The Growing Conflicts in the Global Energy Enterprise

Michael L Knotek, PhD
Naval Postgraduate School
Monterey California
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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

Climbing The Energy Ladder
A Continuously Changing Relationship

GJ/capita

[Graph showing energy consumption and GDP/capita for various countries]

Energy intensity in selected countries and regions, 2015
gross domestic product
tillion 2010 dollars

less energy intensive

more energy intensive

OECD countries
non-OECD countries

China

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Energy:
Where Do We Get It?
How Do We Use It?
Sankey Diagram of Energy Flows in US Economy

Estimated U.S. Energy Use in 2014: ~98.3 Quads

Source: LLNL 2015. Data is based on DOE/EIA-0035(2013-03), 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-410327
Energy Generation and Use

- **2012 Primary Energy Supply**
  - Coal, 17 Q, 18%
  - Nuclear, 8.1 Q, 8%
  - Hydropower, 2.7 Q, 3%
  - Natural gas, 26 Q, 28%
  - Other Renewable, 0.7 Q, 1%
  - Wind, 1.4 Q, 1%
  - Other, 0.4 Q, 0%
  - Biomass liquids, 1.7 Q, 2%
  - Oil and gas liquids, 34 Q, 36%

- **2012 Sectoral Energy Use**
  - Buildings, 38 Q, 40%
  - Industry, 31 Q, 32%
  - Transport, 27 Q, 28%

- **Electricity Generation by Fuel**
  - Coal, 16 Q, 41%
  - Natural gas, 9.5 Q, 24%
  - Petroleum, 0.2 Q, 1%
  - Nuclear power, 8.1 Q, 21%
  - Hydropower, 2.7 Q, 7%
  - Solar, 0.04 Q, 0%
  - Wind, 1.4 Q, 4%
  - Other, 0.4 Q, 1%

- **Electricity Sales by Sector**
  - Buildings, 28 Q, 73%
  - Industrial, 10 Q, 27%
  - Transportation, 0.1 Q, 0%
Buildings: Energy Supply and Use

Building Sector Energy Supply

- Marketed renewables, 0.6 Q, 2%
- Distillate Fuel Oil, 0.9 Q, 2%
- Natural Gas, 7.2 Q, 19%
- Other fuels, 0.8 Q, 2%
- Electricity, 28 Q, 75%

38 Quads (2012)

Building Sector End Use

- Other uses, 9.5 Q, 25%
- Ventilation, 1.6 Q, 4%
- Space heating, 6.8 Q, 18%
- Space cooling, 4.4 Q, 12%
- Refrigeration, 2.3 Q, 6%
- Water heating, 3.5 Q, 9%
- Electronics, 2.4 Q, 6%
- Appliances, 1.3 Q, 4%
- Cooking, 0.8 Q, 2%

38 Quads (2012)
Industry: Supply and Use

**Industry Sector Energy Supply**

- Purchased electricity, 10, 33%
- Coal, 1.5, 5%
- Natural gas, 8.8, 29%
- Biofuels heat and coproducts, 0.5, 2%
- Hydropower, 0.01, 0%
- Municipal waste, 0.2, 1%
- Biomass, 1.3, 4%
- Petroleum and other liquids, 8.1, 26%

**31 Quads (2012)**

**Industry Sector End Use**

- Chemicals, 5.0 Q, 17%
- Paper, 3.3 Q, 11%
- Primary Metals, Wood Products, 2.6 Q, 8%
- Nonmetallic Mineral Products, 1.1 Q, 4%
- Food, 1.8 Q, 6%
- Non-manufacturing heat and power, 4.0 Q, 13%
- Petroleum and Coal Products, 5.2 Q, 17%
- Other Sectors, 2.5 Q, 8%
- Nonfuel uses, 4.3 Q, 14%

**31 Quads (2012)**
Transportation: Supply and Use

Transportation Sector Energy Supply

- Biomass liquids: 1.2 Q, 5%
- Natural gas: 0.8 Q, 3%
- Electricity and system losses: 0.1 Q, 0%
- Petroleum products: 24.7 Q, 97%

27 Quads (2012)

Transportation Sector End Use

- Military use: 1 Q, 3%
- Air: 2 Q, 9%
- Shipping: 1 Q, 2%
- Rail: 1 Q, 2%
- Freight trucks: 5 Q, 19%
- Commercial light trucks: 1 Q, 2%
- Light-duty vehicles: 15 Q, 58%

27 Quads (2012)
US Carbon Dioxide Emissions

- **Carbon Dioxide Emissions by Source**
  - Coal, 1,657 MMT, 31%
  - Natural Gas, 1,366 MMT, 26%
  - Petroleum, 2,254 MMT, 43%
  - Other, 12 MMT, 0%

- **Carbon Dioxide Emissions by Sector, 2012 MT**
  - Transport, 1,811 MMT
  - Buildings, 501 MMT
  - Industry, 938 MMT
  - Industry-Electricity, 543 MMT
  - Buildings-Electricity, 1,492 MMT

Total: 5,290 MMT of CO2 (2012)
Global Energy Demand Growth

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

- China
- European Union
- United States
- India
- Brazil

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Global Energy Growth Patterns

BP Statistical Review of World Energy 2018

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Global Coal Usage

BP Statistical Review of World Energy 2018

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Global Oil Production and Consumption

BP Statistical Review of World Energy 2018

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Global Petroleum Flows

Major trade movements 2017
Trade flows worldwide (million tonnes)

BP Statistical Review of World Energy 2018

We Use ~20 Mb/day, Import ~7Mb/Day
Figure 2.18: Share of inter-regional oil and gas trade through key choke points in the New Policies Scenario.
Low U.S. natural gas prices motivate LNG production and exports

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

- UK: $7.18
- Belgium: $10.86
- Spain: $7.54
- Korea: $10.86
- Japan: $8.10
- China: $10.86
- Argentina: $10.52
- Mexico: $10.18
- Lake Charles: $2.87
- Cove Point: $5.24

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

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

Common Water-Based Fracking Fluid Additives

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Example</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid</td>
<td>Hydrochloric acid</td>
<td>Clears debris from well bore</td>
</tr>
<tr>
<td>Thickener</td>
<td>Guar gum</td>
<td>Increases viscosity of fluid to disperse proppant</td>
</tr>
<tr>
<td>Friction reducer</td>
<td>Polycrylamide</td>
<td>Aids flow of fluid deep underground</td>
</tr>
<tr>
<td>Scale inhibitor</td>
<td>Ethylene glycol</td>
<td>Prevents carbonate/sulfate deposits</td>
</tr>
</tbody>
</table>

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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
- Chemical storage trucks
- Wellhead
- Frac tanks - stimulation fluid storage
- Frac pumps
- Sand storage units
- Frac blender

Aquifer
Cemented well casing protects aquifer

Waste cuttings generated during drilling are brought to a plastic-lined pit at the surface

“Kickoff” point
Drillers begin an arc that levels off horizontally when shale layer is reached

Well drilled horizontally at 914-1,524 m
Production casing inserted into borehole, then surrounded with cement
 Charges then detonated inside a perforating gun, blasting small holes into the shale
 Pressurised mixture of water, sand and chemicals then pumped into the well at 15,900 litres a minute
 The fluid generates numerous small fissures in the shale, freeing trapped gas that flows to the surface

Waste water pit
Municipal water well (over 300 m)
Private well

RISKS
Air emissions
Methane gas associated with natural gas extraction can leak into air
Drinking water
Chemicals used in the 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

Sources: National Geographic, Chesapeake Energy, EIA, USGS

Approx. distance from surface: 2,400 m
Illustration not to scale
Larger, Taller Turbines to Capture Improved Wind Fields

- Empire State Building: 1,454 ft
- Eiffel Tower: 1,063 ft
- Statue of Liberty: 305 ft
- New GE Haliade-X: 853 ft
- Tallest onshore US turbine: 574 ft
- Block Island offshore wind project: 590 ft

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The Impacts of Renewables
Capacity Factor

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2/1/2019
Small Modular Reactors: Safety, Reliability, Cost

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2/1/2019
Origins of Anthropogenic CO2


- **Atmosphere in 1870**
  - CO2 concentration: 288 ppm

- **Atmosphere in 2014**
  - CO2 concentration: 397 ppm

- **Coal**
  - Contribution: +89 ppm

- **Oil**
  - Contribution: +67 ppm

- **Gas**
  - Contribution: +28 ppm

- **Cement**
  - Contribution: +5 ppm

- **Land use**
  - Contribution: +69 ppm

- **Land sink**
  - Contribution: −75 ppm

- **Ocean sink**
  - Contribution: −73 ppm

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Global Carbon Project

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COP-21 International INDCs 20-2030, compared with Global Carbon Budgets from 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 GtC 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

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Geological Sequestration Resources
For CO2 Mineralization
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

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

- DG interconnection criteria
- Voltage regulation
- Distribution feeder
- Transmission congestion
- Stability problems
- Oscillations
- CAISO
- WECC

- Harmonic effects
- Distance to premium renewable resources

- One a.c. cycle
- AGC signal
- Hour-ahead scheduling and resolution of most renewables integration studies

- Synchro-phasors
- Protective relay operation
- Dynamic system response (stability)
- Wind and solar output variation
- Service restoration
- T&D planning
- Day-ahead scheduling
- Carbon emission goals

- High-frequency switching devices, inverters
- Demand response

- Millisecond
- Second
- Minute
- Hour
- Day
- Year
- Decade
Modelling and the Grid: Toward Faster-Than-Real-Time Operational Models
Storage Has A Wide Variety of Values

The diagram categorizes storage technologies based on their performance and power ratings. The categories include:

- **UPS - Power Quality**
  - High-energy Supercapacitors
  - Advanced Lead-acid Battery
  - NaNiCl₂ Battery
  - NaS Battery
  - Flow Batteries: Zn-Cl, Zn-Air, Zn-Br, VRB, PSB, New Chemistries

- **T&D Grid Support - Load Shifting**
  - Li-Ion Battery
  - Lead-acid Battery
  - NiCd
  - NiMH
  - High-power Flywheels
  - High-power Supercapacitors

- **Bulk Power Mgt**
  - Pumped Hydro
  - CAES

The performance times are categorized into:

- Seconds
- Minutes
- Hours

The power ratings are:

- 1 kW
- 10 kW
- 100 kW
- 1 MW
- 10 MW
- 100 MW
- 1 GW

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

Potential Limits of Building Energy Efficiency (Commercial)

Commercial Energy (Composite, All Regions)

End Use
- Heating
- Cooling
- Ventilation
- Lighting
- Water Heating
- Refrigeration
- Equip. (PC/Non PC)
- Other

Energy Savings %

Efficiency Scenario

Primary EUI (kBTU/sq. ft.)
0 25 50 75 100 125 150 175 200 225

Stock Energy Star Best Avail. ET 2020 Thermo. Limit
21%* 46%* 47%* 50%*
How Will We Support The Emerging Economies and Technologies???
<table>
<thead>
<tr>
<th>Technology</th>
<th>Component</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>Generators</td>
<td>Neodymium, Dysprosium</td>
</tr>
<tr>
<td>Vehicles</td>
<td>Motors</td>
<td>Neodymium, Dysprosium</td>
</tr>
<tr>
<td></td>
<td>Li-ion Batteries (PHEVs and EVs)</td>
<td>Lithium, Cobalt</td>
</tr>
<tr>
<td></td>
<td>NiMH Batteries (HEVs)</td>
<td>Rare Earths: Cerium, Lanthanum, Neodymium, Praseodymium, Cobalt</td>
</tr>
<tr>
<td>PV Cells</td>
<td>Thin Film PV Panels General*</td>
<td>Tellurium, Gallium, Germanium, Indium, Selenium, Silver, Cadmium**</td>
</tr>
<tr>
<td></td>
<td>CIGS Thin Films</td>
<td>Indium, Gallium</td>
</tr>
<tr>
<td></td>
<td>CdTe Thin Films</td>
<td>Tellurium</td>
</tr>
<tr>
<td>Lighting (Solid State and Fluorescent)</td>
<td>Phosphors</td>
<td>Rare Earths: Yttrium, Cerium, Lanthanum, Europium, Terbium</td>
</tr>
<tr>
<td>Fuel Cells*</td>
<td>Catalysts and Separators</td>
<td>Platinum, Palladium and other Platinum Group Metals, Yttrium</td>
</tr>
</tbody>
</table>

Sources: Table data extracted from Bauer, 2011 (20) and expanded upon with data from other sources per asterisk. *APS/MRS, 2011 (2). **Lifton, 2011 (10)
Critical Materials Institute Palette for Study

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Figure 3. Distribution of documented REE deposits as presented by A. Mariano in (Mariano, 2010).
Rare earth metals are not rare – found in many countries including the United States

Source: Watts 2011

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<table>
<thead>
<tr>
<th>Rare earth elements (in rare earth oxide/REO)</th>
<th>Occur in dilute concentrations in metal ores. Often co-produced with other metals. Concentrations vary widely from ore to ore.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mine production:</strong></td>
<td><strong>Refined metal:</strong></td>
</tr>
<tr>
<td>China</td>
<td>125,000</td>
</tr>
<tr>
<td>Russia</td>
<td>2,470</td>
</tr>
<tr>
<td>India</td>
<td>50</td>
</tr>
<tr>
<td>United States (processing of stockpiled ore at Mt. Pass, CA led to 2,150t REO)</td>
<td>0</td>
</tr>
<tr>
<td><strong>Top-ranked reserve holding countries, in rank order:</strong></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>36%</td>
</tr>
<tr>
<td>CIS</td>
<td>19%</td>
</tr>
<tr>
<td>U.S.</td>
<td>13%</td>
</tr>
<tr>
<td><strong>Total global reserves (in tonnes):</strong></td>
<td>99 million in REO content</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lithium (in lithium carbonate equivalent/LCE)</th>
<th>Most lithium is recovered from subsurface liquid brines or from mining of lithium-carbonate rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mine production:</strong></td>
<td><strong>Refined metal:</strong></td>
</tr>
<tr>
<td>Chile</td>
<td>38,720</td>
</tr>
<tr>
<td>Australia</td>
<td>23,020</td>
</tr>
<tr>
<td>China</td>
<td>12,033</td>
</tr>
<tr>
<td>United States</td>
<td>Withheld</td>
</tr>
<tr>
<td><strong>Top-ranked reserve holding countries, in rank order:</strong></td>
<td></td>
</tr>
<tr>
<td>Chile</td>
<td>76%</td>
</tr>
<tr>
<td>Argentina</td>
<td>8%</td>
</tr>
<tr>
<td>Australia</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Total global reserves (in tonnes):</strong></td>
<td>9.9 million in lithium content</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cobalt</th>
<th>Primary cobalt (15%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Byproduct of nickel mining (50%)</td>
<td></td>
</tr>
<tr>
<td>Byproduct of copper mining (35%)</td>
<td></td>
</tr>
<tr>
<td><strong>Ores, concentrates, or semi-refined materials:</strong></td>
<td></td>
</tr>
<tr>
<td>DRC</td>
<td>25,000</td>
</tr>
<tr>
<td>Australia</td>
<td>6,300</td>
</tr>
<tr>
<td>China</td>
<td>6,200</td>
</tr>
<tr>
<td>Russia</td>
<td>6,200</td>
</tr>
<tr>
<td><strong>Refined metals &amp; chemicals:</strong></td>
<td></td>
</tr>
<tr>
<td>DRC</td>
<td>51%</td>
</tr>
<tr>
<td>Australia</td>
<td>23%</td>
</tr>
<tr>
<td>Cuba</td>
<td>8%</td>
</tr>
<tr>
<td><strong>Total global reserves (in tonnes):</strong></td>
<td>6.6 million in cobalt content</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indium</th>
<th>Byproduct of zinc processing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global:</strong></td>
<td><strong>Metals, alloys, etc.:</strong></td>
</tr>
<tr>
<td>China</td>
<td>73%</td>
</tr>
<tr>
<td>South Korea</td>
<td>16%</td>
</tr>
<tr>
<td>Japan</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total global reserves (in tonnes):</strong></td>
<td>Not available</td>
</tr>
</tbody>
</table>
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
- BP Statistical Review of World Energy 2018
Thank You