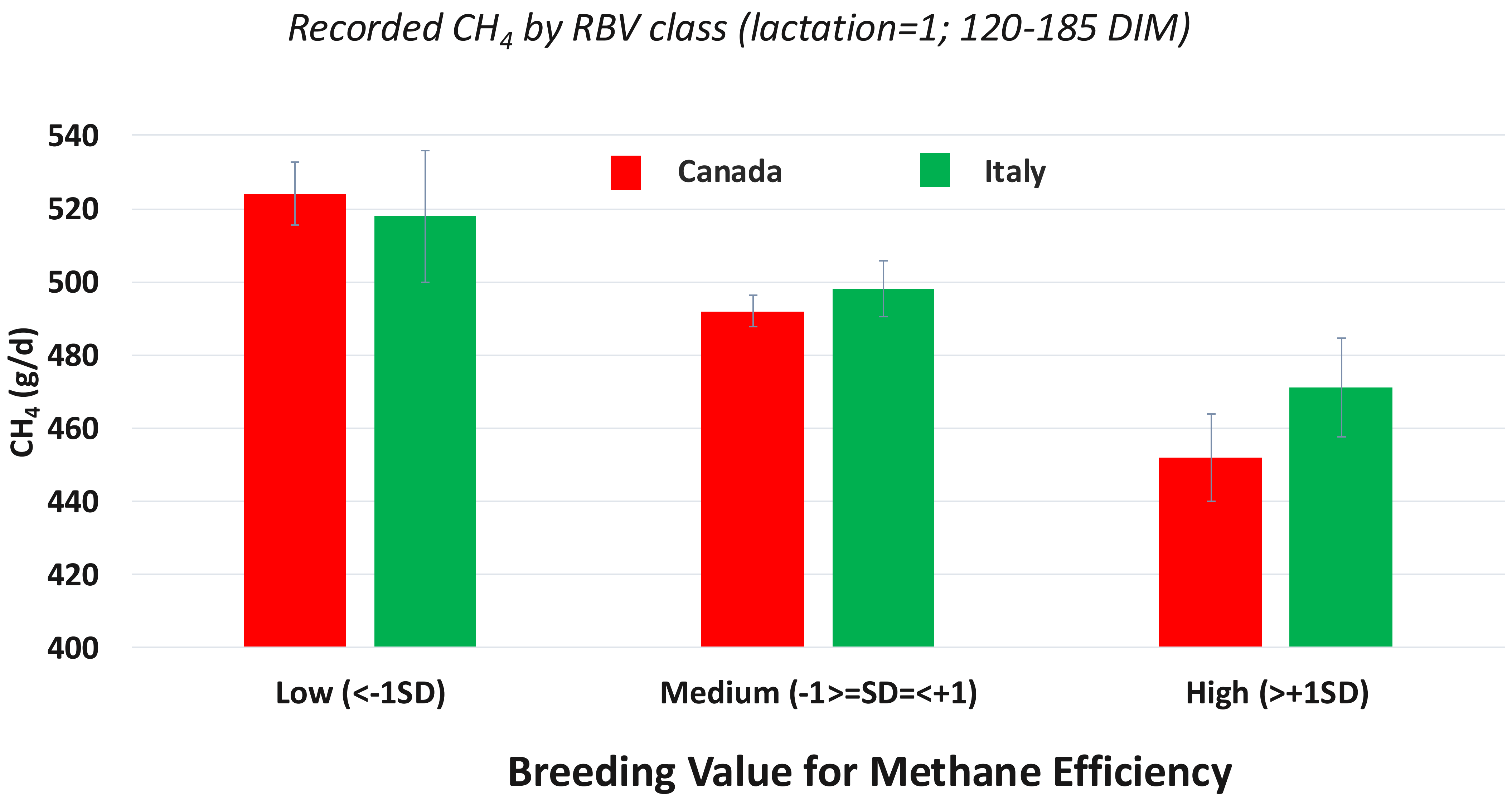
Average Predicted and Collected Methane Production by GEBV class



Summary of Data (Wallace et al., 2019)

CH_4 Measurement Method	No. Cows (Herds)	Country	Breed	No. Genotyped Cows
Chambers	100 (1)	FI	Nordic Red	100
Green Feed	**405 (3)**	**IT**	**Holstein**	**398**
	100 (1)	**SE**	**Nordic Red**	**99**
Sniffers in robots	407 (2)	UK	Holstein	398

External Validation



Data Used for National Genetic Evaluation

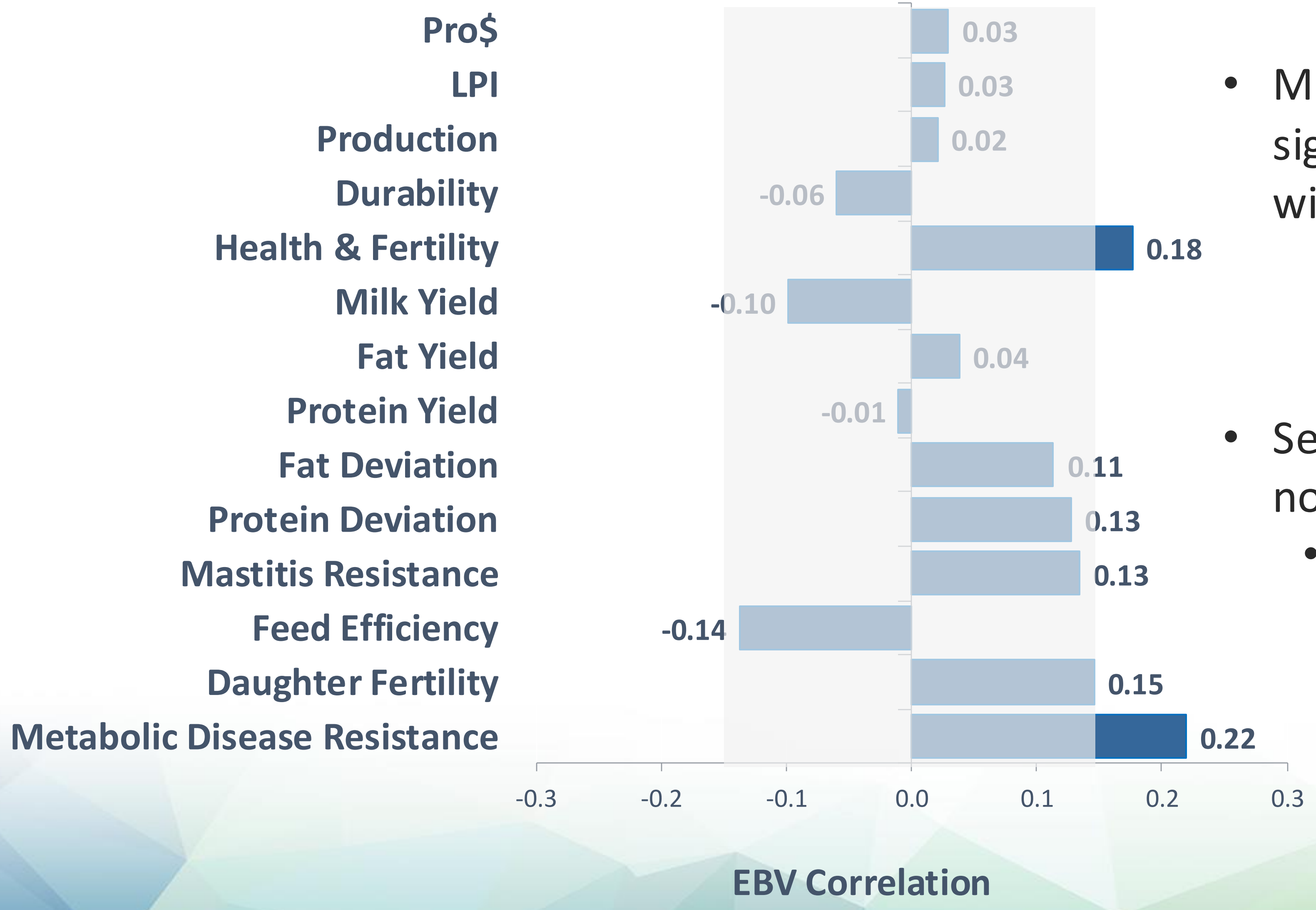
- First lactation Holsteins from 6,128 herds
- Between 120 and 185 DIM

Records	773,743
Cows	541,565
Sires	10,765

Genotyped Animals	134,963
Genotyped Cows	68,138
Genotyped Sires	7,921

*Numbers for April 2023 evaluations

Methane Efficiency is a New Trait



- Methane Efficiency does not have a significant unfavorable correlation with any other evaluated trait
- Selection for Feed Efficiency does not also improve Methane Efficiency
  - Both traits are independent of production yields

Interpretation

Reduce CH_4 production by selecting for higher Methane Efficiency without impacting production traits

5-point ↑ in a sire's RBV for ME, daughters are expected to produce 3kg less CH_4 per year

1.5% decrease in CH_4 emissions per cow per year

Herd owners selecting for ME can achieve 20-30% reduction in CH_4 emissions from their herd by 2050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Implementation of Methane Efficiency Evaluations for Canadian Holsteins

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Section
Articles

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Lactanet Genetic Toolbox

Feed Efficiency
April 2021

Body Maintenance Requirements
April 2023

Methane Efficiency
April 2023

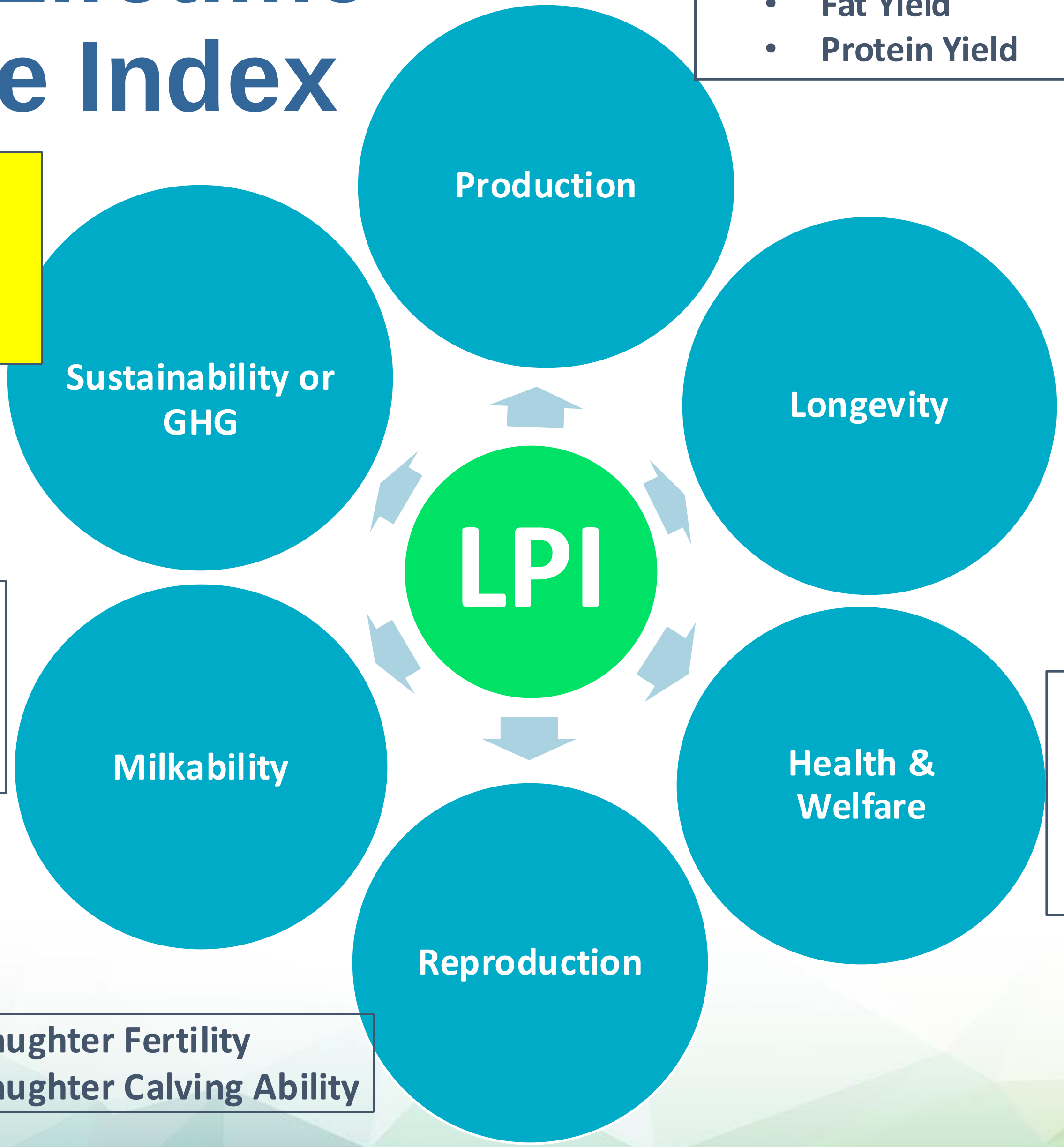
Reduce feed costs

Reduce methane emissions

Modernized Lifetime Performance Index

- Milk Yield
- Fat Yield
- Protein Yield
- Fat Deviation
- Protein Deviation
- Lactation Persistency

- Methane Efficiency
- Feed Efficiency
- Body Maintenance Requirements
- Herd Life



- Herd Life
- Conformation
- Mammary System
- Feet & Legs
- Dairy Strength
- Rump

- Milking Speed
- Milking Temperament
- Udder Depth
- Teat Placement

- Mastitis Resistance
- Somatic Cell Score
- Metabolic Disease Resistance
- Fertility Disorders
- Hoof Health

- Daughter Fertility
- Daughter Calving Ability

Future Strategy: More projects!

The current MIR prediction is for 1st parity Holsteins, 120-185 DIM

Our Goals:

- Enhance milk MIR prediction
  - Increase # CH_4 records with GreenFeed
  - Install CH_4 sniffers (MooLogger) in up to 65 robotic farms across Canada
    - ✓ Including Jersey and Ayrshire, in addition to Holstein
    - ✓ Multiple parities
    - ✓ Full lactation
    - ✓ Different feeding and management systems
- Enhanced genomic evaluation
  - Using new milk MIR prediction
  - Using new milk MIR prediction + collected CH_4 from GreenFeed and sniffers

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University of Alberta

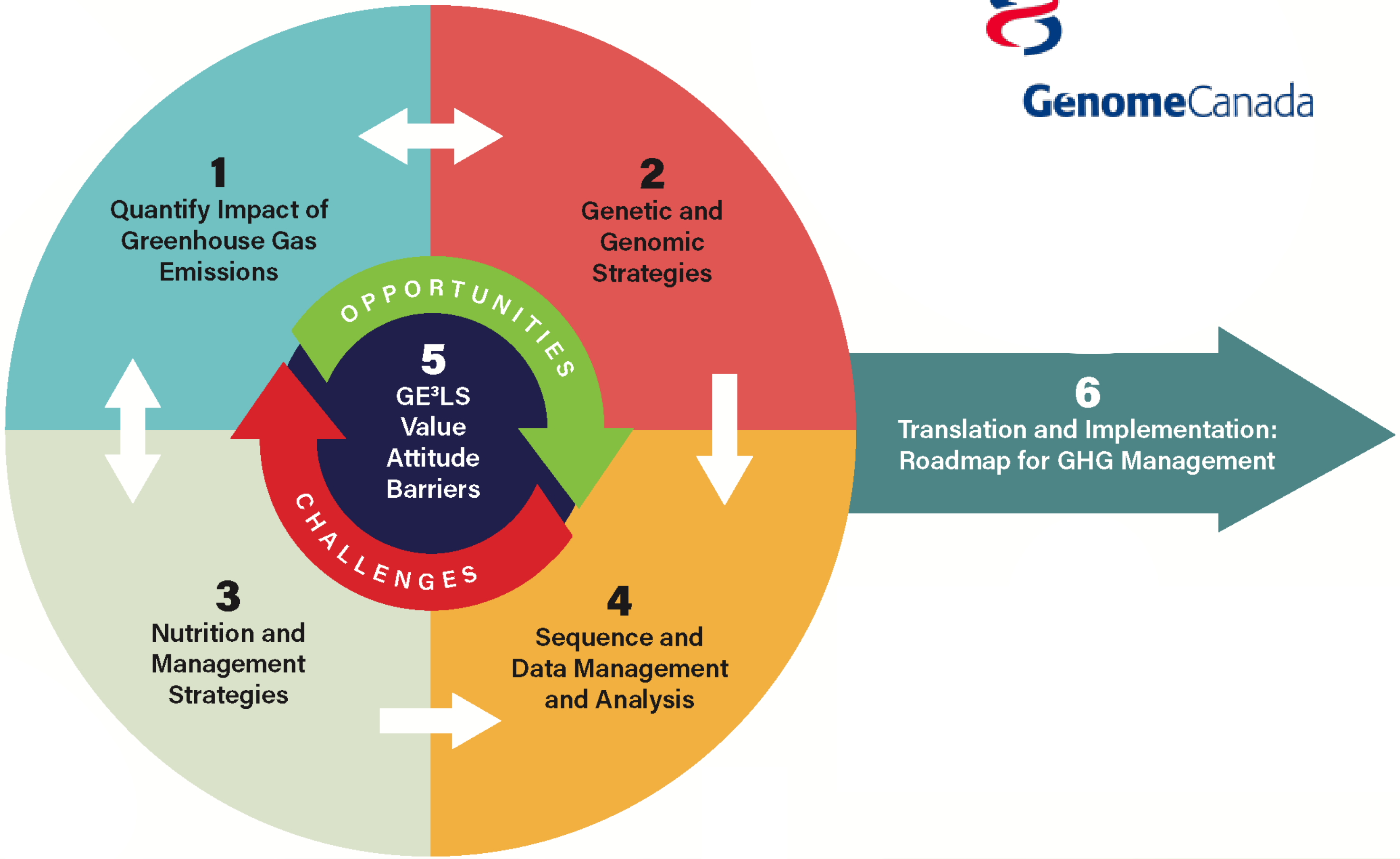
Climate-Smart Agriculture and Food Systems – ICT 2022

Leveraging Genomics to Achieve Dairy Net Zero

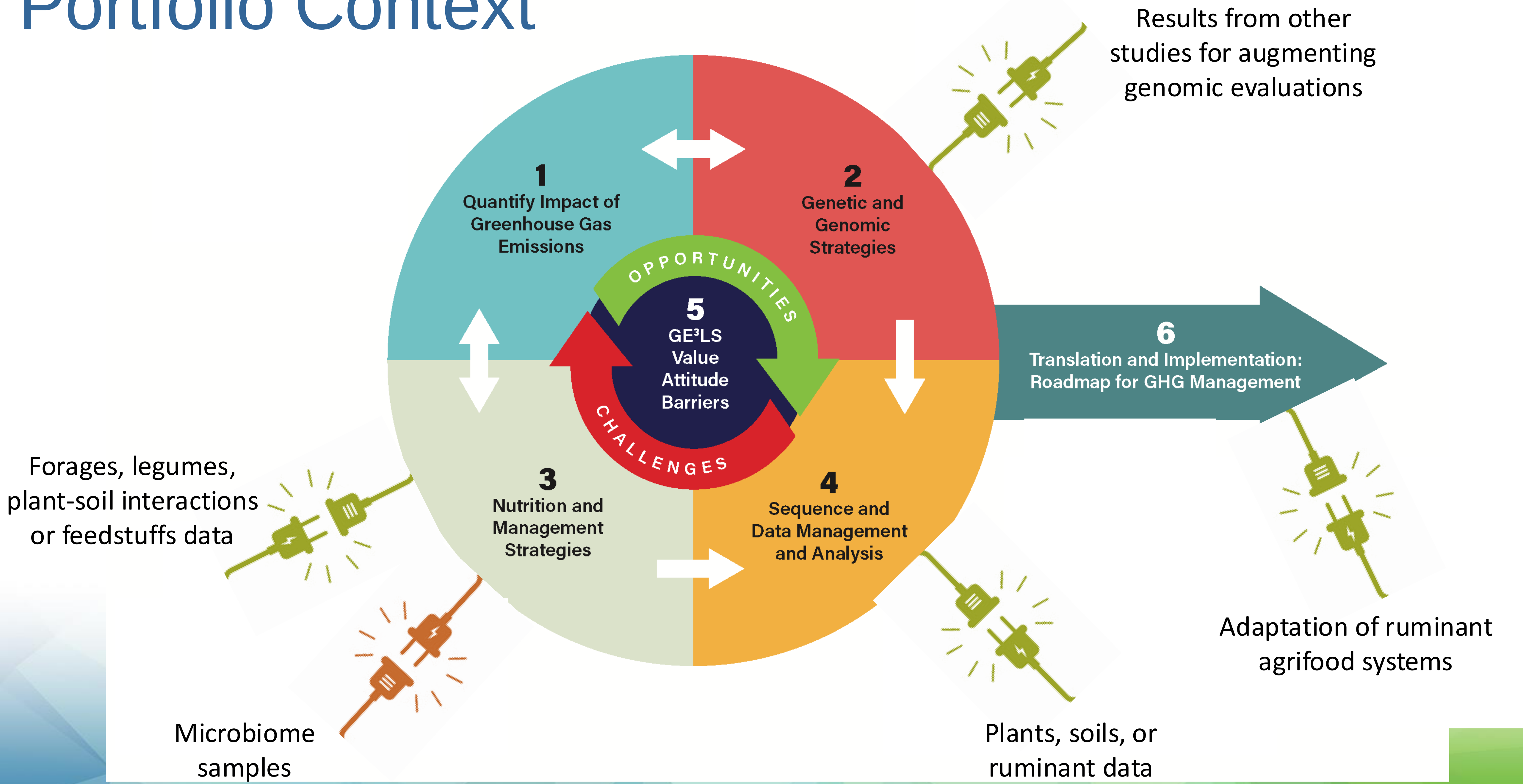
GenomeCanada

GOALS

- Consolidation of existing methane emissions data (including beef)
- Estimate animal and herd-level emissions
- Quantify potential GHG reductions through genetic and nutrition strategies
- Enhance CH_4 genomic evaluations
- Understand public attitudes/behaviours to emissions reductions
- Develop and implement CH_4 herd monitoring and benchmarking tools
- **Develop a roadmap for CH_4 mitigation**



Portfolio Context



A Fully Integrated Partnership

Final Remarks

- National, international, interdisciplinary and multidisciplinary collaborations very important
- Dairy cattle resiliency is a top priority, but requires a lot of high quality phenotypes
  - Fertility, Health, Efficiency
- Deliverables of research shape the future of the industry
- Potential application of dairy results for beef?
- Teamwork makes the dream work – more cake for everyone!

Acknowledgements

Lactanet
CANADIAN NETWORK FOR DAIRY EXCELLENCE

Genome Canada
Genome Alberta
Genome Québec
Genome British Columbia
Leading ▸ Investing ▸ Connecting
Ontario Genomics

University of Guelph
Université Laval
University of Alberta
The University of British Columbia
McGill
University of Calgary
University of Prince Edward Island

Ministry of Economic Development, Job Creation & Trade
Ministry of Agriculture, Food & Rural Affairs
Ministry of Colleges & Universities
RDAR
Results Driven Agriculture Research
Agriculture and Agri-Food Canada
Alberta milk
Alberta Agriculture and Forestry
CDCB
COUNCIL ON DAIRY CATTLE BREEDING

USDA
FFAR
Foundation for Food and Agriculture Research
Wisconsin
University of Wisconsin–Madison
Michigan State University
Iowa State University
Purdue University
University of Georgia

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Confédération suisse
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Allflex
Livestock Intelligence™
afimilk
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