Renewable & Appropriate Energy Laboratory
RAEL

Lecture 6: Pasteur's Quadrant

Daniel Kammen

Class of 1935 Distinguished Professor of Energy
Energy and Resources Group | Goldman School of Public Policy
Director, Renewable and Appropriate Energy Laboratory
University of California, Berkeley

May 2 2016

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? **(4.18.2016)**
Klein, chapter 6 - 8 |

5. A new economics of the planet **(4.25.2016)** **now (5.2.2016)**
Klein, chapter 4 | Optional: Dove & Kammen, chapter 3; Klein 12

6. Pasteur's Quadrant **(5.2.2016)** **now (5.9.2016)**
Klein, chapter 7, 11 | Optional: Dove & Kammen, chapter 4

Resources:

Website: http://rael.berkeley.edu

Twitter: @dan_kammen

New design mentality

- **Redesigning a standard (supposedly optimized) industrial runaround pumping loop cut its power from 70.8 to 5.3 kW (–92%), cost less to build, and worked better**
- **Just two (*key*) changes in design mentality**

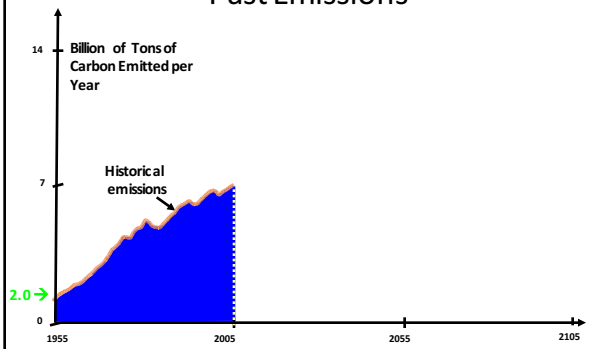
4

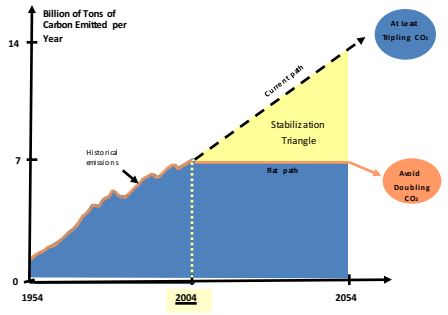
New design mentality: an example

1. Big pipes, small pumps (not the opposite)

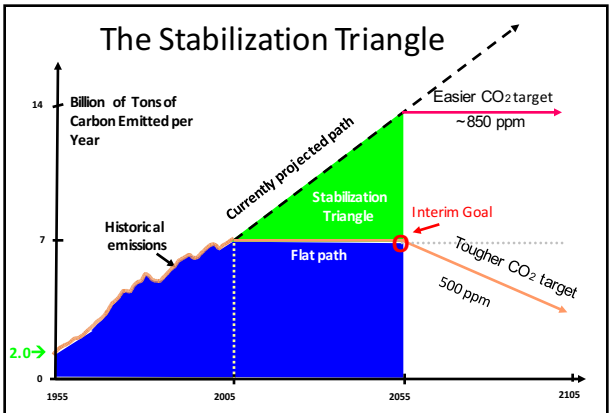
5

Past Emissions



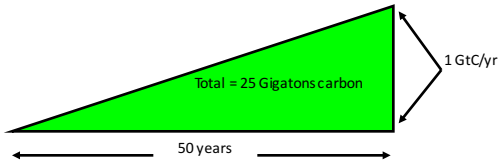


What does it mean to 'solve the carbon and climate problem' over the next 50 years?



What is a "Wedge"?

A "wedge" is a strategy to reduce carbon emissions that grows in 50 years from zero to 1.0 GtC/yr. The strategy has already been commercialized at scale somewhere.



Cumulatively, a wedge redirects the flow of 25 GtC in its first 50 years. This is 2.5 trillion dollars at $100/tC.

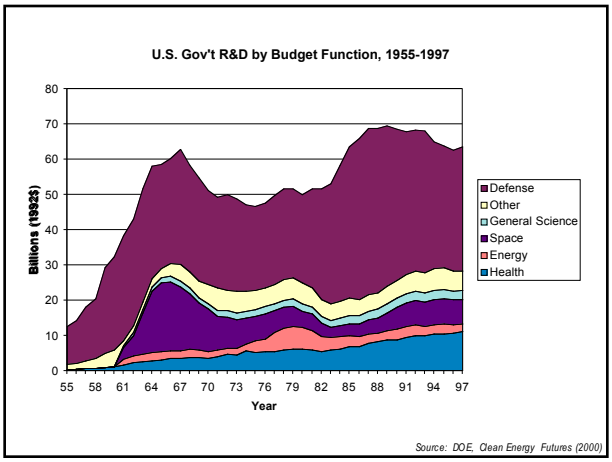
A "solution" to the CO_2 problem should provide at least one wedge.

Wedges #1 - #8 (out of 15)

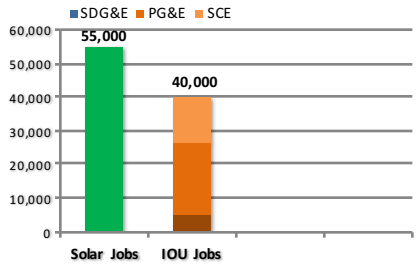
	Option	Effort by 2054 for one wedge, relative to 14 GtC/year BAU	Comments, issues
Energy Efficiency and Conservation	Economy-wide carbon intensity reduction (emissions/$GDP)	Increase reduction by additional 0.15%/year (eg, increase U.S. goal of reduction of 1.96%/year to 2.11%/year)	Can be tuned by carbon policy
	1. Efficient vehicles	Increase fuel economy for 2 billion cars from 30 to 60 mpg	Car size, power
	2. Reduced use of vehicles	Decrease car travel for 2 billion 30-mpg cars from 10,000 to 5,000 miles per year	Urban design, mass transit, telecommuting
	3. Efficient buildings	Cut carbon emissions by one-fourth in buildings and appliances projected for 2054	Weak incentives
	4. Efficient baseload coal plants	Produce twice today's coal power output at 60% instead of 40% efficiency (compared with 32% today)	Advanced high-temperature materials
Fuel shift	5. Gas baseload power for coal baseload power	Replace 1400 GW 50%-efficient coal plants with gas plants (4 times the current production of gas-based power)	Competing demands for natural gas
CO_2 Capture and Storage (CCS)	6. Capture CO_2 at baseload power plant	Introduce CCS at 800 GW coal or 1600 GW natural gas (compared with 1080 GW coal in 1999)	Technology already in use for H_2 production
	7. Capture CO_2 at H_2 plant	Introduce CCS at plants producing 250 MHU/year from coal or 500 MHU/year from natural gas (compared with 40 MHU/year today from all sources)	H_2 safety, infrastructure
	8. Capture CO_2 at coal-to-synfuels plant	Introduce CCS at synfuels plants producing 30 million barrels per day from coal (200 times Sasol), if half of feedstock carbon is available for capture	Increased CO_2 emissions, if synfuels are produced *without* CCS
	Geological storage	Create 3500 Sleipners	Durable storage, successful permitting

Wedges #9 - #15 (out of 15)

	Option	Effort by 2054 for one wedge, relative to 14 GtC/year BAU	Comments, issues
Nuclear Fission	9. Nuclear power for coal power	Add 700 GW (twice the current capacity)	Nuclear proliferation, terrorism, waste
Renewable Electricity and Fuels	10. Wind power for coal power	Add 2 million 1-MW-peak windmills (50 times the current capacity) "occupying" 30×10^6 ha, on land or offshore	Multiple uses of land because windmills are widely spaced
	11. PV power for coal power	Add 2000 GW-peak PV (700 times the current capacity) on 2×10^6 ha	PV production cost
	12. Wind H_2 in fuel-cell car for gasoline in hybrid car	Add 4 million 1-MW-peak windmills (100 times the current capacity)	H_2 safety, infrastructure
	13. Biomass fuel for fossil fuel	Add 100 times the current Brazil or U.S. ethanol production, with the use of 250×10^6 ha (1/6 of world cropland)	Biodiversity, competing land use
Forests and Agricultural Soils	14. Reduced deforestation, plus reforestation, afforestation and new plantations	Decrease tropical deforestation to zero instead of 0.5 GtC/year, and establish 300 Mha of new tree plantations (twice the current rate)	Land demands of agriculture, benefits to biodiversity from reduced deforestation
	15. Conservation tillage	Apply to all cropland (10 times the current usage)	Reversibility, verification



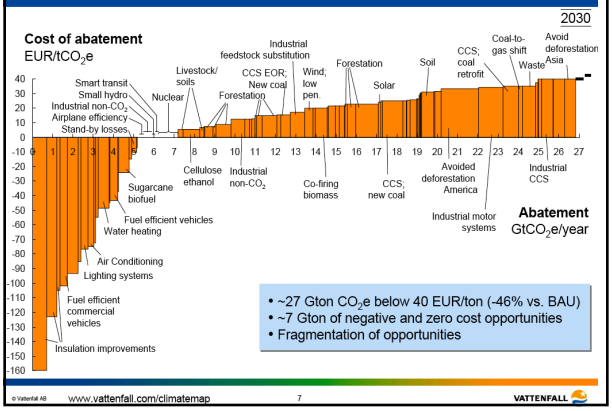
More Solar Jobs in California Than the 3 Investor Owned Utilities Combined



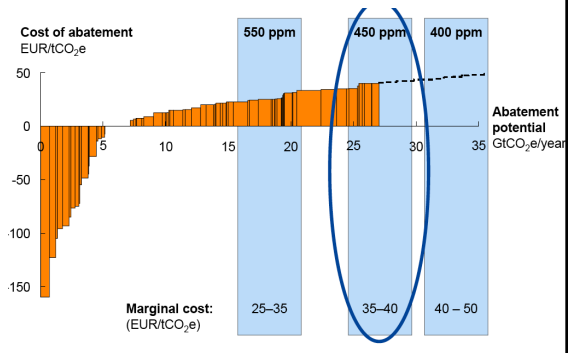
Recall Klein Chapter 4: "Planning and banning"
- Jobs in Ontario, Canada
- Housing is a Climate Issue

Sources:
Solar Foundation, 2014 Solar Jobs Census
U.S. Securities and Exchange Commission, Form 10-K, 2014
http://www.sec.gov/edgar/searchedgar/companysearch.html

Global cost curve of GHG abatement opportunities beyond business as usual



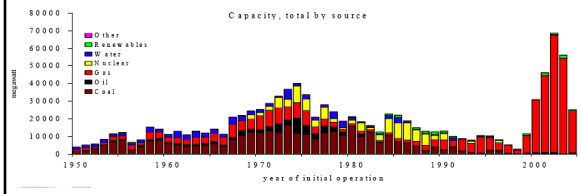
Marginal Abatement Costs for Cooling Scenarios



www.vattenfall.com/climatemap

Just a few examples of big changes…

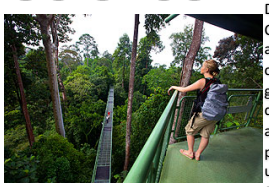
250 GW changes in a decade



Integrating these systems tools with civil society-industry dialog

TIME Science

Borneo Says No to Dirty Energy
By Jennifer Pinkowski
Feb. 22, 2011



Daniel Kammen of the University of California, Berkeley, who directed an energy and environmental-impact study commissioned by a coalition of green groups, which was used widely in the discussions of Sabah's energy options. "It is a turning point that should bring deserved praise and partnerships to Malaysia at the upcoming climate conference in Durban, South Africa,"

http://www.time.com/time/health/article/0,8599,2052627,00.html#ixzz1lvOeiiyz

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Our Ref. : CS/MYY/001(WS)(C 2015 Date : 15th March, 2016
Your Ref. : Please advice

Messrs Harrison Ngau & Co. Advocates
Lot 1046, 1st Floor,
Shang Garden Commercial Centre,
Jalan Bulan Sabit, 98000 Miri,
Sarawak

By Fax 085-421236 only

Dear Sirs,

Re: In the High Court in Sabah and Sarawak at Miri
Suit No. MYY-21NCvC-1/[illegible]-2015
Plaintiffs : Tama Wing Kaling & 3 Ors
Defendants : Superintendent of Lands and Surveys Miri Division & 2 Ors

We refer to the above matter and the "The Land (Native Customary Rights) (No.53) 2014 Direction".

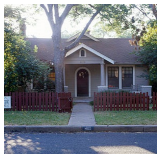
2. We are please to inform you that the above mentioned Direction has been revoked vide "The Land Native Customary Rights (No.2) (Revocation) Direction 2016" published on 18th February, 2016 in the Sarawak Government Gazette under G.N. 569. We forward herewith a copy of the Gazette for your record and further action.

Thank you.

Property-Assessed Clean Energy (PACE)

$$ Upfront

$$ Repaid on tax bill



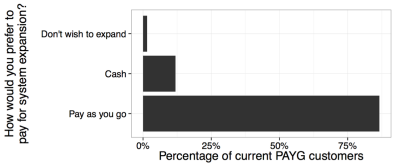
- Creates financing district & approval process
- Provides upfront capital
- Attaches repayment obligation to the building

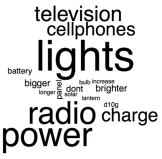
- Identifies work & chooses contractor
- Repays financing as a line item on the property tax bill
- Repayment obligation transfers with ownership

PAYG supports expanded access (energy consumer survey, Kenya)

~80% prefer follow-on financing for expansion…

…beyond basic service





21

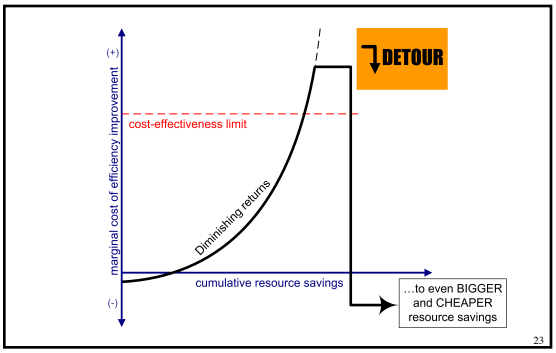
An example opportunity for financing

Transformative opportunities for Research, philanthropy and business development

$2+ Trillion US profits are "parked" overseas

☑☐ Apple	$138B	Cisco	$48B
☑☐ GE	$110B	☑☐ Google	$48B
☑☐ Microsoft	$93B	☑☐ HP	$38B
☑☐ IBM	$52B	☑☐ Pepsi	$34B
☑☐ Johnson & Johnson	$50B	☑☐ Oracle	$33B

New design mentality: expanding returns, "tunneling through the cost barrier"



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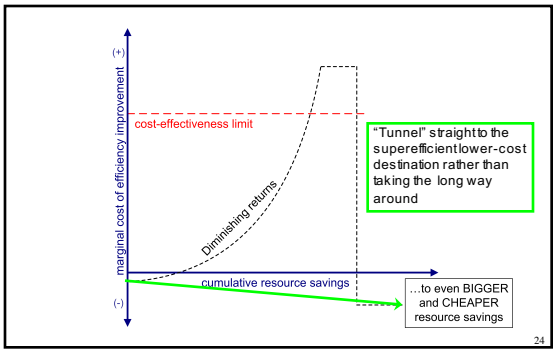
New design mentality: expanding returns, "tunneling through the cost barrier"



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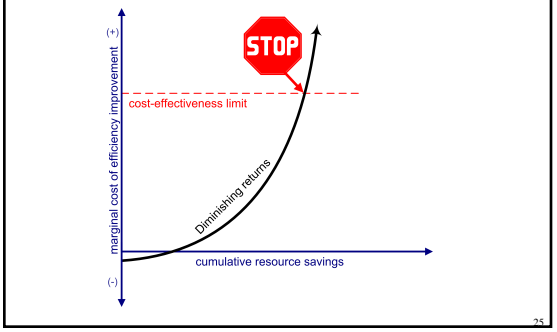
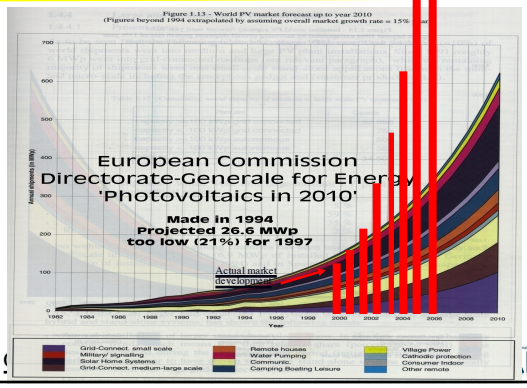
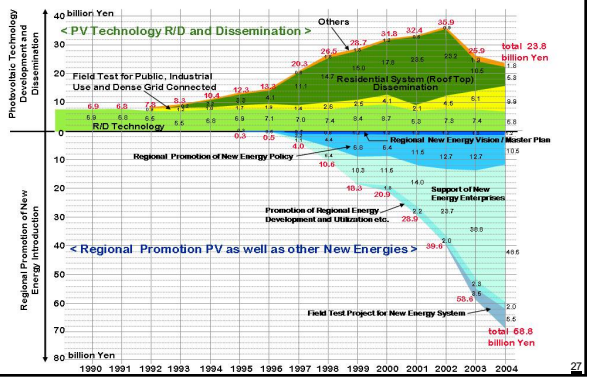
Old design mentality: always diminishing returns…



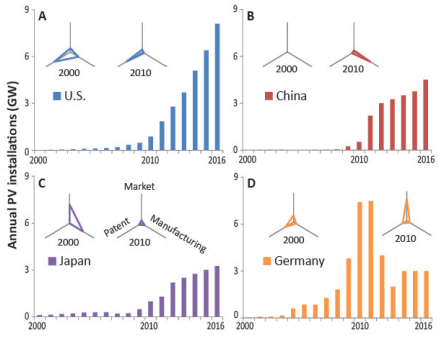
Use Inspired Basic Science …



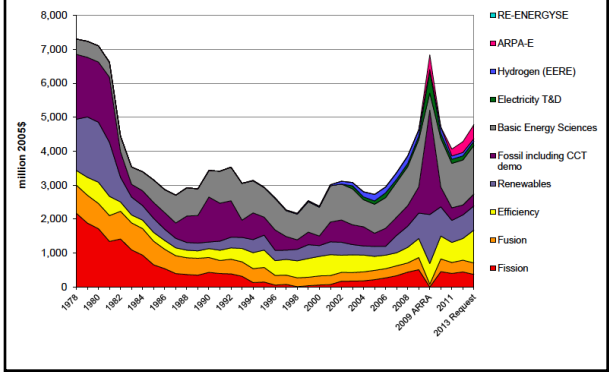
Japanese "Sunshine" Program
way too much detail, but technology push/demand pull is clear



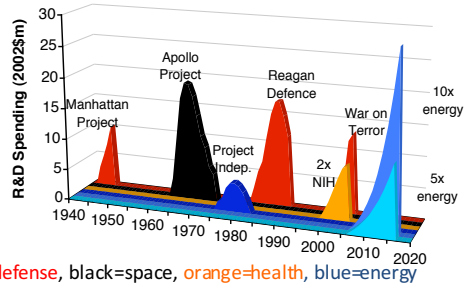
The Evolving Solar Energy Economy



U.S. DOE Energy RD&D FY1978-FY2013 Request



Major U.S. Public R&D programs

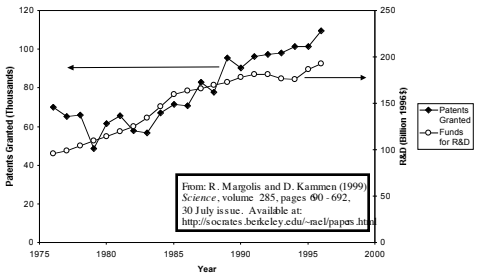


red=defense, black=space, orange=health, blue=energy

Nemet, 2007; Nemet and Kamen 2007; Kammen and Nemet, 2005

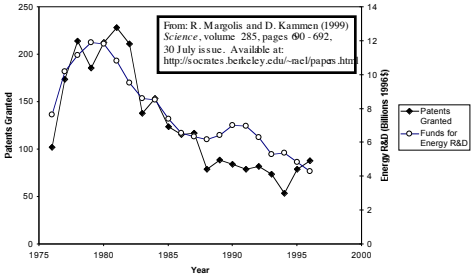
Federal R&D Policy Can be Effective

Figure 1. Total U.S. patents granted and total U.S. investments in R&D.

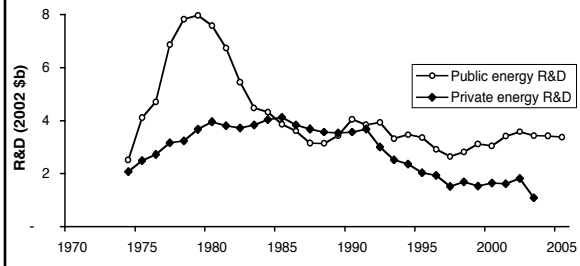


Lack of Federal R&D policy… leads to lack of support for energy options

Figure 2. U.S. energy technology patents and total U.S. energy R&D.

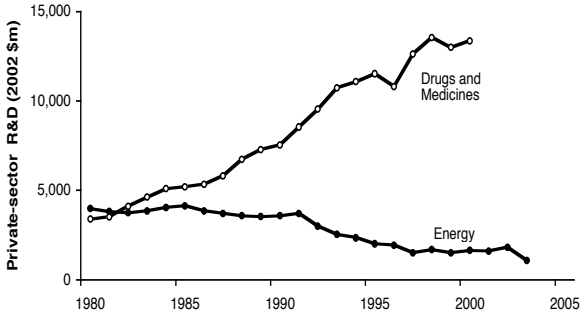


If you think US public sector energy R&D funding is doing poorly …



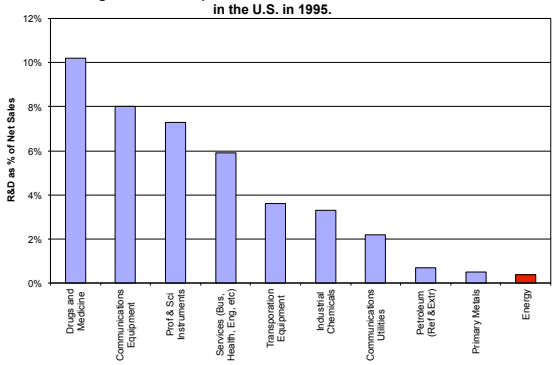
Kammen & Nemet (2005

Private Sector R&D Investment in Health and Energy



Kammen qnd Nemet, 2005

Figure 3. R&D as percent of net sales for selected sectors in the U.S. in 1995.



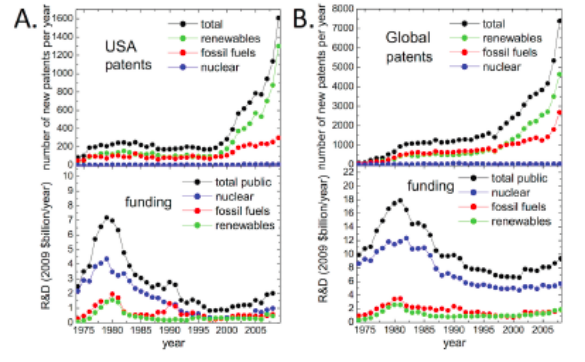
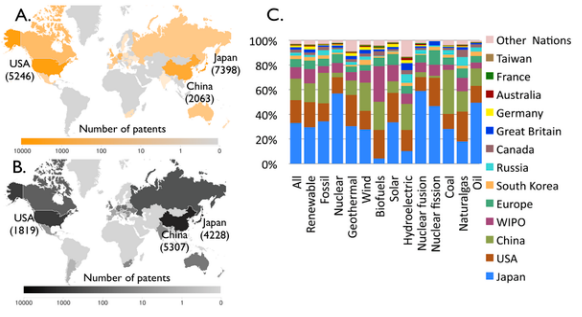


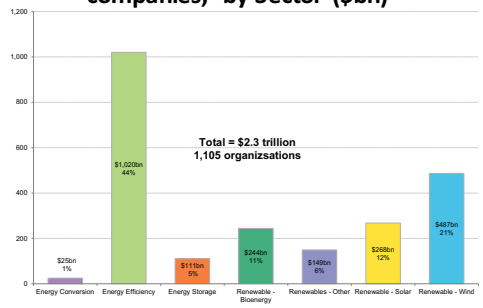
Figure 2. Regional patterns in energy patents.



Bettencourt LMA, Trancik JE, Kaur J (2013) Determinants of the Pace of Global Innovation in Energy Technologies. PLoS ONE 8(10): e67864. doi:10.1371/journal.pone.0067864
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0067864

PLOS ONE

Summary of market Capitalisations for A1-A3 companies, by Sector ($bn)

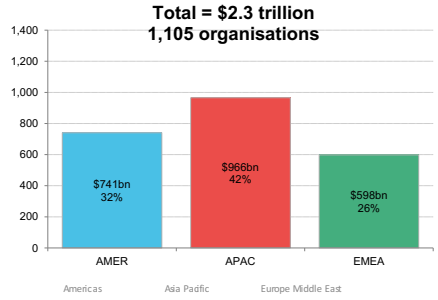


Note: Excluded: OTC, Daily traded share volume = not available 3 months or more, insufficient market cap information available, Carbon Markets and Carbon Capture &Sequestration. Market capitalisations as of 30 June 2015. Companies above A4 Exposure have 10% or more of their value estimated to be attributable to their clean energy activity.

Source: Bloomberg New Energy Finance

9 May 2016

Market capitalisations for A1-A3 companies, by region of listing ($BN)



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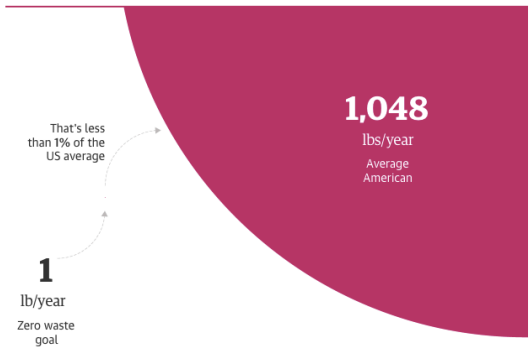
Source: Bloomberg New Energy Finance

Innovation in Electric Vehicles: 100 mile range, recharges in 20 minutes

Proterra Battery Electric Bus

40

The Zero Waste Household



Categorizing R&D and Innovation

Research is inspired by:

Quest for Fundamental Understanding?	Consideration of use? No	Consideration of use? Yes
Yes	Pure Basic Research (Bohr)	
No		Pure Applied Research (Edison)

Adapted from *Pasteur's Quadrant: Basic Science and Technological Innovation*, Donald E. Stokes 1997

Categorizing R&D and Innovation

Research is inspired by:

Consideration of use?

Quest for Fundamental Understanding?	No	Yes
Yes	Pure Basic Research (Bohr)	Use-inspired Basic Research (Pasteur)
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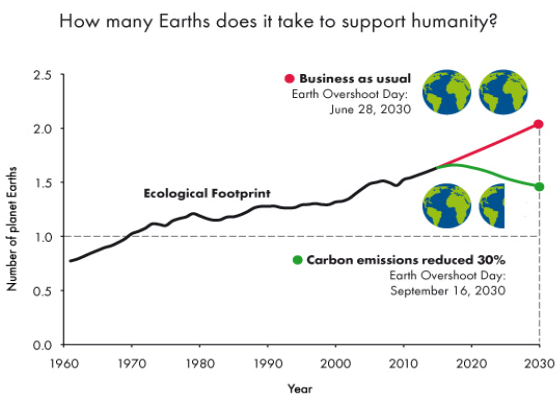
Adapted from *Pasteur's Quadrant: Basic Science and Technological Innovation*, Donald E. Stokes 1997



Discussion: Questions, Directions, Opinions …

From Klein:

Chapter 4: **Planning and Banning**
"But I confess the last five years immersed in climate issues has left me impatient."

Chapter 5: **Beyond Extractivism**
Nauru, the Jared Diamond "Collapse" anecdote. What ability do we have to transition from extraction to investment under current economic models?

Chapter 6: **Fruits, Not Roots**
The Nature Conservancy and "carbon cowdoys" engagement on fracking: When are 'market based' climate solutions workable, and when are they the road to ruin. [See next slide]

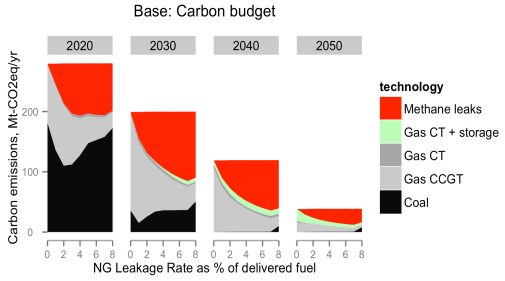
Chapter 7: **No Messiahs**
Where climate science needs a public relations makeover.

Chapter 8: **Dimming the Sun**
Has anyone read Garrett Hardin? "Social problems rarely [if ever] have a technical fix.

Chapter 8: **Blockadia**

Chapter 11: **You and What Army?**

Fugitive Emissions: WECC (If we take the 2 degree cap seriously)



46