Fast-tracking the energy transition

Invited Plenary Address to the “Reset: A Forum And Celebration Of Energy Transitions” Conference, Georgia Institute of Technology, Atlanta, United States, July 25, 2017

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Roadmap

• Data sources
• Conceptualizing energy transitions
• Rethinking transitions (the case for “fast-tracked” transitions, or “deliberate diffusion” or “accelerated transformation”)
• Conclusion
Data sources
Data sources

How long will it take? Conceptualizing the temporal dynamics of energy transitions

Benjamin K. Sovacool
Conceptualizing energy transitions

- What is an energy transition?
  - Change in fuel supply?
  - Shift in technologies that exploit fuel, e.g. prime movers and use devices?
  - Switch from an economic or regulatory system (e.g. Cuba)?
  - Time taken for socio-technical diffusion?
  - At what scale?

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Five definitions of energy transitions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>Source</td>
</tr>
<tr>
<td>A change in fuels (e.g., from wood to coal or coal to oil) and their associated technologies (e.g., from steam engines to internal combustion engines)</td>
<td>Hirsh and Jones [22]</td>
</tr>
<tr>
<td>Shifts in the fuel source for energy production and the technologies used to exploit that fuel</td>
<td>Miller et al. [23]</td>
</tr>
<tr>
<td>A particularly significant set of changes to the patterns of energy use in a society, potentially affecting resources, carriers, converters, and services</td>
<td>O’Connor [24]</td>
</tr>
<tr>
<td>The switch from an economic system dependent on one or a series of energy sources and technologies to another</td>
<td>Fouquet and Pearson [25]</td>
</tr>
<tr>
<td>The time that elapses between the introduction of a new primary energy source, or prime mover, and its rise to claiming a substantial share of the overall market</td>
<td>Smil [26]</td>
</tr>
</tbody>
</table>
Conceptualizing energy transitions

• What does the academic literature say?

• “Energy transitions have been, and will continue to be, inherently prolonged affairs, particularly so in large nations whose high levels of per capita energy use and whose massive and expensive infrastructures make it impossible to greatly accelerate their progress even if we were to resort to some highly effective interventions …”
Conceptualizing energy transitions

Nuclear and wind have not reached 25 percent; photovoltaics hardly registers.
Conceptualizing energy transitions

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Short communication

Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions

Arnulf Grubler\textsuperscript{a,b,\ast}, Charlie Wilson\textsuperscript{a,c}, Gregory Nemet\textsuperscript{d}
Conceptualizing energy transitions

Fig. 1. Durations of formative phases for energy technologies are at a decadal scale [4]. Note: Ranges refer to alternative definitions for the start and end points of formative phases, and so capture measurement uncertainties.

Fig. 2. Diffusion speeds accelerate as technologies diffuse spatially. Notes: Bars show durations of diffusion measured by cumulative total capacity installed, with historical data fitted via a logistic growth curve and the diffusion duration expressed as \( \Delta t \) in years. ‘Core’ is typically within the OECD; ‘Rim’ is typically Asian countries; ‘Periphery’ is typically other world regions. For details and data, see [42,3].
Diffusion durations scale with market size. Notes: X-axis shows duration of diffusion (t) measured in time to grow from 10% to 90% of cumulative total capacity; y-axis shows extent of diffusion normalized for growth in system size. All data are for ‘core’ innovator markets. Round symbols denote end-use technologies; square technologies denote energy supply technologies; triangular symbol denotes general purpose technologies (steam engines). Arrows show illustrative examples of system of systems (refineries describing the rise of multiple oil uses across all sectors, cars describing the concurrent growth of passenger cars, roads, and suburbs, and steam engines are a proxy of the growth of all coal-related technologies in the 19th century). Arrows also highlight examples of single technologies diffusing into existing systems substituting existing technologies (nuclear power, compact fluorescent light bulbs).
Some peculiarities

- **Diffusion thresholds**: what % constitutes a transition (5%, 10%, 25%, 50%)?
- **Co-evolution**: one isolated technology or the seamless web (e.g. mimicry plus rail and telegraph and EVs)?

![Graph showing growth of infrastructures in the United States as a percentage of their maximum network size.](image)

- **Unit of analysis**: big oil or smaller changes in ICEs, steam engines on ships, oil lamps, oil heating boilers and furnaces?
Rethinking transitions: Can they be fast-tracked?

- We have seen at least five fast transitions in terms of energy end-use and prime movers.
- Examples of many rapid national-scale transitions in energy supply also populate the historical record.

<table>
<thead>
<tr>
<th>Country</th>
<th>Technology/fuel</th>
<th>Market or sector</th>
<th>Period of transition</th>
<th>Number of years from 1 to 25% market share</th>
<th>Approximate size (population affected in millions of people)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>Energy-efficient ballasts</td>
<td>Commercial buildings</td>
<td>1991–2000</td>
<td>7</td>
<td>2.3</td>
</tr>
<tr>
<td>China</td>
<td>Improved cookstoves</td>
<td>Rural households</td>
<td>1983–1998</td>
<td>8</td>
<td>592</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Liquefied petroleum gas stoves</td>
<td>Urban and rural households</td>
<td>2007–2010</td>
<td>3</td>
<td>216</td>
</tr>
<tr>
<td>Brazil</td>
<td>Flex-fuel vehicles</td>
<td>New automobile sales</td>
<td>2004–2009</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>United States</td>
<td>Air conditioning</td>
<td>Urban and rural households</td>
<td>1947–1970</td>
<td>16</td>
<td>52.8</td>
</tr>
<tr>
<td>Kuwait</td>
<td>Crude oil and electricity</td>
<td>National energy supply</td>
<td>1946–1955</td>
<td>2</td>
<td>0.28</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Natural gas</td>
<td>National energy supply</td>
<td>1959–1971</td>
<td>10</td>
<td>11.5</td>
</tr>
<tr>
<td>France</td>
<td>Nuclear electricity</td>
<td>Electricity</td>
<td>1974–1982</td>
<td>11</td>
<td>72.8</td>
</tr>
<tr>
<td>Denmark</td>
<td>Combined heat and power</td>
<td>Electricity and heating</td>
<td>1976–1981</td>
<td>3</td>
<td>5.1</td>
</tr>
<tr>
<td>Canada (Ontario)</td>
<td>Coal</td>
<td>Electricity</td>
<td>2003–2014</td>
<td>11</td>
<td>13</td>
</tr>
</tbody>
</table>

视角注：The Ontario case study is the inverse, showing how quickly a province went from 25% coal supply to zero.
Rethinking transitions

Bubble size is indicative of population size affected

Years from 1 to 25% market share


Figure designed by Gert Jan Kramer, used with permission
Rethinking transitions

• Historic energy transitions have not been consciously governed, whereas today a wide variety of actors is engaged in active attempts to govern the transition towards low carbon energy systems.
• International innovation dynamics can work in favor of speeding up the global low-carbon transition.
• The 2015 Paris agreement demonstrates a global commitment to move towards a low carbon economy for the first time.
Rethinking transitions

Nordic Energy Technology Perspectives 2016

Cities, flexibility and pathways to carbon-neutrality
Rethinking transitions: electricity, heat, and buildings

a. Top panel: Electricity generation

b. Bottom panel: Heat supply

a. Top panel: Buildings energy consumption, 2013 and 2050

b. Bottom panel: Energy intensity and emission intensity, 1990 to 2050
Rethinking transitions: transport fuel

a. Top panel: by fuel source, 2010-2050

b. Bottom panel: by transportation mode, 2050
Rethinking transitions: industrial emissions

CCS utilization by 2050:

50% of cement plants
30% of iron & steel, chemical plants

Fig. 11. Nordic Carbon Dioxide Emissions by Country, 2010–2050.
Rethinking transitions

• The total cost of the Nordic transition is roughly $3.57 trillion
• It requires an additional investment of only $333 billion
• This is less than 1% of cumulative GDP over the period
• If you monetize air pollution and fuel savings, it tips the economic equation firmly in favour of the transition
Rethinking transitions: Active phaseouts?

Accelerating low-carbon innovation: the role for phase-out policies

**Policy Briefing 05**
March 2017

1. Control policies
This group of policy instruments aim to reduce carbon emissions from specific technologies or sectors. This is either through market mechanisms (in the UK, examples include the carbon floor price and EU Emissions Trading System (ETS)) or regulation (such as mandatory energy efficiency requirements for appliances, vehicle emission standards, zero carbon buildings, and a ban of incandescent light bulbs).

2. Changing market rules
These are rules that are applied at a broader level than control policies and typically address a whole market, sector or system, or even cross several systems. One example is the UK’s 80% carbon reduction target, as set out in the Climate Change Act 2008.

3. Reduced support for dominant carbon intensive technologies or practises
High-carbon technologies and practises may receive support in a number of forms. These should be acknowledged and then reduced and removed over time. Examples include subsidies or tax exemptions.

4. Ensuring a balanced debate by developing actors or networks in emerging sectors
Incumbent industries can have a strong influence on policy decisions, whereas emerging innovations are unlikely to have well developed and influential networks. This imbalance can be addressed by creating new committees or networks involving actors mainly supporting low- and zero-carbon innovations in order to ensure incumbents are not given unfair weight in policy making processes.
Changes in demand preferences, demand "peaks?"

Global Oil Demand Growth – The End Is Nigh
26 March 2013

Citi Research

Global Oil Demand Growth – The End Is Nigh

Figure 1. Global Oil Demand Projections:-mb/d

Business As Usual
After vehicle efficiency gains
After gas substitution

Figure 2. Potential Natural Gas Substitution For Oil:-mb/d

Shipping
US Trucks
Power Gen
Other

NGVs
Global Trucks (ex US)
Petchem

Source: Citi Research

Source: Citi Research
A perspective from utilities and incumbents?
The energy transition is already happening?

**Disruptive Trend**

<table>
<thead>
<tr>
<th>Achieved</th>
<th>Anticipated</th>
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<tbody>
<tr>
<td><strong>Pre-2015</strong></td>
<td><strong>2015</strong></td>
</tr>
<tr>
<td><strong>Residential PV solar parity</strong>&lt;sup&gt;1&lt;/sup&gt;</td>
<td>California 2012</td>
</tr>
<tr>
<td>Annual sales (GW)</td>
<td>0.51</td>
</tr>
<tr>
<td>New York 2013</td>
<td>New England 2022*</td>
</tr>
<tr>
<td>Hawai‘i Pre-2014</td>
<td><strong>PV plus battery grid defection</strong>&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Electric vehicle penetration</strong>&lt;sup&gt;3,4&lt;/sup&gt;</td>
<td>2014: 100k units sold in yr</td>
</tr>
<tr>
<td><strong>Gas-based distributed generation parity with retail</strong>&lt;sup&gt;5&lt;/sup&gt;</td>
<td>MA, NY, PA &amp; MD 2014</td>
</tr>
<tr>
<td><strong>Net metering penetration</strong>&lt;sup&gt;6,7&lt;/sup&gt;</td>
<td>In 2014, only 6 states without net metering: TX, ID, SD, MS, AL, TN</td>
</tr>
<tr>
<td><strong>Smart Meter installation</strong>&lt;sup&gt;8,9&lt;/sup&gt;</td>
<td>7 million installed by 2007</td>
</tr>
</tbody>
</table>

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* Enables multiple homeowners to participate in the same metering system and share the output from a single facility that is not physically connected to their property or meter
67 Startups Making Your Home Smarter

- **Pet & Baby Monitor**
  - Petnet
  - iBaby
  - Petcube
  - nanit
  - sevenhugs
  - LULLY

- **Safety & Security**
  - leeo
  - BeON
  - myfox
  - August
  - Lockitron
  - canary
  - LATCH
  - cocoon
  - Glue

- **Appliances & Audio Devices**
  - hiku
  - INDEPENDA
  - innit
  - SONOS
  - SECTORQUBE
  - KITU
  - MUSAIC

- **Lighting**
  - LUMETRIC
  - LIFX
  - emberlight
  - Switchmate

- **Miscellaneous**
  - KAMARQ
  - notion
  - Ecoisme
  - sense.
  - thinkeco
  - Rachio
  - ecobee
  - there
  - tado

- **Energy & Utilities**
  - Grove
  - NIWA
  - Edyn

- **Device Controllers**
  - SENTRI
  - Fluent
  - NINJA BLOCKS
  - muzzley
  - wigwag
  - ivee
  - Pool
  - AVION
  - iRule

- **Health & Wellness**
  - SmartMinder
  - beddit
  - Netatmo
  - vivint.SmartHome

- **General Smart Home Solutions**
  - Ecovent
  - KEEN

- **Home Robots**
  - Jibo
  - Rokid
  - Robart

- **Gardening**
  - Grove
  - NIWA
  - Edyn
### Shifts in business models and value creation alongside technology

<table>
<thead>
<tr>
<th>Trends pushing down the cost of solar, other renewables and energy efficiency</th>
<th>Examples</th>
</tr>
</thead>
</table>
| Increasing technical innovation | • New battery chemistries  
• New solar PV technologies |
| Synergistic solutions increasing the value of renewables | • Solar PV + battery storage  
• IT and storage for peak shaving |
| Data and internet of things increasing integration | • Sensors  
• Predictive software  
• Demand response automation |
| Innovative business models increasing customer bases | • No up front costs  
• Funnel analysis  
• Value beyond energy |
| Innovative financing reducing cost of capital | • Third-party financing  
• Green bonds  
• YieldCos |
Concluding remarks

• Whether an energy transition can occur quickly or slowly can depend in great deal about how it is defined, so always check sources, data, assumptions etc.
• Causes are complex: WW2 (France and Kuwait), rural famine (China), 1970s oil crises (Denmark, Brazil), demand (AC in USA)
• Future transitions could be driven by active governance (phase-outs), scarcity, and demand pressures, rather than supply, markets, or abundance
• The past need not be prologue; history can be instructive but not necessarily predictive
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