The Implications of Deep Reductions in Greenhouse Gas Emissions for Carbon Cycle Science

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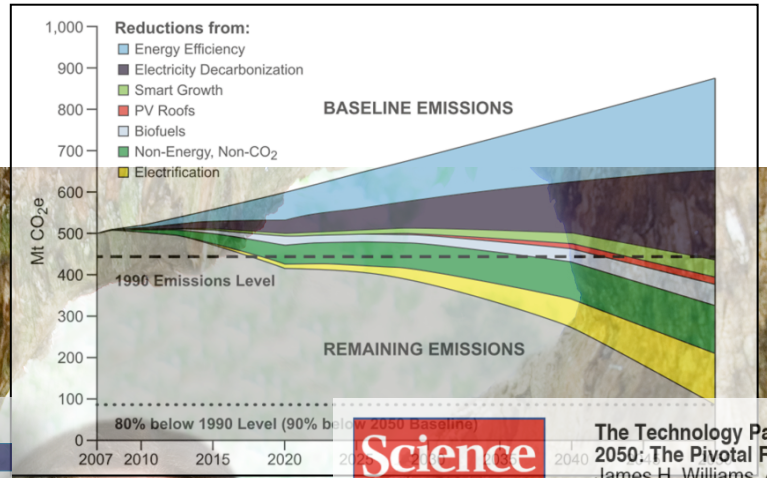
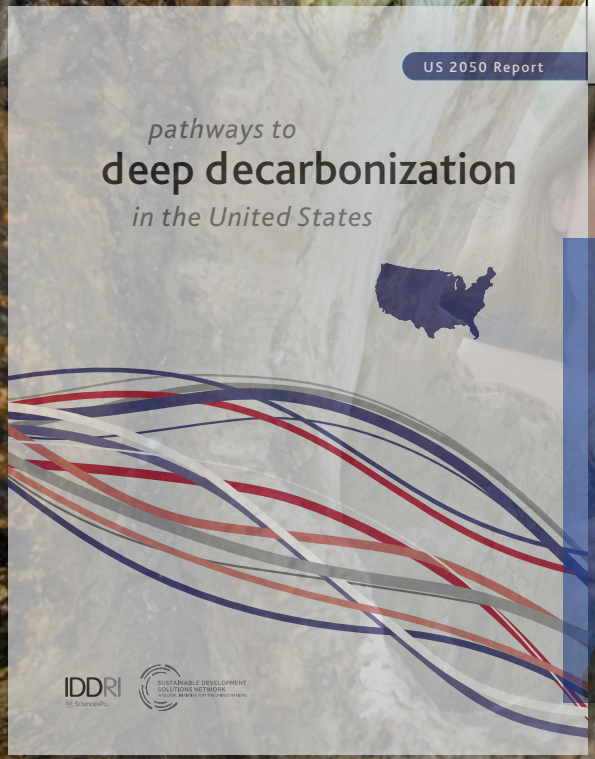
Energy and Environmental Economics, Inc. **(E3)**

North American Carbon Program
Washington, DC.
January 26, 2015

What's a nice biogeochemist like me doing in a place like this?





Science AAAS

The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity
James H. Williams, *et al.*
Science **335**, 53 (2012);
DOI: 10.1126/science.1208365

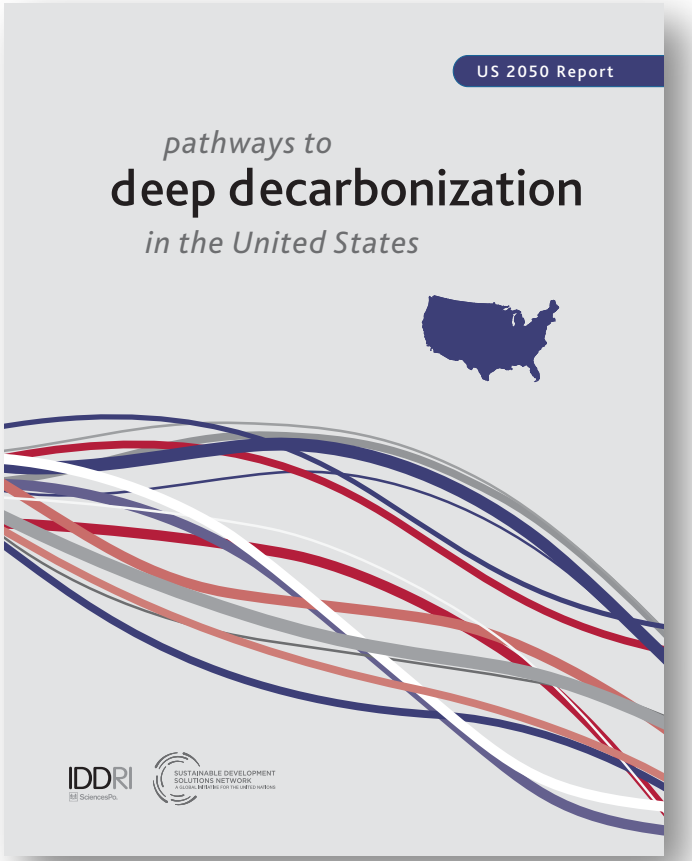
The Technology Path to Deep Greenhouse Gas Emissions Cu 2050: The Pivotal Role of Elect

James H. Williams,[1,2] Andrew DeBenedictis,[1] Rebecca Ghanadan,[1,3] Amber Jack Moore,[1] William R. Morrow III,[4] Snuller Price,[1] Margaret S. Torn[3]*

Take Home Messages and Outline

- It is technically feasible to reduce U.S. GHG emissions by 80% below 1990 by 2050, while supporting economic growth and services
- This transformation of the U.S. energy system would require contributions from carbon cycle science and new approaches to monitoring & verification.
  - Carbon sink from land use, land use change, & forestry
  - Biomass used for Bio-energy
  - Non-energy and non-CO_2 GHGs (CH_4, N_2O, F-gases)
  - Monitoring and verification must address infrastructure change, fuel switching, net-zero fuels

This talk is based on results of the U.S. Deep Decarbonization Pathways report

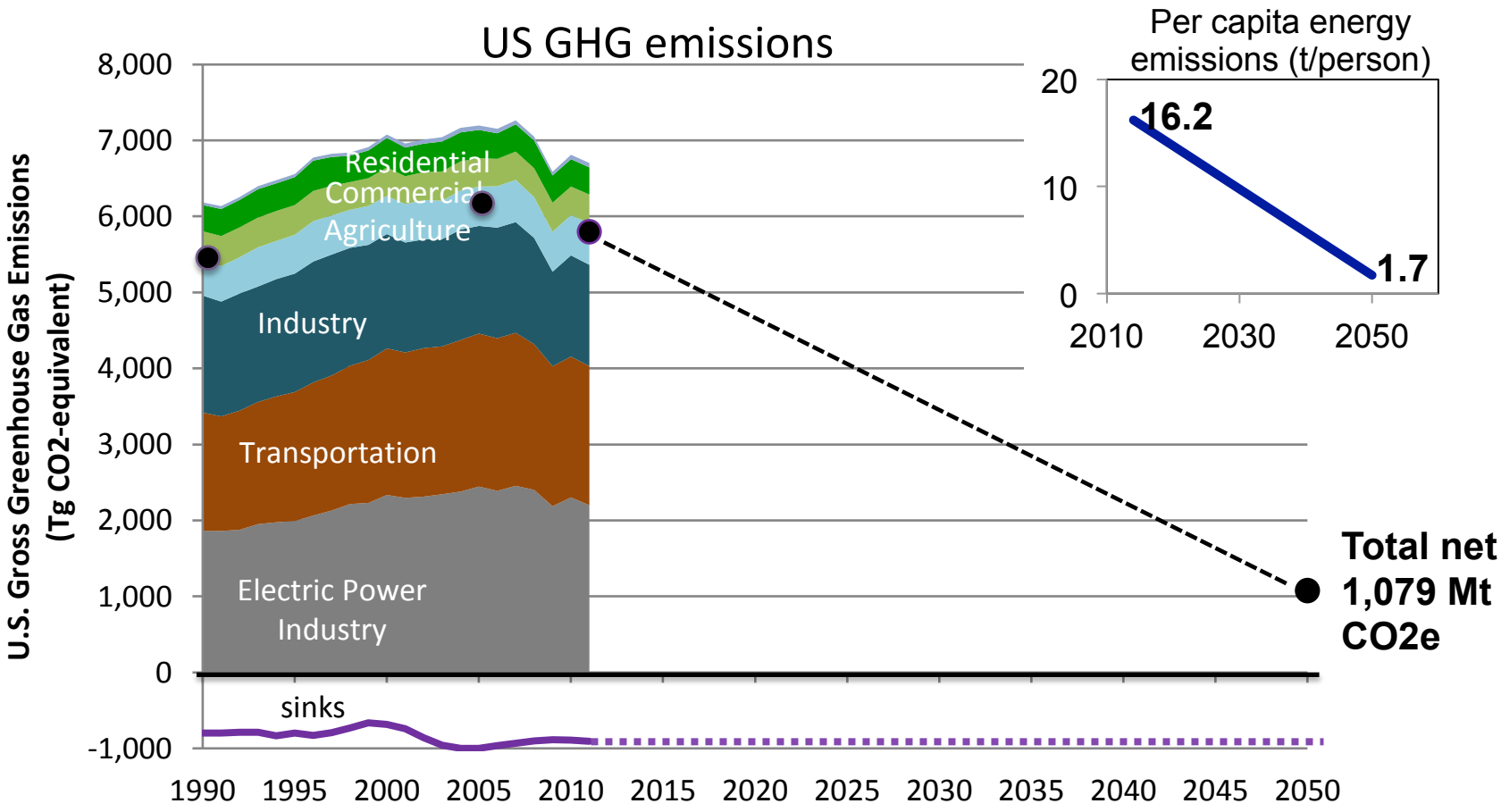


Williams et al. Nov. 2014
Report available at http://unsdsn.org

- Part of the UN Deep Decarbonization Pathways Project.
- National strategies to keep global warming below 2°C
- Target is 80% reduction below 1990 by 2050
- *How do we get there from here?*

Current Emissions & 2050 Target

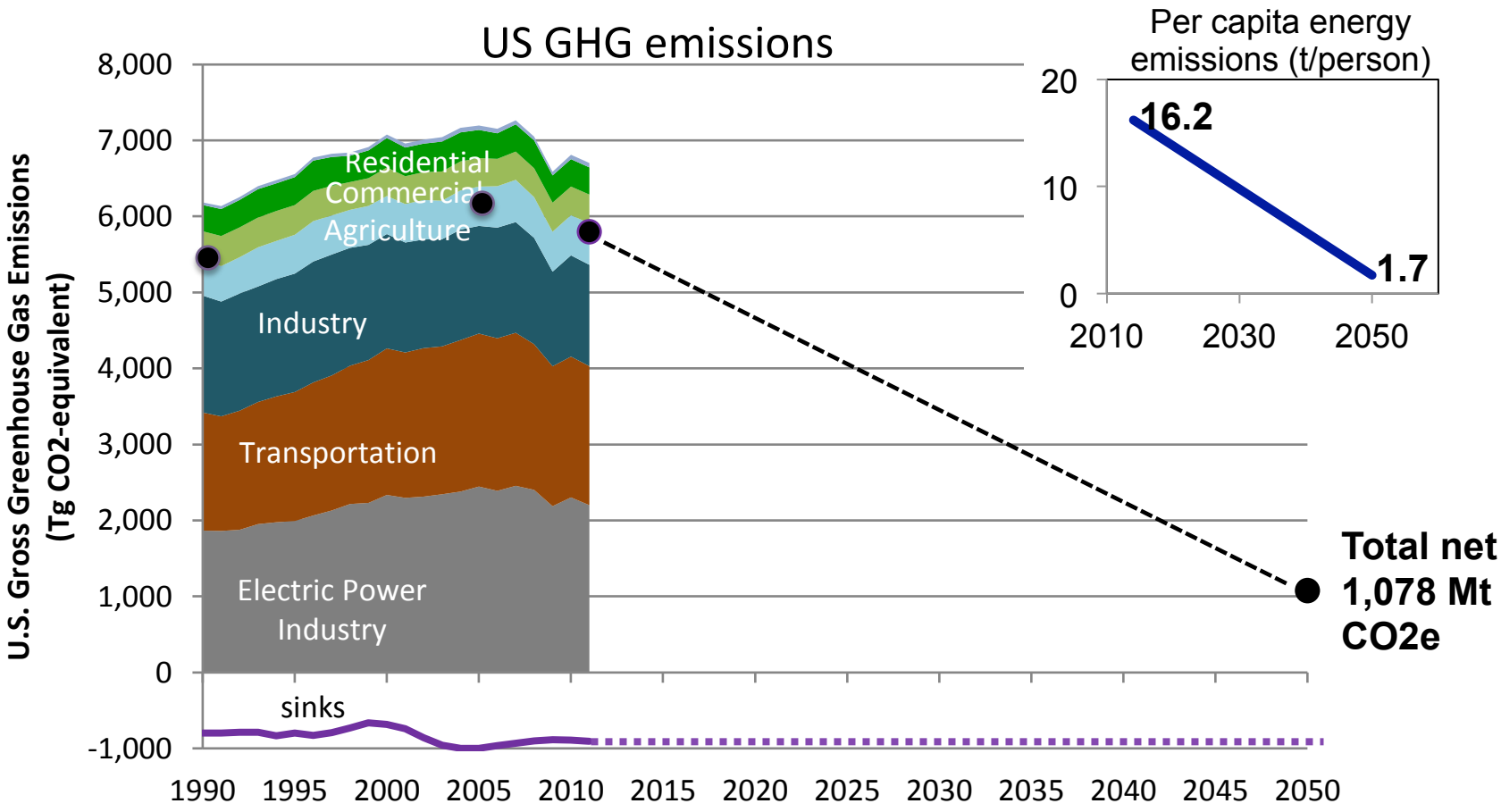
net CO2e emissions 80% below 1990 by 2050



Based on US EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2011, Table 2-2

How do we get there from here?

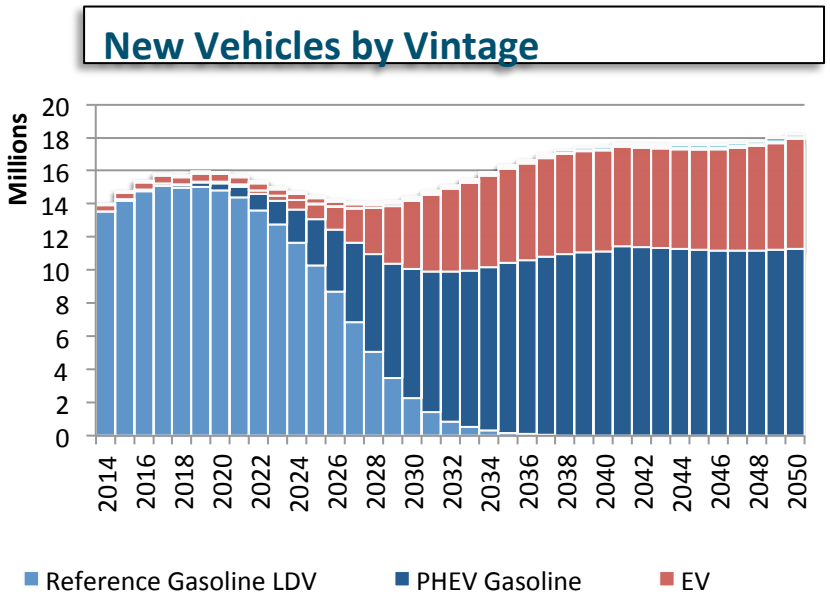
Back trajectory analysis, not a forecast.

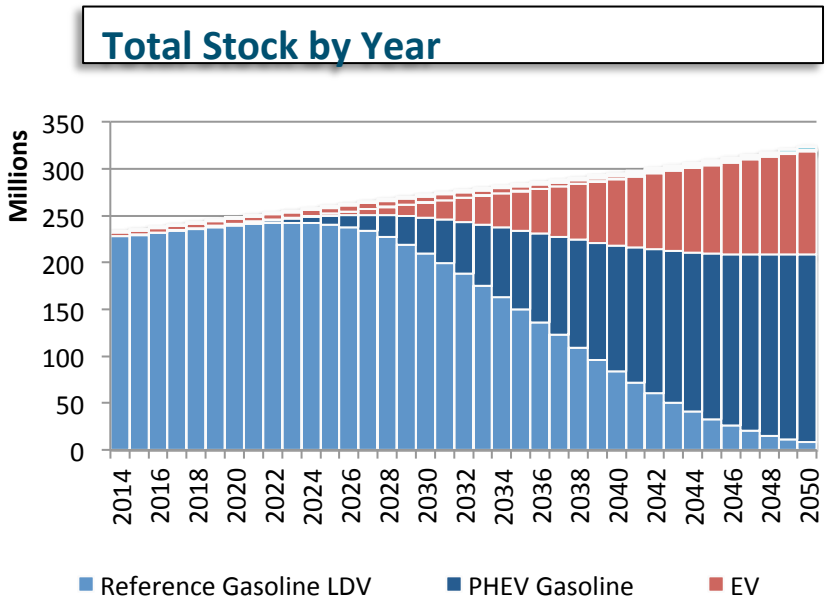


Based on US EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2011, Table 2-2

PATHWAYS Model: Physical Infrastructure & Energy System

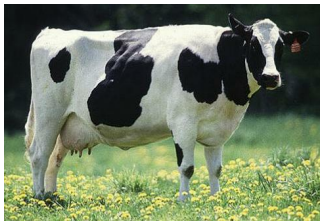
- Multi-sector U.S. energy system model (80 demand categories, 20 supply categories)
- Infrastructure stock rollover for 9 US census regions
- Annual time steps with equipment lifetimes, hourly dispatch
- Illustrates inertia of the physical energy system

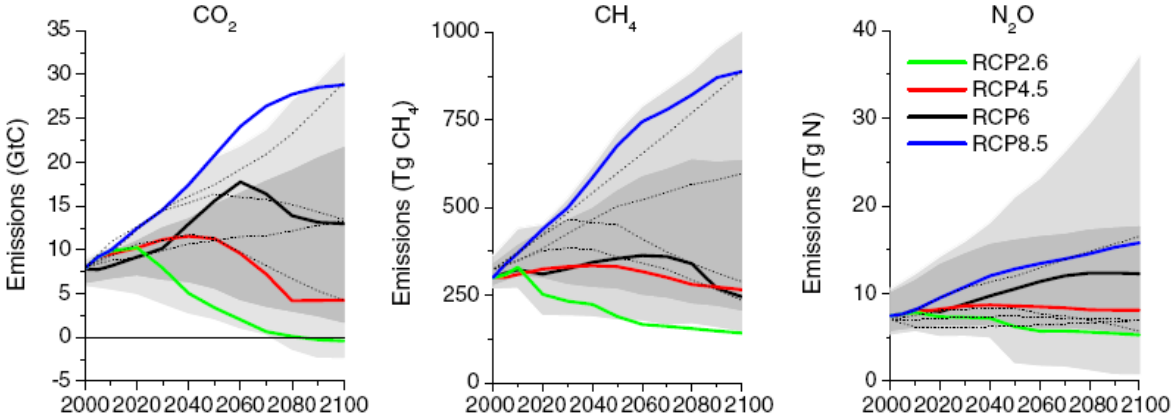




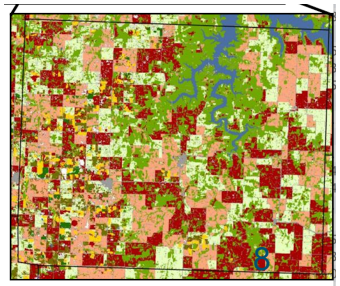
GCAM was used to model non-energy and non-CO_2 emissions

- Well-known IAM (RCP4.5 in IPCC Fifth Assessment)
- Biomass production and indirect LUC emissions
- Non-energy and non-CO_2 GHG mitigation
- Assess sensitivity to terrestrial carbon sink assumptions



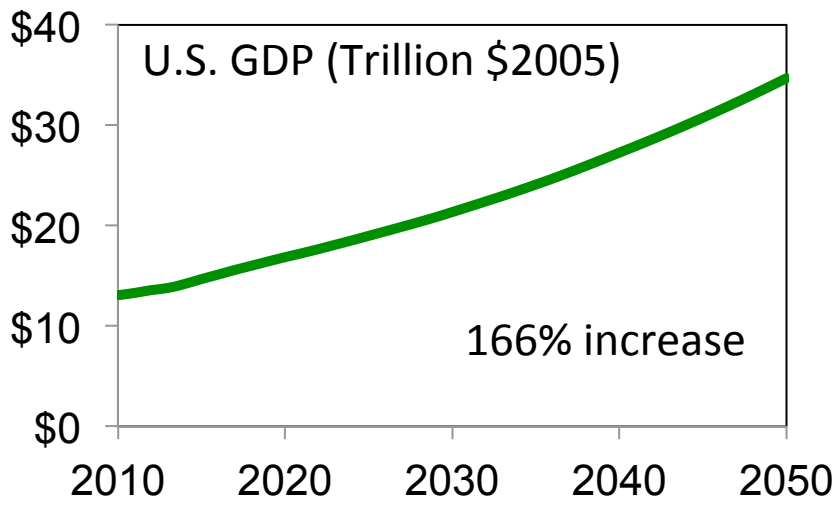


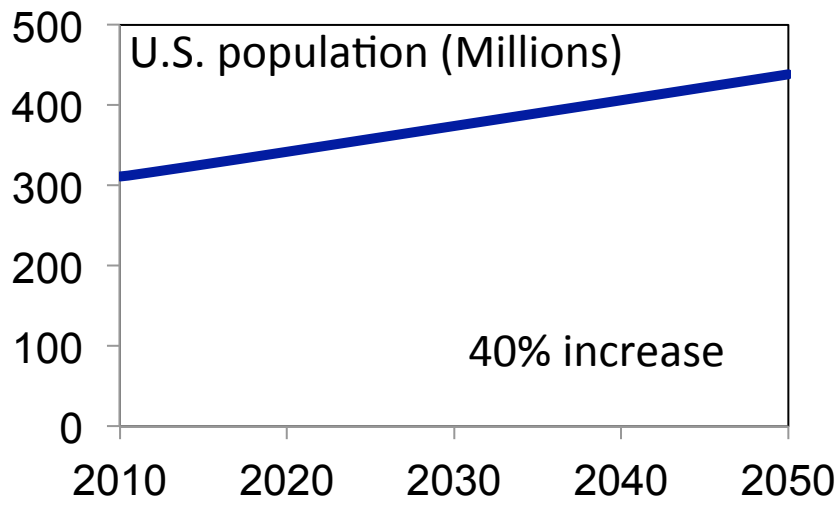
IPCC 2014; van Vuuren et.al. 2011



Design Principles

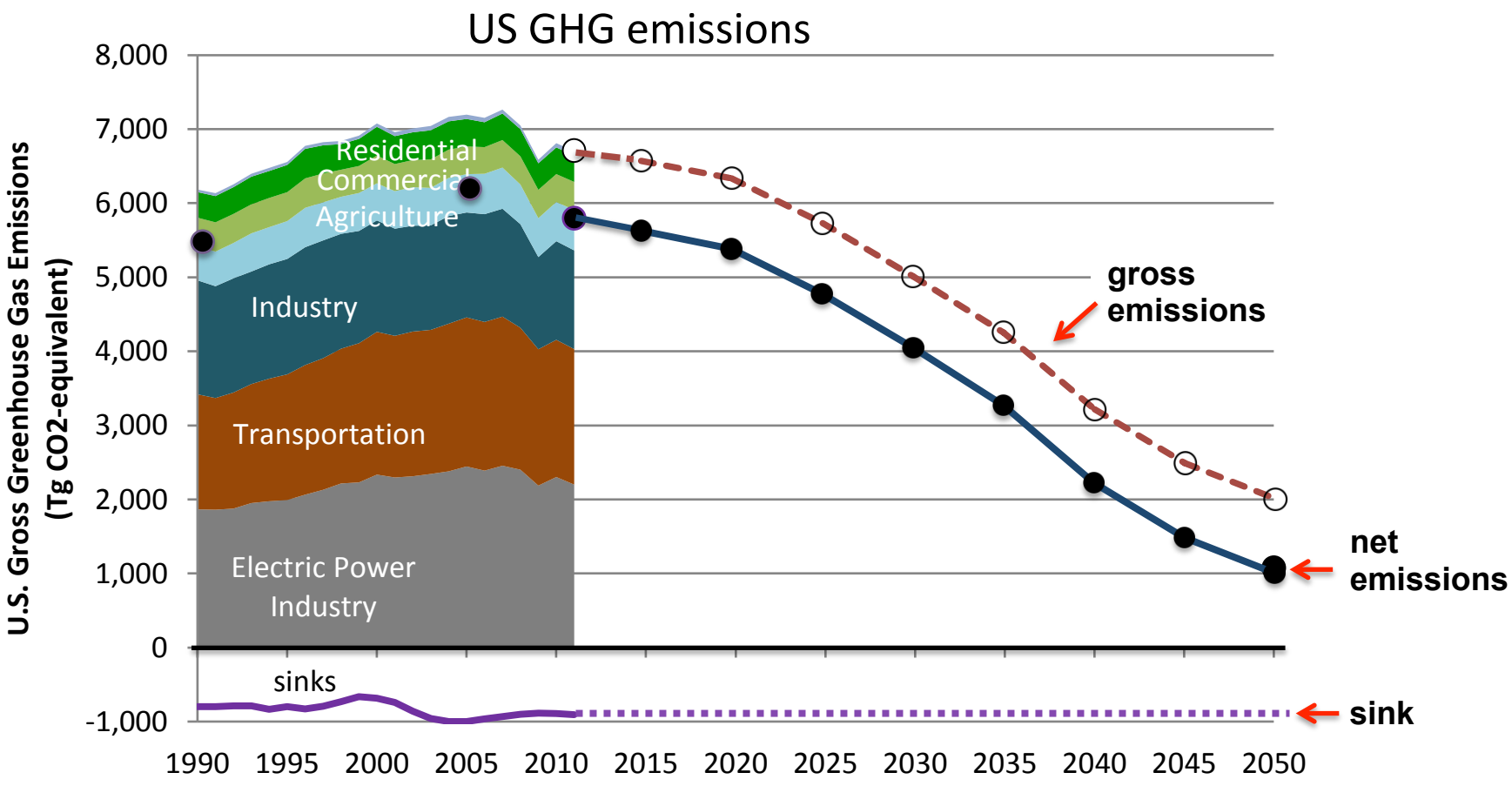
- Conservative assumptions about economy, lifestyles
- Technology is commercial or near-commercial
- Environmental sustainability (limits on biomass, hydro)
- Infrastructure inertia
- Electricity reliability





U.S. National Energy Modeling System and 2013 Annual Energy Outlook reference case

80% Reduction in CO_2e by 2050 is Achievable



Williams et al.. 2014

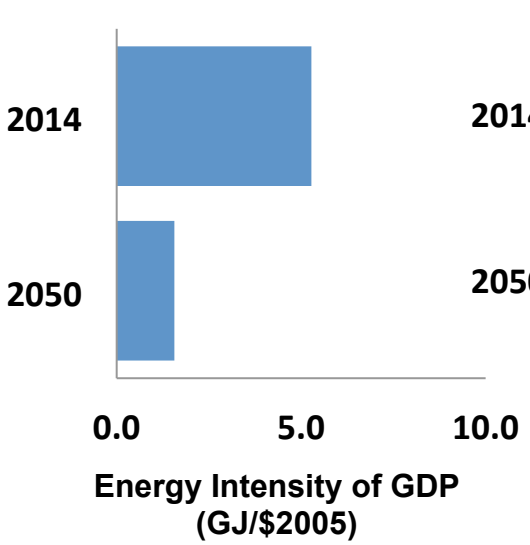
Based on US EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2011, Table 2-2

3 Pillars of Decarbonization

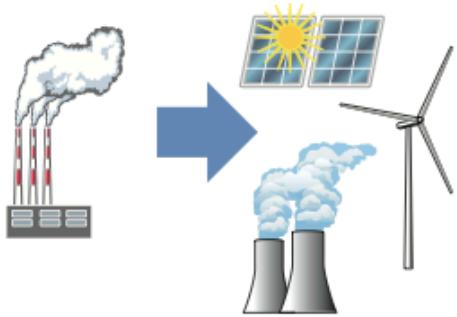
Strategy

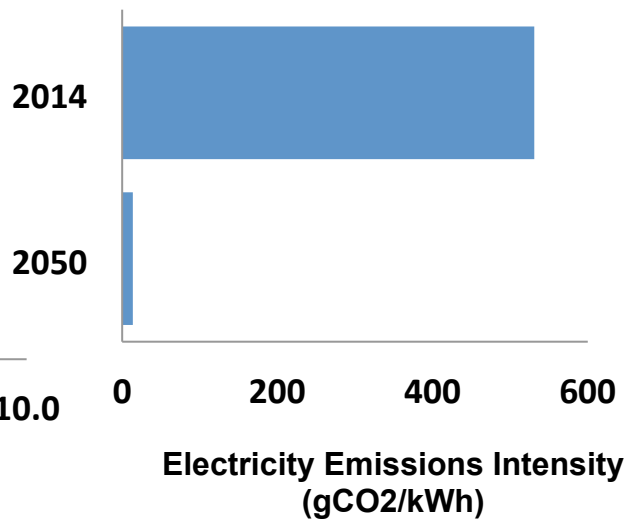
Key Metric of Transformation

Energy Efficiency

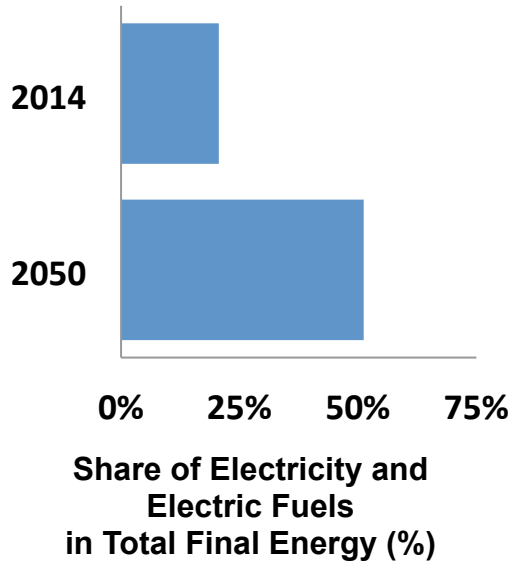


Decarbonization of Electricity



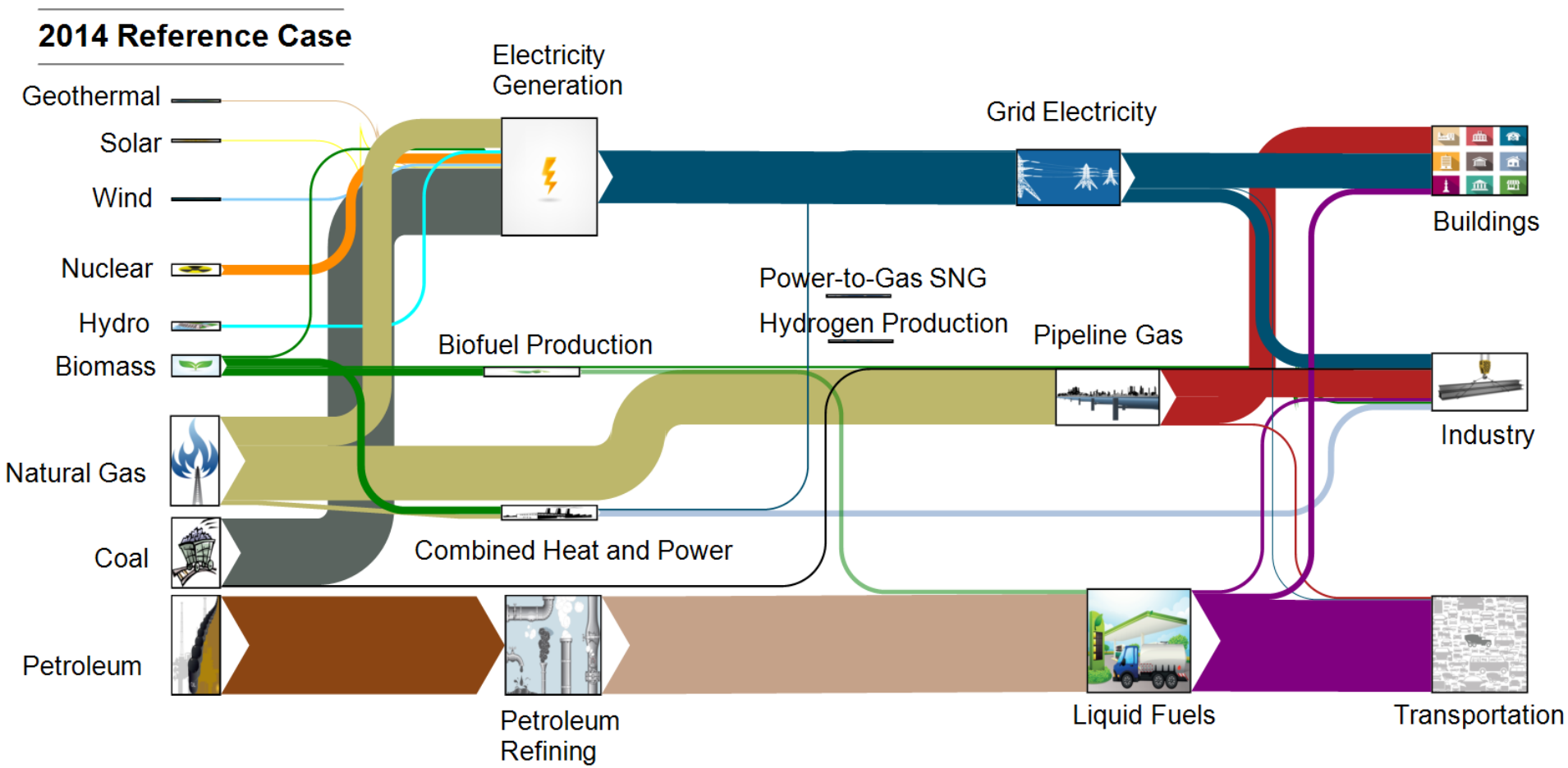


End Use Fuel Switching to Electric Sources



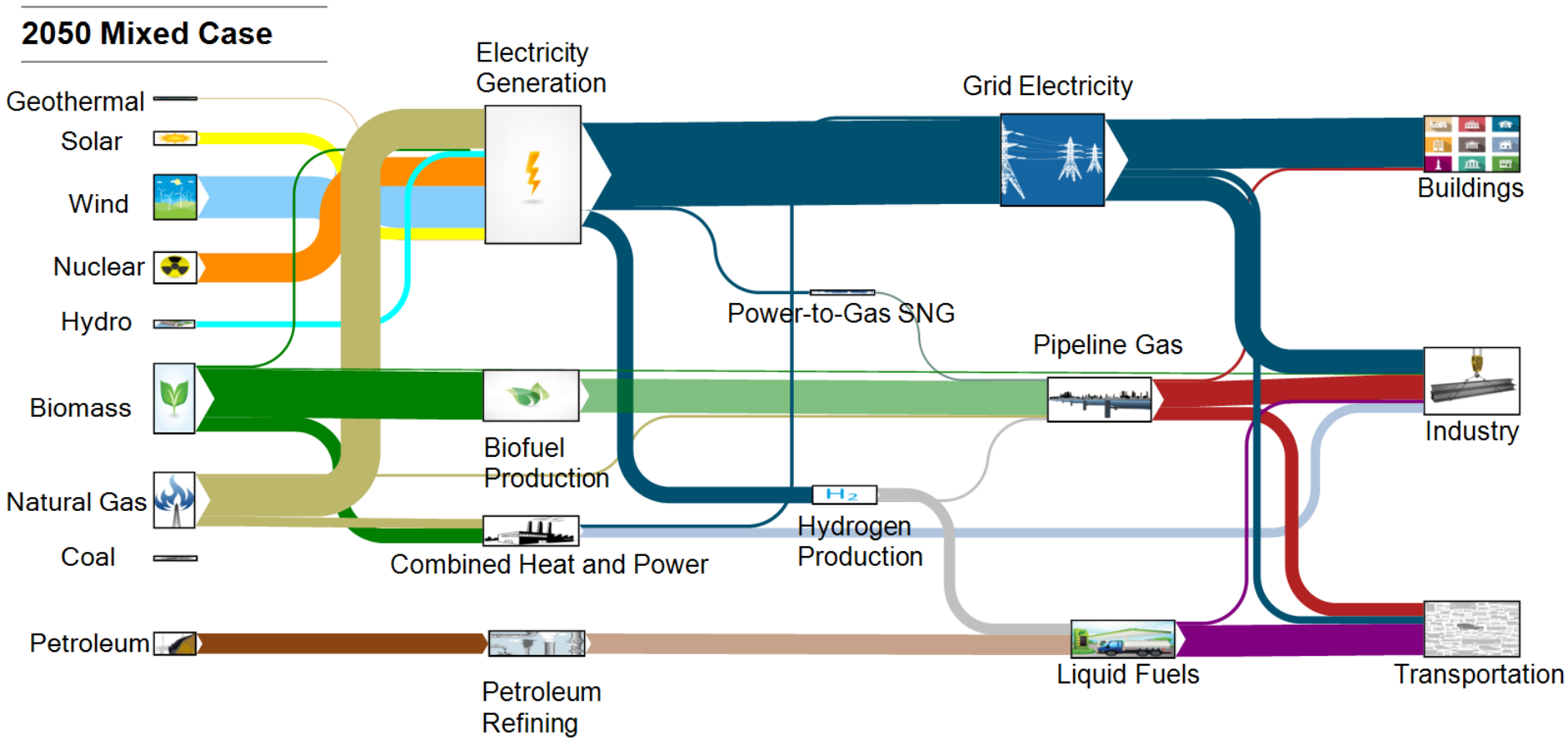
Pathways to Deep Decarbonization in the United States, Mixed case results Williams et al.. 2014

U.S. energy system in 2014



Williams et al.. 2014

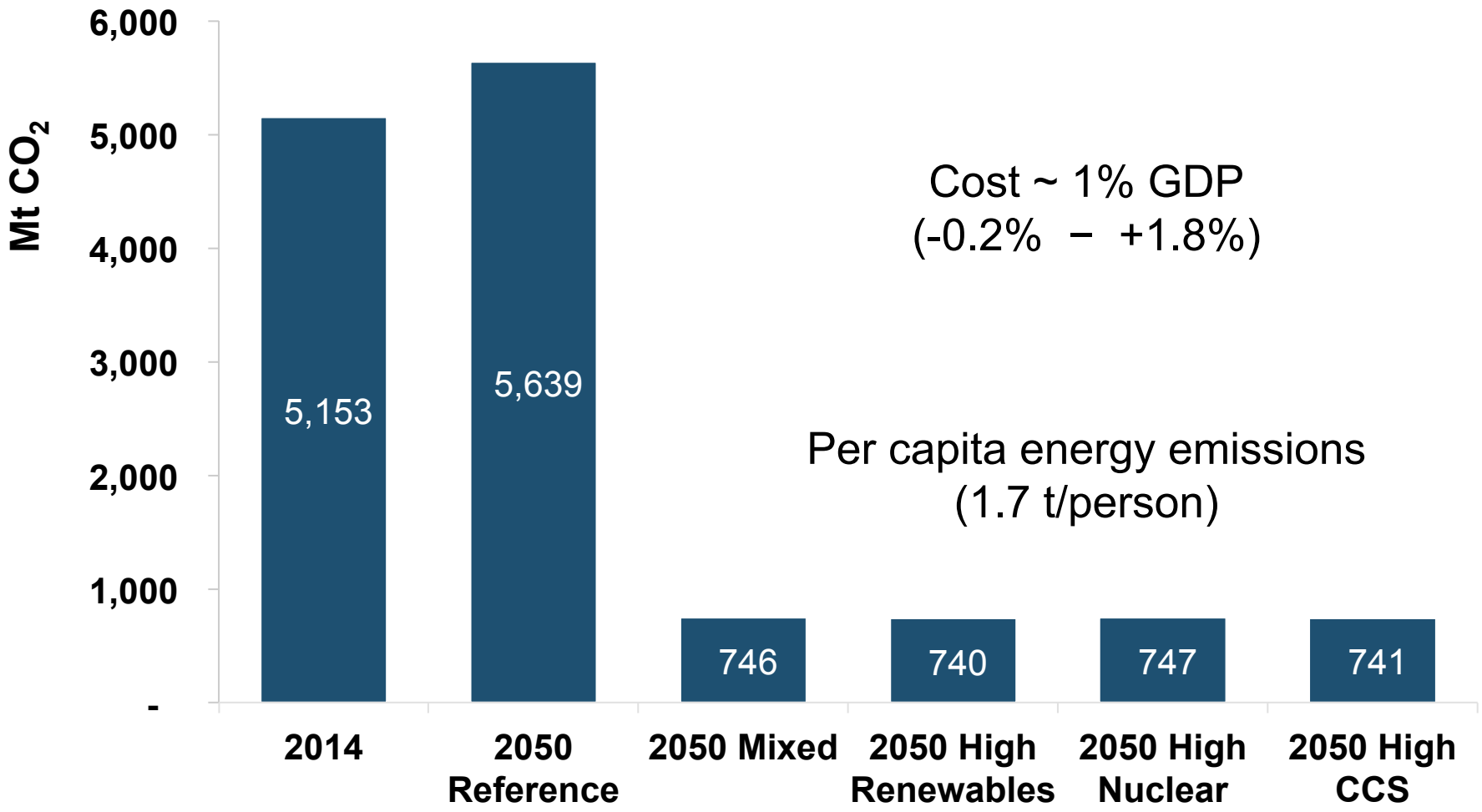
Decarbonized energy system in 2050



Williams et al.. 2014

Pathways to Deep Decarbonization in the United States, Mixed case results

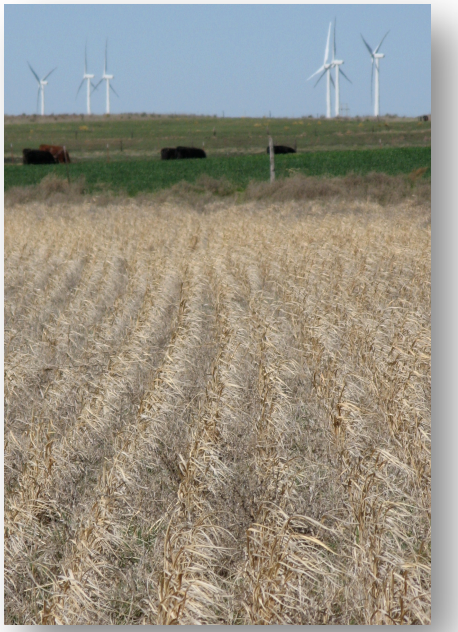
Multiple pathways to deeply reduce U.S. energy emissions



Williams et al.. 2014

Implications for carbon cycle science

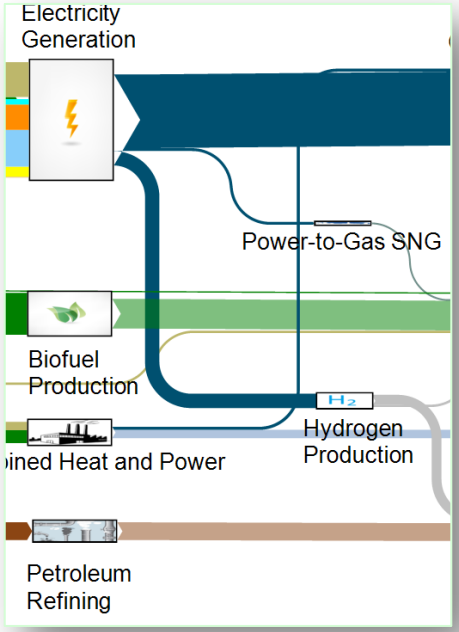
research, manage, predict, verify



Bio-Energy

LULUCF

Non-CO_2 GHGs



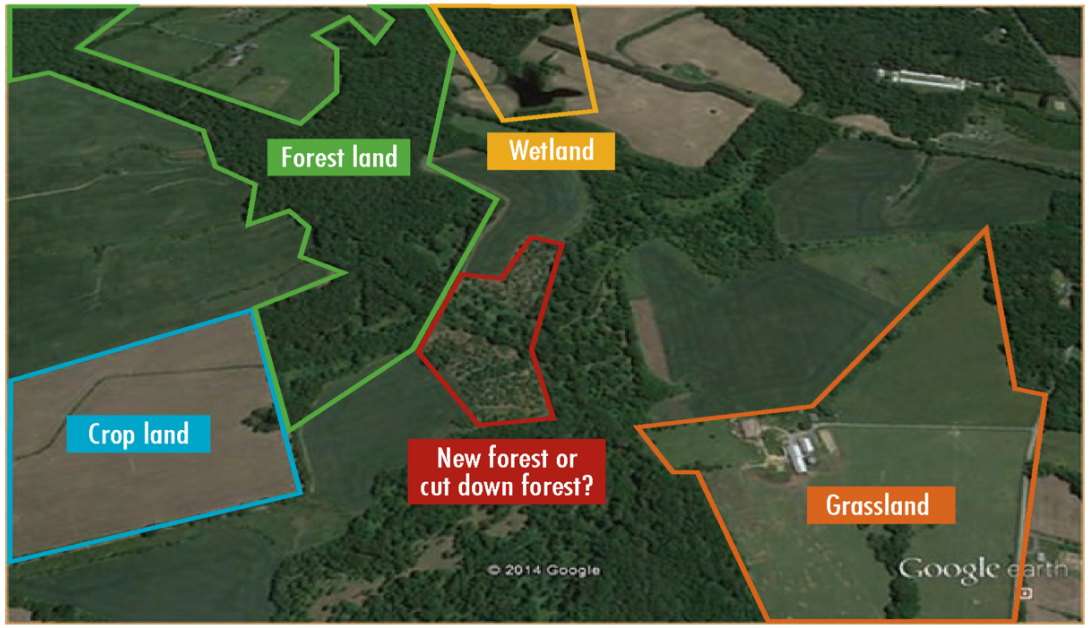
Infrastructure

LBL-USDA switchgrass
M. Torn

UMBS AmeriFlux site
C. Gough

US 2050 report

Carbon sink *due to Land Use, Land Use Change, and Forestry (LULUCF)* ***is Pivotal but Uncertain***

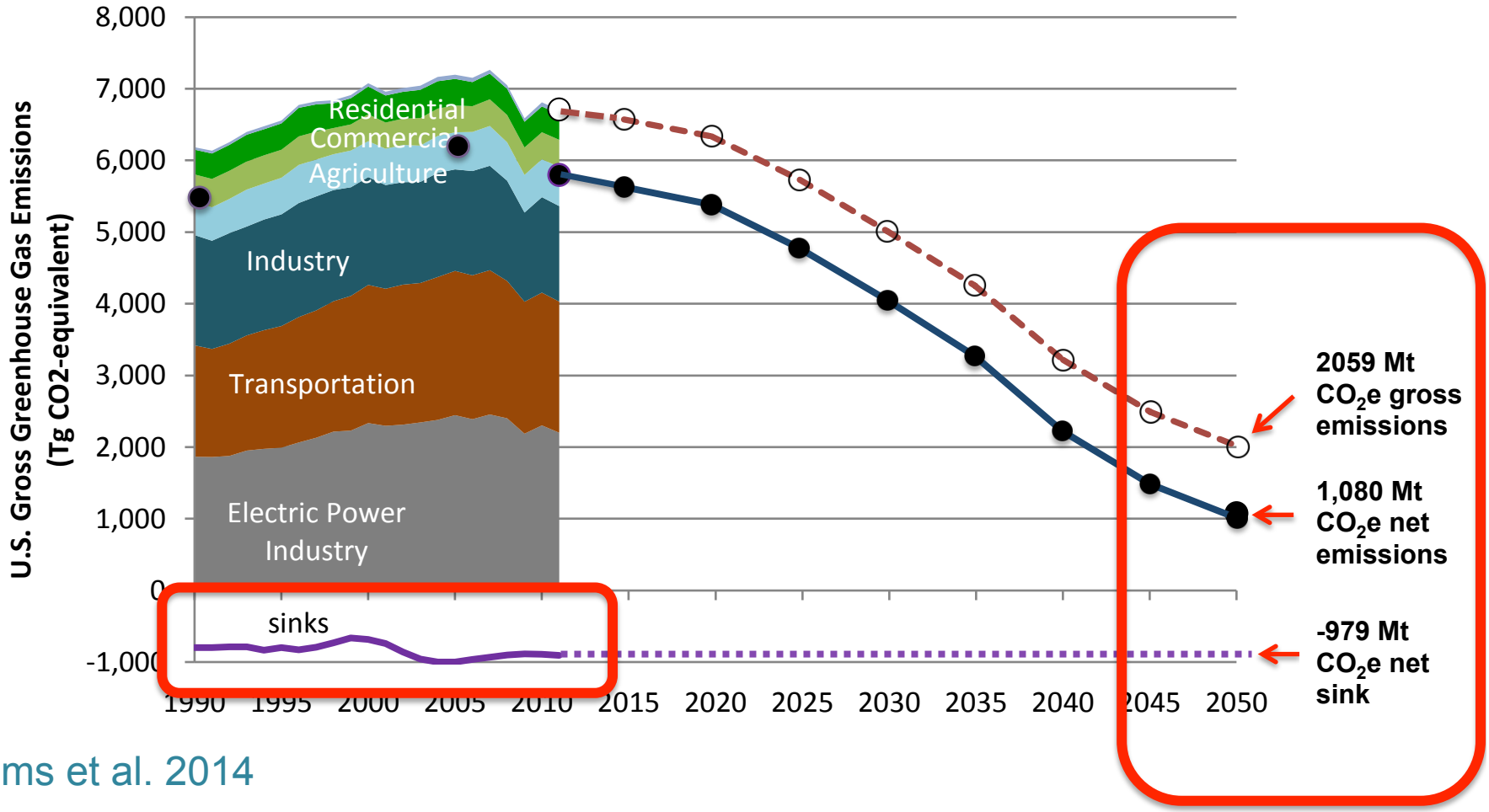


LULUCF Estimation
- Stock-Difference
- Flux measurements
- Activity levels and models

LULUCF Carbon Pools
- Living biomass
- Dead organic matter
- Soil organic carbon
- Harvested Wood Products

Iversen, Lee, and Rocha. 2014. Understanding Land Use in the UNFCCC.

Carbon sink *due to Land Use, Land Use Change, and Forestry (LULUCF)* ***is Pivotal but Uncertain***



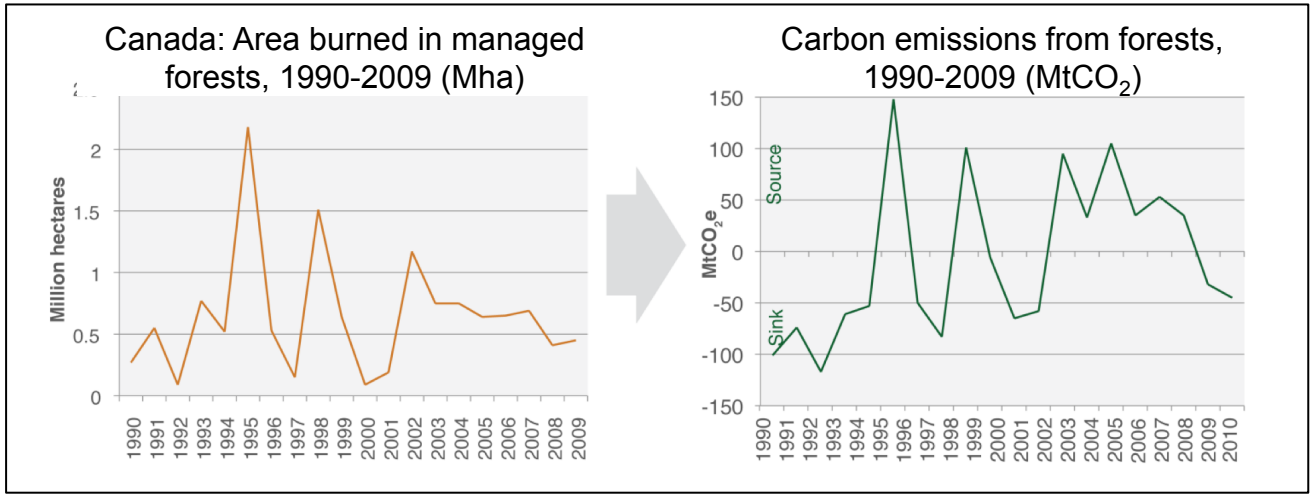
Williams et al. 2014

Based on US EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2011, Table 2-2

Carbon sink *due to Land Use, Land Use Change, and Forestry (LULUCF)* ***is Pivotal but Uncertain***

Research needs

- **Management**
- **Disturbance and legacy effects**
- **Land use change**
- **CO_2 fertilization**



Iversen, Lee, and Rocha. 2014. Understanding Land Use in the UNFCCC.

Bio-energy fills critical energy needs

- Diesel
- Diesel with CCS
- Decarbonized pipeline gas for industry, heavy duty vehicles
- Combined heat & power: pulp and paper industry

nature climate change LETTERS
PUBLISHED ONLINE: XX MONTH XXXX | DOI: 10.1038/NCLIMATE2488

Biomass enables the transition to a carbon-negative power system across western North America

Daniel L. Sanchez[1], James H. Nelson[2], Josiah Johnston[1], Ana Mileva[1] and Daniel M. Kammen[1,3]*

Williams et al. 2014

Table 1. Biomass Supply in PATHWAYS Scenarios

Biomass Category	Data Source	Million Metric Tons Dry biomass
Purpose-grown energy crops	GCAM	371
Currently-used biomass resources	AEO Reference Case Demand	250
Other	DOE Billion Ton Study Update	460
Total		**1,081**

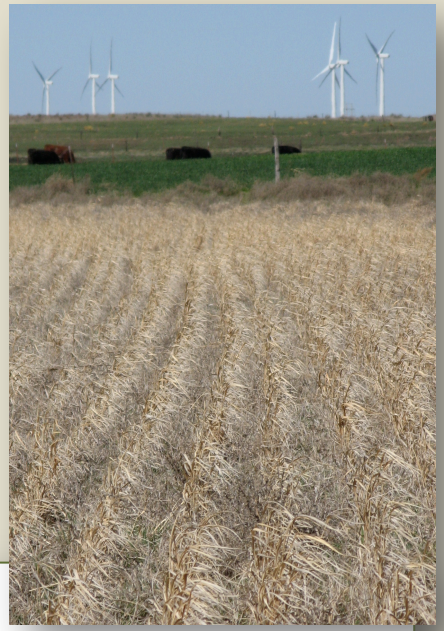
Purpose-grown energy crops: Constrained at level that will not result in ILUC. Transition from corn-ethanol to perennials.
Currently used: fuel wood, mill residues, pulp liq., and forest waste. Primarily used in combined heat and power generation, and direct fuel applications. Williams et al. 2014

Research needs: assess and enhance sustainability of biomass production

Meeting 371 Mt goal with Switchgrass

3 × area of US bioethanol in 2010

4% of global N fertilizer in 2009



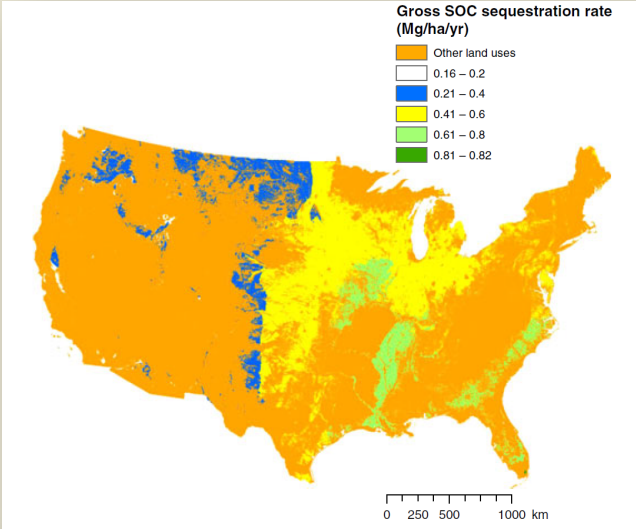
Climatic Change
May 2013, Volume 118, Issue 1, pp 89-103,
Open Access

Date: 06 Feb 2013

Ecological limits to terrestrial biological carbon dioxide removal

Lydia J. Smith, Margaret S. Torn

Planting all US corn-ethanol land with Miscanthus ~ 200 Mt dry biomass

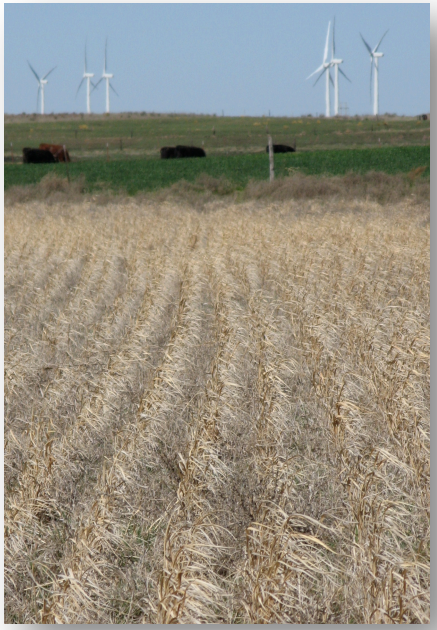


GLOBAL CHANGE BIOLOGY
BIOENERGY
GCB Bioenergy (2013) 5, 391–399, doi: 10.1111/j.1757-1707.2012.01201.x

Miscanthus biomass productivity within US croplands and its potential impact on soil organic carbon

UMAKANT MISHRA*[1], MARGARET S. TORN*‡ and KEVIN FINGERMAN‡[2]
*Earth Sciences Division, Lawrence Berkeley Laboratory, One Cyclotron Rd, 50-4037, Berkeley, CA, 94720, USA, ‡Energy and Resources Group, University of California Berkeley, 310 Barrows Hall, Berkeley, CA, 94720, USA,

Research needs: assess and enhance sustainability of biomass production



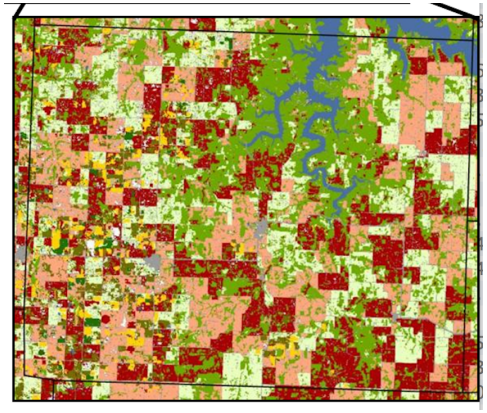
Mitigation analysis needs:

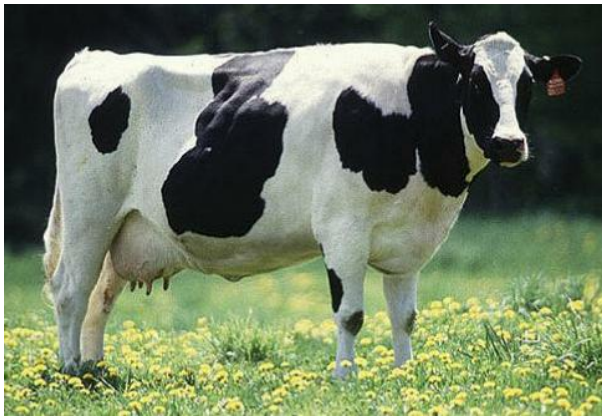
- Amount, type, and cost

Research needs:

- Sustainable production levels
- Sustainable production strategies
- Coordinate w/land use by other sectors
- Efficiently monitoring embedded carbon in bioenergy (cheap Life Cycle Analysis?)

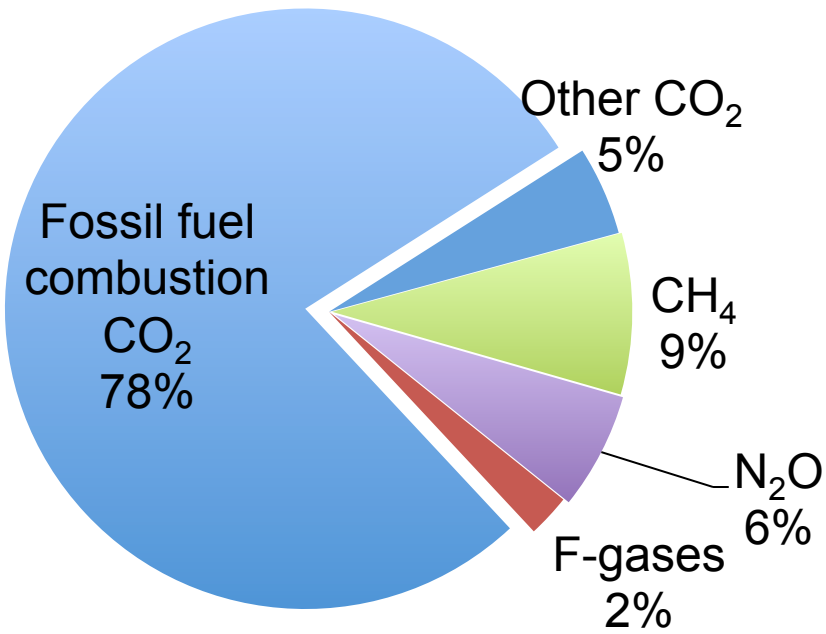
Non-CO_2, non-energy GHGs become increasingly important





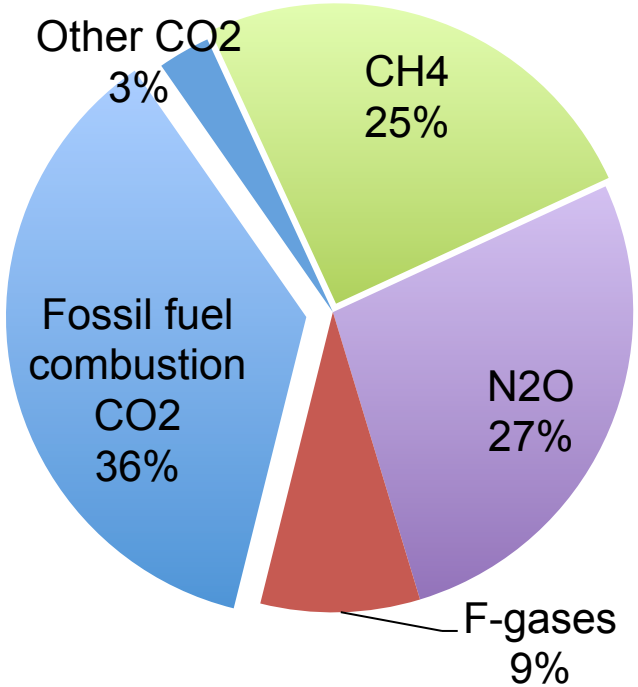
In U.S. Pathways, the fraction of non-CO_2 GHG emissions jumps from **17%** in 2012 to **60%** in 2050

2012 EPA inventory



Energy: 5,066 Mt CO_2e
Non-energy: 1,435 Mt CO_2e

2050 Pathways



Energy: 750 Mt CO_2e
Non-energy: 1,309 Mt CO_2e

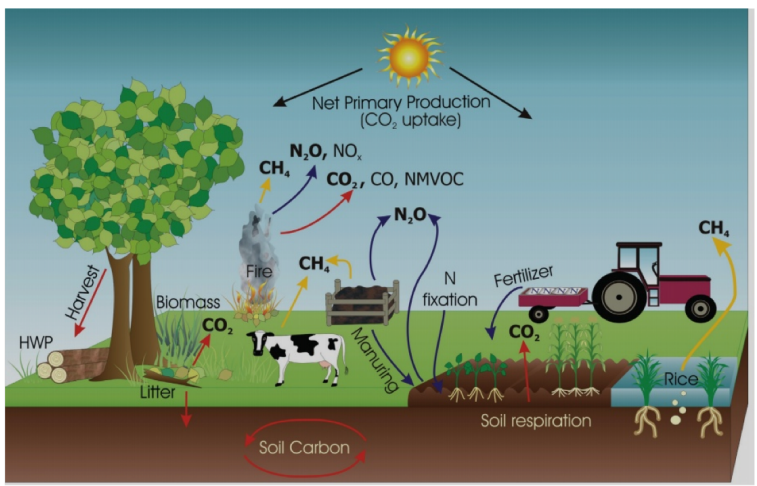
Williams et al. 2014

Non-CO_2, non-energy GHGs could be >50% of emissions in 2050

Because:

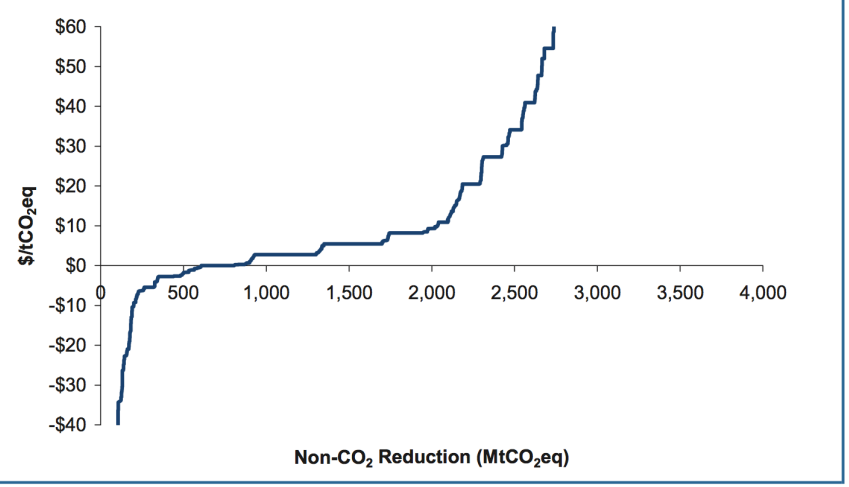
- Supply curve for mitigation gets very steep
- Sources are distributed, variable, and uncertain
- There has been less research on mitigation of non-energy GHGs

Figure 2: Illustration of land uses that result in emissions and removals[9]



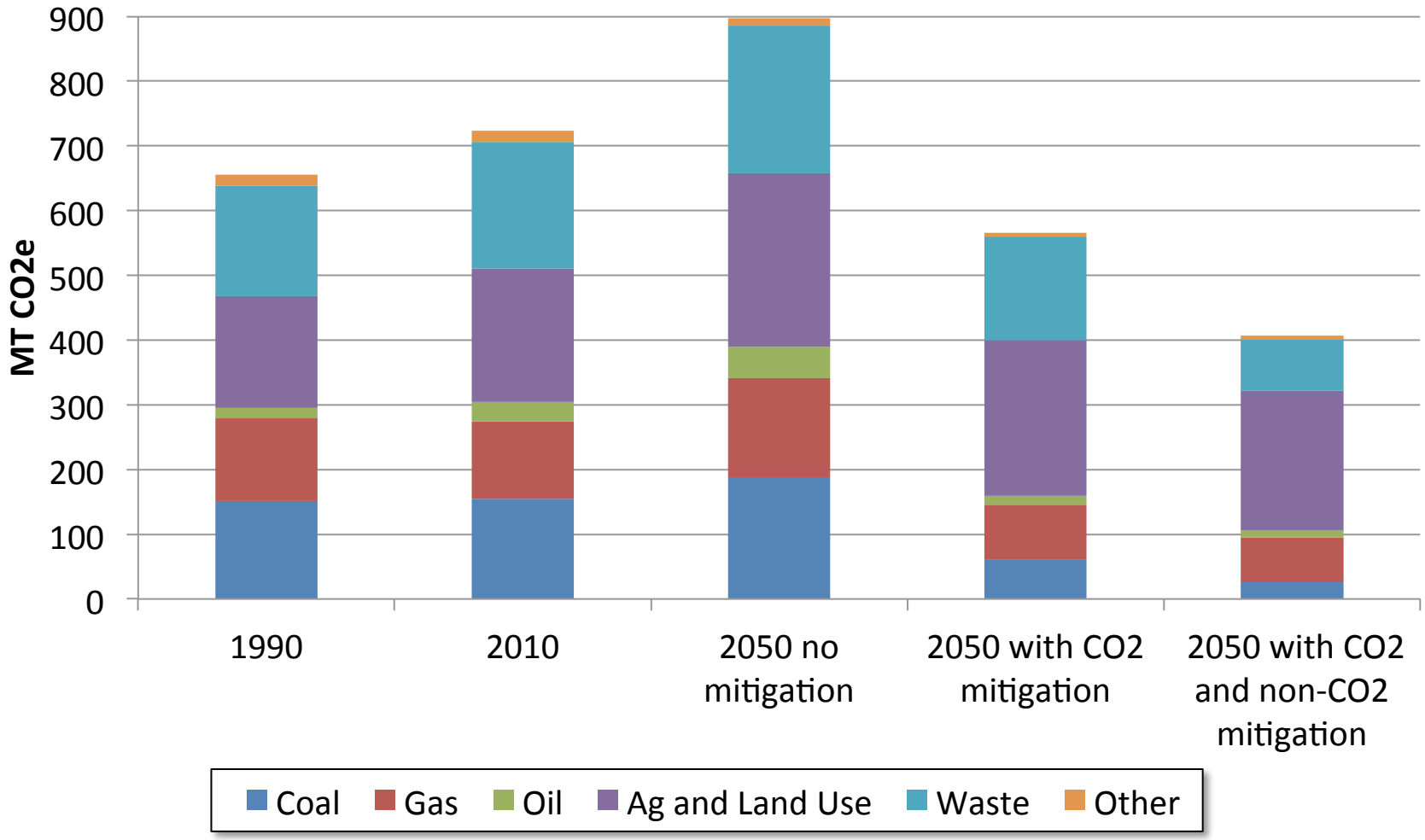
Iversen, Lee, and Rocha. 2014. Understanding Land Use in the UNFCCC.

Figure ES-1: Global Total Aggregate MAC for Non-CO_2 Greenhouse Gases in 2020



EPA. 2006. Global Mitigation of Non-CO2 Greenhouse Gases

CH_4 Emissions



Williams et al. 2014

Fugitive methane emissions

- Need to cut fugitive emissions
- Some will be cut by reduced activity level and by reduced distribution networks
- Need to better estimate fugitive emissions

POLICYFORUM

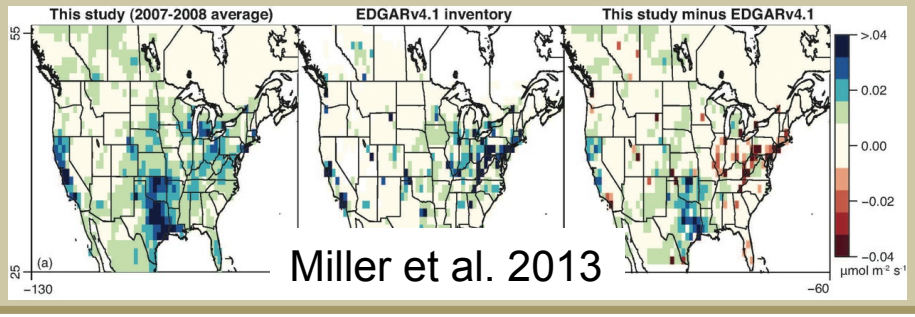
ENERGY AND ENVIRONMENT

Methane Leaks from North American Natural Gas Systems

A. R. Brandt,[1*‡] G. A. Heath,[2] E. A. Kort,[3] F. O'Sullivan,[4] G. Pétron,[5,6] S. M. Jordaan,[7] P. Tans,[5] J. Wilcox,[1] A. M. Gopstein,[8†] D. Arent,[2,9] S. Wofsy,[10] N. J. Brown,[11] R. Bradley,[12] G. D. Stucky,[13] D. Eardley,[13] R. Harriss[14]

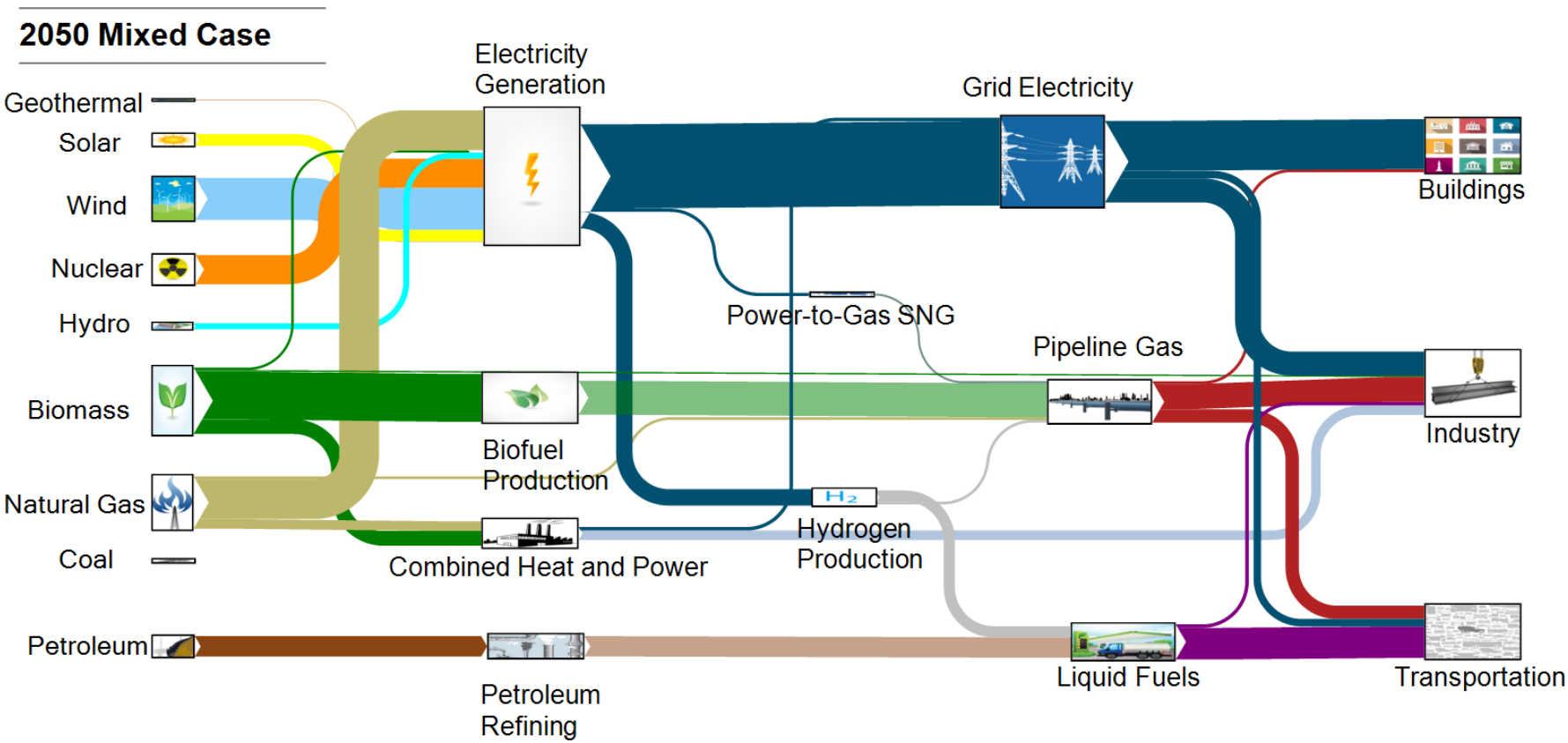
Methane emissions from U.S. and Canadian natural gas systems appear larger than official estimates.

EPA and EDGAR inventories underestimate anthropogenic CH_4 emissions by 1.5-1.7x.



Miller et al. 2013

The transformation of the energy system presents new challenges to Monitoring and Verification

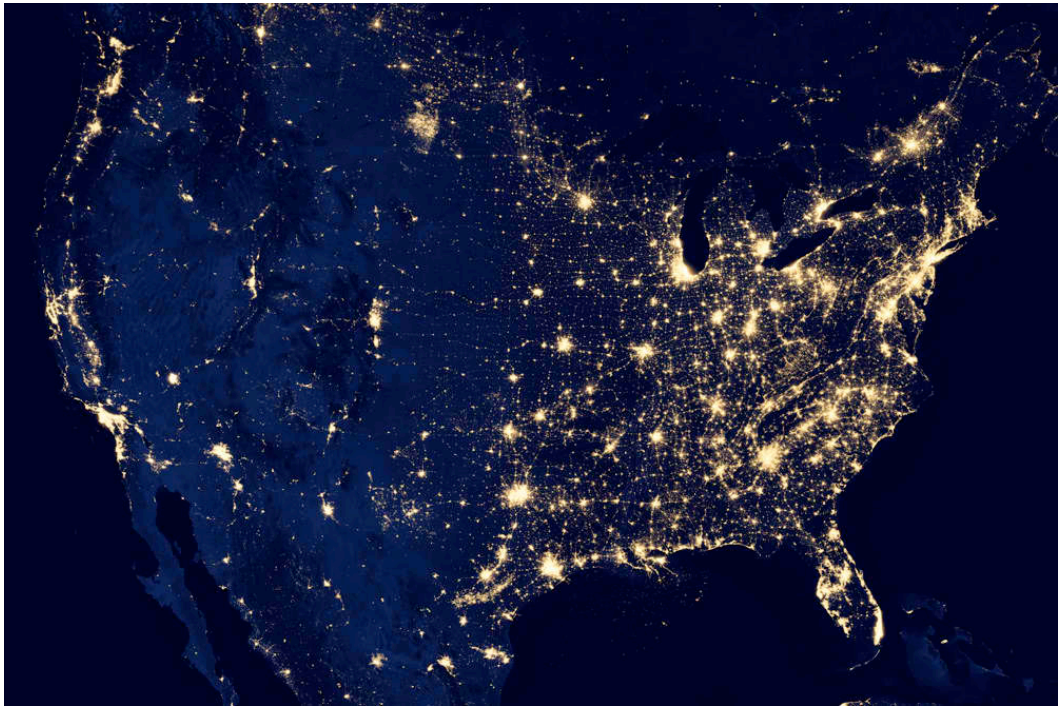


Williams et al. 2014

Fuel Switching: electrification

Light duty vehicles
Buildings
Industry

10^9 points of combustion in 2010
10^6 in 2050?
10^3 in 2070?



Lights from Space, 2012
NASA Suomi NPP satellite

U.S. in 2010

2 x 10^3 Power Plants

230 x 10^6 cars and trucks

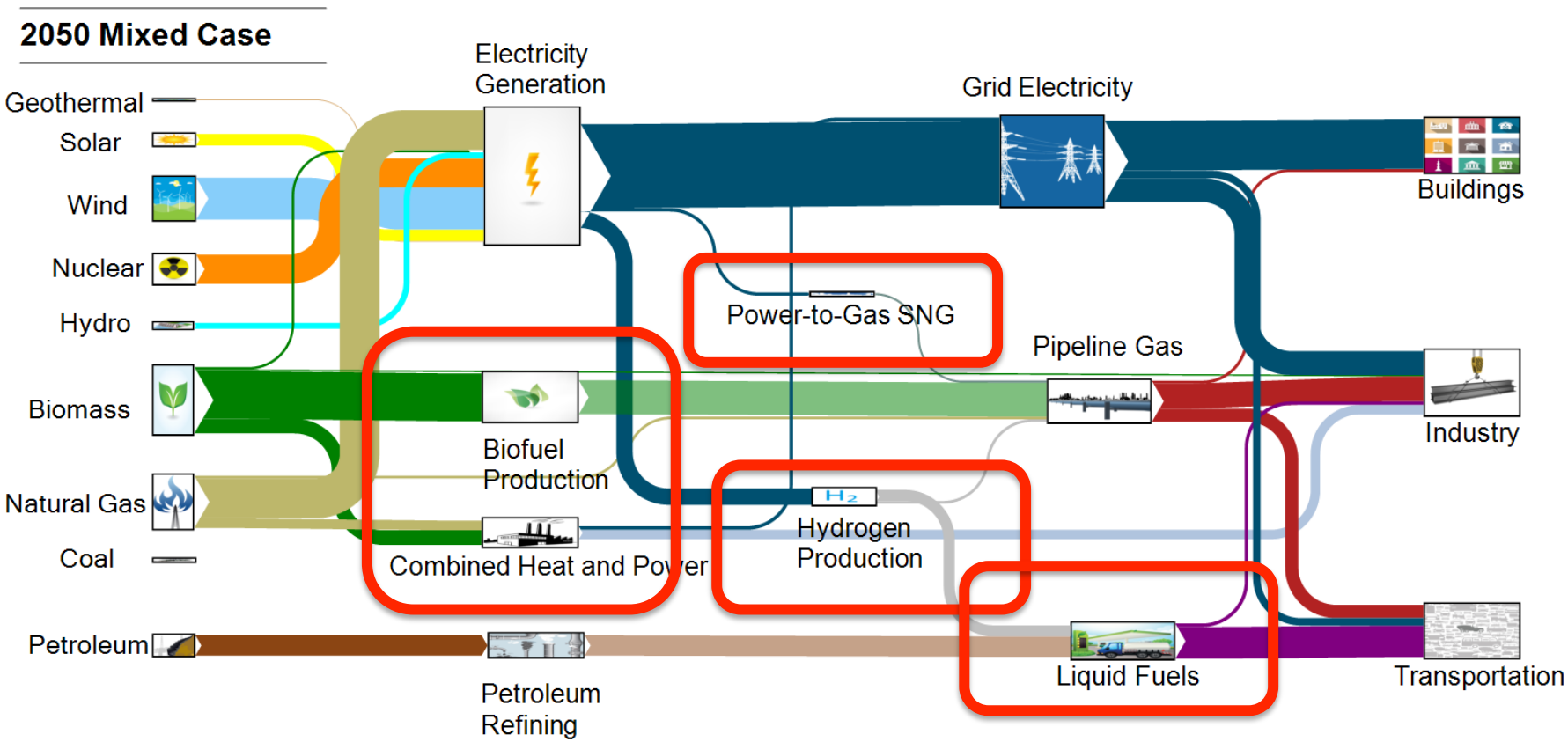
5 x 10^6 Industrial boilers

Residential&Commercial:

- Water Heaters
- Space heaters
- Food preparation

Torn/NACP/2015

C-neutral fuels
Life cycle analysis

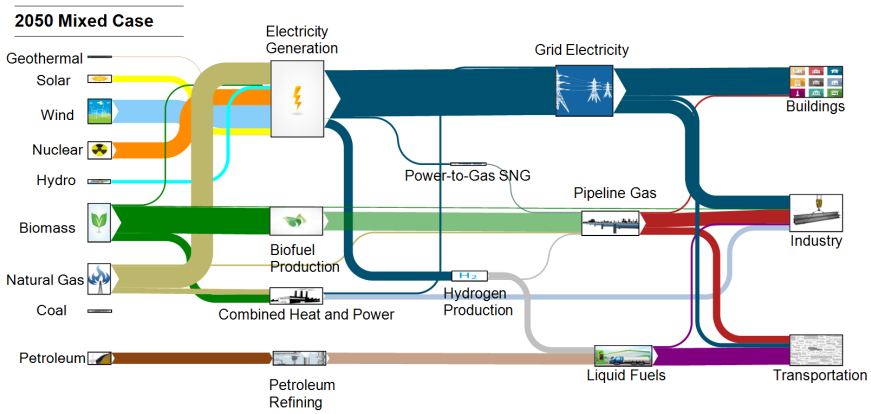


Williams et al. 2014

Implications of having fewer points of combustion and more C-neutral fuels

- Fewer emission sources. Most CO_2 release is net-carbon-neutral.
- There is a signal:noise challenge for attributing CO_2 to fossil fuels, because of net-neutral CO_2 emissions, and the offset is far away.
- Large fraction of pipeline methane may be net-carbon neutral

- **^{14}C becomes critical for attribution.**
- **^{13}C utility decreases because of multiple pipeline gas sources**
- **Life cycle analysis needed to verify carbon-neutrality**



Torn/NACP/2015

Deep decarbonization poses new challenges for Monitoring and Verification

M&V Goal 1. Verify that everyone is playing by the rules.
What is new/different: In the Deep Decarbonization case, emphasis on tracking infrastructure, rather than activity

M&V Goal 2. Monitor and attribute fossil (or net-CO2) emissions.
What is new/different: Fewer sources, more are carbon-neutral.
^{14}C more important, ^{13}C less important relative to today.
More Life cycle analysis to track net-zero emissions.

M&V Goal 3. Monitor other anthropogenic emissions.
What is new/different: Increased emphasis on fugitive emissions (pipeline and CCS) and non-energy emissions

M&V Goal 4. Quantify & attribute change in atmospheric GHGs
What is new/different: Attribution will take place at larger scales because energy system more interconnected. Will it make sense to monitor cities?

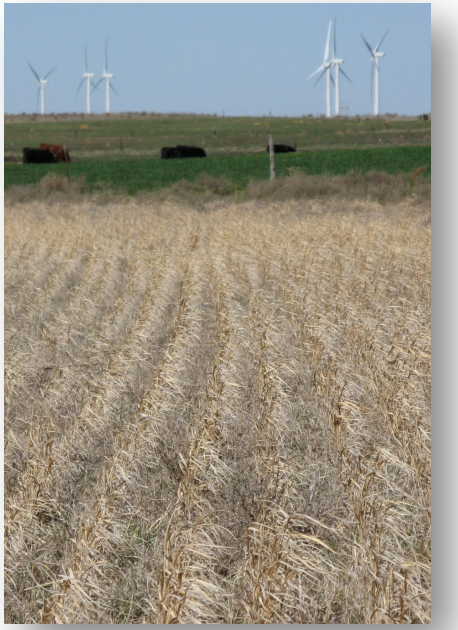
Take Home Messages: U.S. Deep Decarbonization and Carbon Cycle Implications

- It is technically feasible to reduce U.S. GHG emissions by 80% below 1990 by 2050, while supporting economic growth and services

- This transformation of the U.S. energy system requires contributions from carbon cycle science and new approaches to monitoring & verification.
  - Carbon Sink is pivotal but uncertain (LULUCF)
  - Biomass fills critical energy needs
  - Non-CO_2 GHGs will be larger fraction of emissions
  - Monitoring and verification must address infrastructure change, fuel switching, net-zero fuels

Take Home Messages: U.S. Deep Decarbonization and Carbon Cycle Implications

Research needed for prediction, management, monitoring, and verification



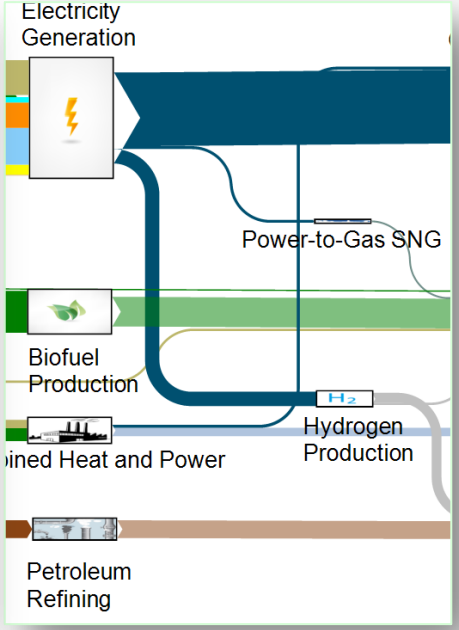
Bio-Energy

LBL-USDA switchgrass expt.
M. Torn

LULUCF

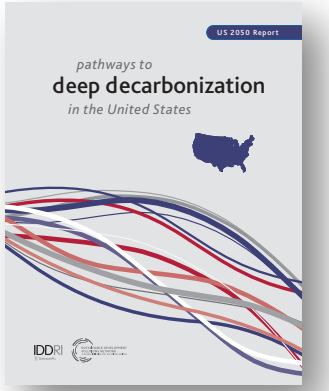
UMBS AmeriFlux site
C. Gough

Non-CO_2 GHGs



Infrastructure

Thank you



Report available at http://unsdsn.org