Life Cycle Implications of Using CO_2-Based Fracturing Fluids as a Substitute for Slickwater

To reduce the carbon and water intensity of unconventional oil and gas

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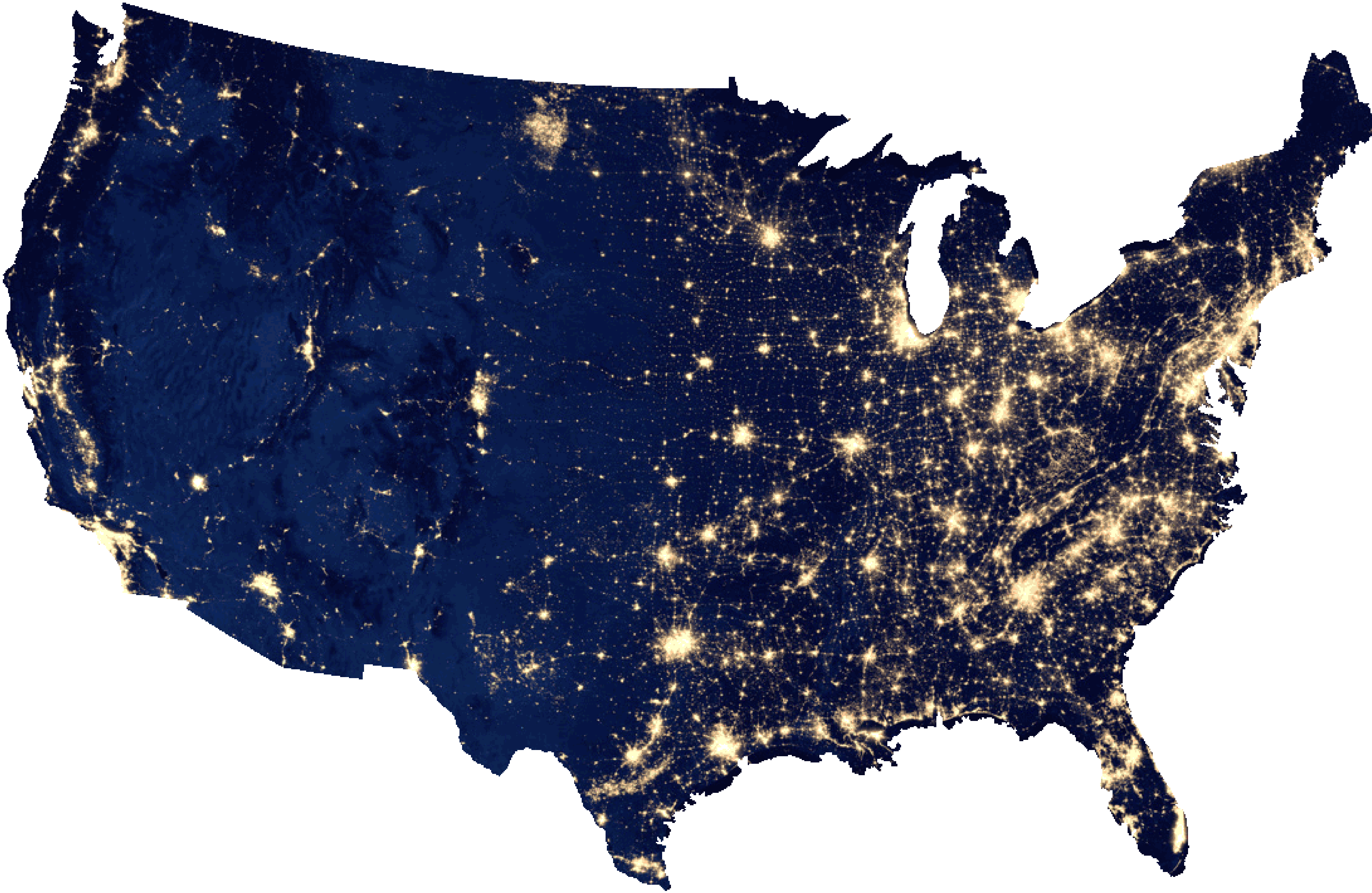
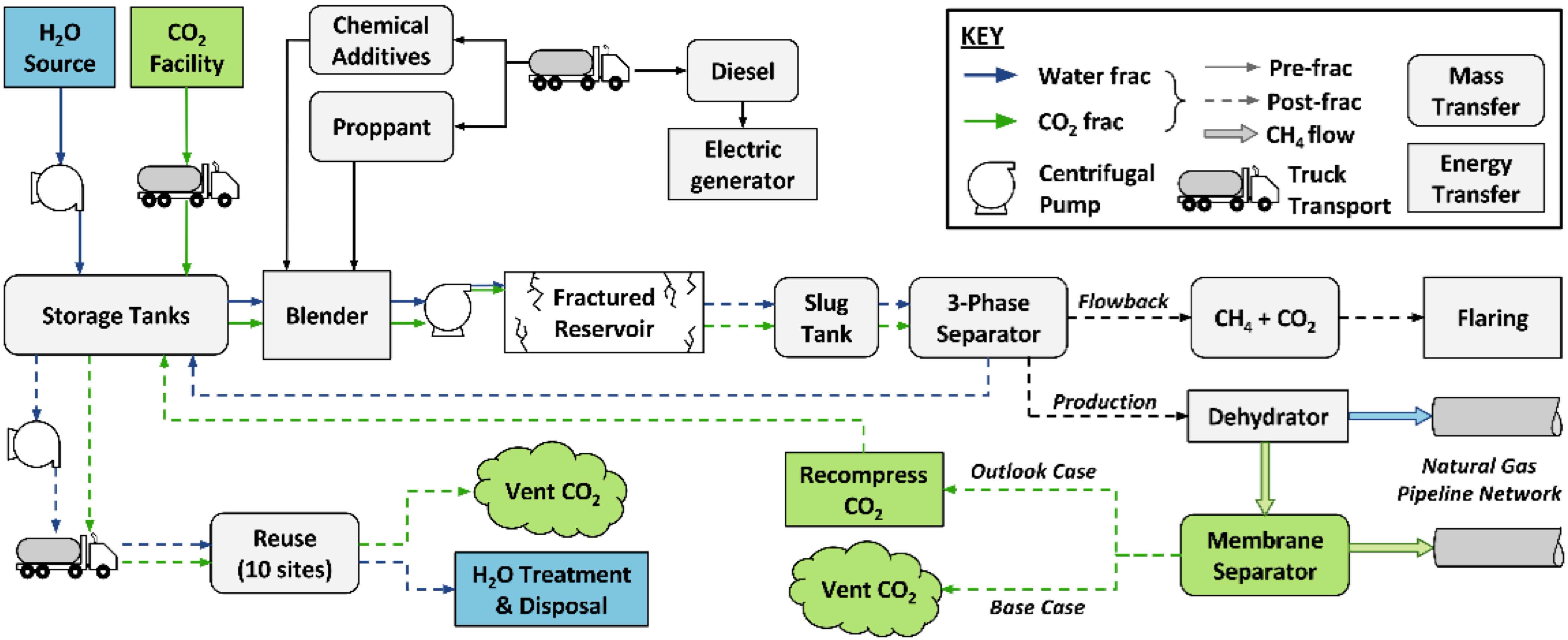
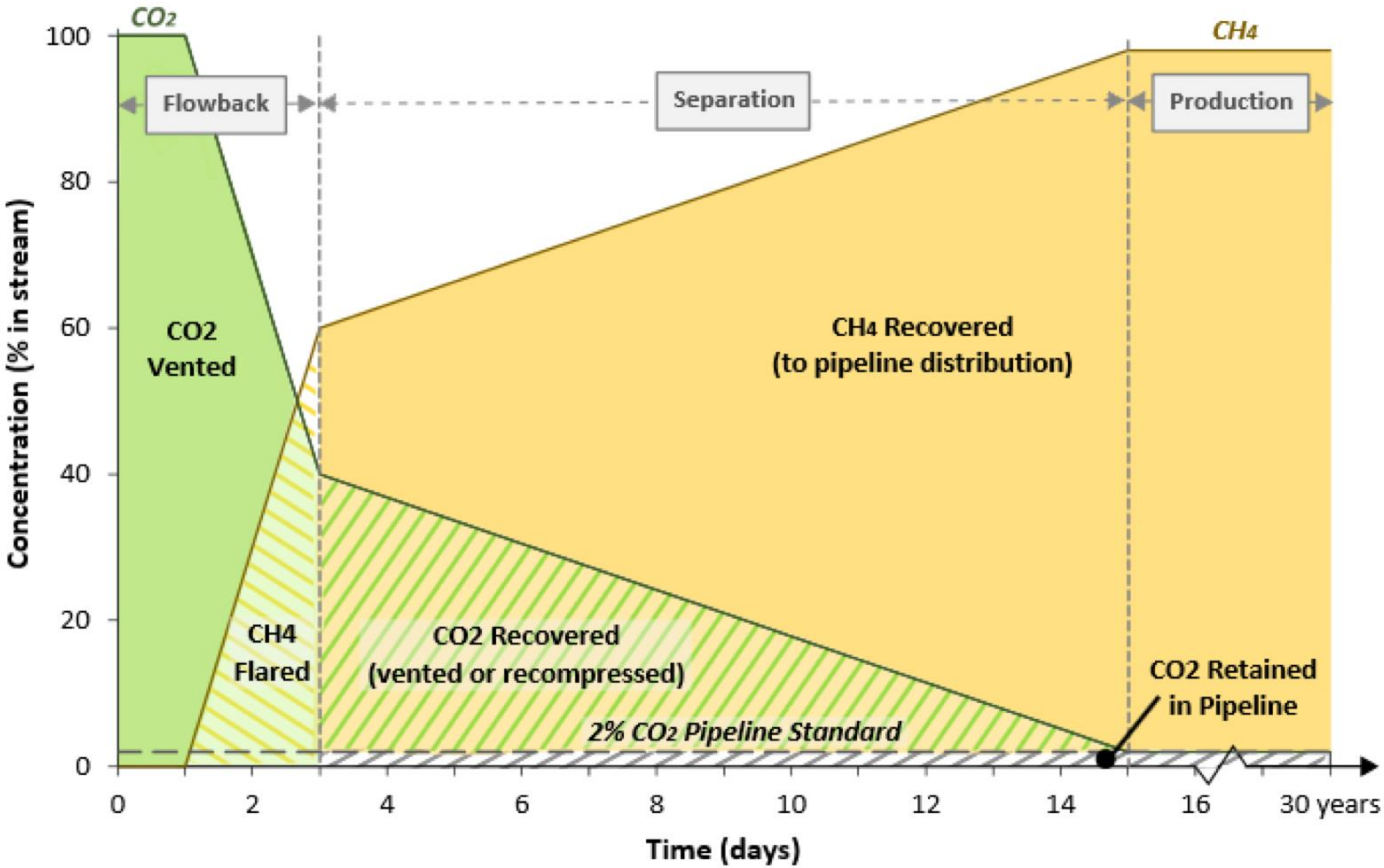
University of Virginia



LCA system boundaries



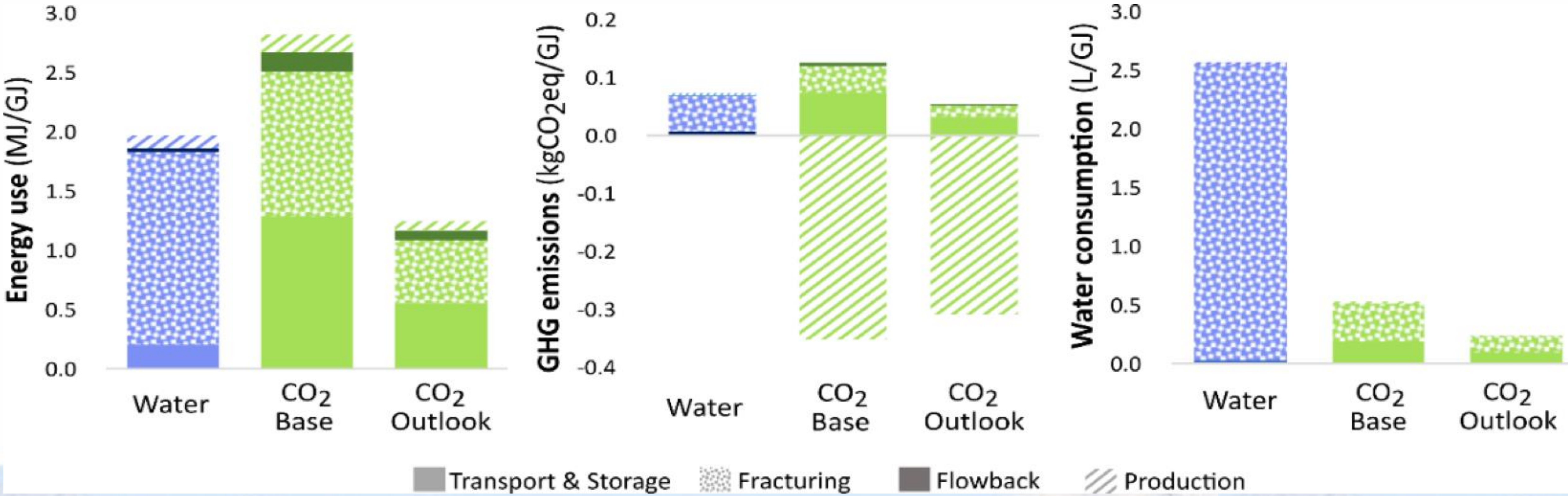
CO_2/CH_4 flow profiles



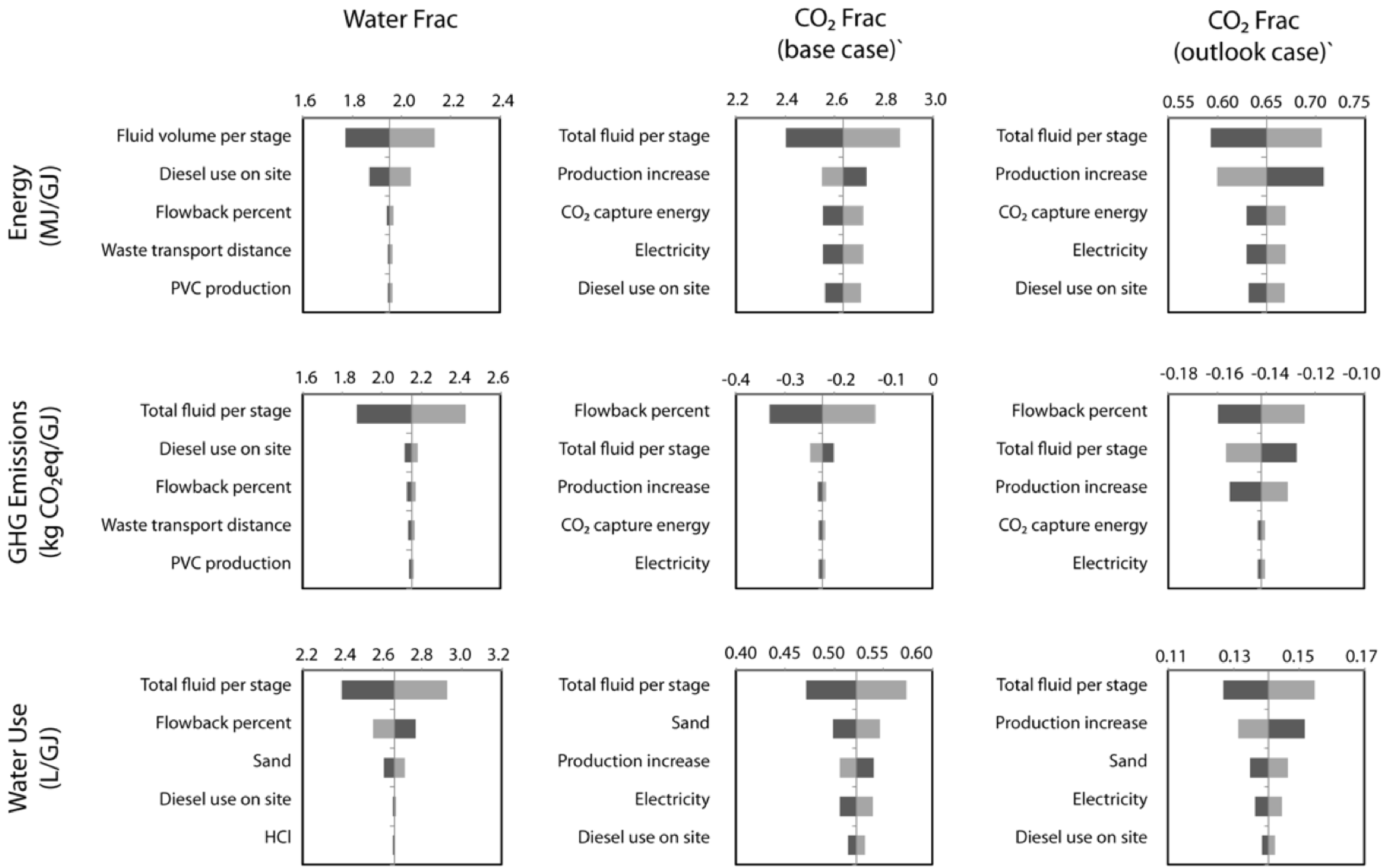
Major inputs

Input	Units	Water frac	CO_2 frac, base	CO_2 frac, outlook
Estimated ultimate recovery (EUR)	GJ	4.98E+06	7.64E+06	2.67E+07
Production increase factor (PIF)	%	--	50 (0-110)	200 (50-1340)
Total fluid volume per well	m^3	9.09E+04	6.36E+04	6.04E+04
Volume of gas flared	m^3	1.03E+04	1.68E+05	1.60E+05
Flowback (% of injected fluid)	%	7 (4-47)	70 (50-90)	50 (10-90)
Produced water volume per well	m^3	1.76E+04	--	--
Truck trips per well	--	1206	3269	3036
Diesel fuel consumption	m^3	626	985	950
CO_2 compression energy (source)	MJ/tCO^2	--	241 (72-285)	241 (72-285)

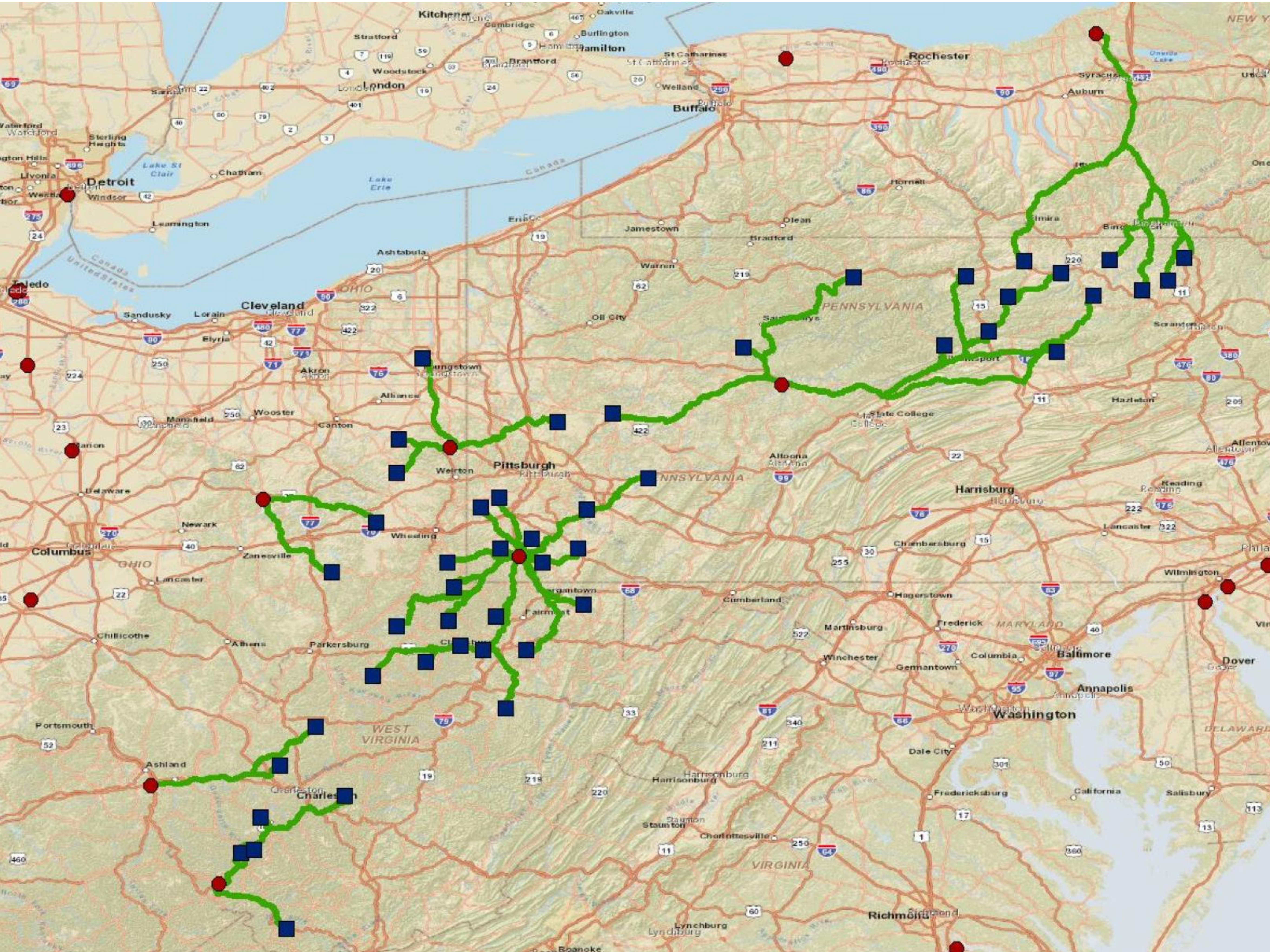
results



Energy use (MJ/GJ)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Water
CO2 Base
CO2 Outlook
GHG emissions (kgCO2eq/GJ)
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
Water
CO2 Base
CO2 Outlook
Water consumption (L/GJ)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Water
CO2 Base
CO2 Outlook
Transport & Storage
Fracturing
Flowback
Production

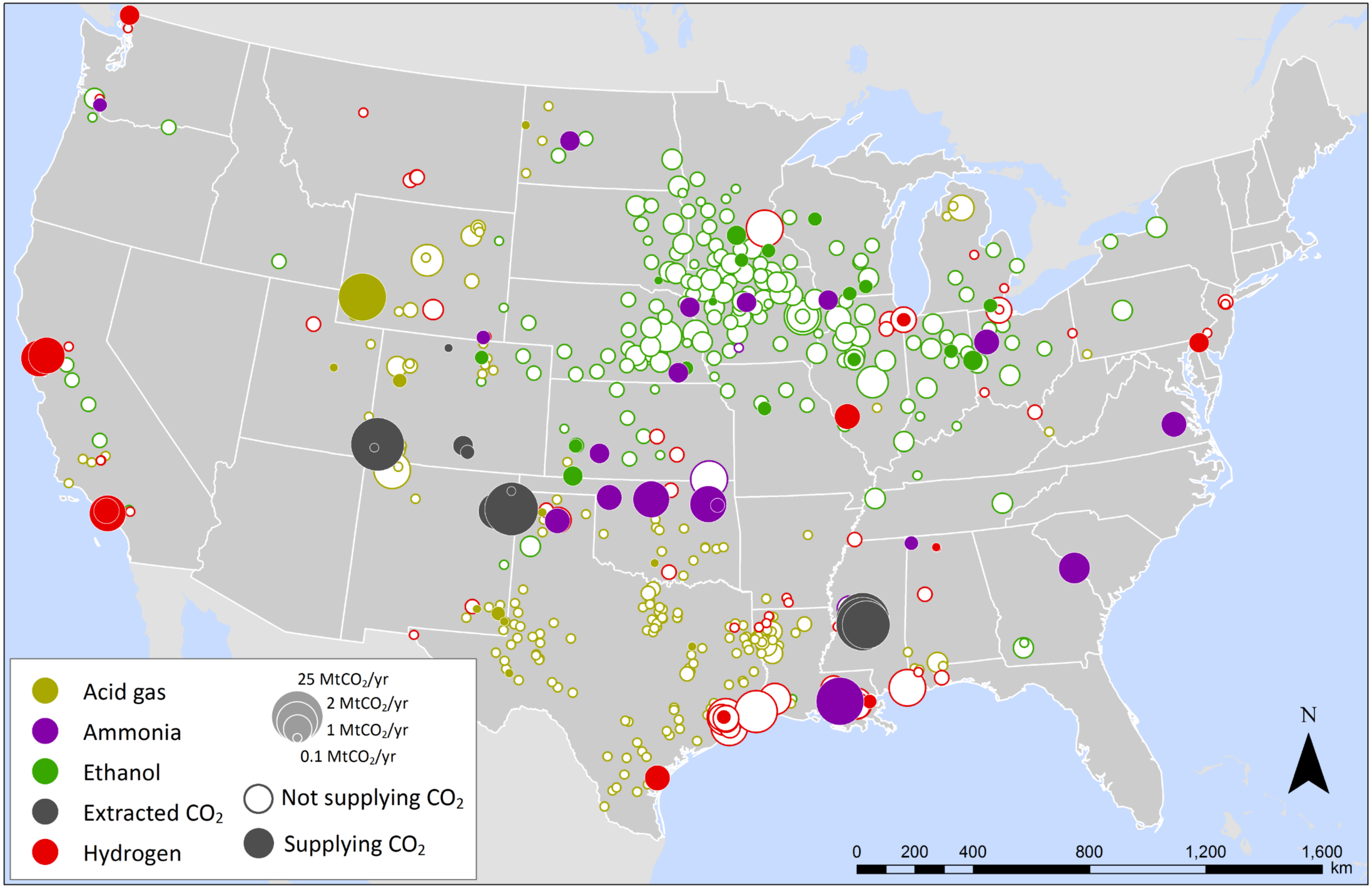


R Wilkins, AH Menefee, AF Clarens (2016)
Environmental science & technology 50 (23), 13134-13141

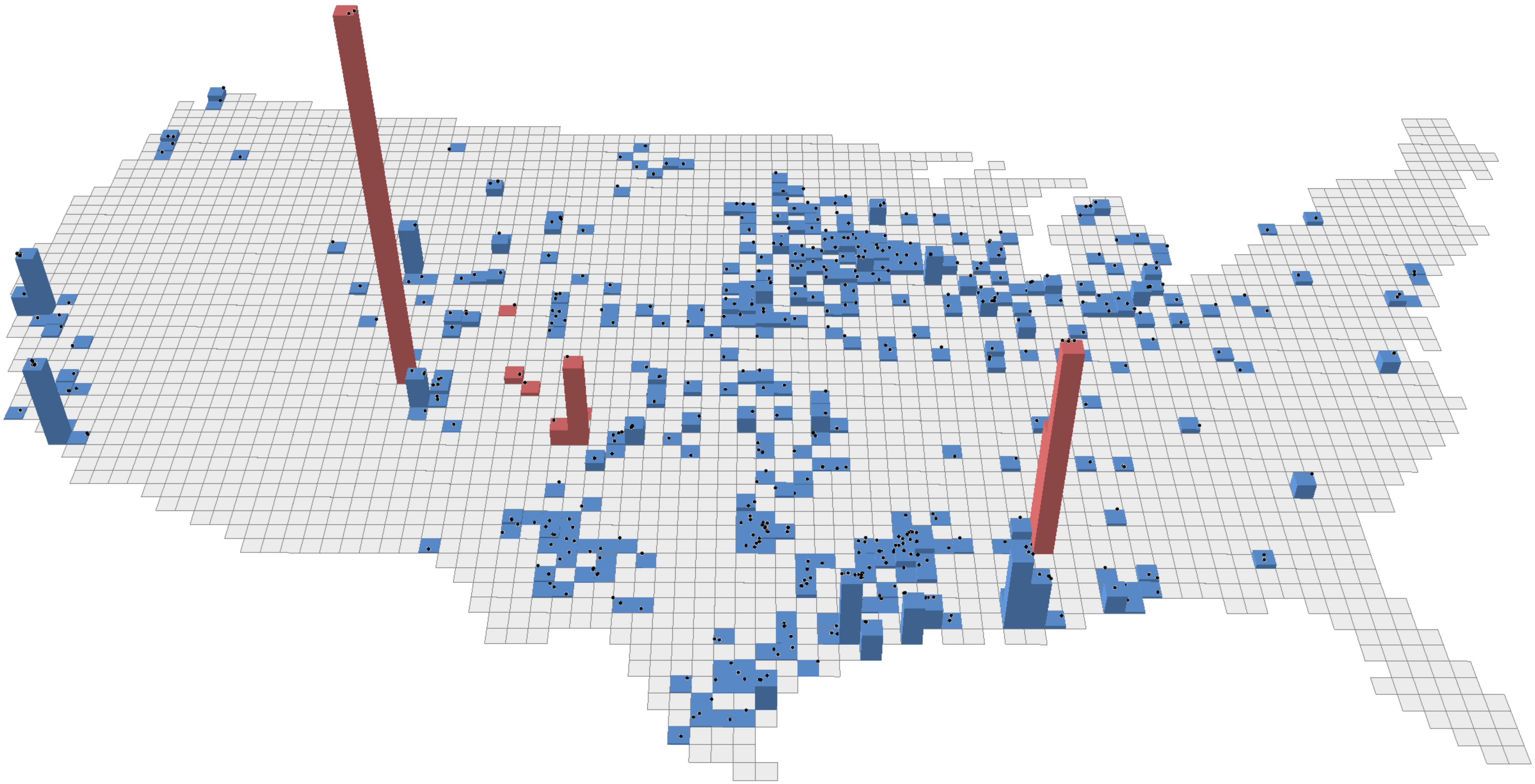


Kitchener
Cambridge
Stratford
Burlington
Hamilton
Oakville
Brantford
Woodstock
London
St Catharines
Welland
Buffalo
Rochester
Syracuse
Auburn
Oneida Lake
Detroit
Windsor
Livonia
Sterling Heights
Waterford
Chatham
Leamington
Lake St Clair
Lake Erie
Toledo
Sandusky
Lorain
Elyria
Cleveland
Ashtabula
Erie
Jamestown
Olean
Bradford
Warren
Hornell
Elmira
Binghamton
Scranton
Oil City
St Marys
PENNSYLVANIA
Williamsport
State College
Hazleton
Allentown
Reading
Harrisburg
Lancaster
Altoona
Akron
Youngstown
Alliance
Canton
Wooster
Mansfield
Marion
Delaware
Newark
Columbus
OHIO
Zanesville
Lancaster
Chillicothe
Athens
Parkersburg
Weirton
Pittsburgh
Wheeling
Morgantown
Fairmont
Cumberland
Hagerstown
Chambersburg
Frederick
MARYLAND
Martinsburg
Winchester
Germantown
Columbia
Baltimore
Annapolis
Washington
Dale City
Wilmington
Dover
DELAWARE
Salisbury
California
Fredericksburg
Harrisonburg
Staunton
Charlottesville
VIRGINIA
Richmond
Lynchburg
Roanoke
WEST VIRGINIA
Charleston
Ashland
Portsmouth

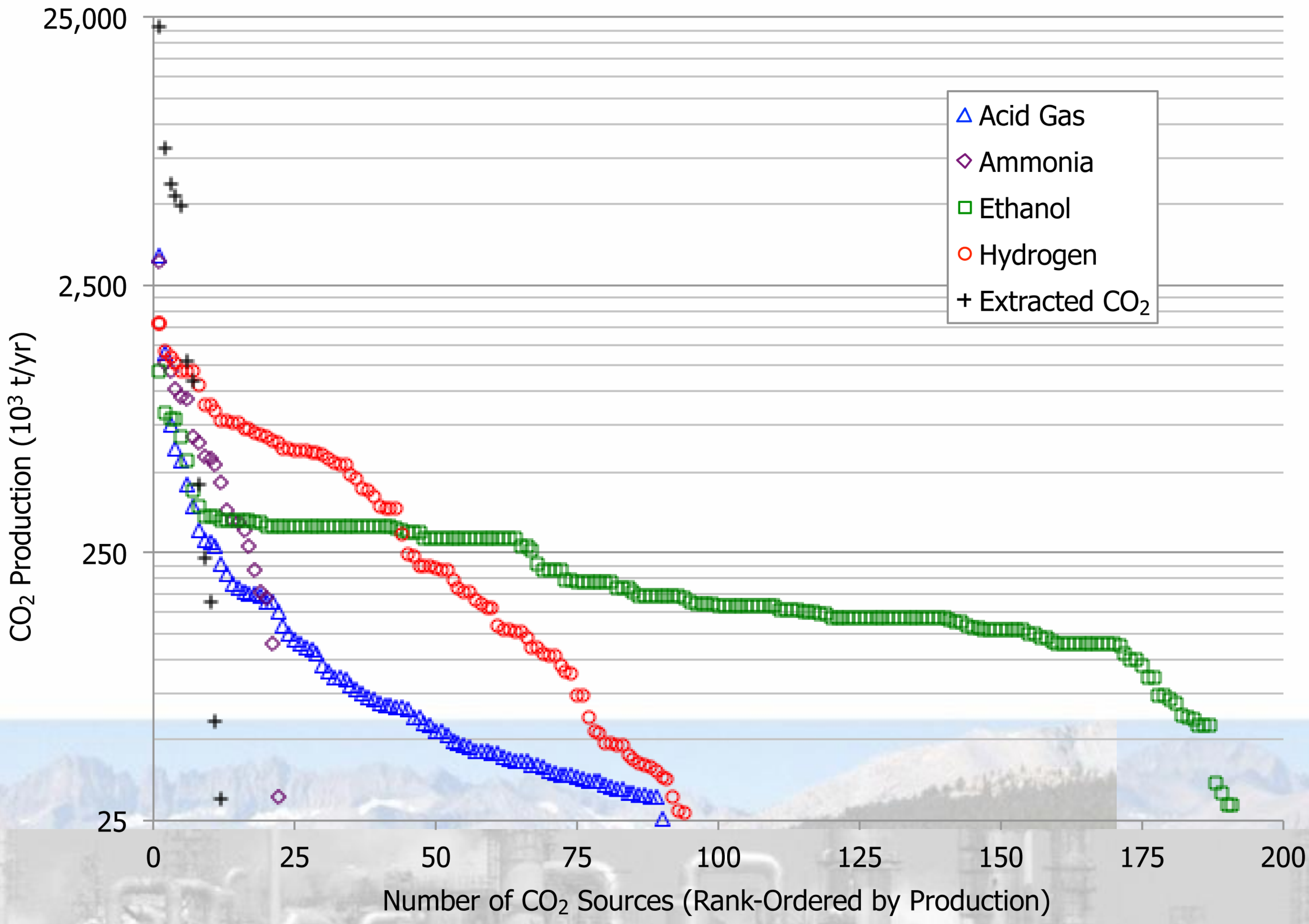
sources of CO_2 (from currently capturable sources)



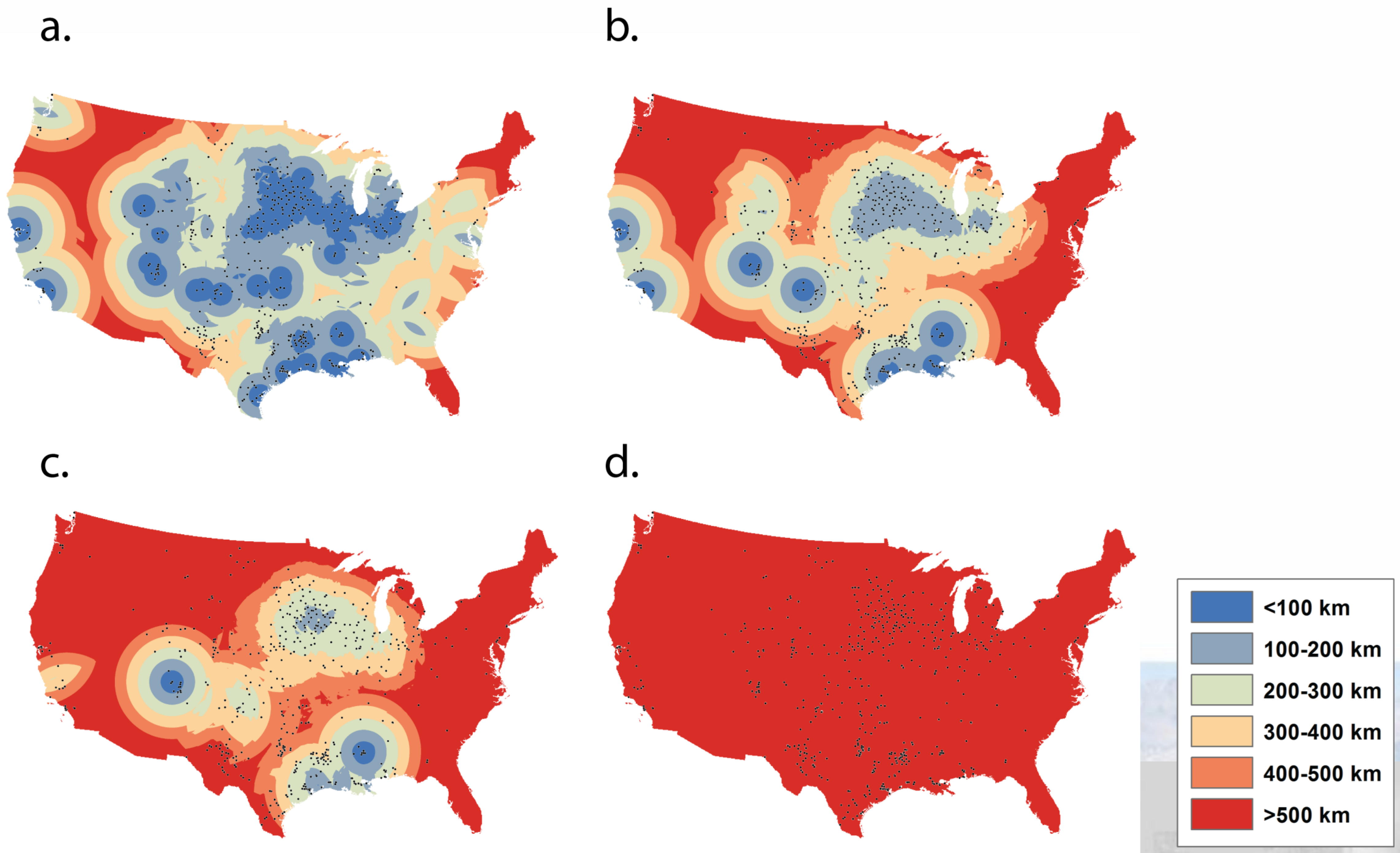
sources of CO_2



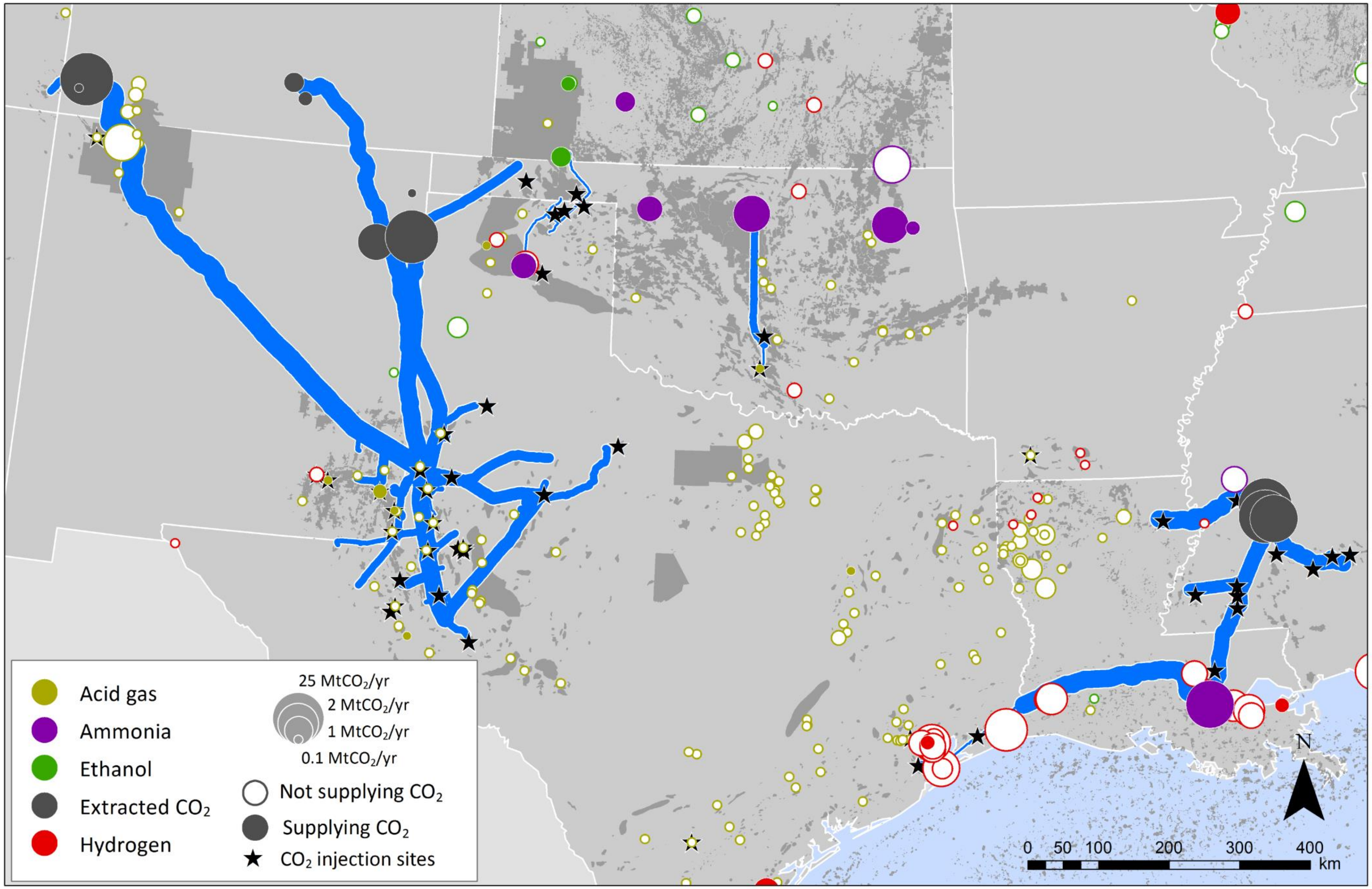
size distribution of the industry



CO_2 deserts

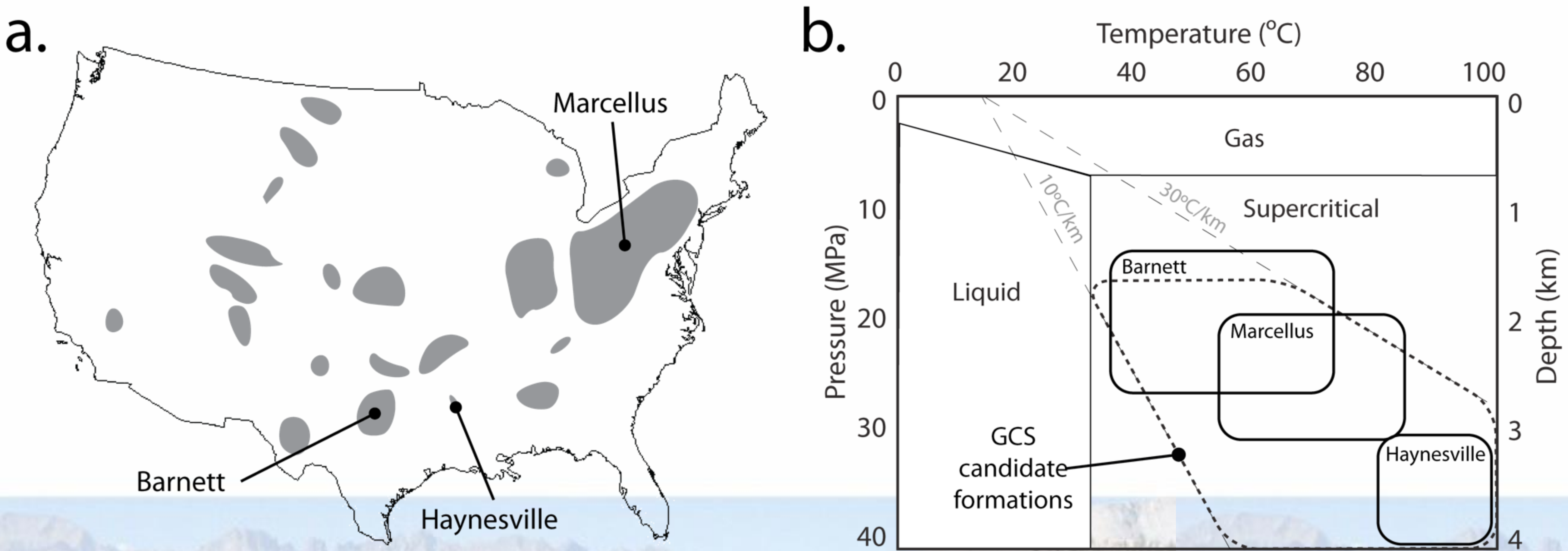


regional implications of CO_2 availability

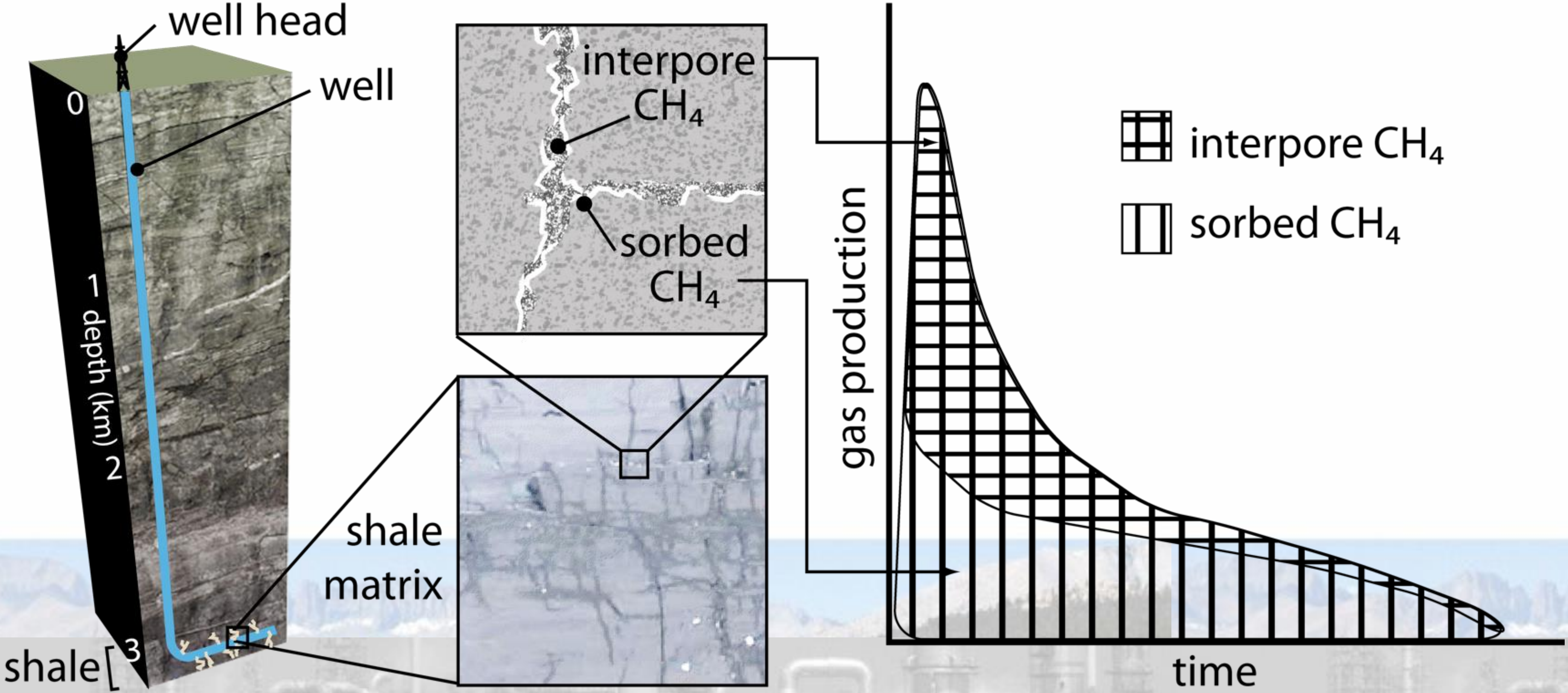


RS Middleton, AF Clarens, X Liu, JM Bielicki, JS Levine (2014)
Environ. Sci. Technol 48 (19), 11713-11720

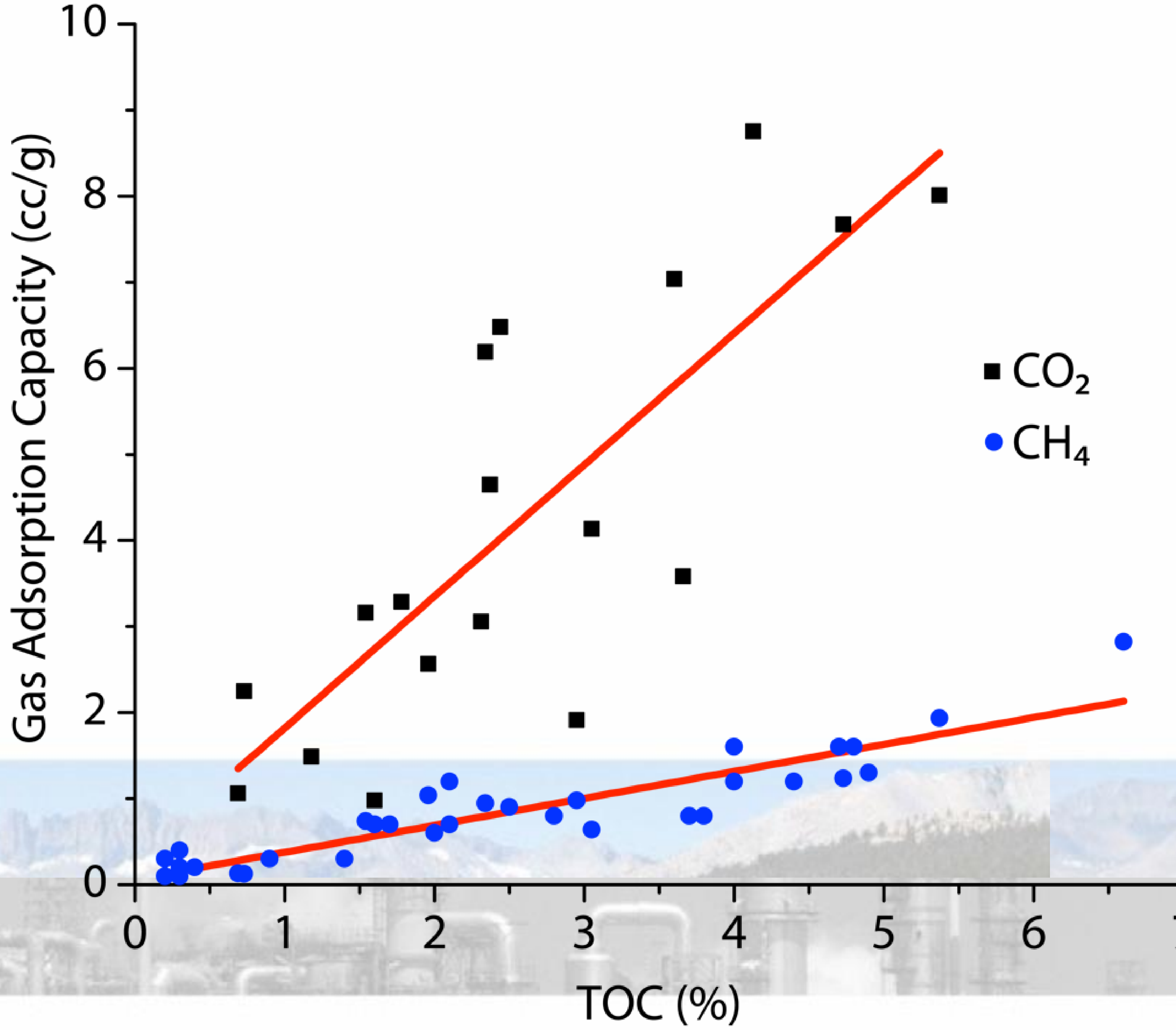
shale formations v. deep saline aquifers



only a fraction of methane in shale matrix is sorbed



sorption on shales a function of TOC



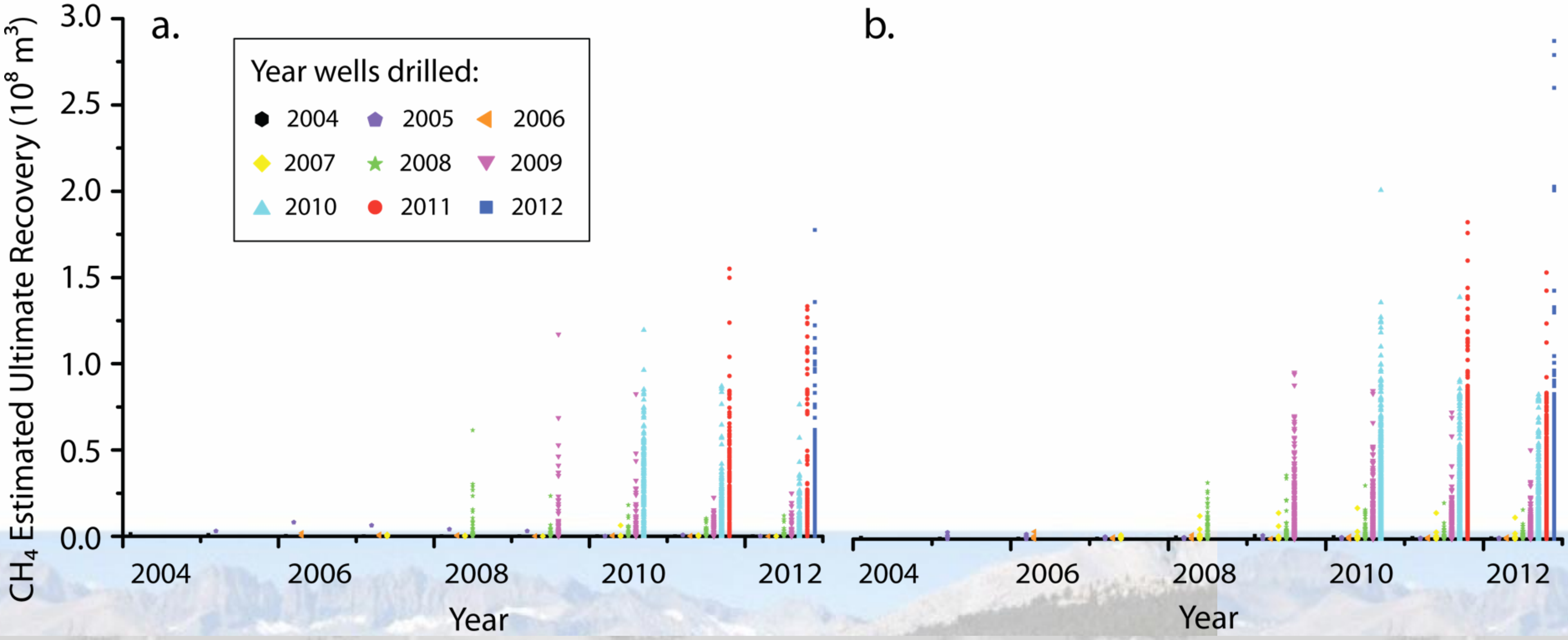
unipore model for gas transport in kerogen

$$\frac{D}{r^2}\frac{\partial}{\partial r}(r^2\frac{\partial C}{\partial r}) = \frac{\partial C}{\partial t}$$

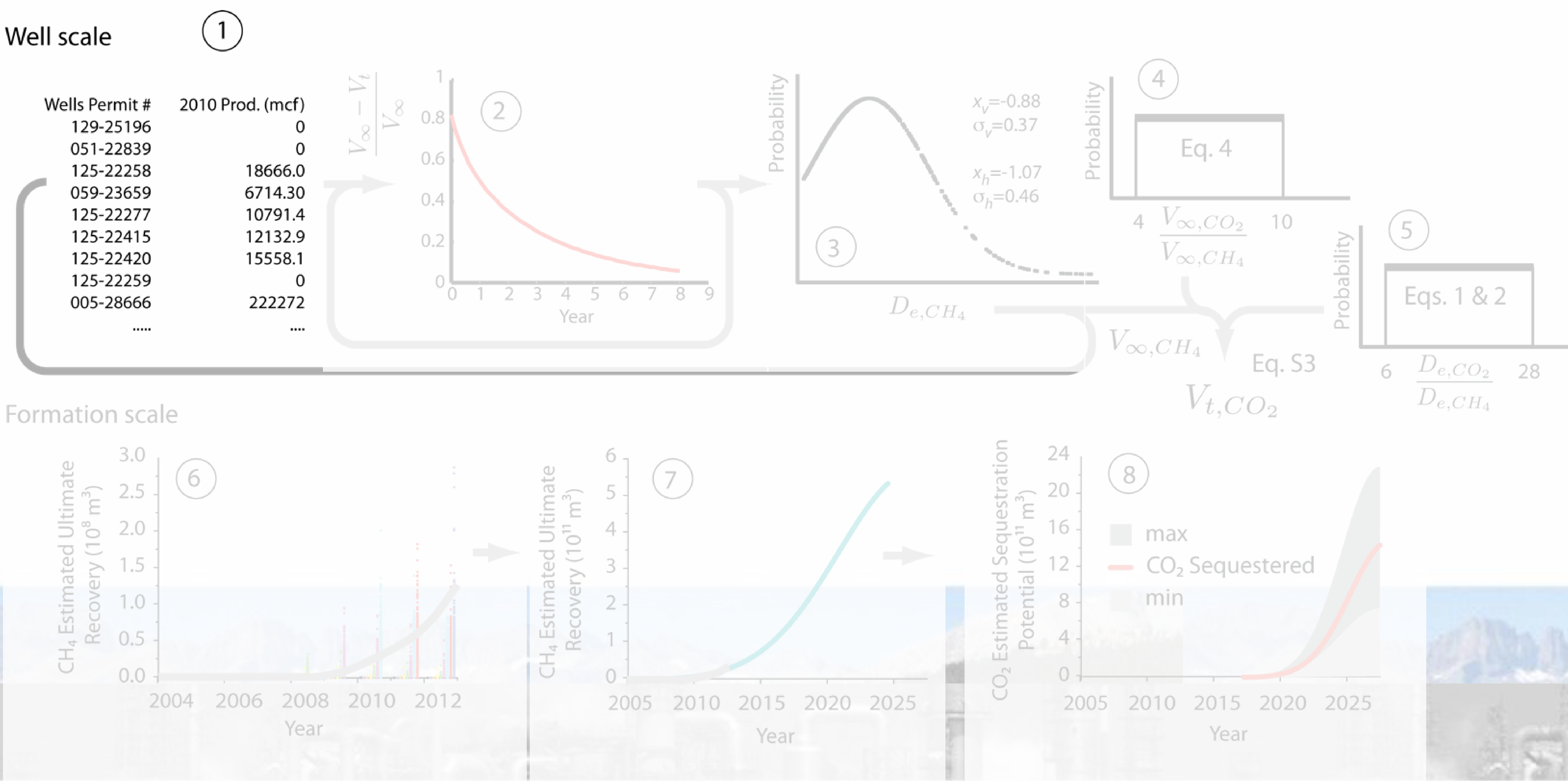
$$\frac{V_t}{V_\infty} = 1 - \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp(\frac{-n^2 D\pi^2 t}{r_p^2})$$

$$D_{e,CH_4} = \frac{D_{CH_4}\pi^2}{r_p^2}$$

model contains three independent parameters

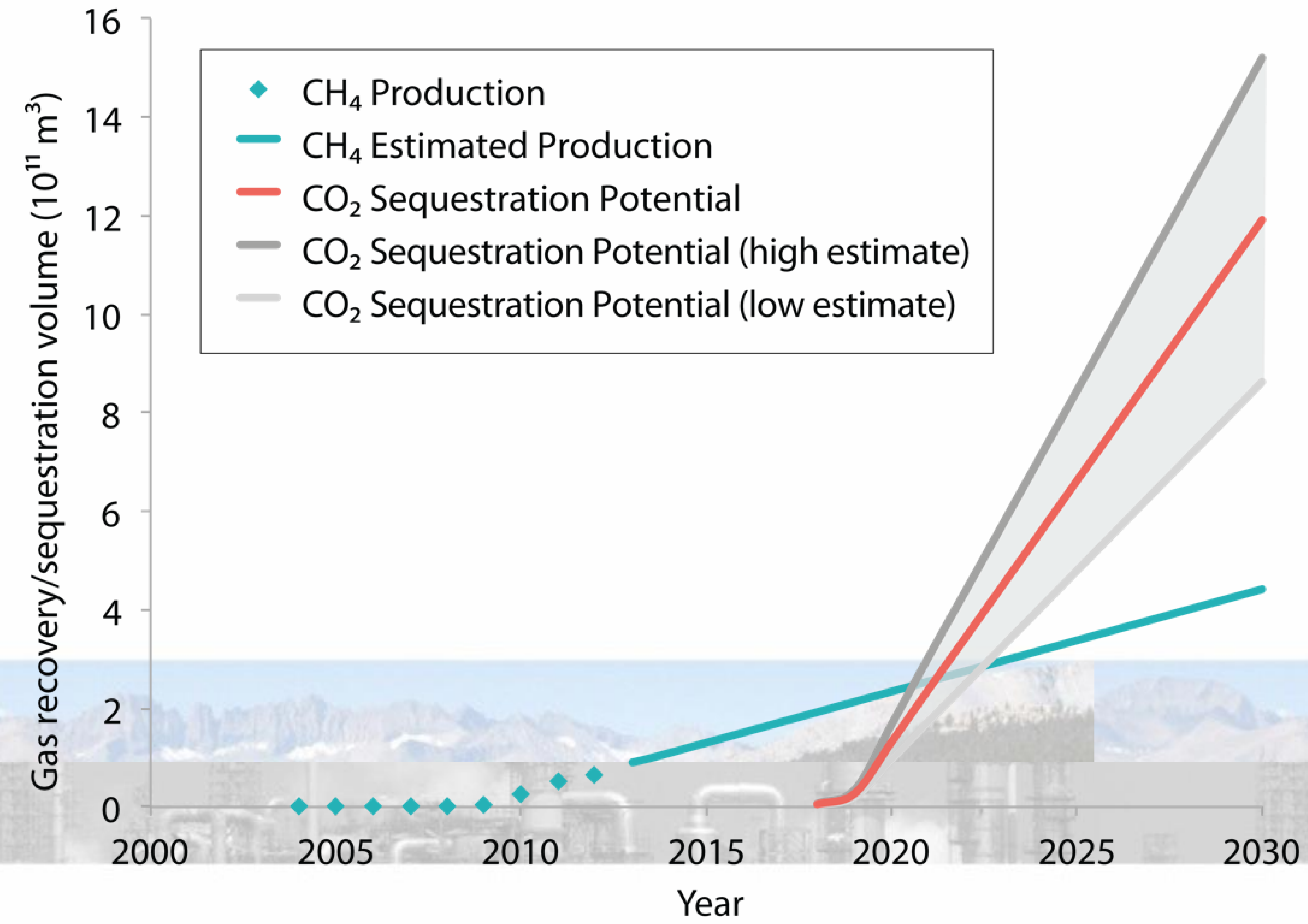


model architecture



Wells Permit #	2010 Prod. (mcf)
129-25196	0
051-22839	0
125-22258	18666.0
059-23659	6714.30
125-22277	10791.4
125-22415	12132.9
125-22420	15558.1
125-22259	0
005-28666	222272
.....	....

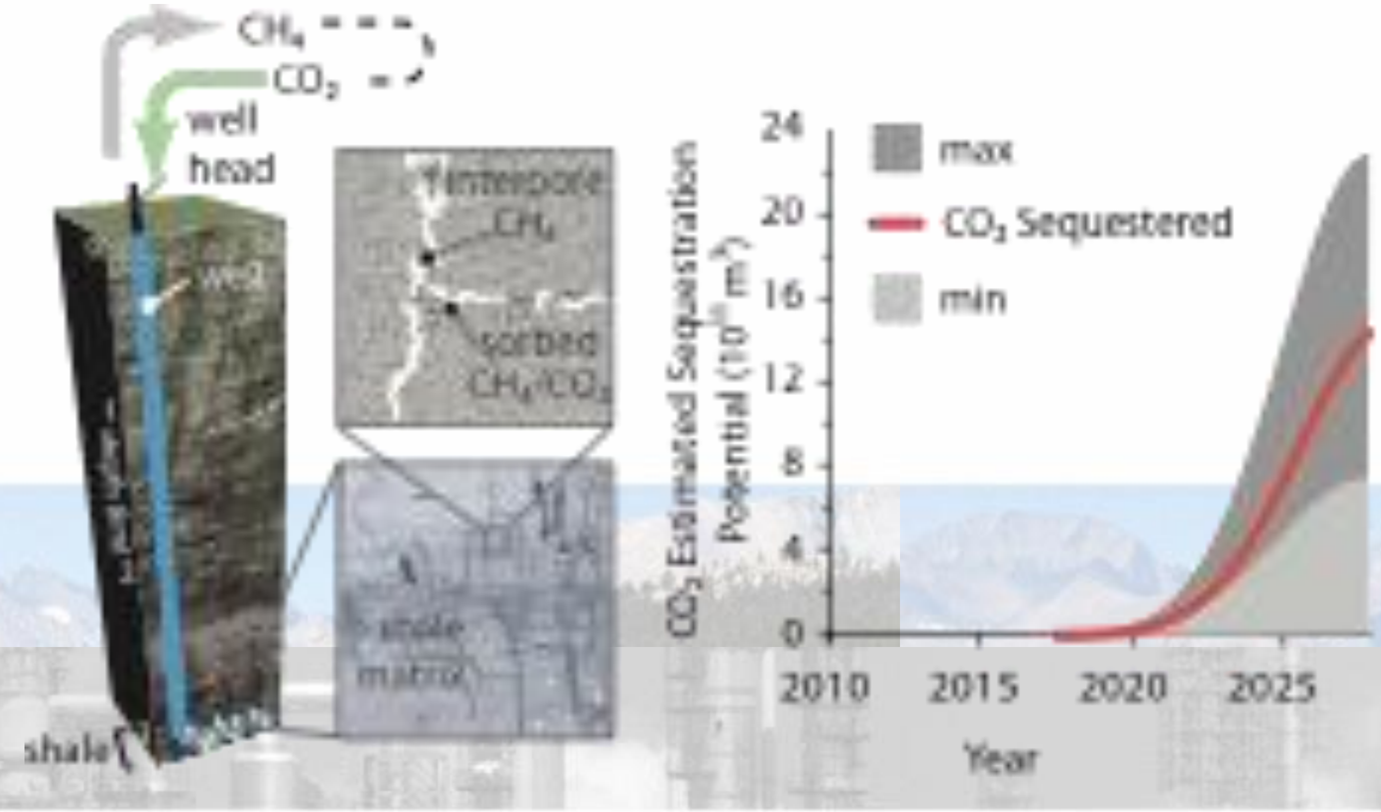
model results



sequestration capacity in context

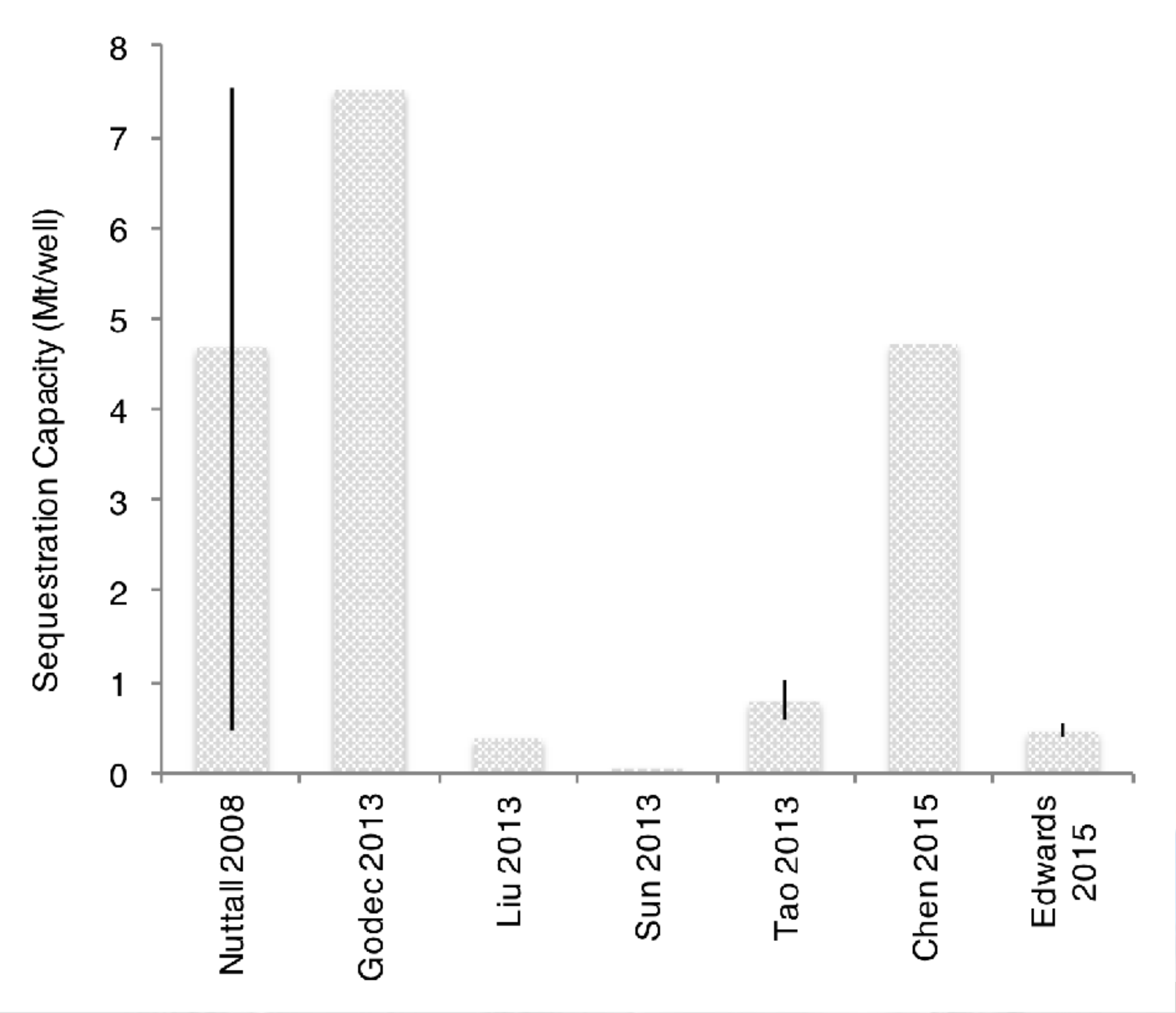
2.2 Gt CO_2/yr

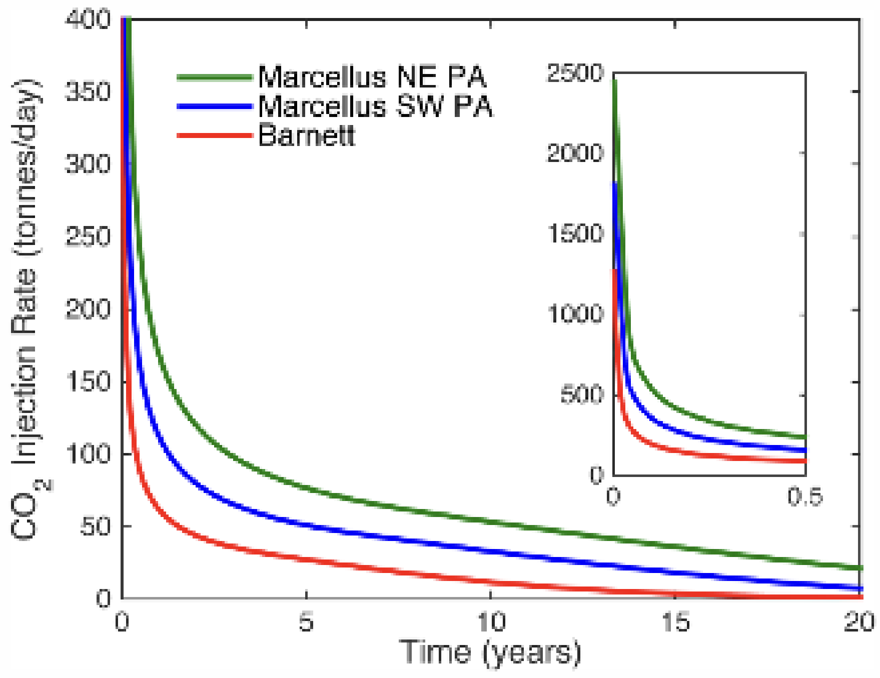
10.4-18.4 Gt CO_2 (2018-2030)

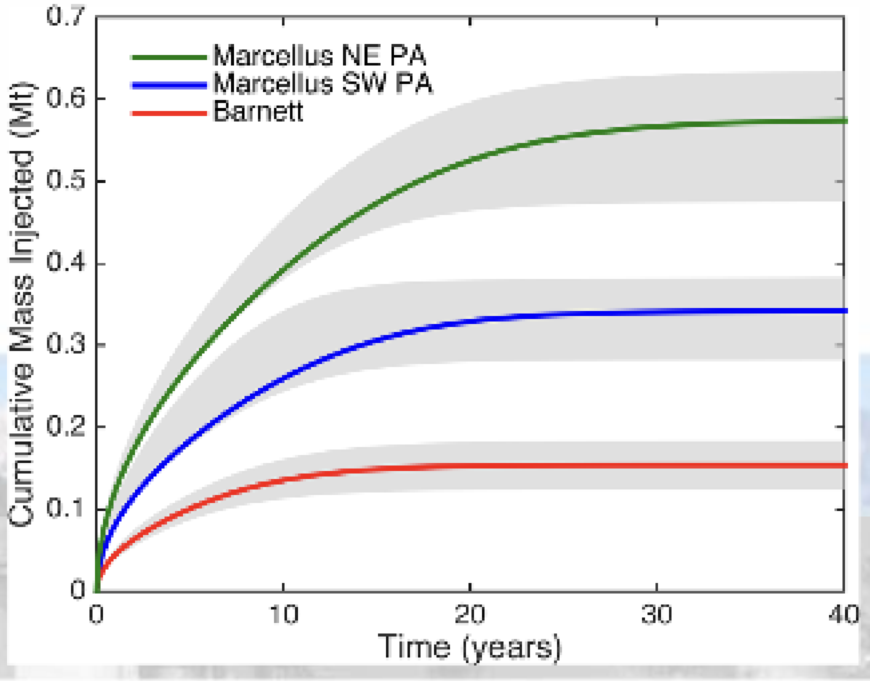


Z Tao, A Clarens (2013) Environmental science & technology 47 (19), 11318-11325

considerable interest in this topic recently

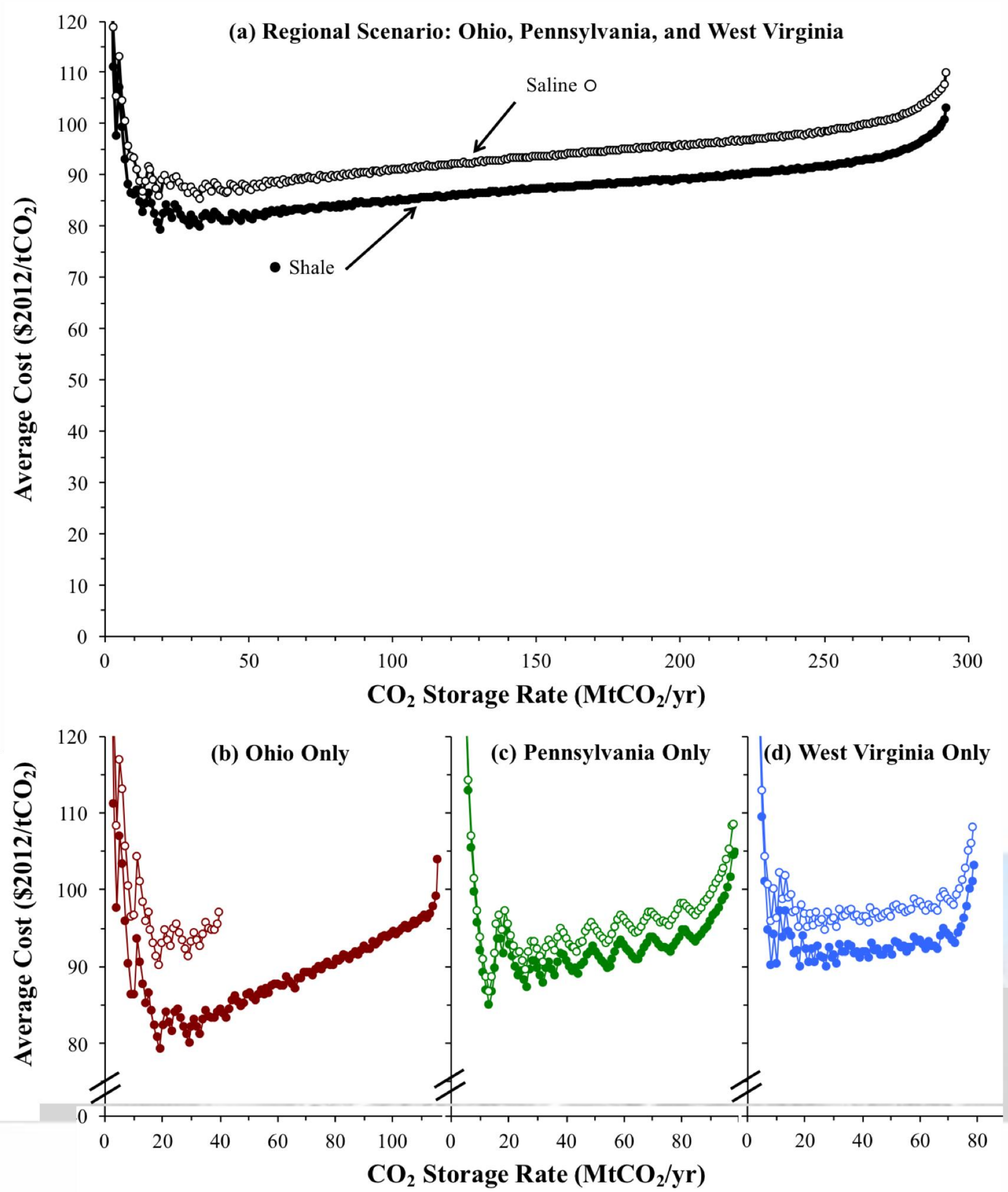


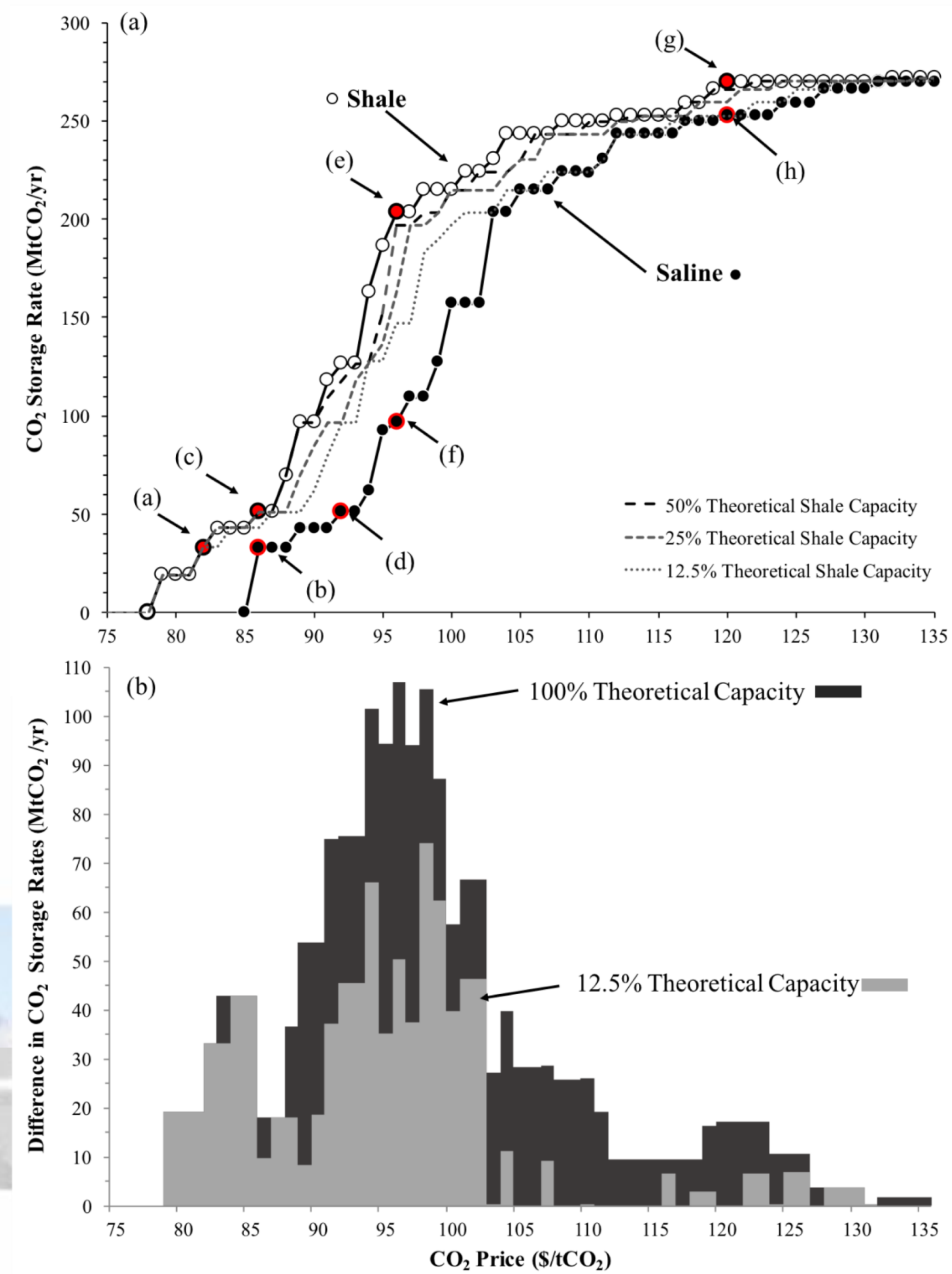




Edwards, R., et al. ES&T 49.15 (2015): 9222-9229.

technoeconomic analysis

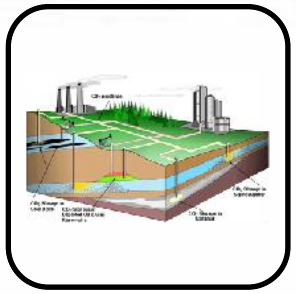




summary

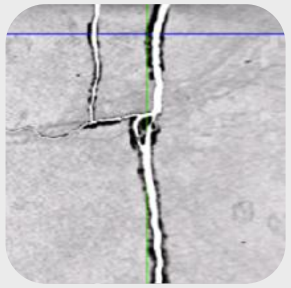
1. shale fracturing will create a large volume of pore space

   enhancing and preserving that pore space by avoiding water would be desirable



2. using CO_2 as a fracturing fluid could produce major emissions reductions

   but learning and optimization will only take place through trial and error

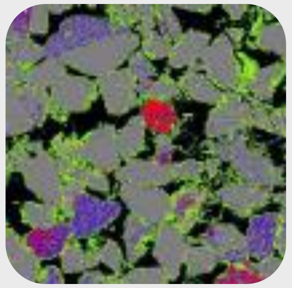


3. shale has a number of favorable characteristics for storage

   low permeability, high TOC, high pressure

4. the Marcellus shale in PA has significant capacity

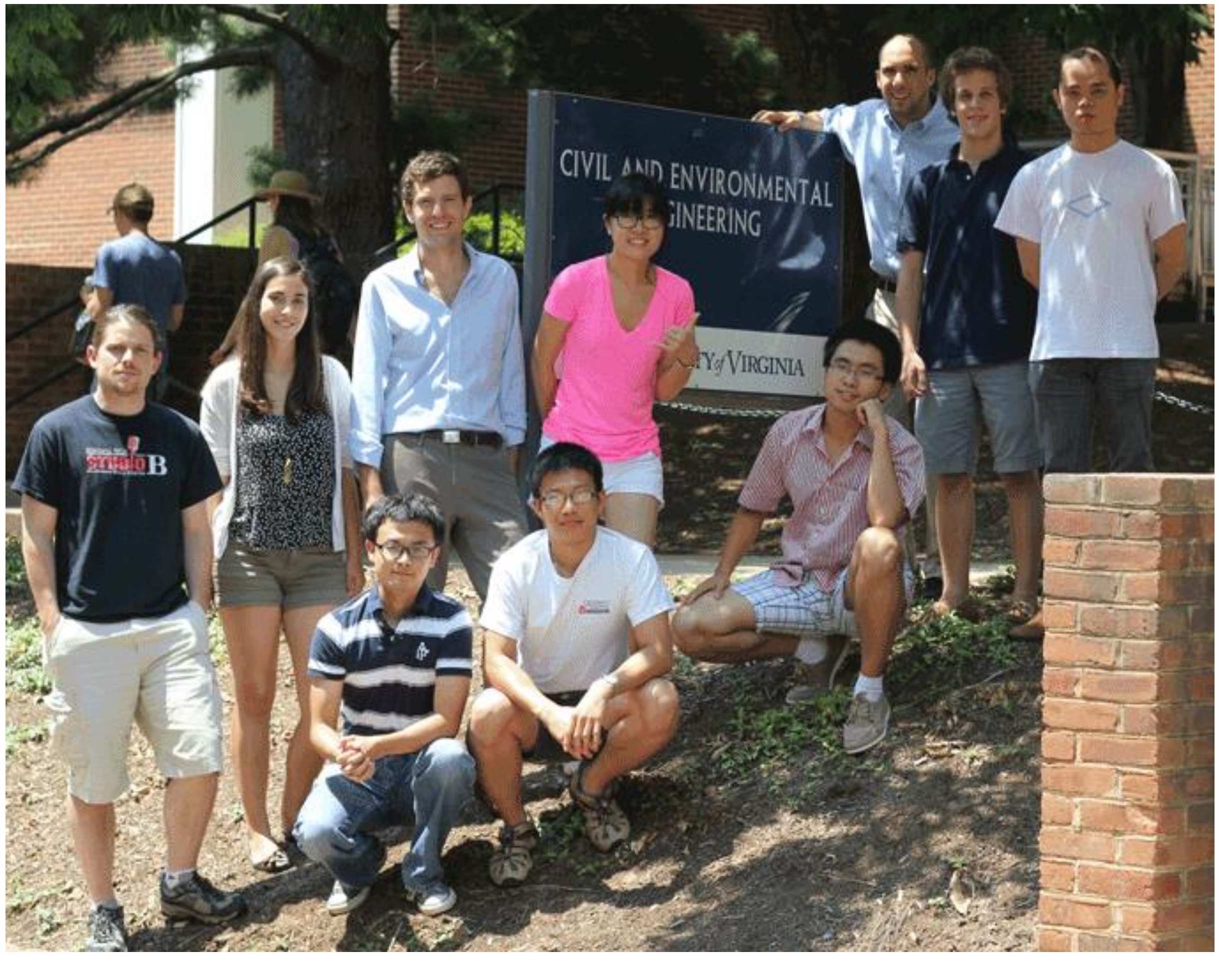
   it could store between 10.4-18.4 Gigatonnes CO_2 before 2030



5. technoeconomics of the process for CCS are favorable

   storage in shales could reduce costs relative to greenfield saline sites by 5-10%

acknowledgments



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