THE ENERGY PILLARS DIAGRAM – An Effective Communication Tool For Biophysical Economists?

John Day, Christopher D’Elia, Charles A.S. Hall, Adrian Wiegman, Jeff Rutherford, Robert Lane

College of the Coast and Environment, Louisiana State University
Environmental Science and Forestry, SUNY, Syracuse
Outline

• Projections for the Second Half of the Fossil Fuel Age
• The Climate-Energy Impasse
• Energy Pillars Diagram
• Renewables to the Rescue?
• A Long-Term View of Energy and the Economy
Can renewables production catch up to a mid-century peak in fossil fuels?

Sources: Original Graph from Maggio & Cacciola 2012, Wind and Solar added using BP data, British Petroleum, 2014
The Energy-Climate Quandary

Roughly 4/5ths of remaining fossil fuel reserves (and the overwhelming majority of resources) must remain in the ground in order to reach 2 degree limit using Anderson’s (2015) estimate of 650 Gt of CO2 emissions.

(Source: McGlade 2015 Nature)
CO2 Emission Trajectories From Mohr et al. 2015

Scenarios of future fossil fuel production from Mohr et al. 2015:
- · · · Low URR Scenario
- - - - Best Guess URR Scenario
- - - - High URR Scenario

Cumulative Carbon Emissions From Fossil Fuel Combustion (Gt CO₂ eq)

- Exceeded b/w 2028-2033
- Exceeded b/w 2035-2045

1000 Gt Threshold (IPCC)
650 Gt Threshold (Anderson)
The Global Economy Supported by Energy Pillars

Earth’s Biophysical System

Source: Energy data from IEA 2015
Take away renewable energy sources and fossil fuels will support the modern economy with little noticeable changes.

Energy data from IEA 2013
Take away fossil fuels and the economic system would be forced to undergo massive upheaval.

Say Goodbye to Hamburger Helper, and 25 Cent Chicken Wings!

Energy data from IEA 2013
Without fossil fuels the economy must shrink, falling back down to earth.

The Devil is In the Details: Who, When, and How and at What Level?
Why aren’t we (at BPE 2016) talking about renewables?

• Can “new renewables” replace fossil fuels for the current scale of the economy?

• Give these factors:
  – Intermittency
  – Low energy density
  – Storage, substitutability
  – Slow market penetration
  – Low EROI
  – Infrastructure needs
  – Material constraints

• Probably not, but have these been adequately investigated (Maybe only by Dale et al. 2012)?
### EROI of Fossil Fuel Replacements?

#### The Range of EROI Reported for Societies Energy Options

<table>
<thead>
<tr>
<th>Energy Option</th>
<th>Fossil Fuels</th>
<th>Biomass</th>
<th>Nuclear</th>
<th>Hydro</th>
<th>NewRenew</th>
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<tbody>
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<td>Coal</td>
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<td>Coke</td>
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<td>Nuclear Fission</td>
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**Range of Reported EROI**

- Mean
- Median

**10:1 Growth Threshold**

(Fizaine & Court 2016, Hall et al. 2009)

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Adapted from: Carbajales-Dale et al. 2012

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Solar PV EROI extended = 0.8 in Germany and Switzerland (Ferroni & Hopkirk 2016)

~3:1 over 25 years with storage (Weisbach et al. 2013, Palmer 2014)

It must be asked weather or not, renewables could exist without Fossil Fuels.
Renewables Replace 100% of Electricity Produced by Fossil Fuels: Difficult but Conceivable

Renewables Replace 100% of Fossil Fuel Energy Uses: Extremely Difficult and Perhaps Impossible

Adapted from: Lawrence Livermore National Laboratory (2014) Energy Flow Charts

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Quantity</th>
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<tbody>
<tr>
<td>Petroleum</td>
<td>180,000</td>
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<td>Coal</td>
<td>190,000</td>
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<tr>
<td>Natural Gas</td>
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<td>Solar</td>
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<td>Geothermal</td>
<td>2,800</td>
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<td>Hydro</td>
<td>13,000</td>
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<td>Nuclear</td>
<td>28,000</td>
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<tr>
<td>Wind</td>
<td>1,600</td>
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<table>
<thead>
<tr>
<th>Energy Use</th>
<th>Quantity</th>
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<tr>
<td>Residential</td>
<td>87,000</td>
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<tr>
<td>Industrial</td>
<td>140,000</td>
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<tr>
<td>Non Energy</td>
<td>34,000</td>
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<tr>
<td>Transport</td>
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<td>Electricity and Heat</td>
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<tr>
<td>Rejected Energy</td>
<td>290,000</td>
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<tr>
<td>Energy Services</td>
<td>210,000</td>
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</tbody>
</table>
What Does a Renewable Economy Look Like?

Human’s of all ages doing manual Labor for sustenance

Slow moving vessels

Limited range of transport...

How much can “new renewables” change make the hard work like food production easier?
A Modern Day Renewable Economy, Ghana (68% renewables, mostly biomass):
Imported oil is Germany’s single largest contribution to energy supply.
Agrarian Society:

- %Workers in 1° Econ ~90%
- $\text{EROI}_{\text{SOC}} < 5:1$
- 0 cities > 1 million
- Pop < 0.5 billion

Industrial Society: The Great Acceleration

- %Workers in 1° Econ < 5%
- $\text{EROI}_{\text{SOC}} \approx 30:1$
- 500 cities > 1 million
- Pop = 7.4 billion

Adapted from Fizaine and Court 2016
Can society hit a sweet spot or will it fall off the net energy cliff?

Human Development Index verses EROI of Society

Source: Adapted from Lambert et al (2014)
Meeting climate goals while providing sufficient per capita energy for a comfortable life will likely require society to dip below the magic 10:1 EROI threshold.

C) SET 2.0 Output – BAU: World Energy Mix (left) Societal EROI (right), *Adapted from Sgouridis et al. (2016)*

D) SET 2.0 Output – 990Gt: World Energy Mix (left) Societal EROI (right), *Adapted from Sgouridis et al. (2016)*
Can society hit a sweet spot or will it fall off the net energy cliff?

Human Development Index verses EROI of Society

Source: Adapted from Lambert et al (2014)
The energy transition will put us somewhere between these two paradigms.

Adapted from Lambert et al. 2014
Summary

• Fossil Fuel Use Will Peak Before Mid Century
• EROI is Decreasing and Likely Will Continue
• Renewables Cannot Replace Fossil Fuels for the Current Economy (Intermittency, low energy density, storage, substitutability, slow market penetration, low EROI, infrastructure needs, material constraints)
• Meeting Climate Goals Will Cause Profound Changes in Society and the Economy
• Modern Industrial Society and Economy are Inherently Unsustainable
Global Biophysical Model of Energy Markets with Hypotheses for future of the energy transition

a. Central Price Scenario – Moderate Transition
b. Low Price Scenario - Successful Climate Policy Rapid Transition
c. High Price Scenario - Unsuccessful Climate Policy Slow Transition

1. Seasonal & Intermittant Solar Flux
2. Total and Discretionary Portion of GDP
3. Fossil Fuel (or Oil) Supply
4. Price of Energy $ EJ
5. Biophysical Systems – Provide Food and Assimilate Wastes
6. WASP – Wind and Solar Power

Key:
- Stocks: Producer, Storage, Consumer, Source
- Modifiers: Flow, Workgate, Waste Heat

Credit: A.R.H. Wiegman