Amory B. Lovins
Chairman and Chief Scientist
“The Future Brought by Small-Scale Distributed Energy Networks”
Japan Renewable Energy Foundation
Tōkyō, 7 November 2013
$5T$ in savings +158% bigger economy

0 oil, coal, nuclear
If a problem can’t be solved, enlarge it.

—attributed to Dwight Eisenhower
Electricity: Key to the New Energy Era
Once-staid utility evolution is going into fast forward

1. Samuel Insull’s model (mostly regulated monopoly) was a mixed success
2. Big plants initially made sense
3. That reversed several decades ago
4. Huge scale mismatch between plants and loads
5. Plants’ economies of scale evaporated or reversed; diseconomies dominate
6. Disappointing new-plant (especially nuclear) cost and performance drove 1990s restructuring, creating new entrants, unbundled prices, and competition at all scales—unleashing a swarm of distributed competitors that are rapidly taking over the world market
7. New-unit scale is rapidly regressing toward customer scale
8. New grid architectures emerging, notably islandable netted microgrids
9. IT, smart grid, and customer-centricity are transforming everything
10. Next disruption now emerging: the unregulated “virtual utility”
Twelve main gamechangers are transforming the electricity industry

Stagnant or shrinking demand

**Efficiency and demand response becoming important**

**Expanding returns to efficiency investments** (integrative design)

Massive **supply shifts** to renewables, gas, and combined-heat-and-power (CHP)

Existential **threats to transmission**—brittle, not resilient

Resilience imperative favors distributed generation and microgrids over remote central plants

Orders-of-magnitude shift in generation **scale**

Utilities’ **financial stability** slipping

System becoming **permeated with information** (“electricity meets IT”)

**Variable renewables** reliably integratable at scale

**Customer-centricity**; competition in not just kWh but also service bundles

Radical **bypass** threatening utilities’ business models
Annual changes in operable global electricity generating capacity (GW), 1980–2012

Source: compilation by Bernard Chabot (http://cf01.erneuerbareenergien.schluetersche.de/files/amfiledata/2/0/9/1/1/8/V1NuclWorld201224313.pdf) of data from: Nuclear: IAEA; Hydro, Fossil Fuels: US-EIA; Wind: GWEC; PV: EPIA
Global Markets are Shifting to Distributed Renewables

Global generating capacity: annual *net additions*, 1990–2012

- Wind
- Photovoltaics
- Nuclear

PV worldwide annual manufacturing capacity (GW/y)

- PV worldwide annual manufacturing capacity (GW/y)
Renewable Energy’s Costs Continue to Plummet

Wind and photovoltaics: U.S. real capital cost trends

Photovoltaic modules
Windfarms
Global micropower (CHP + non-big-hydro renewables) vs. nuclear output, 2000–2012
(expressed as shares of global electricity generation)
Japanese photovoltaic growth in context

Source: Tomas Kåberger, JREF, 8 Sep 2013
German photovoltaic capacity additions by month, 2009–13

PV development in Germany 2009-2013
MW/month registered under EEG. Source of data: BNETZA

Source: BNETZA data from B. Chabot, 31 Oct 2013, “Note on the evolution of the German Solar PV Market and PV FITs”
German cumulative photovoltaic capacity additions by month, 2009–2013

PV development in Germany 2009-2013
MW end of month registered under EEG. Source of data: BNETZA
PV Balance of System: 45–65% cost reductions identified Sept. 2010; US$0.16/W cost drop (excluding module & inverter), or 40% of total installed-cost drop, observed 2009–2010

A US Department of Energy workshop on 11–12 Aug 2010 generally agreed that an installed system PV cost of $1/Wp by 2017 was very ambitious but probably achievable.
Average installed PV system cost (mostly groundmount): US 1Q12 $4.42, Germany (mostly rooftop) 2Q12 $2.24!
PVs alone could scale to supply all U.S. annual electricity needs within a few decades (though actually we’d buy a mix of sources)

![PV Generation vs. U.S. Electrical Demand to 2050](image)

Assumptions:
1. PV Manufacturing Growth declines steadily from the projected 2012 50%/yr rate to 20%/yr, 15%/yr, and 10%/yr in the Manufacturing Led, Moderate and Low Growth Cases, respectively
2. ‘PV Manufacturing Led ‘ assumes unconstrained demand, and is considered achievable by industry manufacturing experts

Source: Mc Kenzie Report for U.S. Electrical Demand, SunPower calculations for PV Energy Growth
US windpower prices falling steeply since 2009; in midwest Windbelt, averaged $32/MWh in 2012 & in mid-2013 even $22, net of Federal Production Tax Credit (which is worth a levelized $18/MWh at a 3%/y or $27 at a 15%/y real discount rate—less subsidy than most nonrenewables get)
German photovoltaic 20-y feed-in tariffs in current ¥/kWh (market exchange rates)

German PV FITs, Yen/kWh on 20 years
Updated on October 31, 2013. Data: BNETZ. Market exchange rate

Rooftop < 10 kW
10 kW < Rooftop < 40 kW
40 kW < Rooftop < 1 MW
1 MW < Rooftop < 10 MW
Ground mounted < 10 MW

Japan FIT

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Analysts have systematically underestimated the speed of drop in PV module prices.

Figure 14. Actual module average selling price reduction vs. average analyst expectations

Sources: Barclays (05/01/09, 11/15/10, & 04/11/11); Citigroup (05/01/12); Deutsche Bank (05/27/08, 01/21/09, 05/06/10, & 01/05/11); Goldman Sachs (10/17/11, 02/29/12, & 06/26/12); Lazard (11/04/08, & 04/02/09); Stifel Nicolaus (07/15/11, 01/25/12, & 04/20/12); Thomas Weisel (10/06/09, & 04/08/10); UBS (08/22/10, 03/08/11, and 10/10/11)
U.S. utilities’ simulated or experienced grid integration costs at various fractions of installed windpower capacity

[Diagram showing integration costs vs. wind penetration]

- **APS (2007)**
- **Avista (2007)**
- **BPA (2009) [a]**
- **BPA (2011) [a]**
- **CA RPS (2006) [b]**
- **ERCOT (2012)**
- **EWITS (2010)**
- **Idaho Power (2007)**
- **Idaho Power (2012)**
- **MN-MISO (2008) [c]**
- **Nebraska (2010)**
- **NorthWestern (2012)**
- **PacifiCorp (2005)**
- **PacifiCorp (2007)**
- **PacifiCorp (2010)**
- **PacifiCorp (2012)**
- **Portland GE (2011)**
- **Puget Sound Energy (2007)**
- **SPS-SERC (2011)**
- **We Energies (2003)**
- **Xcel-MNDOC (2004)**
- **Xcel-PSCo (2006)**
- **Xcel-PSCo (2008)**
- **Xcel-PSCo (2011) [d]**
- **Xcel-UWG (2003)**

[a] Costs in $/MWh assume 31% capacity factor.
[b] Costs represent 3-year average.
[c] Highest over 3-year evaluation period.
[d] Higher-cost line adds the coal cycling costs found in Xcel Energy (2011).
All options face implementation risks; what does market behavior reveal?

Highly cost-effective US alternative potential, vs. US nuclear output ≡ 1.0

- Electric end-use efficiency: 2–3 (EPRI) or 4 (RMI)
- Cogeneration: 1 (industry) plus >1 (buildings)
- On-/nearshore windpower at available windy sites: >45
- Other renewables: far more (5 for PVs = 10–26,000 km²)
- Storage/backup is not a significant problem or cost

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Relative land-use of nuclear, solar PV, and windpower

An urban myth holds that nuclear power uses very little land, while solar and windpower are enormously land-intensive. The empirical data show exactly the opposite.

Nuclear power’s land-use

<table>
<thead>
<tr>
<th>Land Transformation (m²/GWh)</th>
<th>km² per 900 MW&lt;sub&gt;av el&lt;/sub&gt;</th>
<th>Stewart Brand’s claim in Whole Earth Discipline (2009)</th>
<th>evidence-based literature findings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>nuclear (PWR)</strong></td>
<td>0.86 (Cravens)</td>
<td>≥37.2 (Lovins), 37.7 (BNL)</td>
<td></td>
</tr>
<tr>
<td>windpower</td>
<td>&gt;520 (Cravens) to 775 (Ausubel)</td>
<td>In flat open sites, ~0.5–5 (max 13) with permanent roads, ~0.013 without</td>
<td></td>
</tr>
<tr>
<td>photovoltaic</td>
<td>&gt;130 (Cravens) to 151 (Ausubel)</td>
<td>av. US site: ≤39 with horizontal panels; ≤35 if optimized; 0 if on structures, as &gt;90% are today</td>
<td></td>
</tr>
</tbody>
</table>


Best resources far away, or adequate resources nearby?

Source: NERC 2009 LTRA p 72
Denmark’s transition to distributed electricity, 1980–2012

Centralised Generation

Distributed Generation

Source: Risø
Microgrid schematic

- Existing Power Plants
- Network Operations Center
- Home Area Networks (HANs)
- Solar Panels
- Electric Vehicles
- Existing Transmission System
- Storage Systems
- Building Management Systems
- Existing Distribution System
An illustration of how a Texas microgrid could work without storage (which comes into play if the surrounding grid fails)

- Efficiency reduces peak demands
- Demand response shifts load to correspond to local renewables
- CHP ramps to accommodate variations in wind and solar output
- Grid power is used for balancing

PHEVs charge when the most low-marginal cost, renewable energy is available, and batteries absorb excess energy.
Big grids are prone to historically rare but easily caused cascading failures.


14 Aug 2003: 50 million people in 89 states and Ontario blacked out in 9 seconds; note some decentralized systems and specific generators “islanded” successfully.
Grid security threats: probability vs. consequences

Source: Adapted from Pugh, 2010
Cuba’s grid reengineering for resilience


Mandatory, rapid, coordinated, nationwide deployment of:
- a shipload of Chinese efficient end-use devices on credit
- steeply inverted electricity tariffs, massive public education
- distributed generation: too quick to get in wind queue, so 1,854 oil-fired microgenerators (1.8 GW) clustered in 110 municipalities, & 6,000+ critical-site backup gens (0.7 GW)
- refurbished grid rearchitected: netted islandable microgrids
- worst 5 of 11 geriatric Soviet-era big oil plants retired

By 2007, over half of Cuba’s 5.9 GW was distributed. Payoff:
In 2008, two hurricanes in two weeks shredded parts of the grid, but the resilient grid and DG proved robust and maintained critical services

“Distributed benefits” can make distributed generation (or distributed demand-side resources) far more valuable.
Where does the order-of-magnitude value increase come from?

- Financial-economics benefits: often nearing $\sim 10\times$ renewables, $\sim 3–5\times$ others
- Electrical-engineering benefits: normally $\sim 2–3\times$, far more if the distribution grid is congested or if premium power reliability or quality is required
- Miscellaneous benefits: often around $2\times$, more with thermal integration
- Externalities: indeterminate but may be important; not quantified here
- All these apply to end-use efficiency as well as to decentralized supply!
207 Distributed benefits: $\sim 10\times$ value
(Actual value is very technology- & site-specific)

◊ $\sim 10^{1\times}$: Minimizing regret (financial economics)
  ○ Short lead times and small modules cut risk
    › Financial, forecasting, obsolescence
    › Overshoot and “lumpiness”

Tom Hoff’s analytic solution shows that it’s worth paying $\sim 2.7\times$ more per kW for a 10-kW overnight resource than for a 50-MW 2-y resource
Financial-economics benefits (continued)

○ Portable resources are redeployable

○ Build as you need, pay as you go—reduces financial risk

○ Rapid learning, mass-production economies

○ Constant-price resources vs. volatile prices

○ Genuinely diversified supply portfolios should have a substantial fraction of “riskless” renewables, even if they cost more: such diversification lowers long-run expected prices for the overall generation portfolio

○ “Load-growth insurance” of cogeneration and efficiency
Variable Renewables Can Be Forecasted At Least as Accurately as Electricity Demand

France, December 2011: actual & forecasted (1 day ahead) wind output (GW) (data from French transmission system operator RTE)

Source: Bernard Chabot, 10 April 2013, Fig. 7, www.renewablesinternational.net/wind-power-statistics-by-the-hour/150/505/61845, data from French TSO RTE
12% Downtime

11% Downtime

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Choreographing Variable Renewable Generation

ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation)
4. Renewables-renewables integration and diversified siting

- Across each of three power pools in the Midwestern U.S. & Texas, choosing an anticorrelated wind portfolio cuts needed capacity by 50–60%.
  - It’s strange that the windpower developers didn’t do that—but they could still do it afterwards by using synthetic contracts.
- Integrating photovoltaics with wind can reduce variability by a further 18%, saving even more capacity (PV output is correlated with peak loads, not with wind output).
- New wind turbines optimized for high capacity factor at low windspeed offer further potential for diversifying across large areas.
- Integrating variable renewables with demand response offers similar potential, generally without requiring bulk electrical storage.
The misunderstanding underpinning nuclear advocates’ criticism of windpower and PVs as unreliable is disproven by theory, practice, and soon policy.

“I think baseload capacity is going to become an anachronism....You don’t need fossil fuel or nuclear [plants] that run all the time....We may not need any [more], ever.”

—Jon Wellinghoff, Chairman
US Federal Energy Regulatory Commission
22 April 2009
Choreographing Variable Renewable Generation

Europe, 2012 or *1H2013
renewable fraction of total electricity

41%  
Denmark (30% wind, with 2013 peak 94%)

23%  
Germany (2013 peak 70%); windpower in two Länder 45–58% (2011)

70%*  
Portugal (peak 100% in 2011, average 70% for the first half of 2013 including 26% wind and 34% hydro)

48%*  
Spain for the first half of 2013 including 24% wind and 18% hydro
Demand response (DR) looks unexpectedly large

Extensive energy modeling and practice have demonstrated major efficiency and demand-response potential in new and retrofit buildings and factories

RMI’s identified potential shown for ERCOT is all automatic, unobtrusive, and several times bigger than had been widely supposed
Four illustrative and feasible scenarios

1. Business-as-Usual
2. Nuclear and “clean coal” (IGCC/CCS)
3. Centralized renewables
4. Distributed renewables
Costs
Four U.S. electricity futures, 2010–2050

System Cost: < $5.7 trillion
System ops illustrated for each Case (not all for the same day)
Volume Production of Electrified Carbon-Fiber Cars

Starting in 2013

**VW XL1** 2-seat plug-in hybrid (2011)
111 km/L (gasoline), 2013 production

**BMW i3** 4-seat battery-electric hatchback (2011) with 0.65-L-engine option to double range to 200 mi, 2013 production, $41–45k
Toyota 1/X concept sedan (2007)
Prius size, 1/2 fuel use, 1/3 weight (420 kg)
3.6×-more-efficient SUV can cruise at 89 km/h with the same power to the wheels that a normal SUV uses on a hot afternoon to run the air-conditioner.
Transportation Without Oil

despite 90% more automobility, 118% more trucking, 61% more flying

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“We must leave oil before it leaves us.”

Fatih Birol
Chief Economist
International Energy Agency 2008
Electric Needs Will Decline as Efficiency Gains Speed

Annual changes in U.S. electricity consumption

Historic

Projected

- Actual
- EIA Baseline
- With Efficiency Only
- Transform with Efficiency + Electric Autos

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3-4x Energy Productivity in Buildings, 2x in Industry

Same or better services

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Integrative Design in Retrofitting the Empire State Building

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ESB Approach

Avoided Chiller Plant Retrofit

$4M $2.7M $5.6M $2.4M $8.7M Minus $17.4 $4.4M Annual Savings

Windows Radiative Barrier DDC Controls VAV AHUs Lighting & Plugs Avoided Chiller Plant Retrofit

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Our Latest Deep Retrofit:
Byron Rogers Building (Federal Offices in Denver)

70% expected saving
(284→85 kWh/m²-y),
meeting central-
government economic
guidelines

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## Benchmarking a big new office

(~10,000+ m², semitropical climate; Japanese comparables)

<table>
<thead>
<tr>
<th></th>
<th>standard US</th>
<th>better</th>
<th>best practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>site MJ/m²-y</td>
<td>1,100/1,737</td>
<td>450–680/566</td>
<td>100–230/293</td>
</tr>
<tr>
<td>el. kWh/m²-y</td>
<td>270/203</td>
<td>160/195</td>
<td>20–40/81</td>
</tr>
<tr>
<td>lighting W/m² as-used</td>
<td>16–24/12</td>
<td>10</td>
<td>1–3</td>
</tr>
<tr>
<td>plug W/m² as-used</td>
<td>50–90/12</td>
<td>10–20</td>
<td>2</td>
</tr>
<tr>
<td>glazing W/m² K COG</td>
<td>2.9</td>
<td>1.4</td>
<td>0.3–0.5</td>
</tr>
<tr>
<td>glazing Tvis/SC</td>
<td>1.0</td>
<td>1.2</td>
<td>&gt;2.0</td>
</tr>
<tr>
<td>perimeter heating</td>
<td>extensive</td>
<td>medium</td>
<td>none</td>
</tr>
<tr>
<td>roof ρ, ε</td>
<td>0.8, 0.2</td>
<td>0.4, 0.4</td>
<td>0.08, 0.97</td>
</tr>
<tr>
<td>m²/kWth cooling</td>
<td>7–9</td>
<td>13–16</td>
<td>26–32+</td>
</tr>
<tr>
<td>cooling syst. COP</td>
<td>1.85</td>
<td>2.3</td>
<td>6.8–25+</td>
</tr>
<tr>
<td>relative cap. cost</td>
<td>1.0</td>
<td>1.03</td>
<td>0.95–0.97</td>
</tr>
<tr>
<td>relative space eff.</td>
<td>1.0</td>
<td>1.01</td>
<td>1.05–1.06</td>
</tr>
</tbody>
</table>

Japan standard: median of 40 buildings, Energy Conservation Center of Japan; better: average of six SHASEJ Junen Award-winning buildings; best: the most efficient of those six buildings (Nissei Yokkaichi Building); data courtesy of Urabe-san, CRIEPI, via Asano-sensei, Todai

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Lovins House, Old Snowmass, Colorado

2200 m (7100 ft) elevation, 1984
lowest temperature –44°C (47°F,) up to 39 days of continuous winter
1984:

- Saved space and water heating energy
- Saved electricity
- Month payback
Saving Electricity
motors, pumps, and pipes
Less Capital Investment

smaller equipment
radically efficient industrial redesign
Heresy Happens

U.S. energy intensity

Government and Industry Forecasts, 1975

Lovins, *Foreign Affairs*, Fall 1976

Reinventing Fire, 2011

Index of U.S. Primary Energy Per Dollar of Real GDP

1.25
1
0.75
0.5
0.25
0

1975 1990 2005 2020 2035 2050

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Reinventing Fire: U.S. Economy Free From Oil and Coal

Oil
Coal
Nuclear
Natural Gas
Renewables

More-Productive Driving
Efficiency Savings
EIA's Projected Savings

Extrapolated

USEIA forecast

Quadrillion BTU/y

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Rocky Mountain Institute’s Implementation Initiatives

- Next-Generation Electricity
- Superefficient Affordable Housing
- Transformational Trucking
- 10xE: Factor Ten Engineering
- Project Get Ready

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Japan can lead this global energy *hiyaku* (飛躍)

Japanese frogs jump too!

*The old pond frog jumps in plop*

—Bashō, 1686
ご静聴ありがとうございました