Innovative Solutions for Sustaining Rural America

FEWtures
Resilient Farms • Thriving Communities

Presentation via Zoom by Mary C Hill, University of Kansas,

to the School of Global Environmental Sustainability (SoGES)

Colorado State University

Tuesday September 22, 2020

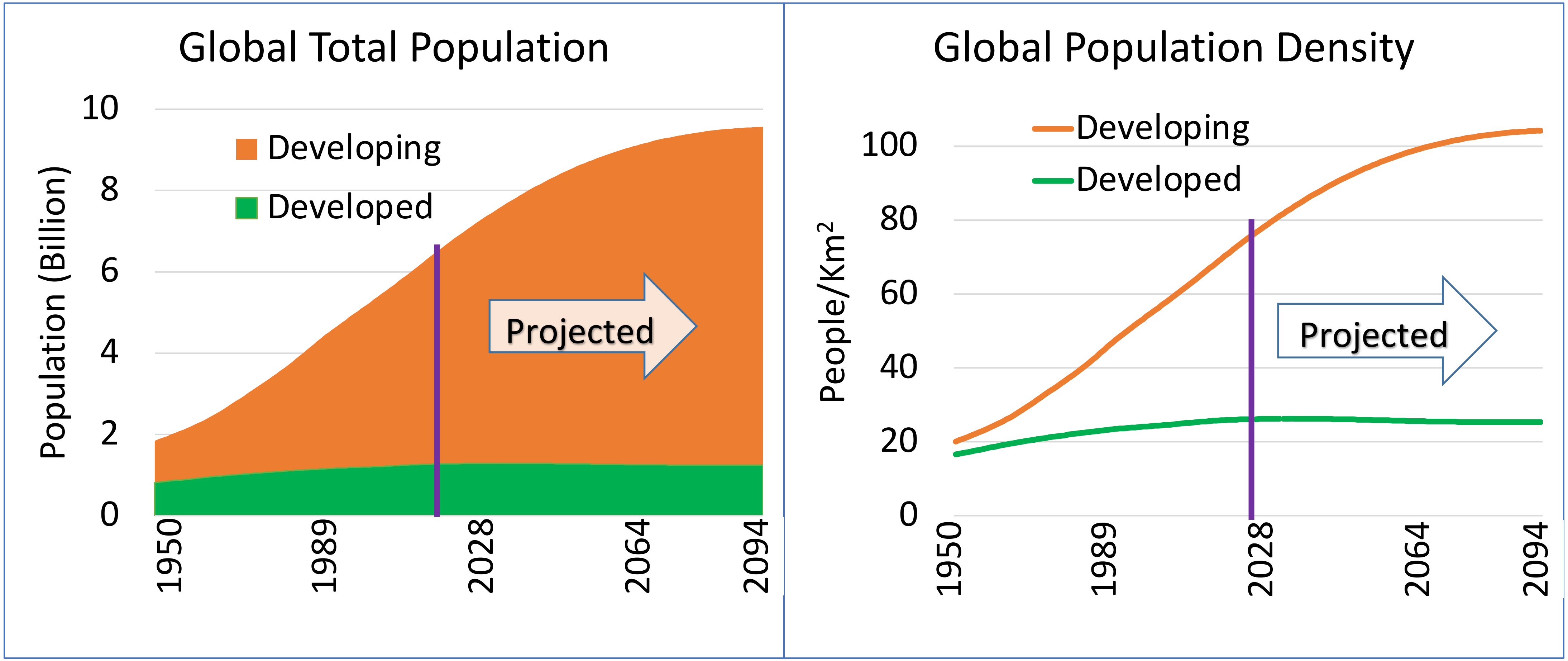
General framework of study and talk

- **Problem** Increased agricultural demands and challenges
- ***Regional testbed*** Central Arkansas River Basin (CARB) –
  - Challenges common to semi-arid ag landscapes
  - 30% of ag lands worldwide are arid
- **Hypothesis** New renewable-energy supported technology ➔ transformative opportunities for Small Town and Rural (STAR) communities and economies.
- **Approach**
  - Emphasize local **stakeholders** (Farmers, local energy execs)
  - Use model abstractions and metrics to develop user-focused DSS for two innovative opportunities for these landscapes
    - water treatment
    - local-scale ammonia production

Basic Problem

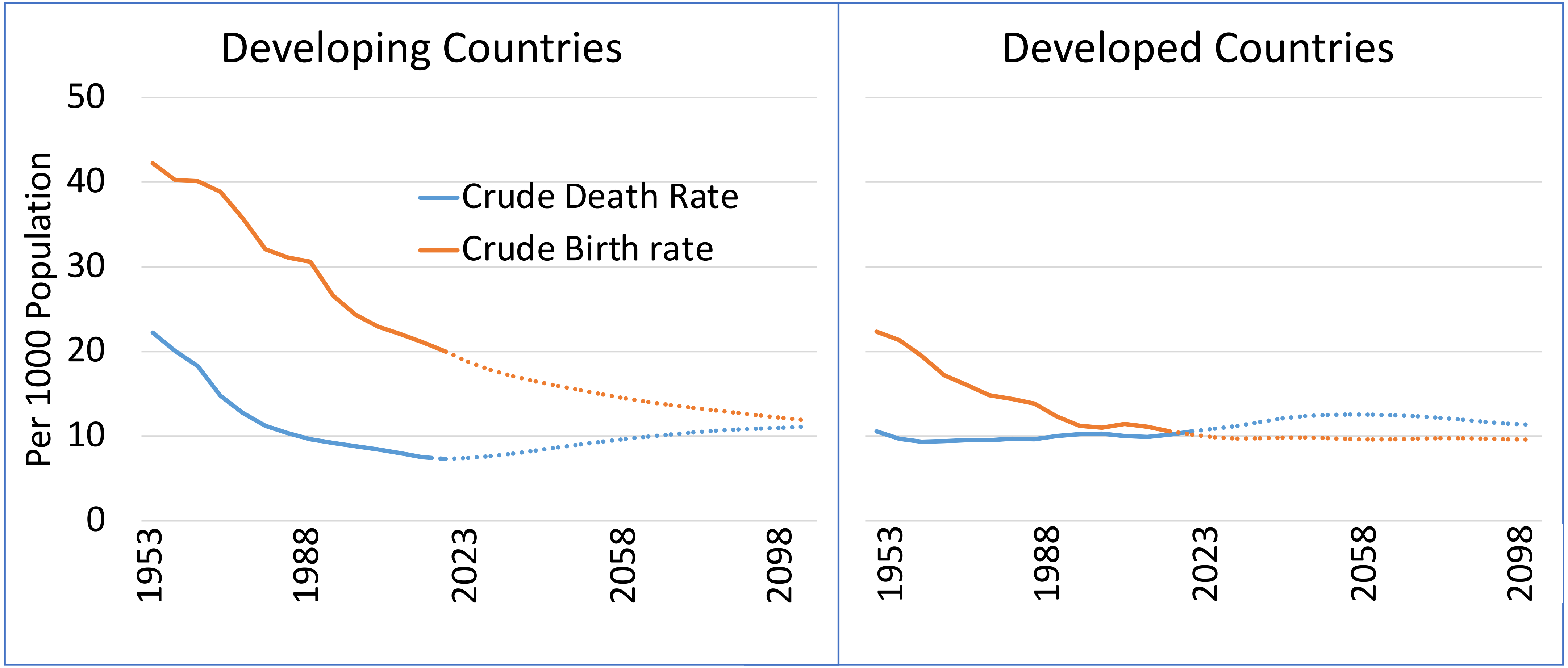
- Expanding global population increasing pressure on non-renewable and difficult to renew resources (e.g. water, energy) and limited resources (e.g., land)
- This pressure threatens global food production, making food the principal challenge facing the world as it marches toward 2100
- Need innovative solutions to sustain human wellbeing and dignity

Unfolding Population Reality



United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition. Rev. 1.)

Behind the Growing Global Population



United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition. Rev. 1.)

Basic Problem

Never enough food where it is needed the most

- High population areas often depend on food imports

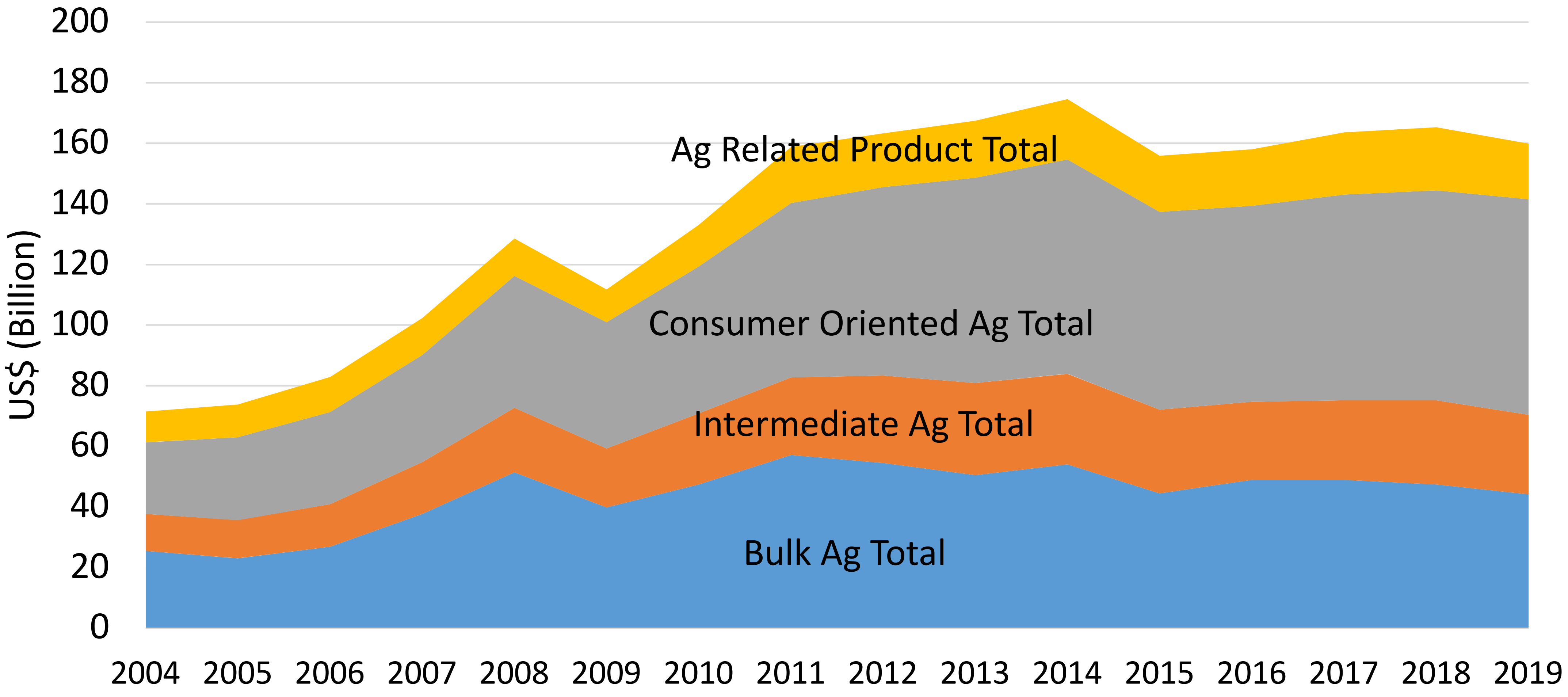
US has been a major source of global food supply since the end of WWII

- US ability to continue performing this role is threatened by its own increasing resource constraints in the main agri-food commodity producing regions of the country

US Agri-Food Exports

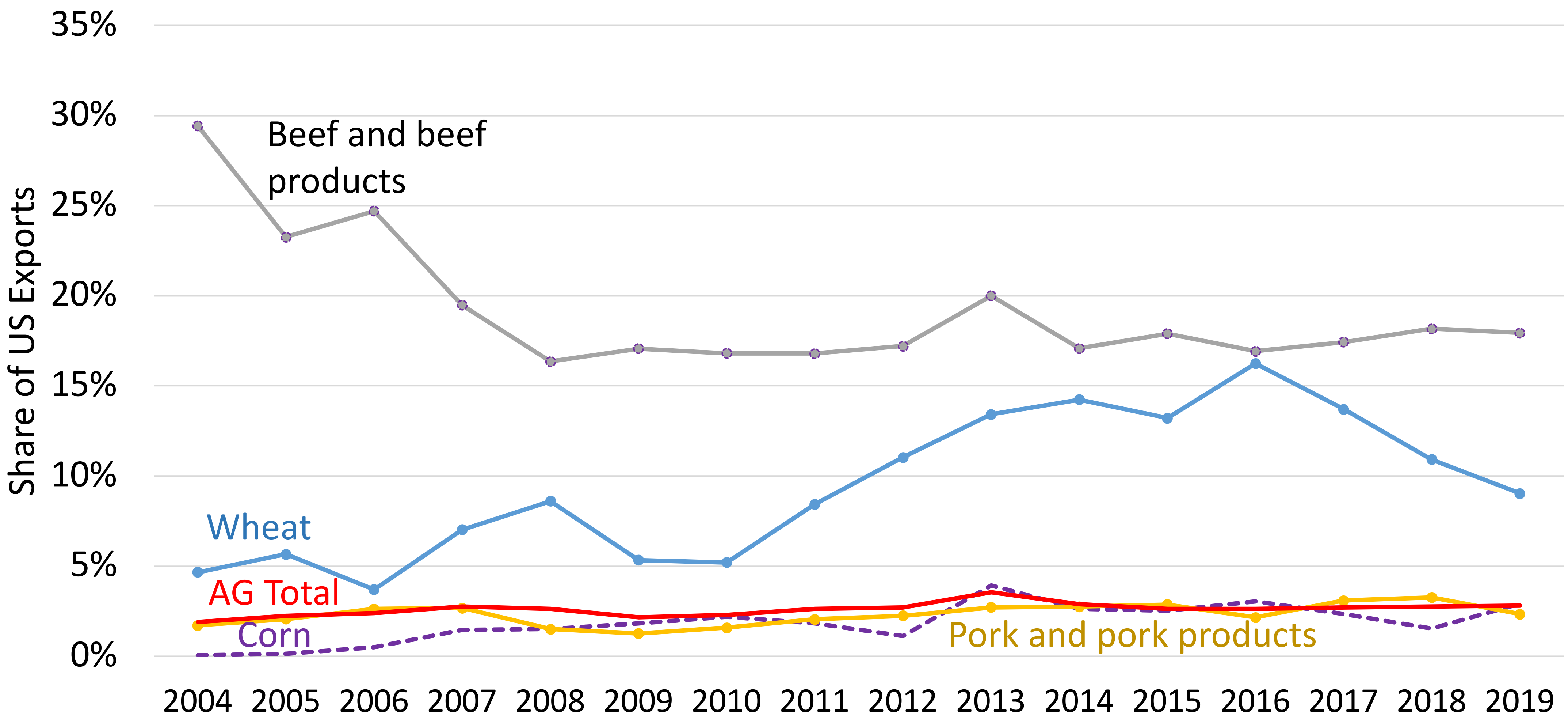
- Four main agri-food export groups
  - Bulk commodities (little or no processing)
  - Intermediate (industrial inputs, e.g., soybean meal)
  - Consumer-oriented (meat, processed fruits & vegetables)
  - Agricultural Related (alcohol, biofuels, forest products, fish products)

US Agri-Food Exports by Aggregate Groups ($B)



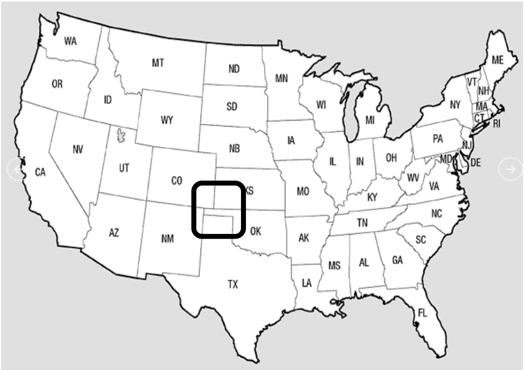
USDA/Foreign Agricultural Service. Global Agricultural Trade Statistics (https://apps.fas.usda.gov/gats)

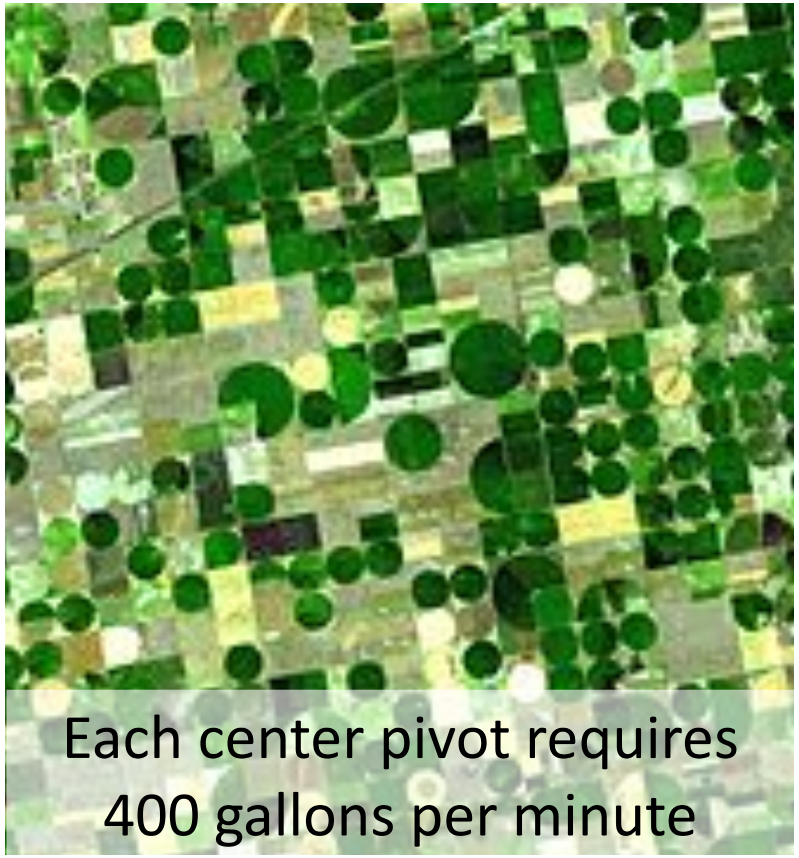
Kansas Share of Selected US Agri-Food Exports



Central Arkansas River Basin (CARB)

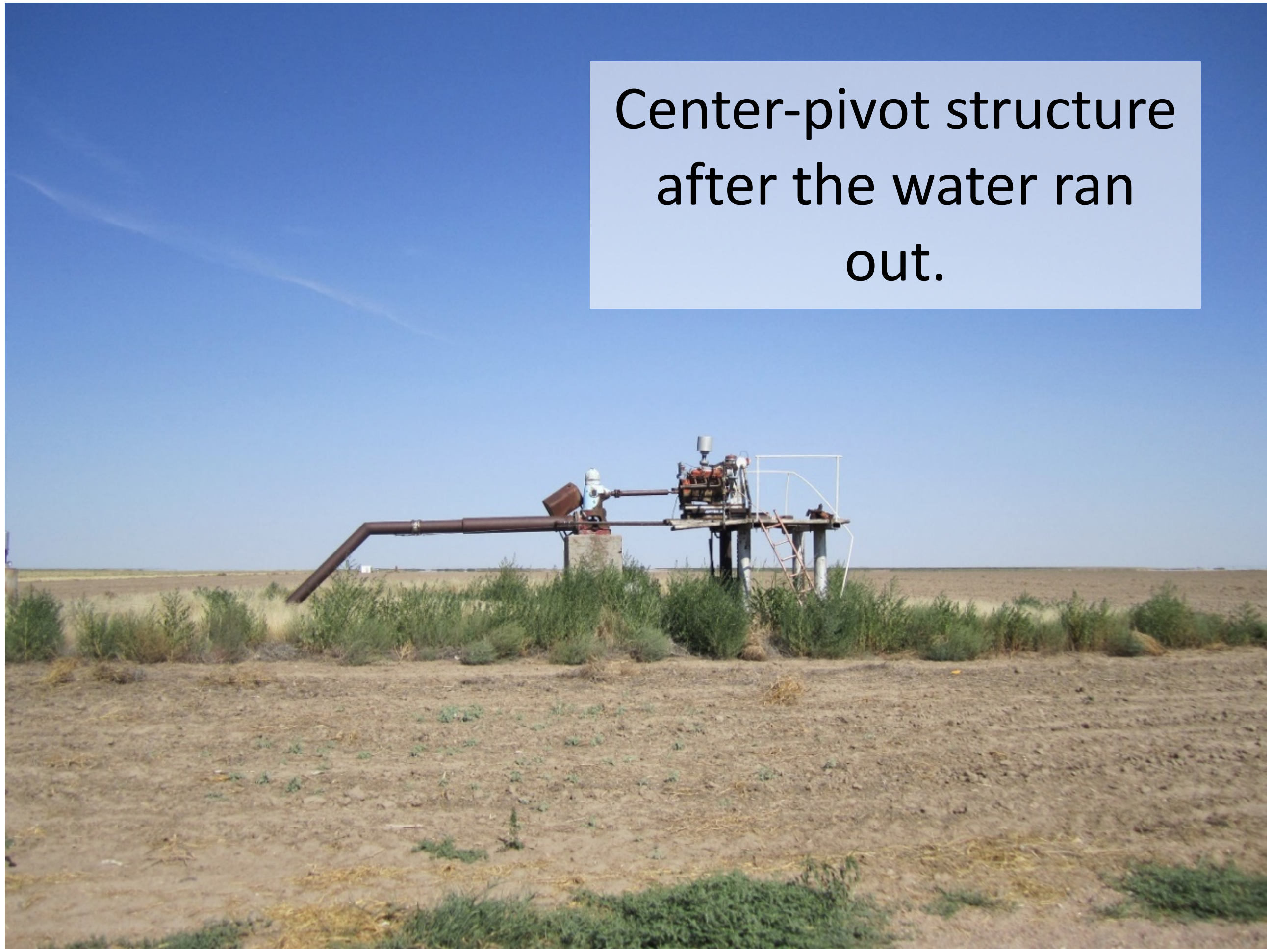
Parts of KS, CO, OK, TX, NM





Each center pivot requires 400 gallons per minute (91 cubic meters per hour)

https://en.wikipedia.org/wiki/Center_pivot_irrigation
https://airfreshener.club/quotes/america-map-conus-outline.html

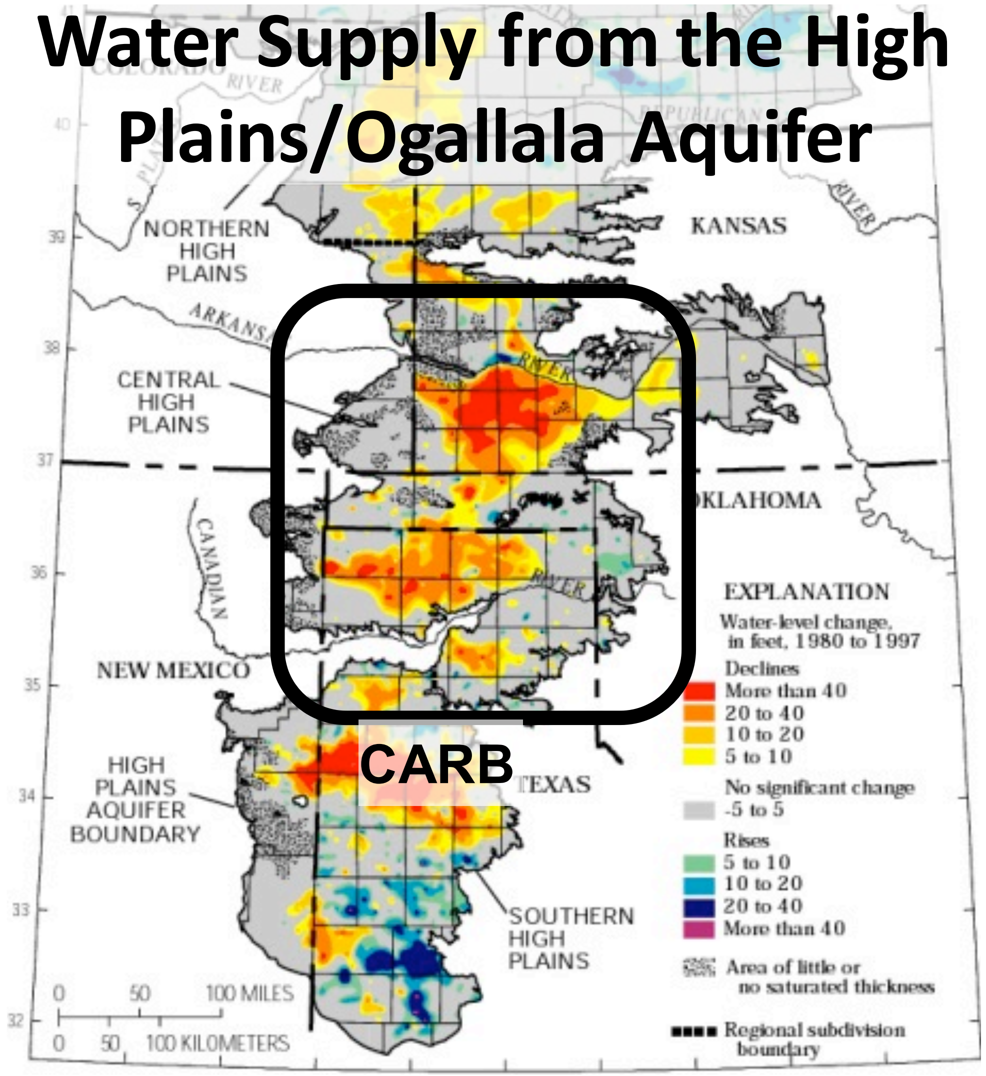


Center-pivot structure after the water ran out.

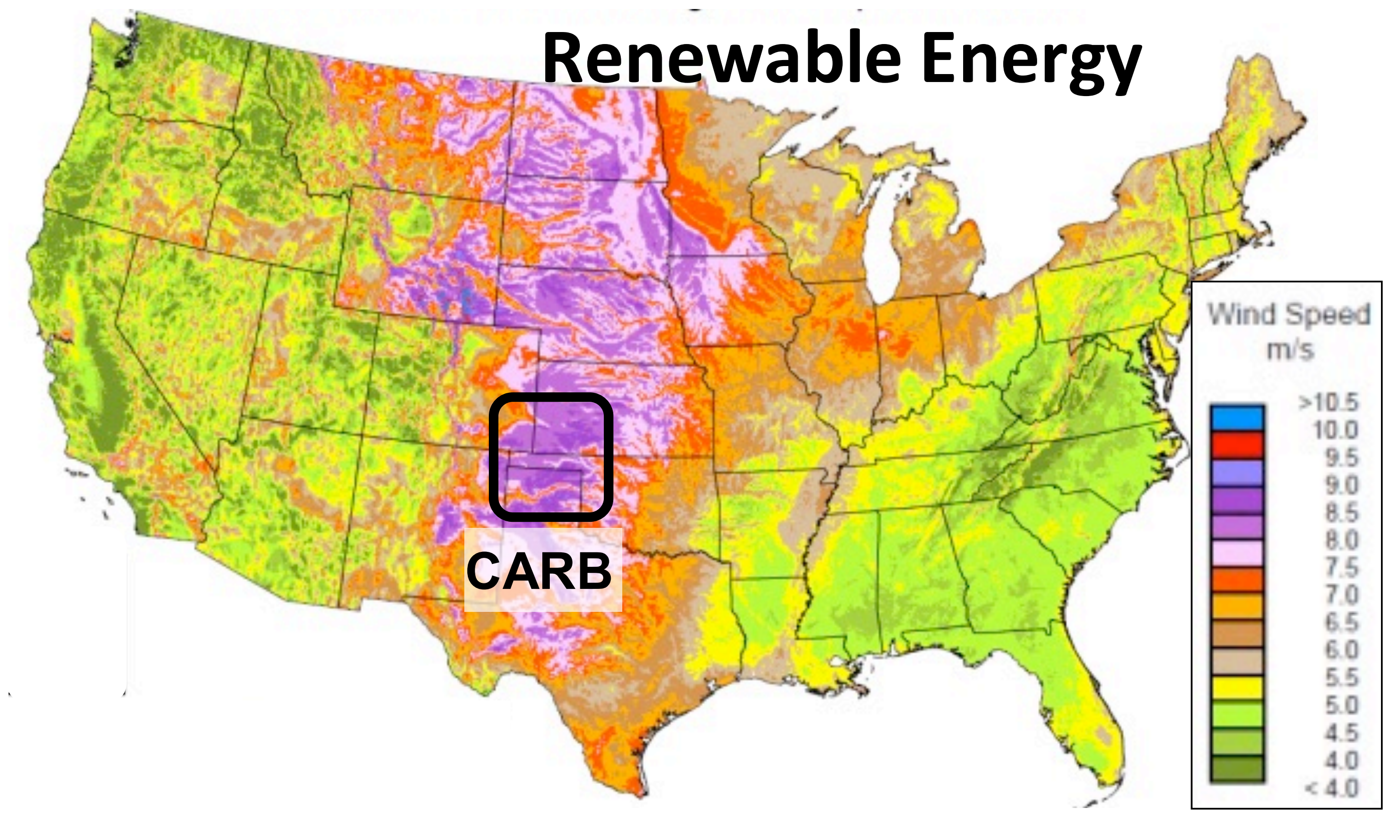
Photo credit, BJ Gray, 2016, KU

CARB – water challenge, energy abundance

Water Supply from the High Plains/Ogallala Aquifer



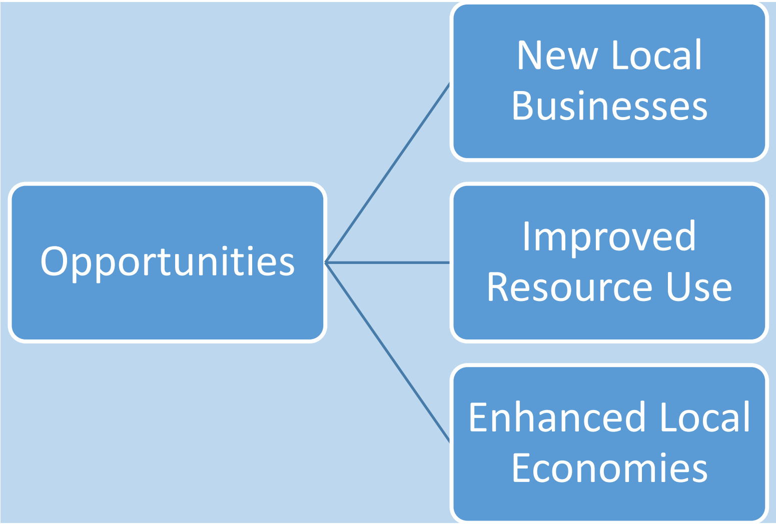
Renewable Energy

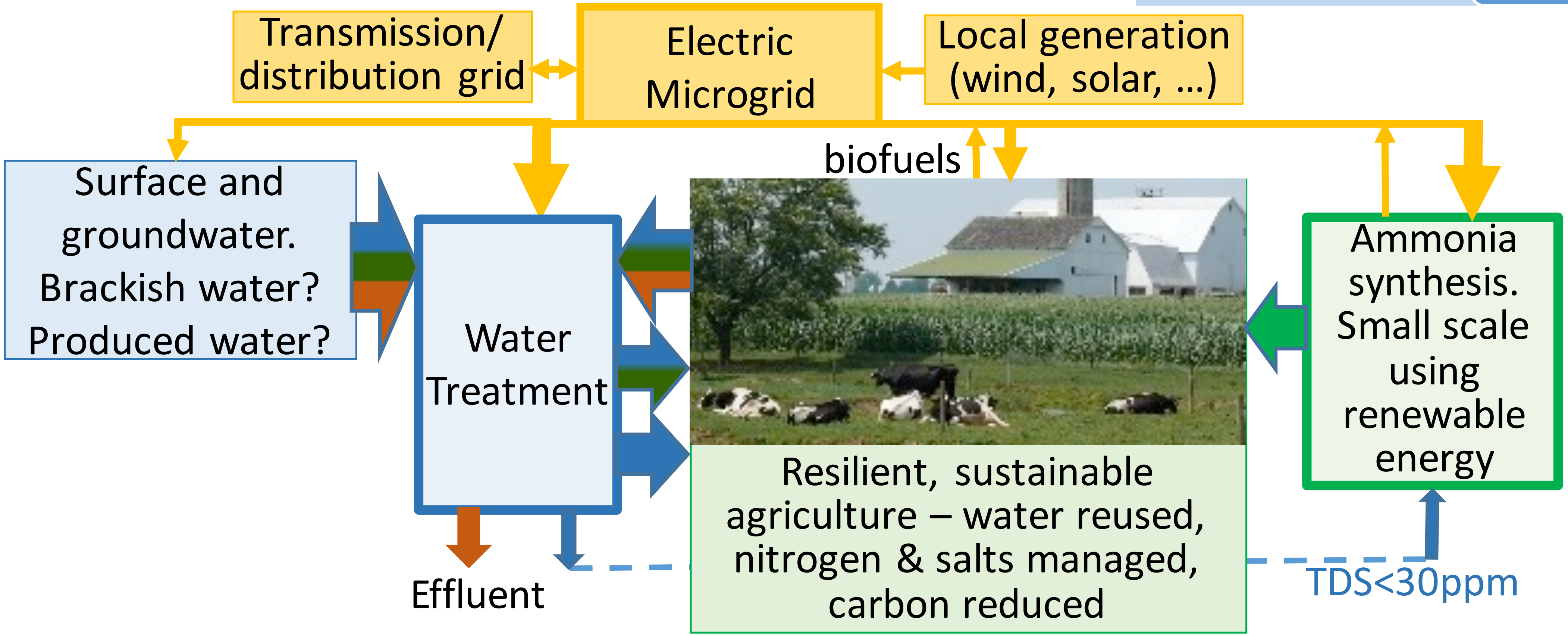


FEWtures Research Purpose

- Could …
  - the right set of technologies
  - use local energy to address local agricultural challenges
  - to enhance competitive food production in the Heartland, and improve its socio-economic viability so it can continue feeding the world?
- FEWtures proposes to explore alternative designs of energy microgrid energy solutions to:
  - Recycle water through water treatment, thereby reducing pressure on the Ogallala and other natural water bodies
  - Produce ammonia for energy storage and fertilizer

FEWtures Research Purpose





A Bit of Depth on Three Topics – 3 slides each

- Ammonia production (Mohammadi, Pfromm WSU)
- Water treatment (Pfromm WSU, Peltier KU)
- Decision support system (Phetheet, Hill, Barron, Gray, Wu, Amanor-Boadu, Heger, Kissekka, Golden, Rossi, Modarressi, Symons, KU, WNEU, KSU, UC Davis, CU)

Growing interest in ammonia as an energy (H_2) vector

Peter Pfromm, WSU

For scale:
1,000 tons NH_3/year for 11,000 acres of corn.
World makes 170MM tons NH_3/year

Australia 4/2020

ARENA awarded AU$995,000 to Yara and ENGIE for solar ammonia pilot

U.S. House of Representatives 1/2020
CLEAN Future Act Draft

(B) INCLUSION.—
The term "qualified low-carbon fuel" includes, subject to subparagraph (A)—
(i) ammonia; and
(ii) hydrogen.

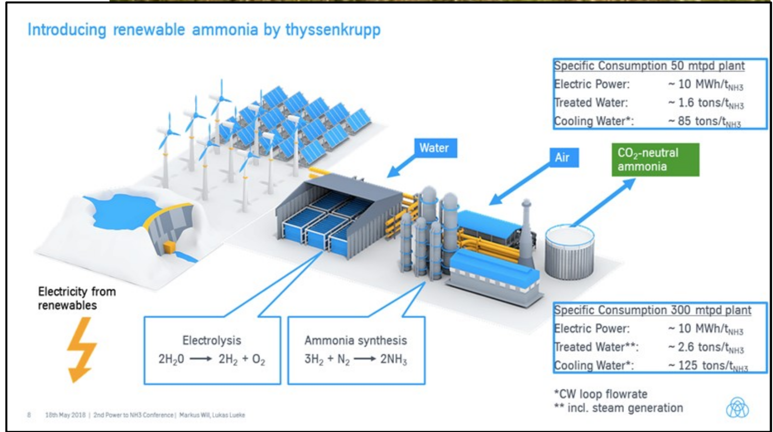
Supply 10% of energy & fertilizer for a 320 acre farm via ammonia http://solarhydrogensystem.com/

UK, Siemens
30kg ammonia/day
(109 metric tons/year)
modular ammonia plant

Large plants are 2500 mtpd

Ultra-large containership design -- ammonia-fueled. Dalia Shipbuilding Industry Company and MAN Energy 12/2019

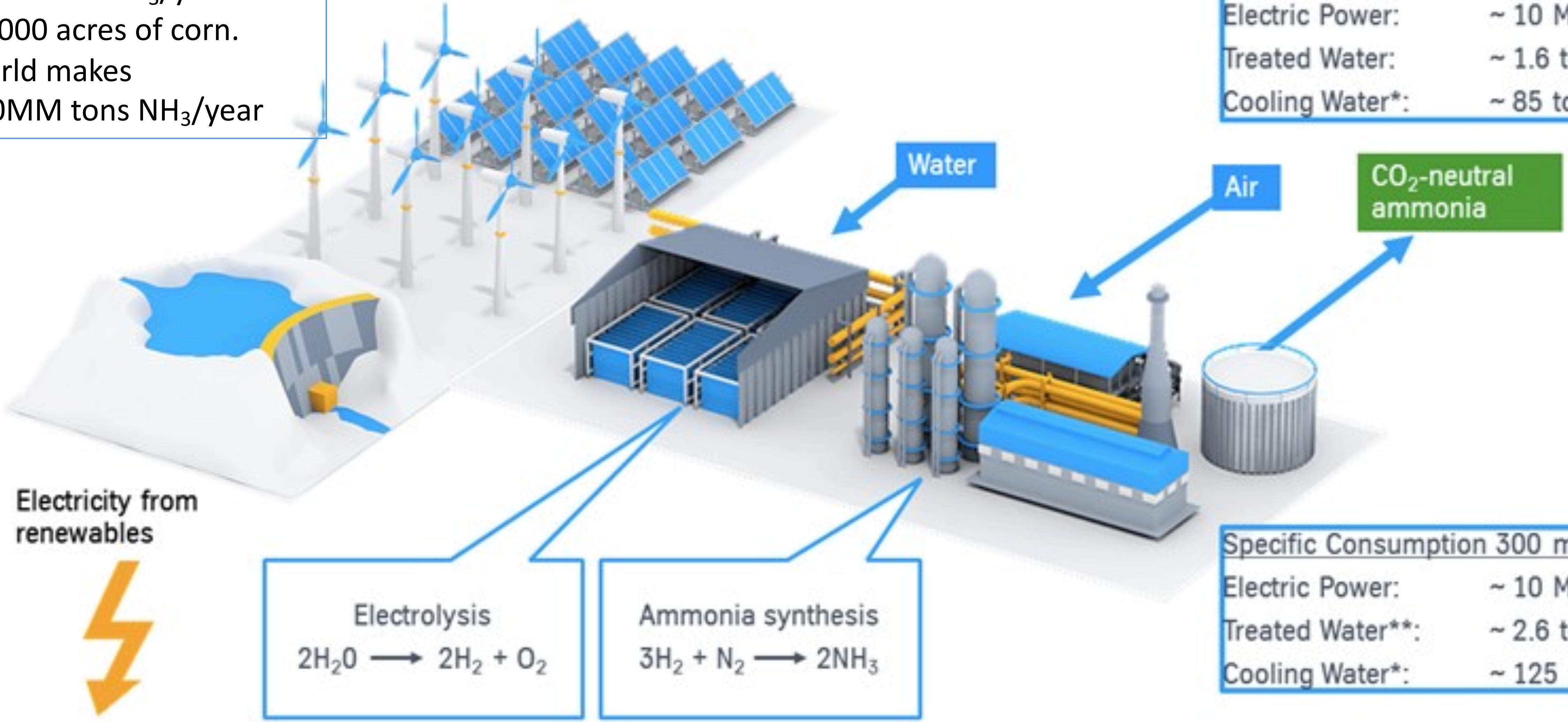
ThyssenKrupp ammonia many ton/day scale modular system



Introducing renewable ammonia by thyssenkrupp

1 ton water = 1 m^3
= 8 x 10^{-4} acre-feet
50 mtpd = 18,250 mtpy

For scale:
1,000 tons NH_3/year for
11,000 acres of corn.
World makes
170MM tons NH_3/year



Specific Consumption 50 mtpd plant	
Electric Power:	~ 10 MWh/t_{NH3}
Treated Water:	~ 1.6 $tons/t_{NH3}$
Cooling Water*:	~ 85 $tons/t_{NH3}$

Specific Consumption 300 mtpd plant	
Electric Power:	~ 10 MWh/t_{NH3}
Treated Water**:	~ 2.6 $tons/t_{NH3}$
Cooling Water*:	~ 125 $tons/t_{NH3}$

*CW loop flowrate
** incl. steam generation

Adding the economics

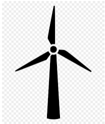
Peter Pfromm, WSU

Renewable (electrolytic) Ammonia: ~$230/ton, at $0.0235/kWh, energy ONLY

About 10GWh to make 1000 metric tons Ammonia, or $28.9*10^6$ $J_{electric\ consumed}$/kg Ammonia

Renewable only
$/J real-time pricing
OR Power Purchase Agreement

Grid electricity



static trigger:
buy when
<$0.02/kWh
=$20/MWH

J

$/J

Ammonia generation and storage
Minimum
28,900,000 J_{elect}/kgNH3

kg NH3

Transport

$/kgNH3

Markets

Local fertilizer, Int. Comb. fuel

Global fertilizer and chemicals

H2 vector (future market)

kg NH3

Renewable electricity Generation (dispatchable)

9,400,000 $J_{electrical,produced}$/kg NH3

NH3 fuel cell
or NH3-to-H2-to
generator set

$/J Power Purchase Agreement Trigger:
generate&sell if $/J sold >3*$/J used for NH3
(at min. energy demand for NH3)

Efforts to improve ammonia generation:

Mohammadi, Huang, Pfromm, "Chemical Looping of Manganese to Synthesize Ammonia at Atmospheric Pressure: Sodium as Promoter", Chemical Engineering & Technology, (Impact factor 3.74, 2019), Accepted 8/2020

Mohammadi, Pfromm, "Chemical Looping of Manganese to Synthesize Ammonia: Nitrogen Transport in Manganese", in prep

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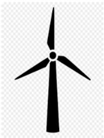
Water treatment using renewable energy

Renewable only 
U.S. $/J, real time pricing
or PowerPurchaseAgreement

Grid electricity, possible through microgrid

static trigger? J

Water Treatment
by electrodialysis
4,320,000 J_{elect}/m^3 $H2O_{usable}$
= $1.2 kWh/m^3$

Water, usable= 0.9*unusable water, m^3

	TDS, ppm
Agriculture	<1,000
Human	<100
Animal	<10,000

Brine= 0.1*unusable water, m^3

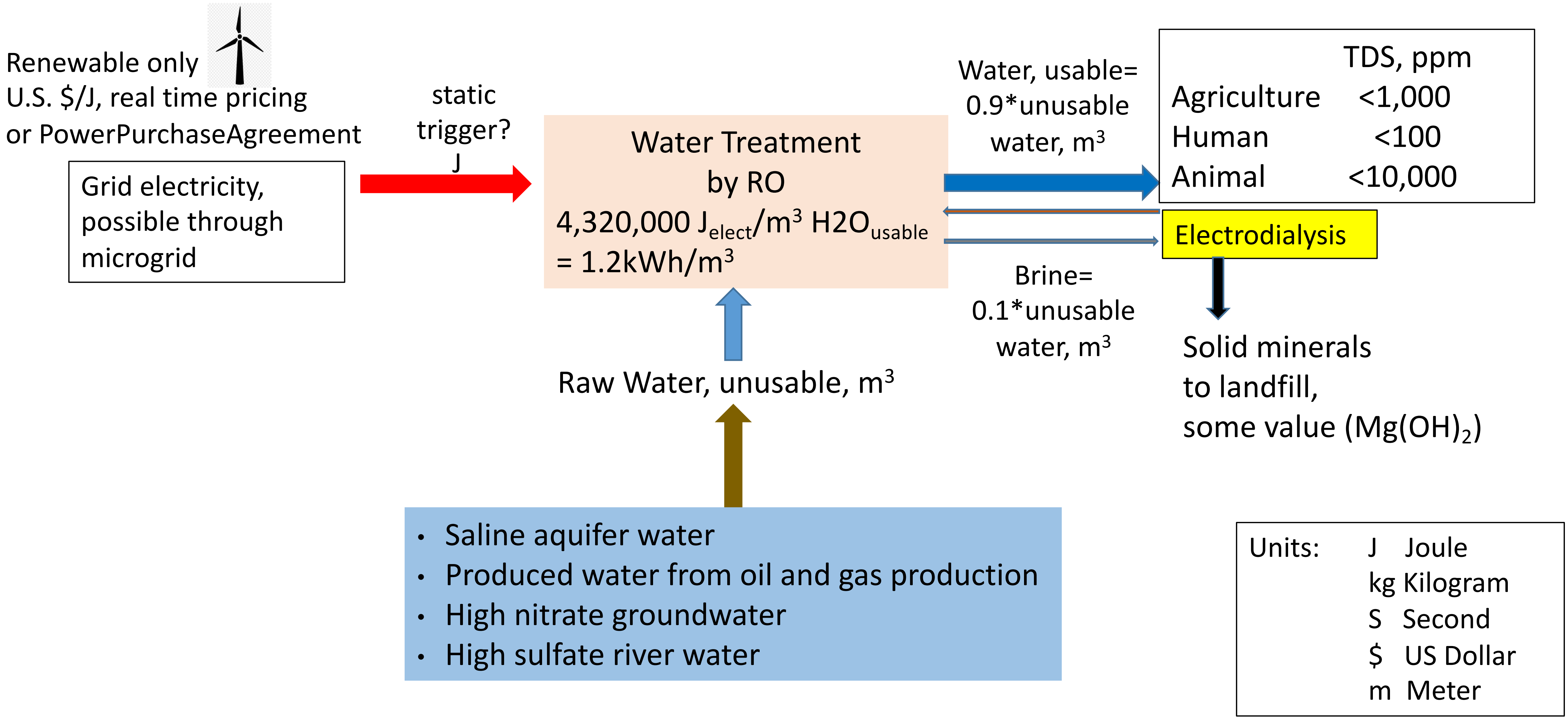
Injection? Class 1 or 2 injection wells.

Raw Water, unusable, m^3

- Saline aquifer water
- Produced water from oil and gas production
- High nitrate groundwater
- High sulfate river water

Units:	
J	Joule
kg	Kilogram
S	Second
$	US Dollar
m	Meter

Water treatment with zero liquid discharge



Brackish groundwater treatment for irrigation

- Additional water available at irrigation scale -- from aquifers with high dissolved solids[1]
- Water treatment for brackish/high dissolved solids water ➔ drinking water from has been extensively investigated[2,3]. Use here as a surrogate.
  No operating or capital expense to distribute water is included.
  - Use deep well injection of concentrated brine: $499 per acre foot
  - ZDD (zero discharge desalination, no brine disposal, minerals disposed as solids): $815 per acre foot (might be able to sell some minerals)
    - Verified via Pfromm at $370 per acre foot, based on known economics of seawater desalination, but brine disposal neglected
- No-cost energy may lower overall cost up to about 30% max.
- RESULT: Economical only for selected high value uses.
  Probably not large-scale field irrigation.

	TDS, ppm
Agriculture	<1,000
Human	<100
Animal	<10,000

1 USGS, Hydrogeology, Distribution, and Volume of Saline Groundwater in the Southern Midcontinent and Adjacent Areas of the US, Report 2013-5017; USGS, Analysis of Regional Aquifers In The Central Midwest Of The United States In Kansas, Nebraska, And Parts Of Arkansas, Colorado, Missouri, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming, Paper 1414A

2 Brackish Groundwater National Desalination Research Facility , Alamogordo, NM

3 Demonstration of Zero Discharge Desalination, US Bureau of Reclamation Report No. 165, 2014, https://www.usbr.gov/research/dwpr/reportpdfs/report165.pdf

This work was produced by highly experienced individuals from academia and industry.

A Bit of Depth on Three Topics – 3 slides each

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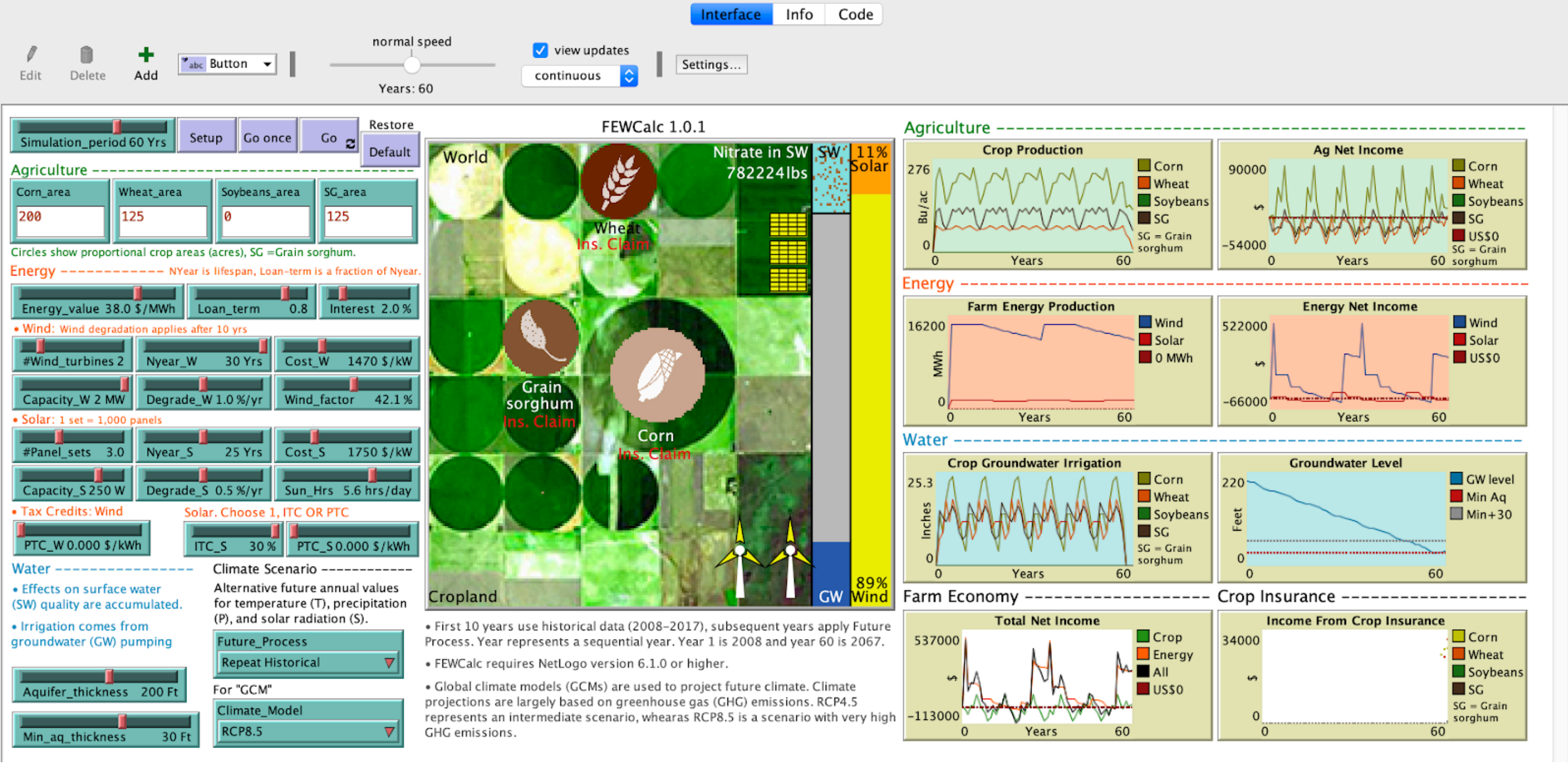
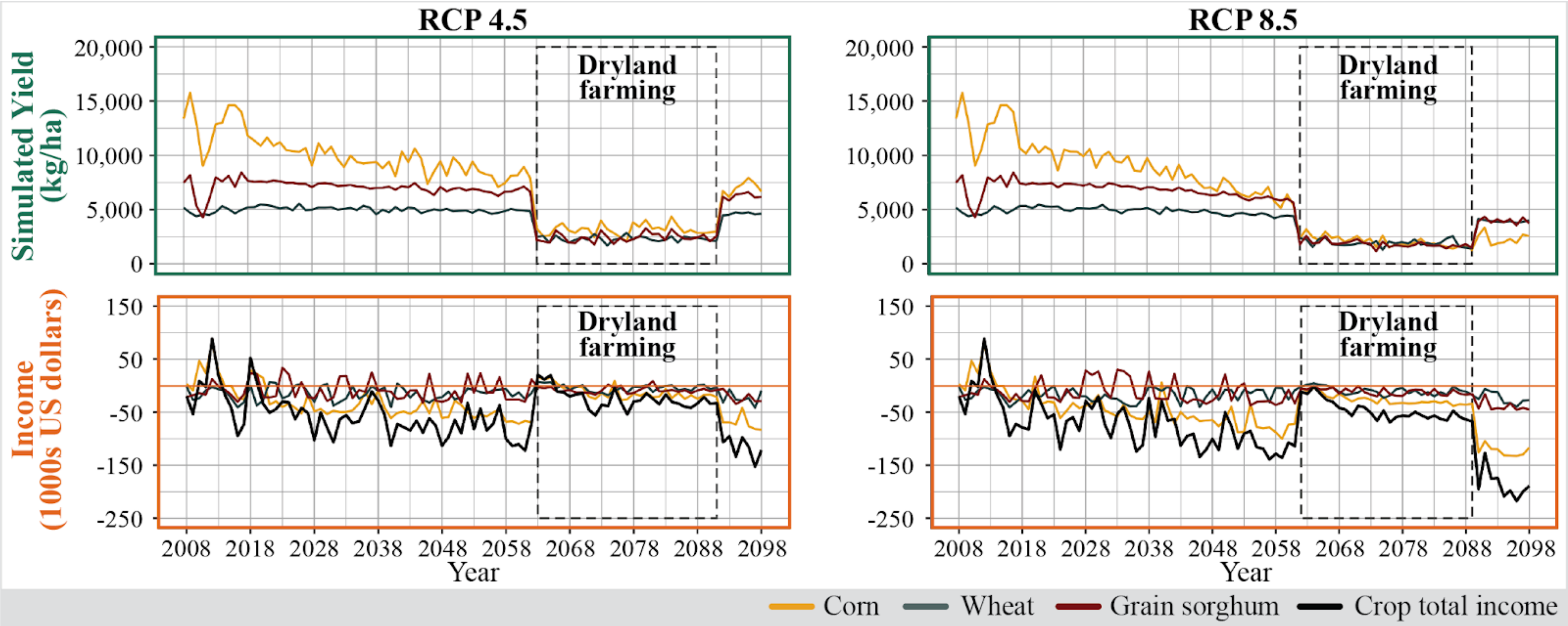
FEWCalc Agent Based Model Programmed with NetLogo



Example results: Agricultural consequences of climate change without adaptations

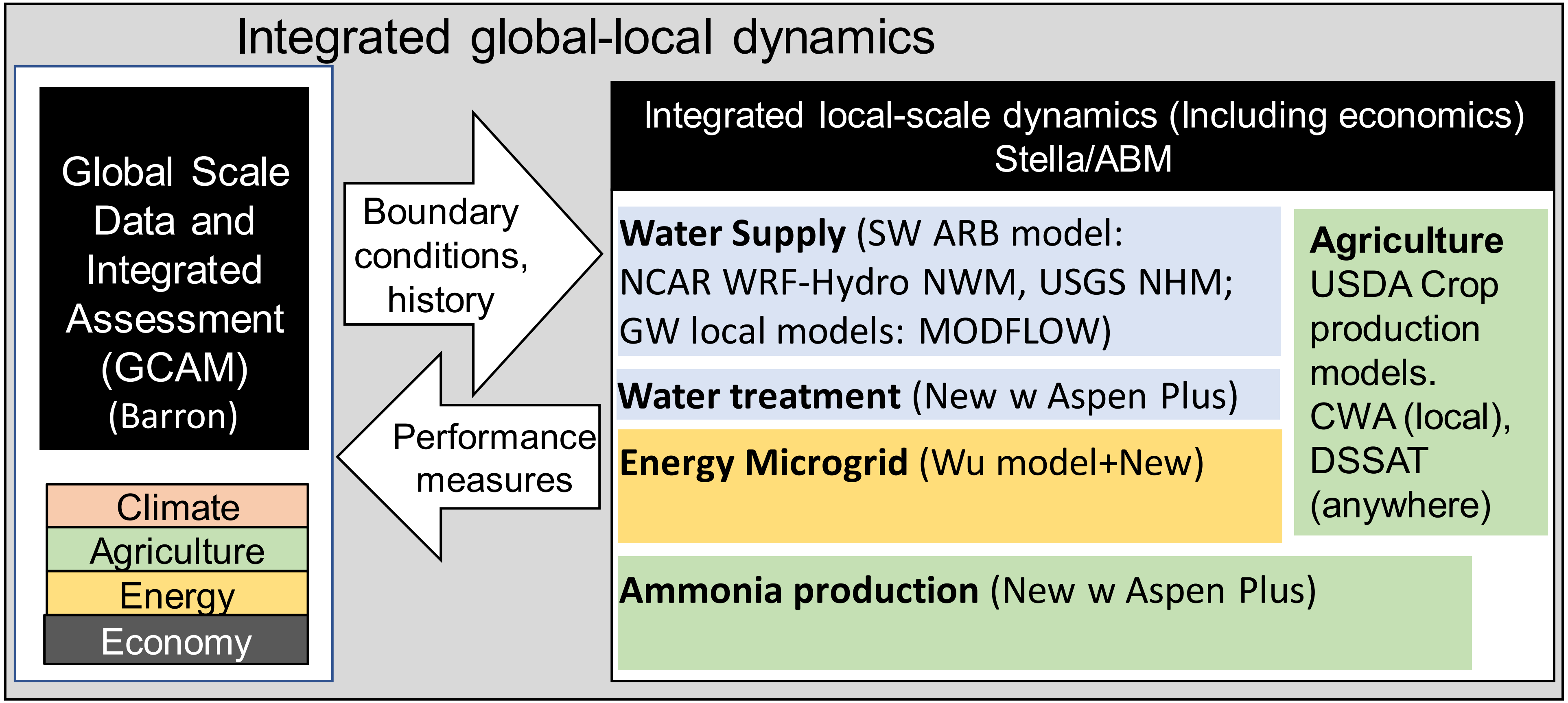


- Adaptations are needed to maintain productivity and attain profitability
- Adaptations can be local (like irrigation choices) and/or global (market crop prices)

Phetheet Hill Barron Rossi Amanor-Boadu, Climate Change and Food-Energy-Water Systems in Arid Regions: Dynamics and Economics Simulated Using FEWCalc and DSSAT. Resources, Conservation, and Recycling, Special Issue on Food-Energy-Water Nexus. In Revision.

Phetheet Hill Barron Gray Wu Amanor-Boadu Heger Kisekka Golden Rossi Relating Agriculture, Energy, and Water Decisions to Farm Incomes using 50-Year Projections from FEWCalc and DSSAT. Agricultural Systems. Submitted.

Decision Support System Goals for FEWtures

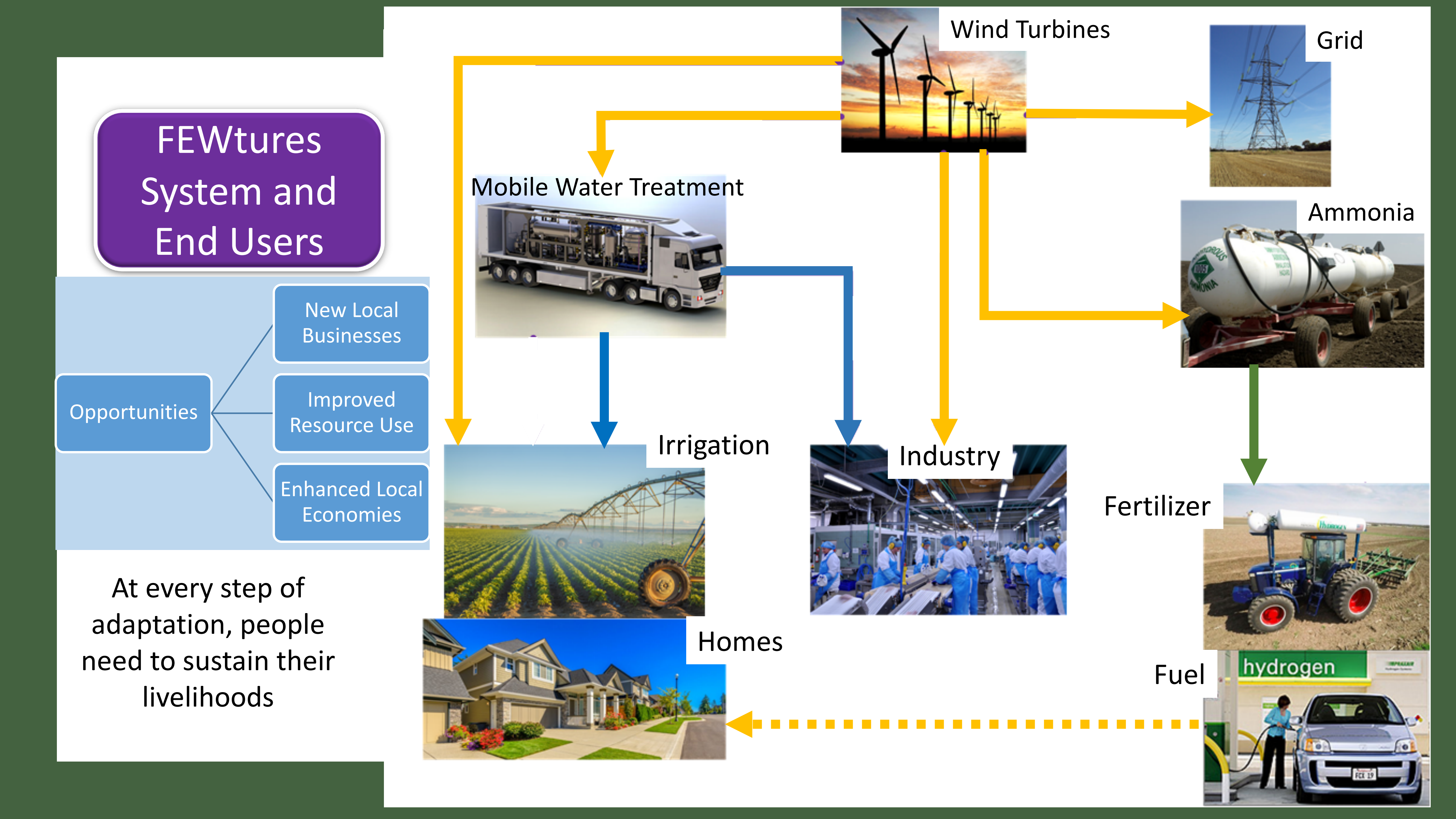


DataX Science Gateway from UT Austin for model integration

CHORDS from UT Austin to display scenario definition and model results on cell phones

Metrics to communicate results to stakeholders

Modarresi, Amir, and John Symons. "Resilience and technological diversity in smart homes." Journal of Ambient Intelligence and Humanized Computing (2020): 1-19.


FEWtures System and End Users
Opportunities
New Local Businesses
Improved Resource Use
Enhanced Local Economies
At every step of adaptation, people need to sustain their livelihoods
Wind Turbines
Grid
Mobile Water Treatment
Ammonia
Irrigation
Industry
Fertilizer
Homes
Fuel
hydrogen

Take Away

- We seek to provide **stakeholders** with decision-support tools that assist them, ***In their own situations***, to:
  - Assess components of food, energy and water technology interactions needed to understand the on-going feasibility of on-going technical, operational and economic choices
  - Engage partners in conversation to discover viable opportunities via Advisory Groups, surveys, interviews (Gray, Campbell)
- Develop DSS so stakeholders can identify “best” solutions to invest in for profit and/or community economic development
- Support the broader objective of securing the Heartland’s future and feeding the world

Conversations

We hope the FEWtures research produces wind energy designs that prove more profitable than current systems

- That it creates opportunities for economic development in our small towns and rural communities

Economic feasibility depends on operational feasibility

- What barriers stand in the way of adoption? (Bloodgood)
- What regulatory challenges exist?
- What enabling policies are needed to enhance operational feasibility of the FEWtures initiative? (Stover)

Thank You

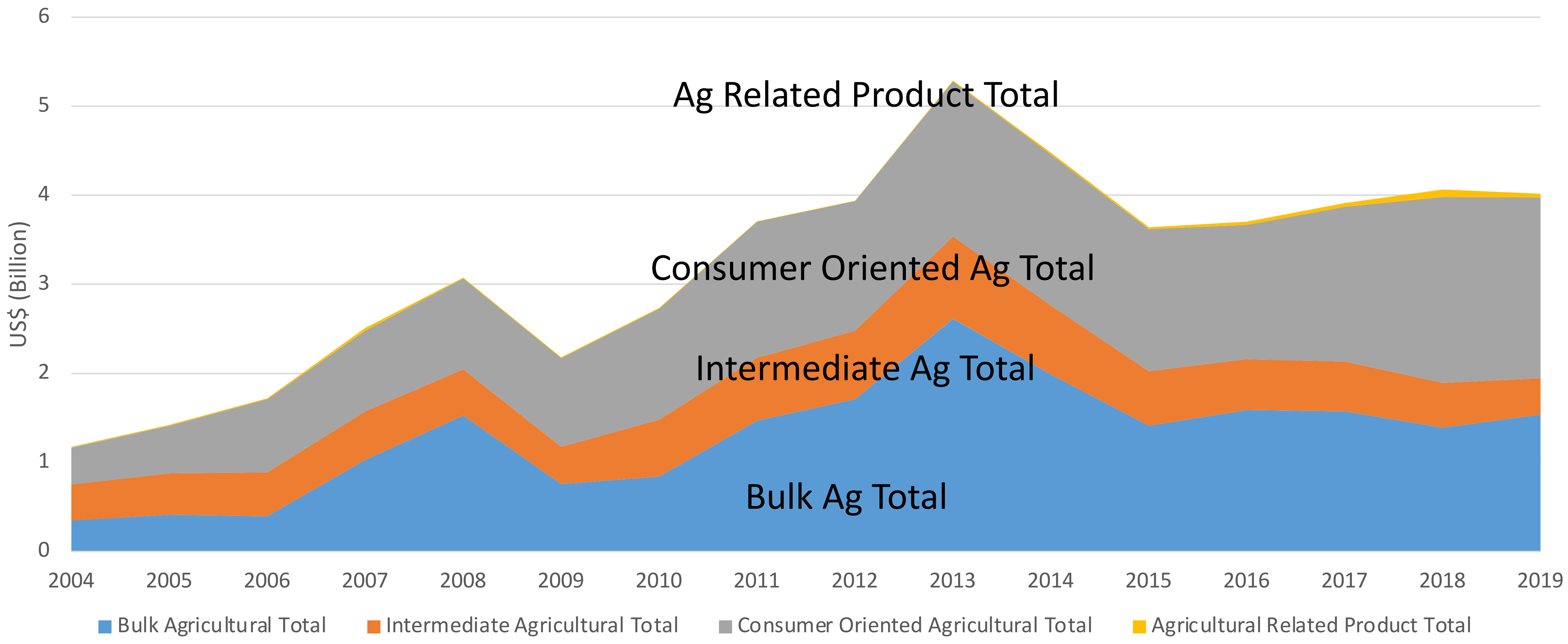
FEWtures

Resilient Farms • Thriving Communities

http://ipsr.ku.edu/FEWtures
https://facebook.com/fewtures
@fewtures.nsf
fewtures@ku.edu

mchill@ku.edu

Kansas Agri-Food Exports by Aggregate Groups ($B)



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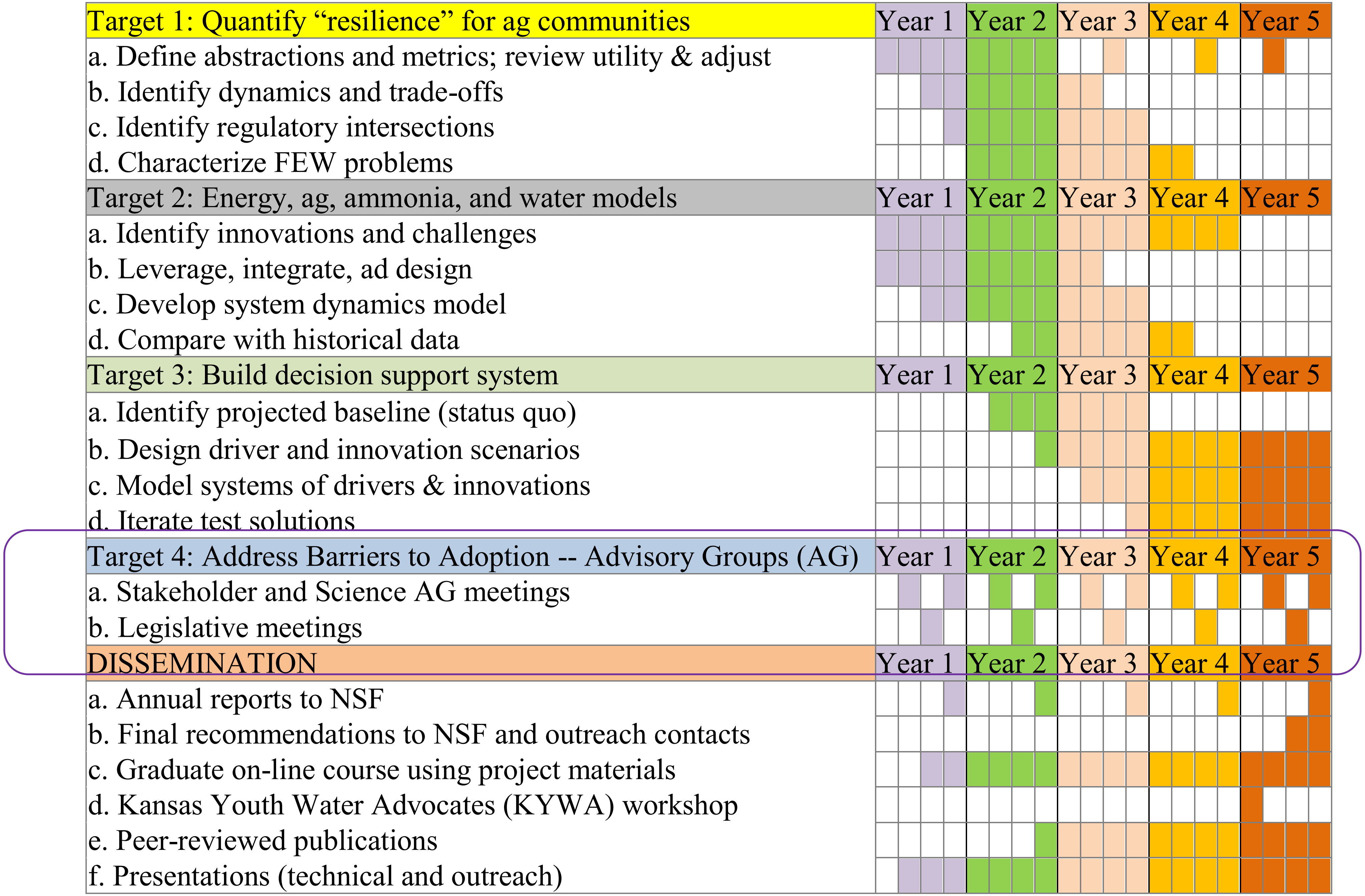

Target 1: Quantify “resilience” for ag communities
Year 1
Year 2
Year 3
Year 4
Year 5
a. Define abstractions and metrics; review utility & adjust
b. Identify dynamics and trade-offs
c. Identify regulatory intersections
d. Characterize FEW problems
Target 2: Energy, ag, ammonia, and water models
a. Identify innovations and challenges
b. Leverage, integrate, ad design
c. Develop system dynamics model
d. Compare with historical data
Target 3: Build decision support system
a. Identify projected baseline (status quo)
b. Design driver and innovation scenarios
c. Model systems of drivers & innovations
d. Iterate test solutions
Target 4: Address Barriers to Adoption -- Advisory Groups (AG)
a. Stakeholder and Science AG meetings
b. Legislative meetings
DISSEMINATION
a. Annual reports to NSF
b. Final recommendations to NSF and outreach contacts
c. Graduate on-line course using project materials
d. Kansas Youth Water Advocates (KYWA) workshop
e. Peer-reviewed publications
f. Presentations (technical and outreach)