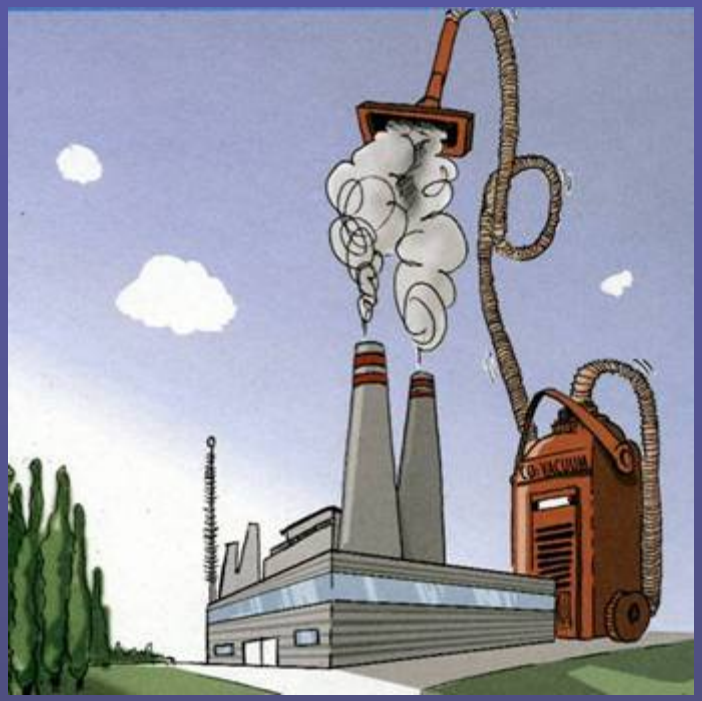
At the Cross Roads

The Challenge of the Management of Greenhouse Gases and the Role of Geologic Storage

Tim Carr

Overview



CO_2 Capture and Storage: Not This Simple

- Energy – Basis for Civilization
- Energy Transitions
  - Decades to Centuries
  - Energy Quality
- Scale of the Challenge
  - The Resource is Adequate
  - The Challenge is Management & Cost
- Carbon Capture & Storage
  - Primer on CO_2
  - Geologic Storage
  - Focus on Kansas

Promethean Energy Technology

Pieter Paul Rubens: "Prometheus Bound,'

Supply Challenge

China Energy Consumption increased 15% in 2006

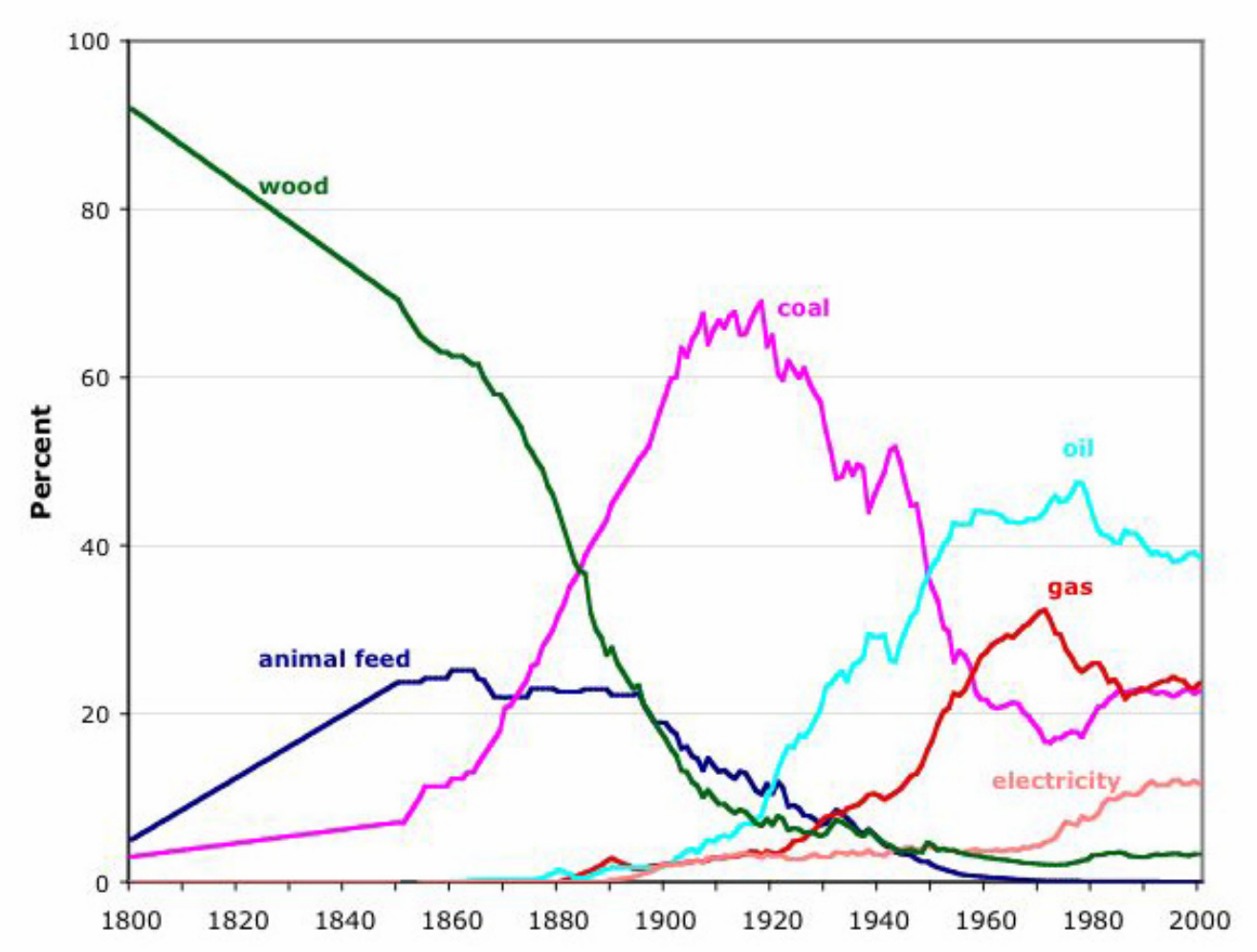
Coal increased 18%

2008 China will add 1.5 million vehicles

OECD Energy Consumption increased 1% in 2006

- Energy Today - 214 MMBOE/D
  - US 45.6 MMBOE/Day
- Energy 2025 - 300 MMBOE/D
  - US 60.2 MMBOE/Day
- Energy 2099 – 600^{+} MMBOE/D
- Energy – Basis for Civilization
- Energy – Basis of Health

Energy Transitions
Composition of U.S. Energy Use



Cutler Cleveland, 2008

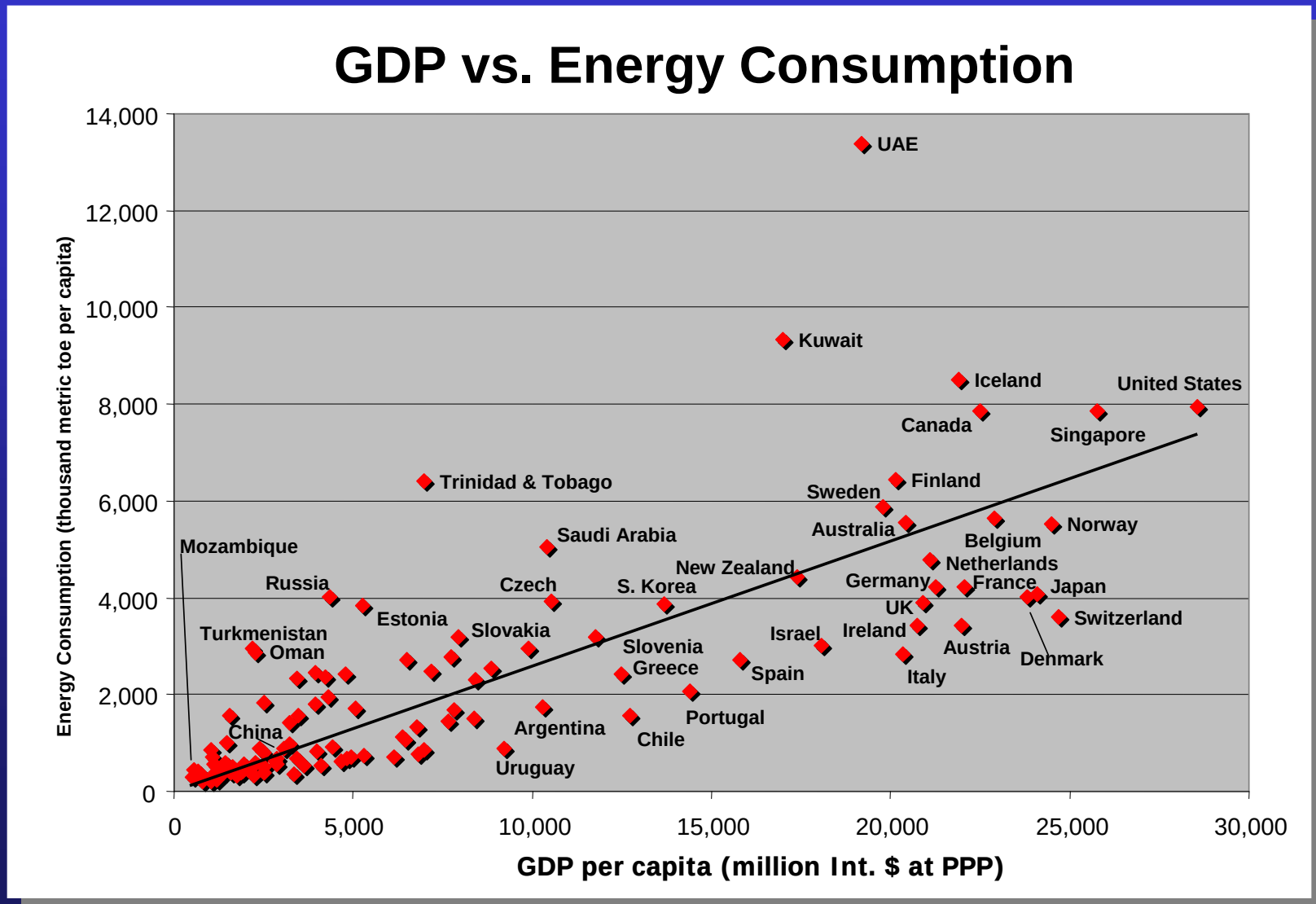
The Need for Action

Today, 1.6 billion people – one quarter of the world population have no access to electricity.

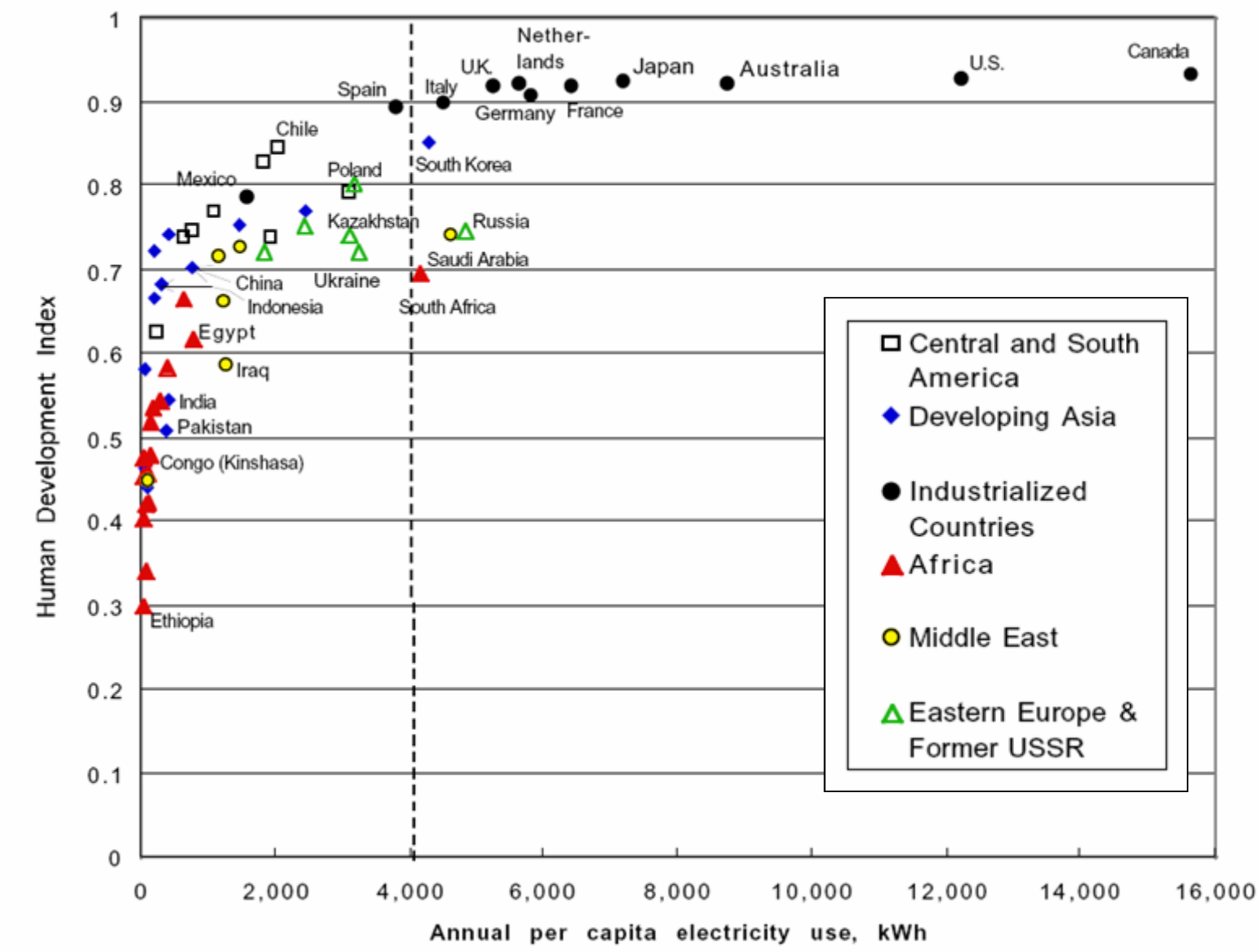
In 2030, 1.4 billion people 17% of the world population will still not have electricity.

2.4 billion people rely on traditional biomass – wood, agricultural residues and dung – for cooking and heating.

Energy & Poverty



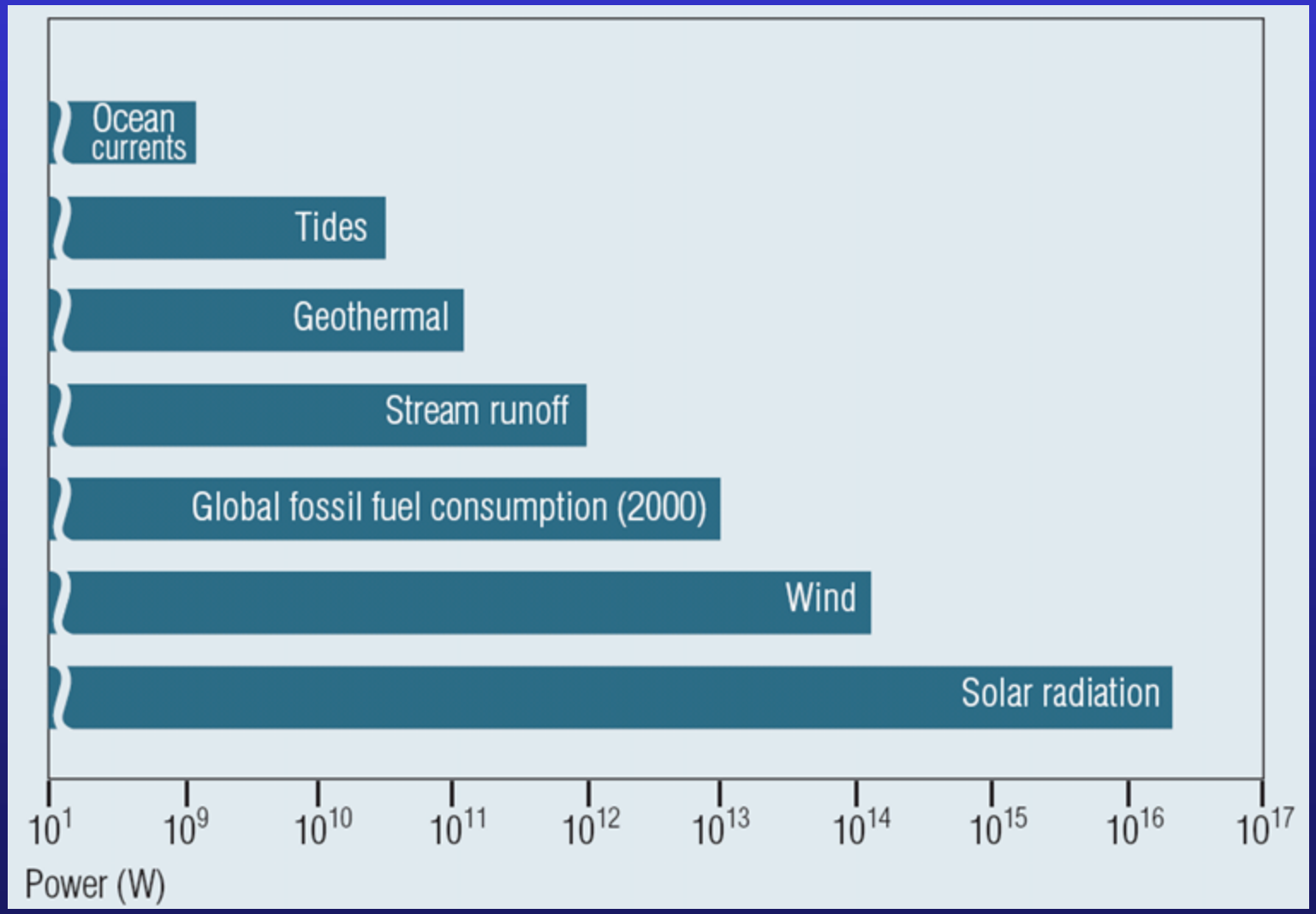
Energy & Well Being



Energy Quality

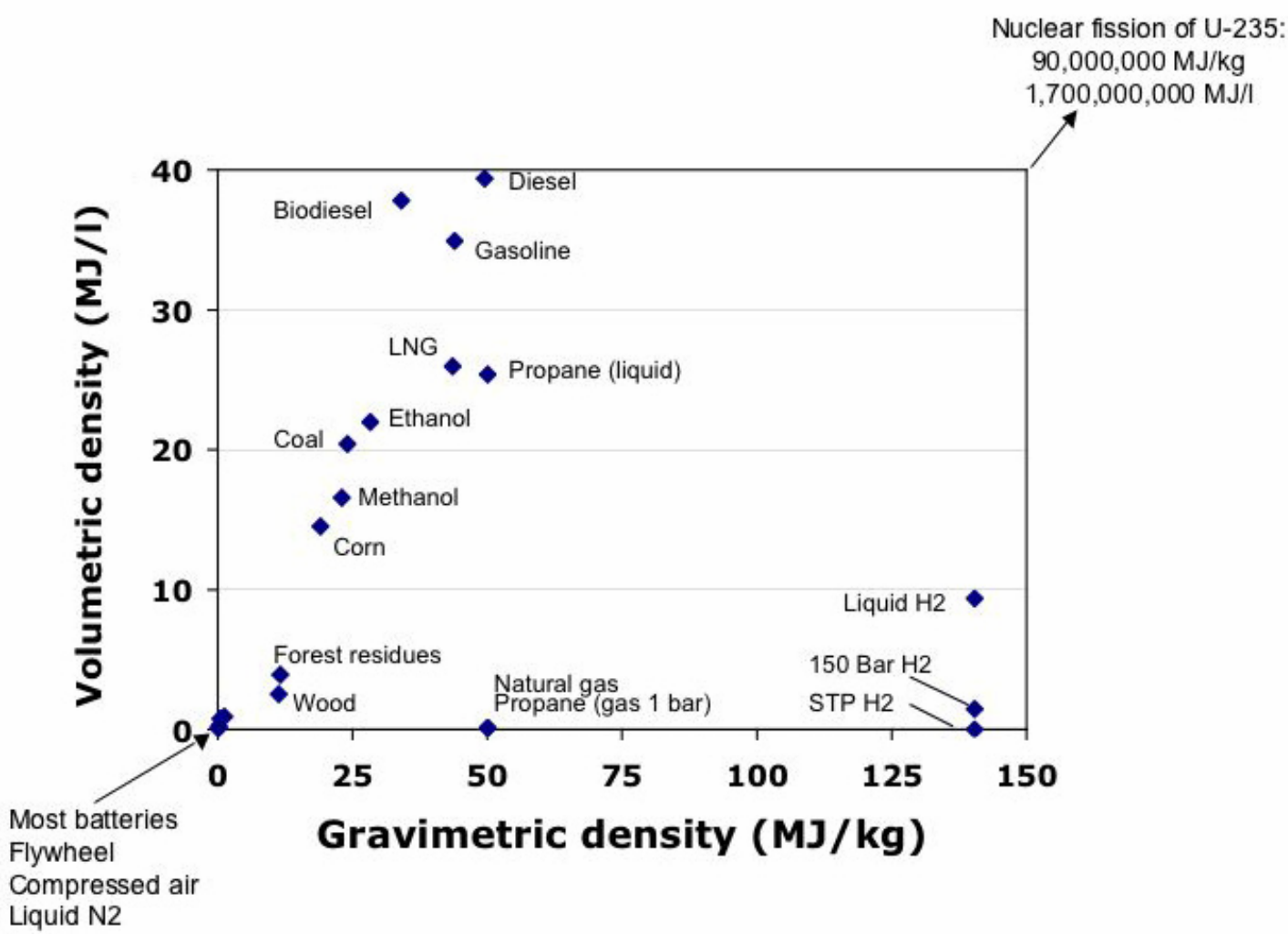
- Aggregated by Heat Content
  - Btu's, Joules, etc.)
  - 1kWh = $3.6*10^6$ joules
  - 1 barrel oil = $6.1*10^9$ joules
- All Btu's or Joules are not equal
  - Electricity – Illumination
  - Oil - Transportation
- Energy Quality
  - Ability of a unit of energy to produce goods or services for people

Energy Availability

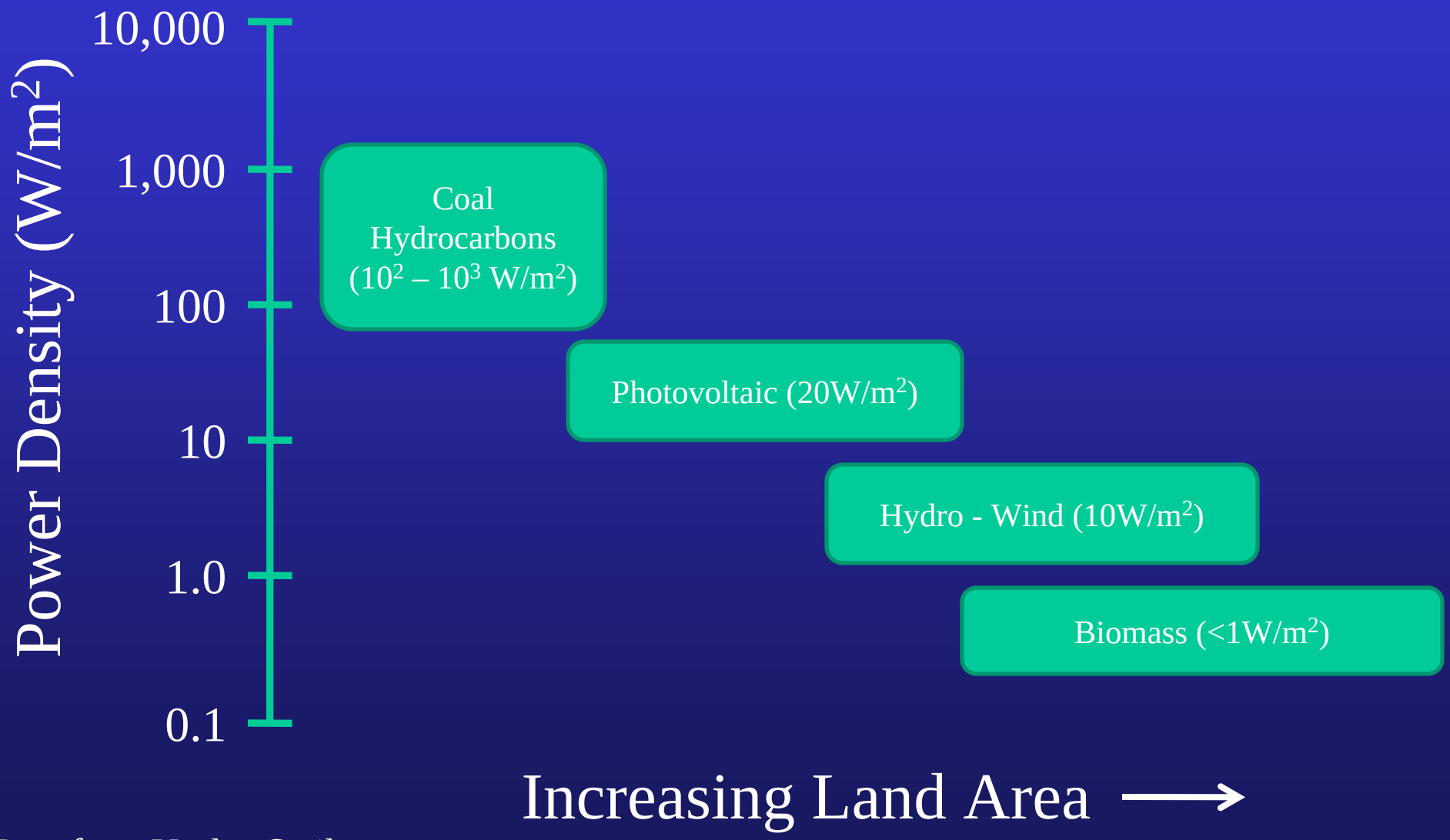


Smil, V. 2006. "21st century energy: Some sobering thoughts." OECD Observer 258/59: 22-23

Energy Density

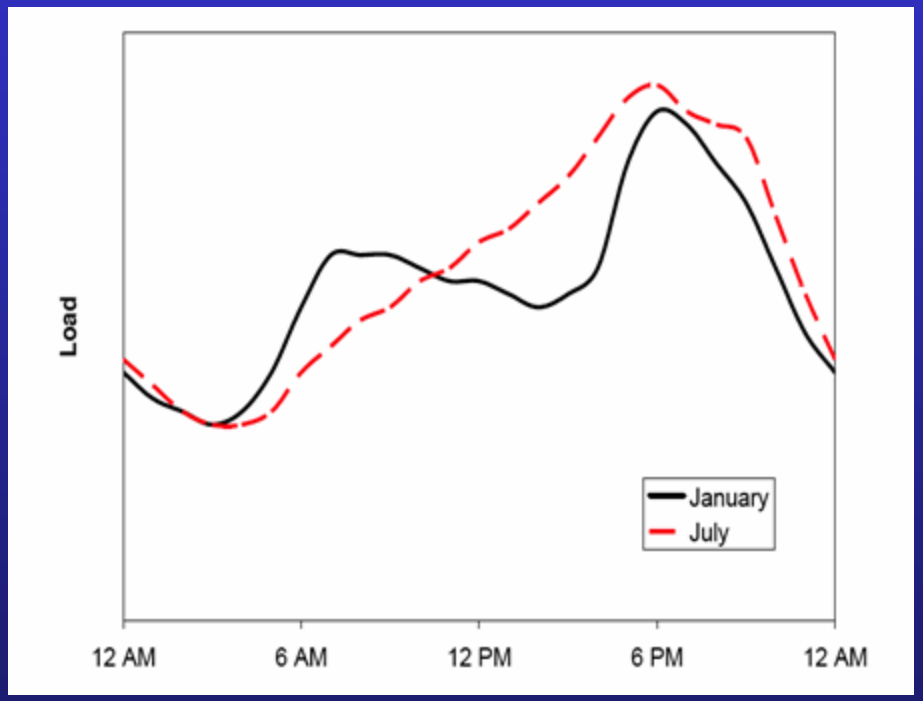


Power Density

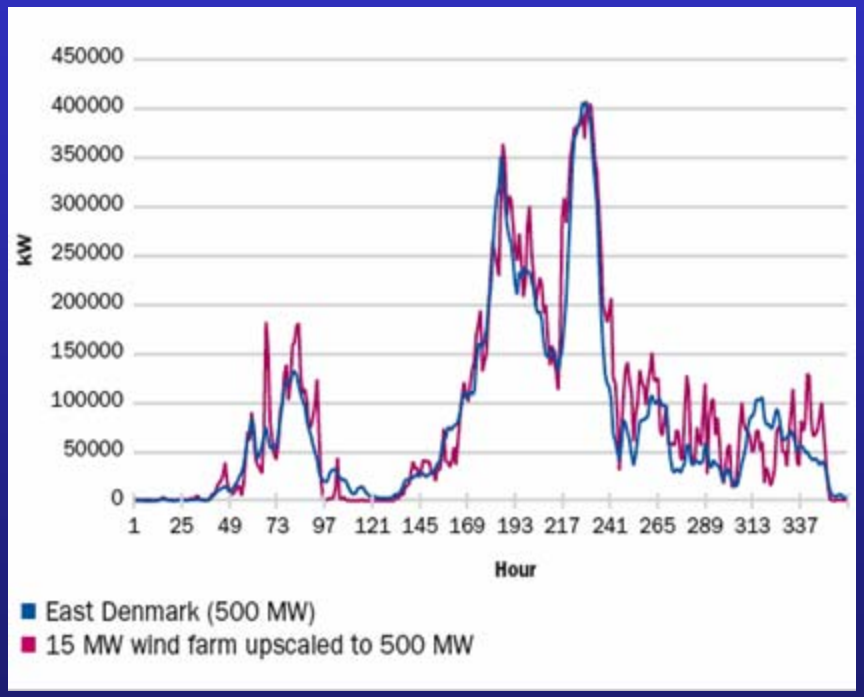


Data from Vaclav Smil

Intermittancy

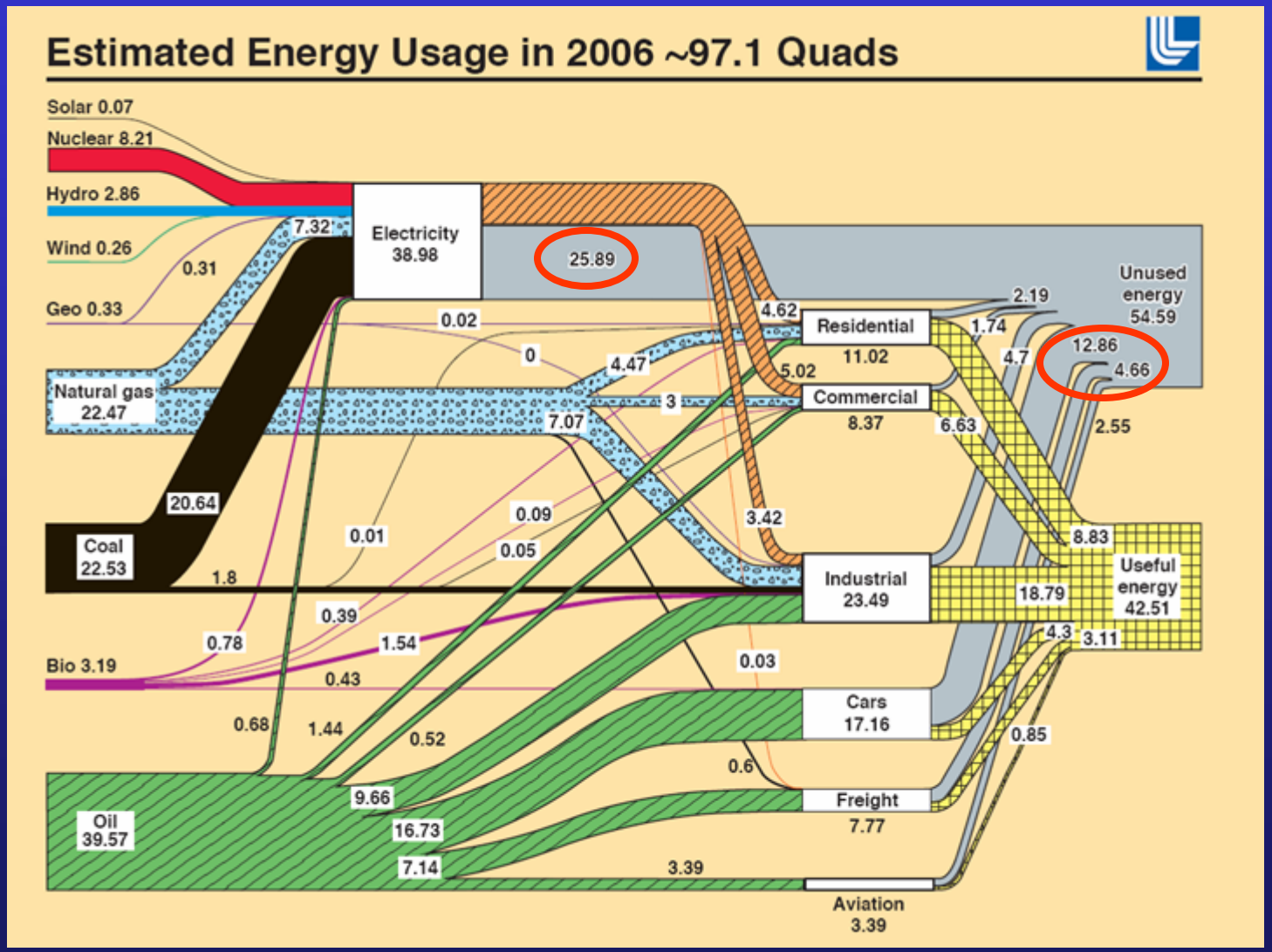


A typical 24 hour load profile for a residence in San Jose, CA. (Source: NREL)



Variability of wind energy over a 15 day period. Hourly output of 500 MW wind power capacity calculated from observed data in Denmark. Source: European Wind Energy Association,

Energy Usage



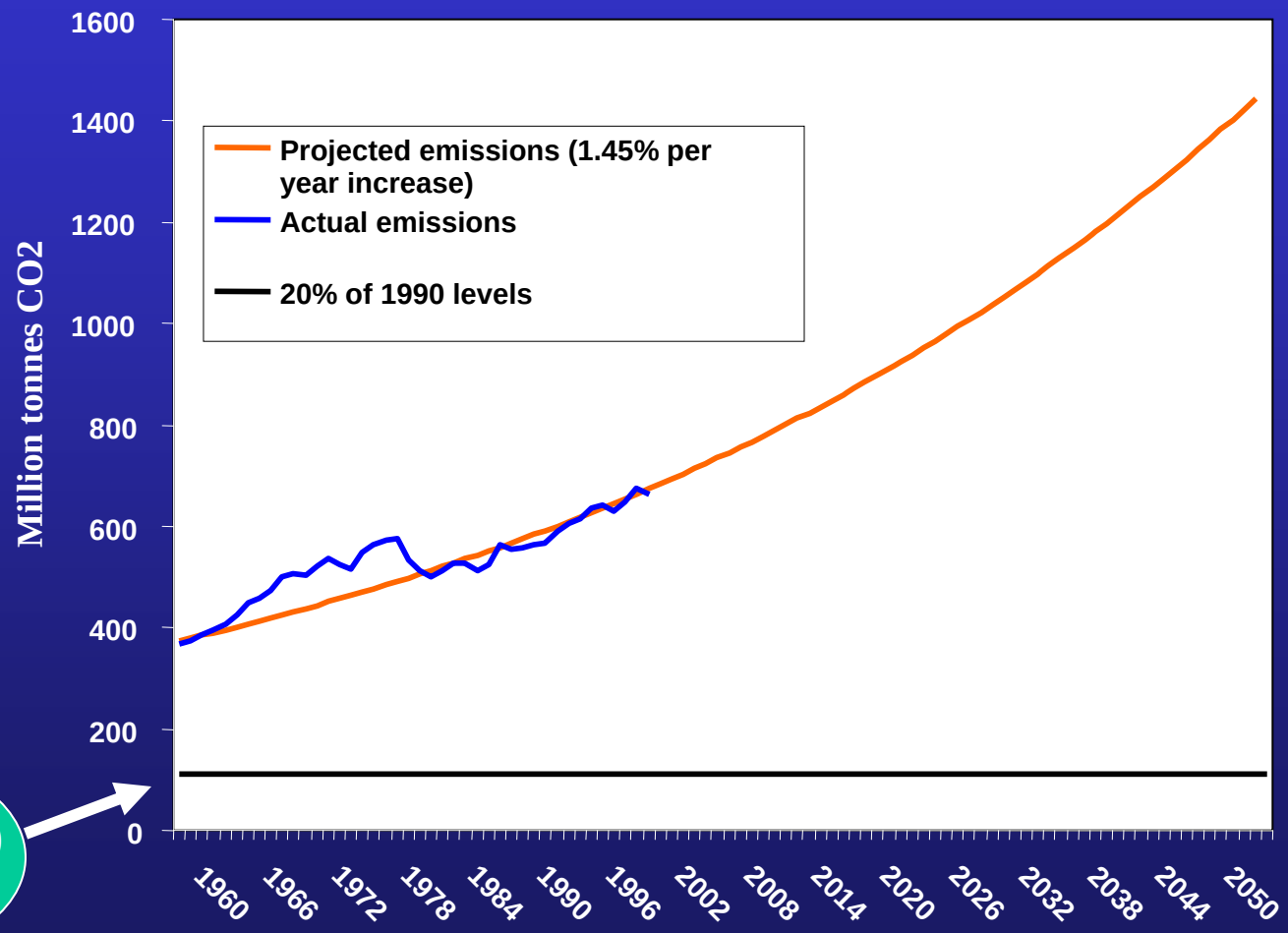
Source: LLNL 2008; data is based on DOE/EIA-0384(2006), June 2007

The Scale of the Challenge

80 m tall Nordex 2.5 MW wind turbine located in Grevenbroich, Germany

- Energy Today - 214 MMBOE/D
  - US 45.6 MMBOE/Day
  - ~3 Terawatts
- Assume 50% Renewables
  - Windpower –
    - 1.2 Million 2 Mw turbines
    - 0% of the lower 48 land area.
  - Biofuels – 310 billion gallons per year, approximately 100 billion bushels of corn, or 4 billion tons of biomass per year

The Future: Projected CO_2 Emissions



20% of 1990 level

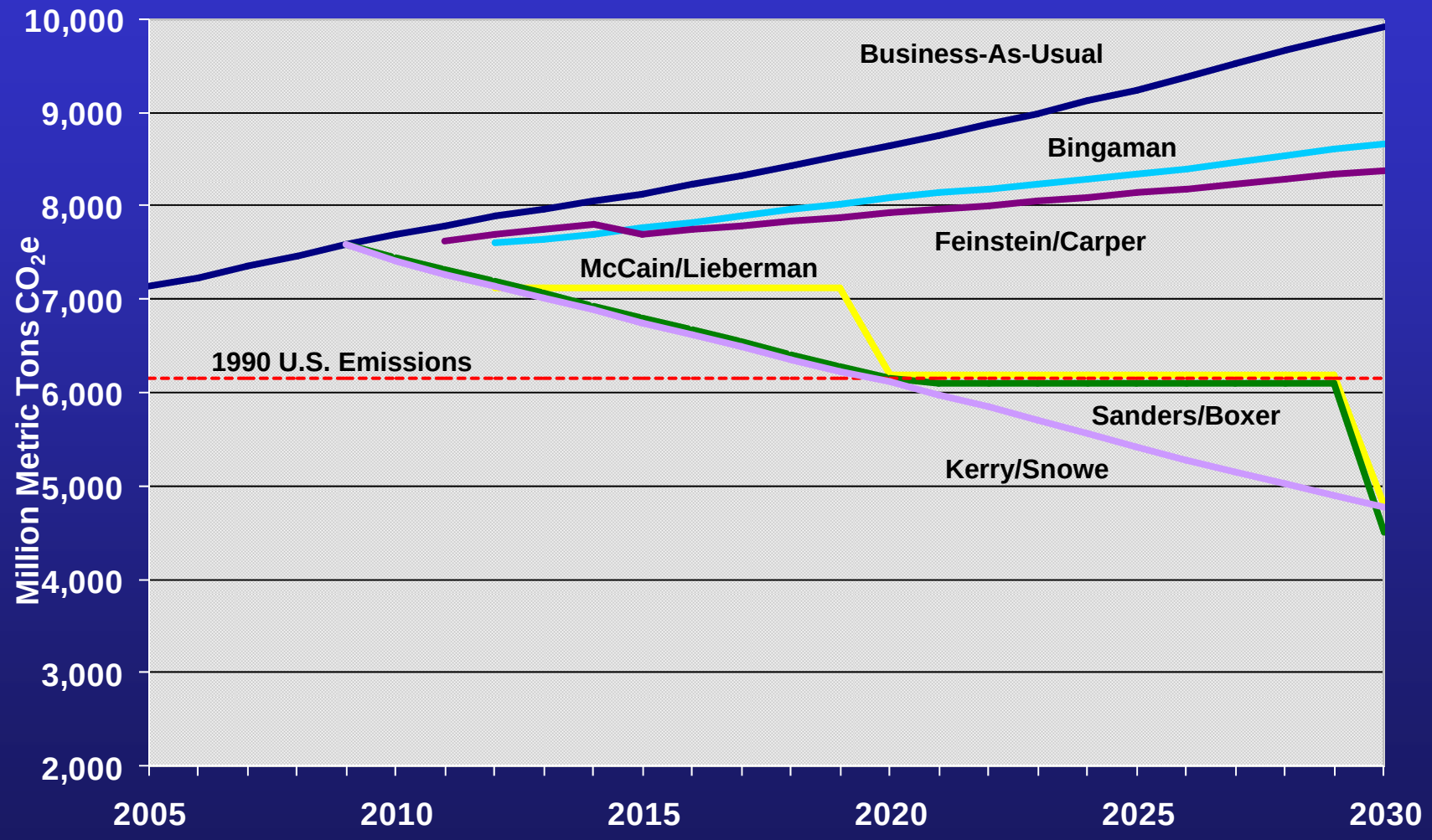
US Electricity Sector: Meeting Future Demand

- U.S. electricity demand forecasted to increase 40% by 2030

- Federal legislation to limit GHG emissions likely within next several years.
  - Patchwork of state and regional regulations emerging

- Electric utilities responsible for 38% of U.S. CO_2 emissions…

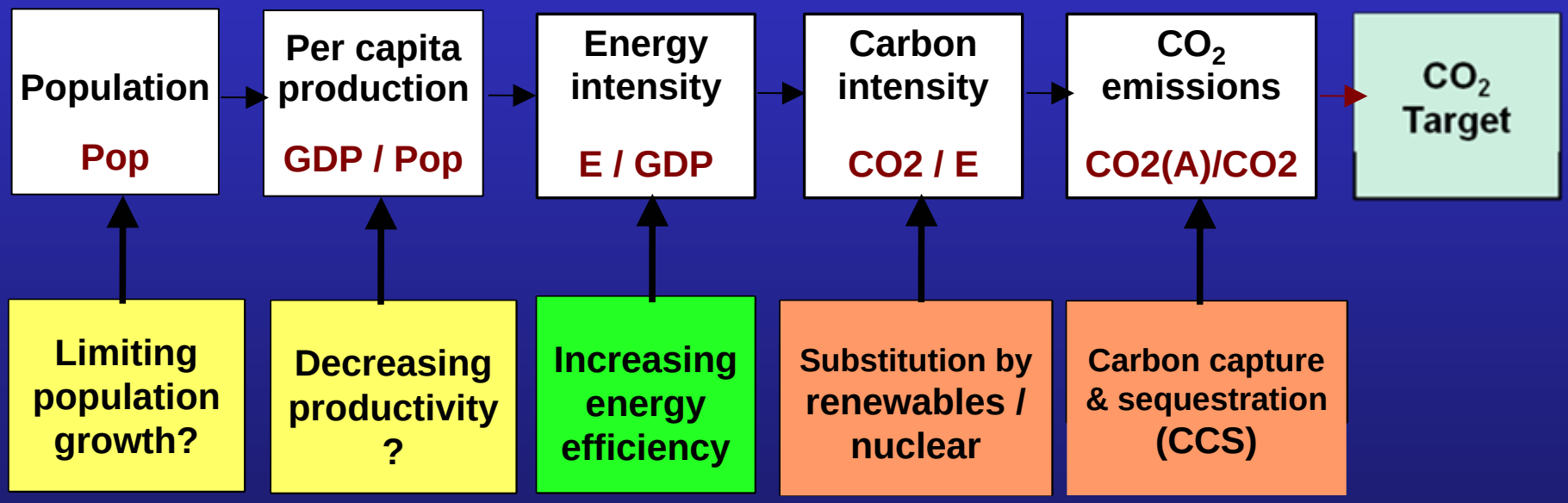
Greenhouse Gas Regulatory Proposals 110th Congress



Sources: EIA & EPA data/forecasts

Approaches To GHG Managment

Possible mitigation options (over time!)
to reach climate protection targets

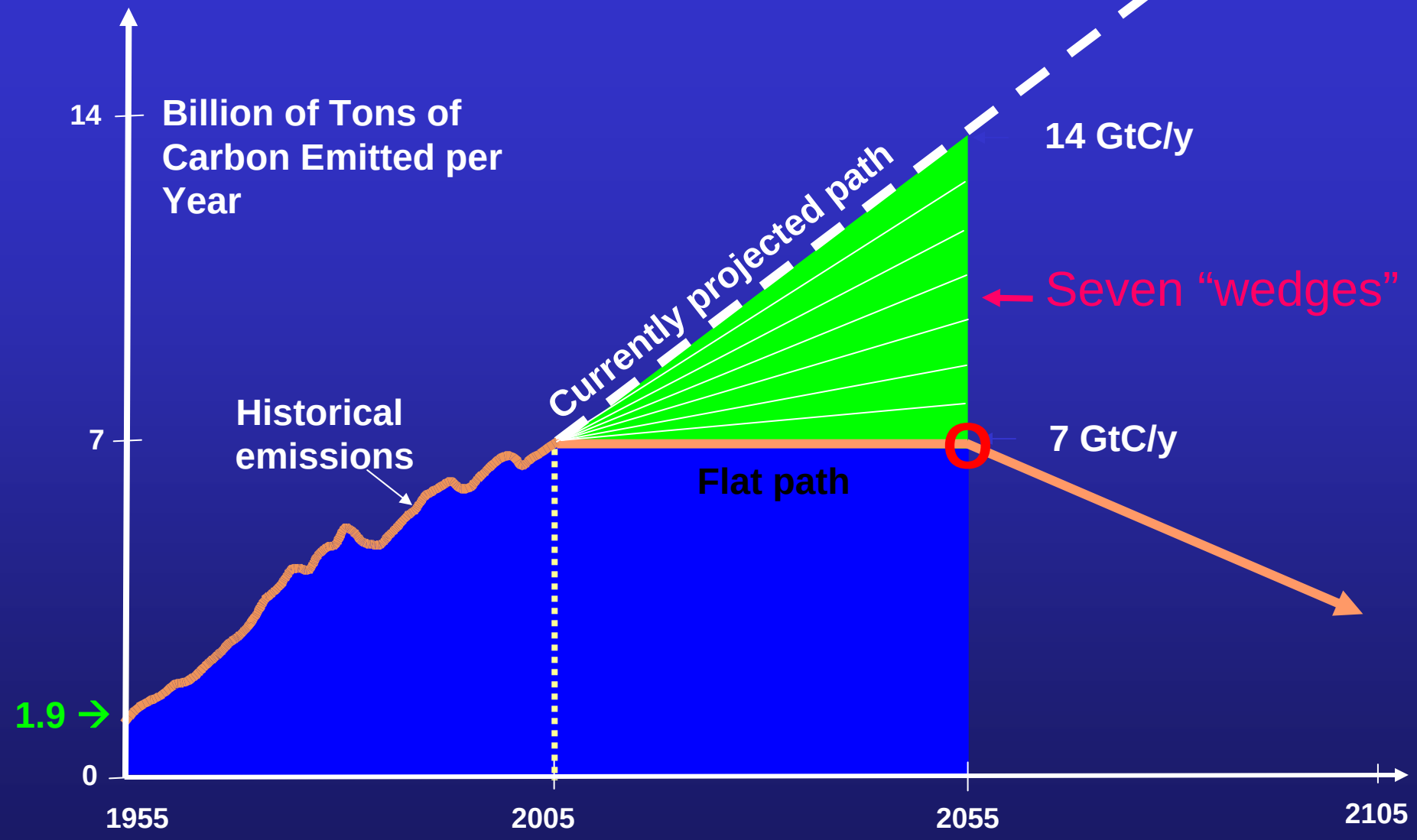


Malthusian options

Technological + Lifestyle

Technological options

Wedges



Graphic Socolow & Pacala

Efficiency and Conservation

transport

buildings

industry

Effort needed by 2055 for 1 wedge:

2 billion cars at 60 mpg instead of 30 mpg.

CCTP Draft, Sept. 2005: 1 billion cars at 40 mpg instead of 20 mpg

power

lifestyle

Graphic Socolow & Pacala

Wind Electricity

Effort needed by 2055 for 1 wedge:

One million 2-MW windmills displacing coal power.

Today: 40,000 MW (2%)

This would cover an area 3 times the area of Kansas (assuming 160 acre spacing).

Prototype of 80 m tall Nordex 2,5 MW wind turbine located in Grevenbroich, Germany (Danish Wind Industry Association)

Graphic Socolow & Pacala

Nuclear Electricity

Effort needed by 2055 for 1 wedge:

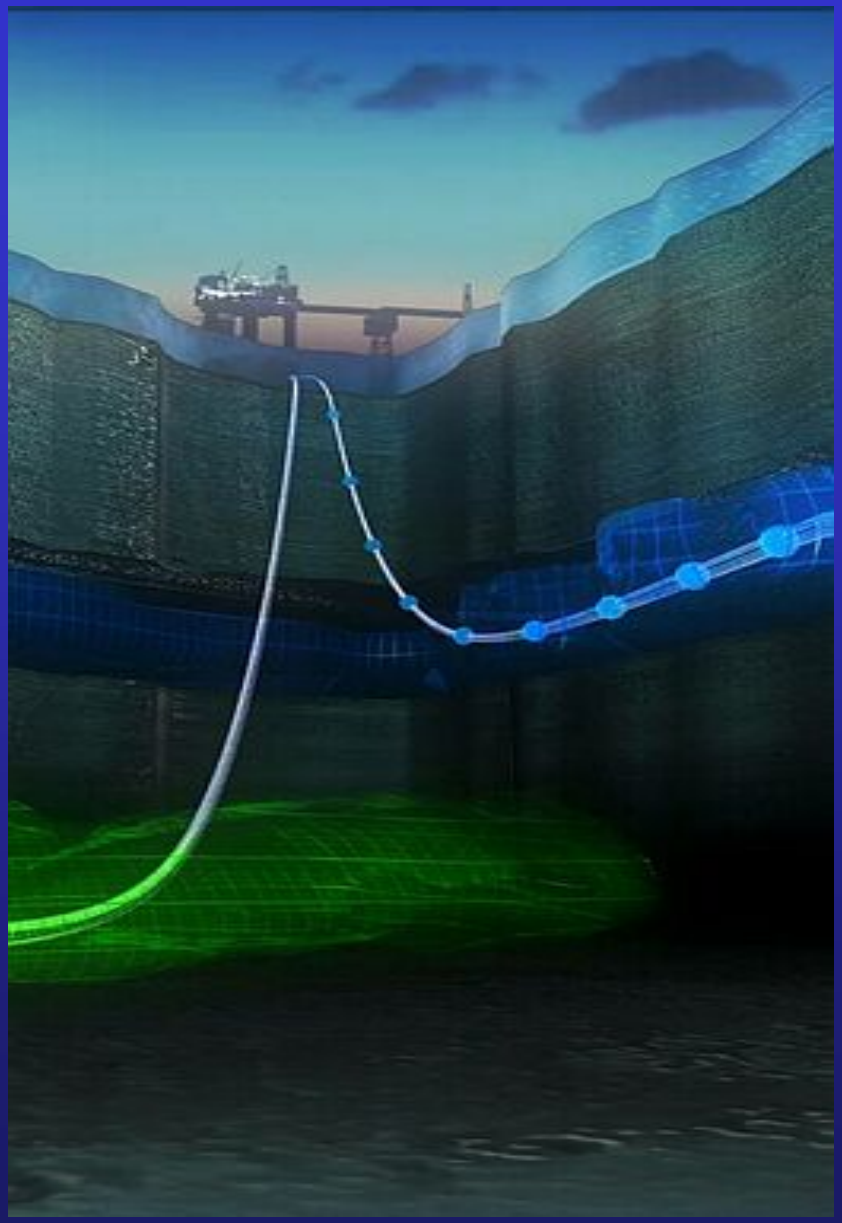
700 GW (twice current capacity) displacing coal power.

Graphic courtesy of NRC

Phase out of nuclear power creates the need for another half wedge.

Graphic Socolow & Pacala

Carbon Storage



Sleipner project, offshore Norway

Graphic courtesy of Statoil ASA

Effort needed by 2055 for 1 wedge:

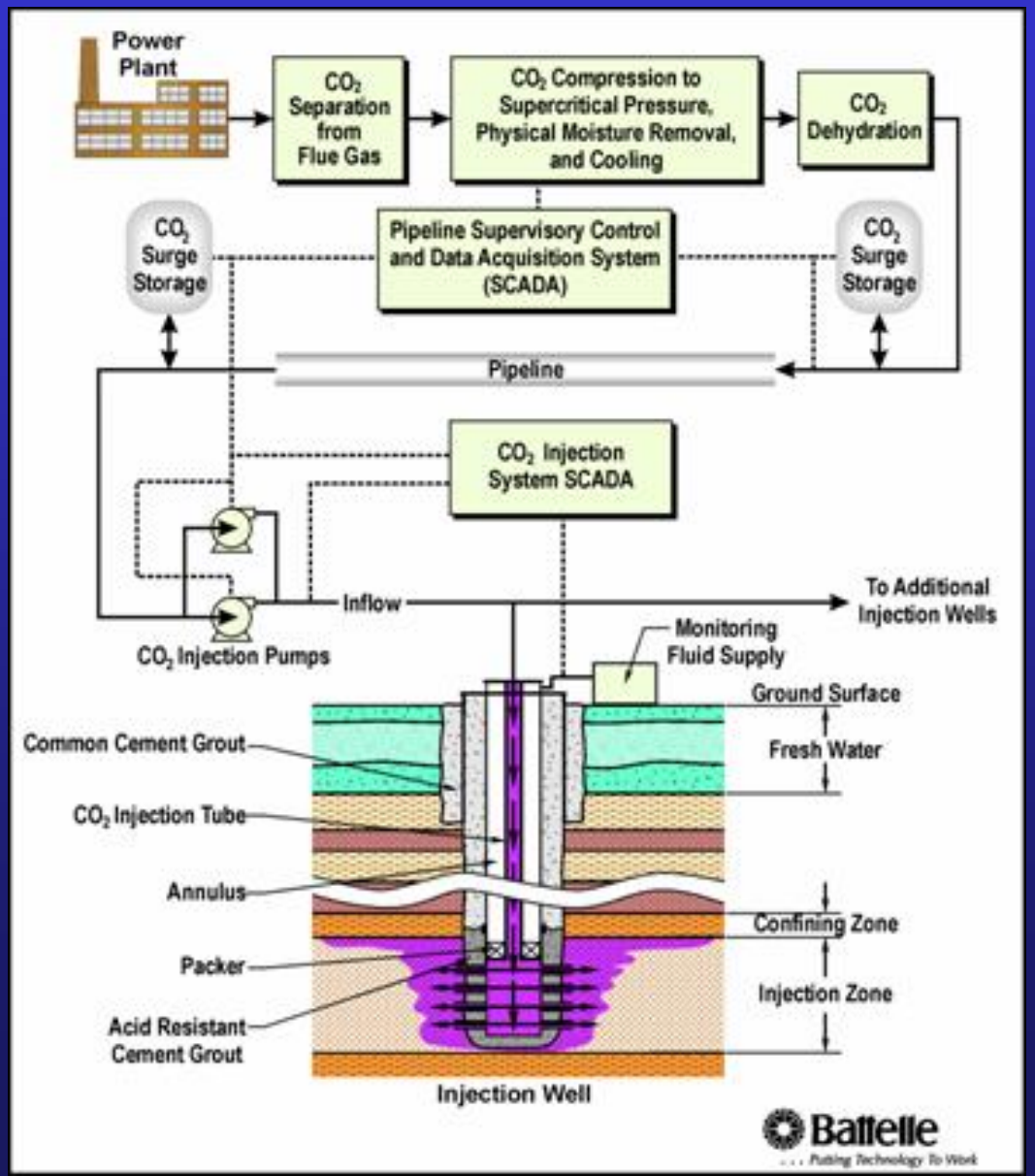
3500 Sleipners @1 $MtCO_2$/yr

100 x U.S. CO_2 injection rate for EOR

A flow of CO_2 into the Earth equal to the flow of oil out of the Earth today

Graphic courtesy of David Hawkins

Carbon Capture & Storage (CCS)



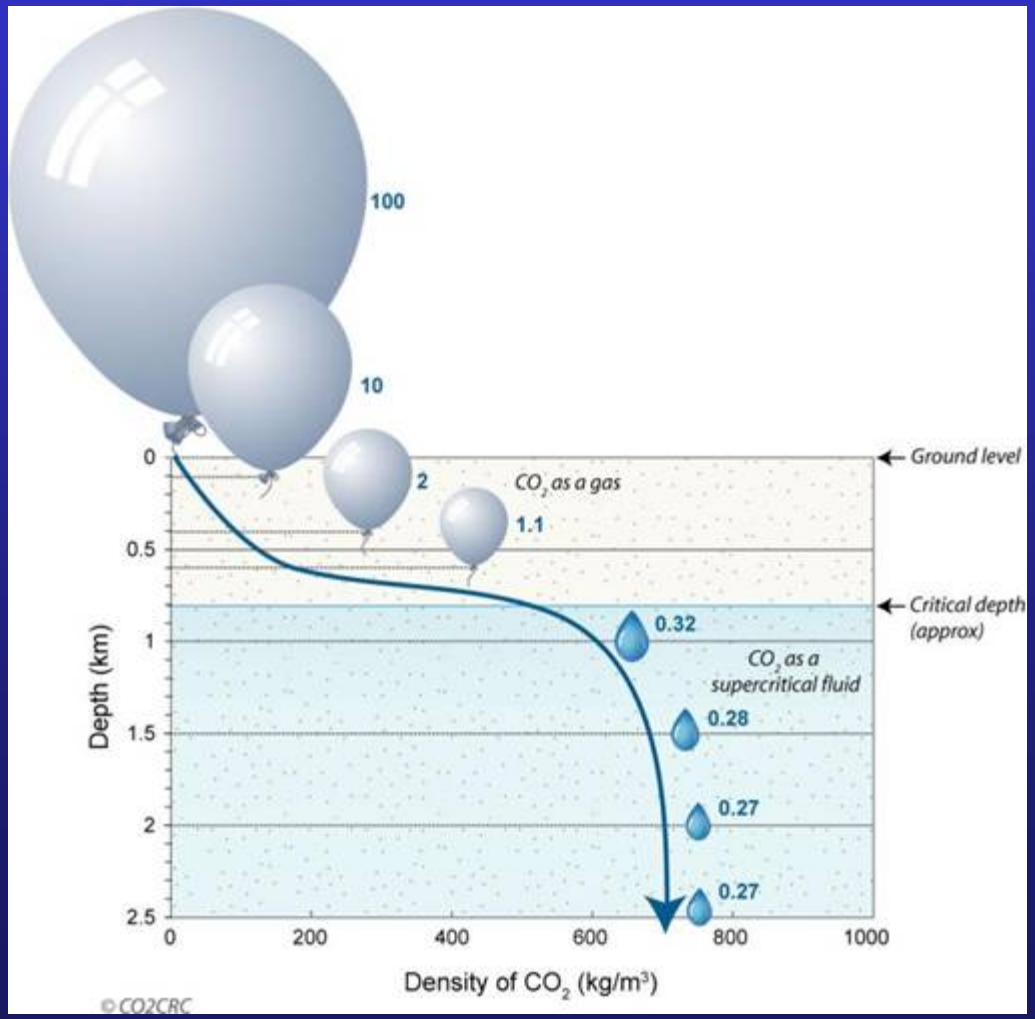
Capture

Transport

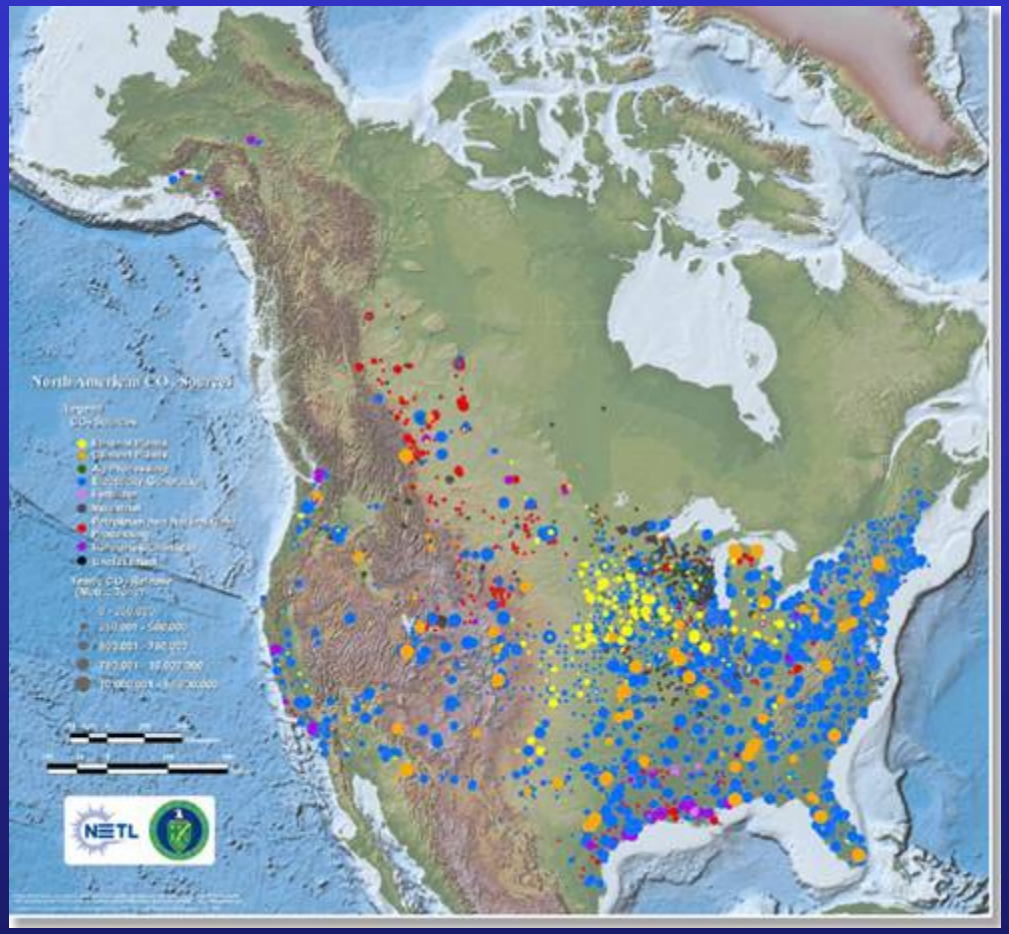
Storage

Graphic Jim Dooley

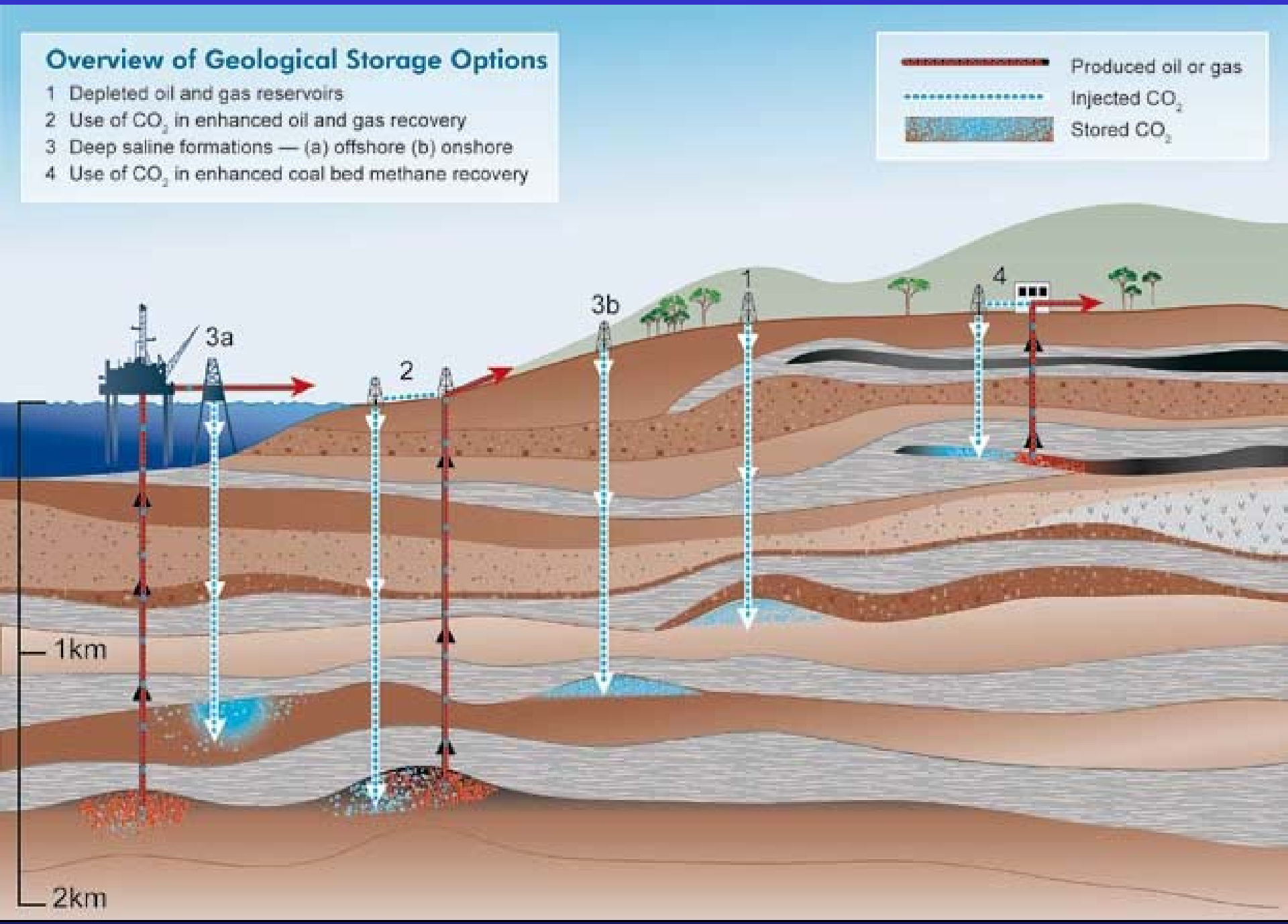
Carbon Dioxide
Product or Hazardous Waste



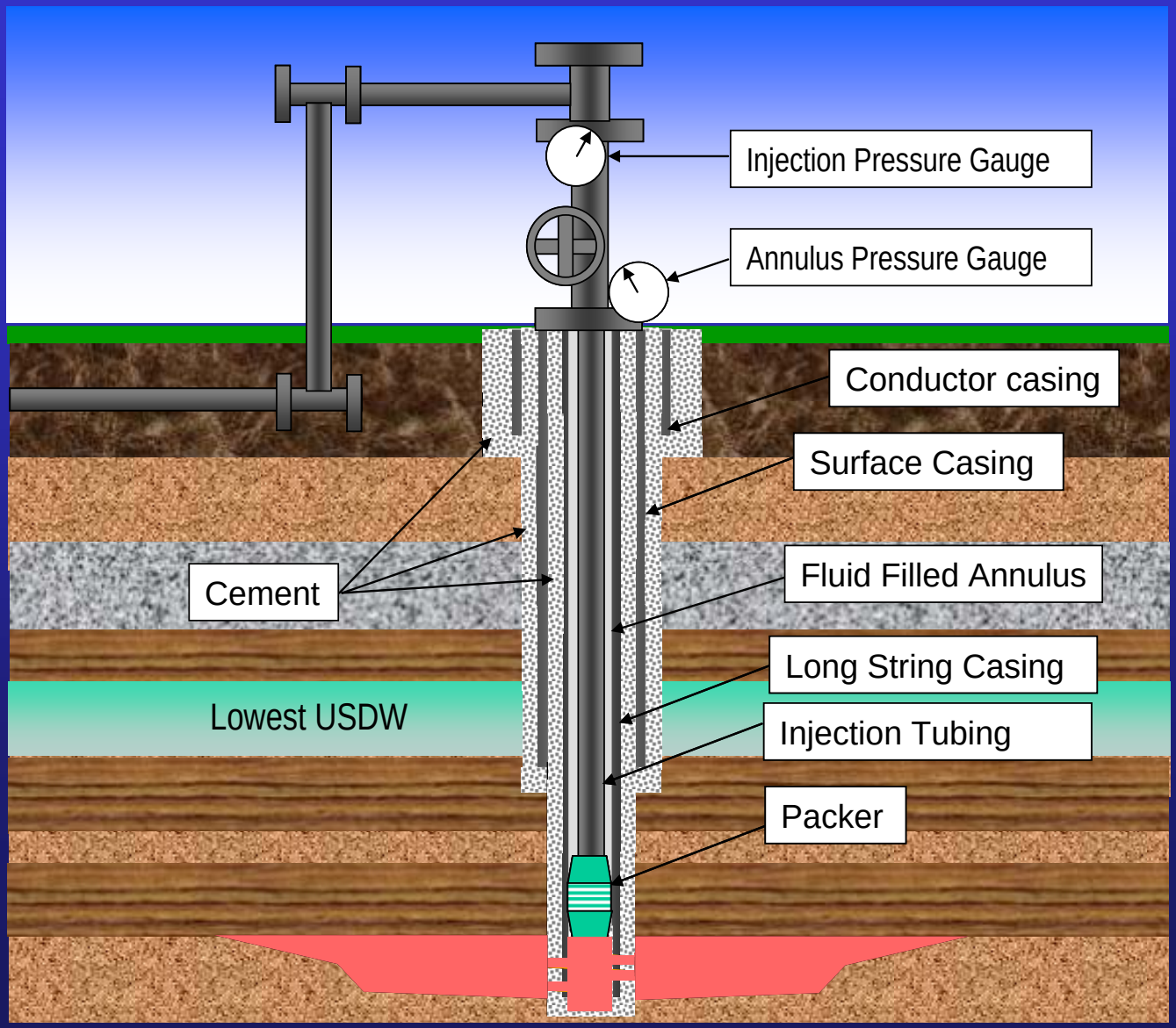
Stationary Sources



Kansas
Total 72.8 Million Metric Tons/Year
Electric Power 37.2 Million Metric Tons/Year


Overview of Geological Storage Options
1 Depleted oil and gas reservoirs
2 Use of CO_2 in enhanced oil and gas recovery
3 Deep saline formations — (a) offshore (b) onshore
4 Use of CO_2 in enhanced coal bed methane recovery
Produced oil or gas
Injected CO_2
Stored CO_2
3a
2
3b
1
4
1km
2km

CO_2 Injection Well



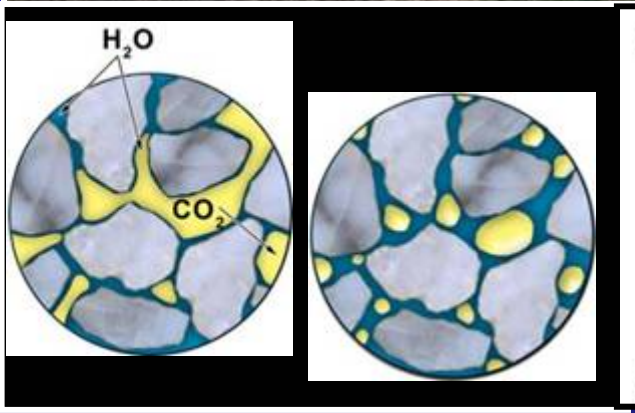
Storage Mechanisms

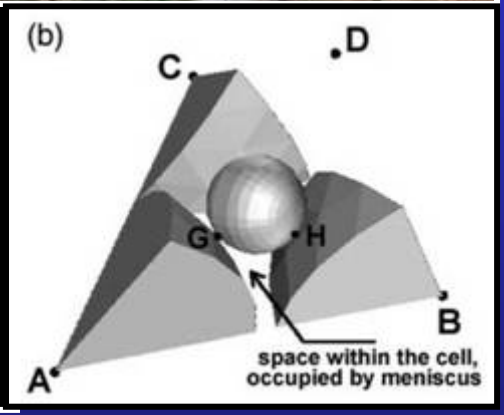
Physical trapping
- Impermeable cap rock
- Either geometric or hydrodynamic stability

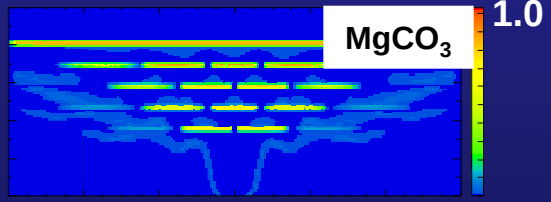
Residual phase trapping
- Capillary forces immobilized fluids
- Sensitive to pore geometry (<25% pore vol.)

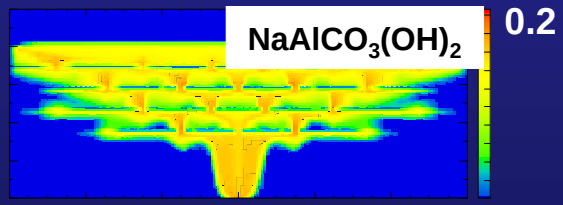
Solution/Mineral Trapping
- Slow kinetics
- High permanence

Gas adsorption
- For organic minerals only (coals, oil shales)

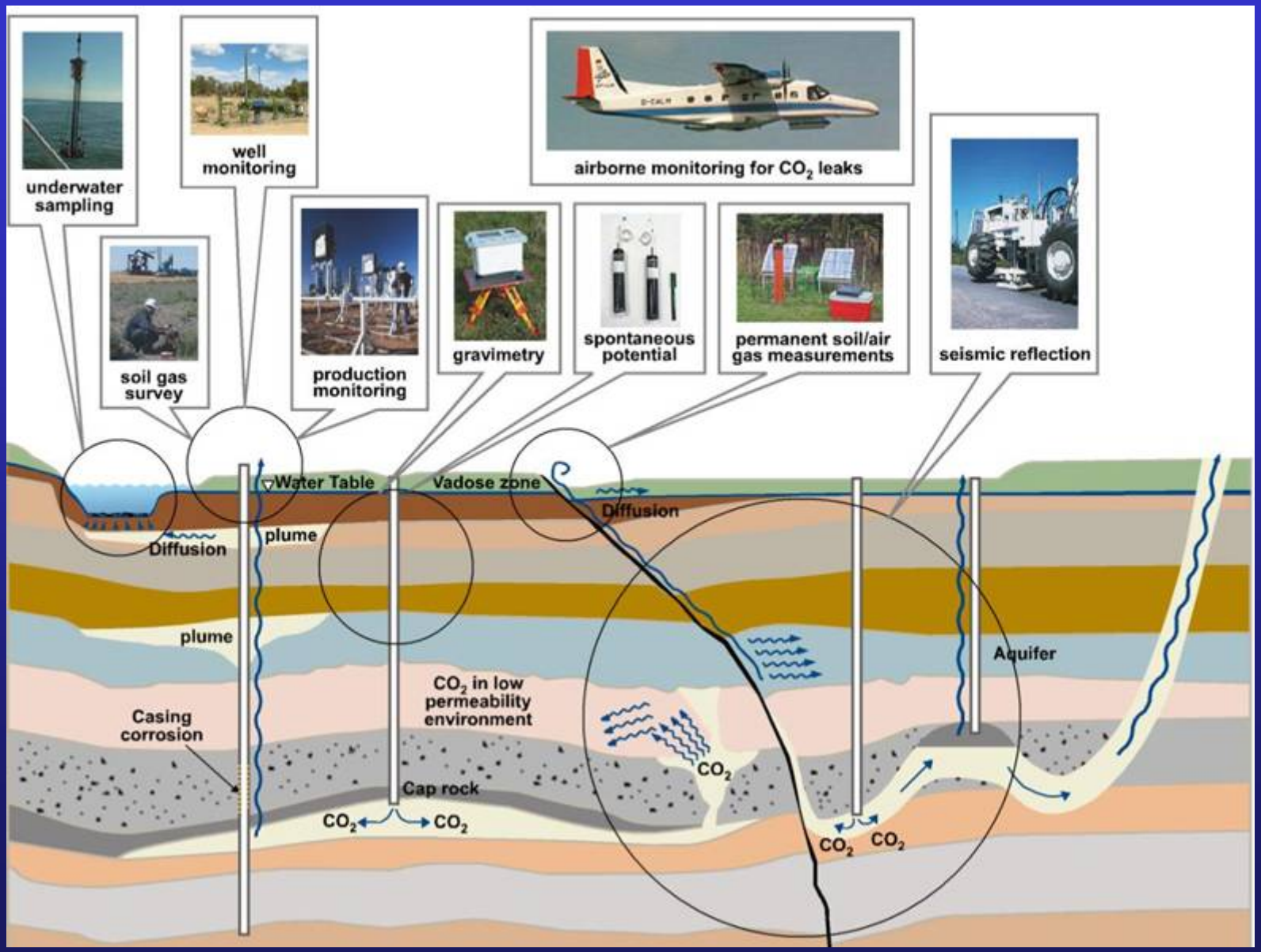




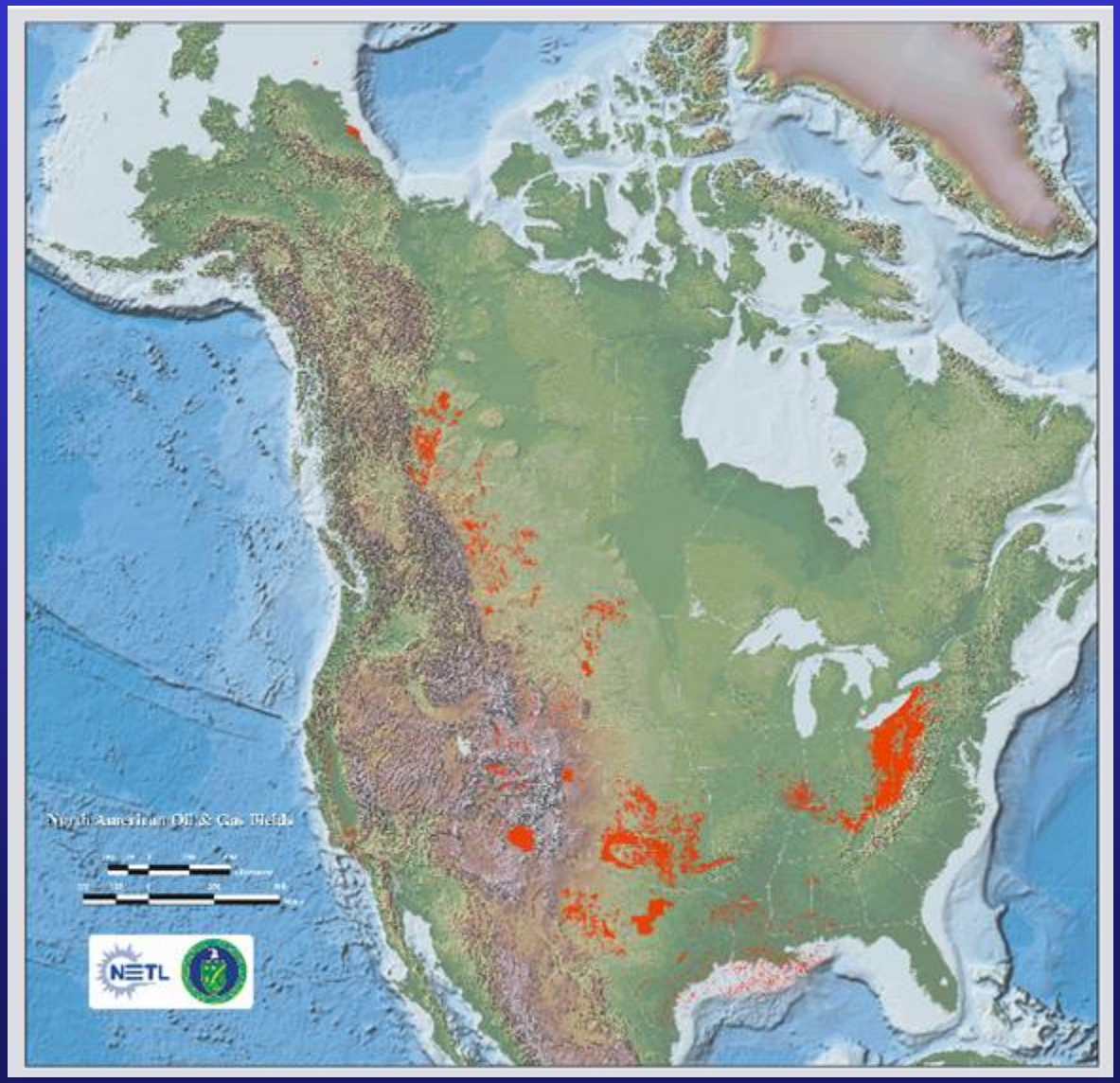




Monitoring Techniques



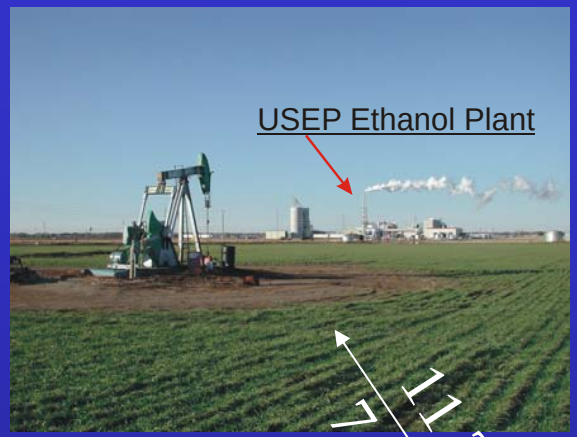
Sinks - Oil and Gas Fields



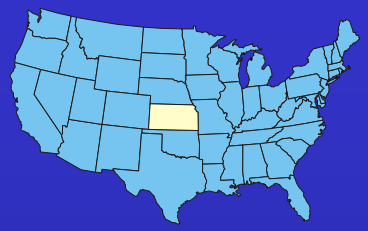
CO_2 Resource Estimates by Regional Carbon Sequestration Partnership for Oil and Gas Reservoirs		
RCSP	Billion Metric Tons	Billion Tons
BSCSP	1.5	1.6
MGSC	0.4	0.4
MRCSP	8.4	9.3
PCOR	24.1	26.5
SECARB	31.1	34.3
SWP	65.0	71.7
WESTCARB	7.7	8.5
TOTAL	138	152

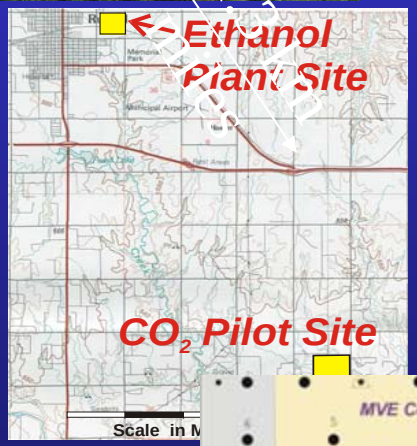
Kansas
Total 1,620 Million Metric Tons
44 years

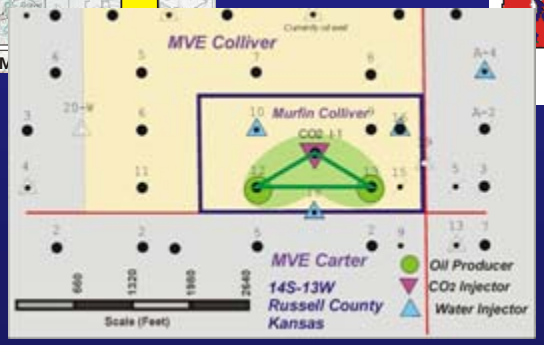
Russell, Kansas Project

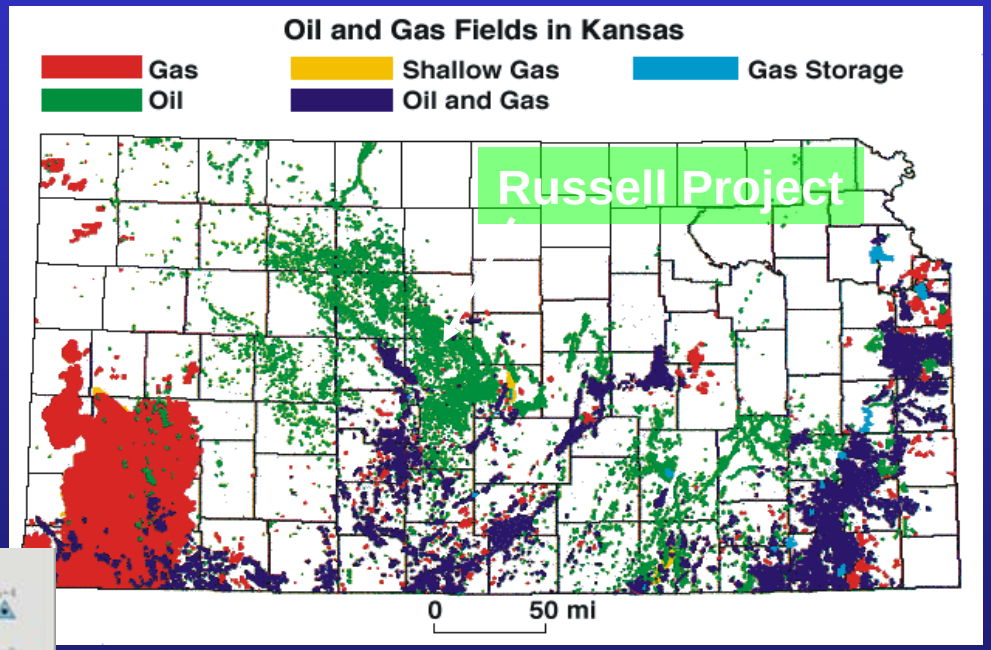


First Sequestration
of Agricultural CO_2





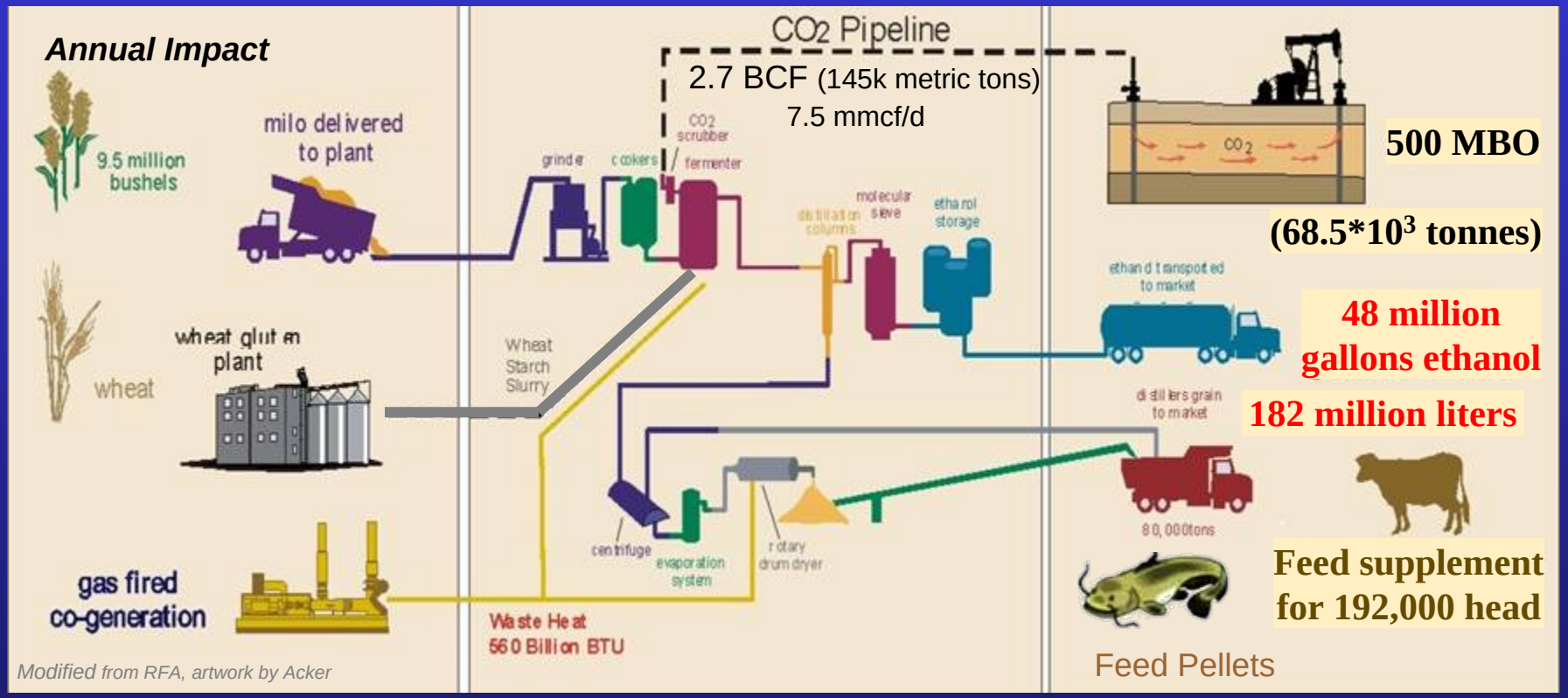




Russell is centered in oil,
grain and cattle region

An Integrated Energy Systems

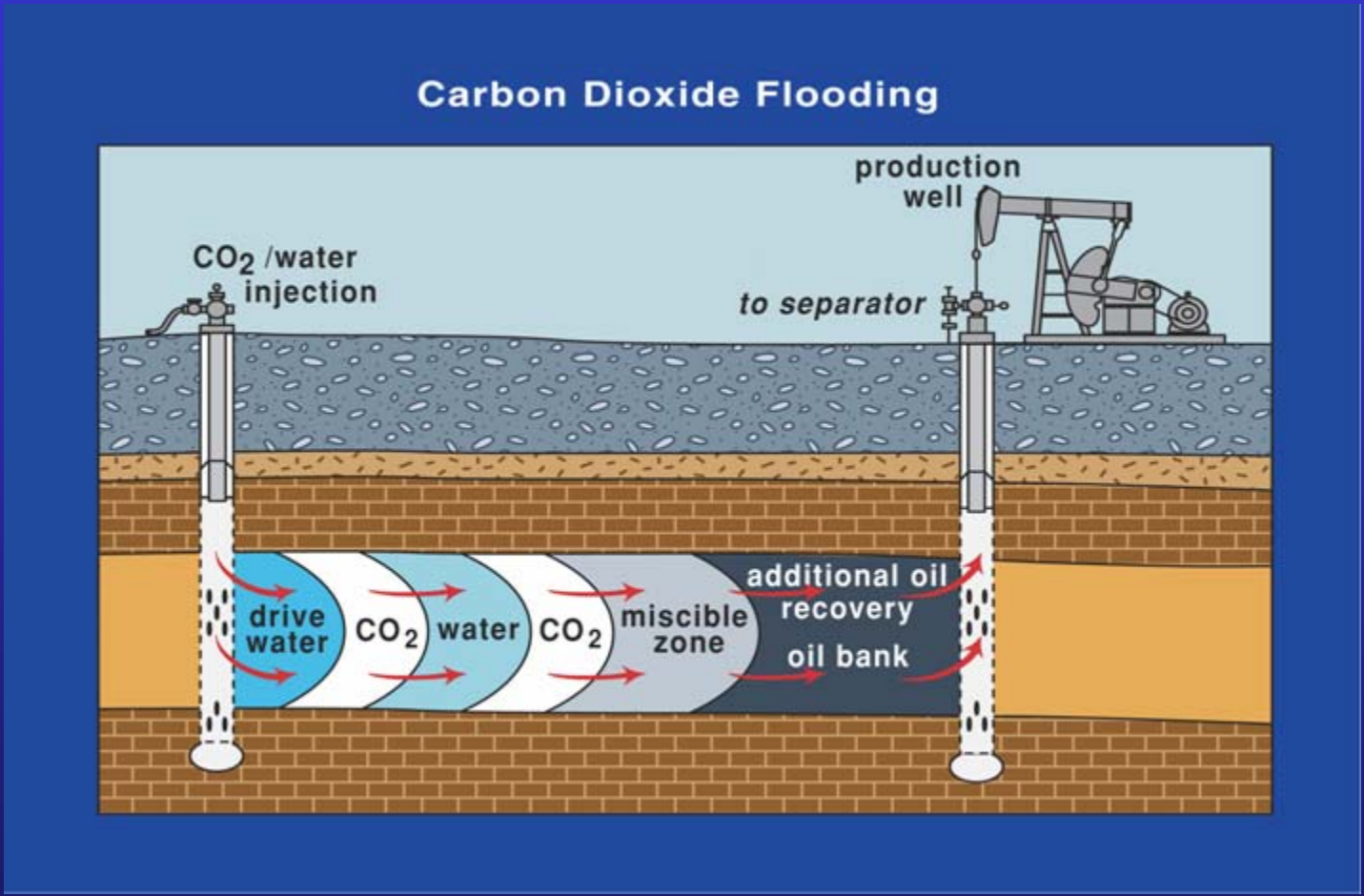
Raw Materials | Ethanol Plant | Products



1 metric ton CO_2 = 19 mcf

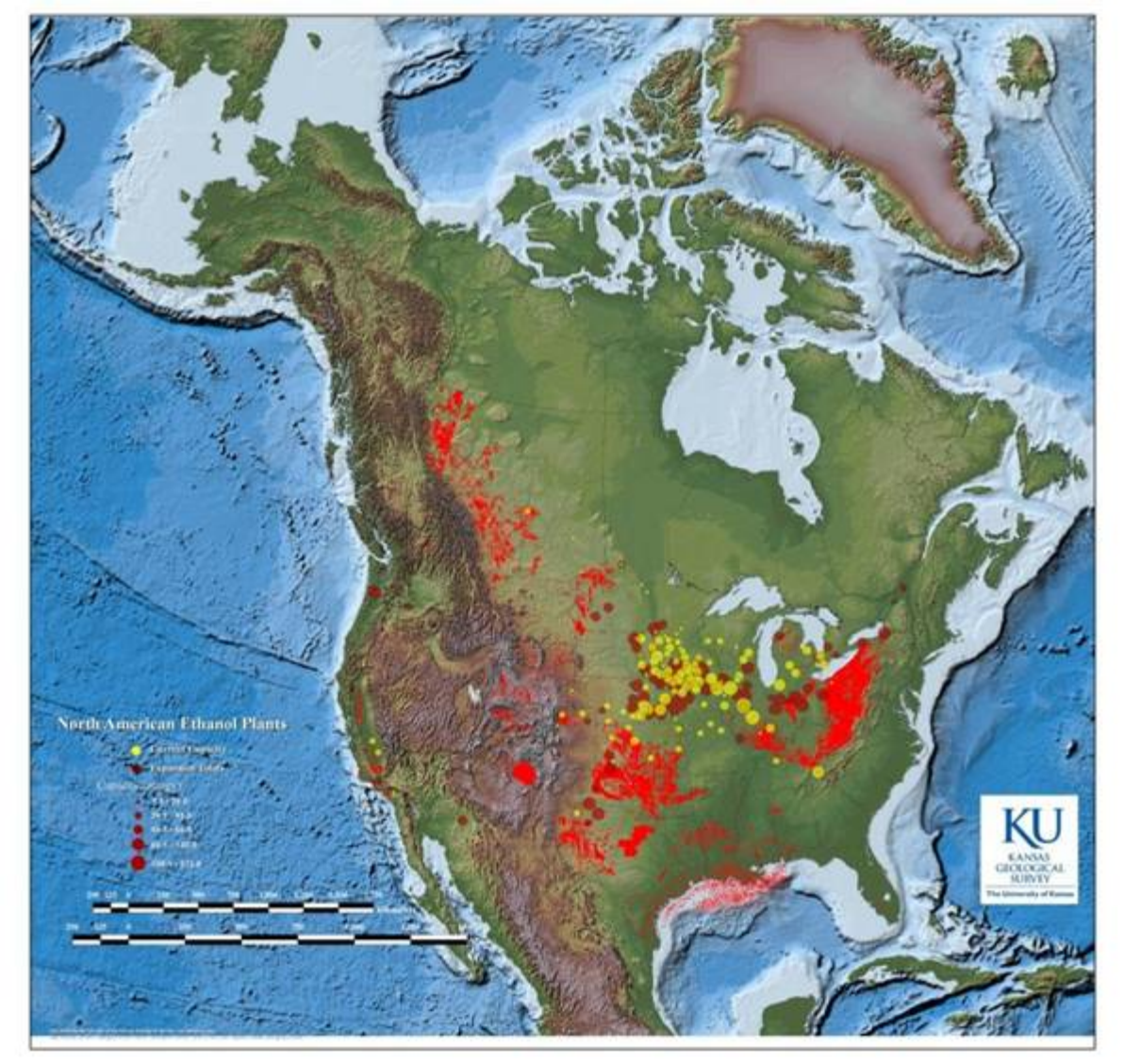
Water
One Bushel Milo
Heat
→ **Fermentation** →
8.4 kg Carbon Dioxide
10 liters Ethanol
8.2 kg Cattle Feed (DDG)

CO2 Miscible Flood Demonstration

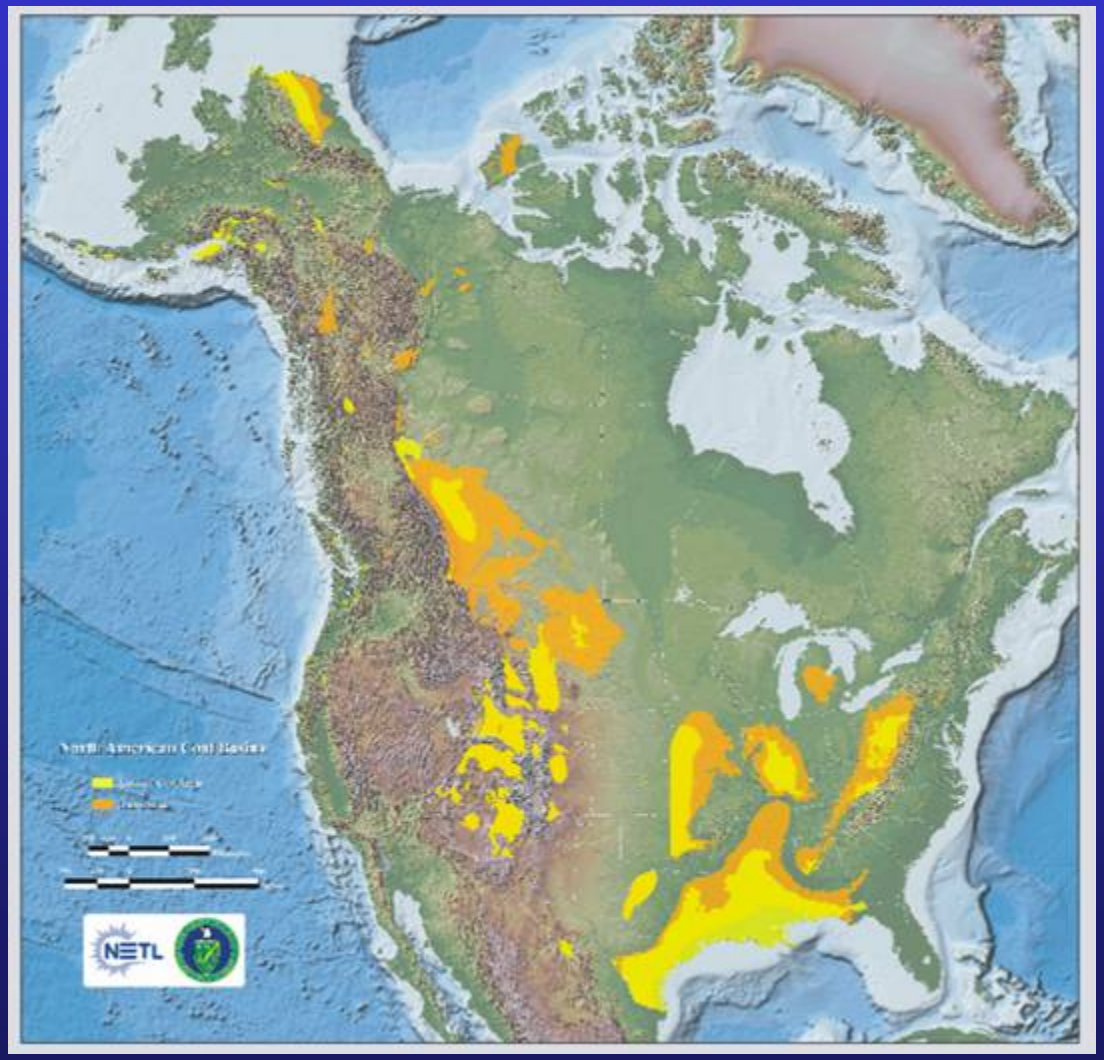


www.kgs.ku.edu/ERC/CO2Pilot

North American Ethanol Capacity and Oil & Gas Fields



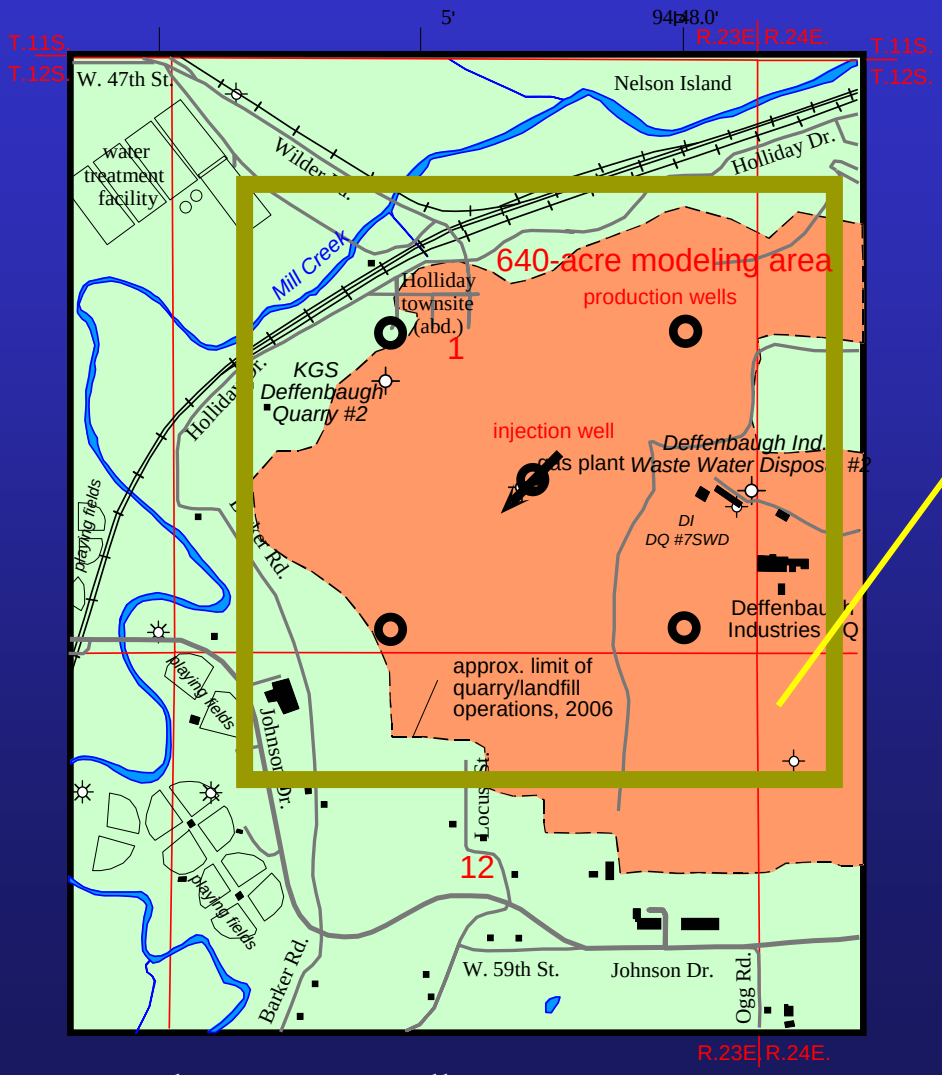
Sinks – Coal Basins



CO_2 Storage Resource Estimates by Regional Carbon Sequestration Partnership for Unmineable Coal Seams				
	Low		High	
RCSP	Billion Metric Tons	Billion Tons	Billion Metric Tons	Billion Tons
BSCSP	12.1	13.3	12.1	13.3
MGSC	1.7	1.8	2.4	2.6
MRCSP	0.8	0.9	0.8	0.9
PCOR	10.7	11.8	10.7	11.8
SECARB	43.8	48.3	63.0	69.4
SWP	0.7	0.8	1.8	2.0
WESTCARB	86.8	95.7	86.8	95.7
TOTAL	157	173	178	196

Kansas
Total 8 Million Metric Tons
< 1 year

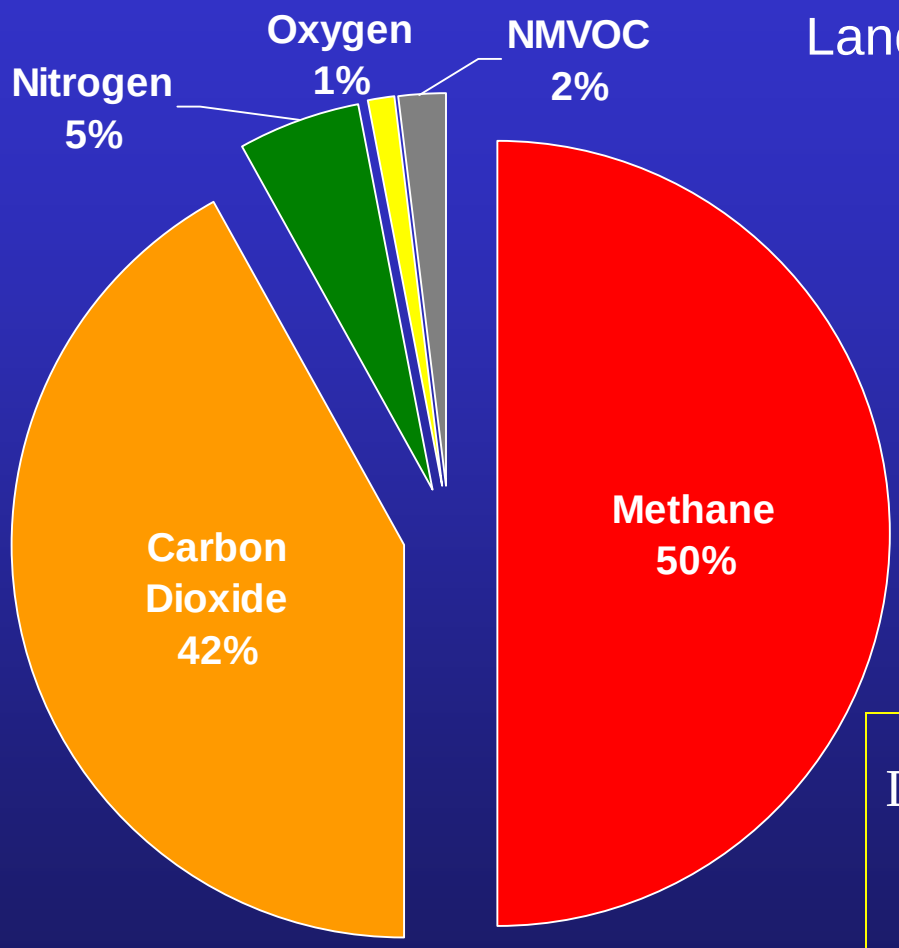
Deffenbaugh Landfill, Kansas City



160-acre drainage per well

Typical LFG well

Landfill Gas

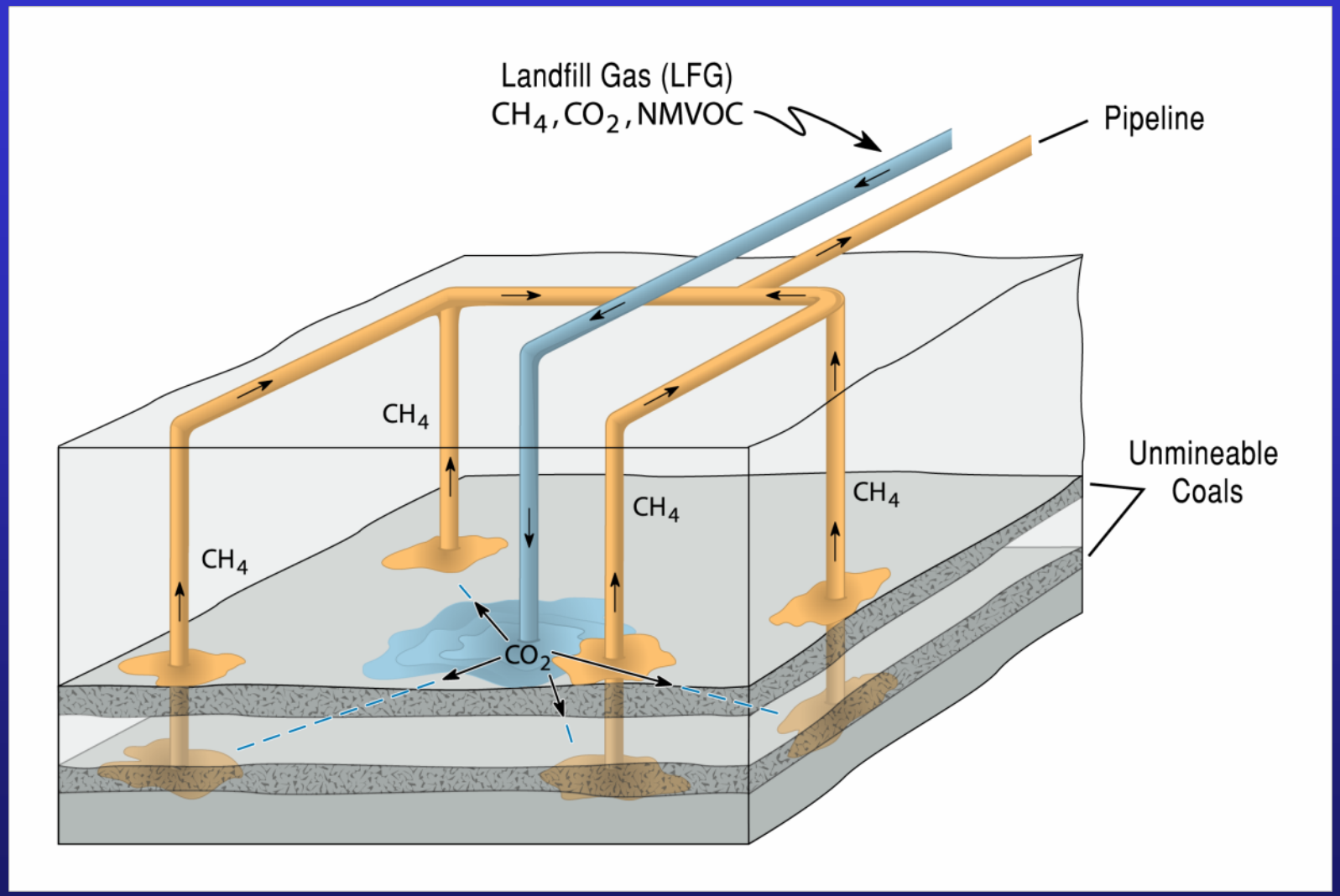


Landfill Gas (LFG)

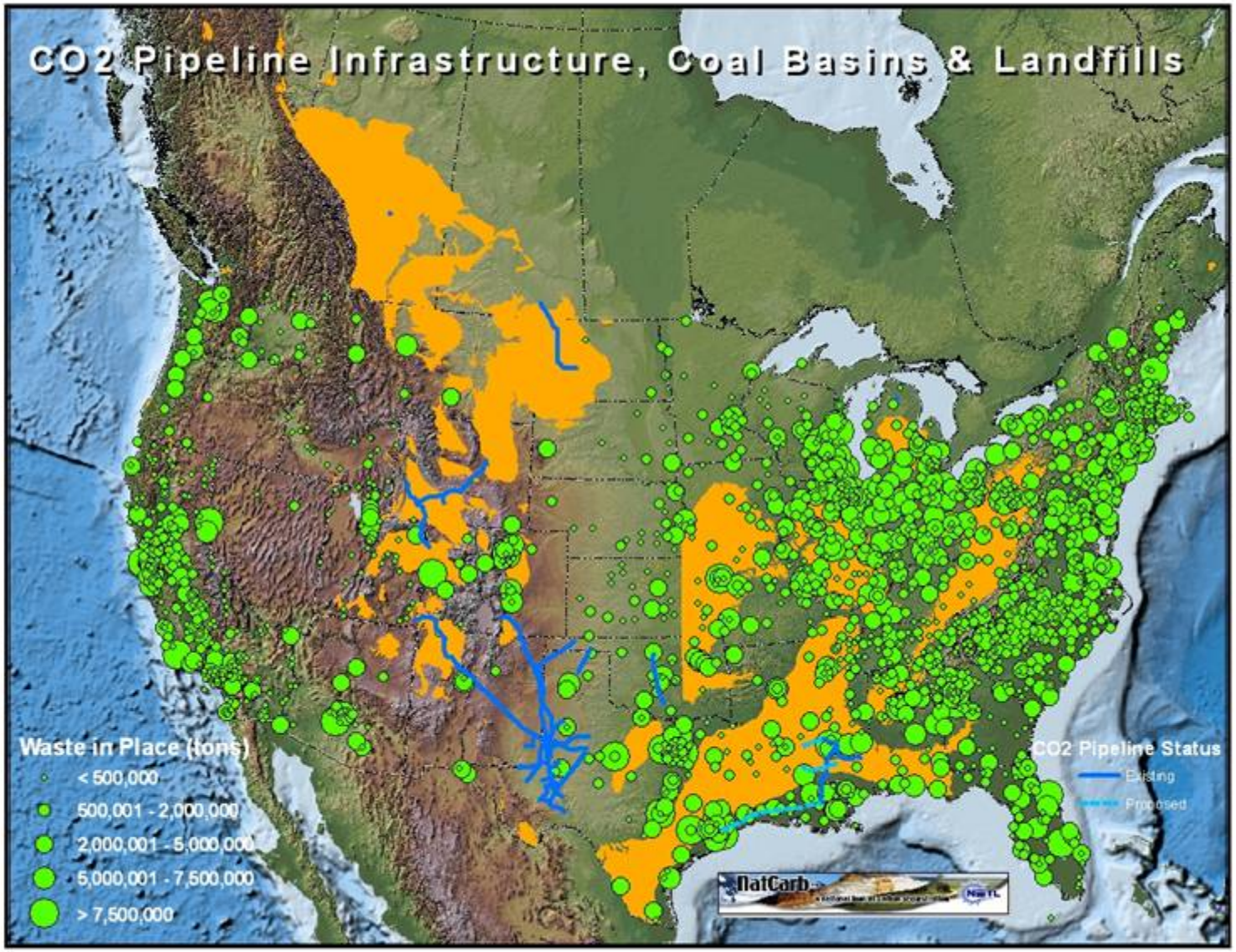
- **9.3 % US Greenhouse Gas Emissions**
- **8.1 Million Metric Tons CH_4**
  - **4.9 Million Captured**
    2.4 Million Flared

Deffenbaugh Facility Upgrade Plant

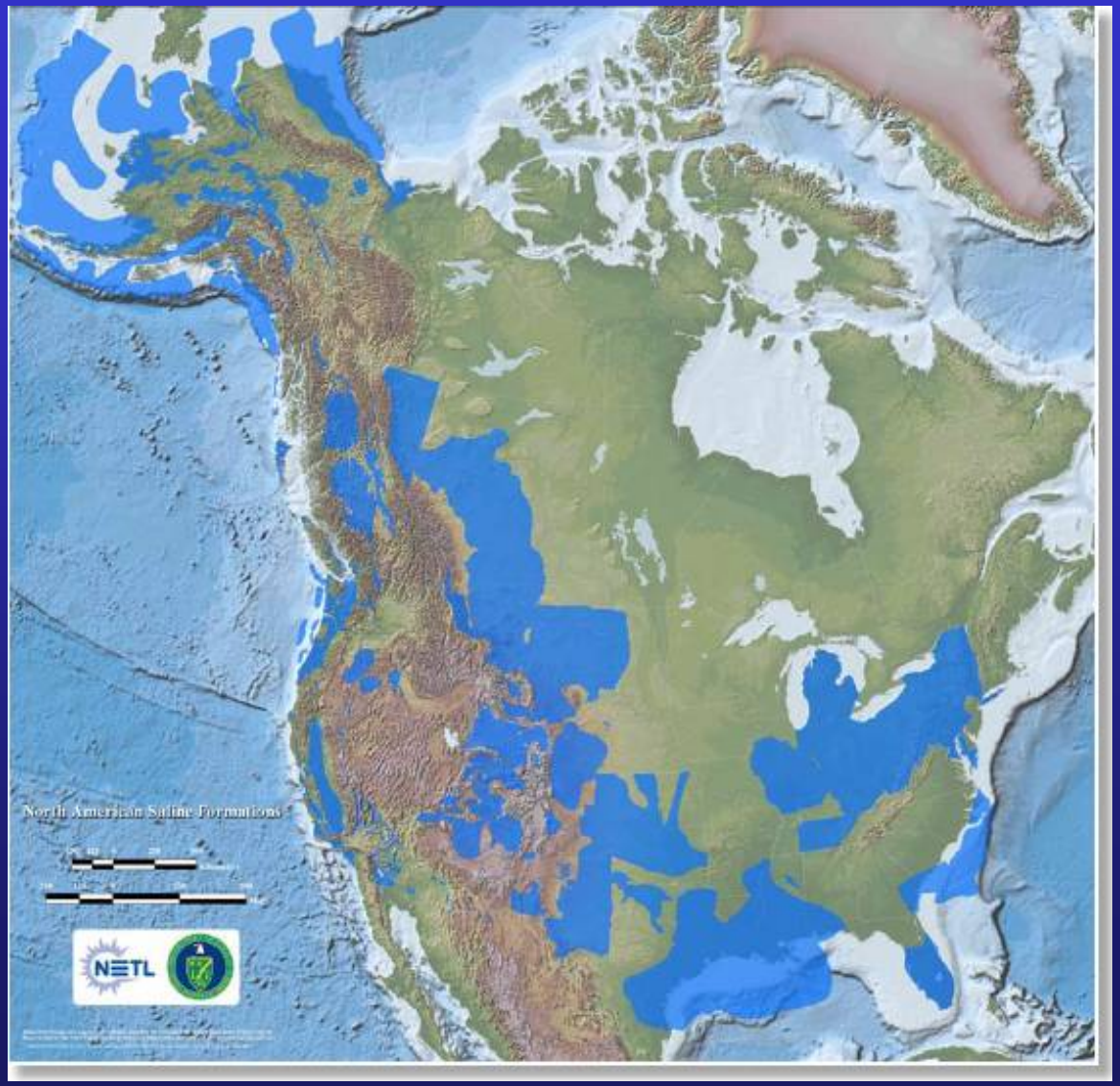
- **LFG 2.2 mmcf/day**
  CO_2 - 1.1 mmcf/d
- **Currently venting CO_2 and selling CH4 to the pipeline**


Landfill Gas (LFG)
CH_4, CO_2, NMVOC
Pipeline
CH_4
CH_4
CH_4
CH_4
CO_2
Unmineable
Coals

United States Landfills and Coal Basins



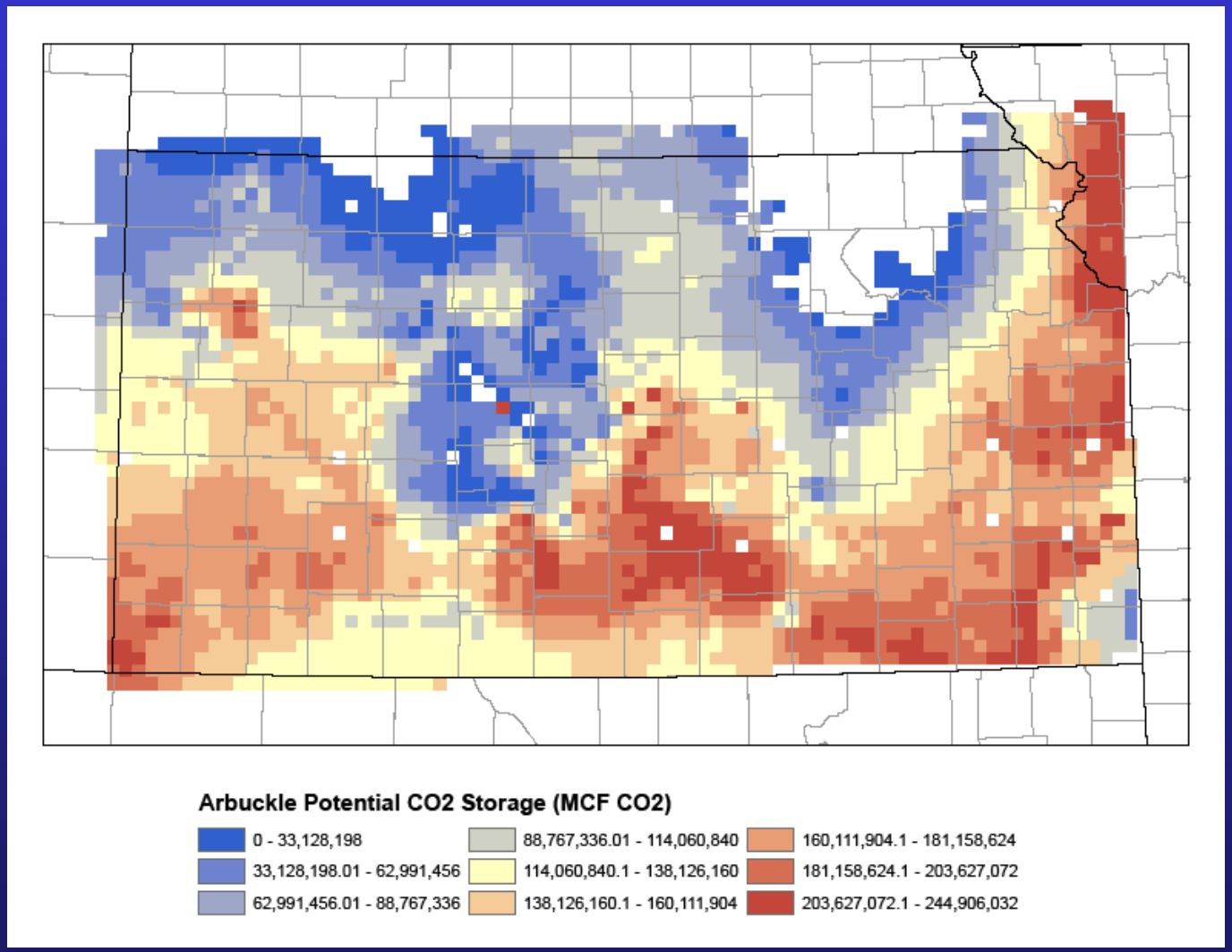
Sinks – Saline Formations



CO_2 Storage Resource Estimates by Regional Carbon Sequestration Partnership for Saline Formations				
	Low		High	
RCSP	Billion Metric Tons	Billion Tons	Billion Metric Tons	Billion Tons
BSCSP	460.9	508.0	1,831.5	2018.9
MGSC	29.2	32.1	116.6	128.6
MRCSP	49.6	54.7	199.1	219.5
PCOR	185.6	204.6	185.6	204.6
SECARB	2,274.6	2,507.3	9,098.4	10029.3
SWP	92.4	101.9	368.9	406.6
WESTCARB	204.5	225.4	818.2	901.9
TOTAL	3,297	3,634	12,618	13,909

Kansas
Total 10,600 Million Metric Tons
285 years

Sinks – Saline Formations



Arbuckle Saline Formation – 1,393 Class II
400 Million Barrels/Year
64 Million Metric Tons/Year

Carr, Merriam & Bartley, 2005

Issues to Address

- **CO_2 capture issues**
  - Operational efficacy of technologies
  - Parasitic load
  - Financial impact
- **CO_2 storage issues**
  - Pipeline network
  - Regulatory jurisdiction
  - Licensing & Permitting
  - Public acceptance
  - Property mineral rights
  - Monitoring & verification protocols
  - Geologic modeling validation & tuning
  - Risk mitigation
  - Life-cycle stewardship

Industrial/Regulatory/Legal Network (transport, injection, inspections, etc.)

Risks, Liabilities & Other Impediments

Project Finance: Uncertainty is a Deal Killer

- No Regulations
- No Technical Standards
- High Cost
- Uncertain Liabilities
- Possible Lack of Public Acceptance
- Uncertain Treatment Under Unknown Climate Regime

Uncertain CCS Costs Make Projects Uneconomic

- Cost of capture = f (technology + industrial process)
- Cost of pipeline = f (distance between source & sink)
  - ✓ *$40k/inch-mile is a decent metric*
- Cost of storage = f (regulatory-liability burden, location, geology, CO_2-EOR/EGR vs. deep saline)

The Coming Train Wreck …

- *Policymakers rushing to implement CCS*
  - ✓ *Senate requires CTL demonstrations to incorporate CCS*
  - ✓ *Senator Reid to Nevada (Aug '07): "No more coal-fired generation unless CCS"*
  - ✓ *Rep. Waxman to EPA (Sept. 30, 2007): "you may only approve the permit if it incorporates CCS," petition to overturn Bonanza permit (Utah)*
  - ✓ *G8-IEA-CLSF, Hokkaido, July 2008, "Governments should urgently establish primary assessment of prospective sedimentary basins using an appropriate CO_2 storage capacity estimation methodology, including source-sink matching."*
  - ✓ *Expect CCS Legislation to be proposed in the next Congress*
- *States are getting in the game, too*
- *Fundamental Transition of our Energy Systems*
  - *High Costs (Multiple Increase in Energy Costs)*
  - *Long Time Frames (50 to 100 years)*

The Need for Action

- Portfolio of Energy/Environmental Options
  - Technically Sound
  - Economically Sustainable
  - Significant in Size
  - Minimize Environmental Impact
- Develop basic research and enabling technologies for subsurface carbon storage to reduce CO_2 in the atmosphere.
- Need for Long-Term Investment
  - Technology
  - Education
  - People

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