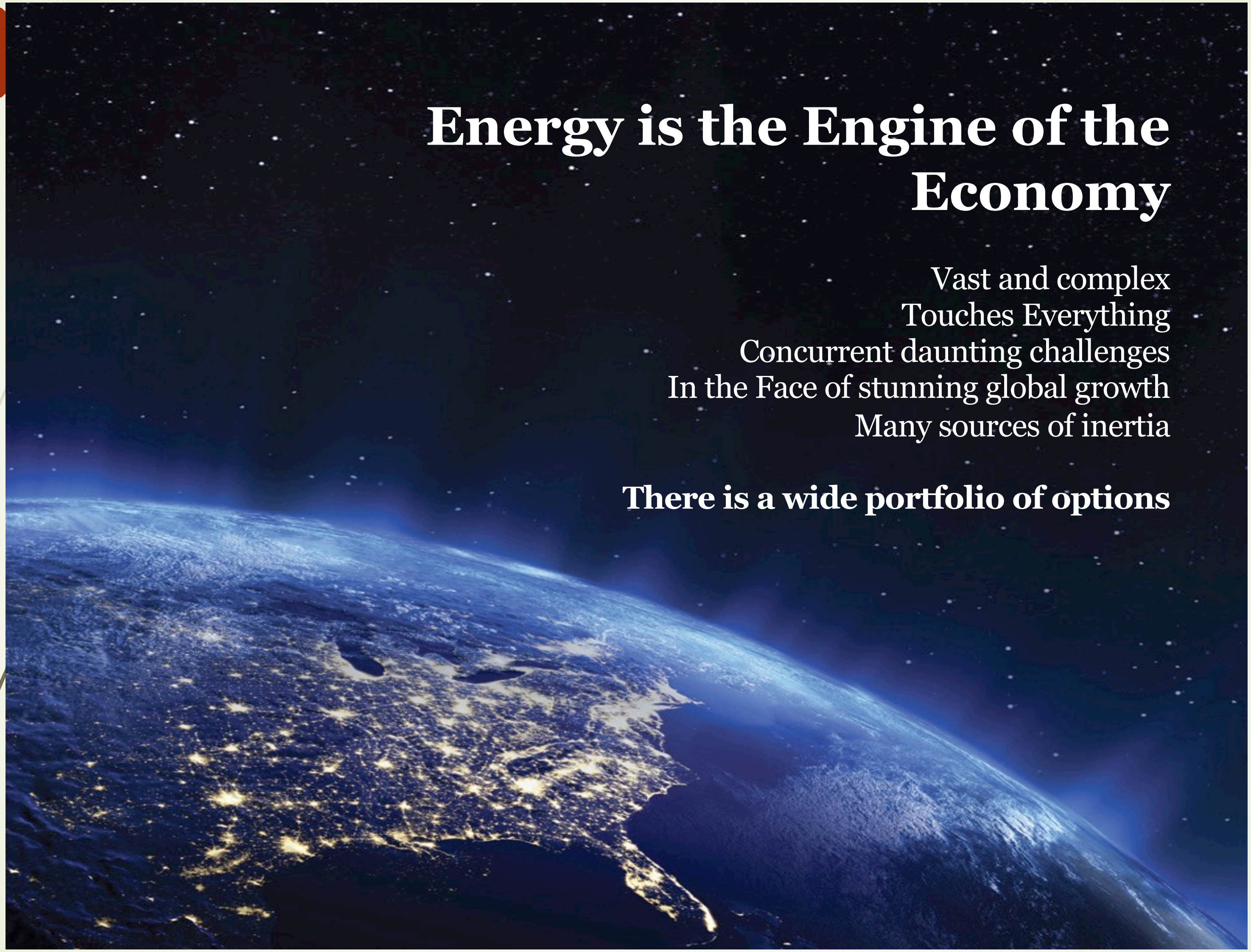
The Growing Conflicts in the Global Energy Enterprise

Michael L Knotek, PhD
Naval Postgraduate School
Monterey California
February 1, 2019



Energy is the Engine of the Economy

Vast and complex
Touches Everything
Concurrent daunting challenges
In the Face of stunning global growth
Many sources of inertia

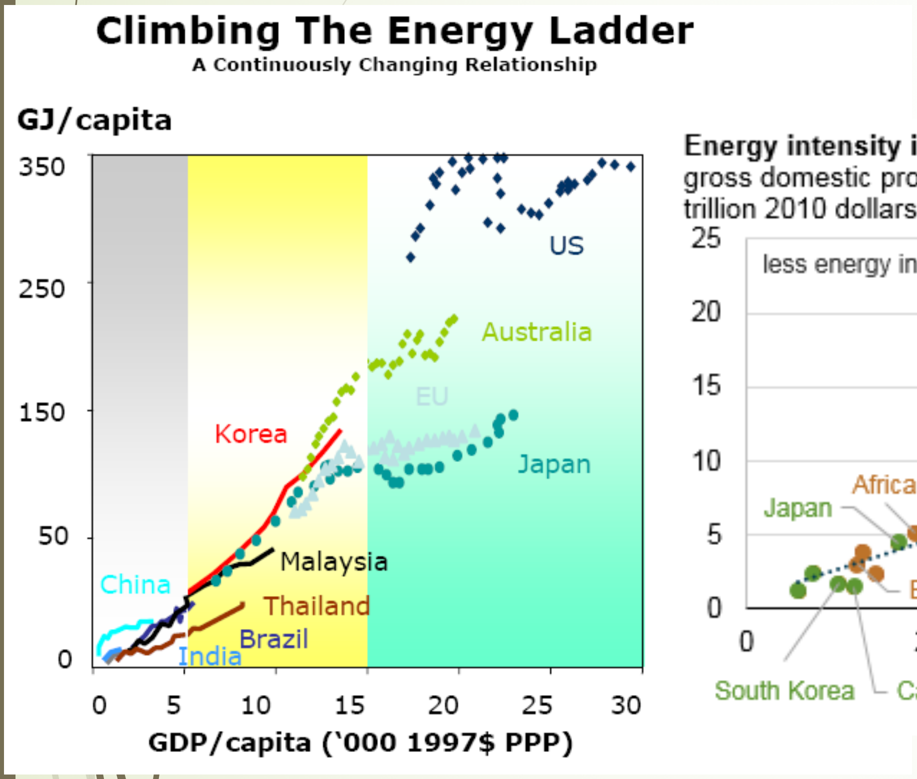
There is a wide portfolio of options

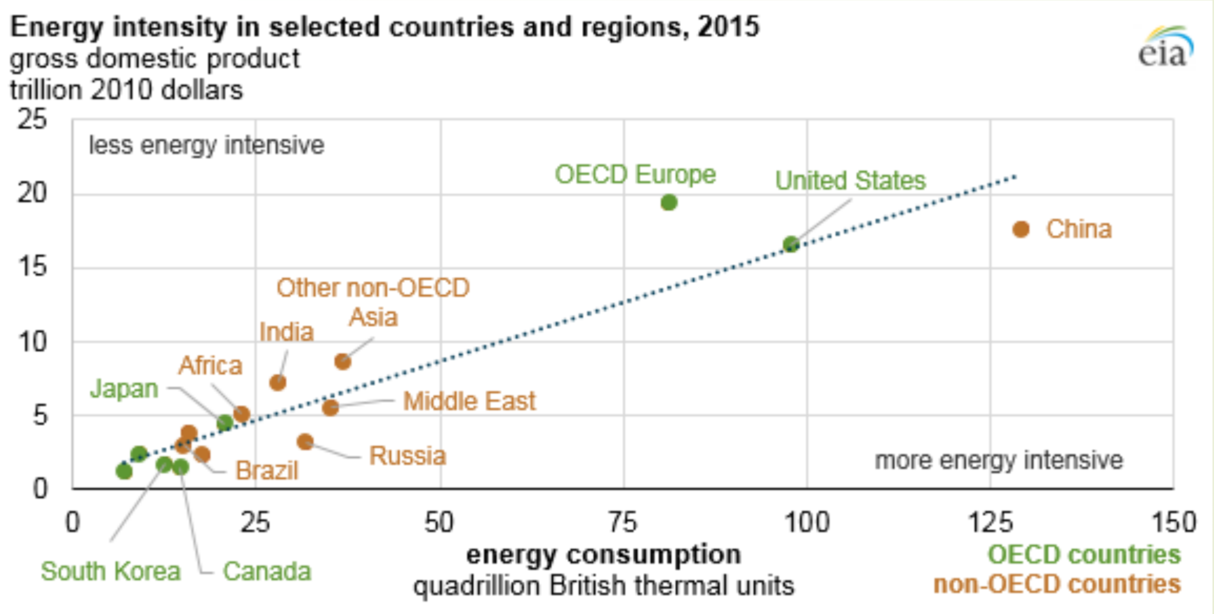
The Global Energy Challenge

A triple challenge

- Global prosperity
  - Energy demand growth
- Energy security
  - Supply challenges
- Climate protection
  - Carbon constraints

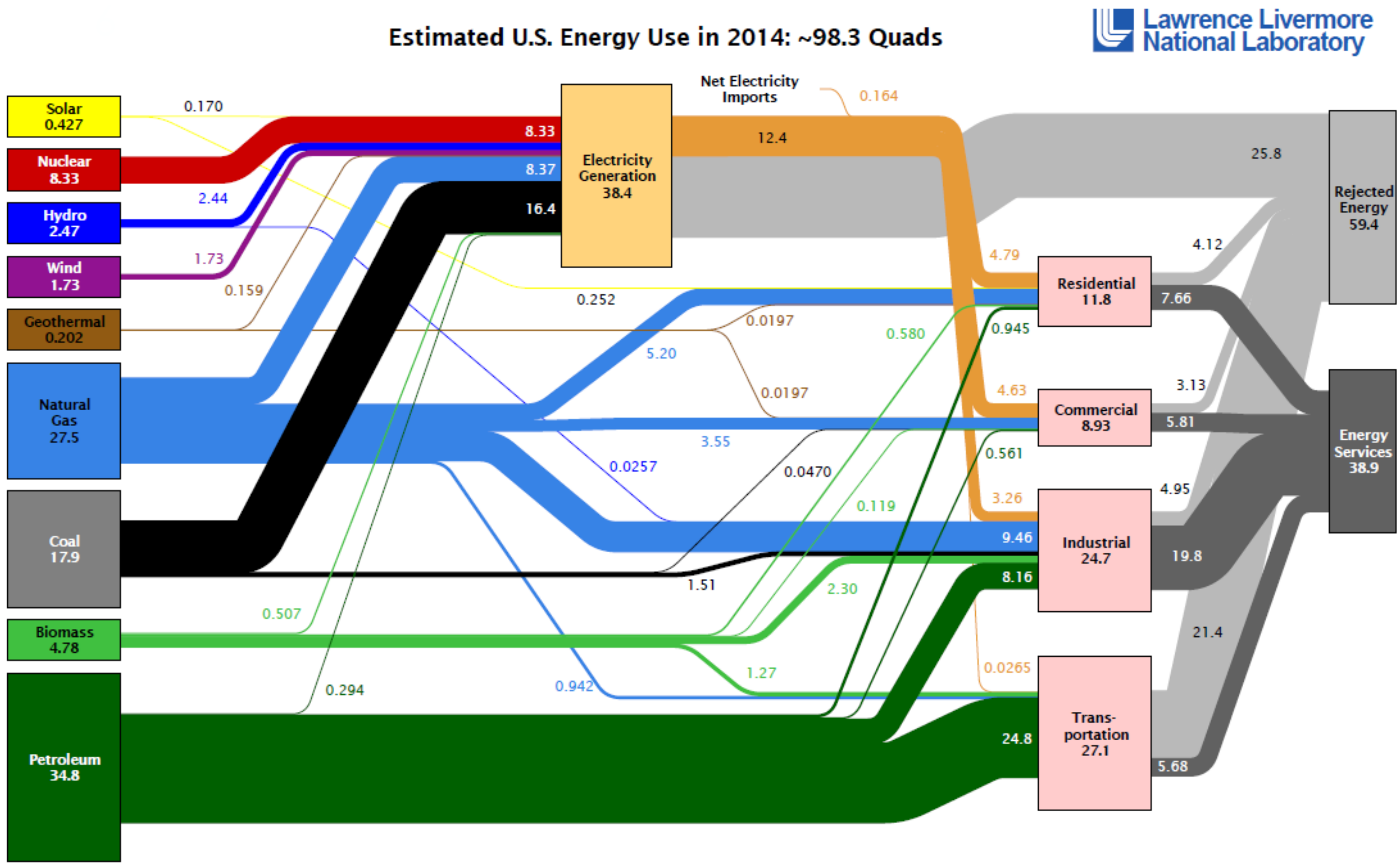
Why Is This Not Going Away?
A: Energy Translates to GDP





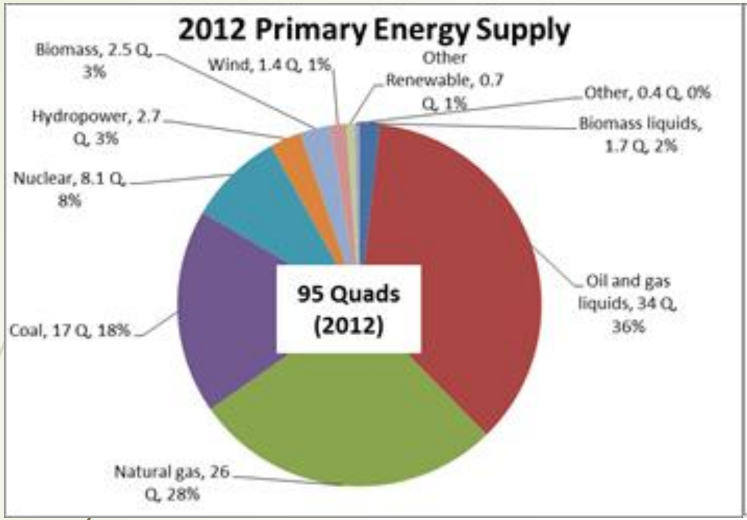
Energy:
Where Do We Get It?
How Do We Use It?

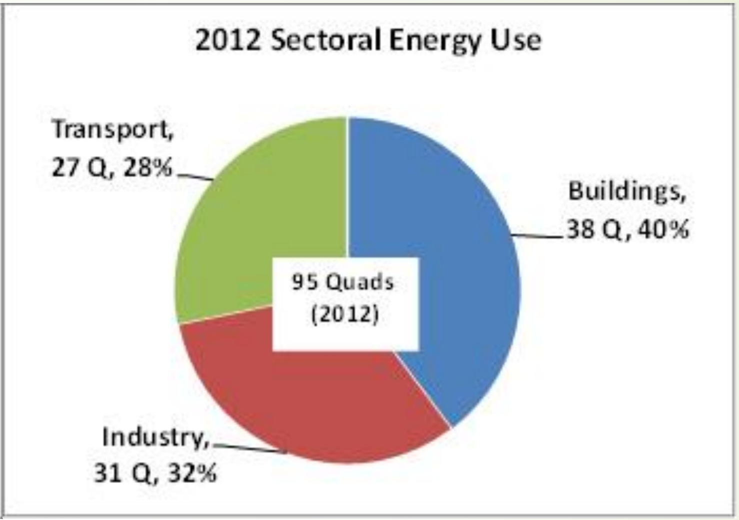
Sankey Diagram of Energy Flows in US Economy

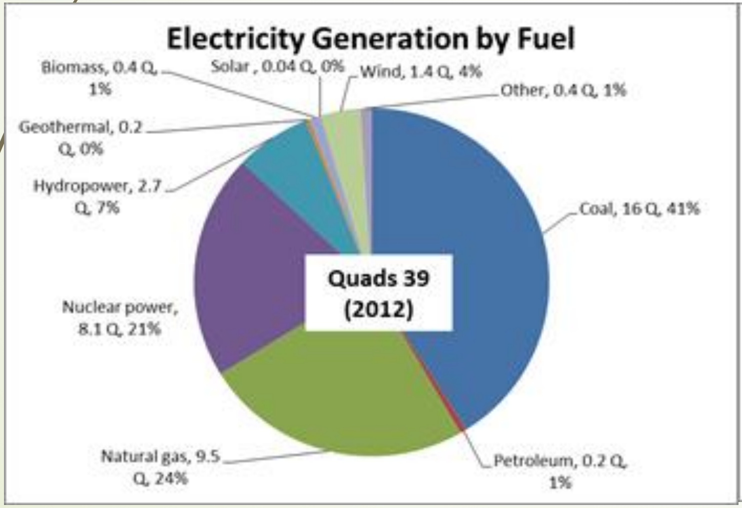


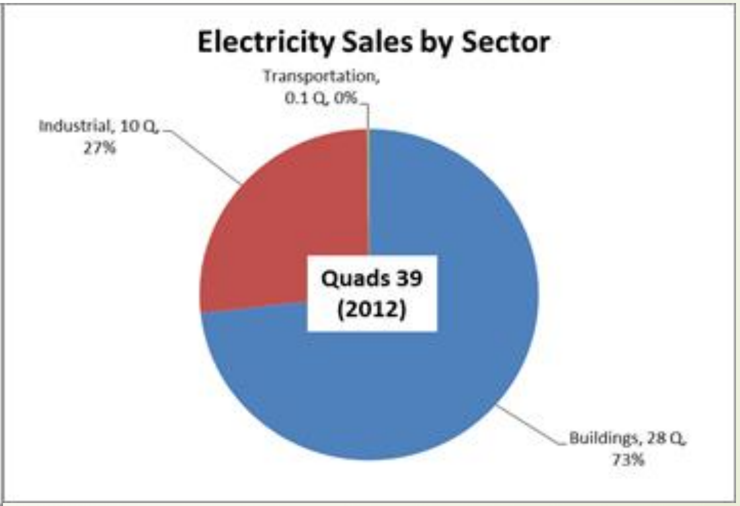
Source: LLNL 2015. Data is based on DOE/EIA-0035(2015-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Energy Generation and Use



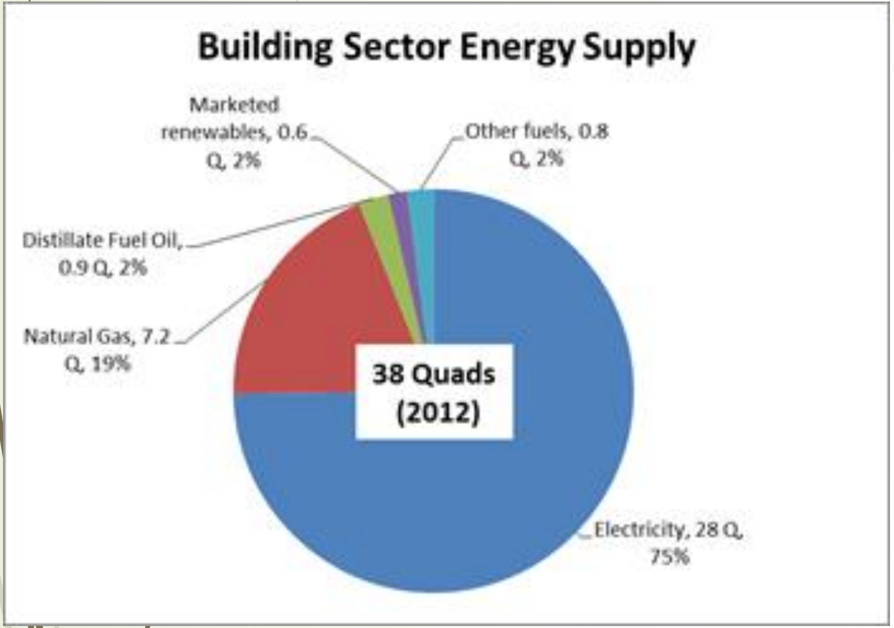


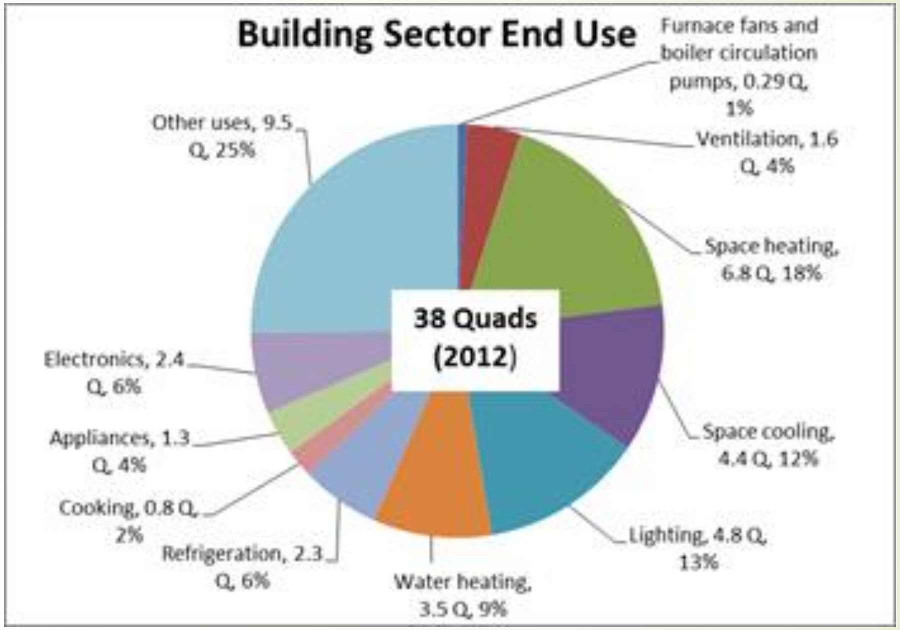




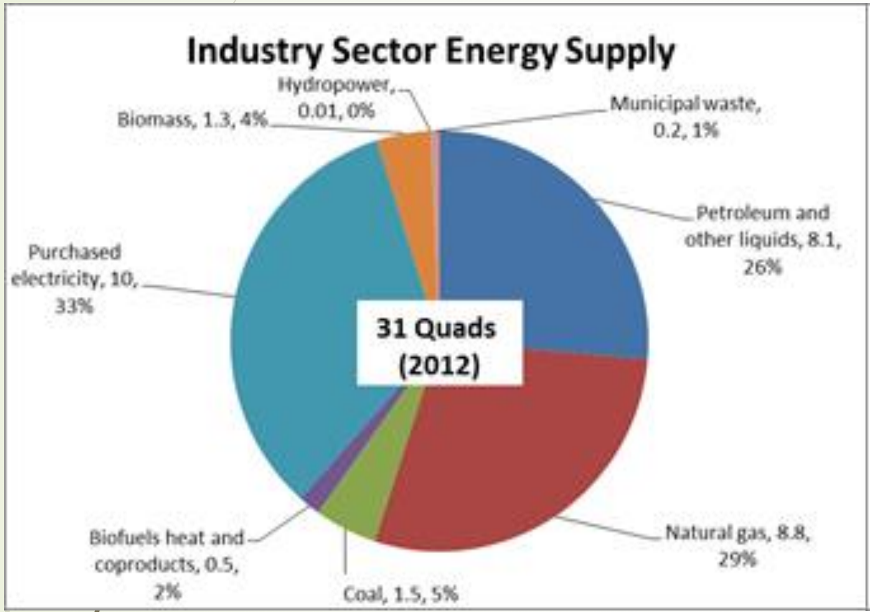
Michael L Knotek, PhD

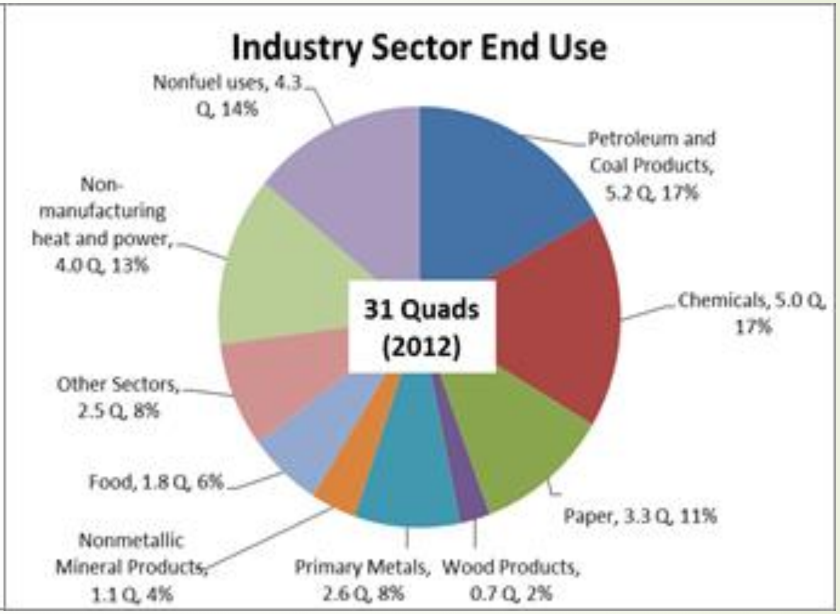
Buildings: Energy Supply and Use



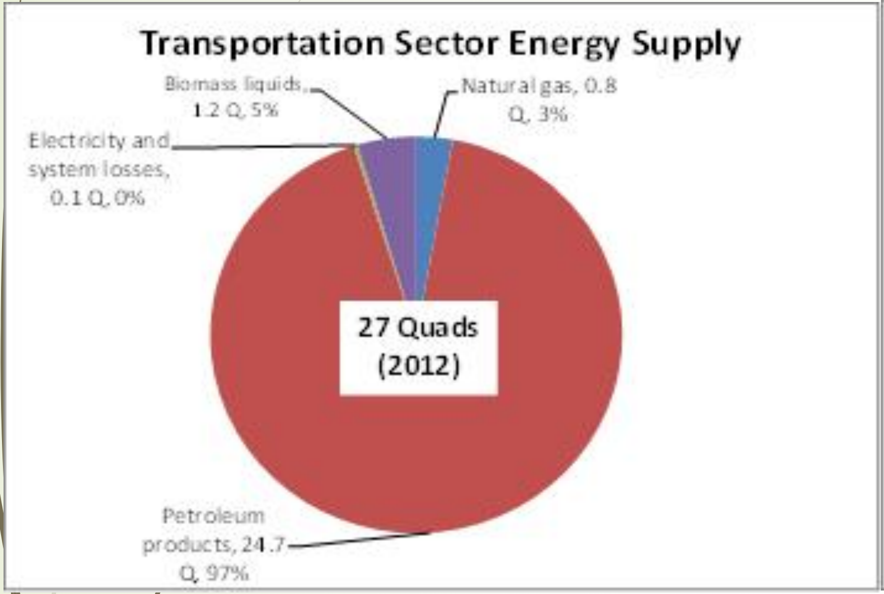


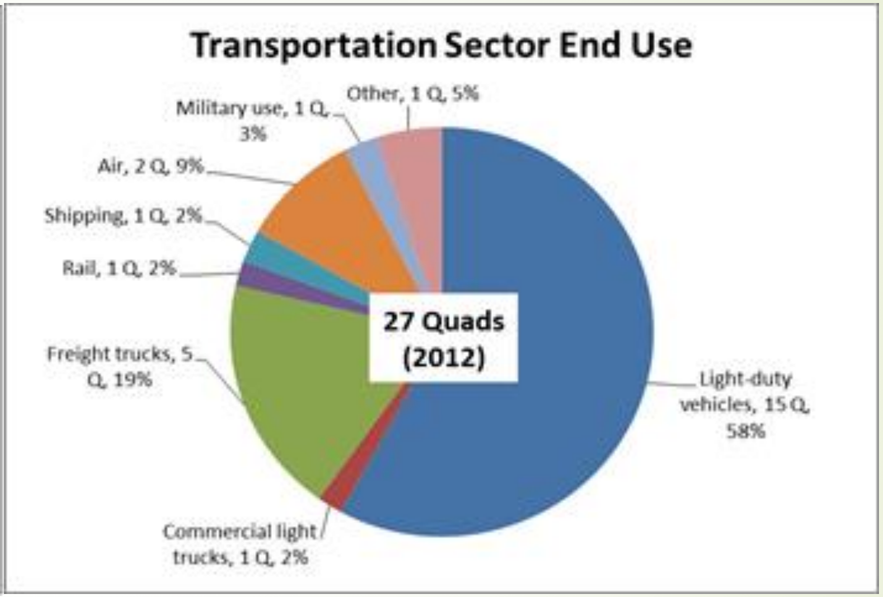
Industry: Supply and Use





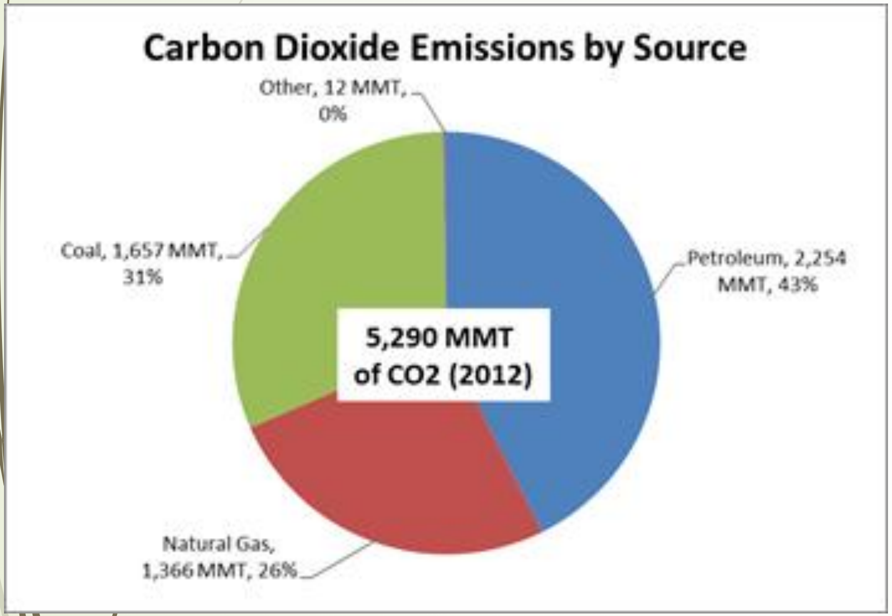
Transportation: Supply and Use

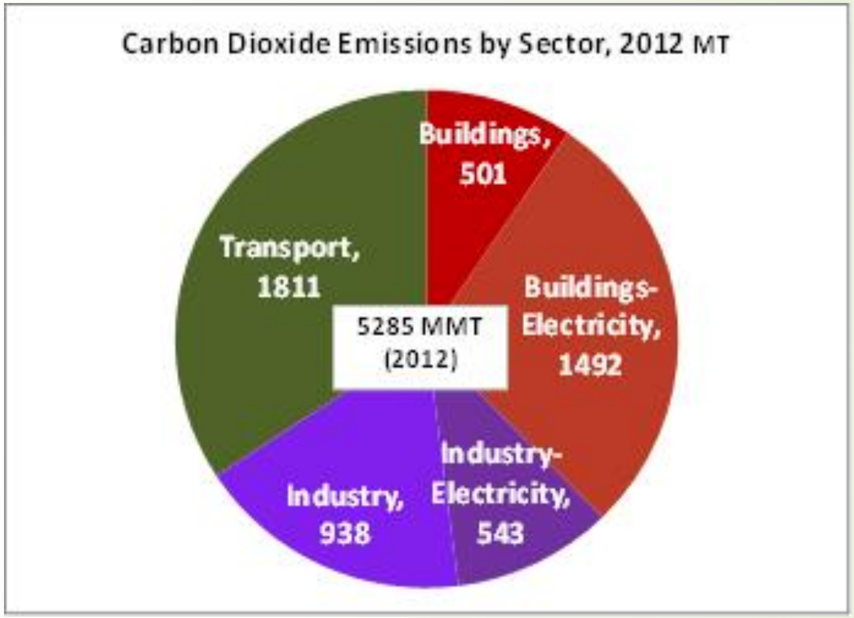




Michael L Knotek, PhD

US Carbon Dioxide Emissions





Global Energy Demand Growth

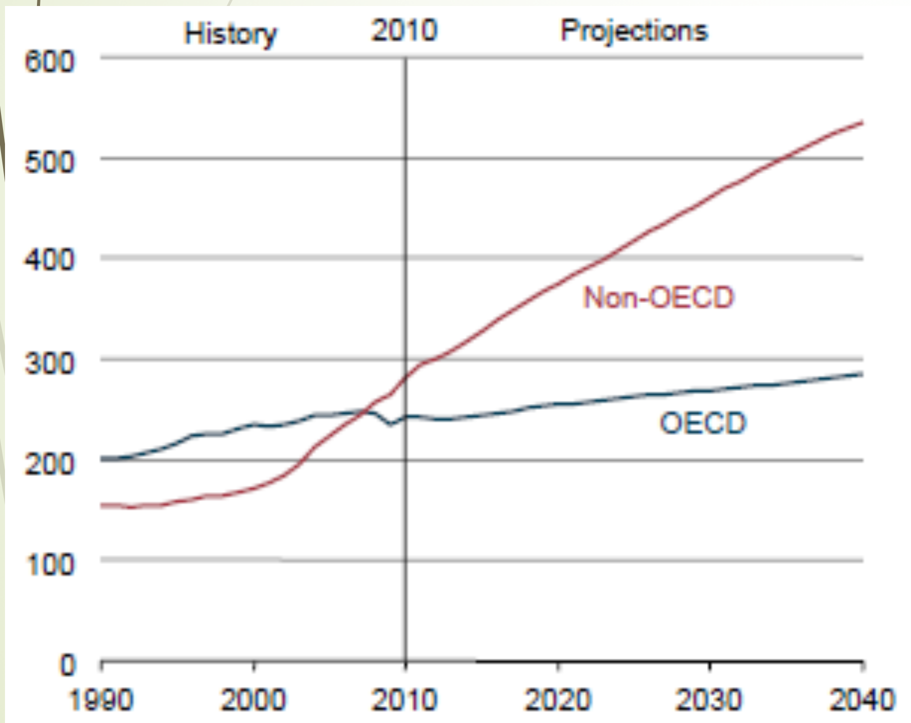
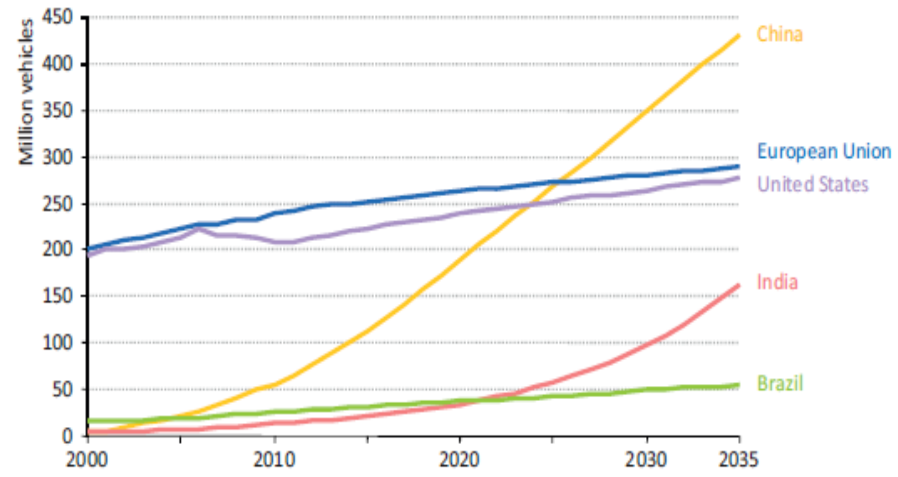
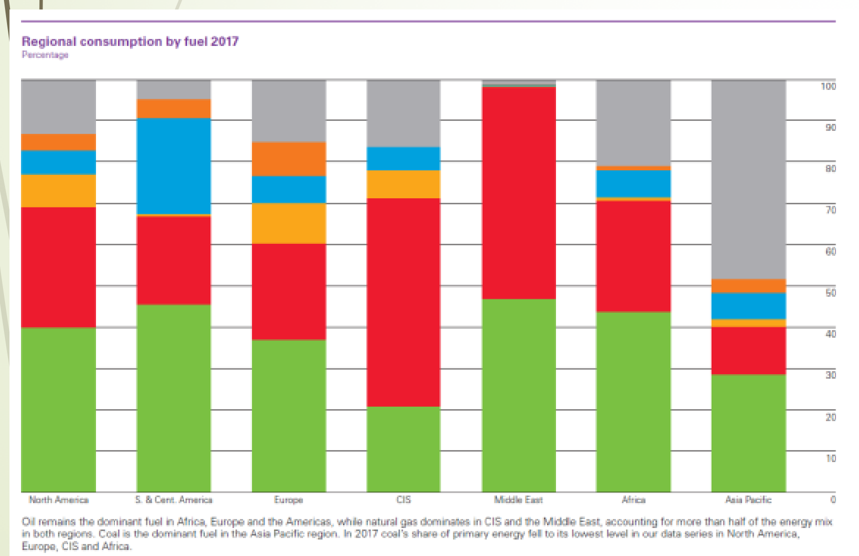
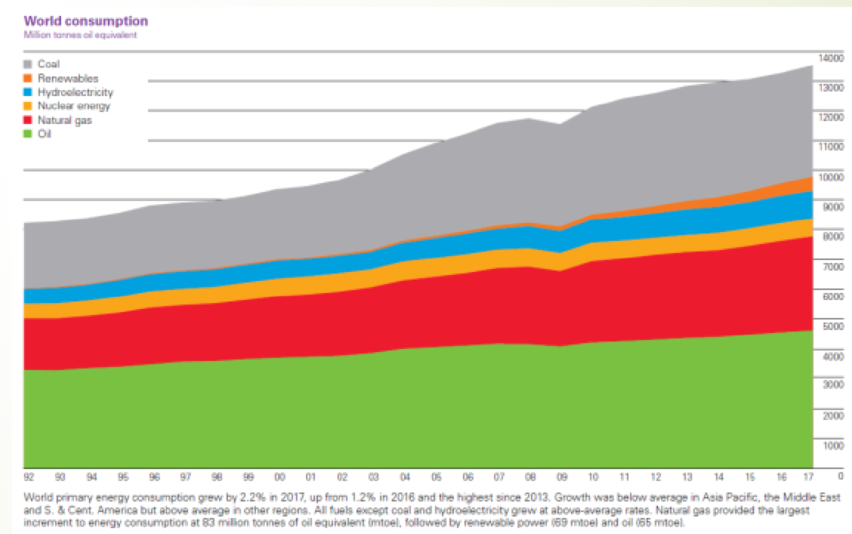


Figure 3.6 ▷ PLDV fleet in selected regions in the New Policies Scenario



Global Energy Growth Patterns

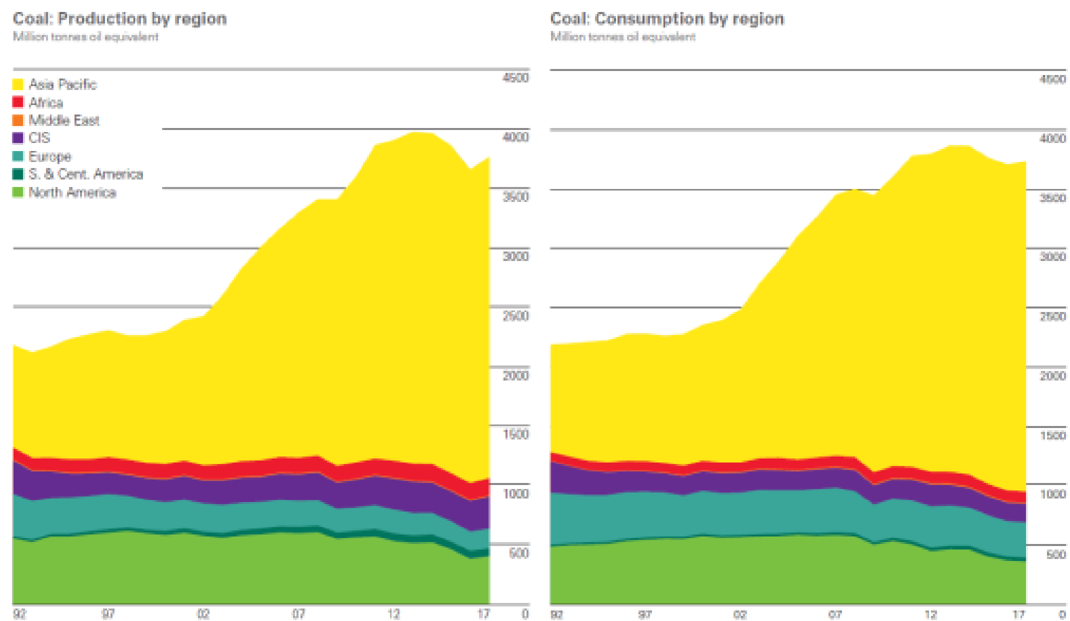




BP Statistical Review of World Energy 2018

Michael L Knotek, PhD

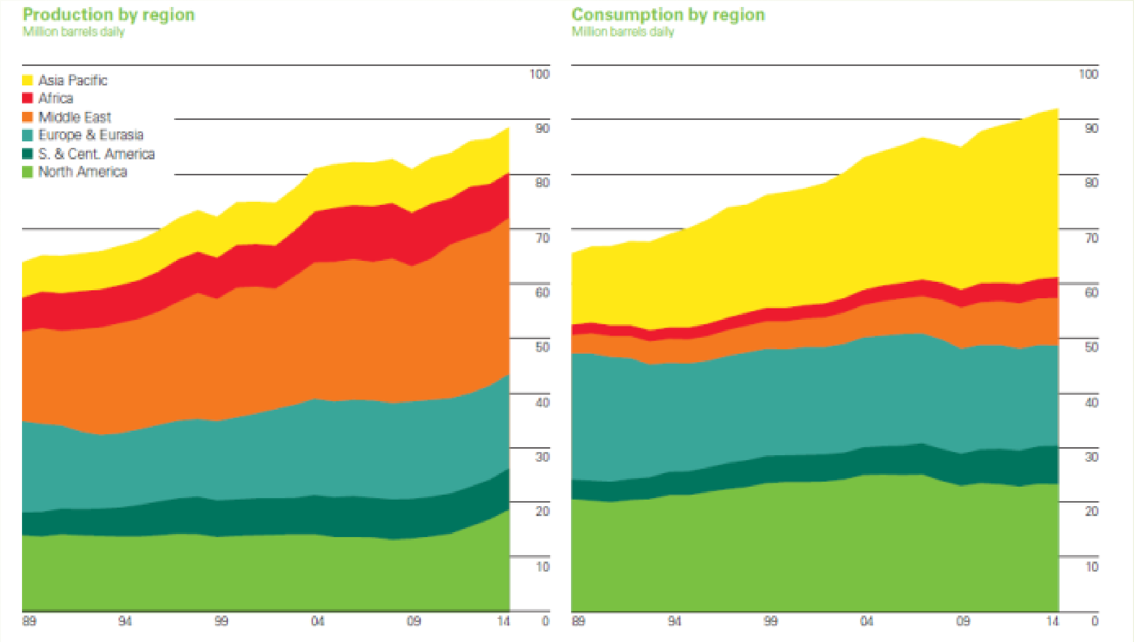
Global Coal Usage



World coal production increased by 105 million tonnes of oil equivalent or 3.2%, the fastest rate of growth since 2011. Production rose by 56 mtoe in China and 23 mtoe in the US. Global coal consumption grew by 25 mtoe, or 1%, the first growth since 2013. Growth was driven largely by India (18 mtoe), with China consumption also up slightly (4 mtoe) following three successive annual declines during 2014-2016. OECD demand fell for the fourth year in a row (-4 mtoe).

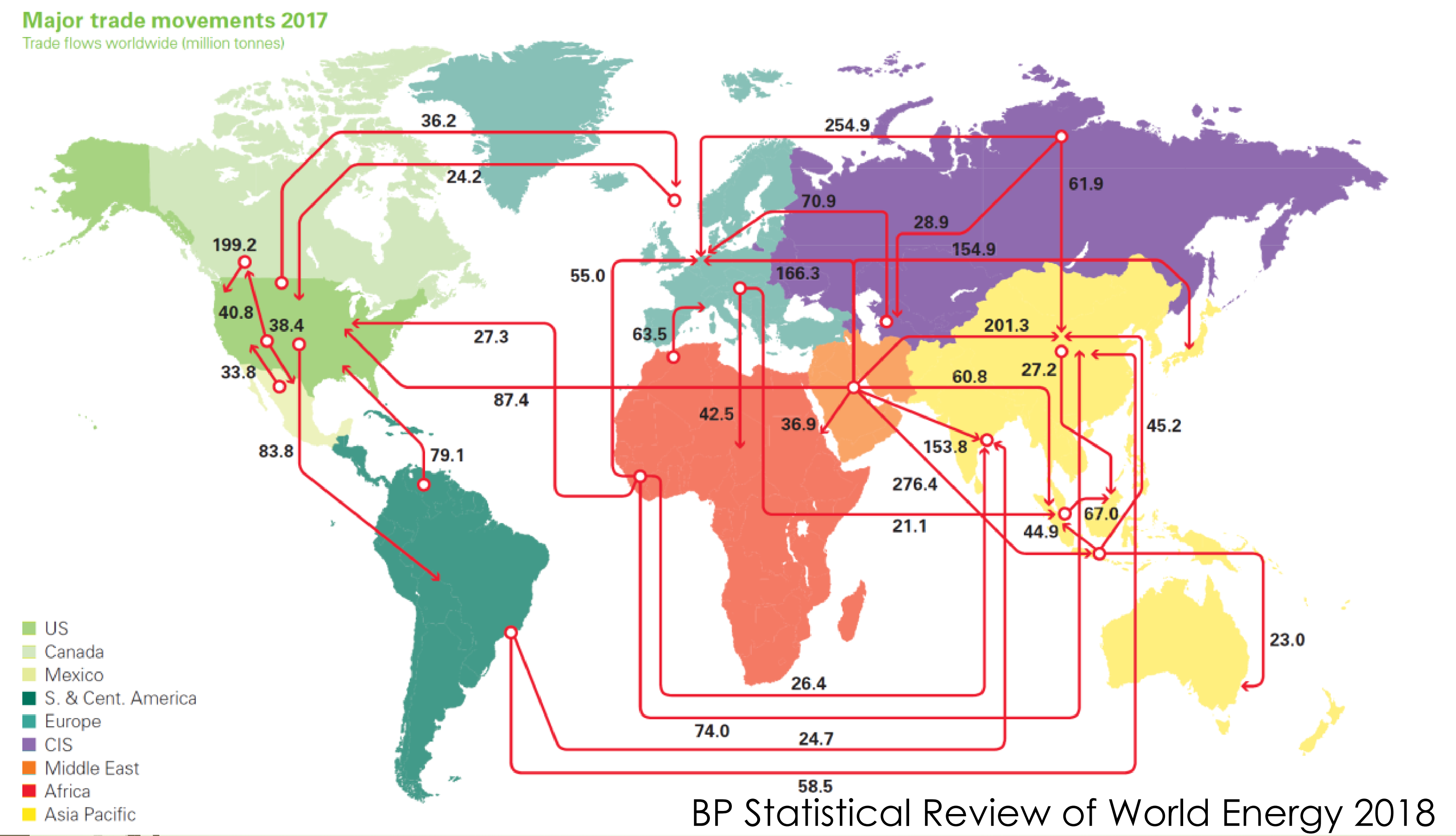
BP Statistical Review of World Energy 2018

Global Oil Production and Consumption



BP Statistical Review of World Energy 2018

Global Petroleum Flows

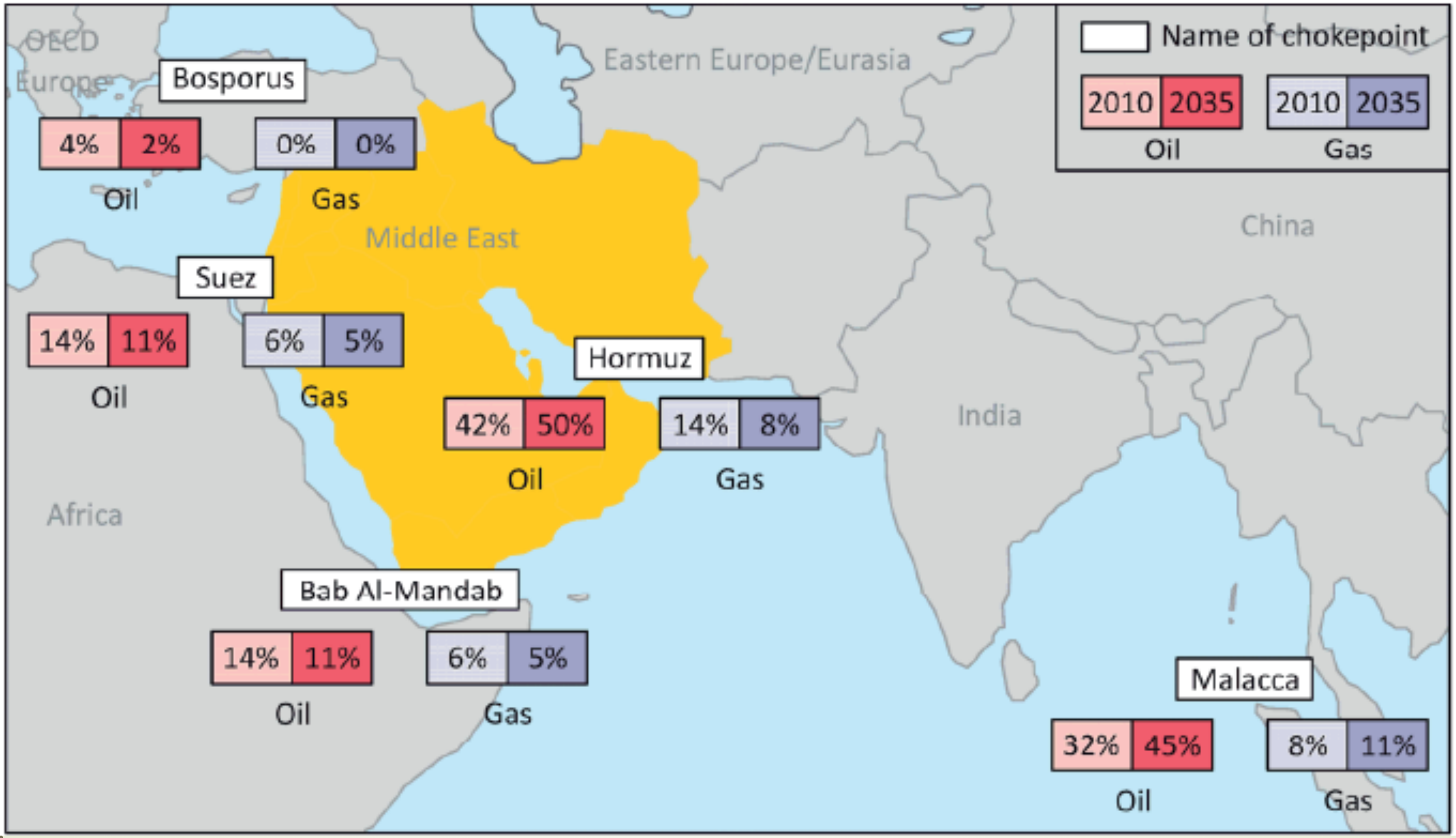


BP Statistical Review of World Energy 2018

We Use ~20 Mb/day, Import ~7Mb/Day

Oil and Gas Transportation Choke Points

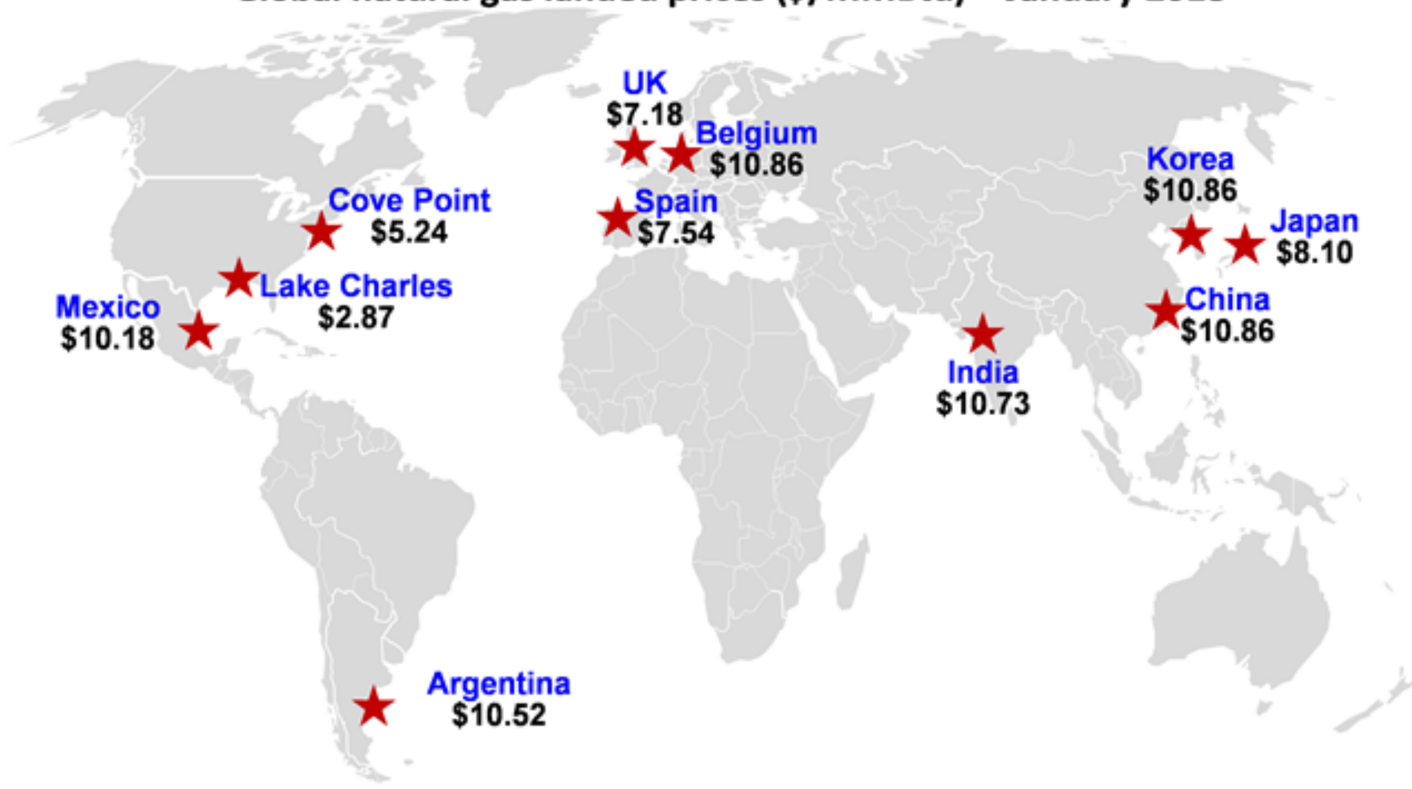
Figure 2.18 ▷ **Share of inter-regional oil and gas trade through key choke points in the New Policies Scenario**



2017 Gas Flows

Low U.S. natural gas prices motivate LNG production and exports

Global natural gas landed prices ($/MMBtu) – January 2018



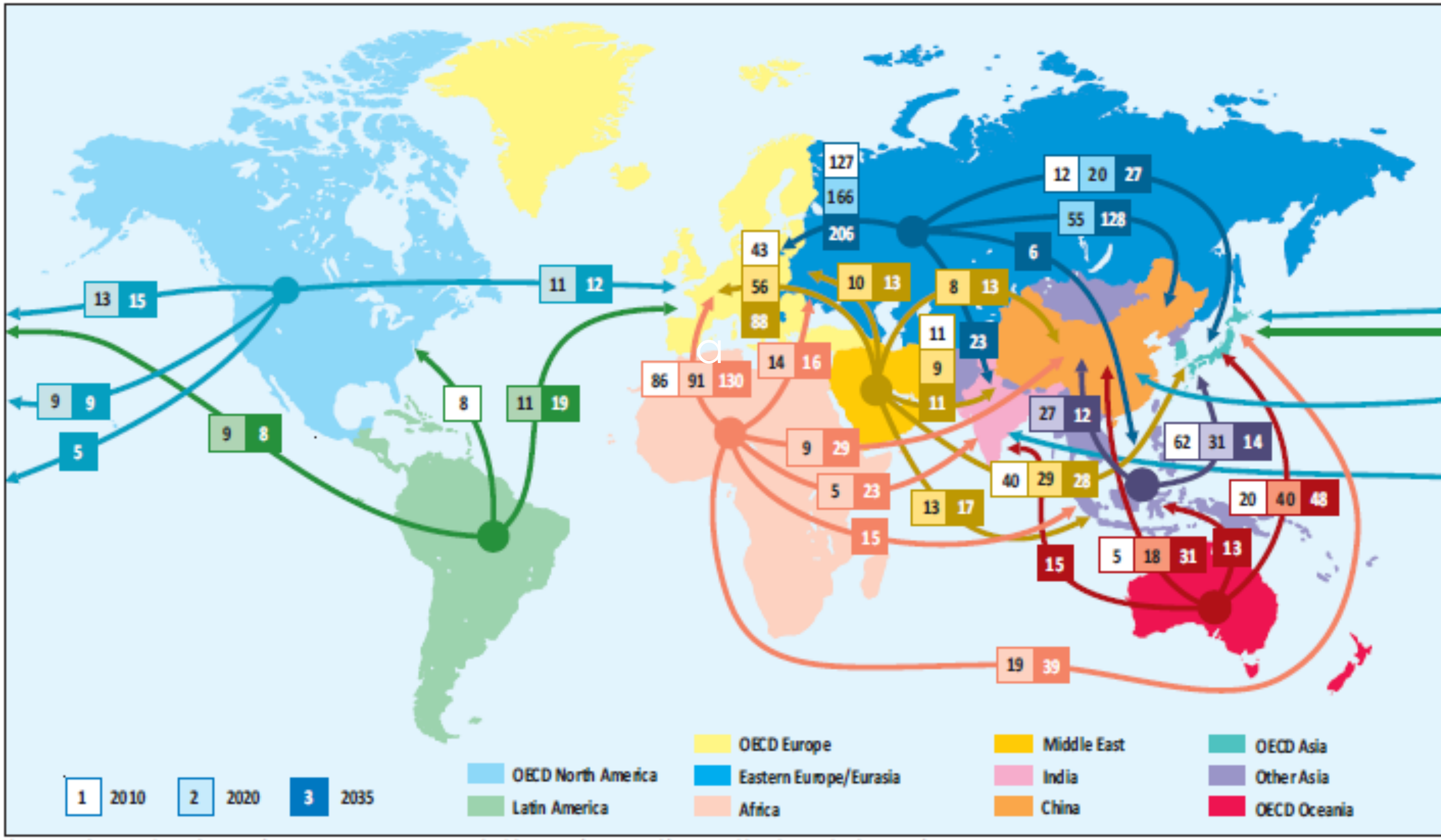
sources: U.S. FERC, World Bank

- At the beginning of 2018, U.S. natural gas prices were as low as 30 percent of international levels, which motivated U.S. production and exports

Projected Global Net Gas Flows

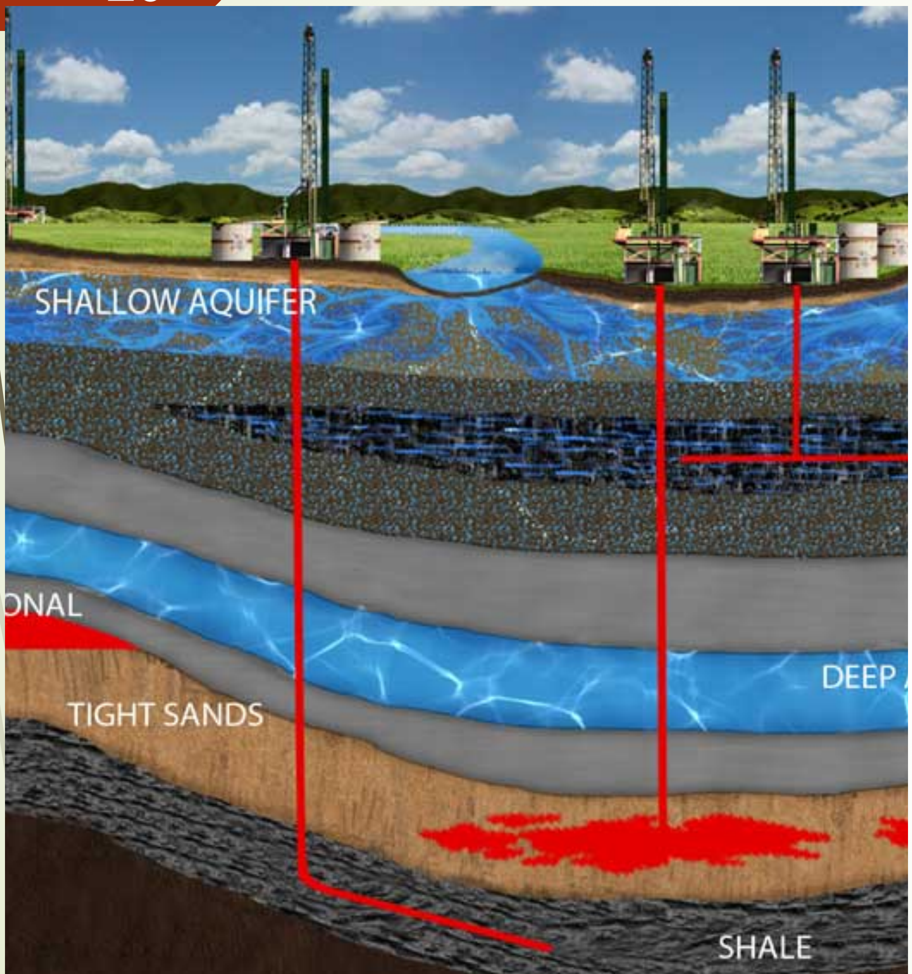
Chapter 4 | Natural gas market outlook

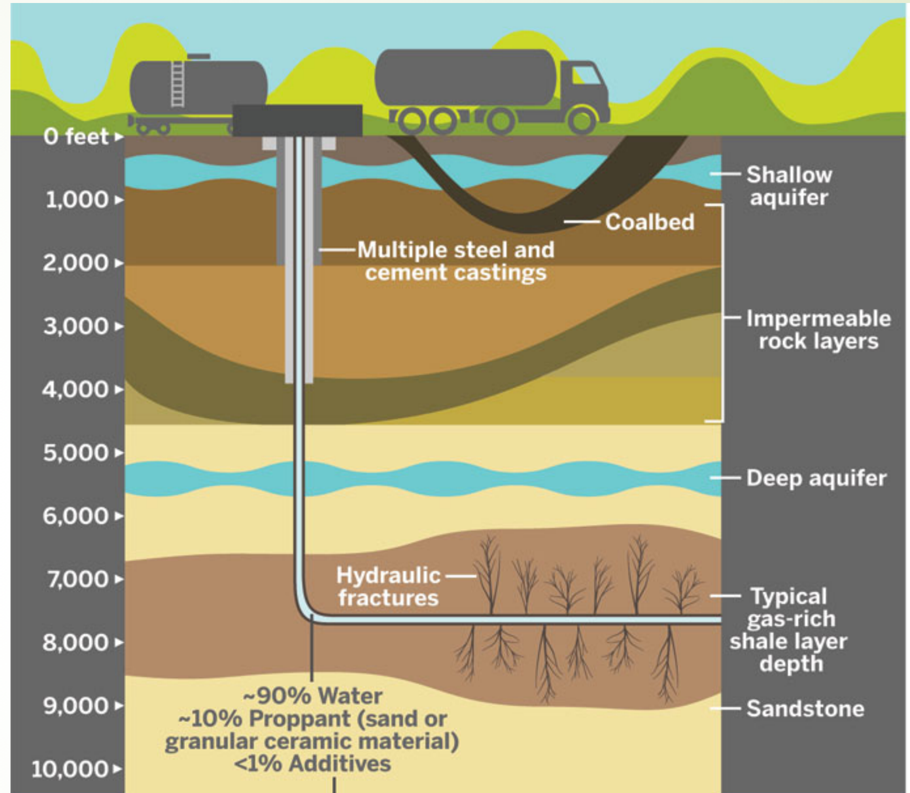
Figure 4.10 ▷ Net inter-regional natural gas trade flows between major regions in the New Policies Scenario (bcm)



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

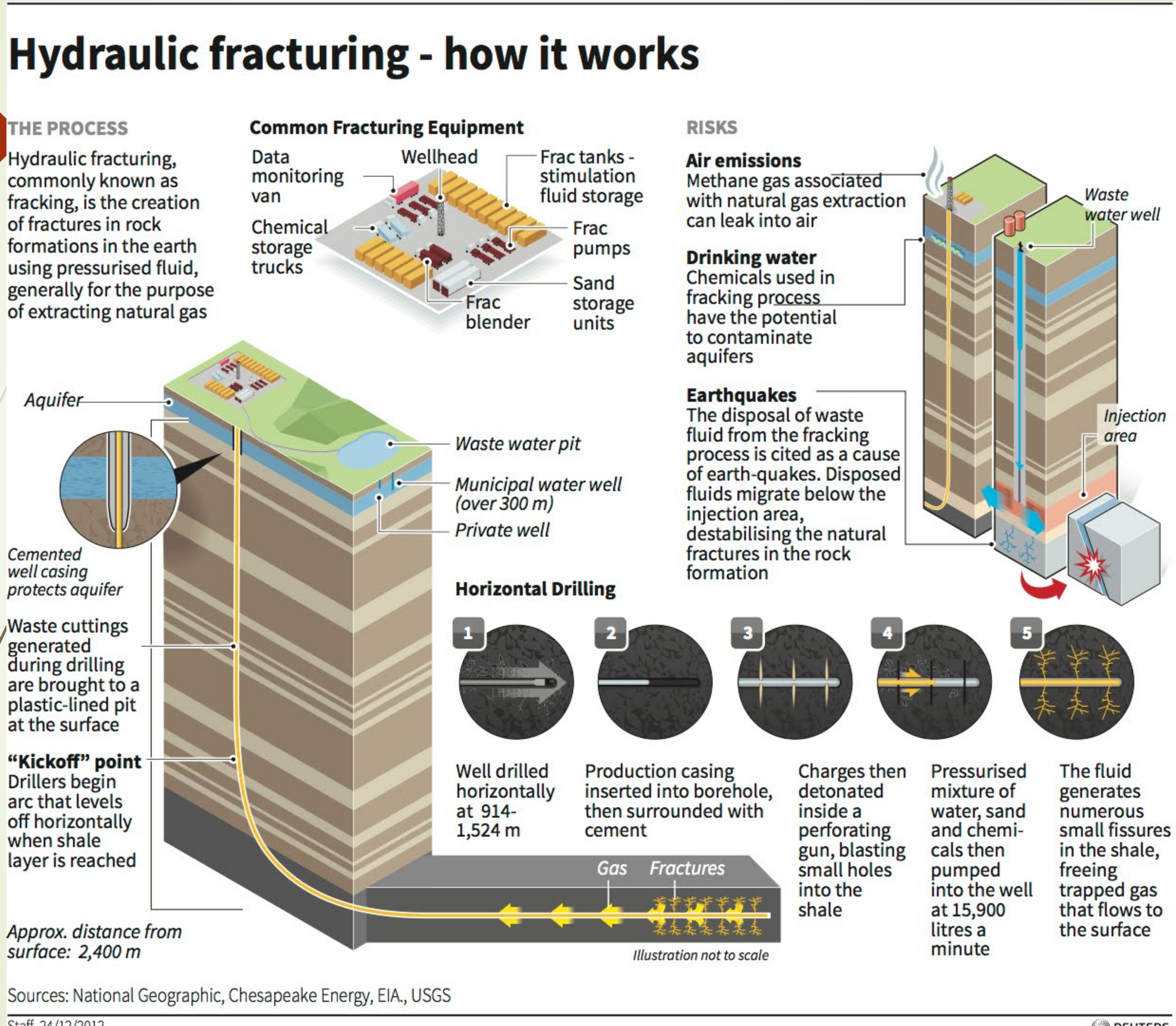
Shale and Fracking



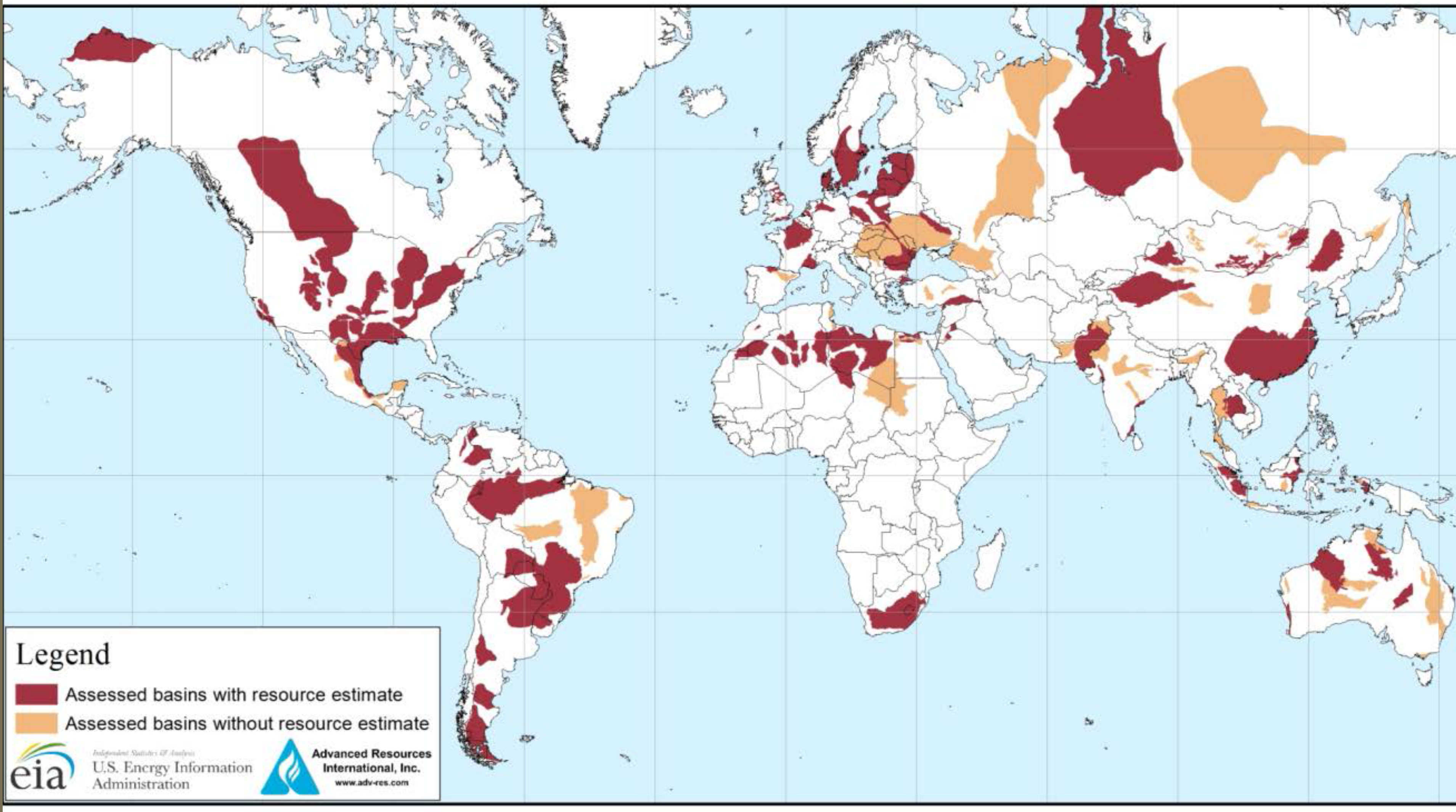


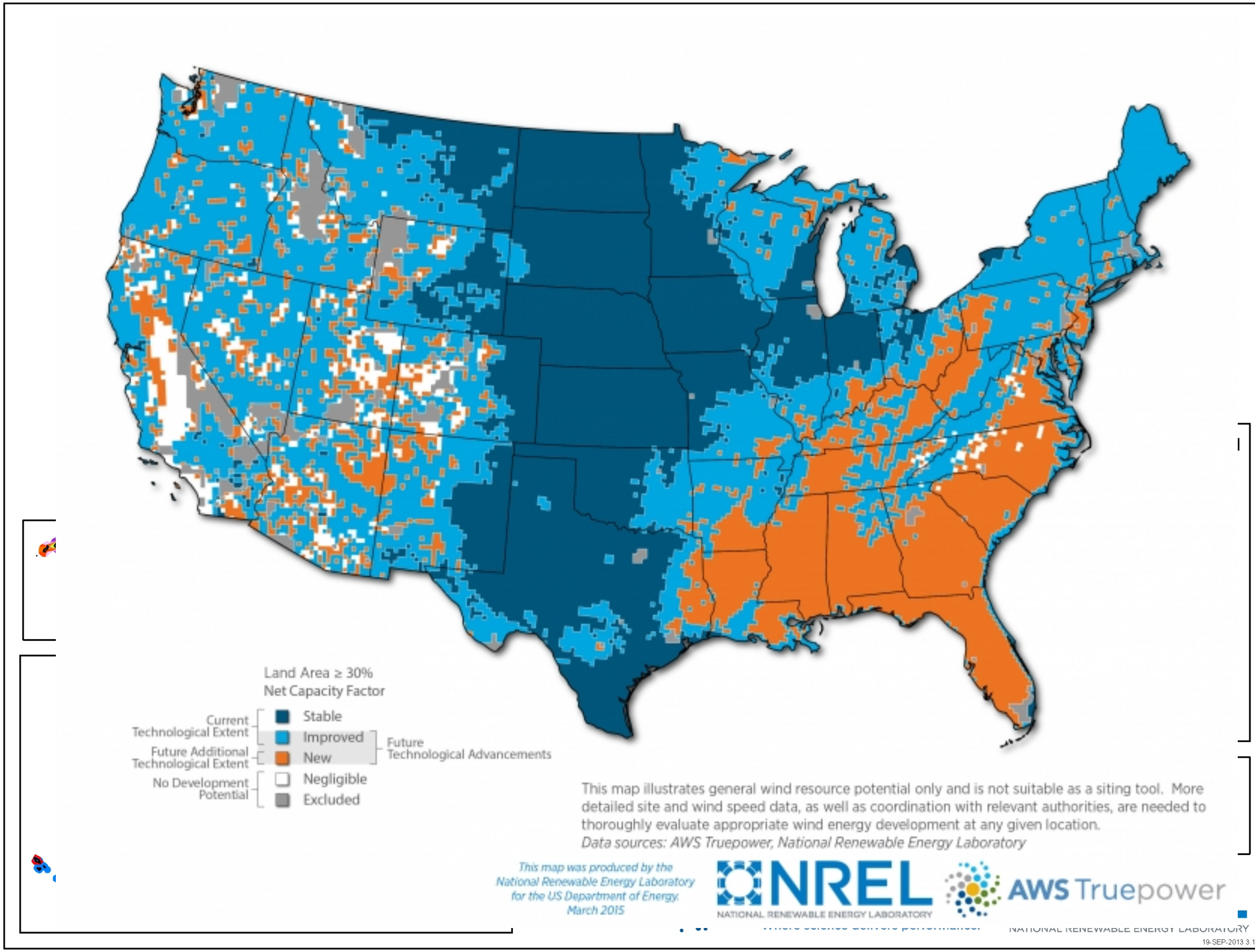
Common Water-Based Fracking Fluid Additives

Ingredient	Example	Function
Acid	Hydrochloric acid	Clears debris from well bore
Thickener	Guar gum	Increases viscosity of fluid to disperse proppant
Friction reducer	Polyacrylamide	Aids flow of fluid deep underground
Scale inhibitor	Ethylene glycol	Prevents carbonate/sulfate deposits

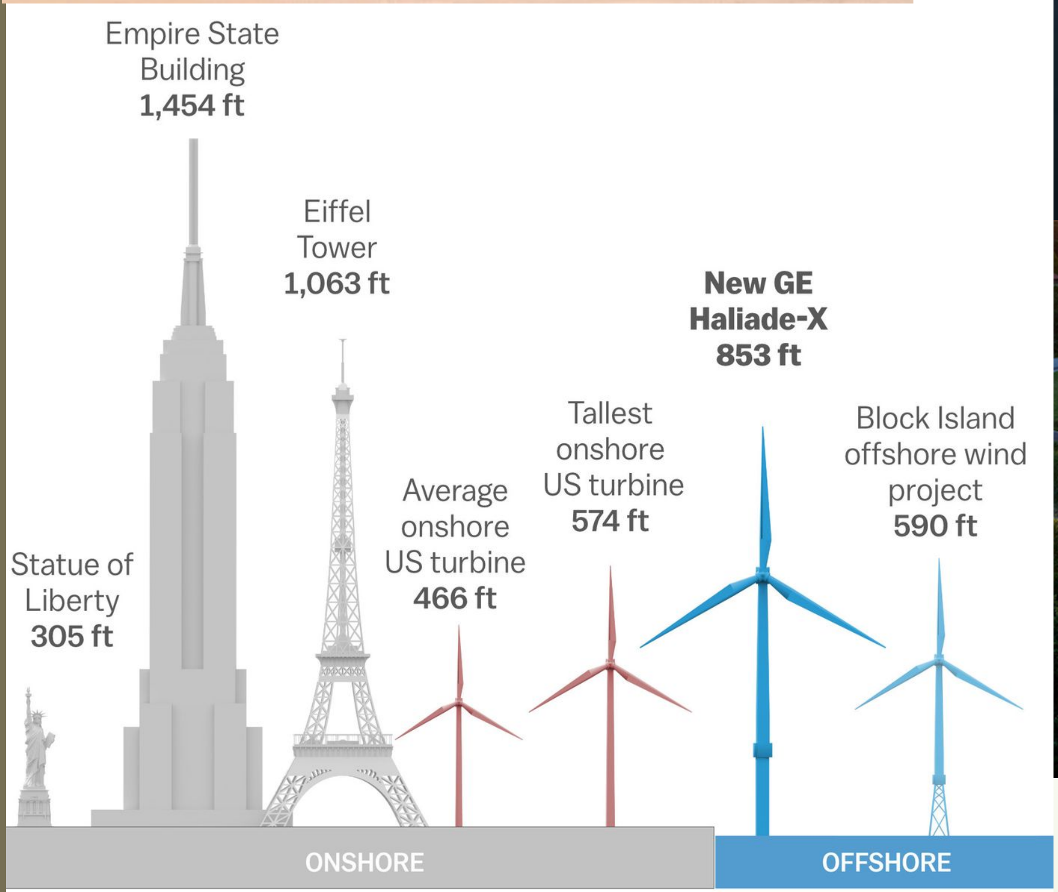

Hydraulic fracturing - how it works
THE PROCESS
Hydraulic fracturing, commonly known as fracking, is the creation of fractures in rock formations in the earth using pressurised fluid, generally for the purpose of extracting natural gas
Common Fracturing Equipment
Data monitoring van
Wellhead
Frac tanks - stimulation fluid storage
Chemical storage trucks
Frac pumps
Sand storage units
Frac blender
RISKS
Air emissions
Methane gas associated with natural gas extraction can leak into air
Drinking water
Chemicals used in fracking process have the potential to contaminate aquifers
Earthquakes
The disposal of waste fluid from the fracking process is cited as a cause of earth-quakes. Disposed fluids migrate below the injection area, destabilising the natural fractures in the rock formation
Waste water well
Injection area
Aquifer
Cemented well casing protects aquifer
Waste water pit
Municipal water well (over 300 m)
Private well
Waste cuttings generated during drilling are brought to a plastic-lined pit at the surface
"Kickoff" point
Drillers begin arc that levels off horizontally when shale layer is reached
Approx. distance from surface: 2,400 m
Gas
Fractures
Illustration not to scale
Horizontal Drilling
1
Well drilled horizontally at 914-1,524 m
2
Production casing inserted into borehole, then surrounded with cement
3
Charges then detonated inside a perforating gun, blasting small holes into the shale
4
Pressurised mixture of water, sand and chemi-cals then pumped into the well at 15,900 litres a minute
5
The fluid generates numerous small fissures in the shale, freeing trapped gas that flows to the surface
Sources: National Geographic, Chesapeake Energy, EIA., USGS

EIA / ARI assessed Shale Oil and Shale Gas resources 2013



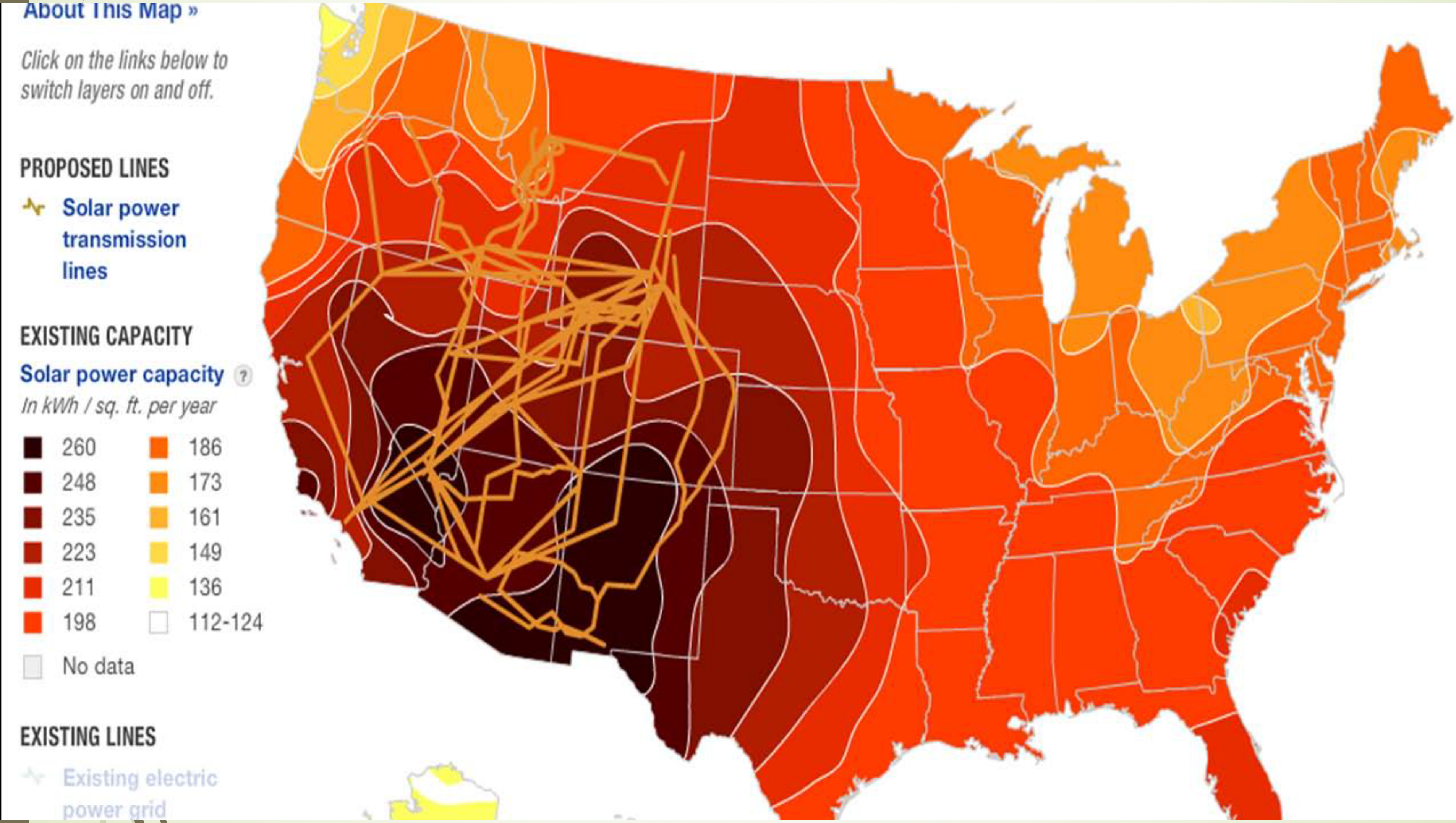

Land Area ≥ 30%
Net Capacity Factor
Current Technological Extent
Future Additional Technological Extent
No Development Potential
Stable
Improved
New
Negligible
Excluded
Future Technological Advancements
This map illustrates general wind resource potential only and is not suitable as a siting tool. More detailed site and wind speed data, as well as coordination with relevant authorities, are needed to thoroughly evaluate appropriate wind energy development at any given location.
Data sources: AWS Truepower, National Renewable Energy Laboratory
This map was produced by the National Renewable Energy Laboratory for the US Department of Energy. March 2015
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
AWS Truepower
19-SEP-2013 3.1.1

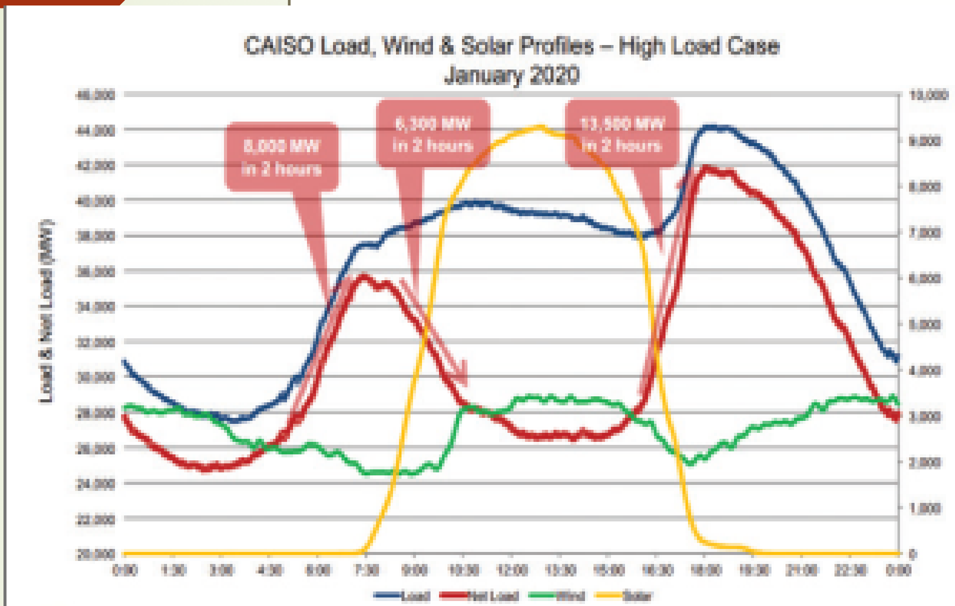
Larger, Taller Turbines to Capture Improved Wind FIelds

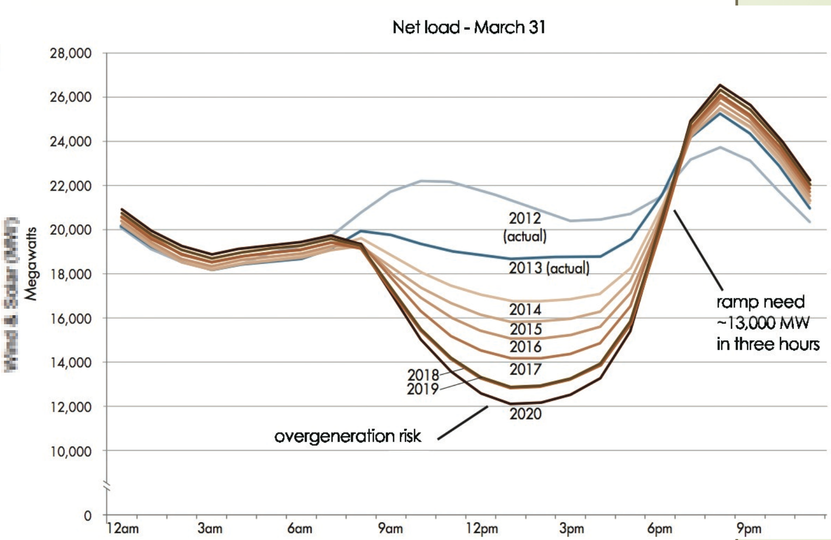


Michael L Knotek, PhD

US Solar Insolation

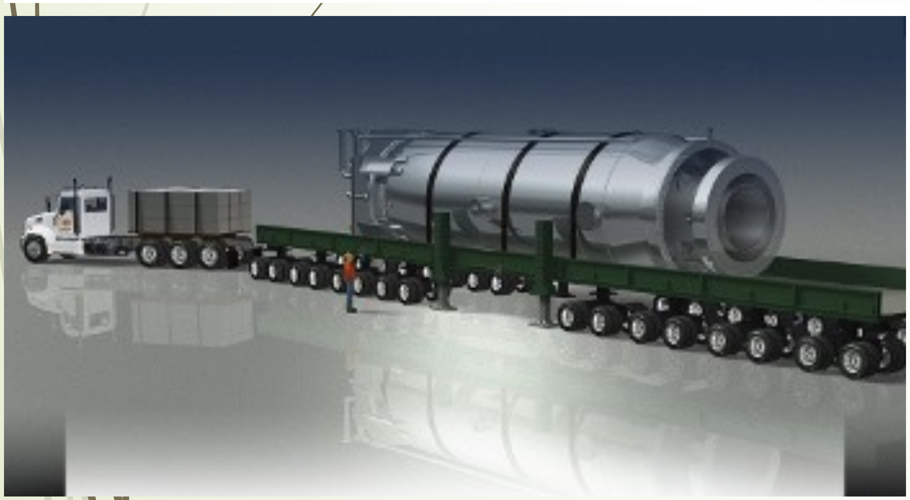


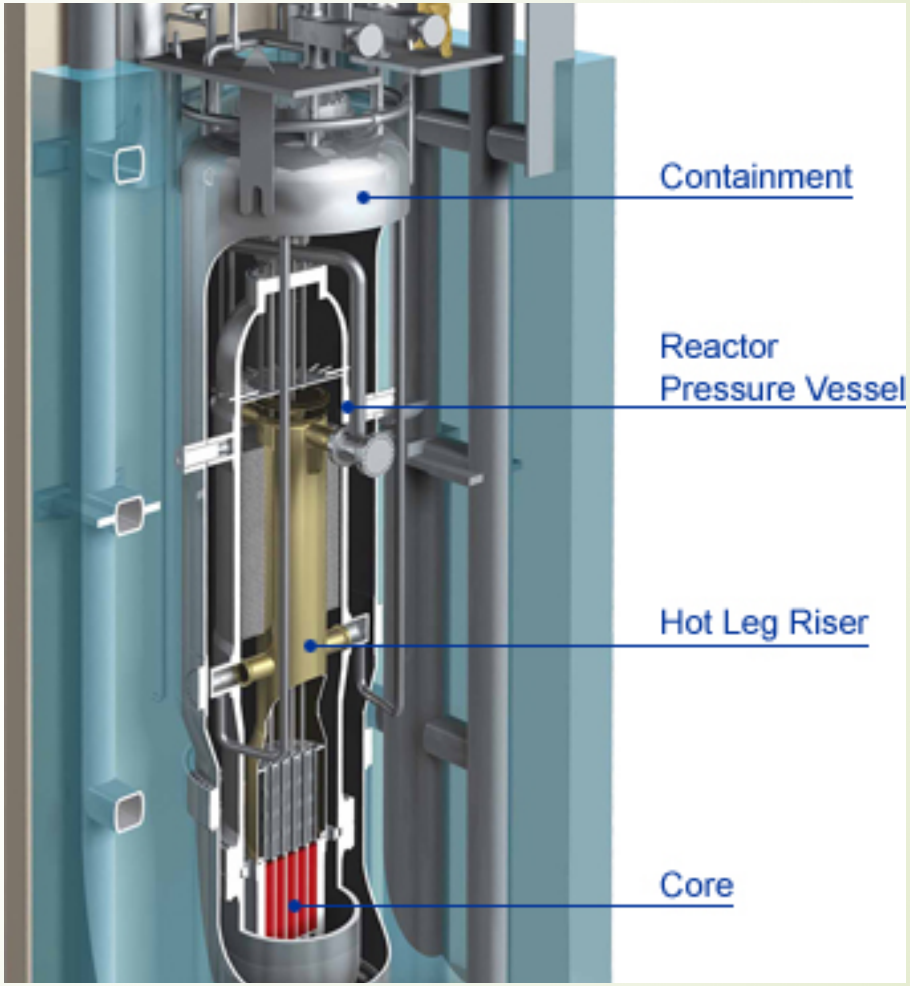




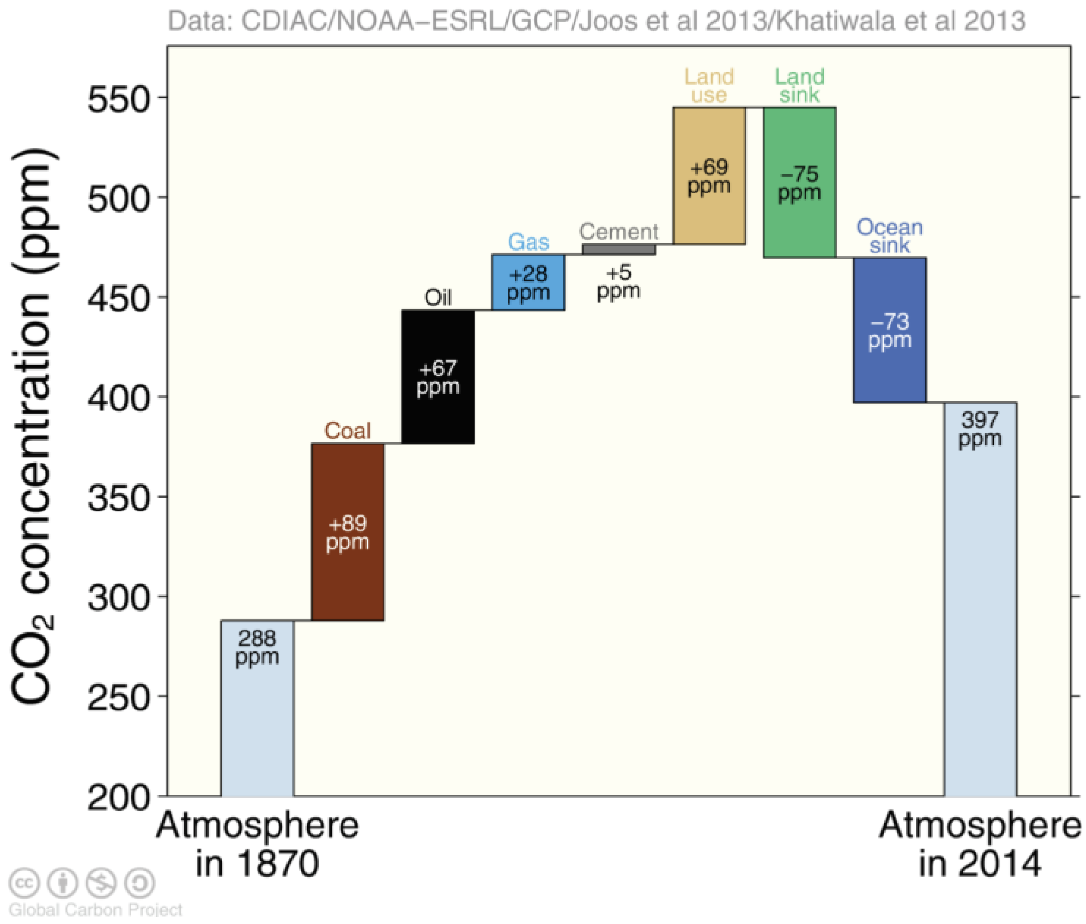
The Impacts of Renewables Capacity Factor

Small Modular Reactors: Safety, Reliability, Cost

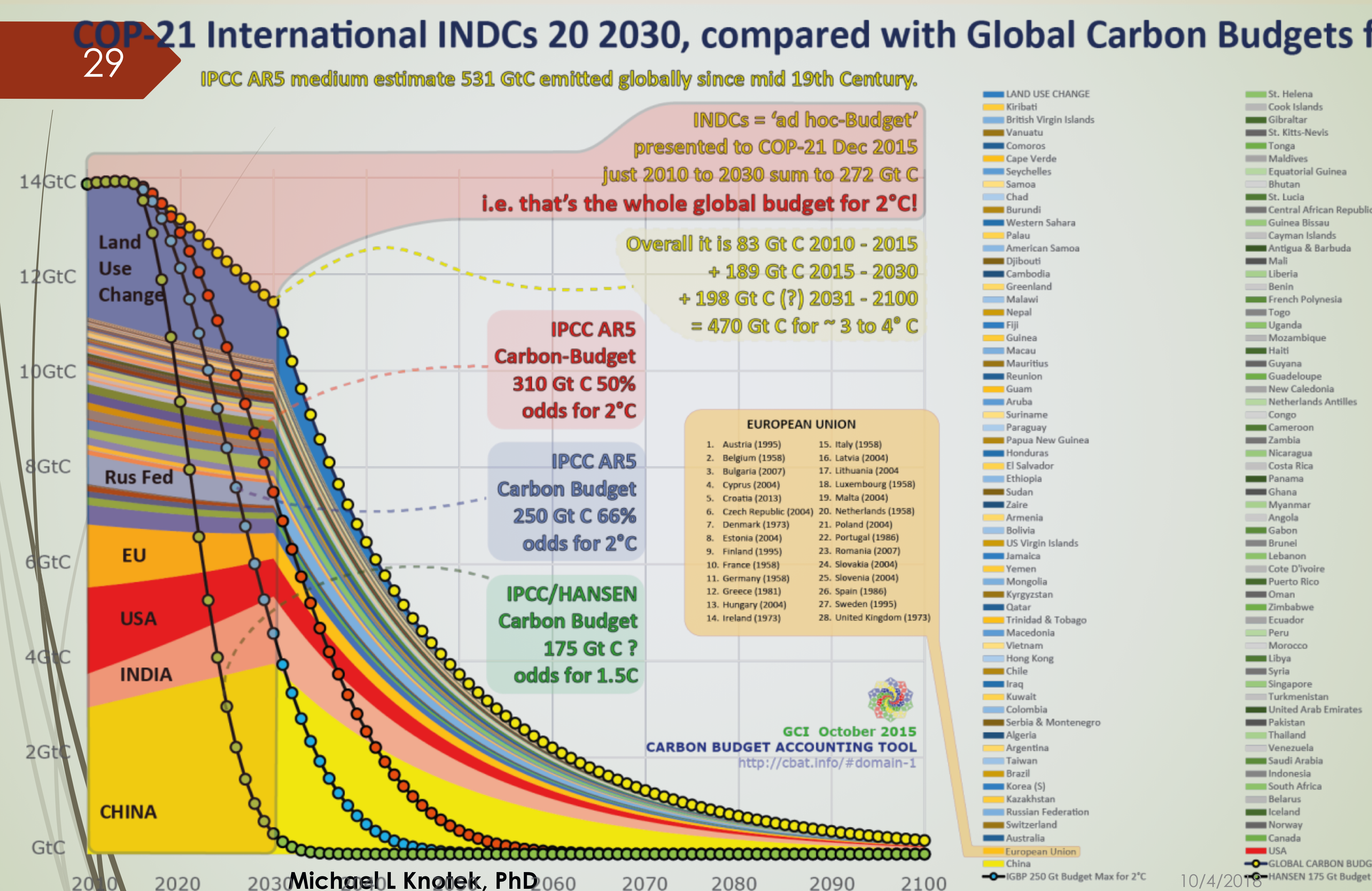




Origins of Anthropogenic CO2



Paris


COP-21 International INDCs 20 2030, compared with Global Carbon Budgets f
IPCC AR5 medium estimate 531 GtC emitted globally since mid 19th Century.
INDCs = 'ad hoc-Budget'
presented to COP-21 Dec 2015
just 2010 to 2030 sum to 272 Gt C
i.e. that's the whole global budget for 2°C!
Overall it is 83 Gt C 2010 - 2015
+ 189 Gt C 2015 - 2030
+ 198 Gt C (?) 2031 - 2100
= 470 Gt C for ~ 3 to 4° C
IPCC AR5
Carbon-Budget
310 Gt C 50%
odds for 2°C
IPCC AR5
Carbon Budget
250 Gt C 66%
odds for 2°C
IPCC/HANSEN
Carbon Budget
175 Gt C ?
odds for 1.5C
14GtC
12GtC
10GtC
8GtC
6GtC
4GtC
2GtC
GtC
Land Use Change
Rus Fed
EU
USA
INDIA
CHINA
2010
2020
2030
2060
2070
2080
2090
2100
EUROPEAN UNION
1. Austria (1995)
2. Belgium (1958)
3. Bulgaria (2007)
4. Cyprus (2004)
5. Croatia (2013)
6. Czech Republic (2004)
7. Denmark (1973)
8. Estonia (2004)
9. Finland (1995)
10. France (1958)
11. Germany (1958)
12. Greece (1981)
13. Hungary (2004)
14. Ireland (1973)
15. Italy (1958)
16. Latvia (2004)
17. Lithuania (2004
18. Luxembourg (1958)
19. Malta (2004)
20. Netherlands (1958)
21. Poland (2004)
22. Portugal (1986)
23. Romania (2007)
24. Slovakia (2004)
25. Slovenia (2004)
26. Spain (1986)
27. Sweden (1995)
28. United Kingdom (1973)
GCI October 2015
CARBON BUDGET ACCOUNTING TOOL
http://cbat.info/#domain-1
LAND USE CHANGE
Kiribati
British Virgin Islands
Vanuatu
Comoros
Cape Verde
Seychelles
Samoa
Chad
Burundi
Western Sahara
Palau
American Samoa
Djibouti
Cambodia
Greenland
Malawi
Nepal
Fiji
Guinea
Macau
Mauritius
Reunion
Guam
Aruba
Suriname
Paraguay
Papua New Guinea
Honduras
El Salvador
Ethiopia
Sudan
Zaire
Armenia
Bolivia
US Virgin Islands
Jamaica
Yemen
Mongolia
Kyrgyzstan
Qatar
Trinidad & Tobago
Macedonia
Vietnam
Hong Kong
Chile
Iraq
Kuwait
Colombia
Serbia & Montenegro
Algeria
Argentina
Taiwan
Brazil
Korea (S)
Kazakhstan
Russian Federation
Switzerland
Australia
European Union
China
IGBP 250 Gt Budget Max for 2°C
St. Helena
Cook Islands
Gibraltar
St. Kitts-Nevis
Tonga
Maldives
Equatorial Guinea
Bhutan
St. Lucia
Central African Republic
Guinea Bissau
Cayman Islands
Antigua & Barbuda
Mali
Liberia
Benin
French Polynesia
Togo
Uganda
Mozambique
Haiti
Guyana
Guadeloupe
New Caledonia
Netherlands Antilles
Congo
Cameroon
Zambia
Nicaragua
Costa Rica
Panama
Ghana
Myanmar
Angola
Gabon
Brunei
Lebanon
Cote D'ivoire
Puerto Rico
Oman
Zimbabwe
Ecuador
Peru
Morocco
Libya
Syria
Singapore
Turkmenistan
United Arab Emirates
Pakistan
Thailand
Venezuela
Saudi Arabia
Indonesia
South Africa
Belarus
Iceland
Norway
Canada
USA
GLOBAL CARBON BUDG
HANSEN 175 Gt Budget

National Academy Analysis of CDR: A Scenario

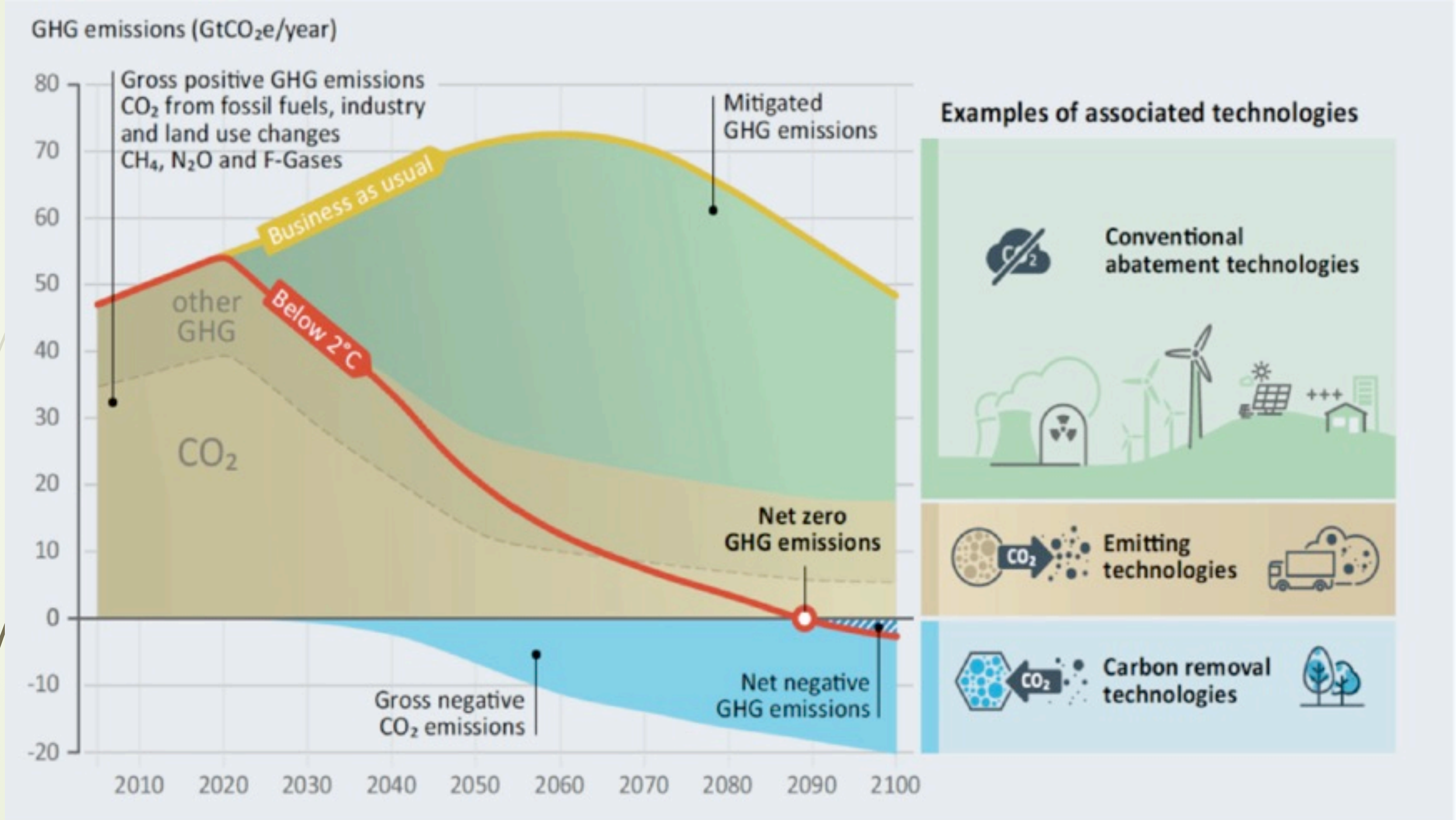
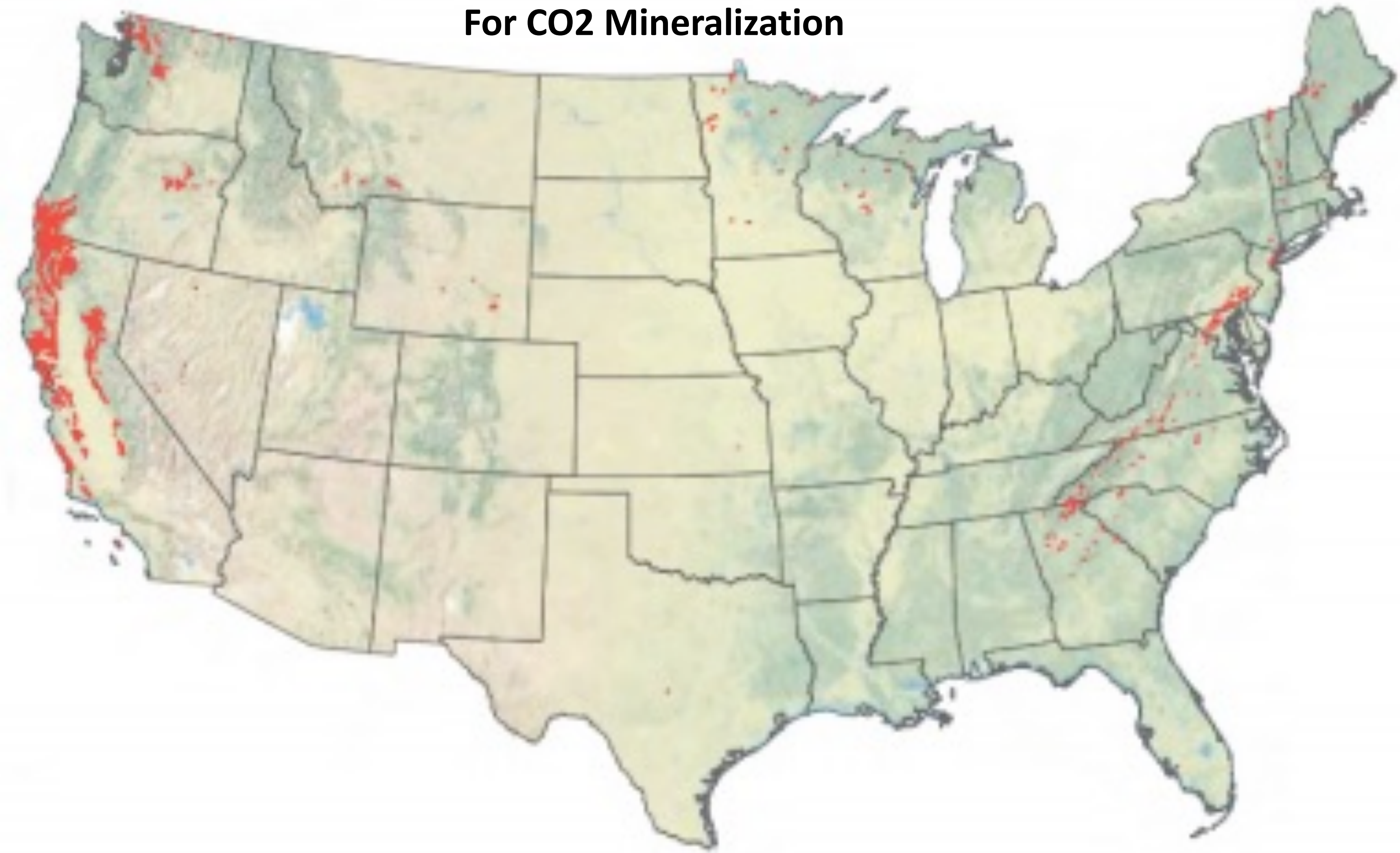


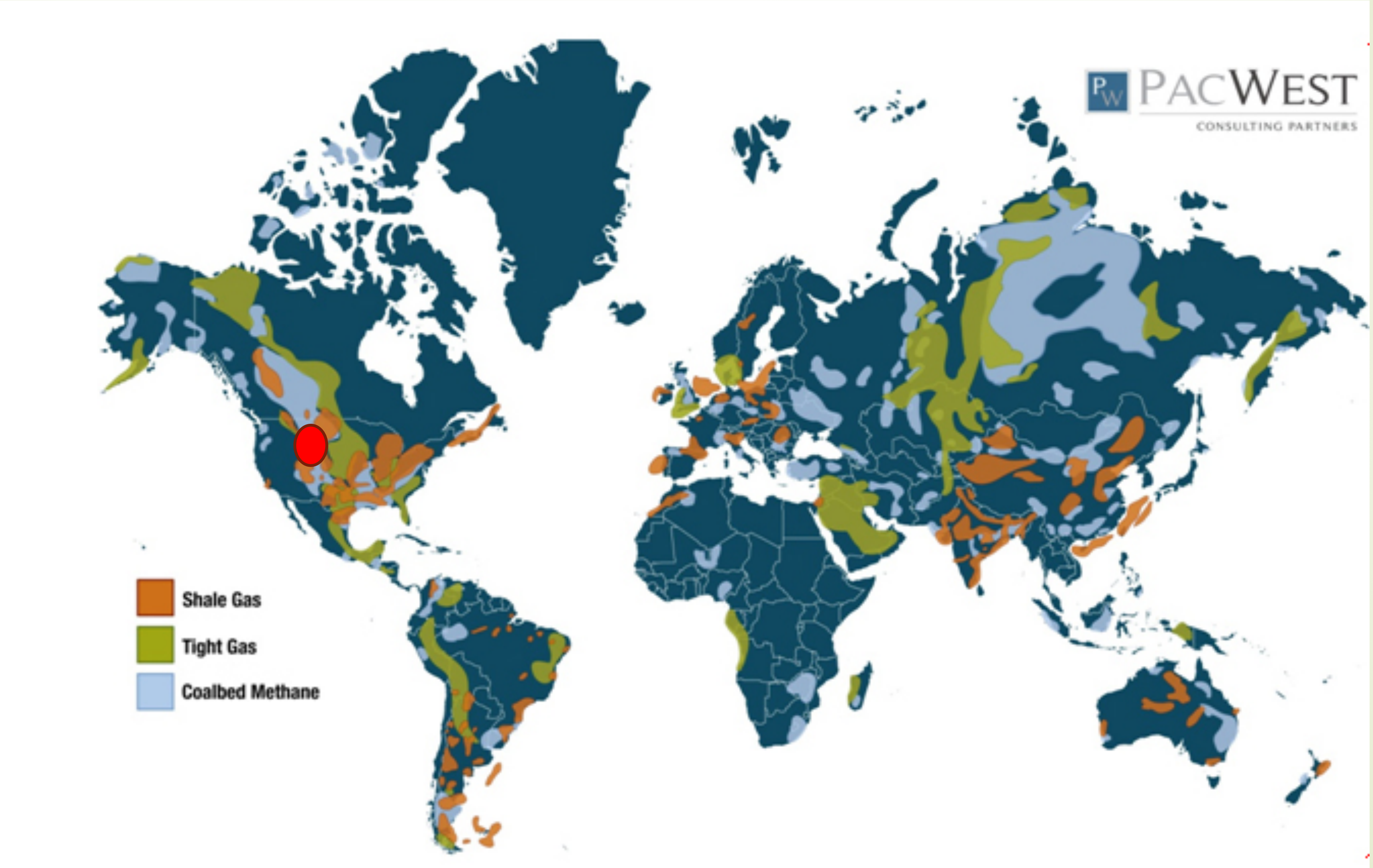
FIGURE S.1. Scenario of the role of negative emissions technologies in reaching net zero emissions.[2] SOURCE: UNEP, 2017.

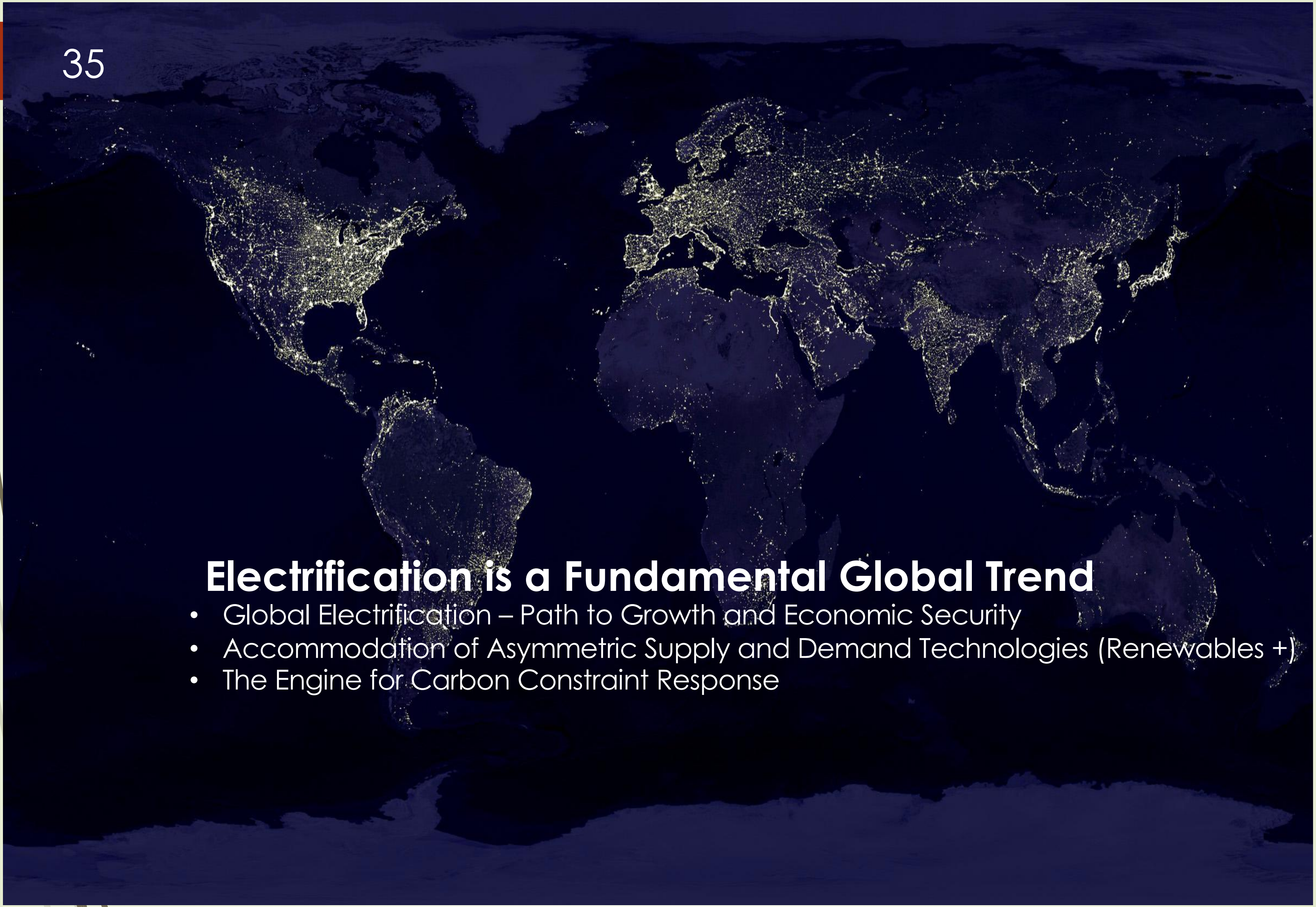
Geological Sequestration Resources For CO2 Mineralization



Michael L Knotek, PhD

Why Are Folks Freaking Out???!!!



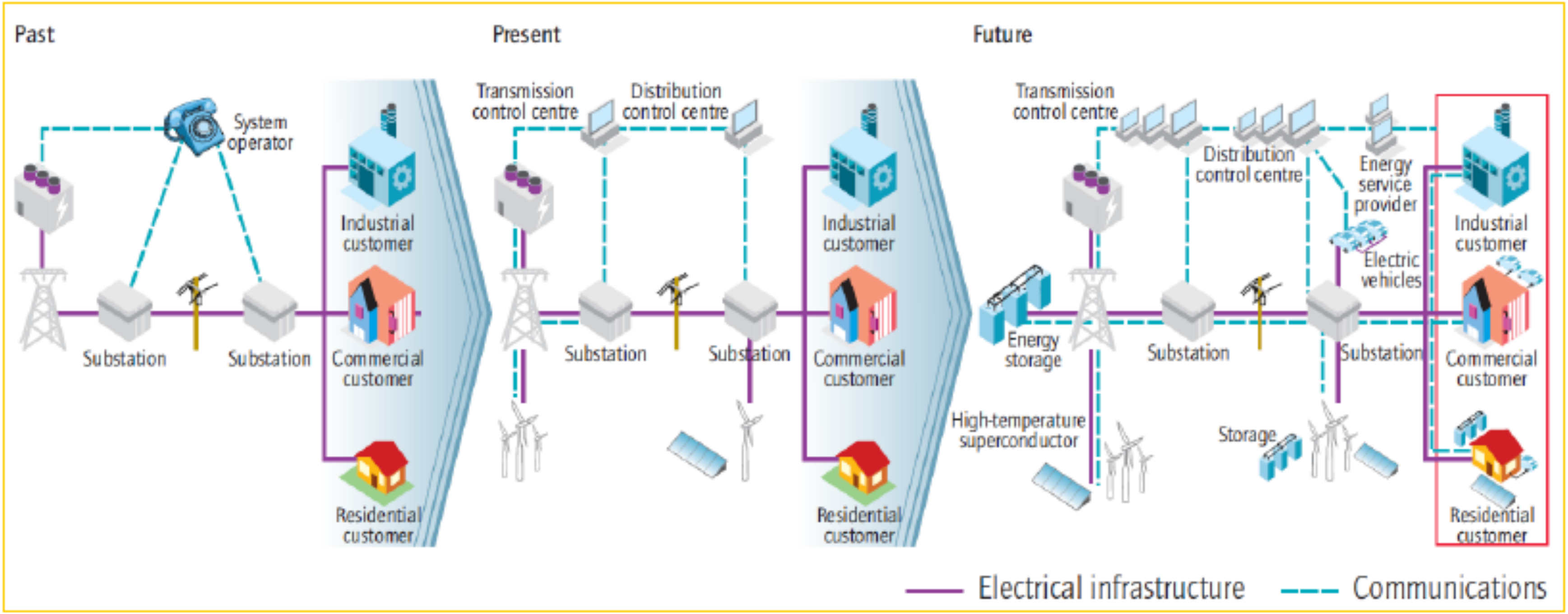


Electrification is a Fundamental Global Trend

- Global Electrification – Path to Growth and Economic Security
- Accommodation of Asymmetric Supply and Demand Technologies (Renewables +)
- The Engine for Carbon Constraint Response

The Future Grid differs Radically from the Present:

Characterized by More Flexibility and Agility



Graphic Source: International Energy Agency

Historical

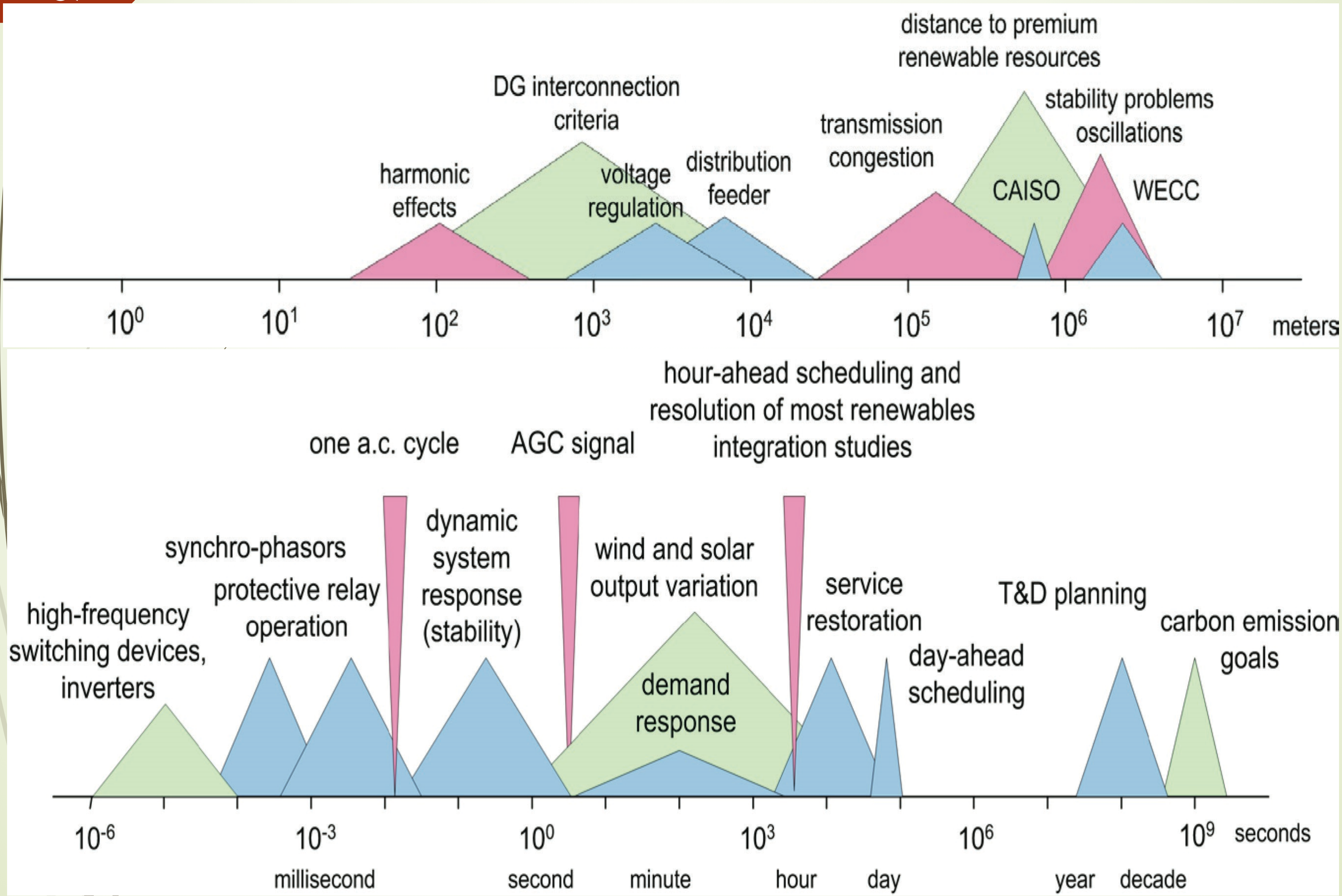
- *Operator-Based Grid Management*
- *Centralized Control*
- *Off-Line Analysis / Limit Setting*

Emerging

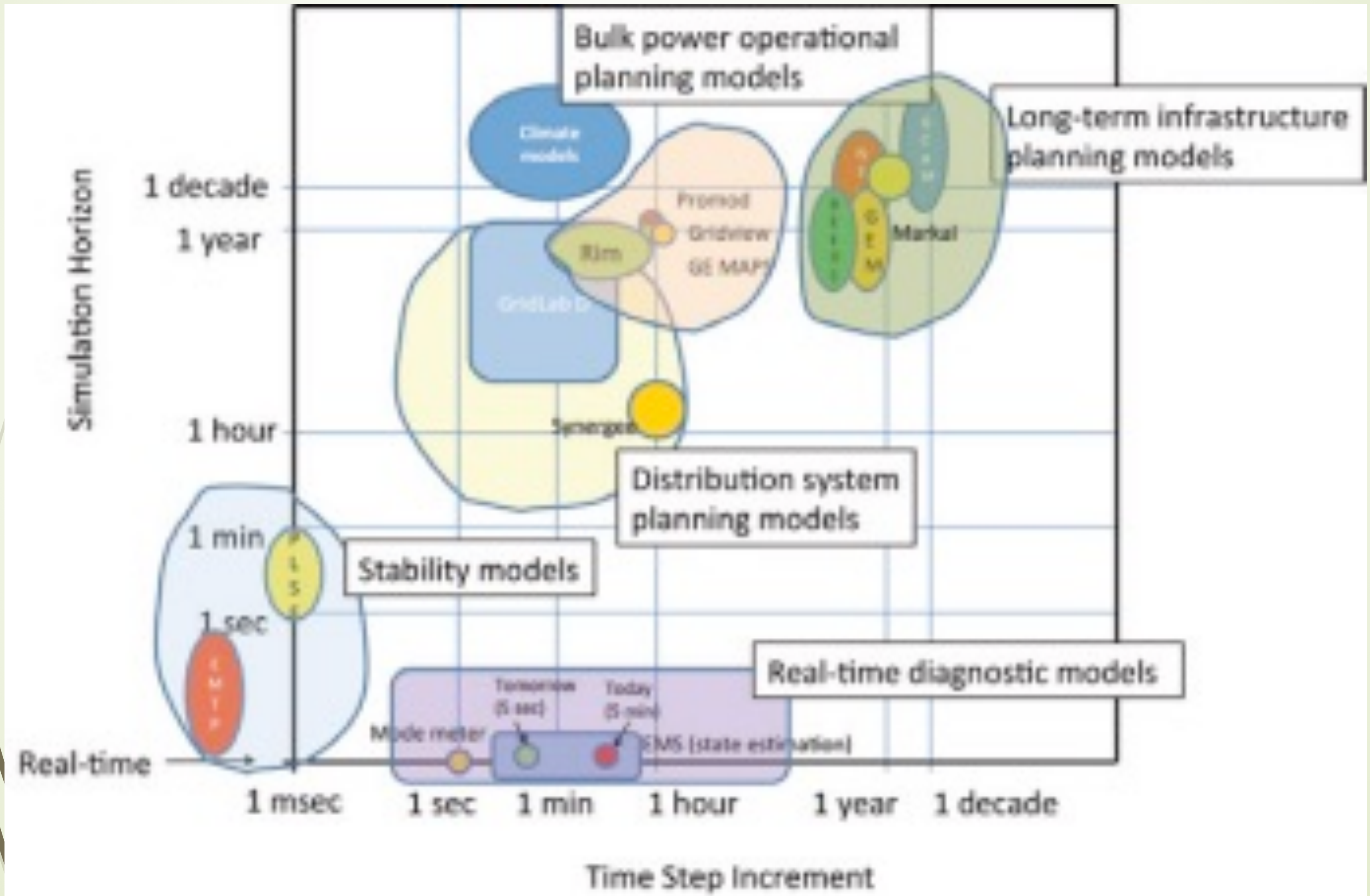
- *Flexible and Resilient Systems*
- *Sensors and Data Acquisition*
- *Algorithms and Computer Infrastructure*
- *Multi-Level Coordination / Precise Control*
- *Faster-than-Real-Time Analysis*

Growing Vulnerabilities to Instability, Internet Related Intrusion, Foreign Adversaries, Natural Disasters

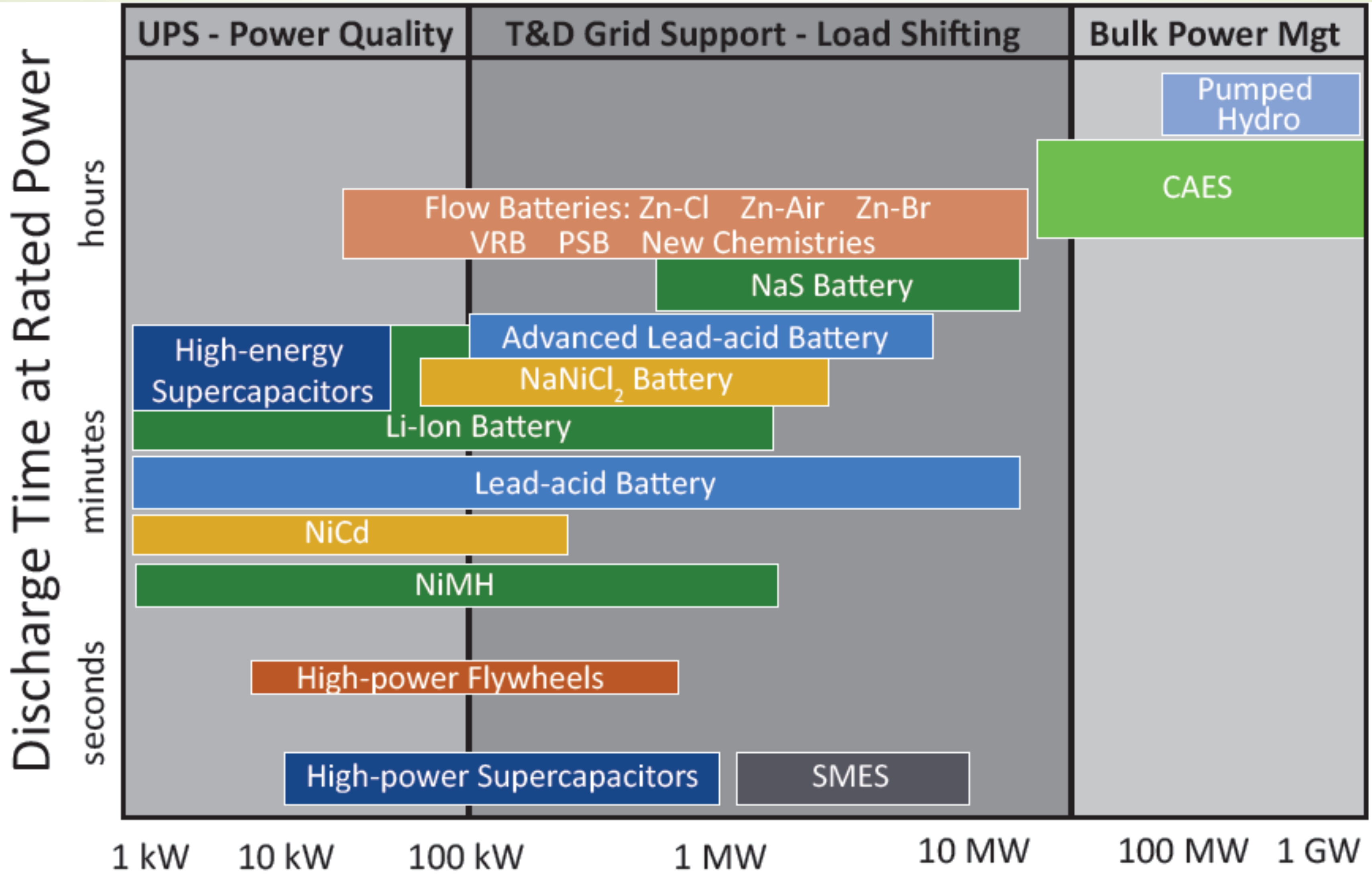
Dynamic Range of the Grid



Modelling and the Grid: Toward Faster-Than-Real-Time Operational Models



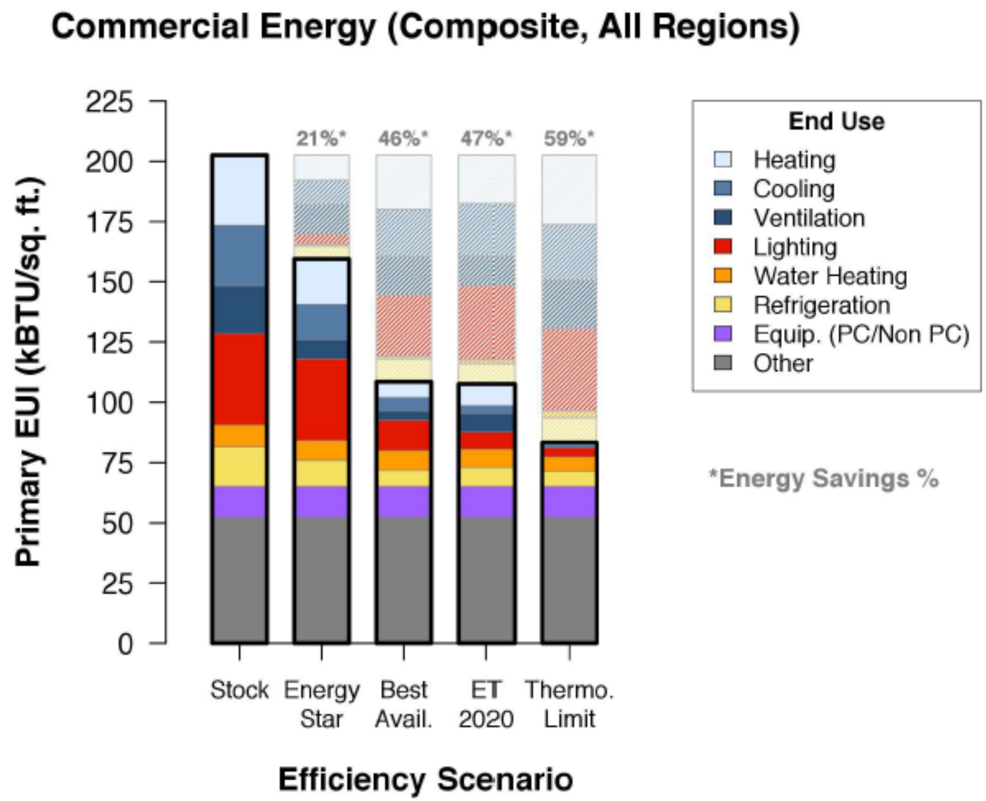
Storage Has A Wide Variety of Values



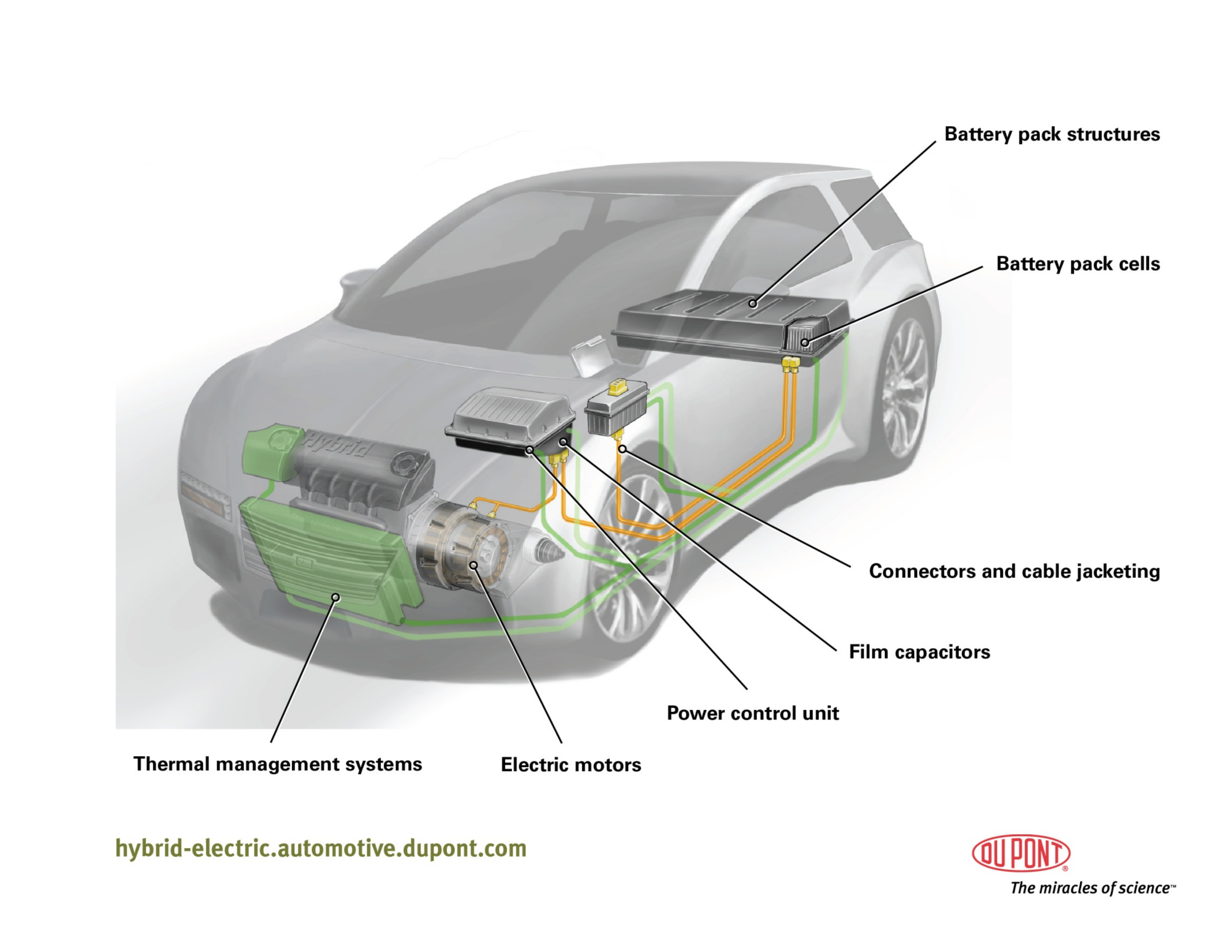
Michael L Knotek, PhD

Efficiency as a Core National Strategy (and an indisposable global strategy)

Potential Limits of Building Energy Efficiency (Commercial)



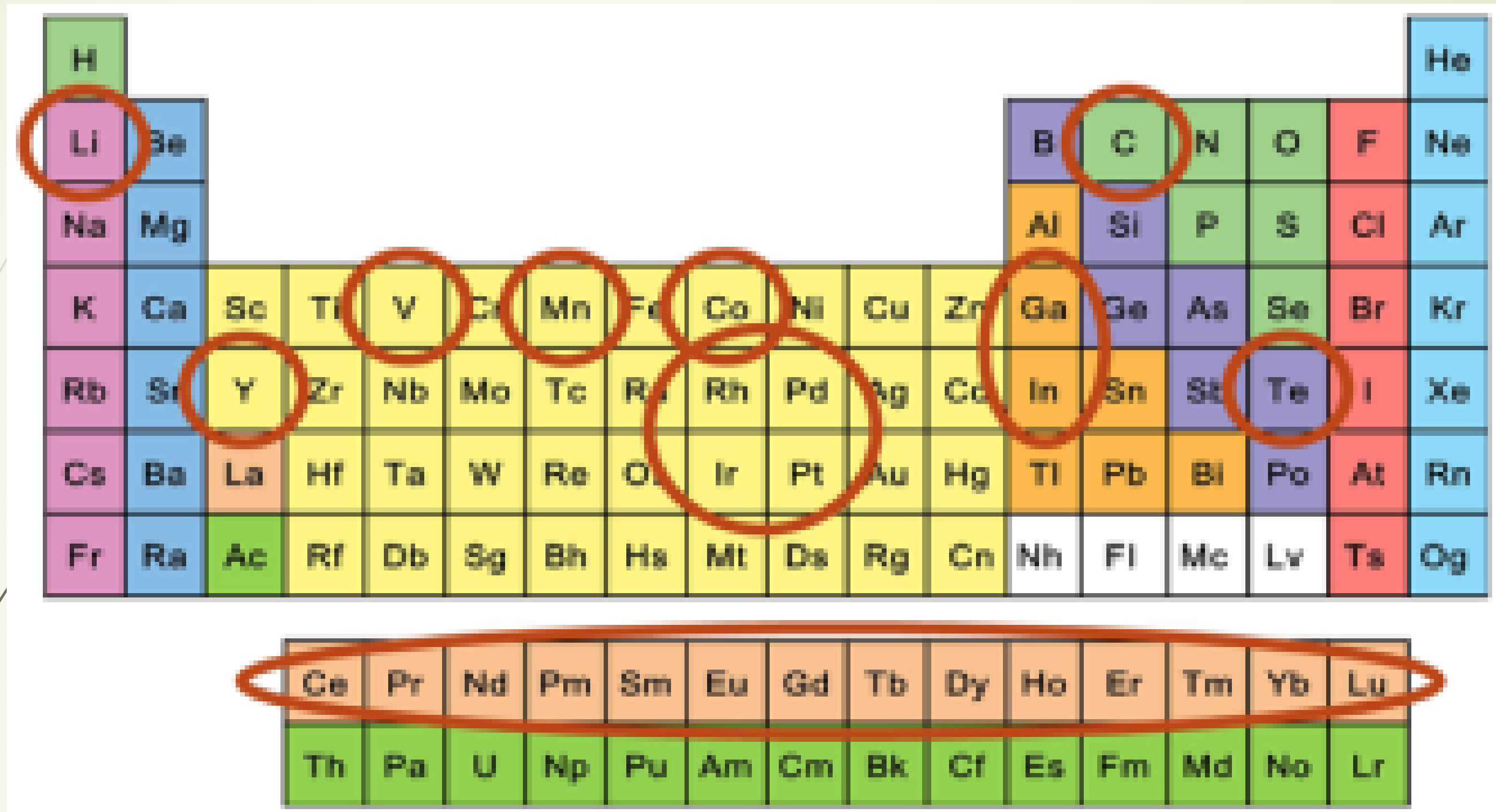
How Will We Support The Emerging Economies and Technologies???


Battery pack structures
Battery pack cells
Connectors and cable jacketing
Film capacitors
Power control unit
Thermal management systems
Electric motors
Hybrid
hybrid-electric.automotive.dupont.com
The miracles of science™

Critical Materials Found in Clean Technologies

Technology	Component	Material
Wind	Generators	Neodymium
		Dysprosium
Vehicles	Motors	Neodymium
		Dysprosium
	Li-ion Batteries (PHEVs and EVs)	Lithium
		Cobalt
	NiMH Batteries (HEVs)	Rare Earths: Cerium, Lanthanum, Neodymium, Praseodymium
		Cobalt
PV Cells	Thin Film PV Panels General*	Tellurium
		Gallium
		Germanium
		Indium
		Selenium
		Silver
		Cadmium**
	CIGS Thin Films	Indium
		Gallium
	CdTe Thin Films	Tellurium
Lighting (Solid State and Fluorescent)	Phosphors	Rare Earths: Yttrium, Cerium, Lanthanum, Europium, Terbium
Fuel Cells*	Catalysts and Separators	Platinum, Palladium and other Platinum Group Metals, Yttrium

*Sources: Table data extracted from Bauer, 2011 (20) and expanded upon with data from other sources per asterisks. *APS/MRS, 2011 (2). **Lifton, 2011 (10)*



Critical Materials Institute Palette for Study

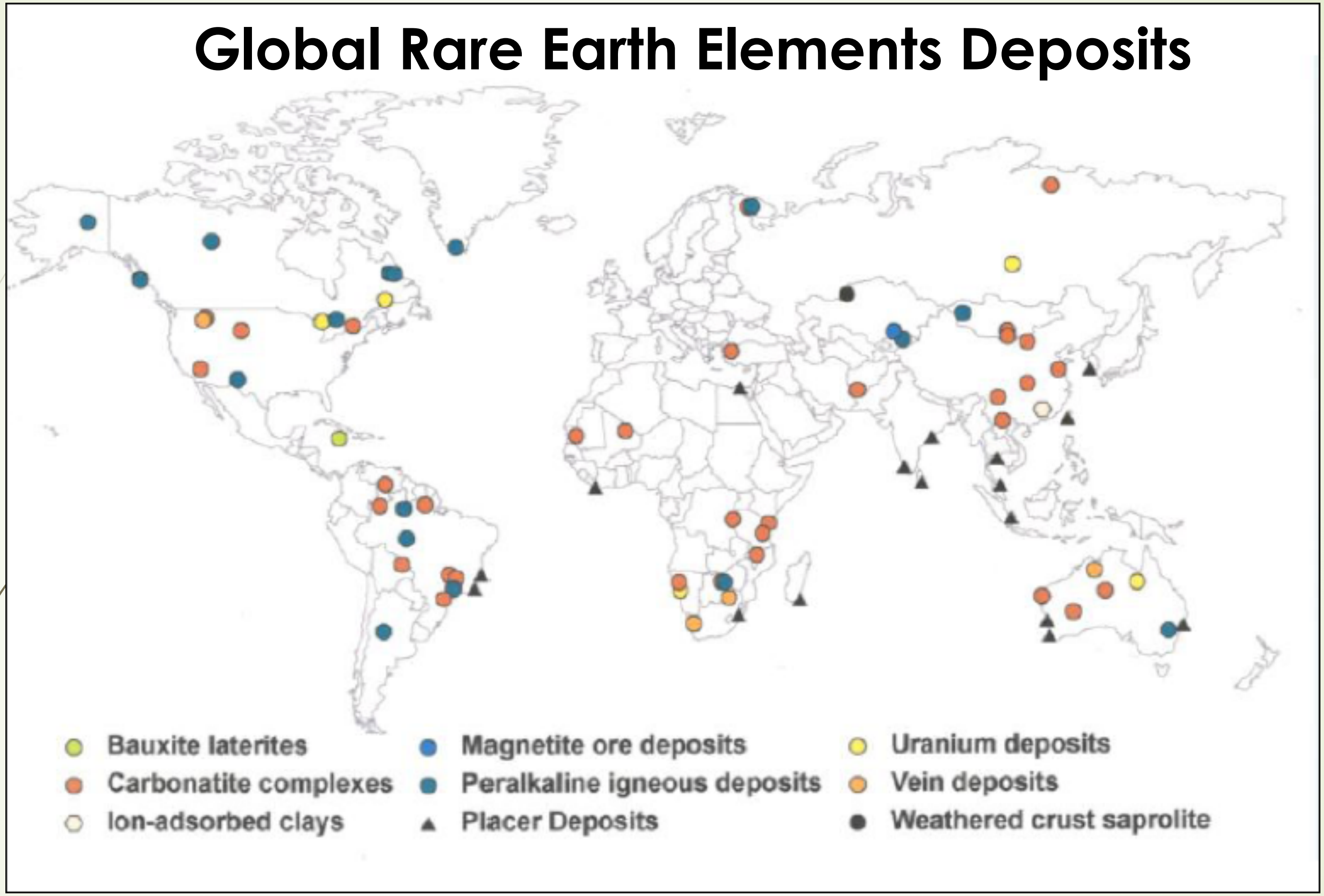


Figure 3. Distribution of documented REE deposits as presented by A. Mariano in (Mariano, 2010).

Source: Watts 2011

Rare earth metals are not rare – found in many countries including the United States

Table 3-1. Production and Reserves Information on Key Materials[10]

	Production characteristics	2009 top-ranked global primary and refinery producers plus U.S.-related information (in *tonnes* unless otherwise indicated)				Top-ranked reserve holding countries, in rank order		Total global reserves (in *tonnes*)
		Mine production:		*Refined metal:*				
Rare earth elements (in rare earth oxide/ REO)	Occur in dilute concentrations in metal ores. Often co-produced with other metals. Concentrations vary widely from ore to ore.	China	125,000[11]	Not available		China	36%	99 million in REO content
		Russia	2,470			CIS	19%	
		India	50			U.S.	13%	
		United States (processing of stockpiled ore at Mt. Pass, CA led to 2,150t REO[12])	0					
Lithium (in lithium carbonate equivalent/LCE)	Most lithium is recovered from subsurface liquid brines or from mining of lithium-carbonate rocks	Chile	38,720	Not available		Chile	76%	9.9 million in lithium content
		Australia	23,020			Argentina	8%	
		China	12,033			Australia	6%	
		United States	Withheld					
Cobalt	Primary cobalt (15%) Byproduct of nickel mining (50%) Byproduct of copper mining (35%)	Ores, concentrates, or semi-refined materials:		Refined metals & chemicals:		DRC	51%	6.6 million in cobalt content
		DRC	25,000	China[13]	23,000	Australia	23%	
		Australia	6,300	Finland	8,900	Cuba	8%	
		China	6,200	Canada	4,900			
		Russia	6,200	U.S.	0			
		U.S.	0					
Indium	Byproduct of zinc processing	Global: Not available		Metals, alloys, etc.:		China	73%[14]	Not available
				China	300	Others	16%	
				South Korea	85	U.S.	3	
				Japan	60			
				U.S.	0			

Things to Read

- The Quadrennial Technology Review: energy.gov/qtr
  - Plus the technology assessments
- The Quadrennial Energy Review
- The Annual Energy Outlook: DOE.EIA.GOV/AEO
- World Energy Outlook: https://www.iea.org/weo2018/
- BP Statistical Review of World Energy 2018

Thank You