Renewable & Appropriate Energy Laboratory
RAEL

Lecture 4: What are the Barriers to Action?

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1. The climate crisis reinvented (3.28.2016)
Klein, chapters 1 & 2 | Optional: Dove & Kammen, chapter 1

2. Our mistrust of the future makes it hard to give up the past (4.4.16)
Klein, chapters 3 | Optional: Dove & Kammen, chapter 5

3. We don't tenure Mother Teresa (4.11.2016)
Klein, chapter 9 | Optional: Dove & Kammen, chapter 2

4. What are the barriers to action? [Toys] (4.18.2016)
Klein, chapter 6 - 8 |

5. A new economics of the planet [Money] (4.25.2016)
Klein, chapter 4 | Optional: Dove & Kammen, chapter 3; Klein 12

6. Pasteur's Quadrant [Ideas] (5.2.2016)
Klein, chapter 7, 11 | Optional: Dove & Kammen, chapter 4

Resources:

Website: http://rael.berkeley.edu

Twitter: @dan_kammen

WHO HAS THE "CHEAP" (TO PRODUCE) EASY (TO EXTRACT) READILY ACCESSIBLE OIL...

WORLD CONVENTIONAL OIL *RESERVES* MAP (Billion barrels of oil)

More than half in the least stable part of the world

DRAWN SO THAT AREA CORRESPONDS TO RESERVES

...NOT THE U.S. OR CHINA

2009 BP statistics

A WIDER VIREW ON KEY ENERGY ISSUES: HOW CAN WE..

SLOW GLOBAL WARMING and increase the probability that catastrophic climate change can be avoided.

REDUCE DEPENDENCE ON OIL and the associated problems of economic vulnerability, national security risks, and ultimate resource depletion.

James Woolsey, former Director CIA: "For Security, Get Off Oil"
... when a Wahabi madrassa is teaching little boys the virtues of becoming a suicide bomber, you and I are paying for that through our gasoline purchases"

We (US) use about 150 billion gallons of gasoline/yr
1¢ / gal tax = $1.5 billion/yr in revenue
$1 / gal = $150 billion/yr ≈ Annual cost of Iraq/Afghanistan wars

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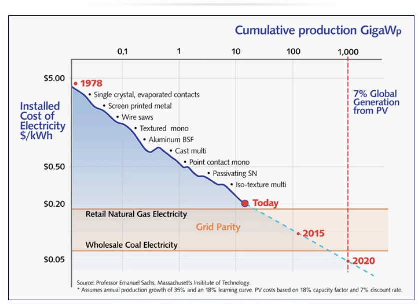
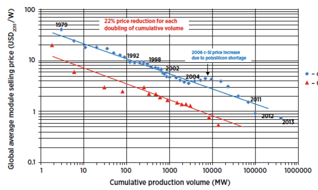
Solar cost decreases 10% per year



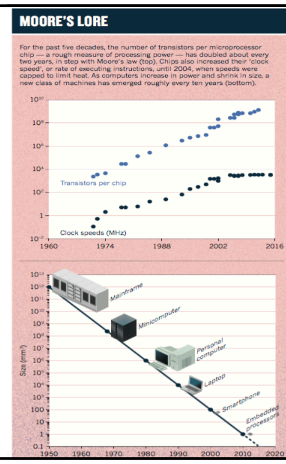
Source: Professor Emanuel Sachs, Massachusetts Insititute of Technology.
*Assumes annual production growth of 35% and an 18% learning curve. PV costs based on 18% capacity factor and 7% discount rate.

Crystalline silicon PV module learning curve, 1979–2013



Based on data from EPIA and the EU PV platform 2011; Liebreich, 2011; pvXchange, 2012 and IRENA analysis

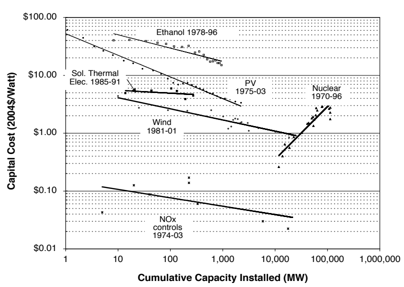
Solar PV cost reductions have followed a predictable path



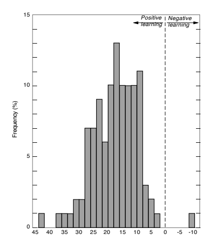
"My bet is that we run out of money before we run out of physics,"

- Daniel Reed

Prof. of Computer Science and VC for Research, University of Iowa in Iowa



Learning Rates of 108 Technologies



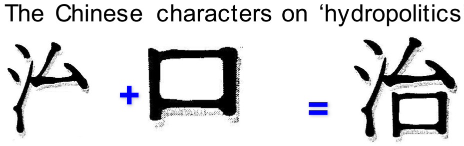
Negative learning: Lockheed Tristar French nuclear reactors

Source: Argote&Epple, 1990

86025 Energy Systems Analysis Arnulf Grubler

Rivers as political systems….

- Management of rivers is political; management of international rivers is very political…
- Rivals… dwellers on opposite banks of a river
- The Chinese characters on 'hydropolitics':



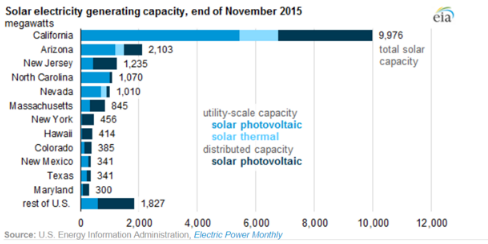
river + dyke = Political order

They were quietly removed by the Reagan administration during a roof resurfacing in 1986

In 1986 the Reagan administration quietly dismantled the White House solar panel installation while resurfacing the roof. "Hey! That system is working.

Why don't you keep it?" recalls mechanical engineer Fred Morse, now of Abengoa Solar, who helped install the original solar panels as director of the solar energy program during the Carter years and then watched as they were dismantled during his tenure in the same job under Reagan.

"Hey! This whole [renewable] R&D program is working, why don't you keep it."



ELECTRICITY is cheaper than gasoline

... even using photovoltaics

Conventional 25 mpg: $\frac{\$3.50 / \text{gal}}{25 \text{ miles/gal}} = 14¢ / \text{mile}$

Hybrid 45 mpg: $\frac{\$3.50 / \text{gal}}{45 \text{ miles/gal}} = 7.8¢ / \text{mile}$

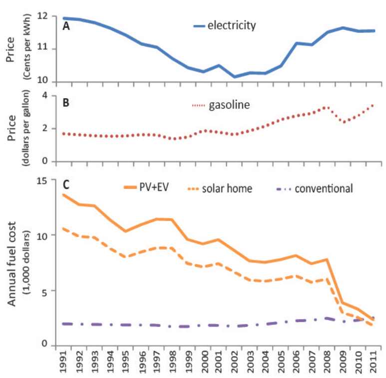
Electric 3.5 miles/kWh: $\frac{12¢ / \text{kWh}}{3.5 \text{ miles/kWh}} = 3.4 ¢/\text{mi}$

off peak it is ≈ 6¢

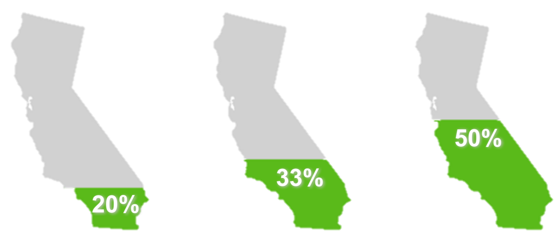
Photovoltaics: $\frac{\$0.13 / \text{kWh}}{3.5 \text{ miles/kWh}} = 3.7 ¢ / \text{mile}$

$4/Wdc,stc (after 30% tax credit), 5.5 hr/day, 0.75 derating, 5% loan, 34% MTB

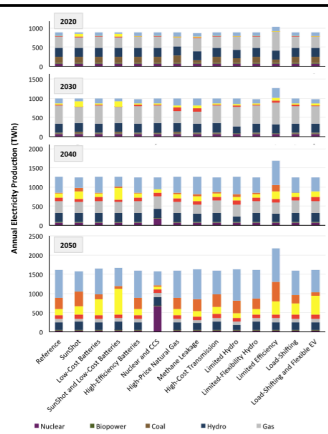
Run your home and car on solar power



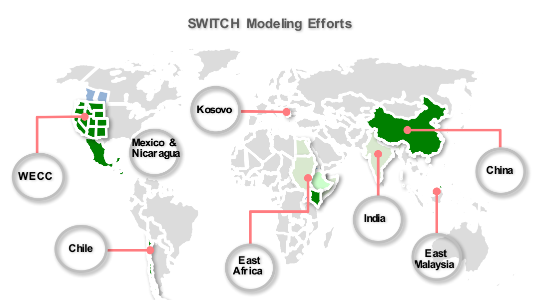
Binding commitments to renewables



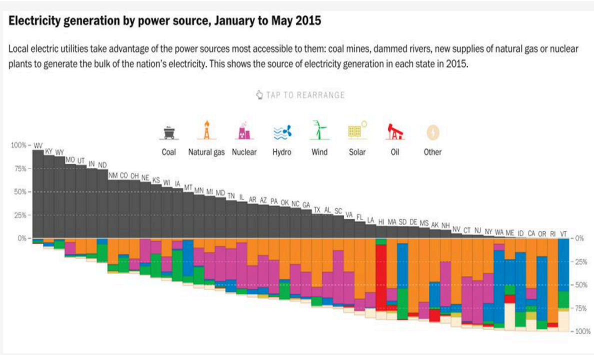
16



Modeling the 2° Scenarios



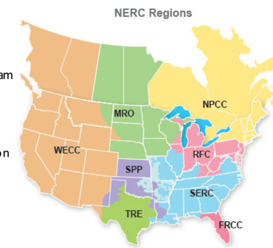
https://rael.berkeley.edu/project/switch-a-modeling-tool-for-the-electricity-sector/



The Empire Strikes Back:
Challenges to Decarbonization and the Clean Power Plan

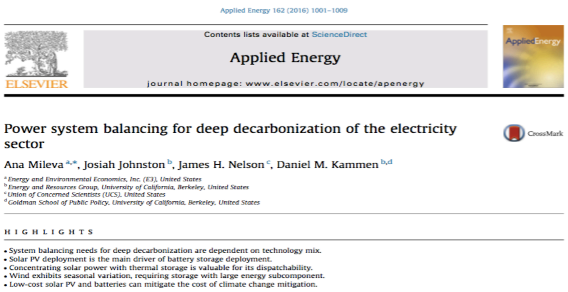
SWITCH WECC model

- Capacity expansion deterministic linear program
- Minimizes total power system cost:
  - Generation investment and operation
  - Transmission investment and operation
- Geographic:
  - Western North American Power System (the WECC)
  - 50 load areas
- Temporal:
  - 4 investment periods: 2016-2025 ("2020"); 2026-2035 ("2030"); 2036-2045 ("2040"); 2046-2055 ("2050");
  - 144 distinct hours simulated per period
    - Dispatch simulated simultaneously with investment decisions



http://rael.berkeley.edu/switch

rknightbki@gmail.com



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Power system balancing for deep decarbonization of the electricity sector

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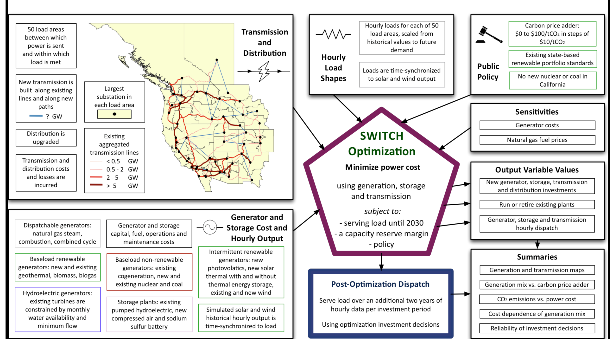
[d] Goldman School of Public Policy, University of California, Berkeley, United States

HIGHLIGHTS

- System balancing needs for deep decarbonization are dependent on technology mix.
- Solar PV deployment is the main driver of battery storage deployment.
- Concentrating solar power with thermal storage is valuable for its dispatchability.
- Wind exhibits seasonal variation, requiring storage with large energy subcomponent.
- Low-cost solar PV and batteries can mitigate the cost of climate change mitigation.

The SWITCH-WECC Model



Optimization and data framework of the western North American SWITCH model.

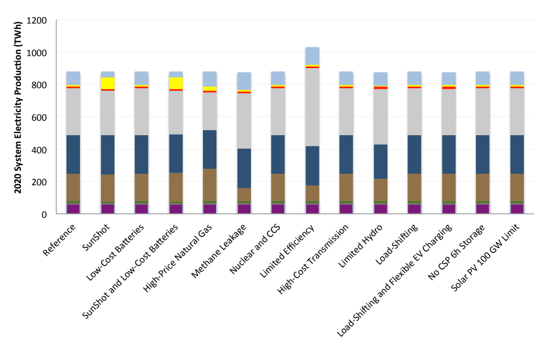
http://rael.berkeley.edu/switch

Linear Program Around Least Cost

Objective function: minimize the total cost of meeting load			
Generation and Storage	Capital	$\sum_{g,i} G_{g,i} \cdot c_{g,i}$	The capital cost incurred for installing a generator at plant *g* in investment period *i* is calculated as the generator size in MW $G_{g,i}$ multiplied by the cost of that type of generator in \$2007 / MW $c_{g,i}$.
	Fixed O&M	$+ (ep_g + \sum_{g,i} G_{g,i}) \cdot x_{g,i}$	The fixed operation and maintenance costs paid for plant *g* in investment period *i* are calculated as the total generation capacity of the plant in MW (the pre-existing capacity ep_g at plant *g* plus the total capacity $G_{g,i}$ installed through investment period *i*) multiplied by the recurring fixed costs associated with that type of generator in \$2007 / MW $x_{g,i}$.
	Variable	$+\sum_{g,t} O_{g,t} \cdot (m_{g,t} + f_{g,t} + c_{g,t}) \cdot hs_t$	The variable costs paid for plant *g* operating in study hour *t* are calculated as the power output in MWh $O_{g,t}$ multiplied by the sum of the variable costs associated with that type of generator in \$2007 / MWh. The variable costs include per MWh maintenance costs $m_{g,t}$, fuel costs $f_{g,t}$, and carbon costs $c_{g,t}$, and are weighted by the number of hours each study hour represents, hs_t.
Transmission		$+\sum_{a,a',i} T_{a,a',i} \cdot l_{a,a'} \cdot t_{a,a',i}$	The cost of building or upgrading transmission lines between two load areas *a* and *a'* in investment period *i* is calculated as the product of the rated transfer capacity of the new lines in MW $T_{a,a',i}$, the length of the new line $l_{a,a'}$, and the regionally adjusted per-km cost of building new transmission in \$2007 / MW · km, $t_{a,a',i}$. Transmission can only be built between load areas that are adjacent to each other or that are already connected.
Distribution		$+\sum_{a,i} d_{a,i}$	The cost of upgrading local transmission and distribution within a load area *a* in investment period *i* is calculated as the cost of building and maintaining the upgrade in \$2007 / MW $d_{a,i}$.
Sunk		$+ s$	Sunk costs include ongoing capital payments incurred during the study period for existing plants, existing transmission networks, and existing distribution networks. The sunk costs do not affect the optimization decision variables, but are taken into account when calculating the cost of power at the end of the optimization.

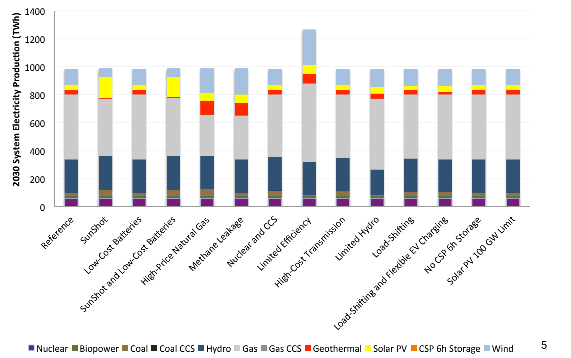
Electricity Mix, 2020, WECC

- Coal, hydropower, and gas generation dominate the system



Electricity Mix, 2030, WECC

- Electricity production heavily dominated by natural gas



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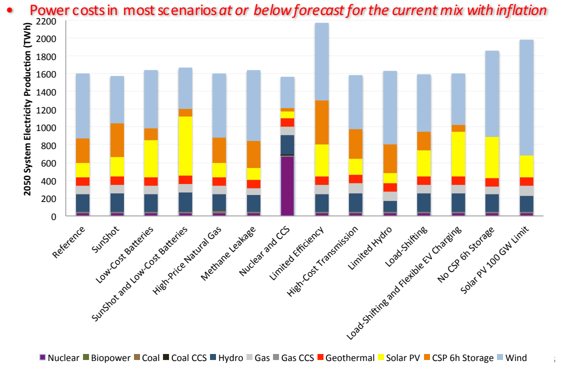
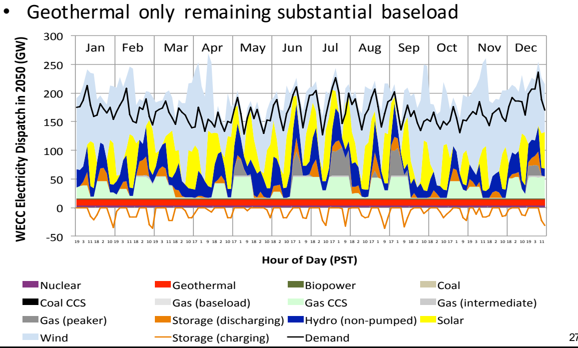
Electricity Mix, 2050, WECC

- Electricity production mix is much more dynamic by 2050
- Power costs in most scenarios *at or below forecast for the current mix with inflation*

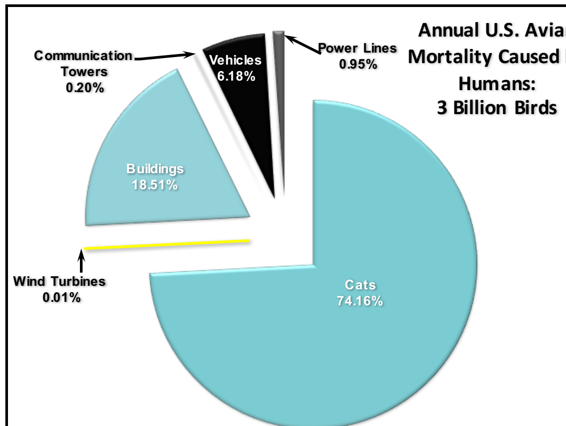


Dispatch in 2050:
Flexibility and variable renewables dominate

- Storage almost exclusively moves solar to the night
- Geothermal only remaining substantial baseload



27



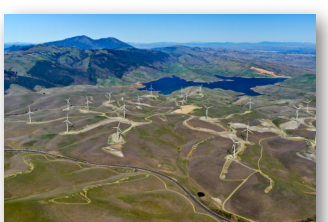
Annual U.S. Avian Mortality Caused by Humans: 3 Billion Birds

Source: The State of Birds Report,2014
http://www.stateofthebirds.org/

28

Reducing Impacts:
Vasco Wind Energy Center Repowering

432 small turbines removed and replaced with 34 new turbines



Vasco Wind Energy Center, 78MW
Contra Costa County

RESULT: Energy production tripled & avian mortality cut by 70%

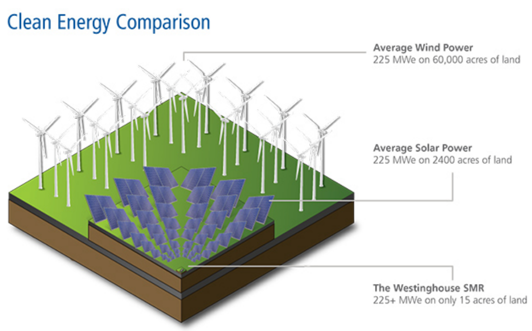
29

"Default risks are 32% lower in energy efficient homes"

- *Home Energy Efficiency and Mortgage Risks Research Report* (March 2013, Institute for Market Transformation)

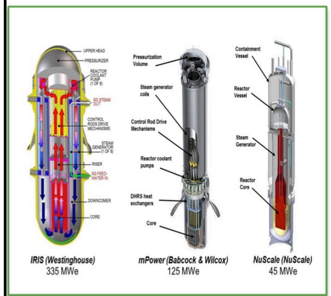
30

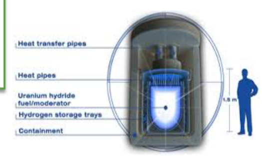
Footprint comparison



31

Small Modular Reactors: A New Hope?





32