Reset: A Forum and Celebration of Energy Transitions

Georgia Institute of Technology ▪ Tech Square Research Building

July 25, 2017 – 8:30 am - 5:00 pm

Reset: A Forum and Celebration of Energy Transitions

Connecting to WiFi:

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Fill in your information

Prepaid Pass: X527C

Agenda

- 9:00 am – Welcoming Remarks
- 10:15 – Solar PV Systems
- 12:00 noon – Lunch and Table Talks
- 1:00 pm – Energy Storage for PV and EV Systems
- 1:45 pm – Energy Efficiency and Solid State Lighting
- 3:00 pm – Plenary Address
- 4:30 pm – Conclusion

WELCOME

- Dr. Kaye Husbands Fealing
- Professor Elsa Reichmanis

"Current Status of the Energy Transition“

Professor Scott Valentine

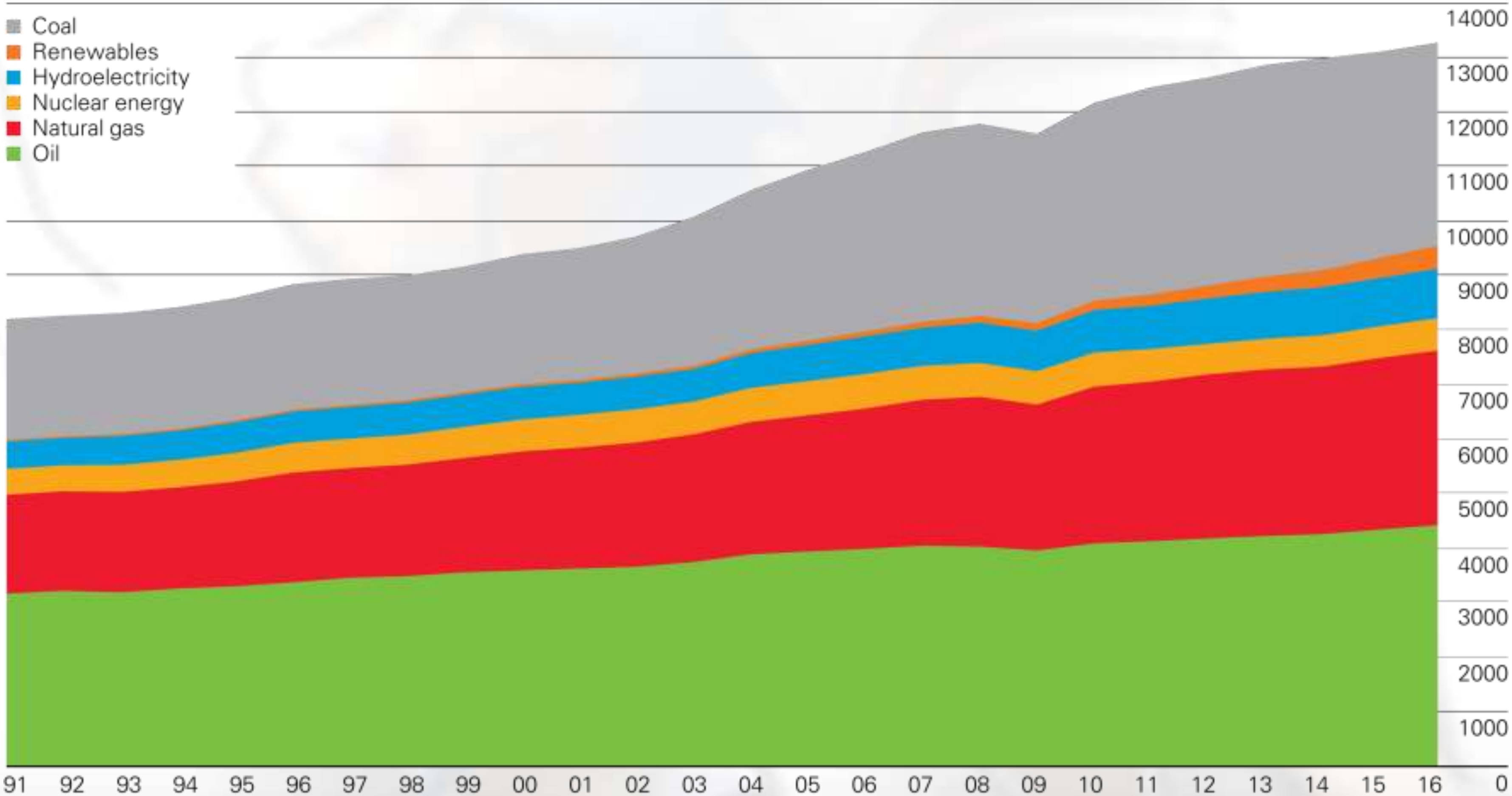
National University of Singapore

Current Status of the Energy Transition

Associate Prof. Scott V. Valentine, Assistant Dean (Research)
Lee Kuan Yew School of Public Policy

Lee Kuan Yew School of Public Policy

On the surface - gloom



Source: BP Statistical Review of World Energy 2017

But trends tell another story…

Trends 1 & 2
Price Inflation and Market Volatility

Fuel stock	2015 Proven reserves	2015 Production	Reserves to Production
Oil (billion barrels)	1698	33.5	50.7
Natural Gas (trillion cbm)	187	3.5	52.8
Coal (million tonnes)	891531	7820	114

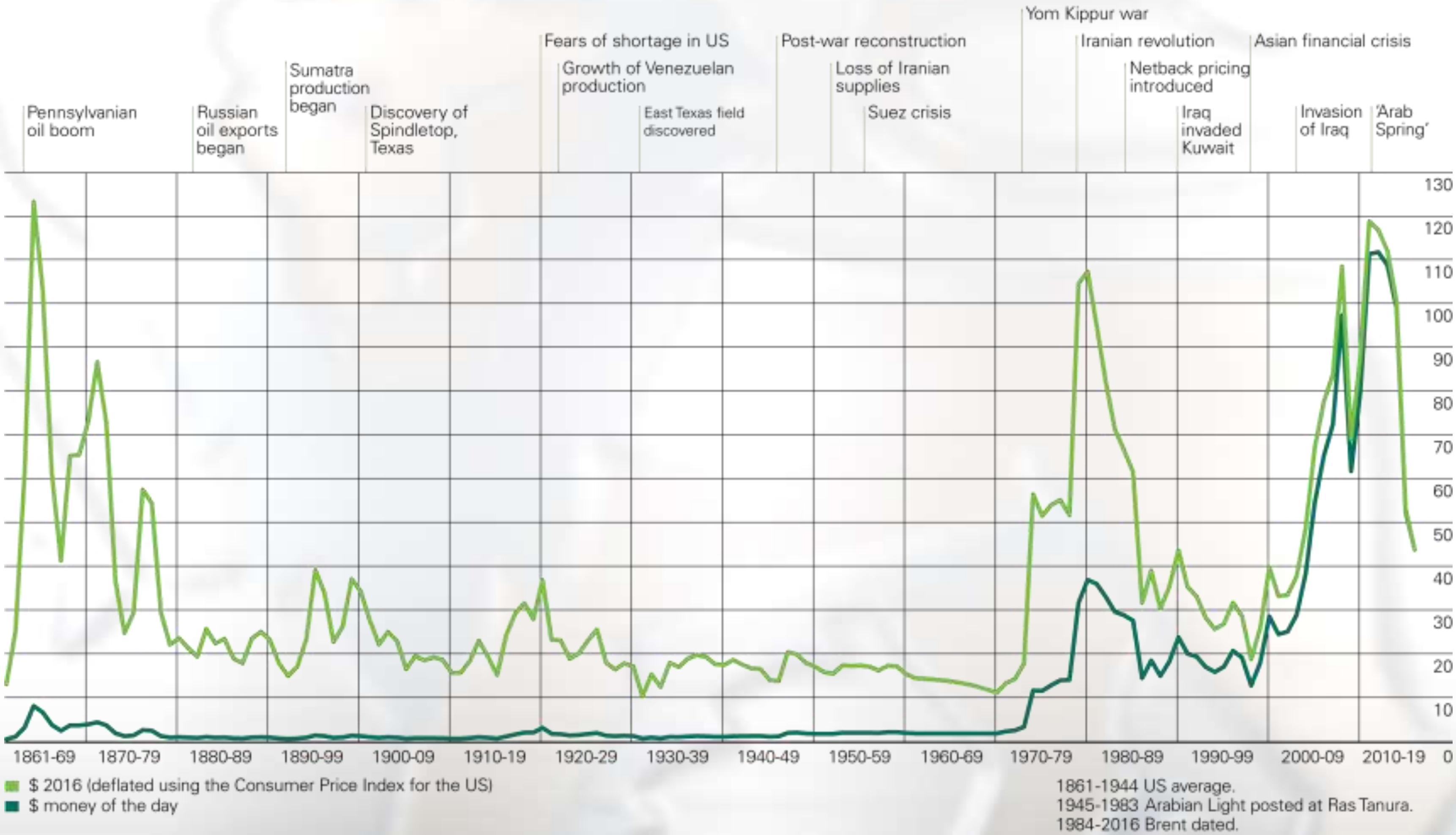
BP Statistical Review of World Energy 2017

Fuel stock	1995 Proven reserves	Change
Oil (billion barrels)	1126	572 (51%)
Natural Gas (trillion cbm)	120	67 (56%)
Coal (million tonnes)	1031610	-140079 (-14%)

Next 20 years

Energy demand +30%

Oil Prices ($/barrel)



Source: BP Statistical Review of World Energy 2017

Gas Prices ($/mmBTU)

Source: BP Statistical Review of World Energy 2017

Coal Prices (US$tonne)

Source: BP Statistical Review of World Energy 2017

Fossil fuels do the superman

Table 1.6 ▷ Fossil-fuel import prices by scenario

		New Policies Scenario			Current Policies Scenario			450 Scenario			Low Oil Price Scenario		
	2014	2020	2030	2040	2020	2030	2040	2020	2030	2040	2020	2030	2040
Real terms (2014 prices)													
IEA crude oil imports ($/barrel)	97	80	113	128	83	130	150	77	97	95	55	70	85
Natural gas ($/MBtu)													
United States	4.4	4.7	6.2	7.5	4.7	6.3	7.8	4.5	5.7	5.9	4.7	6.2	7.5
Europe imports	9.3	7.8	11.2	12.4	8.1	12.5	13.8	7.5	9.4	8.9	5.9	8.9	11.4
Japan imports	16.2	11.0	13.0	14.1	11.4	14.9	16.0	10.7	11.8	11.1	8.8	10.7	12.4
OECD steam coal imports ($/tonne)	78	94	102	108	99	115	123	80	79	77	88	97	102
Nominal terms													
IEA crude oil imports ($/barrel)	97	89	153	210	92	176	246	85	131	156	61	95	140
Natural gas ($/MBtu)													
United States	4.4	5.2	8.3	12.3	5.2	8.6	12.8	5.0	7.6	9.7	5.2	8.3	12.3
Europe imports	9.3	8.6	15.1	20.3	9.0	16.9	22.6	8.4	12.7	14.6	6.6	12.1	18.7
Japan imports	16.2	12.2	17.6	23.1	12.6	20.1	26.3	11.9	15.9	18.2	9.8	14.4	20.3
OECD steam coal imports ($/tonne)	78	104	138	178	110	155	202	89	106	126	98	130	168

Notes: MBtu = million British thermal units. Gas prices are weighted averages expressed on a gross calorific-value basis. All prices are for bulk supplies exclusive of tax. The US price reflects the wholesale price prevailing on the domestic market. Nominal prices assume inflation of 1.9% per year from 2014.

Source: EIA, World Energy Outlook 2015

Trend 3
The Strategic Need to Diversity

Trend 4
The Needs to Sever Links to Instability

Rank	Exporter	2016 Crude Oil Exports	% World Total
1.	Saudi Arabia	US$136.2 billion	20.1%
2.	Russia	$73.7 billion	10.9%
3.	Iraq	$46.3 billion	6.8%
4.	Canada	$39.5 billion	5.8%
5.	United Arab Emirates	$38.9 billion	5.7%
6.	Kuwait	$30.7 billion	4.5%
7.	Iran	$29.1 billion	4.3%
8.	Nigeria	$27 billion	4.0%
9.	Angola	$25.2 billion	3.7%
10.	Norway	$22.6 billion	3.3%

CIA World Factbook

Lee Kuan Yew School of Public Policy

Not Much Better for Natural Gas

RANK	COUNTRY	(CU M)
1	RUSSIA	184,500,000,000
2	QATAR	118,900,000,000
3	NORWAY	114,400,000,000
4	EUROPEAN UNION	93,750,000,000
5	CANADA	77,960,000,000
6	NETHERLANDS	53,650,000,000
7	TURKMENISTAN	45,790,000,000
8	UNITED STATES	42,870,000,000
9	ALGERIA	40,800,000,000
10	MALAYSIA	34,870,000,000
11	INDONESIA	31,780,000,000
12	AUSTRALIA	31,610,000,000
13	NIGERIA	25,000,000,000
14	GERMANY	22,270,000,000
15	BOLIVIA	17,860,000,000

CIA World Factbook (2014 data)

Trend 5
Improved Understanding of Environmental / Health Connections

China and India 2015
- Around 2.2 million deaths annually from air pollution (State of Global Air 2017)

US annually:
- Vehicle emissions:
  - 58,000 premature deaths
- Power plant emissions:
  - 54,000 premature deaths

(Caiazzo et al., 2013)

Trend 6
Enhanced Evidence of CC Severity

- Hurricane Sandy (2012): US$65 Billion
- 41 Extreme Weather events in 2013
  - Damages over US$1 billion each

- Before:
  - Benefit now; Pay later
- Now:
  - Pay now; Pay later

Trend 7
Disparate Approaches to Nuclear Power

- Before:
  - Installed nuclear power capacity growth +38% ~ +208% by 2030 (World Nuclear Association, 2008).
  - 60+ nations investigating adoption of nuclear power (Sovacool and Valentine, 2012).
- Post Fukushima:
  - Financial Woes: Westinghouse, Toshiba, Areva

Trend 8
Tech Progress and Renewable Energy

Figure 6: Levelized Cost of Electricity for New Power Plants

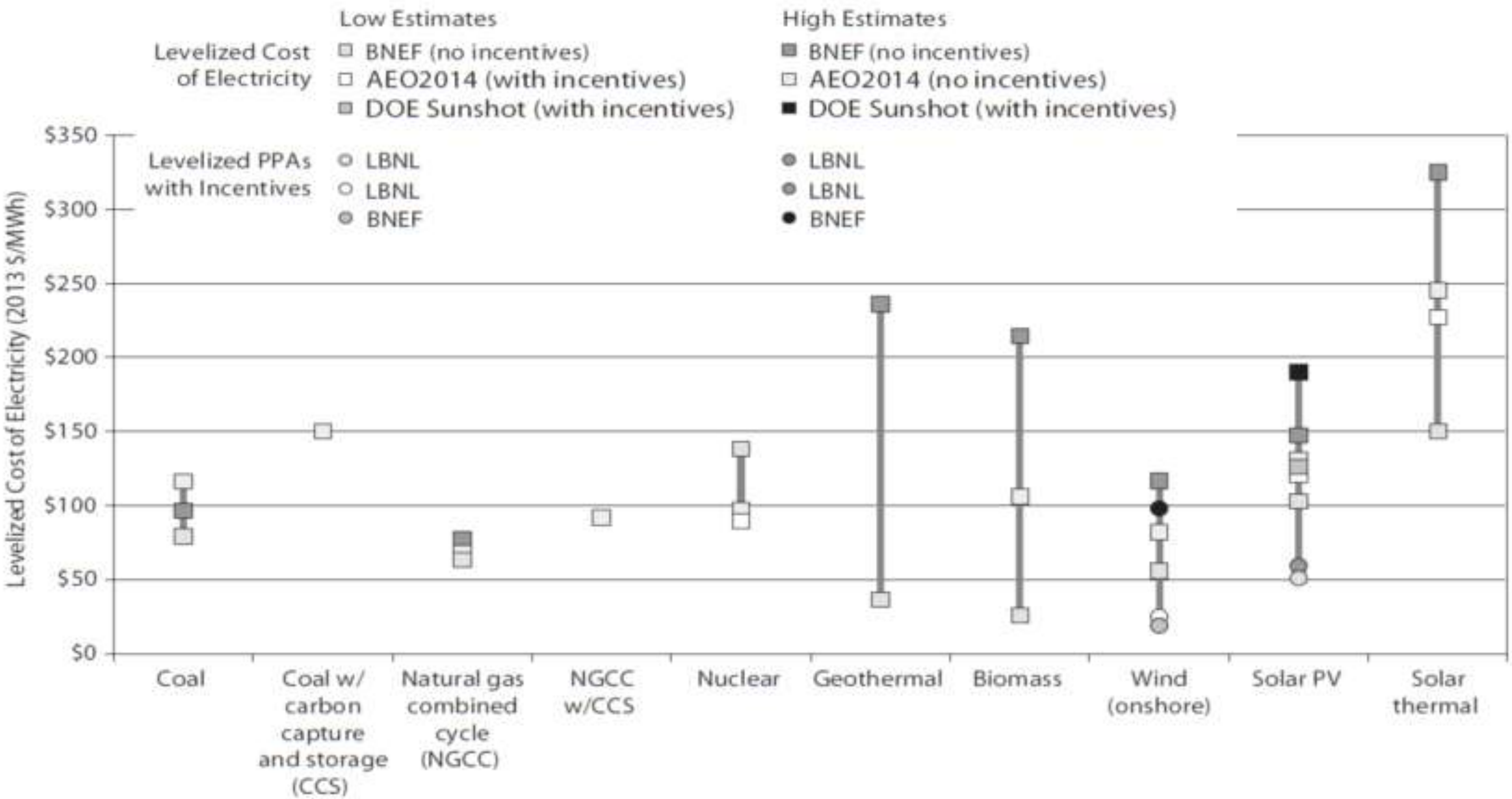


Figure 6.2. Levelized Cost of Electricity for New Power Plants, 2013. *Source:* World Resources Institute (WRI), *Seeing Is Believing* (Washington, DC: WRI, October 2014). *Note:* AEO = US Energy Information Administration's Annual Energy Outlook; BNEF = Bloomberg New Energy Finance; DOE = US Department of Energy; LBNL = Lawrence Berkeley National Laboratory; PPA = power purchase agreements; PV = photovoltaic.

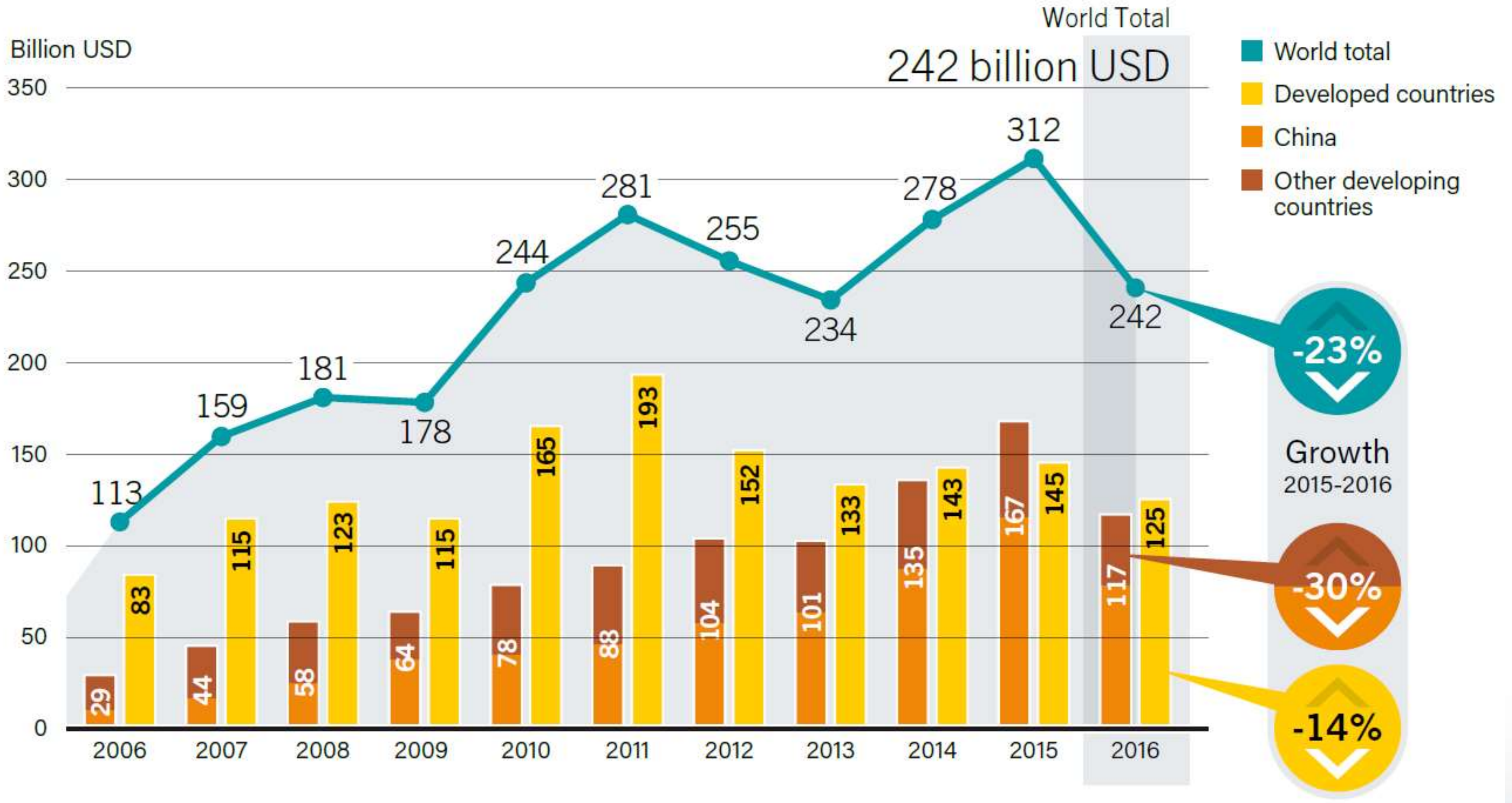
Trend 9
The Rise of Government and Market Support for Renewable Energy

Number of Renewable Energy Regulatory Incentives and Mandates, by Type, 2014-2016

Source: REN21 (REN21, 2017)

Investment in Renewable Energy: 2006-2016

Critical Mass of Investment



Source: REN21 (REN21, 2017)

Investment in Renewable Energy: 2006-2016

Trend 10: First mover advantages

Clean-tech sector - €4 trillion in sales by 2025
(Roland Berger Strategy Consultants, 2011).

Top 10 onshore wind turbine manufacturers

Rank 2016	Manufacturer	Capacity commissioned in 2016 (GW)	New-build market share in 2016 (%)	Rank 2015	Capacity commissioned in 2015 (GW)	New-build market share in 2015 (%)
1↑	Vestas	8.7	16.5%	2	7.3	12.6%
2↑	GE	6.5	12.3%	3	5.9	10.2%
3↓	Goldwind	6.4	12.1%	1	7.8	13.5%
4→	Gamesa	3.7	7.0%	4	3.1	5.3%
5↑	Enercon	3.5	6.6%	6	3.0	5.2%
6↑	Nordex group	2.7	5.0%	unranked	unranked	unranked
7→	Guodian	2.2	4.2%	7	2.8	4.8%
8↓	Siemens	2.1	3.9%	4	3.1	5.3%
9↓	Ming Yang	1.96	3.7%	8	2.7	4.7%
9↓	Envision	1.94	3.7%	8	2.7	4.7%

Source: Bloomberg New Energy Finance

The Wild Card?

Lee Kuan Yew School of Public Policy

scott.valentine@nus.edu.sg

THANK YOU

"Envisioning Future Energy Technologies"

Aaron Melda
Tennessee Valley Authority

Where We Are Going

amazon

CO_2

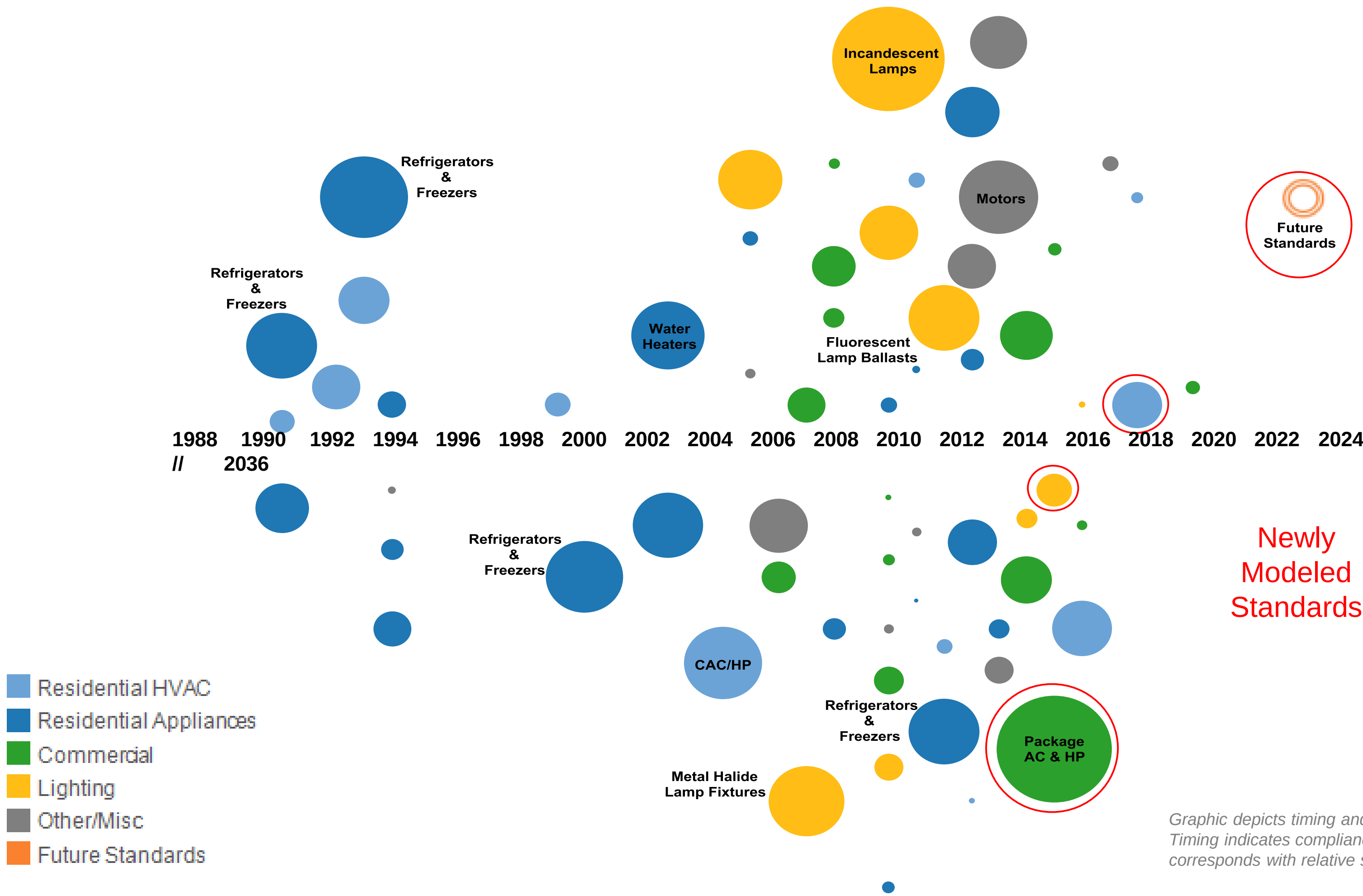
COMBINED
HEAT
AND POWER

RE 100

What Could the Future Look Like?

Flat Base Case	Growth Case	Steady Decline Case
		
Economic growth offset by efficiencies drives flat load outlook CAGR ~0.0%	Economic growth drives additional industry and customer count growth CAGR +0.6%	Technology enables incremental efficiencies and distributed solutions CAGR -1.0%

Impact of DOE Standards Continues to Grow



Graphic depicts timing and magnitude of DOE standards. Timing indicates compliance year and size of bubble corresponds with relative savings.

Residential Use Impacted by Lighting Efficiencies

Lighting percent of average use
is forecasted to be
more than cut in half,
from

13% in 2005

to

6% in 2025,

driven by codes and standards
and economics

What if every household
replaced one light bulb
with an LED bulb?

 60 Watts –  9 Watts = 51 Watts

4 Hours a Day = 204 Watt hours

365 Days a Year = 75 kWh

4,000,000 Residential Customers = 298 GWh

Equates to **0.5%** reduction in residential load

Equates to **0.2%** reduction in TVA's total load

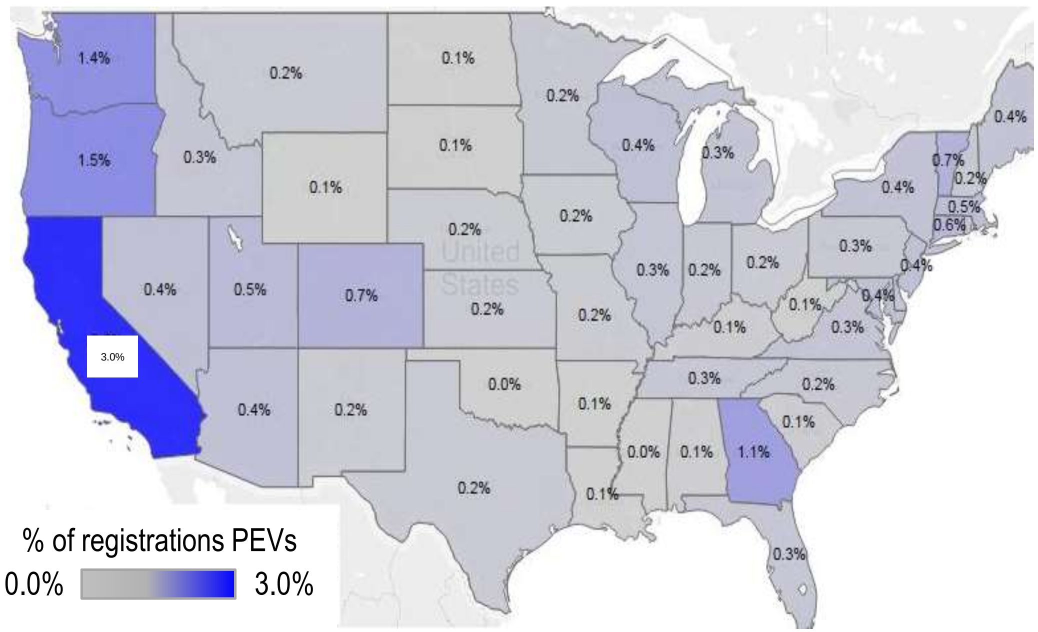
Equates to **$30 million** in annual revenue

Plug-In Electric Vehicles (PEV) – TVA Snapshot

PEV's were introduced in 2010/2011 and 7 PEV models are available from various OEMs in the Valley (Nissan, Chevy, Ford, Tesla, BMW)

As of May 2016:

- About 5,400 PEVs have been registered in the TVA Service Territory
- PEVs = 0.2% of registrations and < 2% of market share
- About 3MW "diversified load at transformer" representing about 16 GWh annually



About 550,000 PEVs needed for 1% of TVA sales (25% market share over 5 years)

Renewable Product Demand

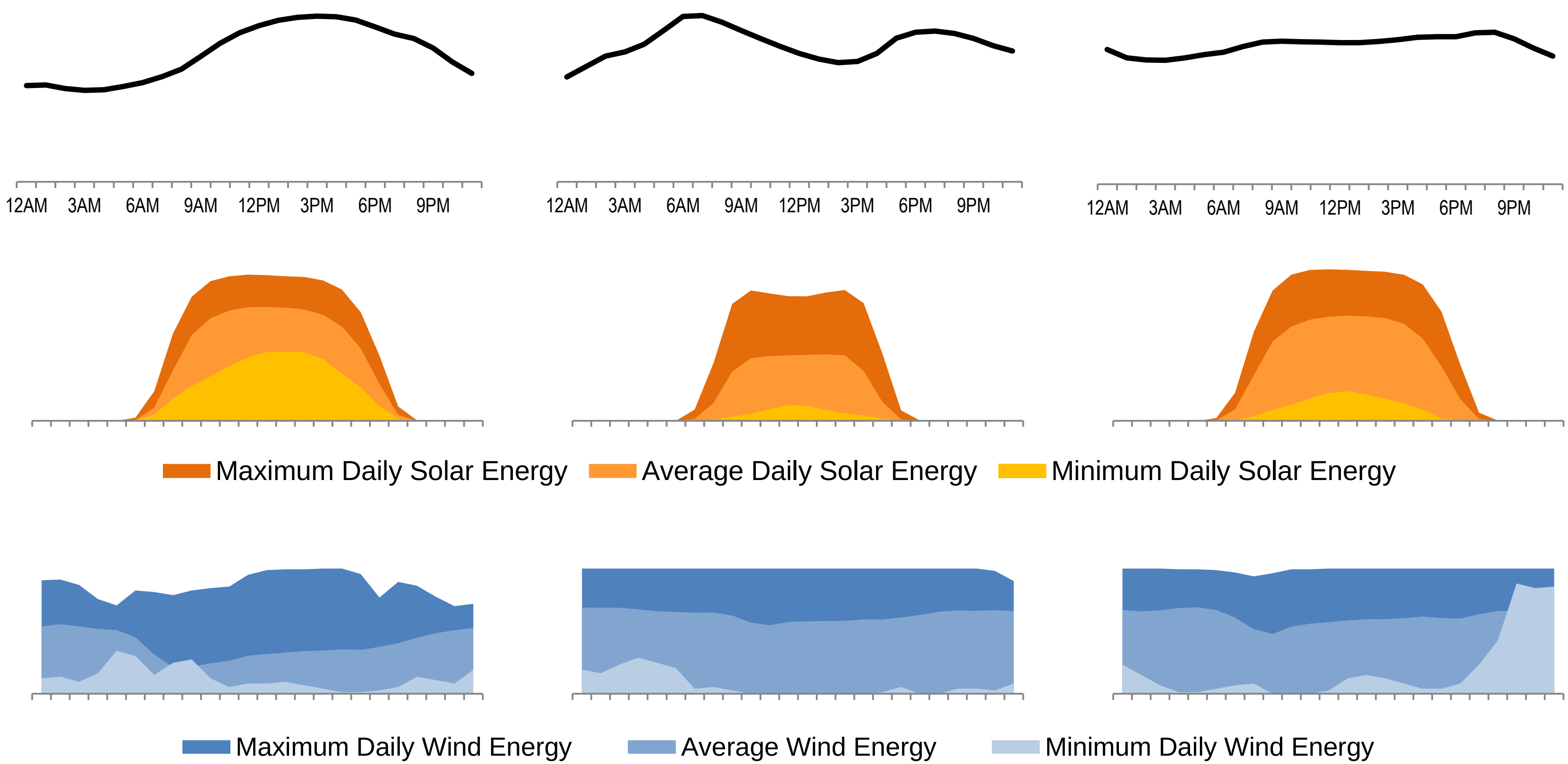
Seasonal Wind and Solar Shapes

SUMMER | **WINTER** | **FALL / SPRING**

LOAD SHAPES

SOLAR

WIND



Key Takeaways

- Current load outlook is flat to slightly declining
- Energy efficiency standards and technologies continue to evolve
- Substantial PEV adoption in the Valley is needed to impact load
- Meeting customer demand for renewables and attractive combination of low rates and carbon is a focus
- Future energy technologies needed to flatten loads and increase flexibility to optimize the future value proposition

Break

- Restrooms
- Snacks/Drinks
- 15 minutes

SOLAR PV SYSTEMS

Setting the stage by Georgia Tech NSF IGERT Faculty:
--Professor Dan Matisoff, *School of Public Policy*
--Professor Martha Grover, *Chemical and Biomolecular Engineering*

Research results presented by Georgia Tech NSF Fellows:
Materials and Systems:
--Michael McBride, *Chemical and Biomolecular Engineering*
--Rebecca Hill, *Chemistry and Biochemistry*
--Matt Smith, *Materials Science and Engineering*
Policy and Economics:
--Ross Beppler, *School of Public Policy*

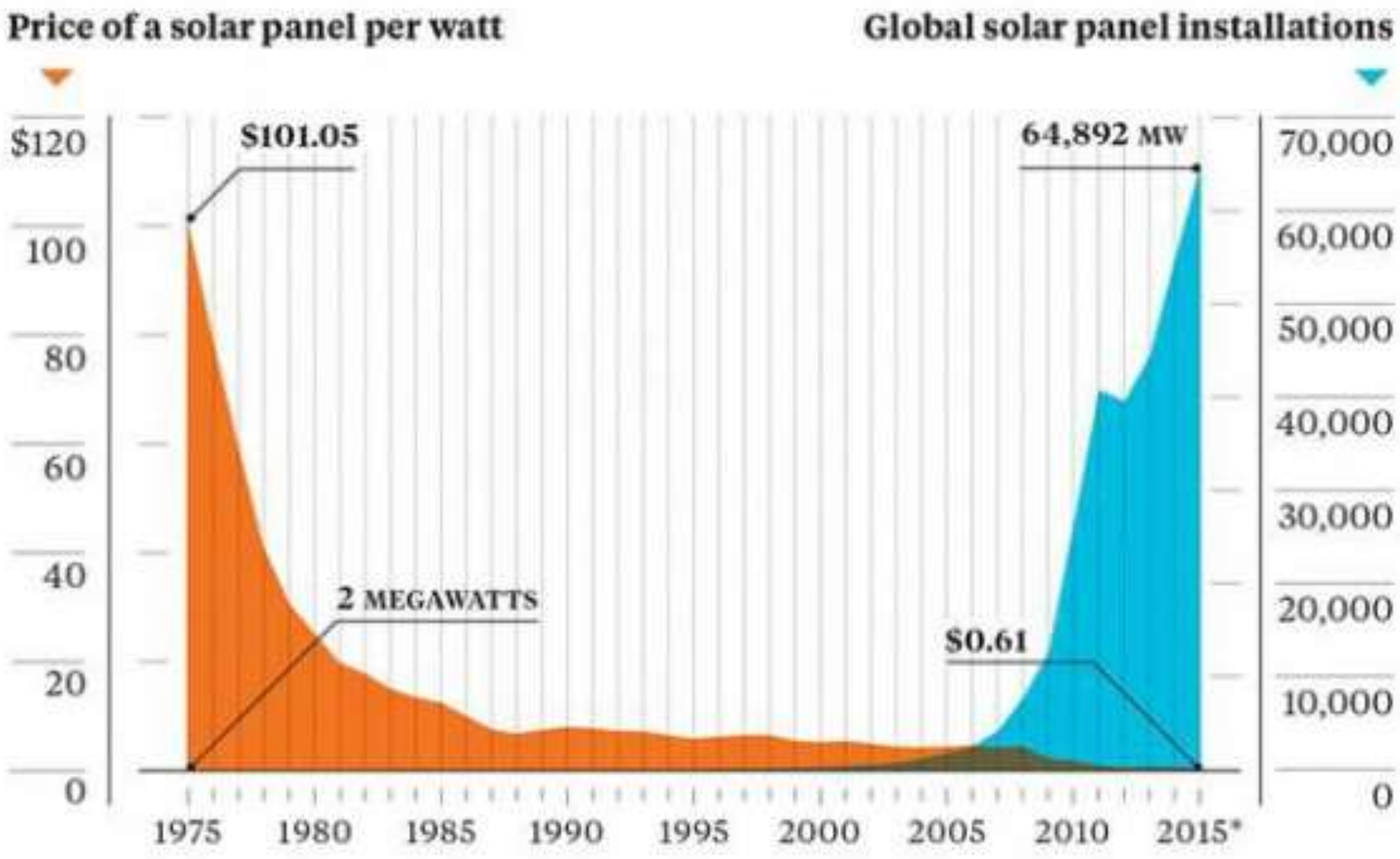
Solar Economics and Policy

Trends and Implications

Daniel Matisoff

Associate Professor

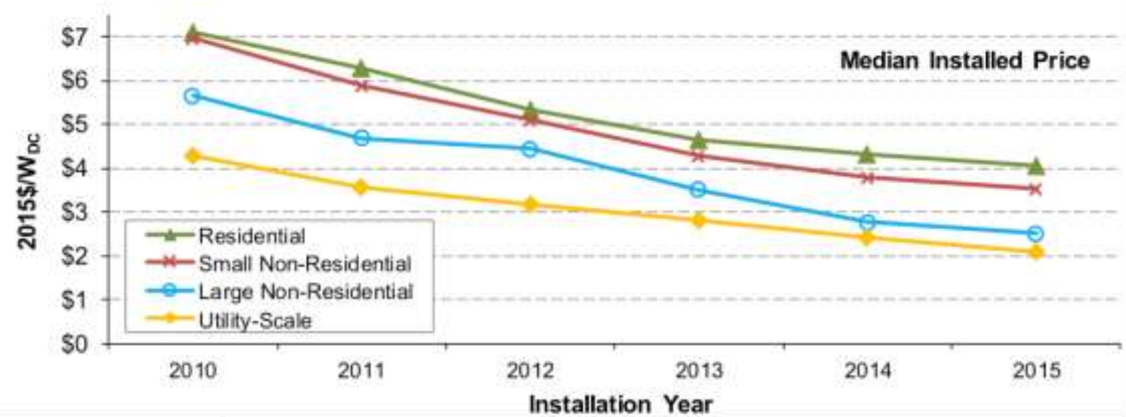
Dropping Solar Costs

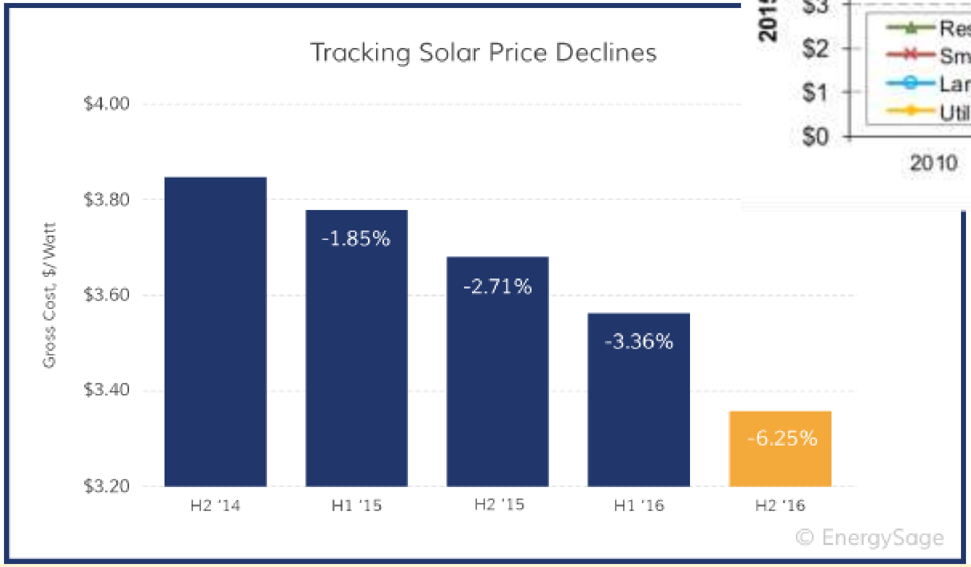


Panel costs vs. Balance of Systems

- Decreasing Panel Costs
- Efficiencies in Balance of Systems
- Decreases in Soft Costs
- Financing Innovations

- Price decreases have continued to decrease rapidly!





Competitiveness of Renewable Costs

	U.S. Capacity-Weighted[1] Average LCOE (2016 $/MWh) for Plants Entering Service in 2022							
Plant Type	Capacity Factor (%)	Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System LCOE	Levelized Tax Credit[2]	Total LCOE including Tax Credit
Dispatchable Technologies								
Coal 30% with carbon sequestration[3]					NB			
Coal 90% with carbon sequestration[3]					NB			
Natural Gas-fired								
Conventional Combined Cycle	87	14.0	1.4	42.0	1.1	58.6	NA	58.6
Advanced Combined Cycle	87	14.0	1.3	37.5	1.0	53.8	NA	53.8
Advanced CC with CCS					NB			
Conventional Combustion Turbine	30	36.8	6.6	54.3	3.0	100.7	NA	100.7
Advanced Combustion Turbine	30	22.8	2.6	58.8	3.0	87.1	NA	87.1
Advanced Nuclear	90	70.8	12.6	11.7	1.0	96.2	NA	96.2
Geothermal	90	29.2	13.3	0.0	1.5	44.0	-2.9	41.1
Biomass	83	47.2	15.2	34.2	1.2	97.7	NA	97.7
Non-Dispatchable Technologies								
Wind – Onshore	41	39.8	13.1	0.0	2.9	55.8	-11.6	44.3
Wind – Offshore					NB			
Solar PV[4]	25	59.8	10.1	0.0	3.8	73.7	-15.6	58.1
Solar Thermal					NB			
Hydroelectric[5]	60	54.1	3.1	5.2	1.5	63.9	NA	63.9

Georgia Tech

IGERT
Energy Materials & Policy

But despite Favorable prices, policy can Either help or hinder

SECTIONS HOME SEARCH The New York Times matisoff

Rooftop Solar Dims Under Pressure From Utility Lobbyists

Counseled by Industry, Not Staff, E.P.A. Chief Is Off to a Blazing Start

Climate-Altering Gases Spiked in 2016, Federal Scientists Report

FEATURE
Arks of the Apocalypse

CLIMATE

Rooftop Solar Dims Under Pressure From Utility Lobbyists

Renewable energy

A world turned upside down

Wind and solar energy are disrupting a century-old model of providing electricity. What will replace it?

Forbes / Energy

JAN 30, 2015 @ 12:20 PM 15,932

Will Solar Cause A 'Death Spiral' For Utilities?

Harvard Business Review

Are Electric Utilities in a Death Spiral?

SAVE SHARE 14 COMMENT TEXT SIZE PRINT

With Americans installing more solar panels, utilities are selling less electricity. But the utilities' costs haven't dropped, so prices per kilowatt hour are rising, which makes rooftop panels even more cost-competitive and further encourages the spread of solar power. The result of this and related trends, including increased energy efficiency nationwide, may be a "death spiral" for electric utilities, says the *Wall Street Journal*. U.S. electricity consumption in 2013 is expected to be **2% below** the peak in 2007.

Key Policy Issues

- Solar incentives
  - 30% Federal Tax Credit
  - Many state level incentives
- Net Metering Policies
  - How to pay for distributed energy resources
  - Impacts on rates and bills
  - Implications for utility business model
- Renewable Portfolio Standards
  - In the face of stagnant federal policy
- The Adoption and Diffusion of Innovative Technologies

And IGERT efforts have Supported Research to answer these questions

Contents lists available at ScienceDirect
Energy Policy
journal homepage: www.elsevier.com/locate/enpol

The comparative effectiveness of residential solar incentives

Daniel C. Matisoff[a,*], Erik P. Johnson[b]

[a] School of Public Policy Georgia Institute of Technology, 685 Cherry St NW, Atlanta, GA 30332, United States
[b] Department of Economics, Carthage College, Kenosha, WI 53140, United States

ARTICLE INFO

Keywords:
Financial incentives
Solar technology
Solar incentives
Subsidies
Tax salience
Incentive salience
Solar financing
Renewable Energy policy

ABSTRACT

We use temporal and spatial variation to evaluate the effectiveness of nearly all (over 400) state and utility incentives that promote the installation of residential solar photovoltaic (PV) panels. Using a unique data set that values a wide array of solar incentives including cash incentives, tax credits, and solar renewable energy credits, we evaluate and compare the impact of incentives using a standardized net present value of each incentive. We pair these data the amount of new residential solar installations within each state and year to examine the relationship between incentive type and new residential PV installations. We find that each additional dollar of incentives has led to on average, an additional 500 W of additional installed capacity per thousand residential electric customers. This effect is enabled by the presence of net metering and financing availability. Direct cash incentives, when coupled with financing initiatives and net metering, drive much of the impact on installations. Results are consistent with research that shows that incentive salience may drive variation in effectiveness. Results suggest that approximately 67% of state and utility incentives, up to $1.9 billion over 11 years, were likely spent on incentives that did not increase residential solar PV installations.

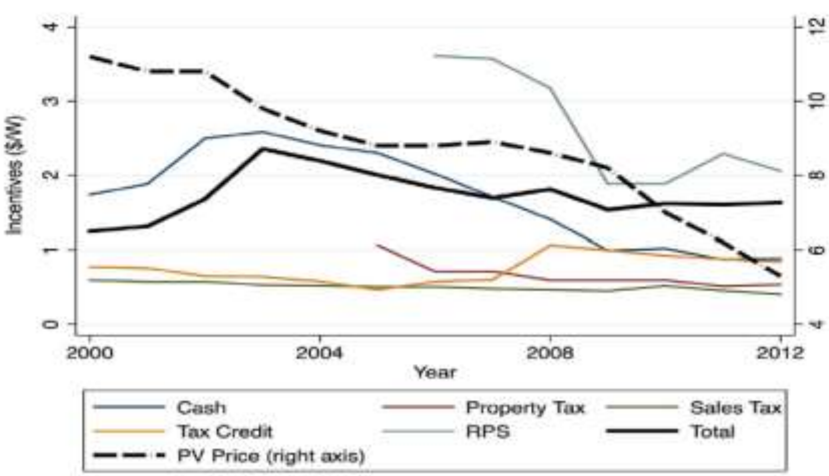


Fig. 1. Average Value of Non-zero Incentive by Type and Year ($/Watt).

Contents lists available at ScienceDirect
Energy Policy
journal homepage: www.elsevier.com/locate/enpol

Peak shifting and cross-class subsidization: The impacts of solar PV on changes in electricity costs*

Erik Johnson[a,*], Ross Beppler[b], Chris Blackburn[a], Benjamin Staver[b], Marilyn Brown[b], Daniel Matisoff[b]

[a] School of Economics, Georgia Institute of Technology, 221 Bobby Dodd Way, Atlanta, GA 30332, United States
[b] School of Public Policy, Georgia Institute of Technology, 685 Cherry Street NW, Atlanta, GA 30313, United States

ARTICLE INFO

Keywords:
Solar electricity
Net energy metering
Distributed generation
Electricity rate design

ABSTRACT

The expansion of distributed solar necessitates additional research into the impacts on both utilities and their customers. In this paper we use New Jersey solar data, PJM market data, and demand profiles from a PJM utility to investigate rate and bill impacts of large-scale solar penetration. In addition to the subsidization of solar adopters by non-participants, we highlight the channels through which cross-subsidization of rate classes can arise in practice. The results of our study indicate that the fear of a utility "death spiral" may be exaggerated. Significant solar can be incorporated with only a 2% increase in non-participant bills. At high levels of penetration, distributed solar has the potential to alter the system peak hour which affects the allocation of costs across rate-classes. As the peak hour shifts to the evening when solar production diminishes, residential customers face higher distribution costs. Policy makers and utilities need to be aware of these challenges in designing the next generation of rates that are better aligned with cost causality.

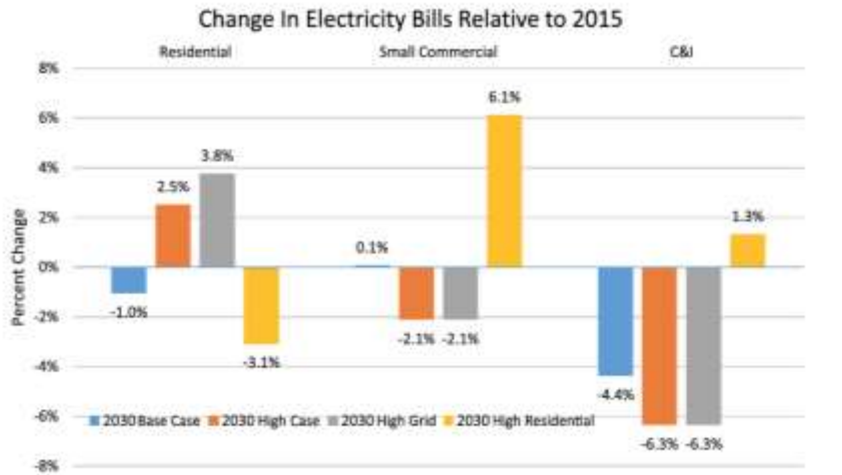


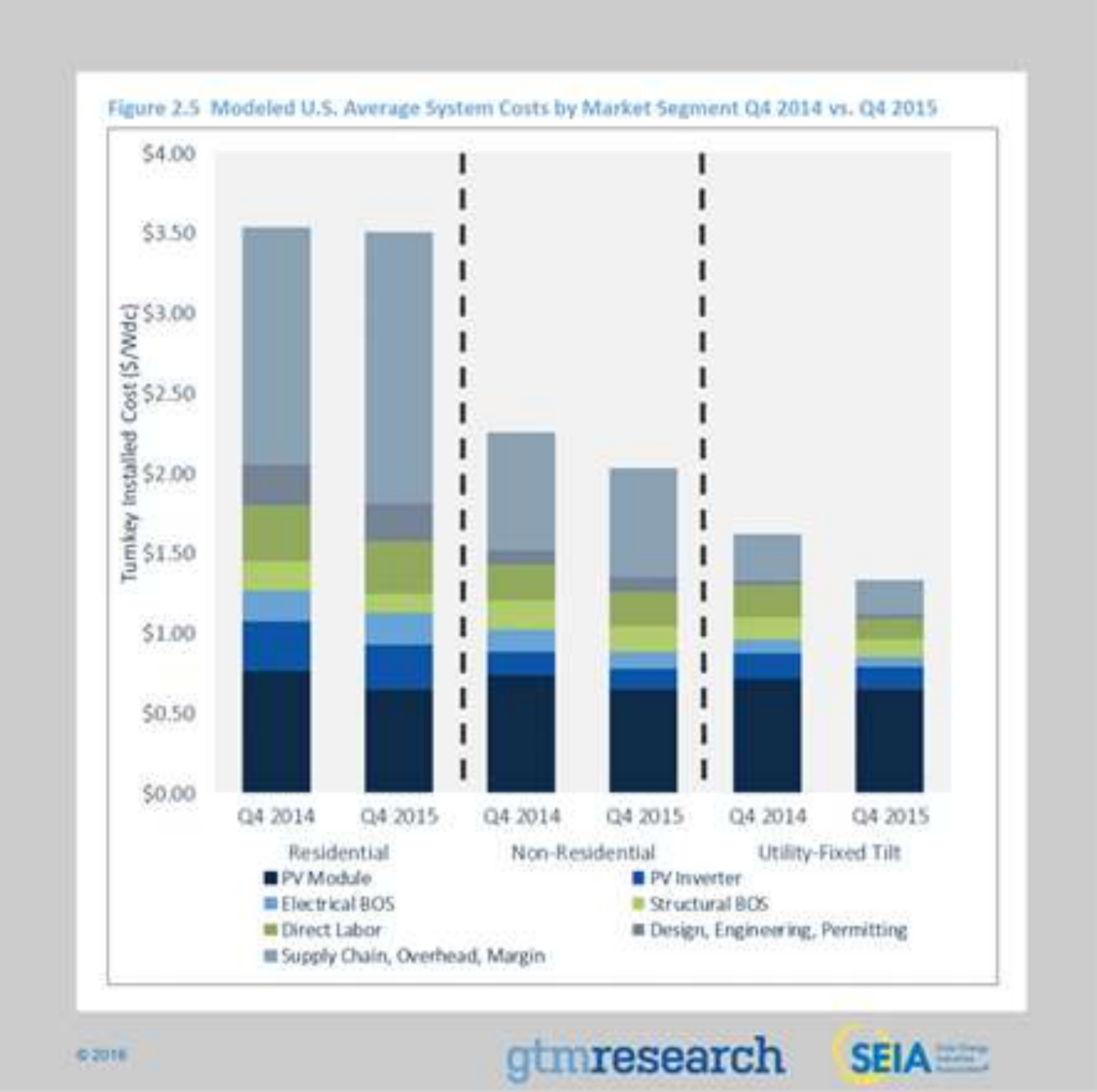
Fig. 3. Average percent changes in electricity bills: 2015 – 2030.

Process-Structure-Property Relationships

Nils Persson,
Michael McBride,
Elsa Reichmanis,
Martha Grover

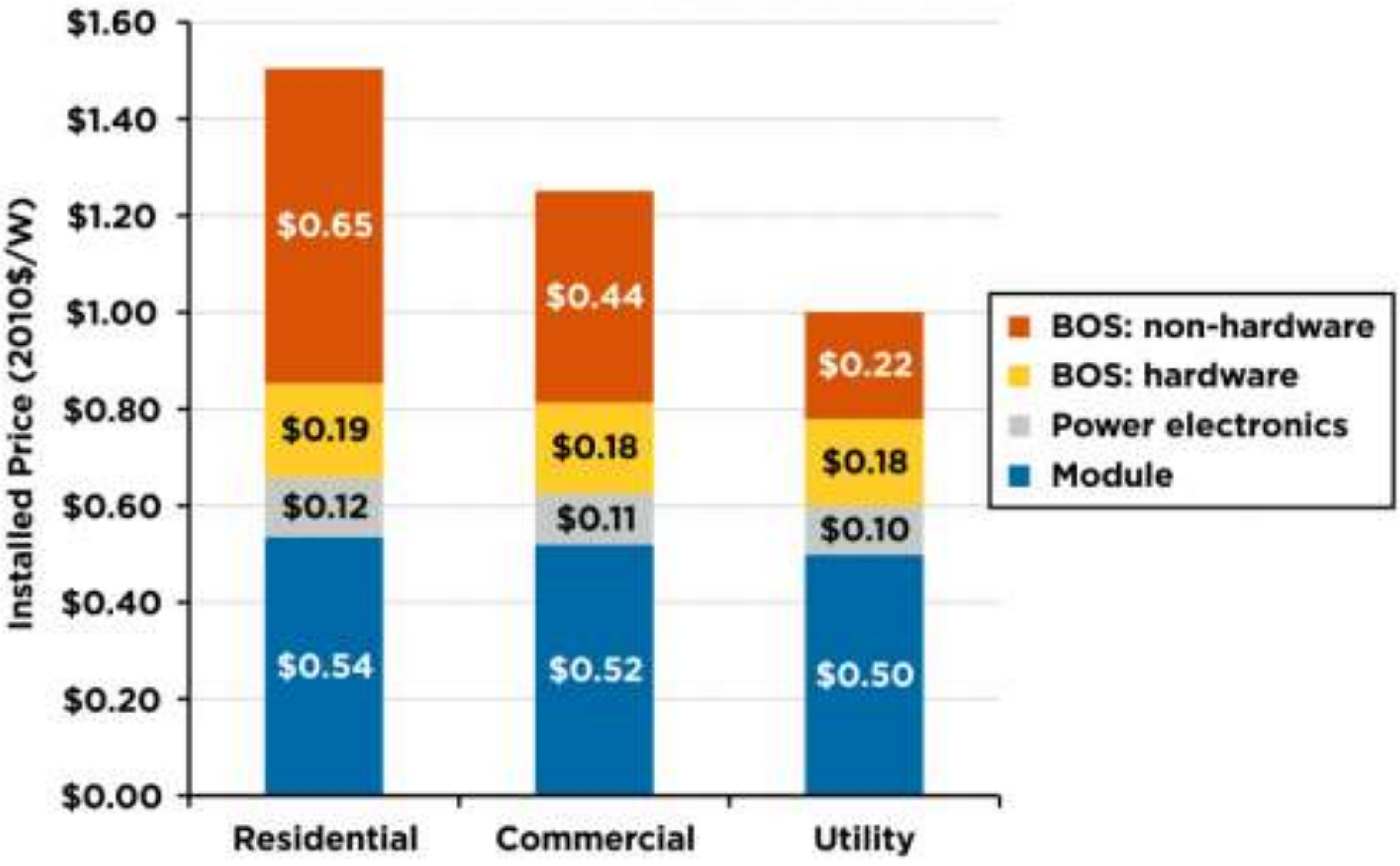
Chemical & Biomolecular Engineering
Georgia Institute of Technology
Tuesday July 25th, 2017

Module Costs are Significant

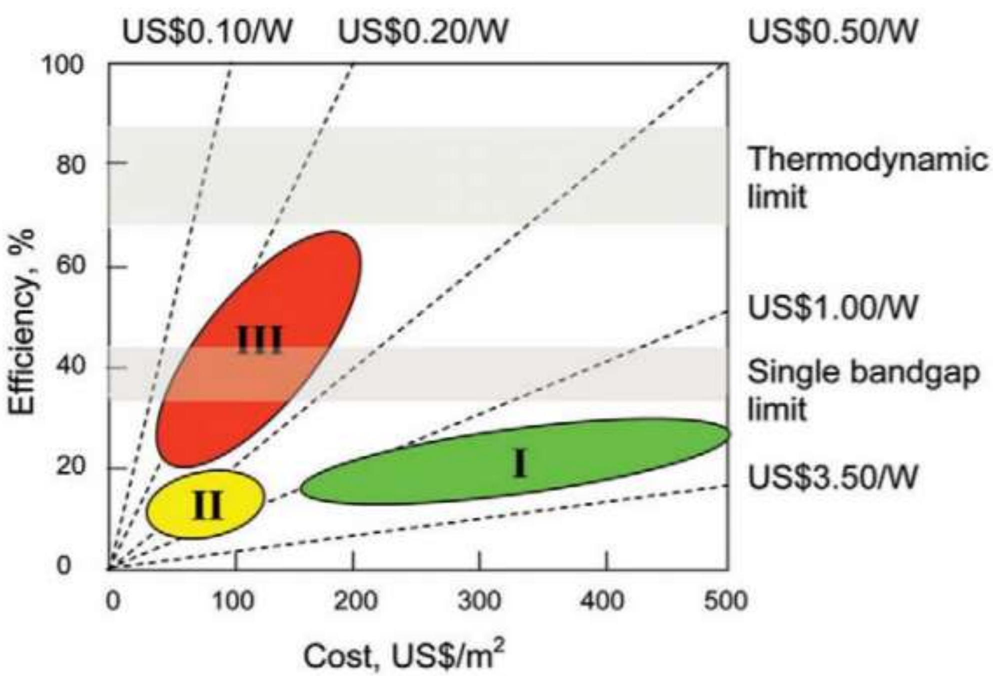


Module Costs Need to be Reduced

Figure 4-6. Estimated Subsystem Prices Needed to Achieve 2020 SunShot Targets



Solar Cell Technology Nodes



1st Generation: "Wafer Based"
- Monocrystalline silicon
- Polycrystalline Silicon

2nd Generation: "Thin Films"
- Copper Indium Gallium Selenide
- Cadmium Telluride
- Amorphous Silicon

3rd Generation: "Advanced Materials"
- Organic Photovoltaics (OPV)
- Perovskites
- Quantum Dot Solar Cells
- Dye Sensitized Solar Cells

G. Conibeer, "Third-Generation Photovoltaics," *Materials Today*, vol. 10, no. 11, Nov. 2007.

Approach

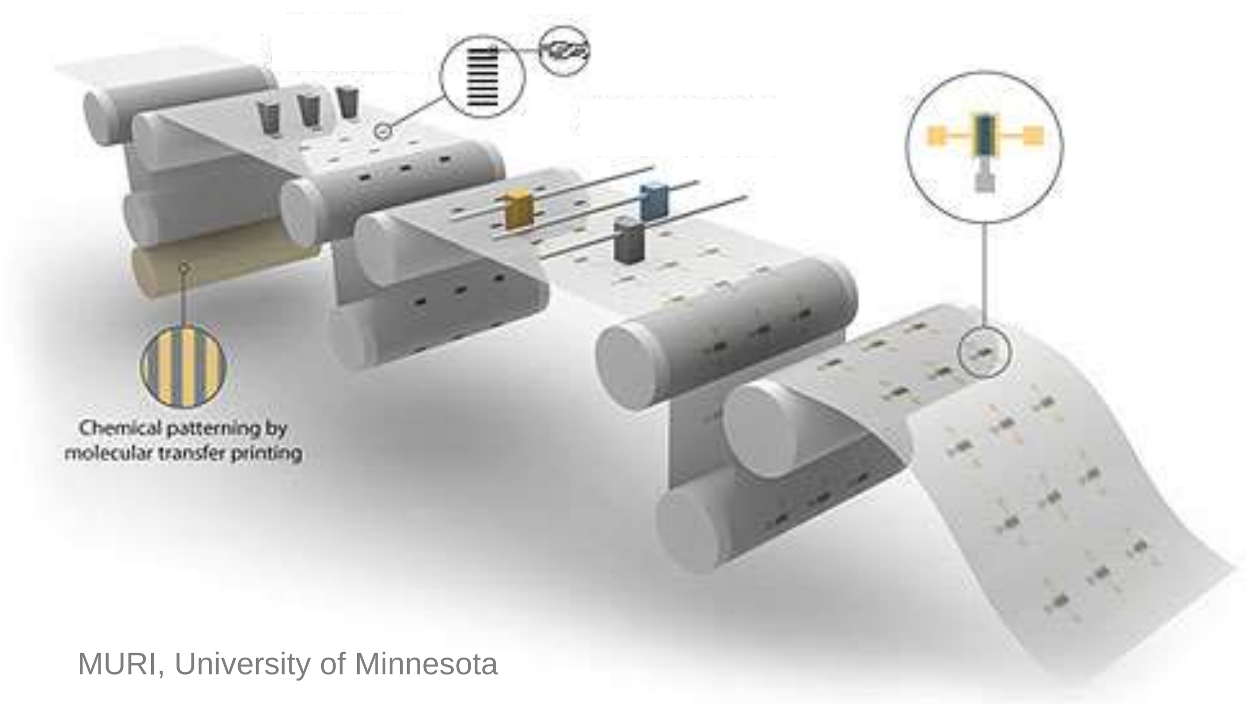
- Employ all sources of information available to extract knowledge
- Emphasis on process-structure relationship
- Apply manual text mining to the scientific literature
  - Give structure to unstructured data
  - What a Watson-style text miner would do in an ideal case
- Data extraction from figures for property values
- Enable better searching and filtering of literature results

Sumpter, B. G.; Vasudevan, R. K.; Potok, T.; Kalinin, S. V. “A Bridge for Accelerating Materials by Design,” *Computational Materials* **2015**.
Potyrailo, R.; Raja, K.; Stoewe, K.; Takeuchi, **I**; Chisholm, B.; Lam, H. “Combinatorial and High-Throughput Screening of Materials Libraries: Review of State of the Art,” *ACS Combinatorial Science* **2011**.

Large area, flexible electronic devices

Images: CNN Money, Blah, blah! Technology, Progress Lighting, International Business Times, Business Korea

Roll-to-roll printing processes

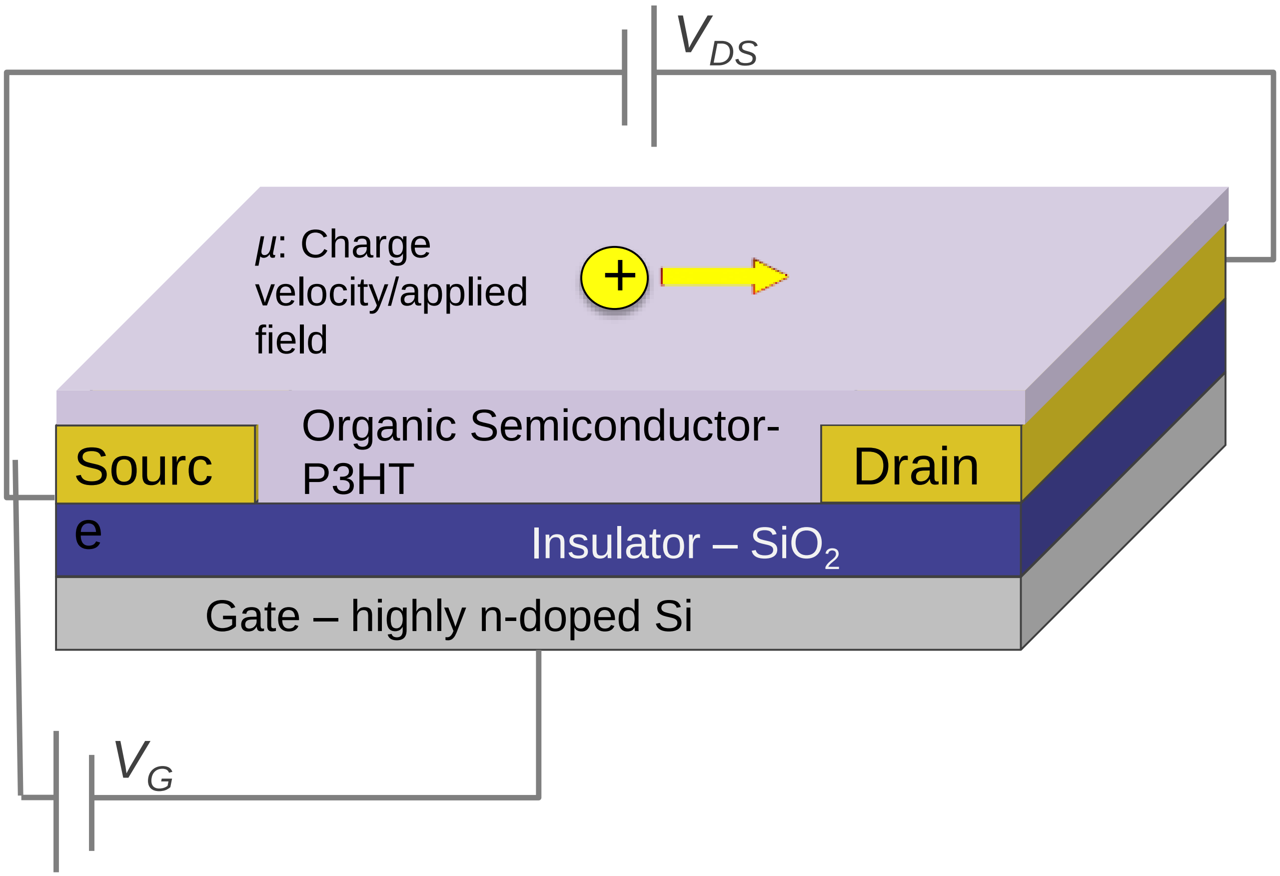


MURI, University of Minnesota

The OFET

Field effect transistors (FETs) drive many electronics applications and provide a platform to study process-structure-property relationships.

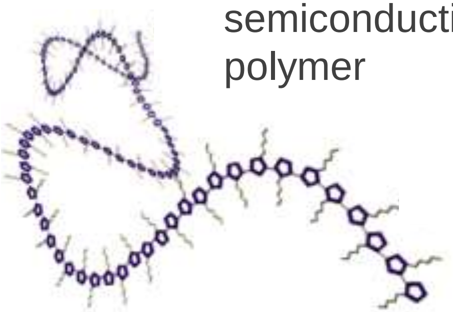
Mobility (μ) is a model parameter fitted from electrical characterization that determines attainable switching frequencies in transistors.

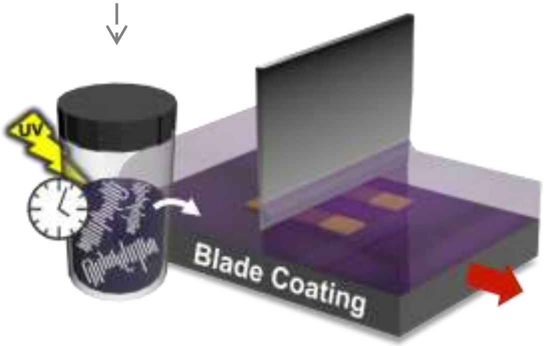


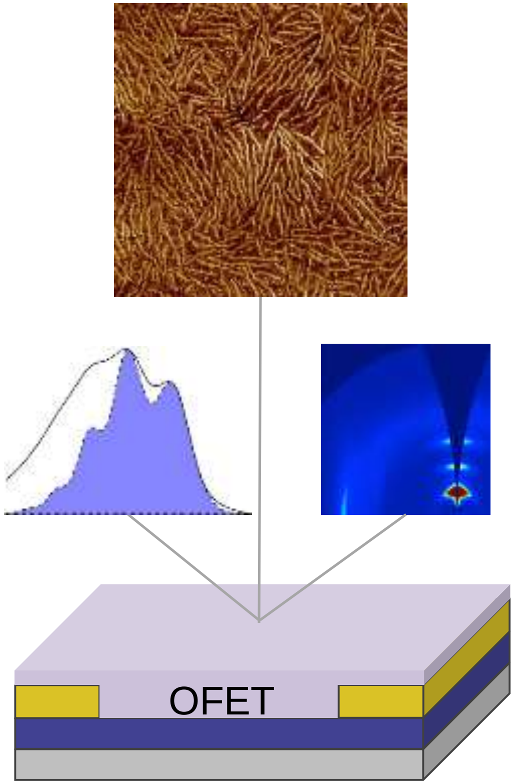
Solution Processing

Process	Structure	Property

P3HT – model semiconducting polymer



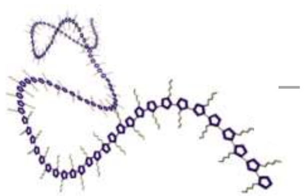


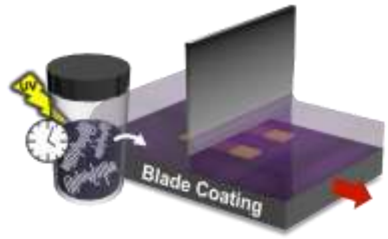


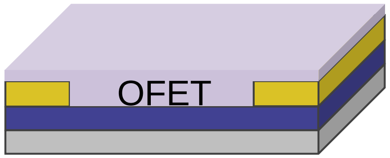
Charge Carrier Mobility **(μ)**

Johnson, C. E.; Gordon, M. P.; Boucher, D. S. "Rationalizing the Self-Assembly of Poly-(3-hexylthiophene) Using Solubility and Solvachromic Parameters," *Journal of Polymer Science: Polymer Physics* **2015.**

The OFET Database







Electrical Properties

Material

Number Average Molecular Weight (M_n)
Polydispersity (PDI)
Regioregularity (RR)

Solution Treatment

Initial Concentration
<u>Solvents:</u>
- Volume Fractions
- Boiling Point
- Hansen Radius

Aging Time/Temp.
Sonication Time
UV Irradiation Time
Cooling Regimen

Deposition

Substrate Treatment
Deposition Method
<u>Spin Coated:</u>
- RPM
- Time

<u>Dip Coated:</u>
- Dip Rate
- Time

<u>Blade Coated:</u>
- Velocity
- Temperature

Film Thickness
Environment (N_2/Air)

Post-Processing

Annealing Time
Annealing Temp.
Film Thickness

Device Architecture

Electrode Configuration
Electrode Material
Channel Length
Channel Width

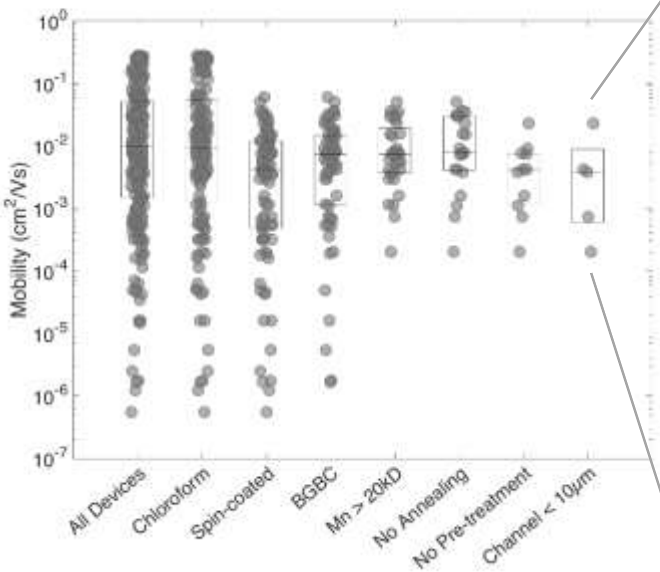
Characterization

Mobility
Mobility Regime
Environment

Many process parameters influence mobility
Reporting is generally incomplete
What can we learn?

Persson, N.; McBride, M.; Grover, M. A.; Reichmanis, E. *Current Opinion in Solid State and Materials Science* **2016**, *20*, 338–343.

The OFET Database



Author/Year	Aiyar 2011	Bielecka 2011	Chang 2013	Park 2014	Verilhac 2006
Mn (kD)	24		40.3	24	27
Mw (kD)	47.7	65.5	91.5	47.7	60.8
PDI	2.0		2.27	2.0	2.25
R.R. (%)	93	96.6	92	92	98
Solvent	CHCl3	CHCl3	CHCl3	CHCl3	CHCl3
Init. Conc. (mg/mL)	4	10	5	3	2
Substrate Treatment					HMDS
Deposition Method	Spin-coated	Spin-coated	Spin-coated	Spin-coated	Spin-coated
Spin Rate (rpm)	1500	900	1500	2000	300
Spin Time (s)			60	60	30
Processing Environment	Air	Air	Air	N2	Air
Mobility Environment	Air	Vacuum	N2	Vacuum	N2
Mobility Regime	Linear	Saturation	Saturation	Linear	Saturation
Electrode Configuration	BGBC	BGBC	BGBC	BGBC	BGBC
Electrode Material	Au	Au	Au	Au	Au
Channel Length (μm)	50	10	50	200	20
Channel Width (mm)	2	10	2	0.5	9
Mobility (cm^2/Vs)	**0.000202**	**0.00073**	**0.00423**	**0.005**	**0.0229**

This study demonstrated the value of a searchable device data repository and the need for greater standardization.

Persson, N.; McBride, M.; Grover, M. A.; Reichmanis, E. *Current Opinion in Solid State and Materials Science* **2016**, *20*, 338–343.

The OFET Database

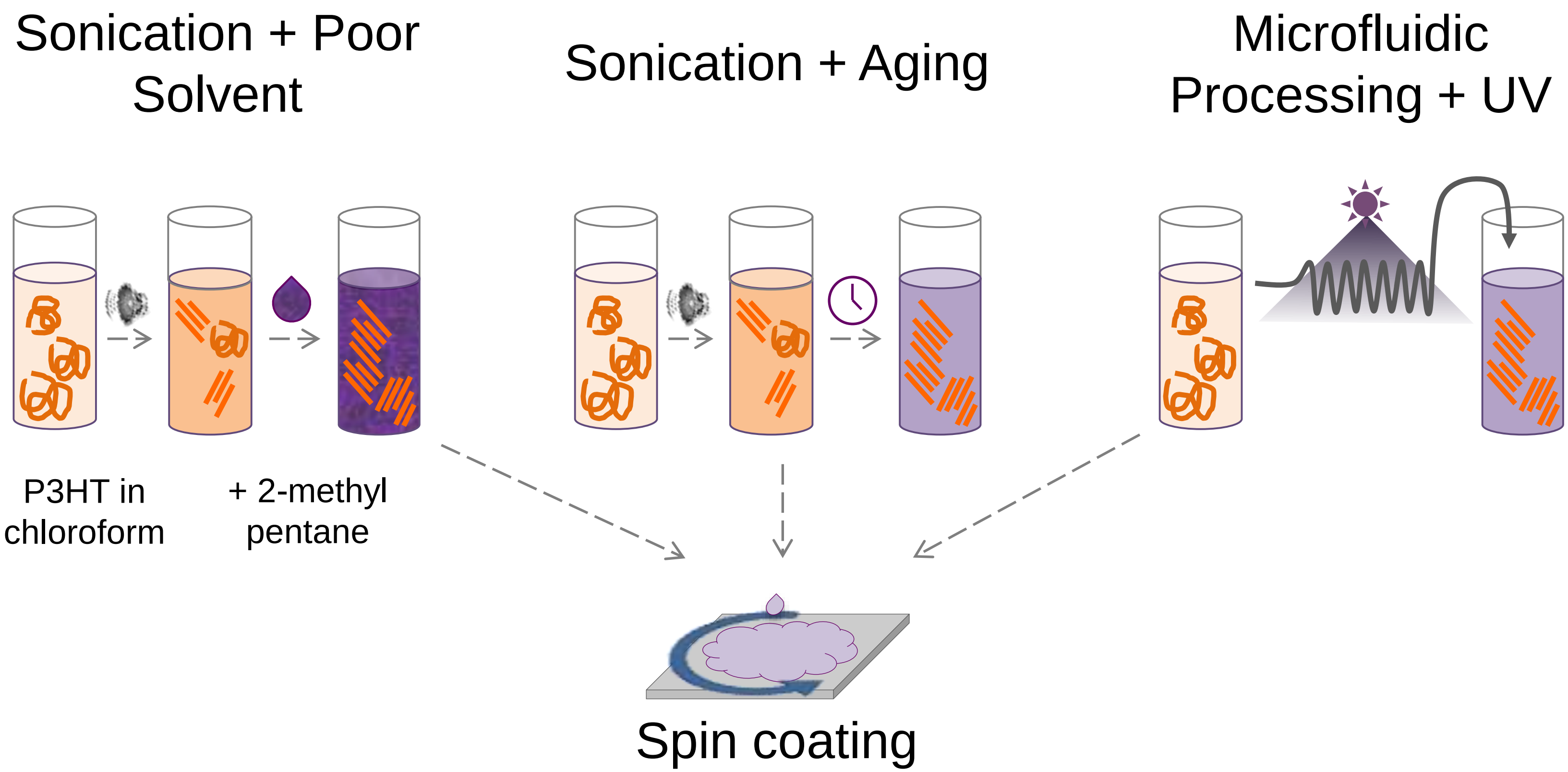
Challenges

How to maintain such a database with *minimal effort from researchers*?

How to extract more quantitative knowledge when information is composed of *mixed data types*?

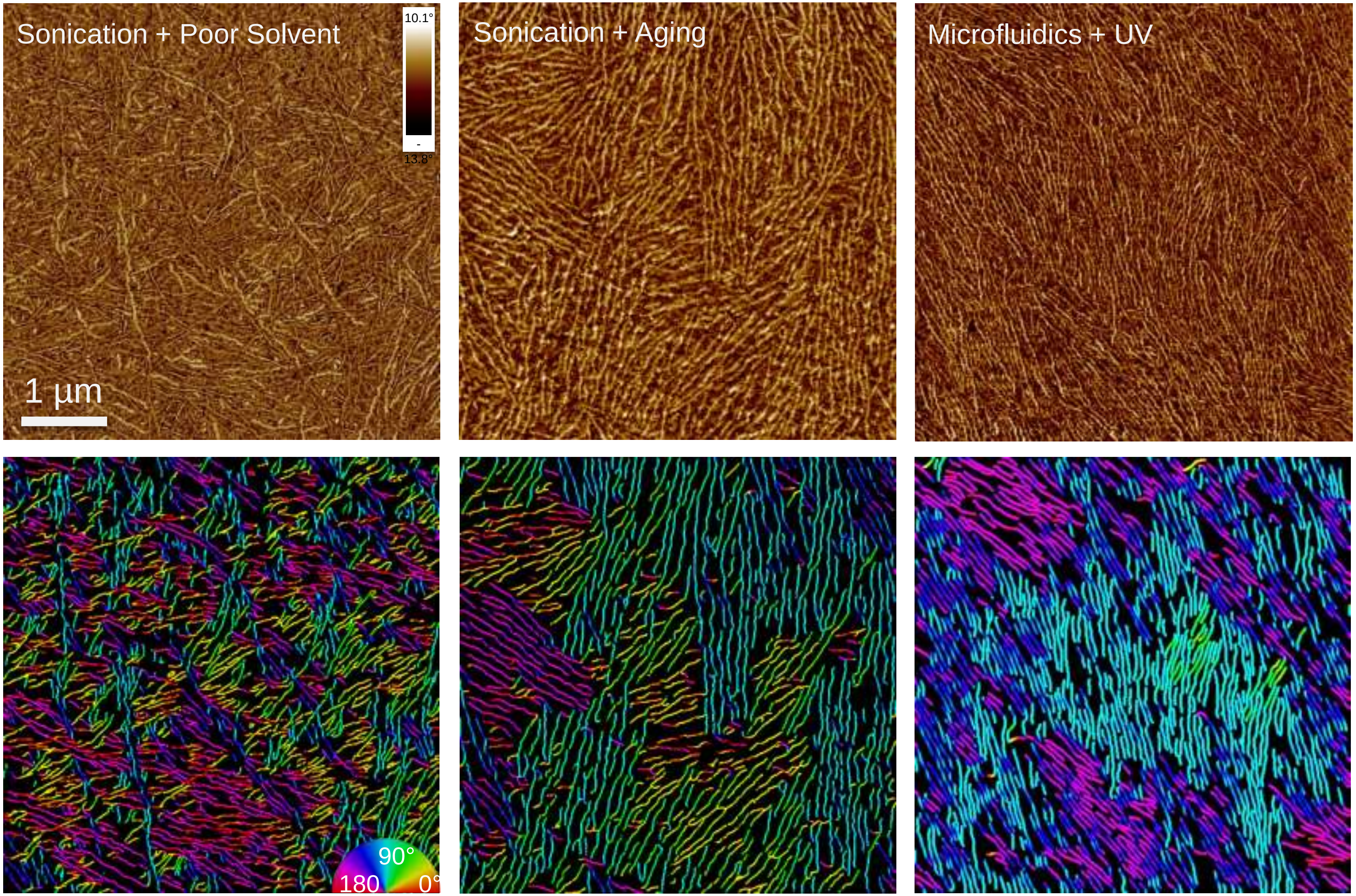
Who hosts and pays for the *data storage*?

Process-Structure Relationships



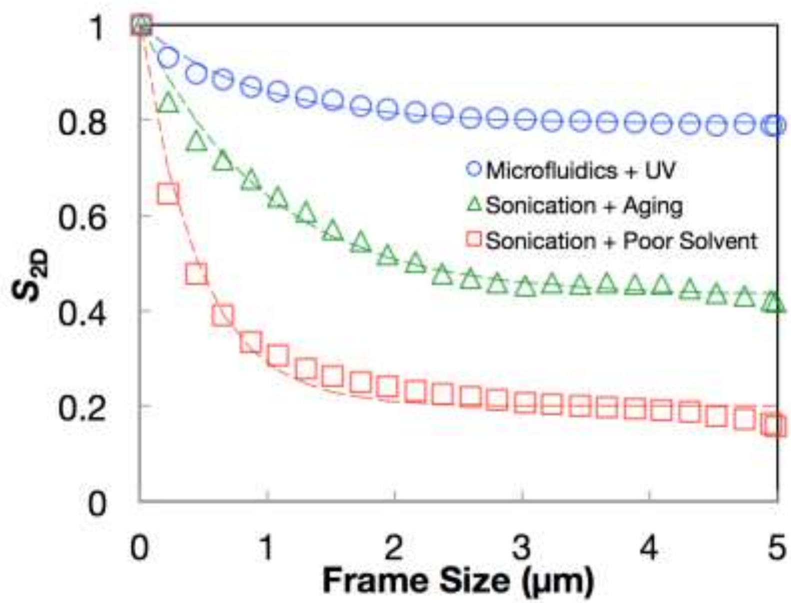
Choi et al., *Adv. Funct. Mater.* **2015**, *25*, 920–927
Kleinhenz et al., *Chem. Mater.* **2016**, *28*, 3905−3913
Wang et al., *ACS Nano* **2015,** *9*, 8220–8230

Process-Structure Relationships



Persson, N.; McBride, M.; Grover, M. A.; Reichmanis, E. *Chemistry of Materials* **2016**, *29*, 3–14.

Process-Structure Relationships



	S_{full}	λ_C (nm)
Microfluidics + UV	0.79	886
Sonication + Aging	0.45	977
Sonication + Poor Solvent	0.20	434

Process-Structure Relationships

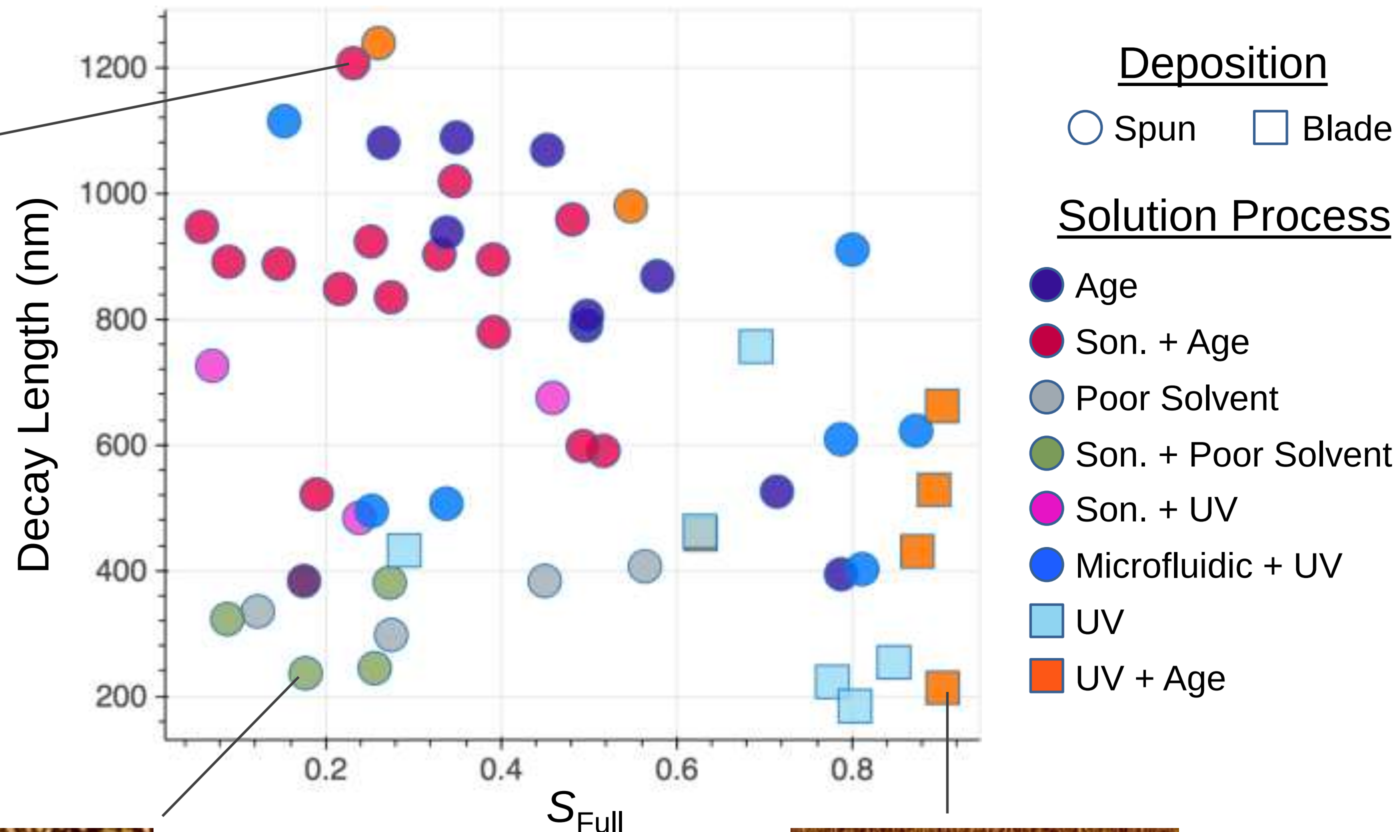
Solvent-phobic, retracted fringe chains

Extended, interacting fringe chains

Shish-kebab nuclei

Persson, N.; McBride, M.; Grover, M. A.; Reichmanis, E. *Chemistry of Materials* **2016**, *29*, 3–14.

Visualization of Structural Parameters



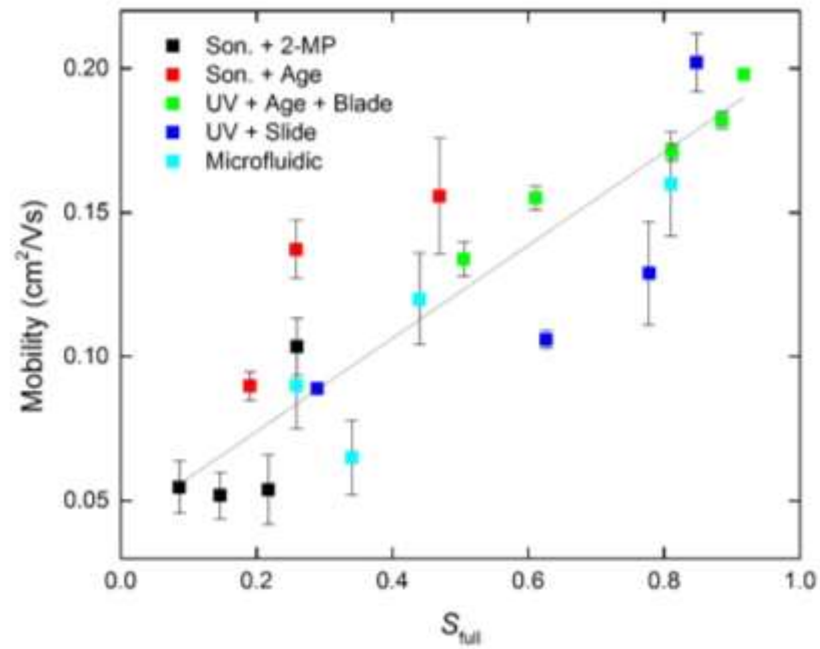
Structure-Property Relationships

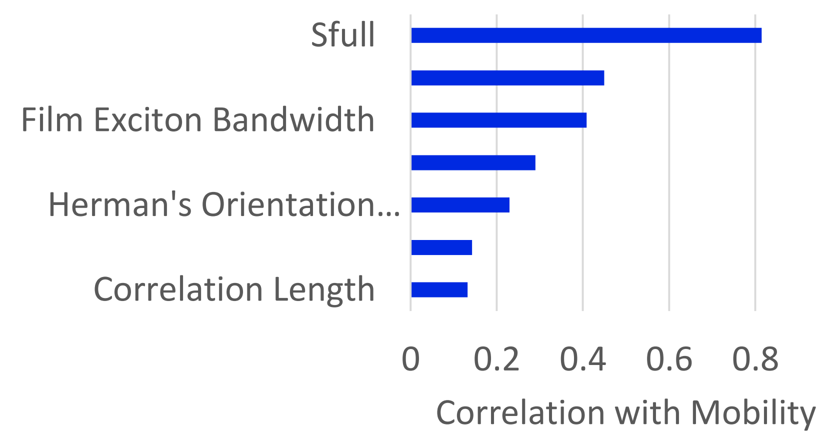
A general relationship emerged between fiber alignment and mobility.

A similar relationship was not found with UV-Vis and GIWAXS due to *buried raw data* and *changing models*.

A centralized database with *version-controlled analysis* could reveal more informative trends.

Note: All data is from the Reichmanis group.



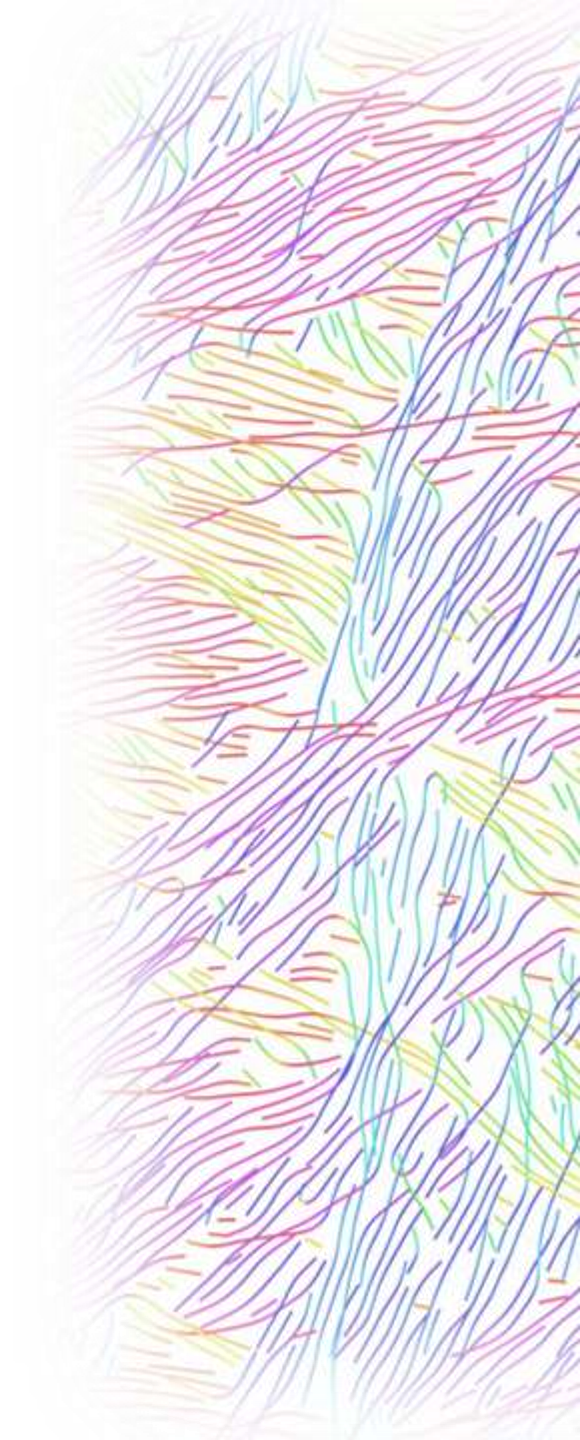


Persson, N.; Chu, P.H.; McBride, M.; Grover, M. A.; Reichmanis, E. *Accounts of Chemical Research* **2017**, DOI: 10.1021/acs.accounts.6b00639.

Conclusions

- Centralized process-structure-property databases enable high level materials knowledge extraction
- GTFiber automates fiber extraction and measurement from images
- Orientational order is fundamentally linked with mobility and fiber growth in P3HT-based transistors

GTFiber: gtfiber.github.io
OFET Database: github.com/Imperssonator/OFET-Database



Acknowledgements

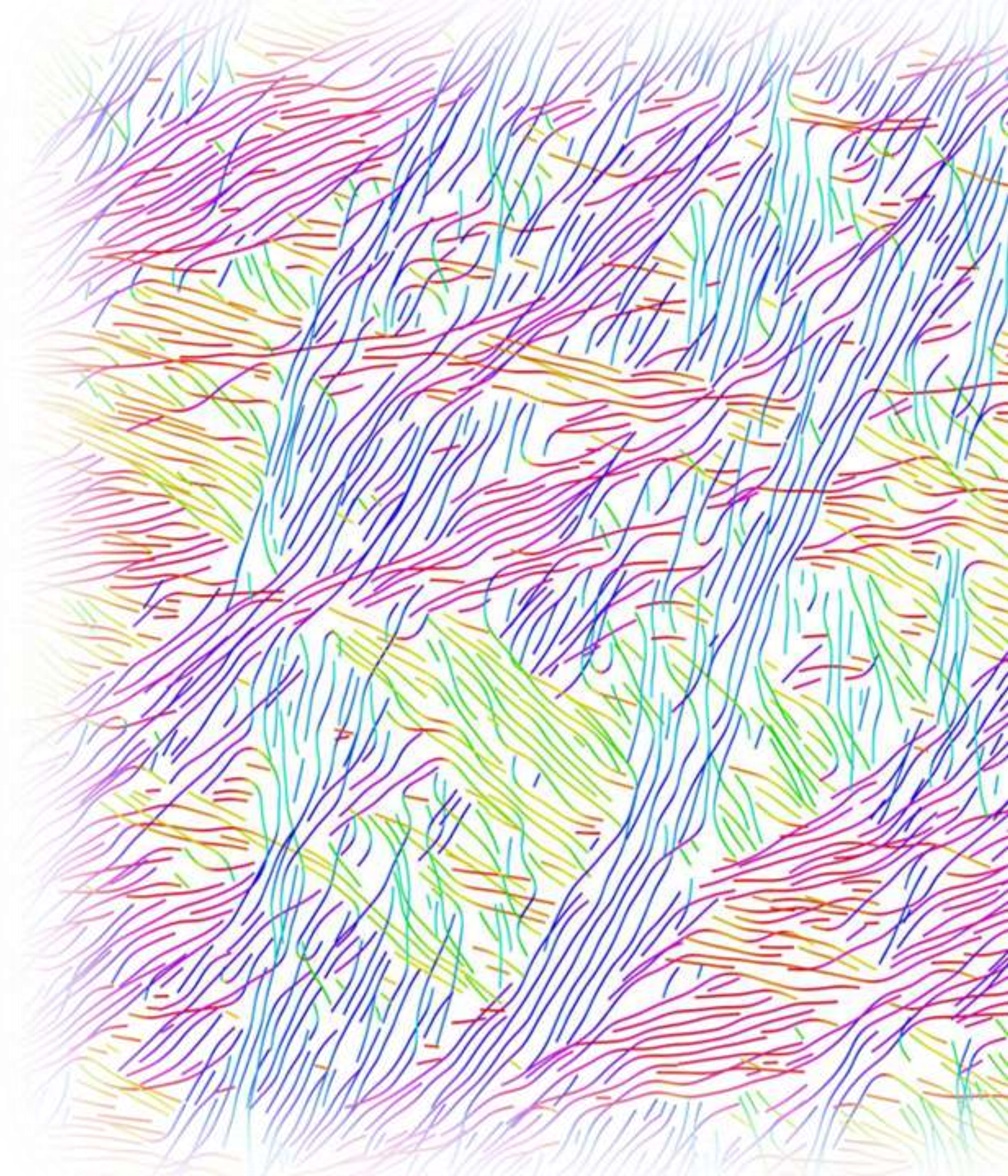
- Mike McBride
- Ping-Hsun Chu
- Dr. Nabil Kleinhenz
- Dr. Tony Fast
- Dr. Gang Wang
- Prof. Surya Kalidindi
- Kaylie Naghshpour
- Josh Rafshoon

<u>Funding</u>

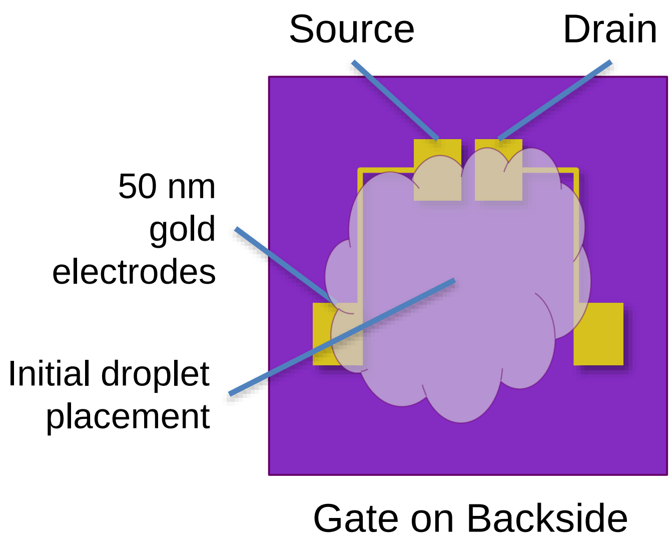
- NSF CBET-1264555, “Morphology and Mobility Control for Functional Robust Flexible Electronics and Photovoltaics”
- NSF IGERT FLAMEL Traineeship
- GA Tech IMAT Fellowship

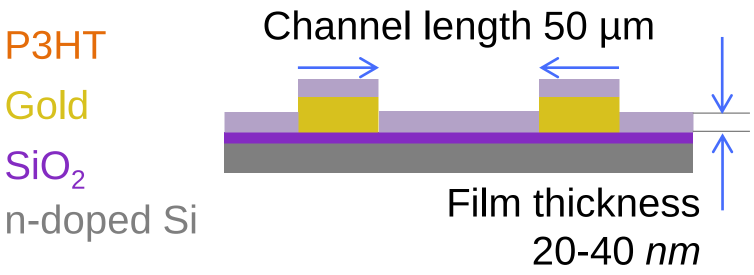
FLAMEL IGERT

Thank you!

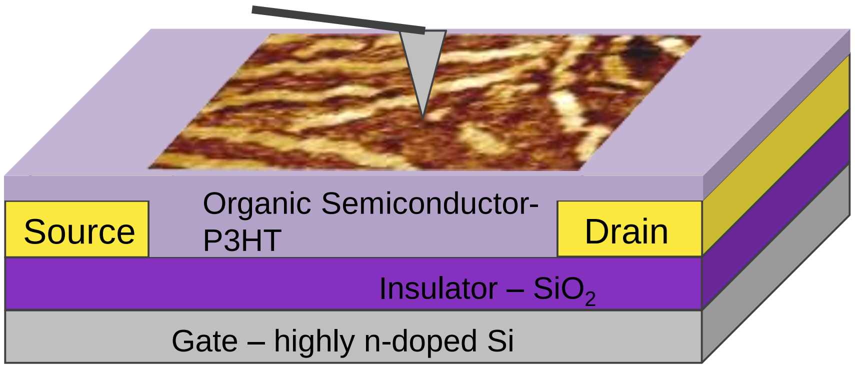


Transistor layout and thin film characterization

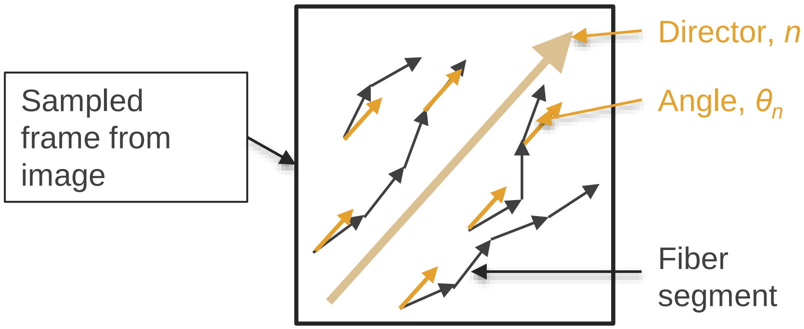




Atomic Force Microscopy (AFM) reveals fibrillar regions, their length and orientation.

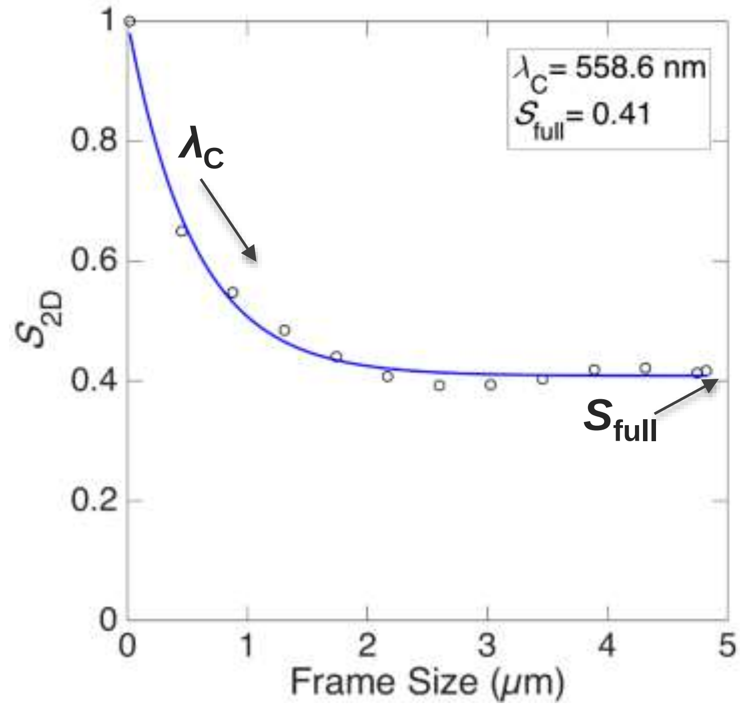


Quantifying Orientational Order



<u>Orientational Order Parameter for each frame</u>

$$S_{2D} = 2\langle \cos^2 \theta_n \rangle - 1$$



Model for the decay of orientational order with increasing frame size:

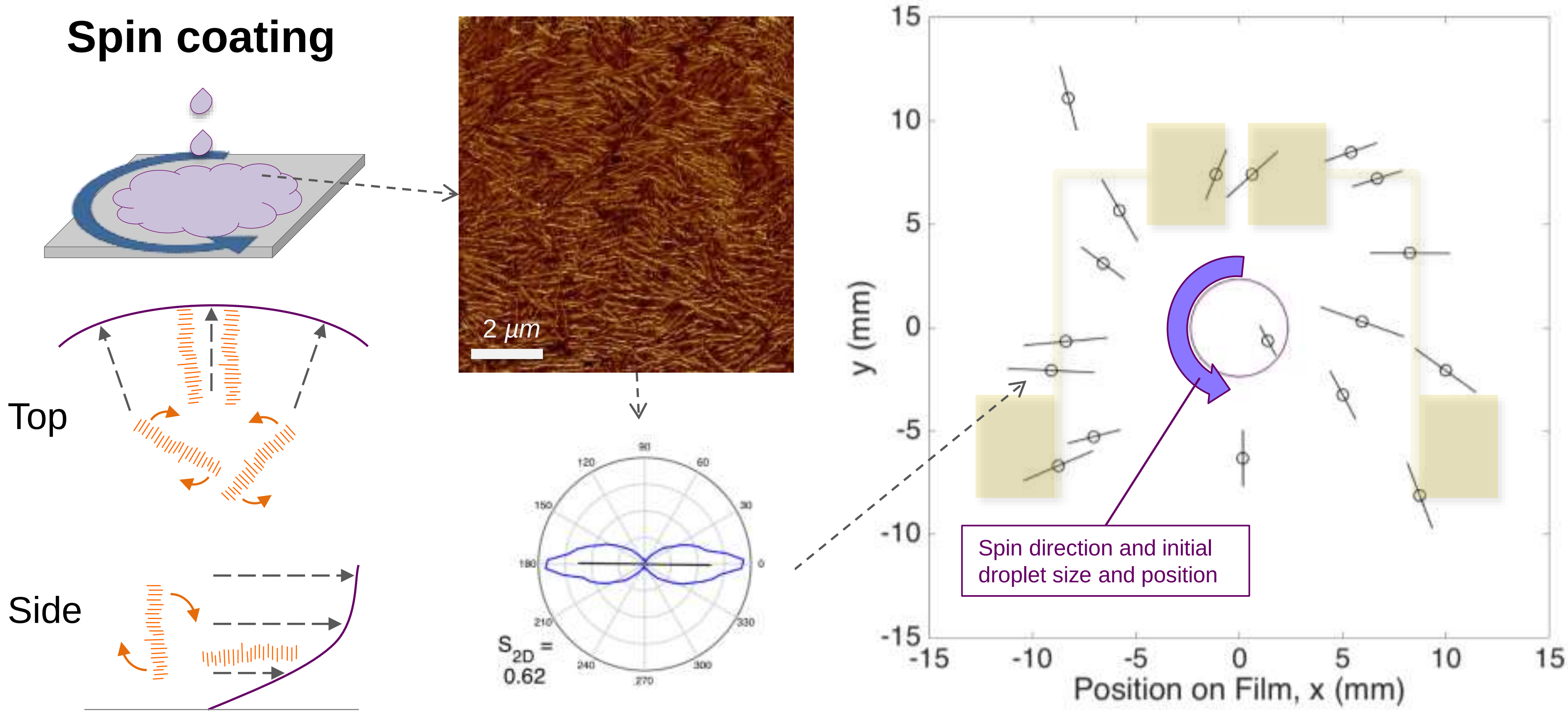
$$S_{2D} = S_{full} + (1 - S_{full})e^{-r/\lambda_C}$$

S_{full}: How aligned is the structure at long range?

λ_C: How quickly does alignment decay?

Persson et al., ACS *Chem. Mat.*, **2016**, accepted

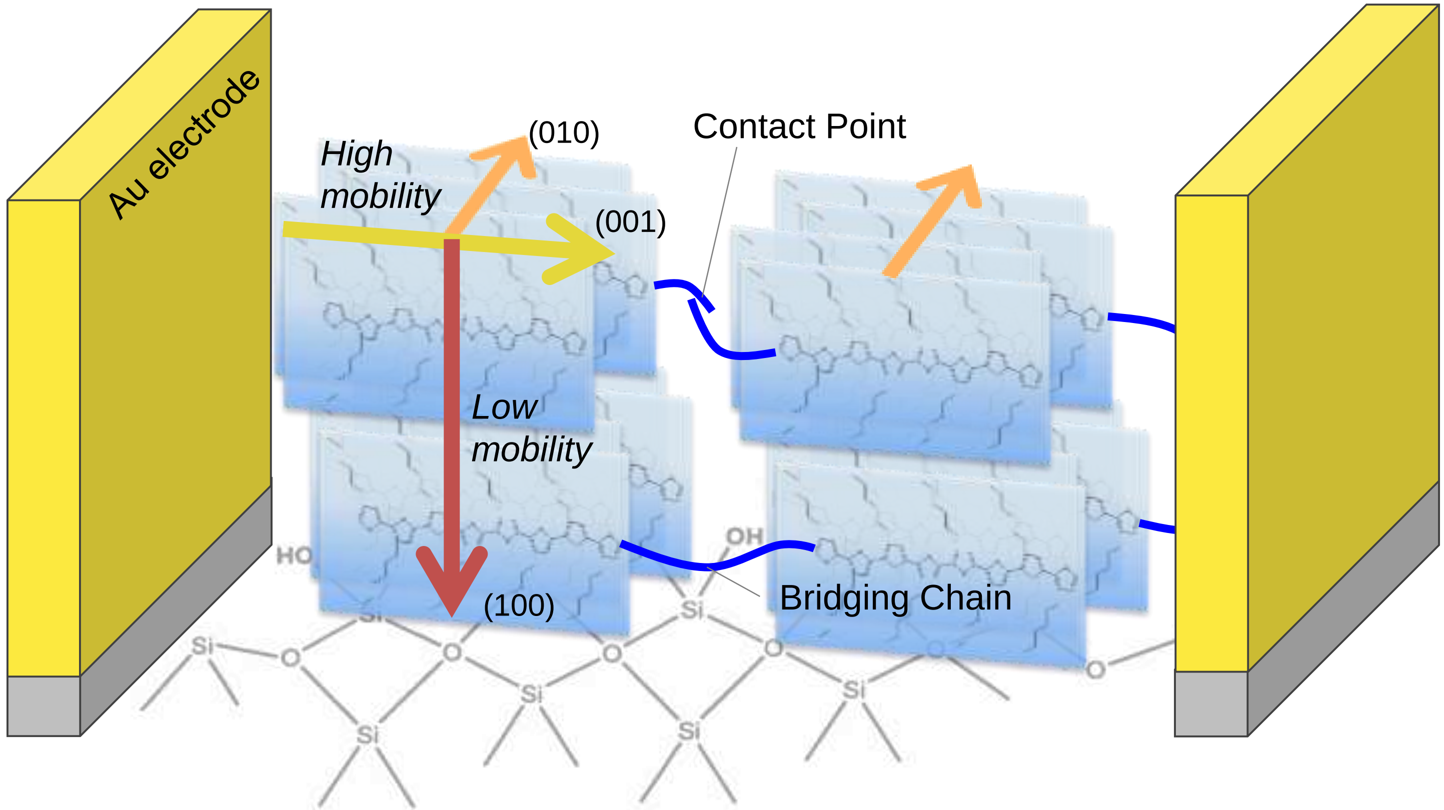
Effect of deposition method on fiber orientation



If the solution can be oriented, it follows the expected radial flow profile.

Persson et al., ACS *Chem. Mat.*, **2016**, In Press

Inter-fiber connectivity



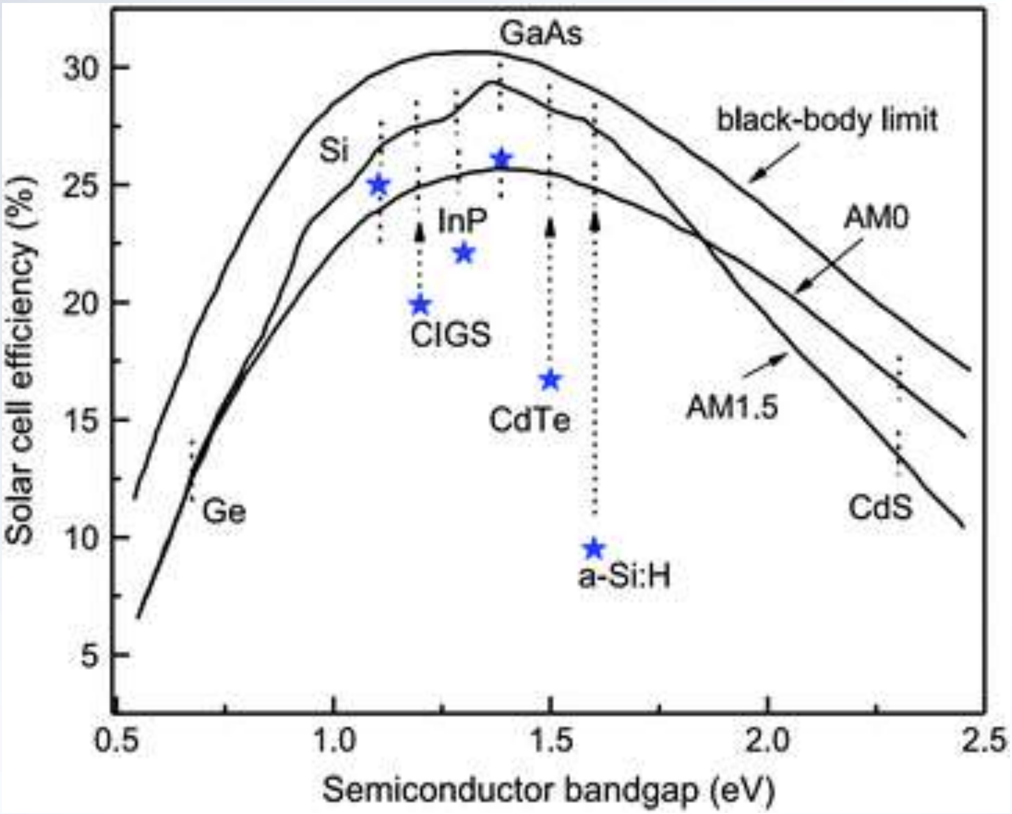
Both local (λ_C) and global (S_{full}) orientational order influence charge transport. Local ordering promotes planarization of the P3HT backbone and inter-fiber connectivity, while global ordering reduces the number of grain boundaries charges must cross.

Introduction to Photovoltaic Technologies

Michael McBride
Chemical & Biomolecular Engineering
Tuesday, July 25th, 2017

Georgia Institute of Technology

A Plethora of PV Materials



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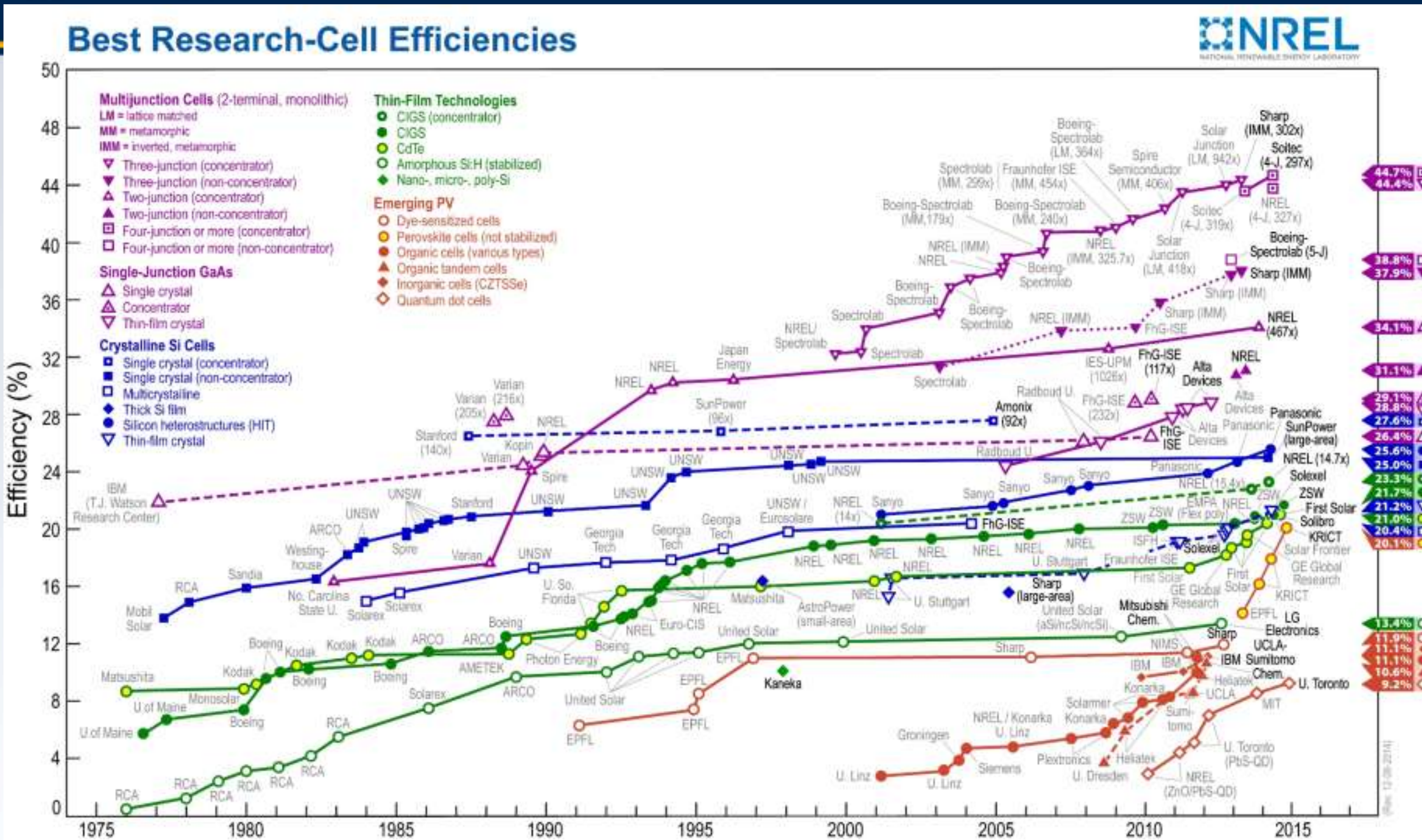
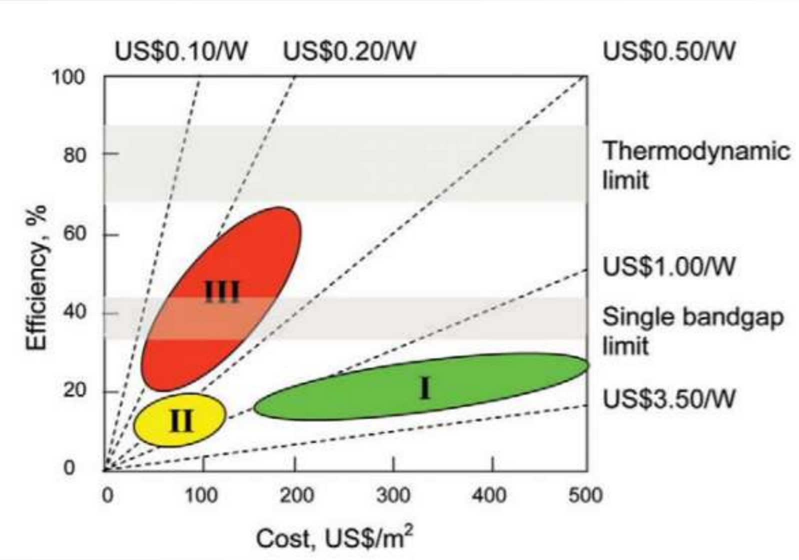

Best Research-Cell Efficiencies
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Multijunction Cells (2-terminal, monolithic)
LM = lattice matched
MM = metamorphic
IMM = inverted, metamorphic
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Two-junction (non-concentrator)
Four-junction or more (concentrator)
Four-junction or more (non-concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal (concentrator)
Single crystal (non-concentrator)
Multicrystalline
Thick Si film
Silicon heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
CIGS (concentrator)
CIGS
CdTe
Amorphous Si:H (stabilized)
Nano-, micro-, poly-Si
Emerging PV
Dye-sensitized cells
Perovskite cells (not stabilized)
Organic cells (various types)
Organic tandem cells
Inorganic cells (CZTSSe)
Quantum dot cells
Efficiency (%)
44.7%
44.4%
38.8%
37.9%
34.1%
31.1%
29.1%
28.8%
27.6%
26.4%
25.6%
25.0%
23.3%
21.7%
21.2%
21.0%
20.4%
20.1%
13.4%
11.9%
11.1%
11.1%
10.6%
9.2%
1975
1980
1985
1990
1995
2000
2005
2010
2015

Solar Cell Technology Nodes

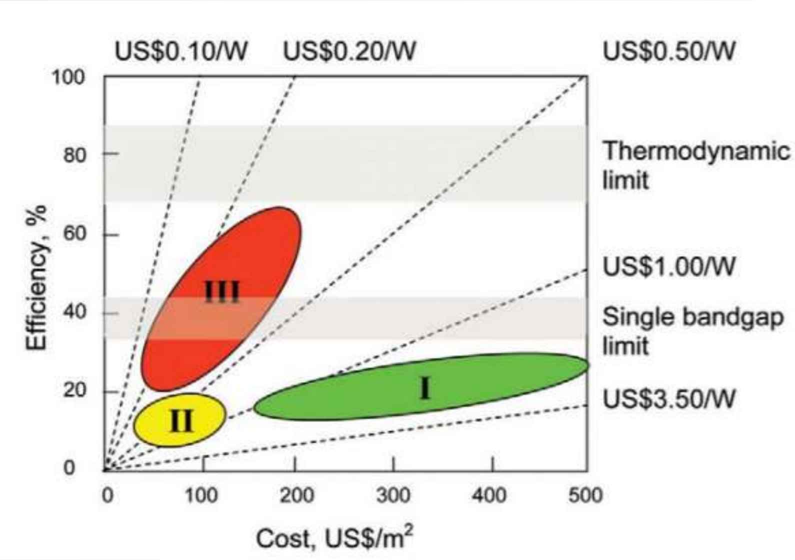


1st Generation: "Wafer Based"
- Monocrystalline silicon
- Polycrystalline Silicon

2nd Generation: "Thin Films"
- Copper Indium Gallium Selenide
- Cadmium Telluride
- Amorphous Silicon

3rd Generation: "Advanced Materials"
- Organic Photovoltaics (OPV)
- Perovskites
- Quantum Dot Solar Cells
- Dye Sensitized Solar Cells

Solar Cell Technology Nodes



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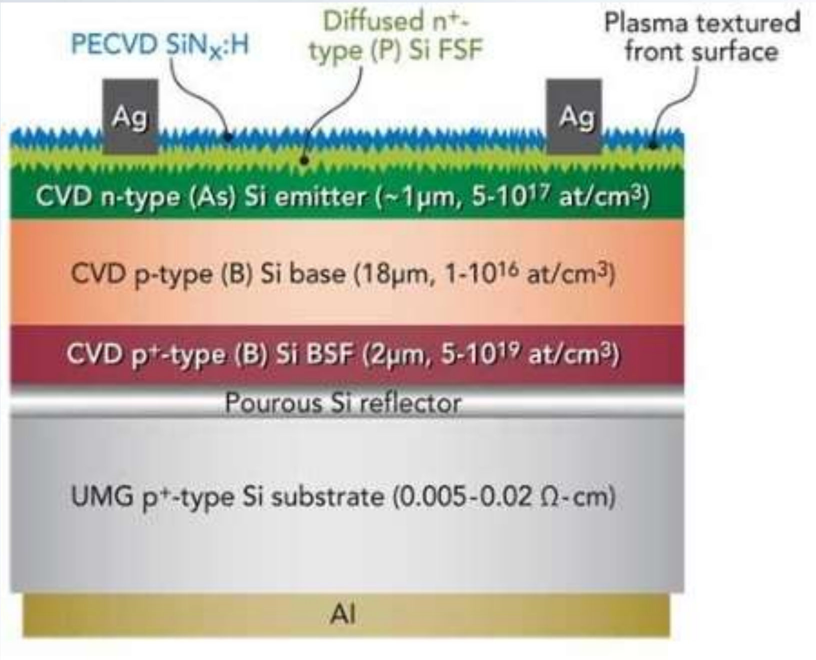
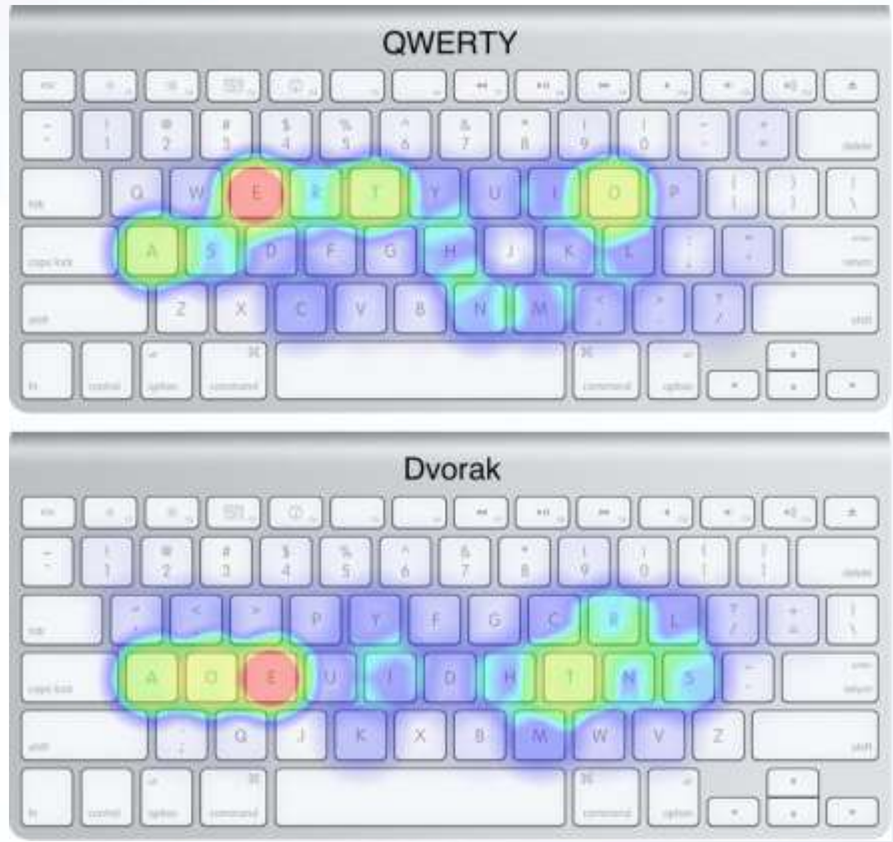
The Silicon Solar Cell



- Expensive processing cost
- Wasteful
  - ~50% of silicon material is lost during manufacturing
- Limited light absorbance
  - Band gap=1.1 eV
- Potential for higher balance of system costs (BOS)

Prevalence of Silicon PV Systems

Path Dependent Technologies

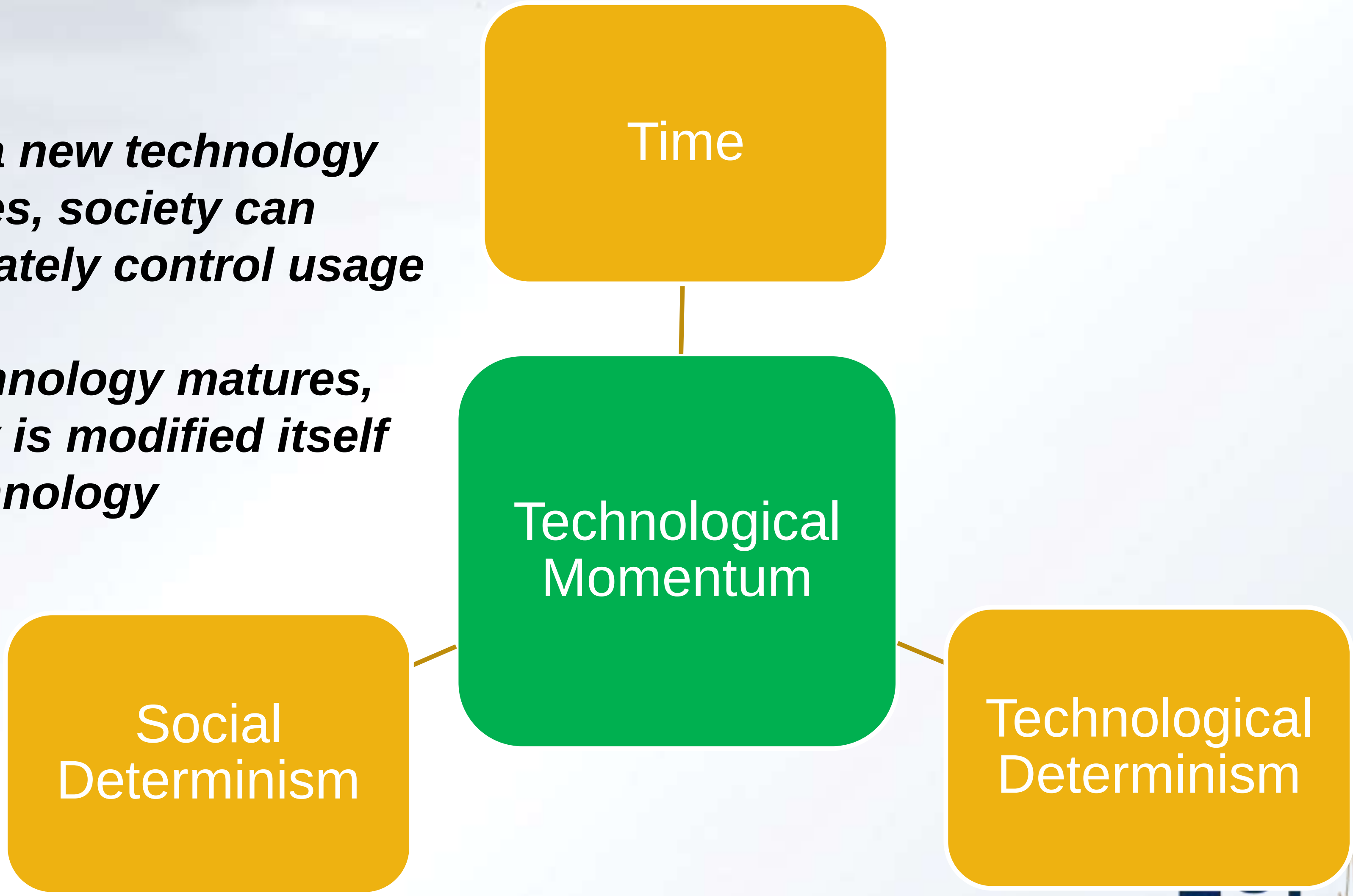


History of technology matters

Prevalence of Silicon PV Systems

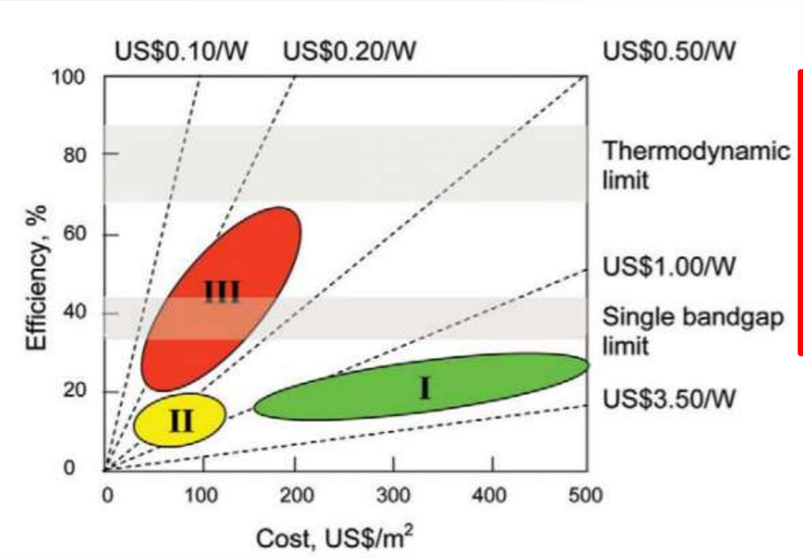
When a new technology emerges, society can deliberately control usage

As technology matures, society is modified itself by technology



Tech

Solar Cell Technology Nodes



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3rd Generation: "Advanced Materials"
- **Organic Photovoltaics (OPV)**
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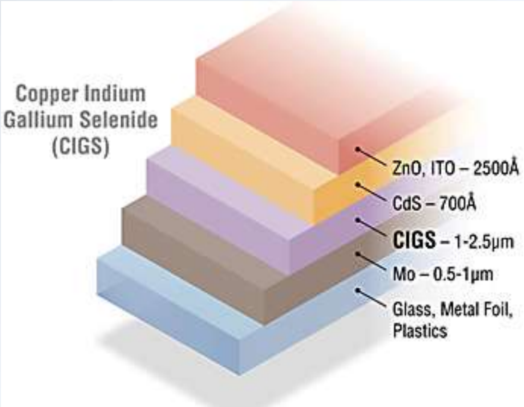
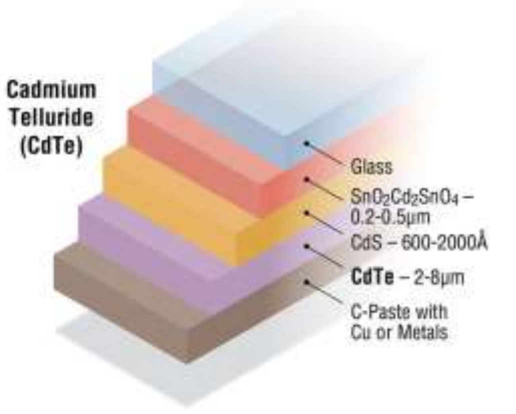
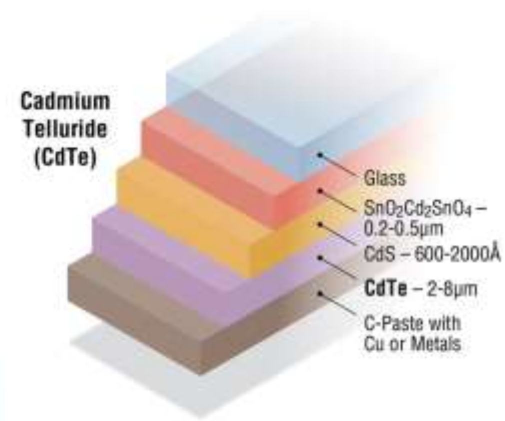
2^{nd} Generation Devices Provide Opportunity for Cost Effective Production





		Efficiency (%)					
Gen.	Node	Theo. Max	Best R&D	Typical Module	Bottom-Up cost (2015$/W)	Degradation Rate (%/yr)	EPBT (yrs)
1st	C-Si	29	27.6	18	0.74	0.65	1.7-2.7
2nd	CIGS	29	20.3	13	0.67	0.85	1.5-2.2
2nd	CdTe	29	17.3	12	0.51	0.85	0.8-2.1
2nd	a-Si	20	12.5	10	-	1.15	1.8-3.5

Health and Safety Concerns



Cadmium	Kidney Damage
	Bone Damage
	Cancer
	Reproductive hormones

Regulated by:

EPA
-Clean Air Act
-Toxic Substance Control Act
-Water standards
-Soil standards

OSHA
-Exposure limits

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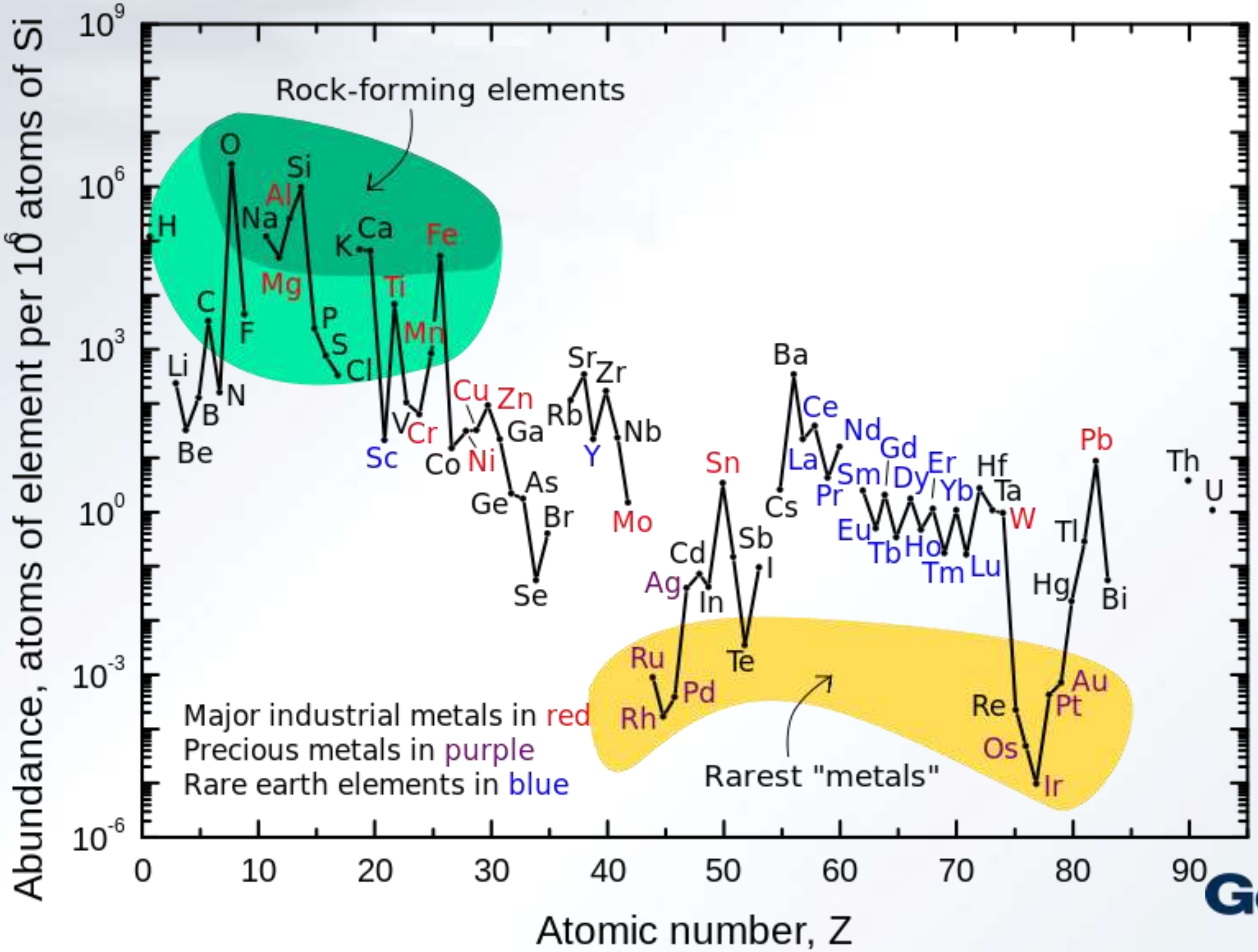
Material Availability



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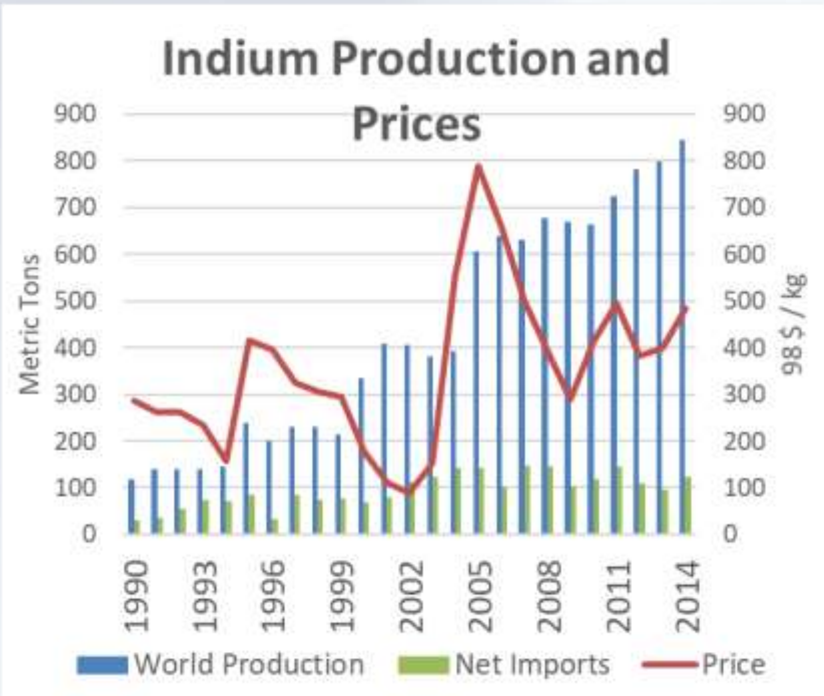
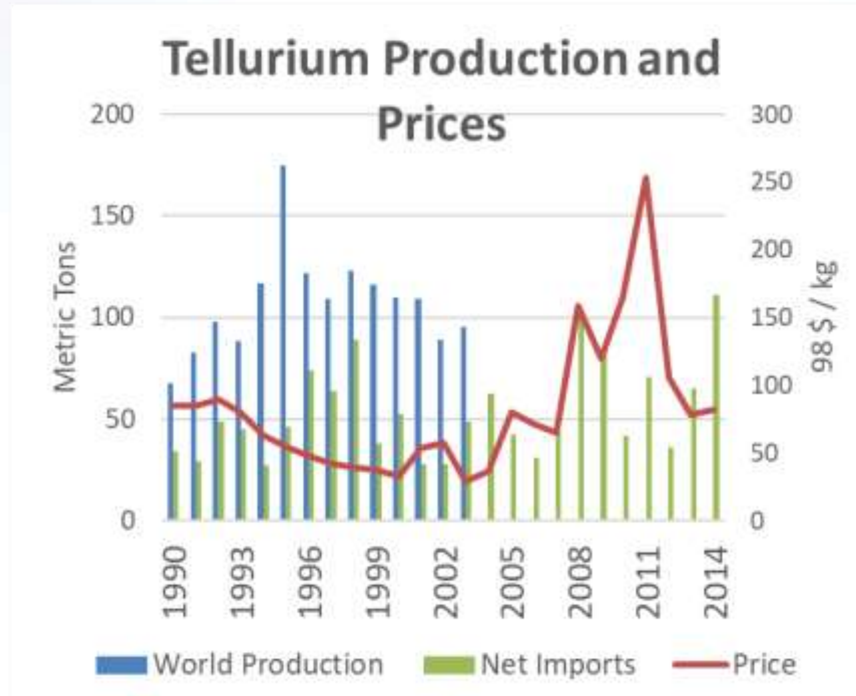
Production & Prices

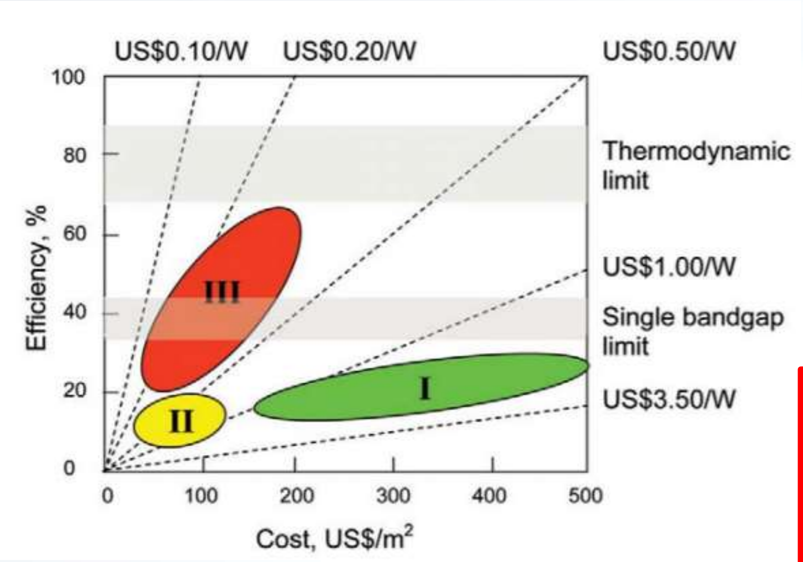




Import Sources (2011–14): Canada, 21%; China, 16%; Belgium, 15%; Republic of Korea, 10%; and other, 38%.

Import Sources (2011–14): Canada, 59%; China, 21%; Philippines, 9%; Belgium, 9%; and other, 2%

Solar Cell Technology Nodes



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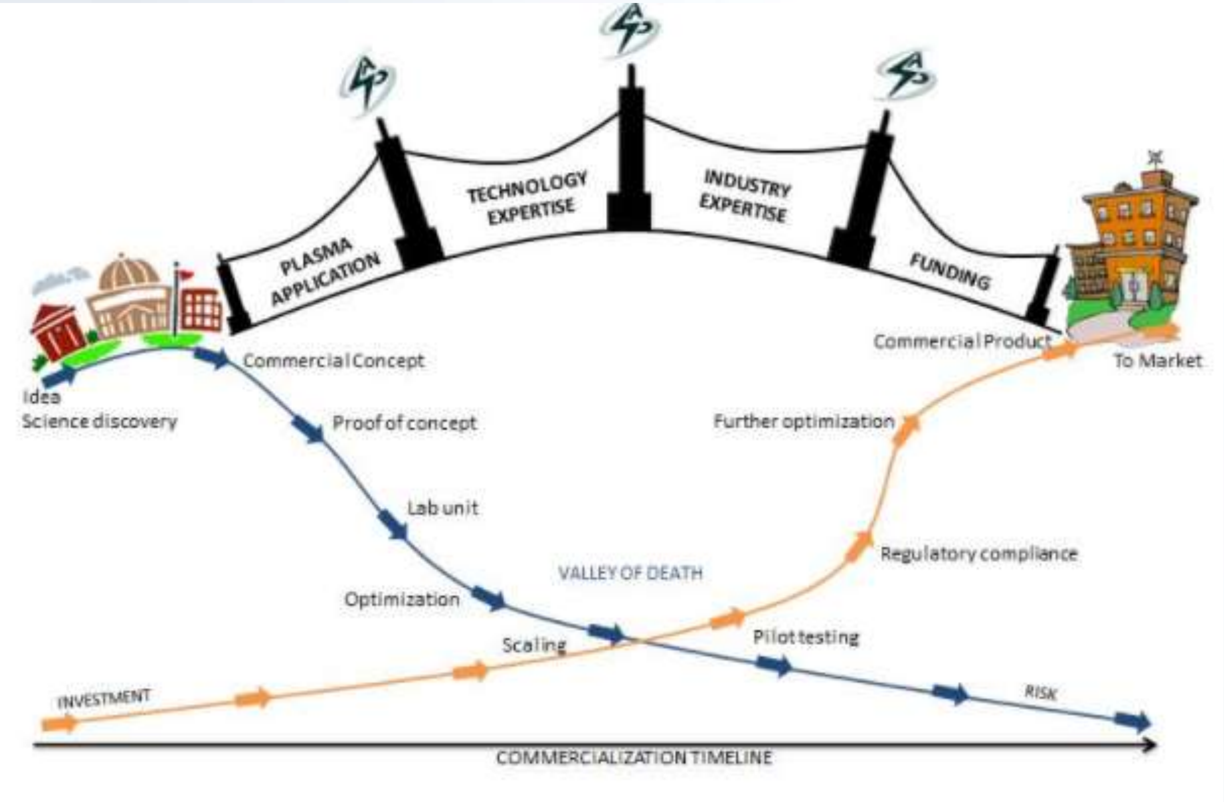
New Product Development Cycles



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Heliatek Raises $90M From EU Investors for Roll-to-Roll Organic Solar Cells

A big bet that organic solar cells will finally reach economical mass production

by Eric Wesoff
September 27, 2016

New Heliatek solar energy façade on ENGIE's research center

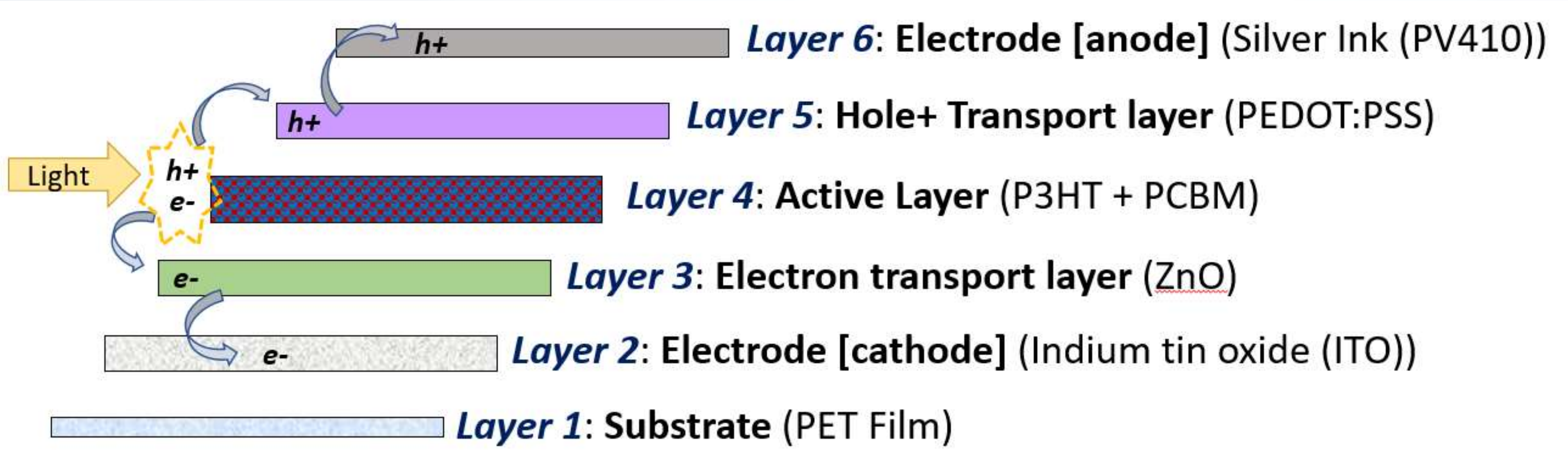
30.06.2017

Dresden, Germany – 30 June 2017 - Solar films manufactured by German company Heliatek have been installed on ENGIE Laborelec's building in Linkebeek. The HeliaFilm® organic films have been incorporated into the façade and windows and will enable the testing of new solar technology systems.

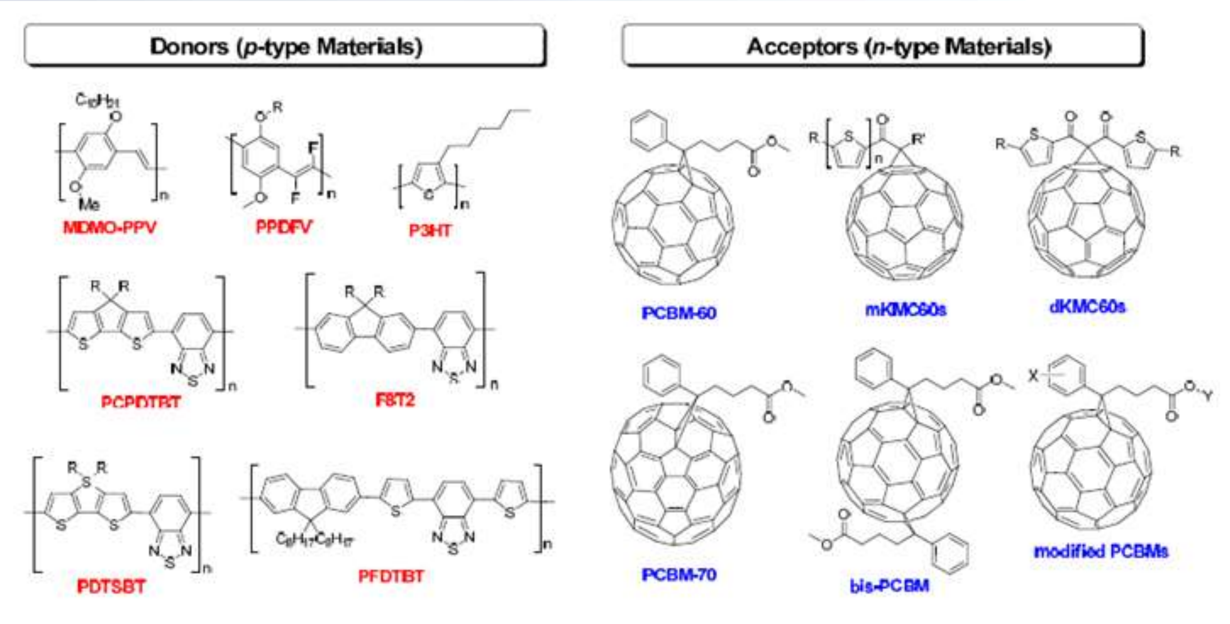
Solar active façade with HeliaFilm® at ENGIE labs

The energy sector is in rapid transition, meaning that in the future energy will no longer be generated and consumed in the way that it is today. Against this backdrop, in 2016 the ENGIE Group acquired a 6.6% stake in Heliatek, one of the world leaders in the production of organic photovoltaic (OPV) films. Together with Heliatek, ENGIE decided to retrofit the façades of the Group's research centre, ENGIE Laborelec, in Linkebeek, for a new project involving the installation of their HeliaFilms®.

The Organic Photovoltaic Sandwich



Technical Issues with Organic Photovoltaics



- Degradation
  - Heat and moisture
- Low efficiency
- Scale up feasibility
- Material availability
- Halogenated solvents


WHAT'S NEXT?

Hybrid Organic–Inorganic Photovoltaics

Rebecca Hill

IGERT Review

July 25, 2017

Georgia Institute of Technology

Hybrid Organic-Inorganic Photovoltaics (HOPV)

- Inorganic quantum dots used as sensitizer or in active layer: **quantum dot solar cells**
- Metal oxide used as electron transporting layer (ETL) with organic active layer or sensitizer: **organic or dye-sensitized solar cells**
- Hybrid organic-inorganic crystal used as the active layer: **perovskite solar cells**

(1) Romande Energie. *EPFL News Mediacom.* Lausanne, Switzerland May 11, 2013. (2) Adikaari, A. A. *et al. IEEE J. Sel. Top. Qu. Electr.* **2010**, *16* (6), 1595–1606.

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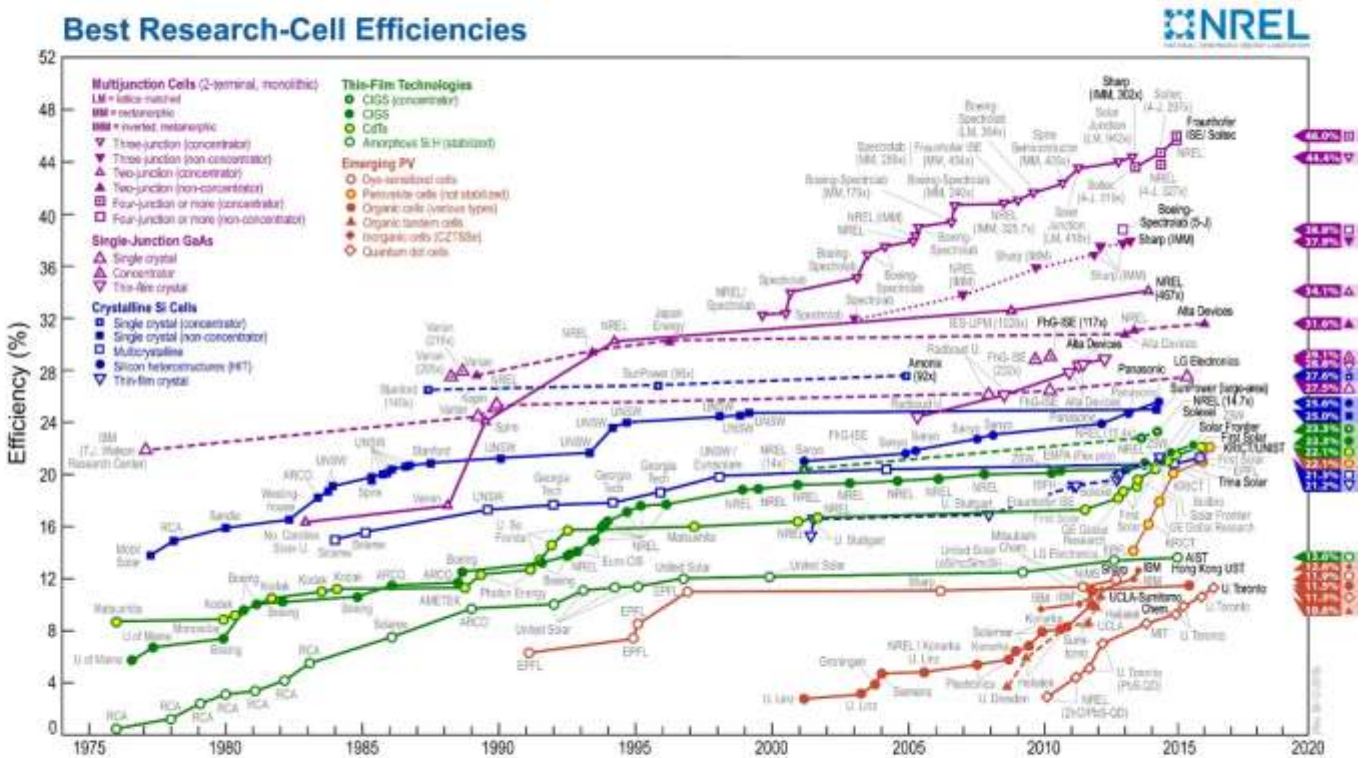
Progress in Photovoltaics



(1) Photovoltaic Research | NREL https://www.nrel.gov/pv/ (accessed Feb 17, 2017).

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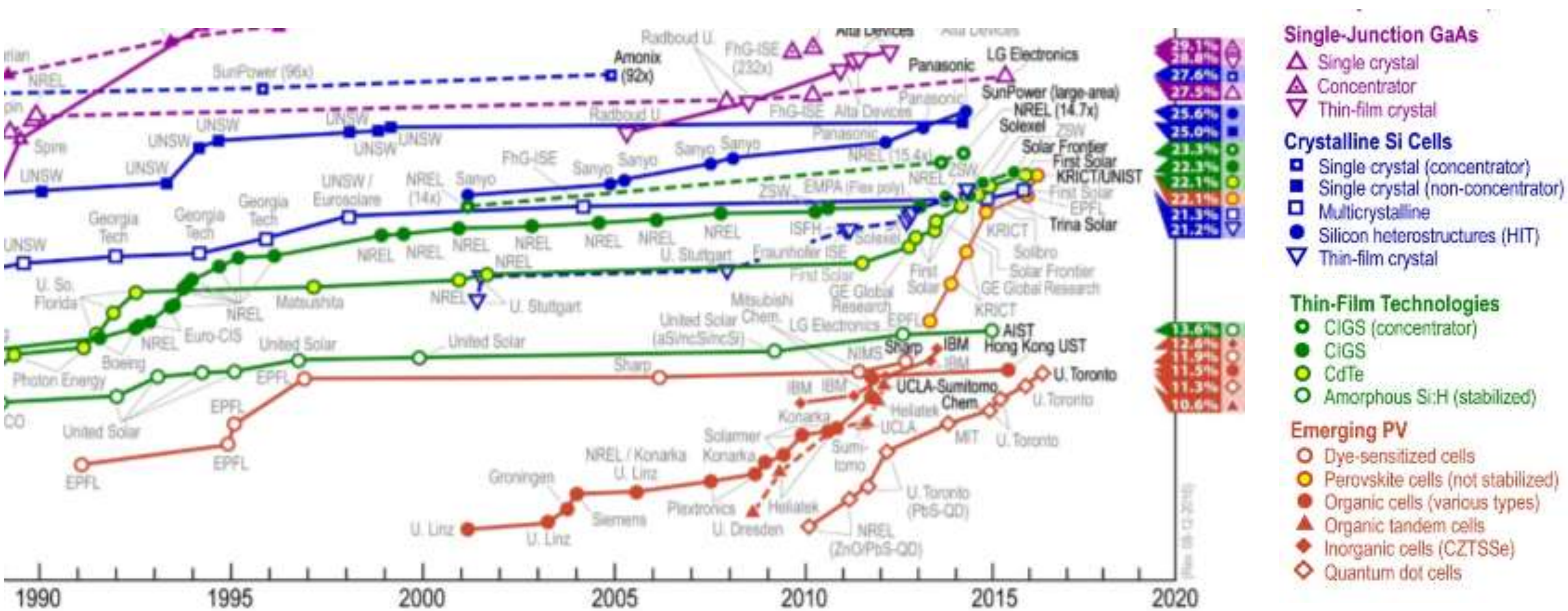
Progress in Photovoltaics



(1) Photovoltaic Research | NREL https://www.nrel.gov/pv/ (accessed Feb 17, 2017).

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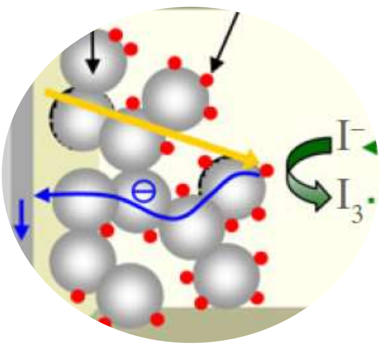
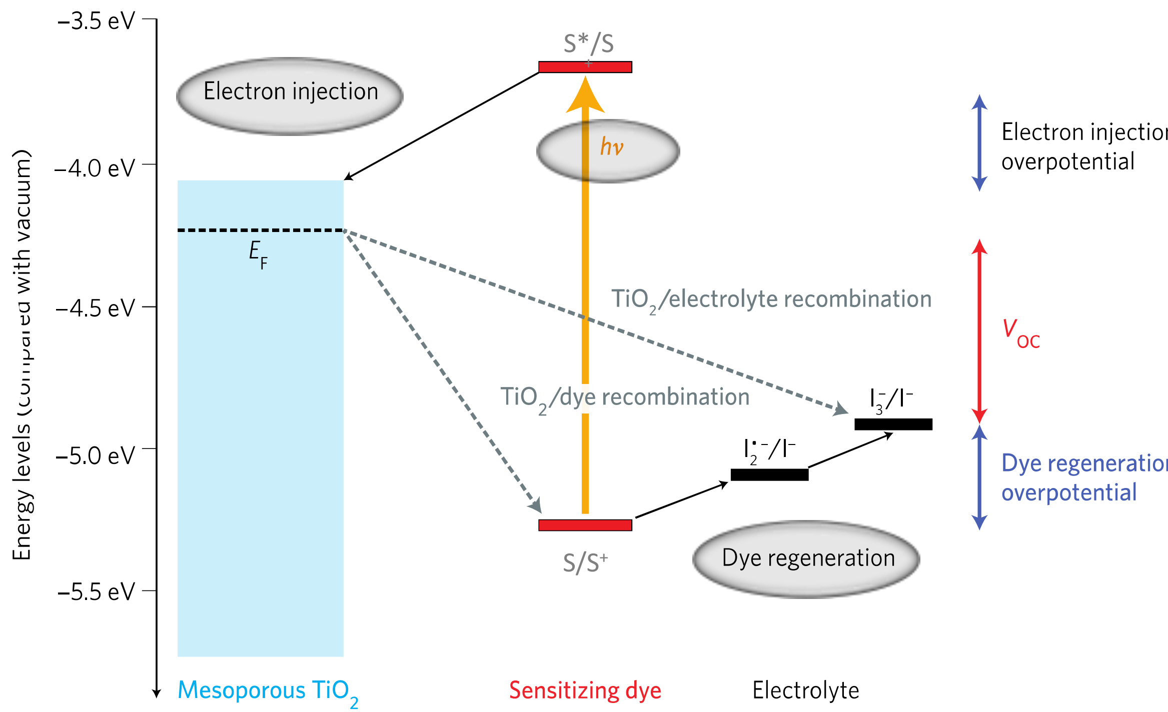
Dye sensitized solar cells

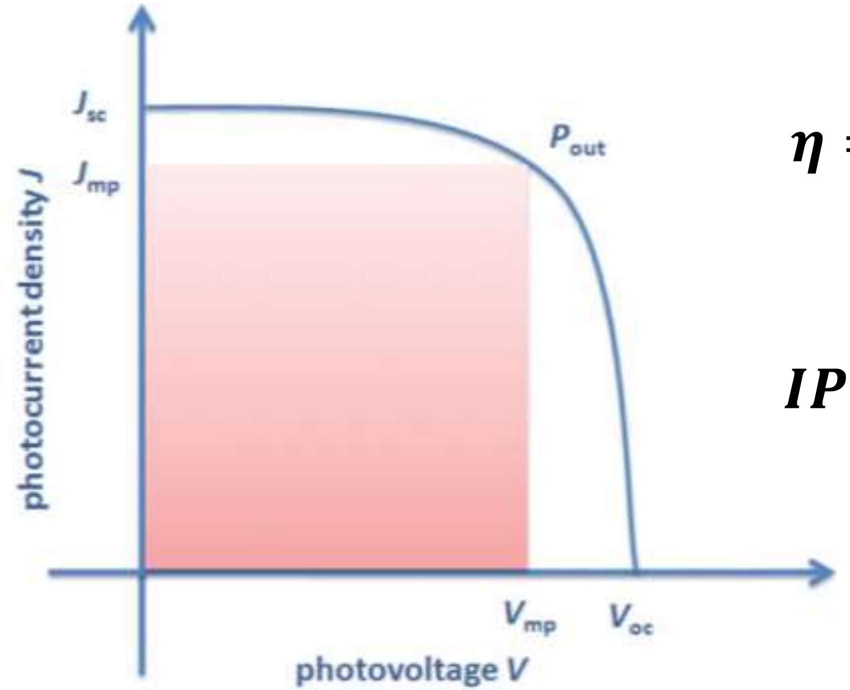
Dye-Sensitized Solar Cells





With modification from Hardin, B. E.; Snaith, H. J.; McGehee, M. D. *Nature*, **2012**, *6*, 162–169

Photovoltaic device parameters



$$\eta = \frac{J_{sc} \times V_{oc} \times FF}{P_{in}}$$

$$IPCE = \frac{J_{sc}(\lambda)}{e\Phi(\lambda)}$$

Abbotto, A.; Manfredi, N. *Dalton Trans.* **2011**, *40*, 12421. http://www.mibsolar.mater.unimib.it/

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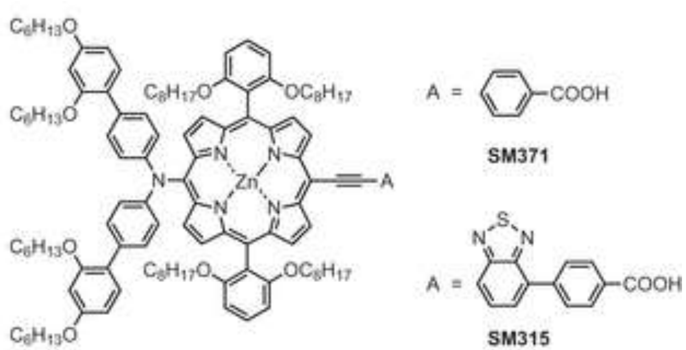
Increasing Power Conversion Efficiency

	V_{oc} [V]	J_{sc} [mAcm^{-2}]	FF	η [%]
Theoretical (λ_{onset}= 940 nm)	0.92	**30.8**	0.73	20
SM315	0.91	**18.1**	0.78	13

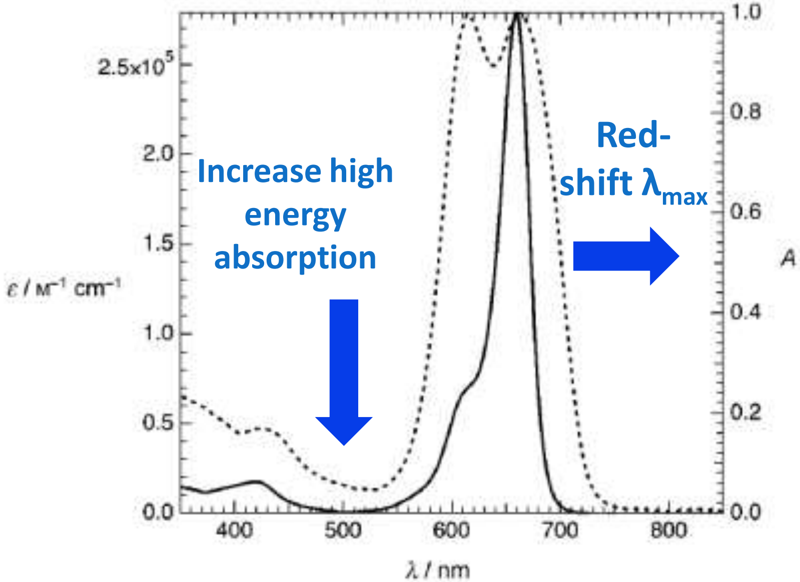


SM315, Feb 2014

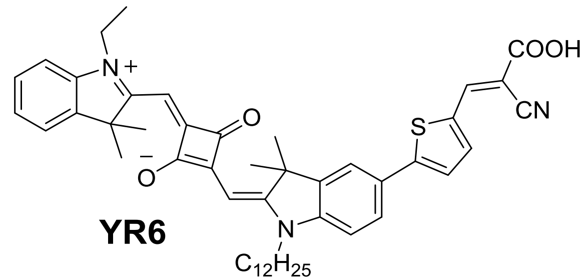
- *Red-shifted absorption onset*
- *Increased Jsc*
- *Decreased recombination*

[1].

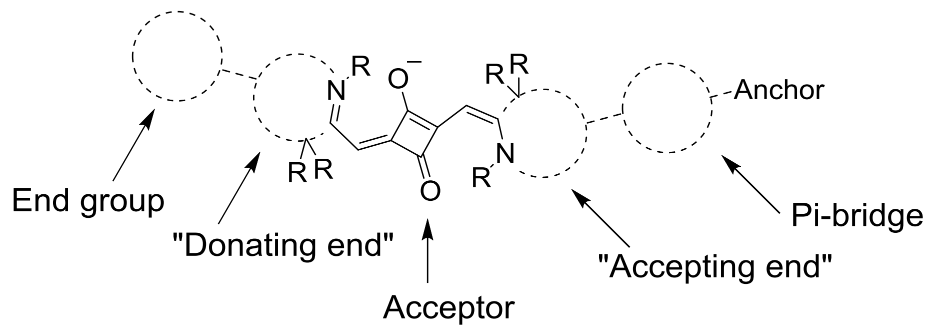
Squaraine sensitizers for DSSCs



Absorption spectra of **YR6** in ethanol (solid line) and on TiO_2 (dotted line).[1]

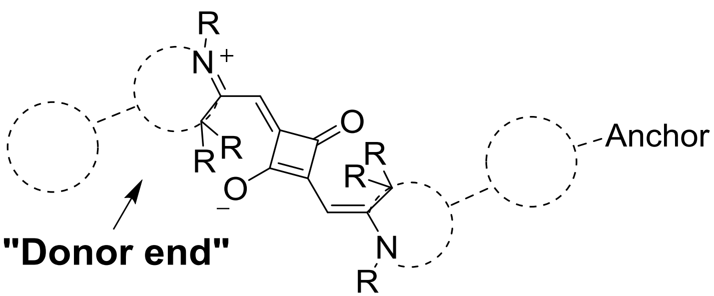


YR6

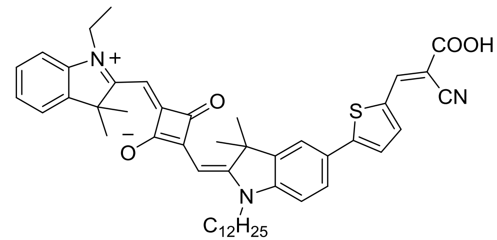


(1) Shi, Y. *et al. Angew. Chem., Int. Ed.* **2011**, *50*, 6619.

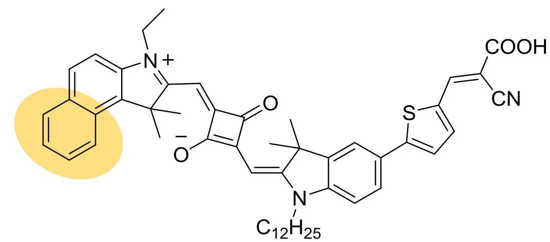
Examining the Effect of the Donor



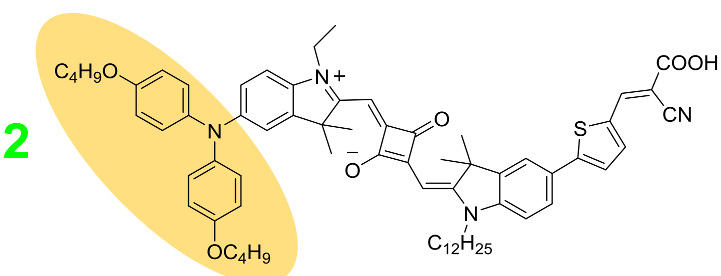
YR6



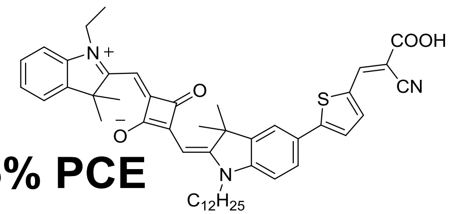
RH1



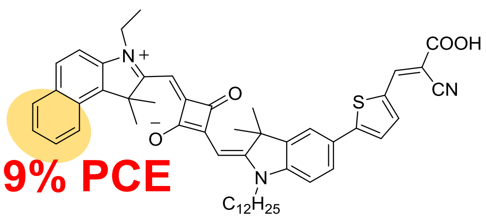
RH2



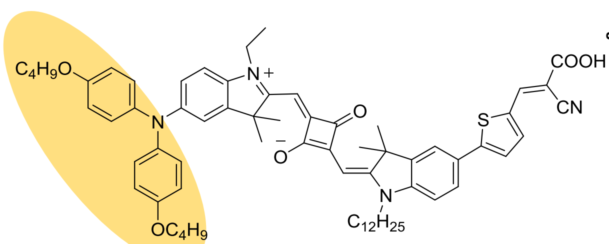
Examining the Effect of the Donor



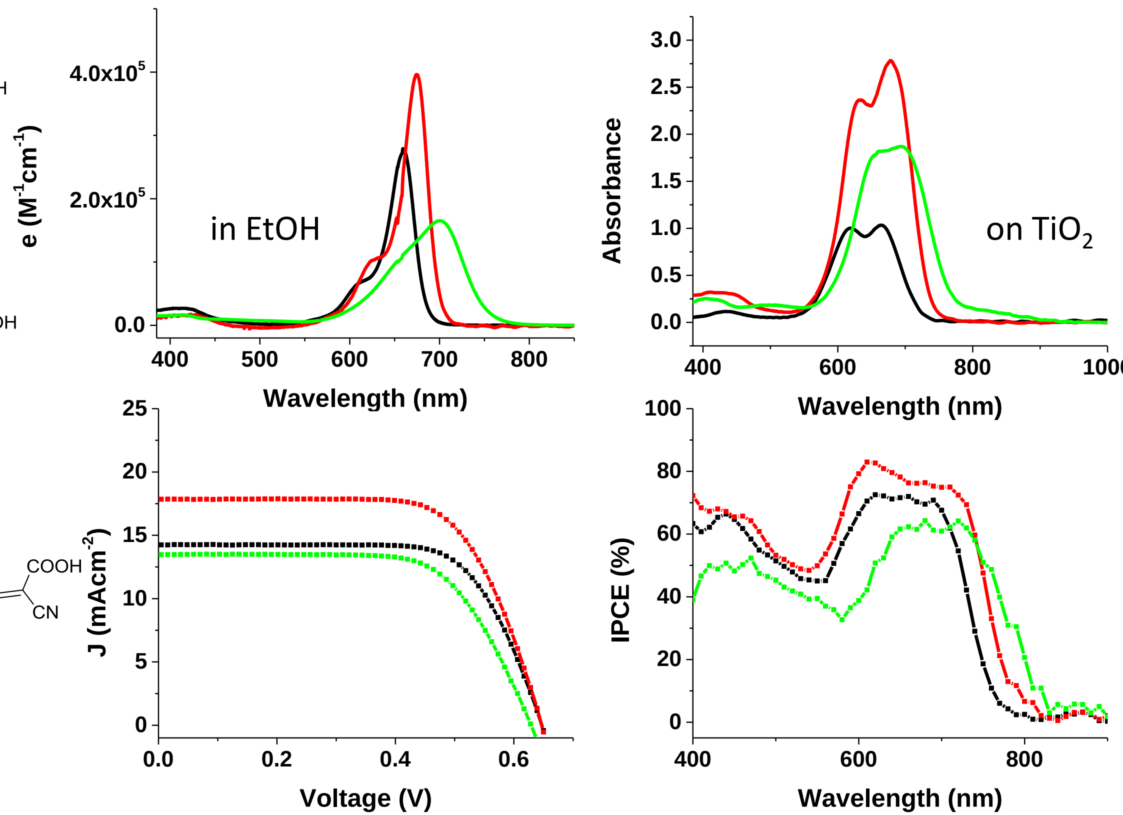
YR6: 6.5% PCE



RH1: 7.9% PCE

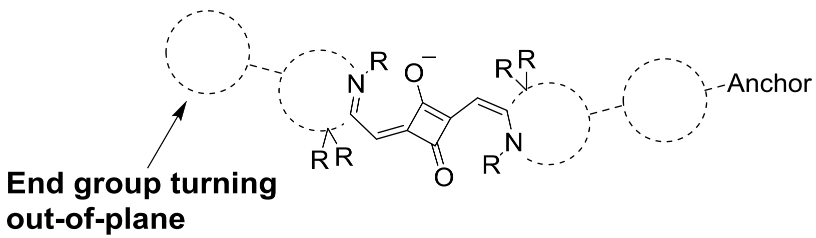


RH2: 5.7% PCE

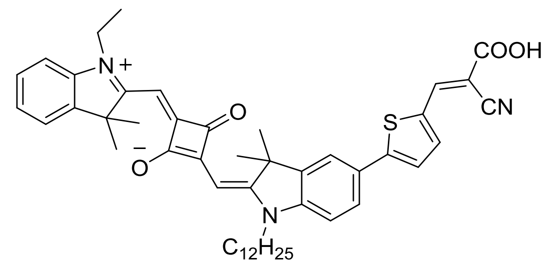


[[1] Hill, R.; Kang, X.; et al.; *in preparation*

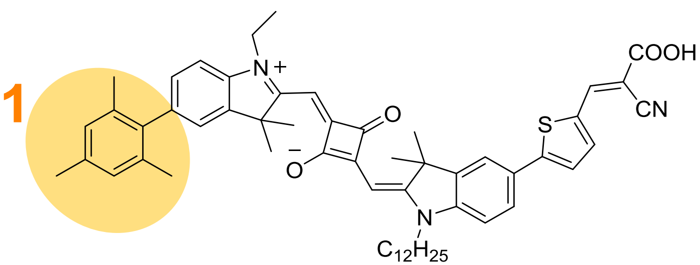
Examining an Out-of-plane End Group



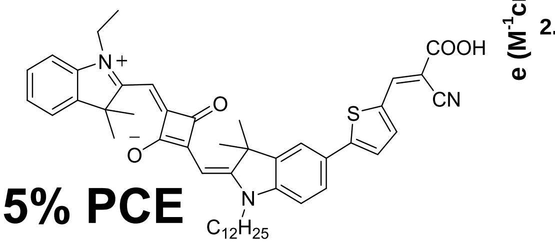
YR6



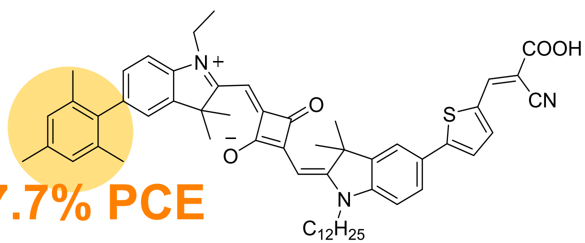
IH1



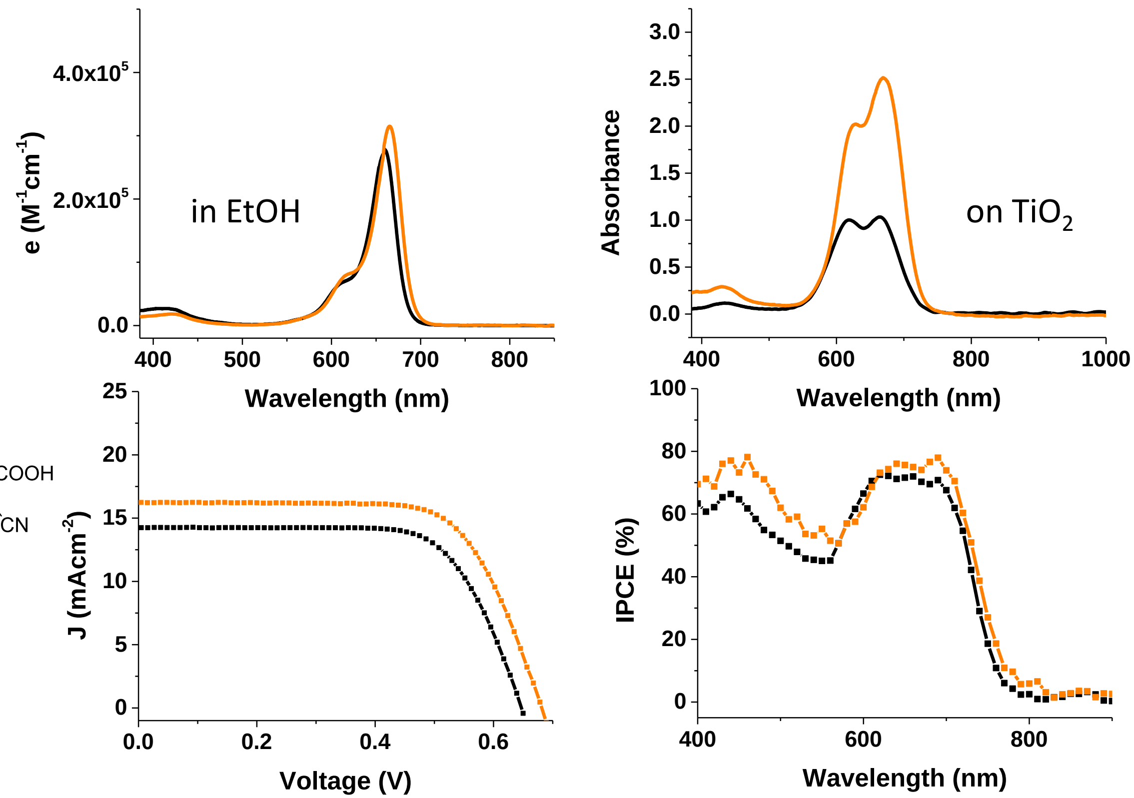
Examining an Out-of-plane End Group



YR6: 6.5% PCE

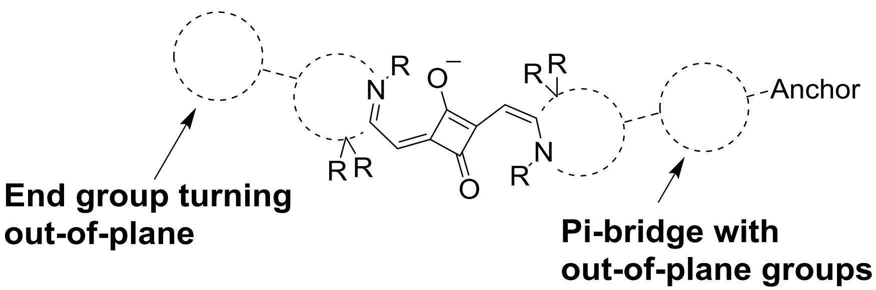


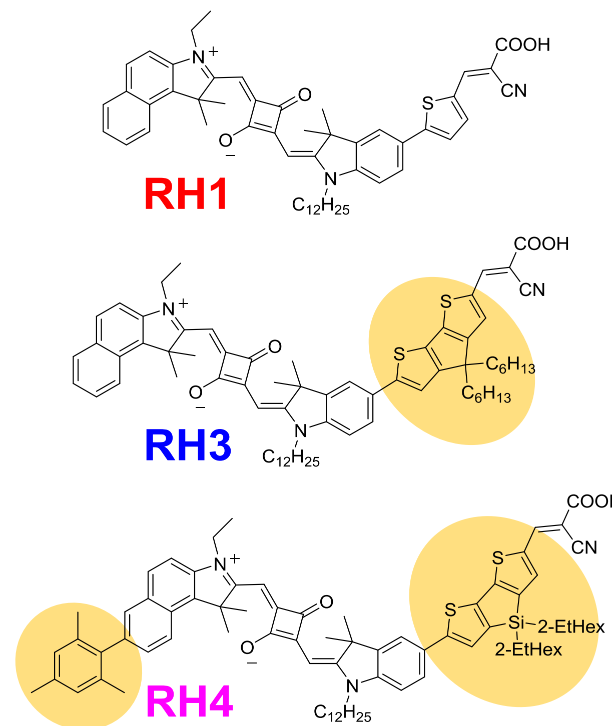
IH1: 7.7% PCE



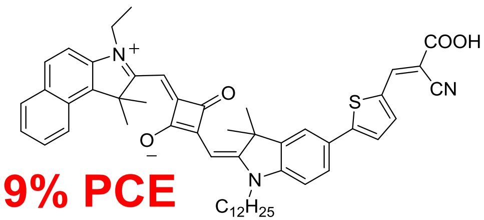
Hill, R.; Kang, X.; et al.; *in preparation*

Out-of-plane Groups and the π-bridge

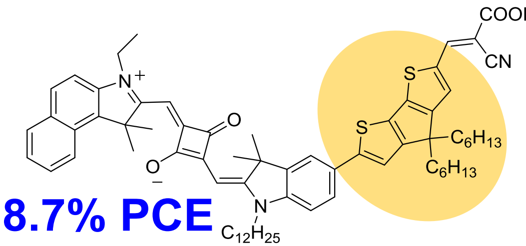




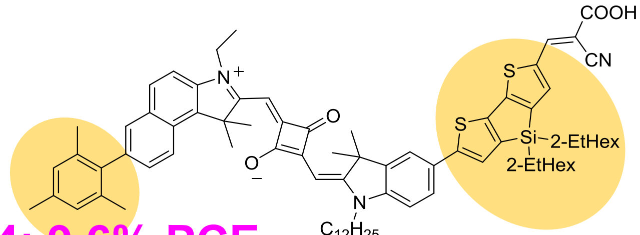
Out-of-plane Groups and the π-bridge



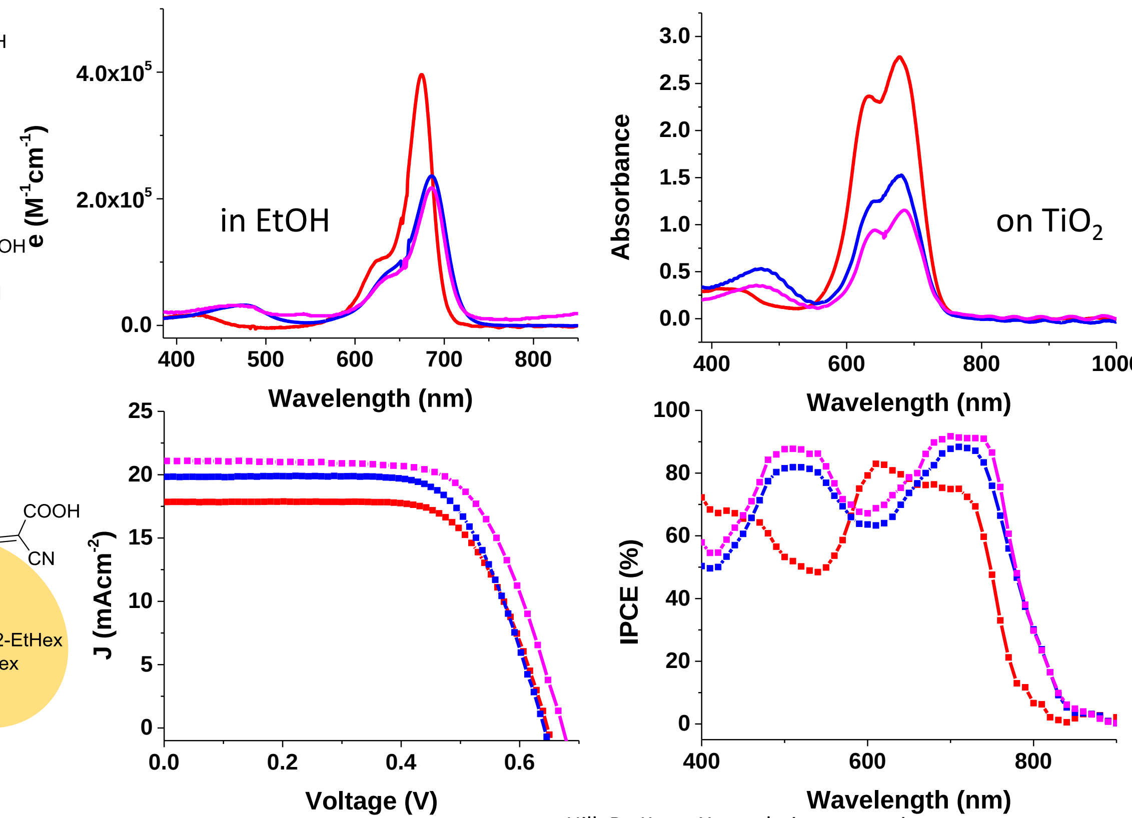
RH1: 7.9% PCE



RH3: 8.7% PCE



RH4: 9.6% PCE



Hill, R.; Kang, X.; et al.; *in preparation*

Georgia Institute of Technology

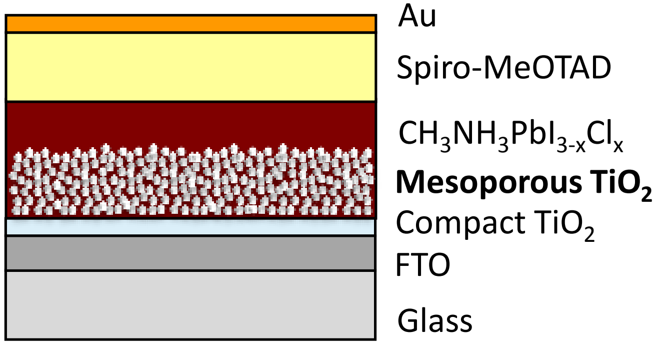
Future challenges

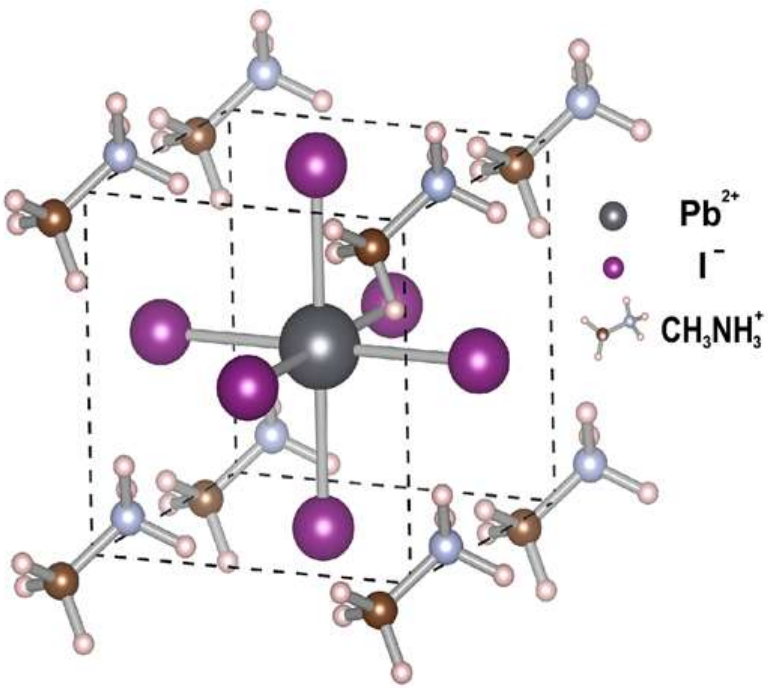
- Understand origin of low fill factor and open circuit voltage

	V_{oc} [V]	J_{sc} [mAcm^{-2}]	FF	η [%]
Theoretical (λ_{onset}= 940 nm)	0.92	30.8	0.73	20.3
RH4	0.68	21.1	0.67	9.6

Lead Organo-halide Perovskite Solar Cells

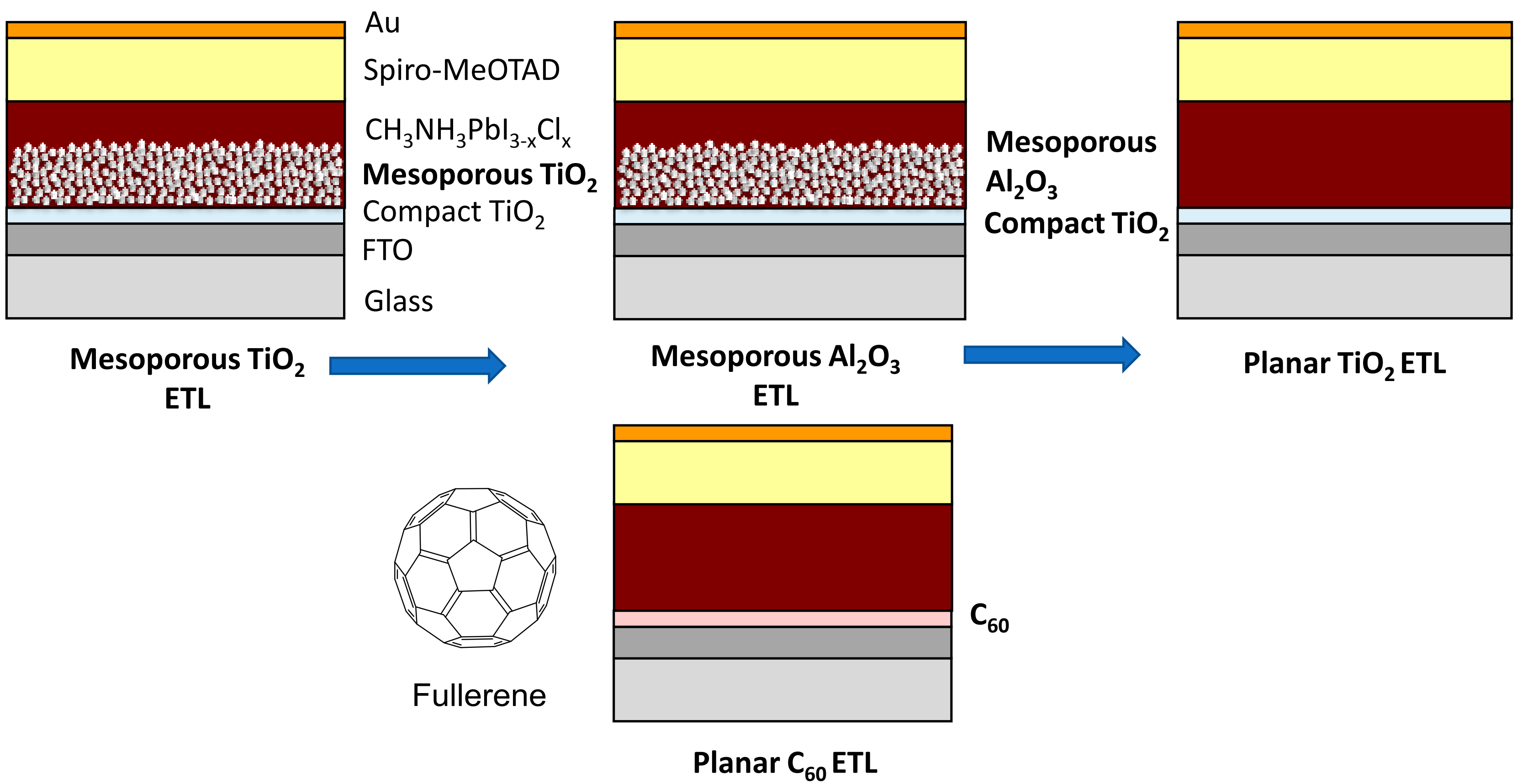
- Perovskite used as active layer
  - Absorbs light to ~800 nm
  - Hole and electron transport



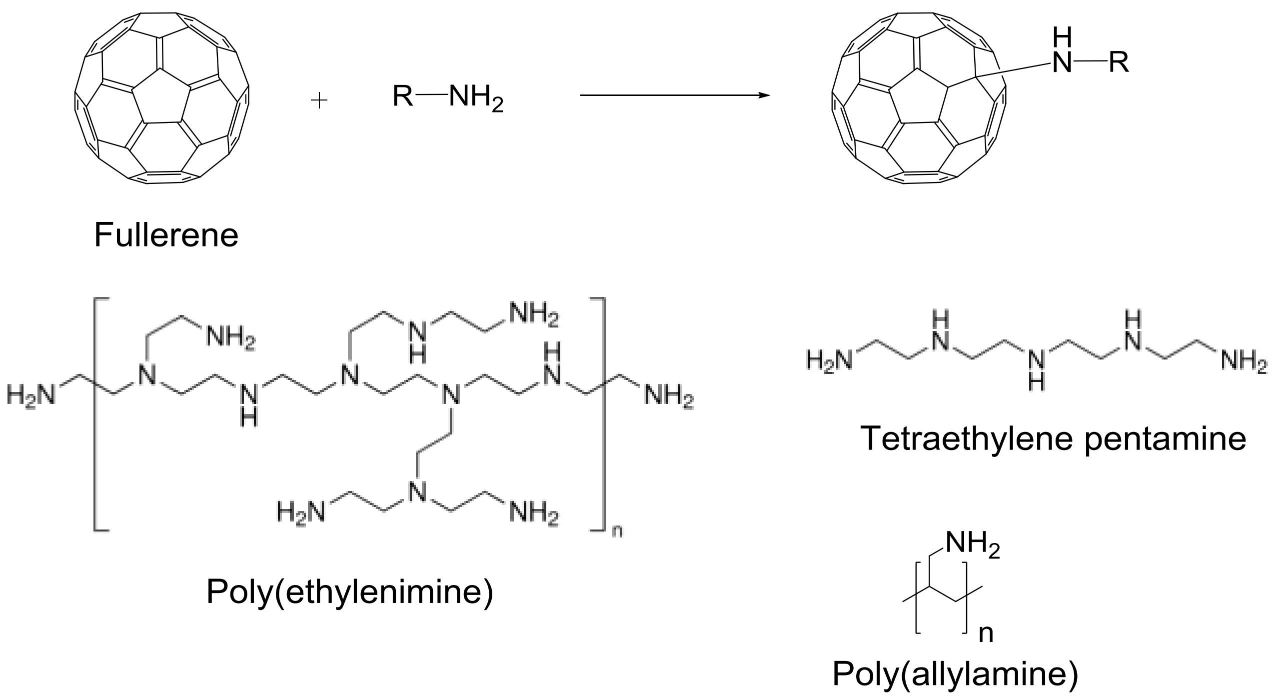


Song, Z.; Watthage, S. C.; Phillips, A. B.; Heben, M. J. *J. Photon. Energy* **2016**, *6* (2), 022001.

Perovskite Solar Cell Architecture Evolution

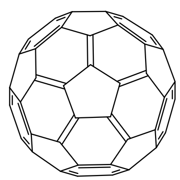


Fullerene-amine reactivity

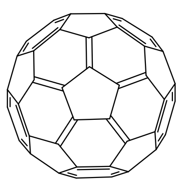


Ramírez-Calera, I. J.; Meza-Laguna, V.; Gromovoy, T. Y.; Chávez-Uribe, M. I.; Basiuk, V. A.; Basiuk, E. V. *Appl. Surf. Sci.* **2015**, *328*, 45–62.

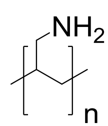
Evidence of bond formation



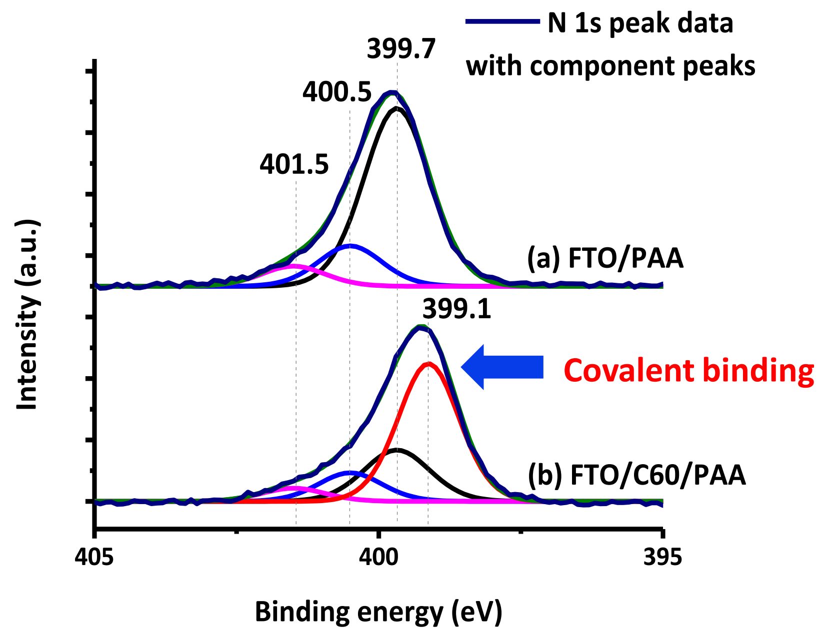
Fullerene



Fullerene



Poly(allylamine)



XPS N 1s peak (in navy blue), and deconvoluted peaks assigned to the protonated or hydrogen bonded amine, the primary amine, and the fullerene-bound amine.

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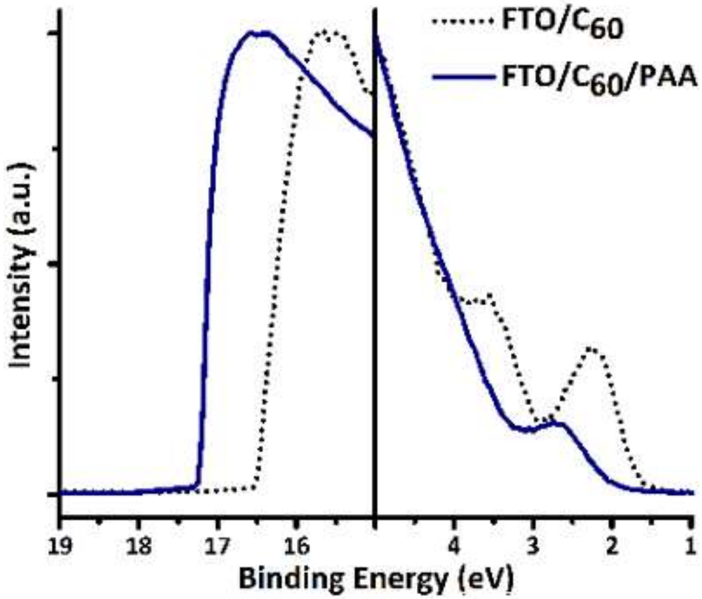
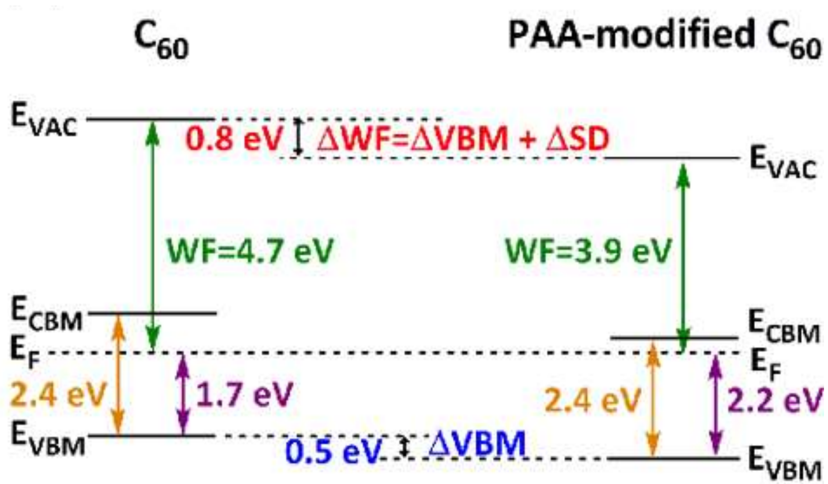
Work function shift



UPS secondary electron edge cutoffs.



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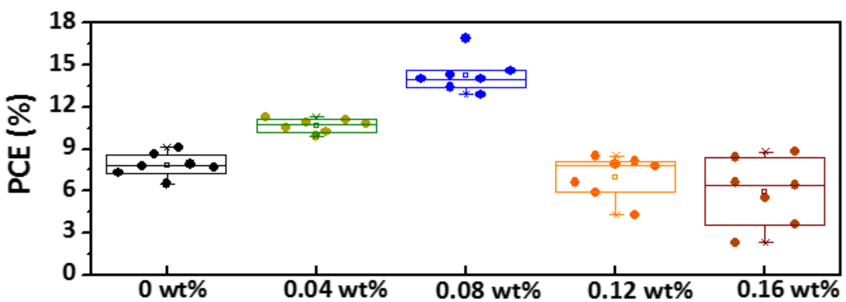
Solar cell device data

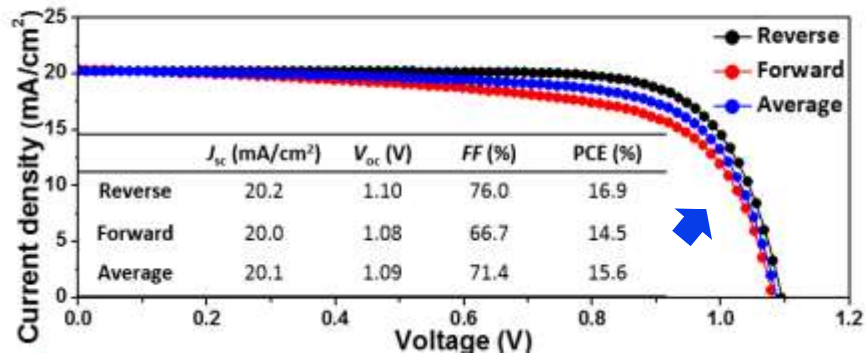
Increased average power conversion efficiency (PCE)



No amine

Optimal amount of amine

Decreased hysteresis



(J-V) curves of the best device employing C60-PAA ETLs.

Acknowledgements

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Dr. Stephen Barlow
Dr. Junxiang Zhang
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Brédas lab members

Prof. Mostafa El-Sayed
Dr. Xiongwu Kang
Dr. Paul Szymanski
Daniel O'Neil

EPFL
Prof. Anders Hagfeldt
Dr. M.K. Zakeeruddin

Dye-sensitized solar cells

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Dr. Maximillian Hoerantner
Konrad Wojciechowski

POSTECH
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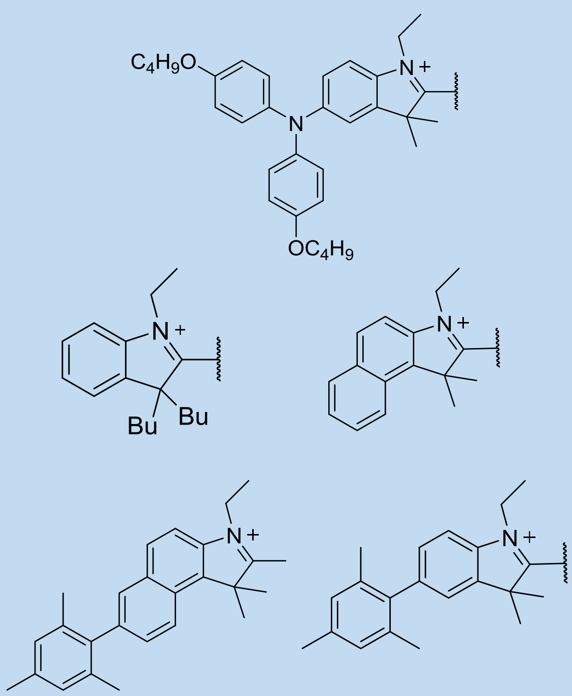
Seulki Song
Kyoungwon Choi

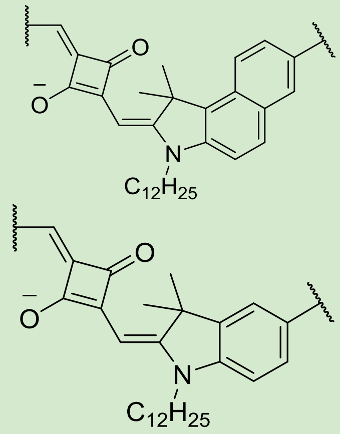
EPFL
Prof. Anders Hagfeldt
Dr. Juan-Pablo Correa-Baena
Silver Hamill Turren-Cruz
Wolfgang Tress

Perovskite solar cells

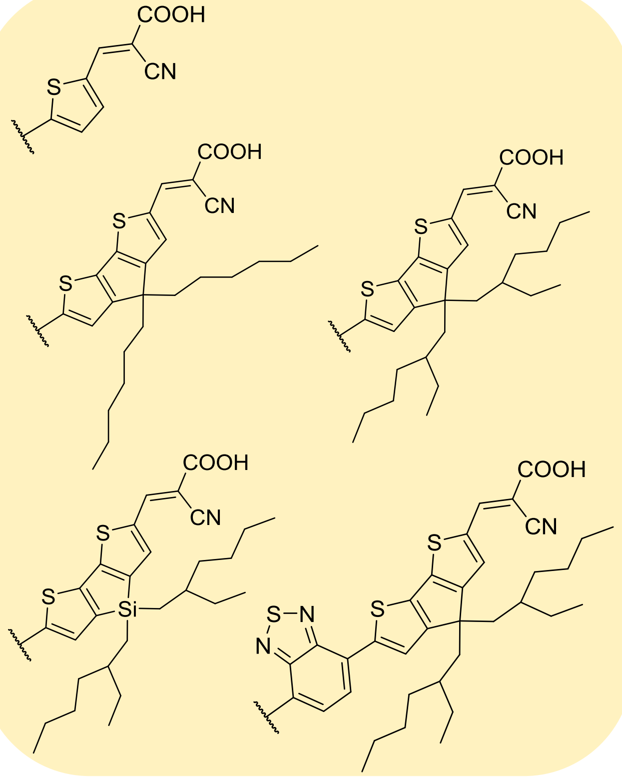
Georgia Institute of Technology

Squaraine Sensitizer Modifications

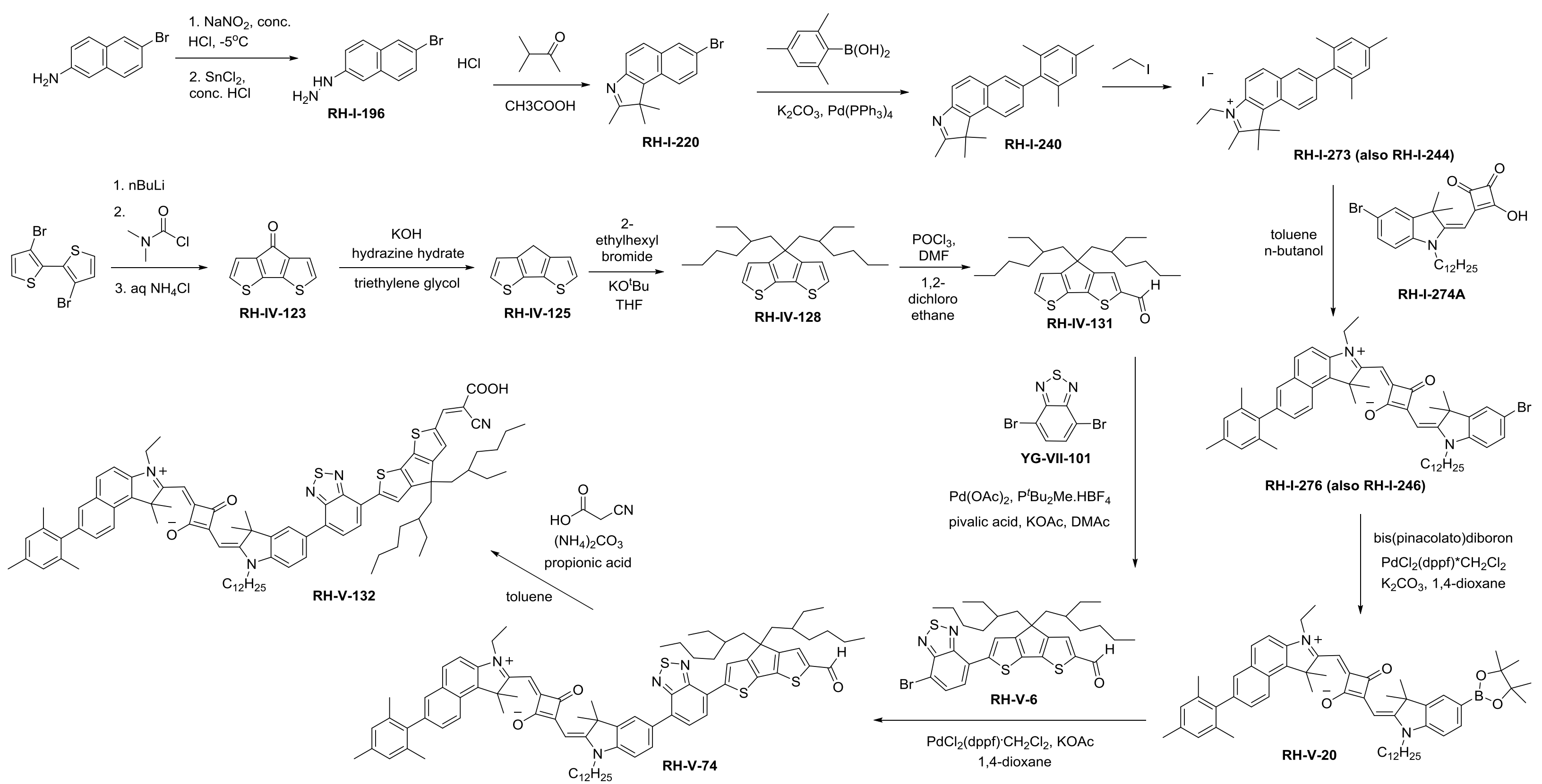




- Red-shift the main absorption band
- Influence dye-dye and dye-electrolyte interactions



Sample Squaraine Synthesis



SOLAR PV SYSTEMS DEGRADATION AND MITIGATION

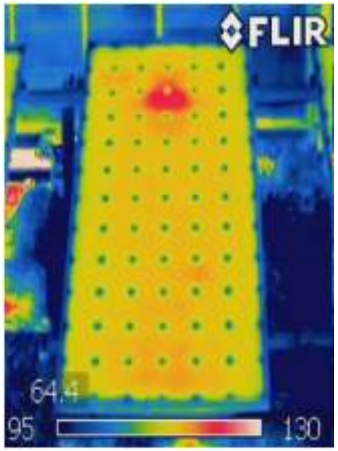
- Power output loss in solar panels from field exposure
- Impact of climate on power loss
- Amorphous vs. silicon materials degradation
- Water cooling to mitigate power output losses (boosting)

Environmental Output losses

Dirty Solar Panels

Solar Panels Covered in Snow

Impact of Panel Temperature

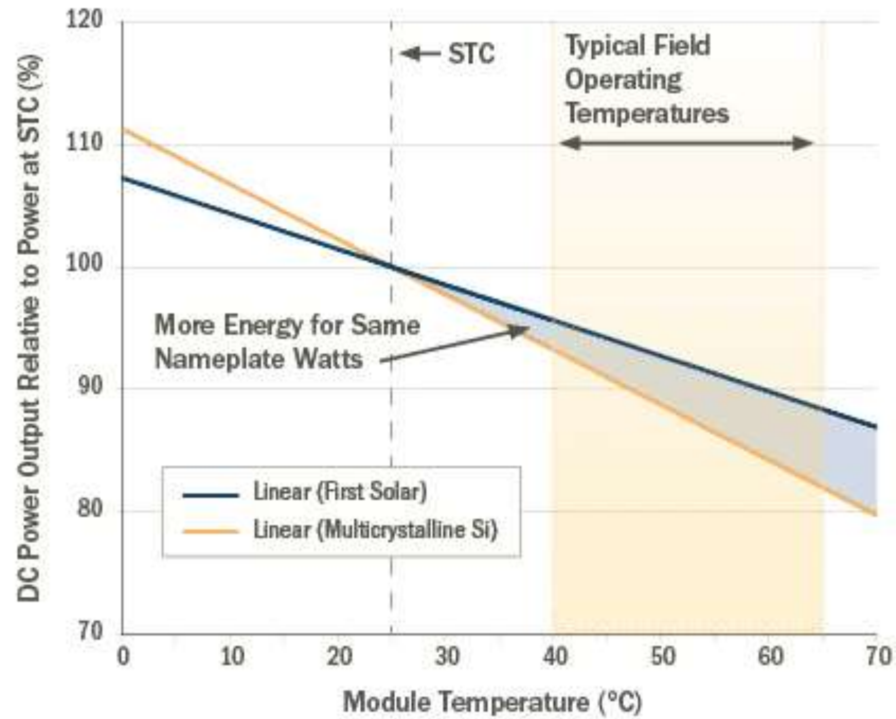


Field studies show performance is temperature and technology dependent

Temperature Coefficients

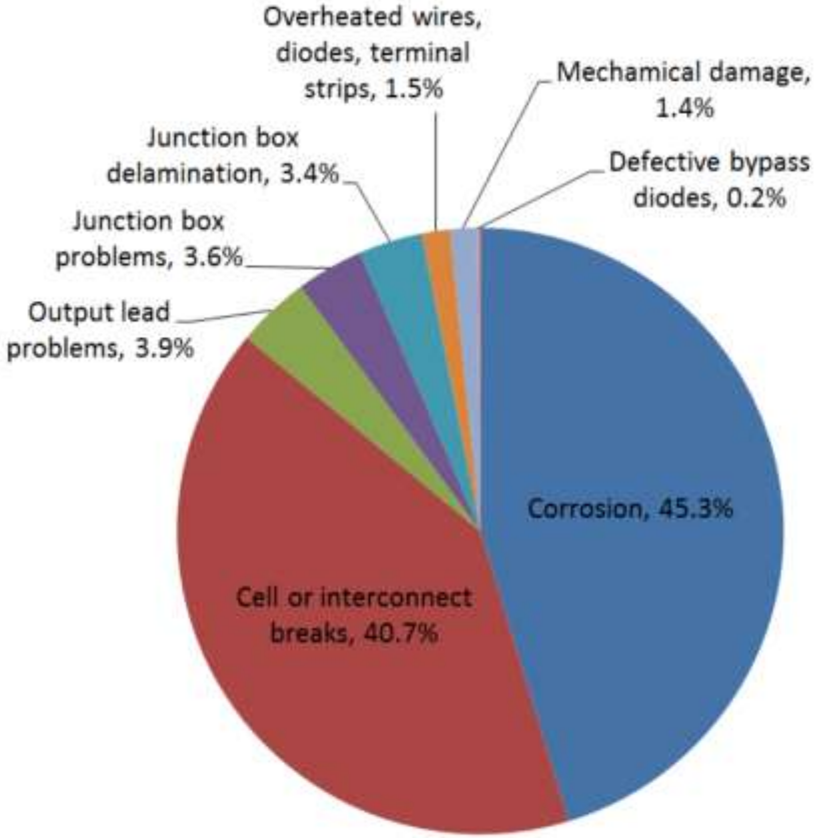
Technology	TC of Power, γ (%/°C)
c-Si	-0.45
μc-Si	-0.44
a-Si (1-, 2- and 3-junction)	-0.24
CdTe	-0.29
CIGS	-0.47

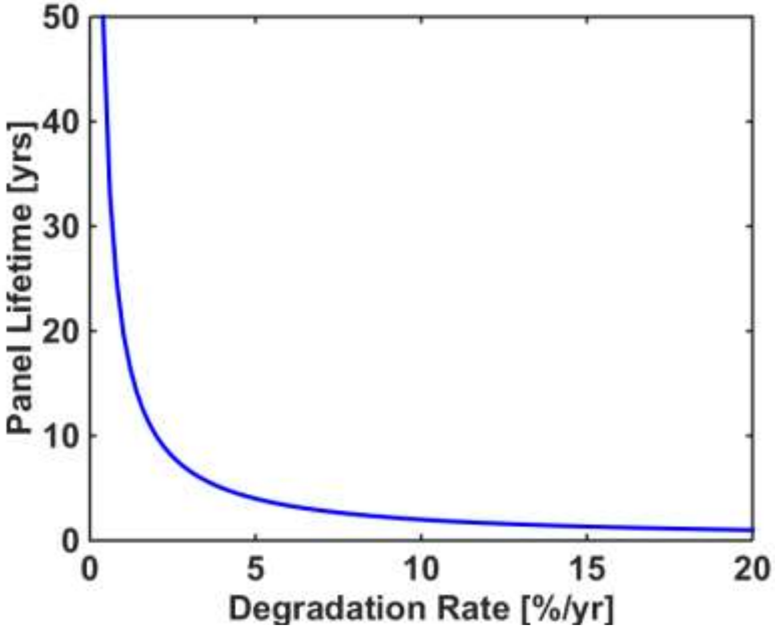
Courtesy NREL (2)



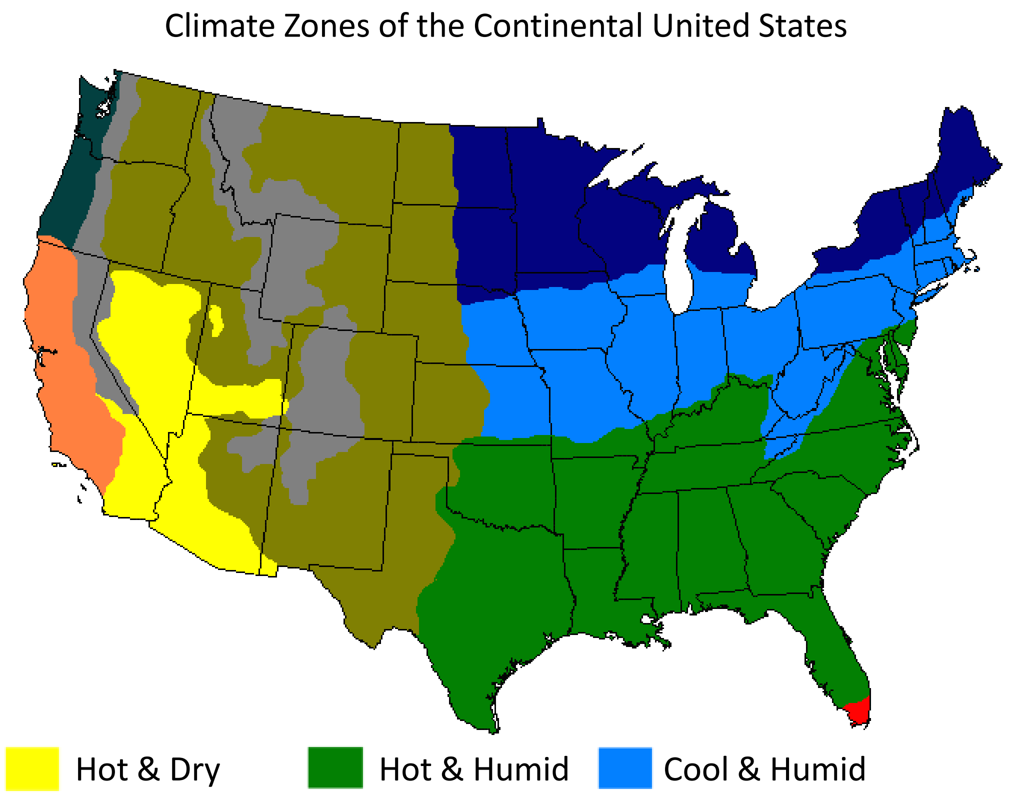
Cadmium Telluride (CdTe) thin film technology

Impact of Panel Temperature

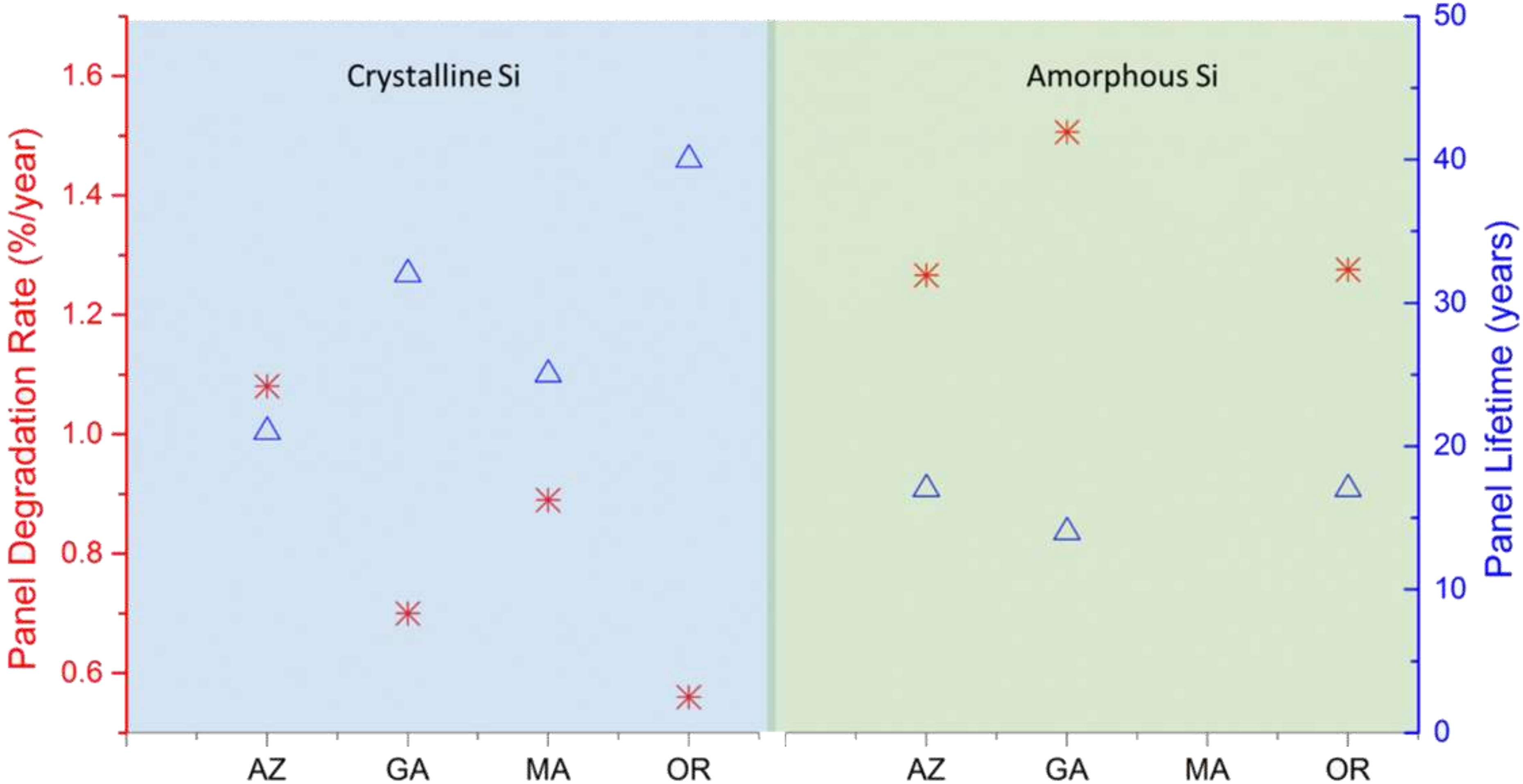




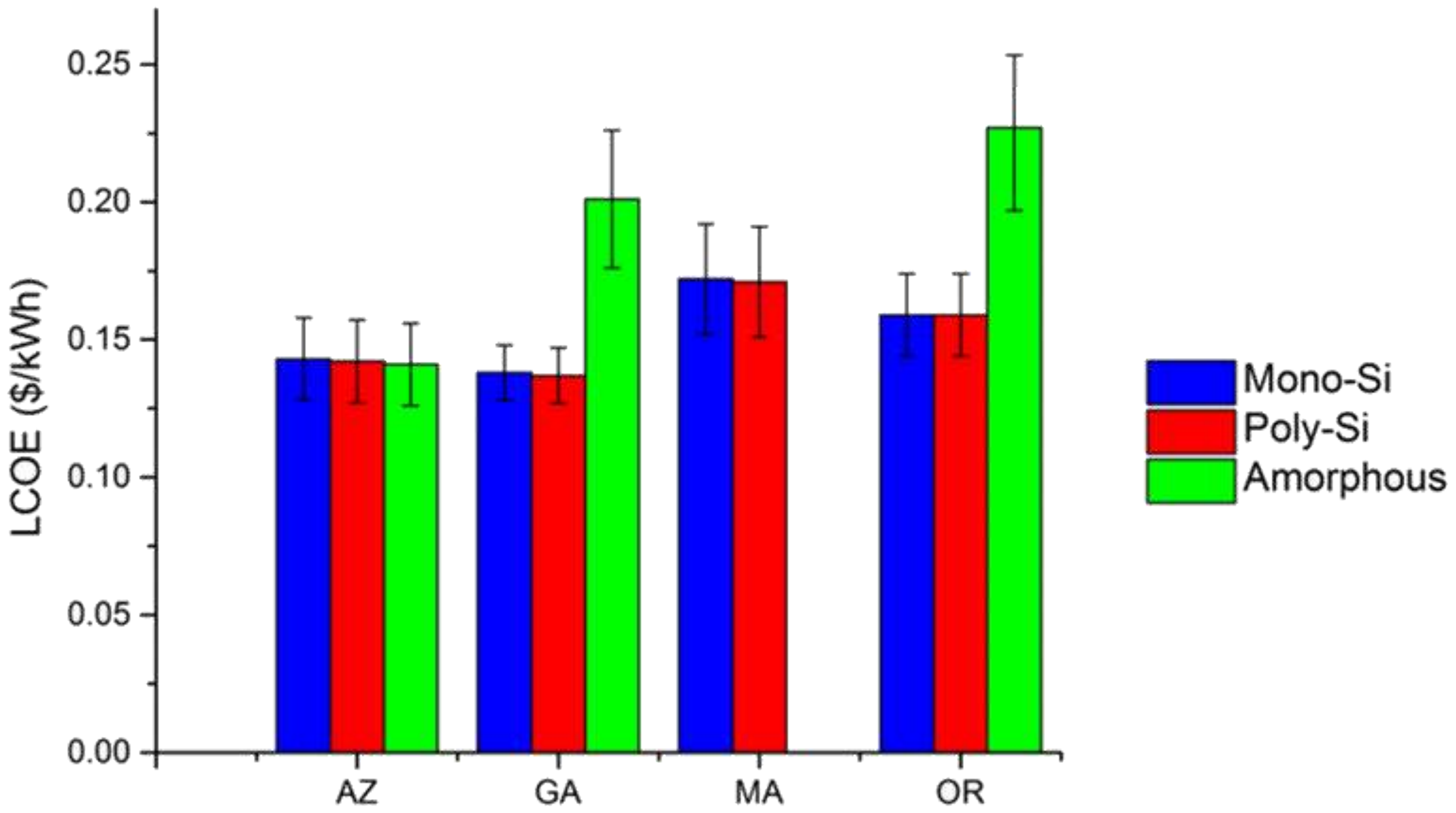
US Climate Zones



Climate Impact On Degradation



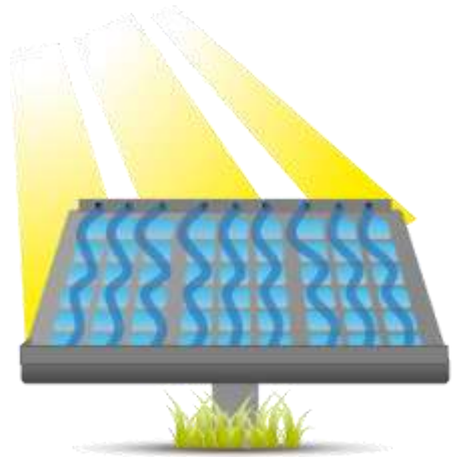
LCOE for Region and Technology



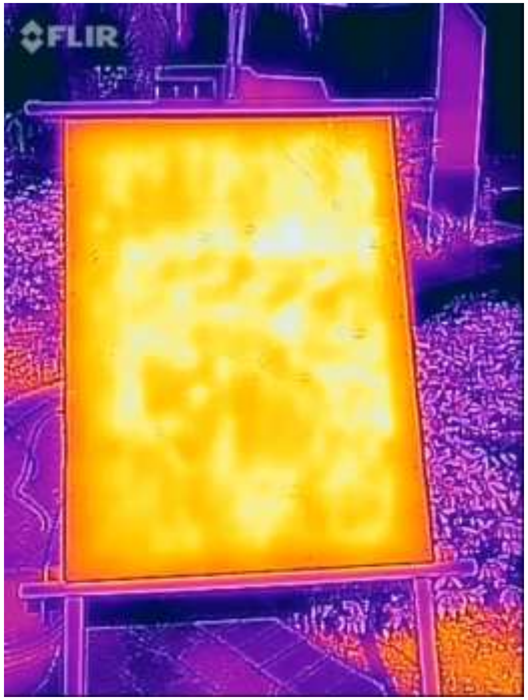
AMANZI SOLAR

Maximizing Solar Panel Performance

AMANZI SOLAR PROTOTYPE

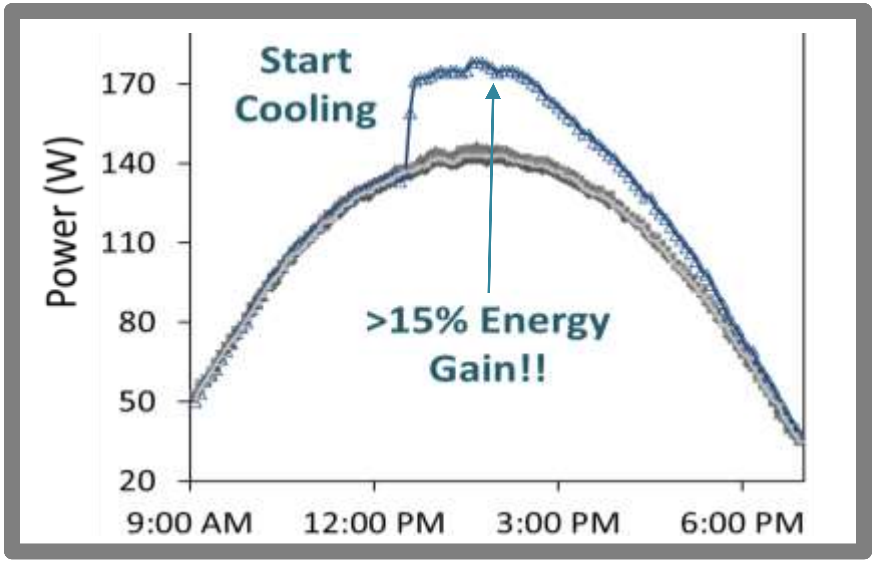


COOLING WITH STORED WATER

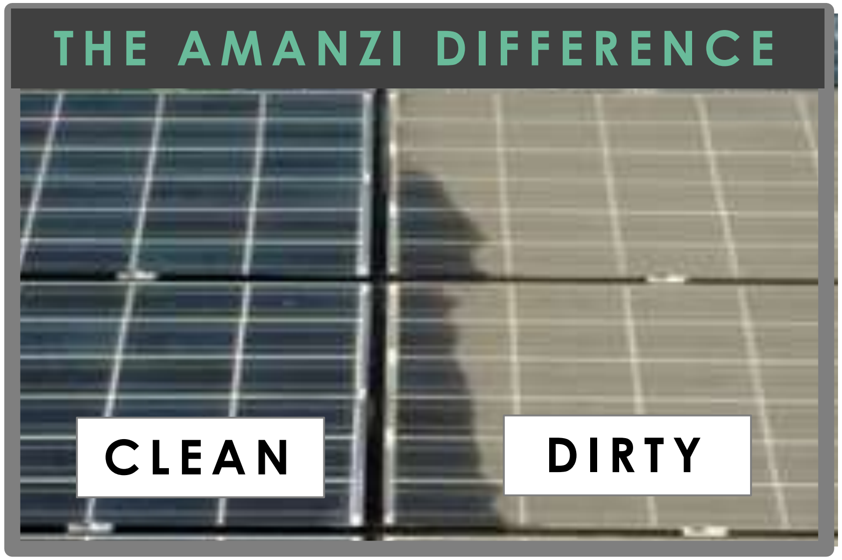


SYSTEM BENEFITS

TEMPERATURE REDUCTION



CLEANING



2 PENDING PATENTS

Georgia Tech

THE POLICY IMPLICATIONS OF SOLAR PENETRATION

Ross Beppler

IGERT Fellow – Public Policy

CREATING THE NEXT®

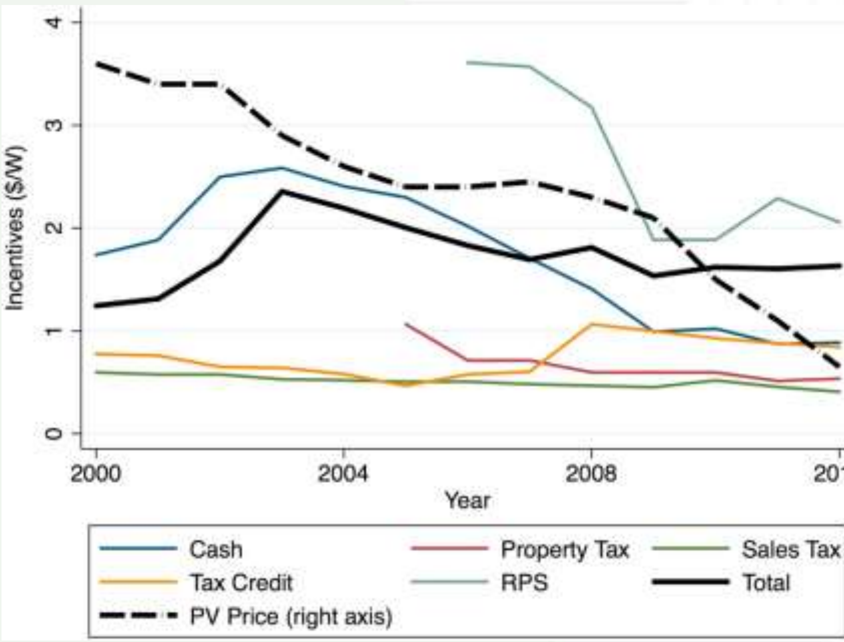
OUTLINE

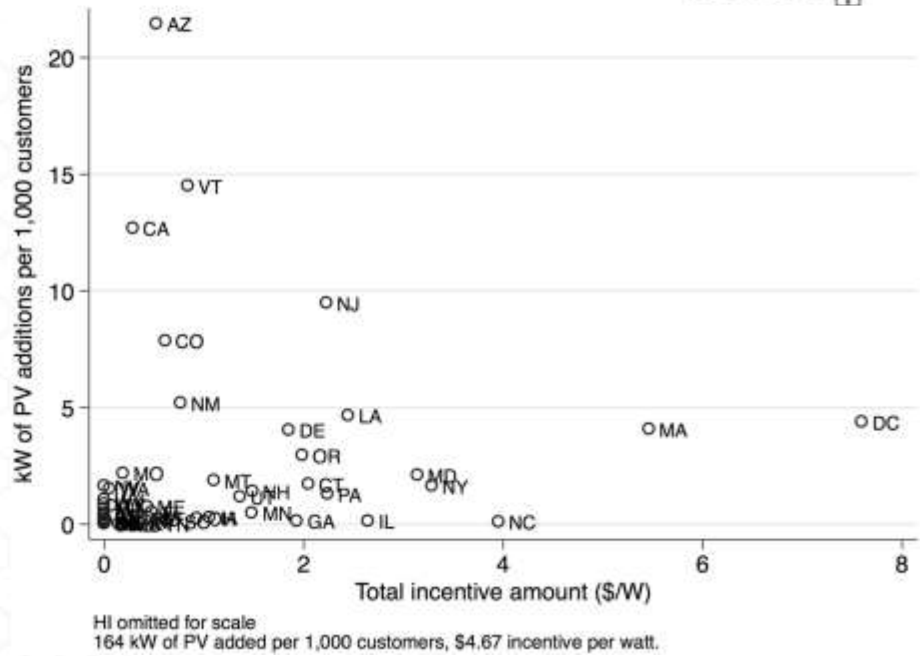
Georgia Tech

1. Solar Policy History
2. Solar impacts on rates and bills
3. The state of the debate on solar
4. Rate design goals (equity; efficiency; rate design)
5. What is the "Value of Solar"
6. Barriers
7. Recommendations and conclusions

WHAT IS DRIVING PV INSTALLATION?

Georgia Tech



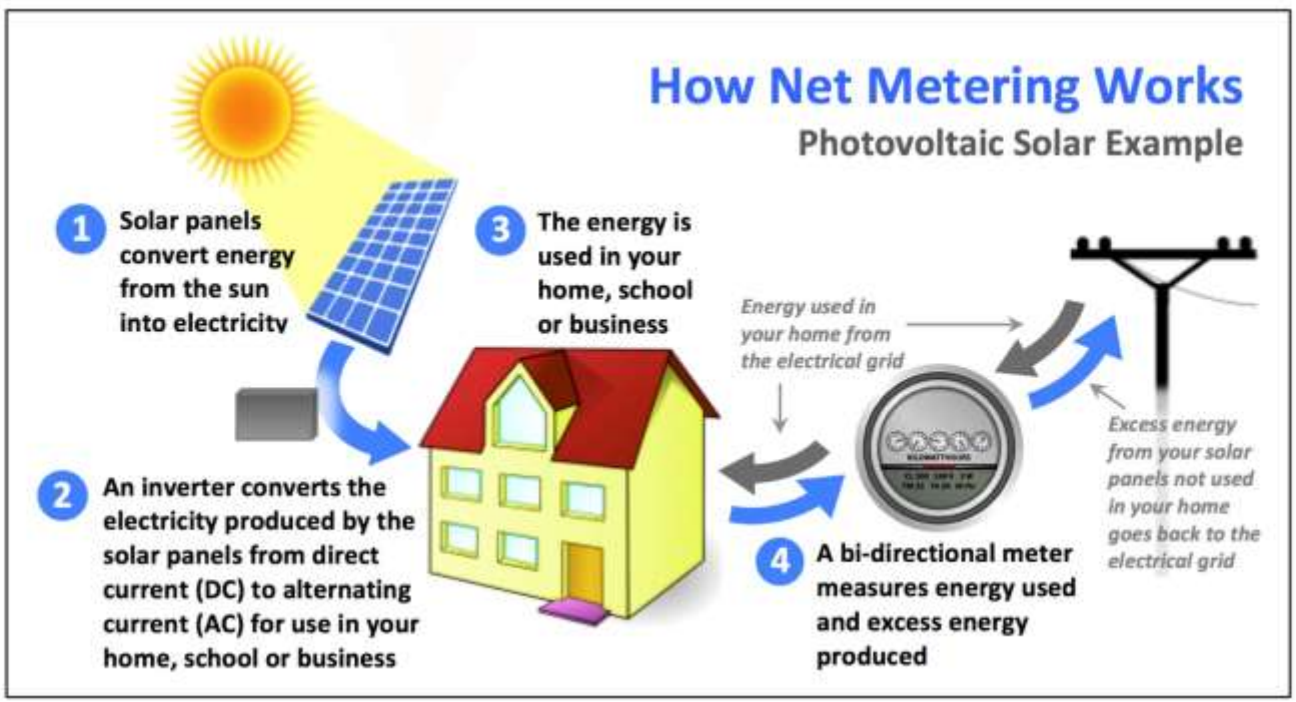


- Until recently the growth in PV was largely policy driven (tax credits, renewable portfolio standards, net metering…)
- The price of PV has continued to decline to the point where some jurisdictions are approaching grid parity

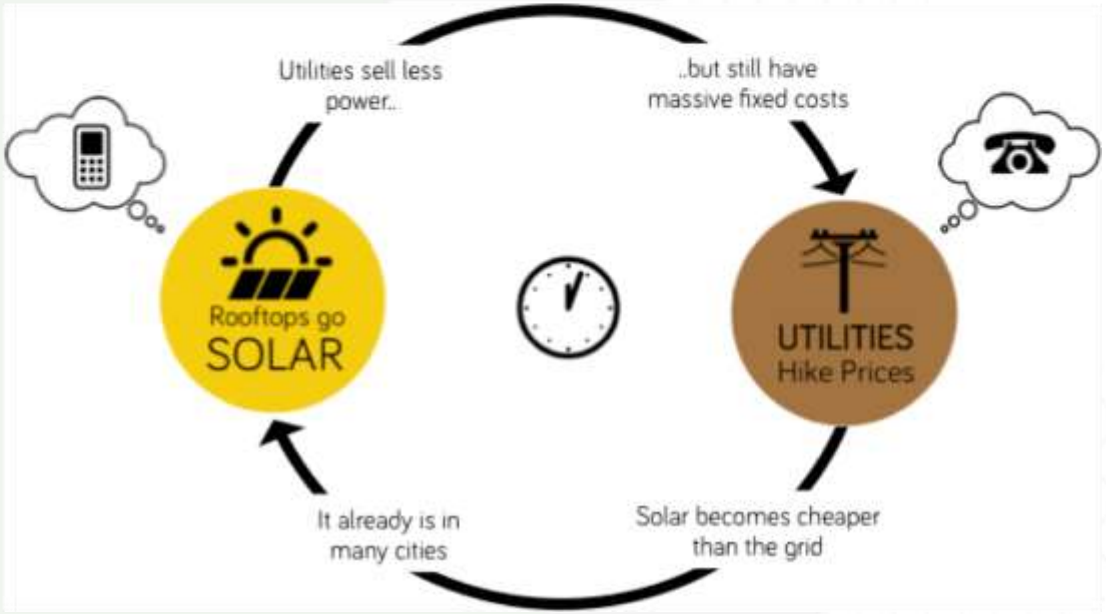
Matisoff, Daniel C., and Erik P. Johnson. "The comparative effectiveness of residential solar incentives." *Energy Policy* 108 (2017): 44-54.

POLICY INCENTIVES

- In 2015 44 states had **net-metering** policies
- 22 states had **renewable portfolio standards** with solar or distributed generation provisions



UTILITY "DEATH SPIRAL"



Thursday, August 4, 1983 — THE NEWS — Page 7A

Utilities grapple new enemy: a rate increase 'death spiral'

By Jack Danforth
Orlando Sentinel

TACOMA, Wash. — There is a new buzz word surfacing in Pacific Northwest electric utilities these days. It is the "death spiral." The concept is simple, and consumers of electric power from Florida to Alaska have recognized it for years.

A death spiral occurs during periods of rising electric rates. The theory is that as electricity demand increases, electric utilities are forced to build expensive new power plants.

This causes electric rates to rise and consumers to use less power. Electric utilities have large fixed costs, so as demand — thus revenue — is reduced, rates must be increased again, causing further reductions in consumption, and the cycle is repeated: a death spiral.

The recent collapse of the Washington Public Power Supply System, also known as Whoops, has focused [illegible]

alternative sources: gas-fired fuel cells, photovoltaic cells and a more efficient end-use of conventional resources, all of which are distinct possibilities within the next decade.

The old days of building more power plants regardless of the cost are gone. Utilities that continue that philosophy ultimately will be priced out of the market.

Conservation still is a vital cog in our energy policy of the 1980s. It is a dangerous oversimplification to say that conservation at a time of surplus energy only further reduces utility revenues, thus causing higher rates.

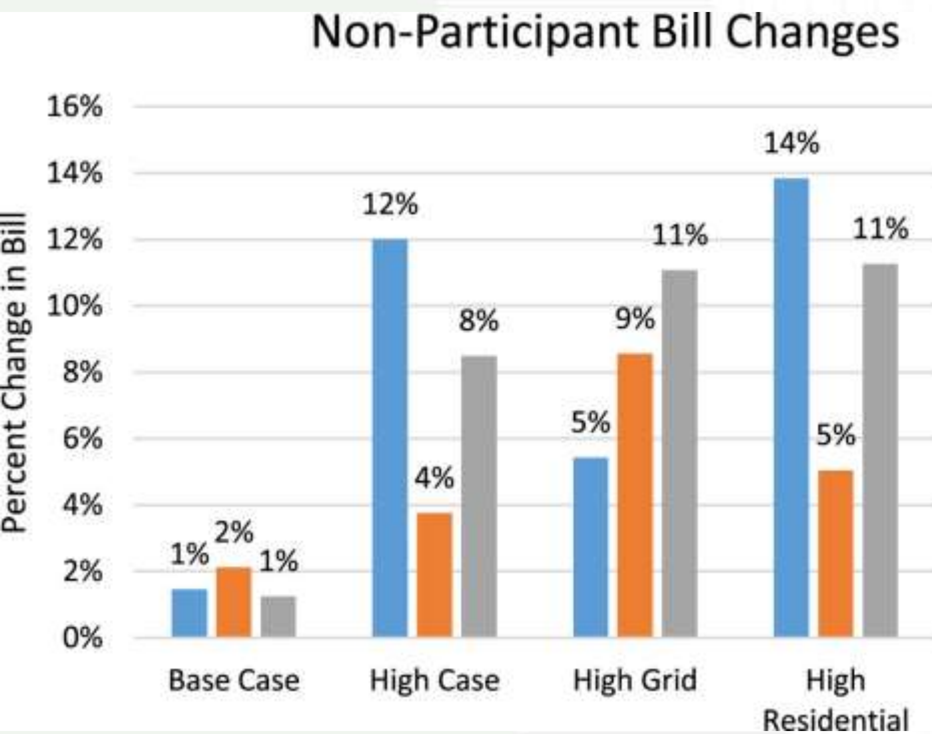
Programs as simple as the rebate program in Kissimmee, Fla., are one of the most cost-effective methods of stimulating energy efficiency in the country.

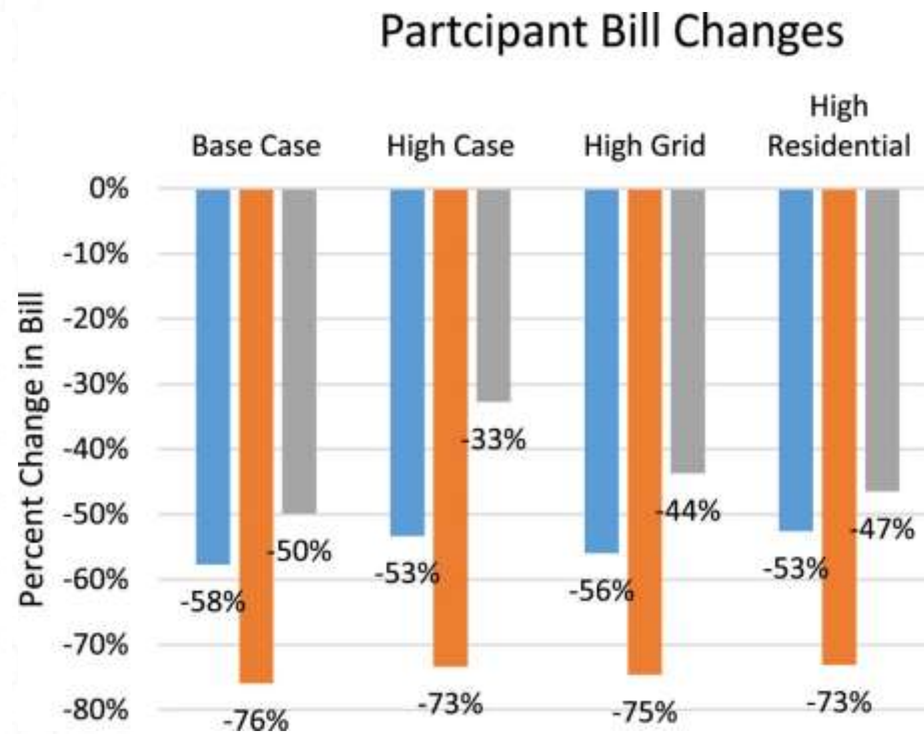
The rebate program concept originated there in [illegible] and now is being used successfully by such major utilities as Pacific Gas & Electric in California. In these programs, utilities help customers pay the cost of conservation improvements, which is cheaper than [illegible]

- Fixed Cost Recovery – Utilities argue that solar adopters are not paying for the grid services that they still use
- Even without net metering rooftop solar leads to an erosion of sales
- Coupled with flat load growth utilities may have to raise rates to recover costs

IGERT FUNDED RESEARCH

Georgia Tech





- Base Case (5% solar) non-participant impacts are minimal
- High Case (15% solar) significant cross-subsidies begin to develop

Johnson, E., Beppler, R., Blackburn, C., Staver, B., Brown, M., & Matisoff, D. (2017). Peak shifting and cross-class subsidization: The impacts of solar PV on changes in electricity costs. *Energy Policy*, *106*, 436-444.

POLICY OPTIONS

Goals: Economic efficiency, consumer equity, positive environmental and social impacts

- Retail Rate Design – AMI provides the opportunity for more sophisticated rate designs which allow costs to be recovered outside the traditional volumetric (per kWh) charges
  - Increased Fixed Charges
  - Residential Demand Charges
  - Minimum Bill
  - Time-of- Use Pricing
  - Alternative Class for Distributed Energy Resource Adopters
  - Value of Resource Methodologies
- Alternative Business Models –
  - Community Solar
  - Third-Party Ownership/Financing
  - Rooftop Rental

Q: WHAT IS THE VALUE OF SOLAR?

Georgia Tech

A: Well… It depends.

- Value of Solar to who? Solar adopters, utility ratepayers, utility, society at large?
- What Benefits and Costs will be considered?
- What techniques are used, assumptions made, and forecasts applied?

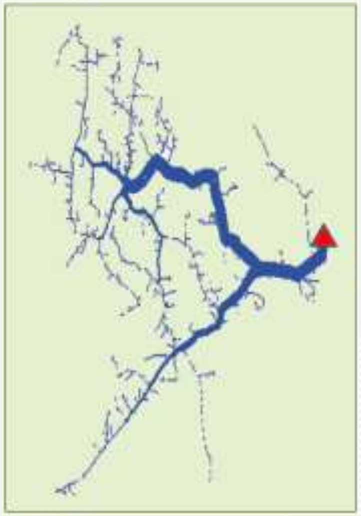
Component	Utility Scale	Distributed Generation
Avoided Fuel and Purchased Power Costs	Benefit	Benefit
Avoided Generation VO&M Costs	Benefit	Benefit
Avoided Environmental Compliance Costs	Benefit	Benefit
Deferred Generation Capacity Costs	Benefit	Benefit
Deferred Generation FO&M Costs	Benefit	Benefit
Reduced Transmission Losses (Energy Related)	Benefit	Benefit
Reduced Transmission Losses (Capacity Related)	Case by Case	Benefit
Deferred Transmission Investment	Case by Case	Benefit
Reduced Distribution Losses (Energy Related)	N/A	Case by Case
Distribution Operations Costs	N/A	Cost
Generation Remix	Cost or Benefit	Cost or Benefit
Ancillary Services – Reactive Supply and Voltage Control	N/A	Cost
Ancillary Services – Regulation	Cost	Cost
Support Capacity (Flexible Reserves)	Cost	Cost
Bottom Out Costs	Cost	Cost

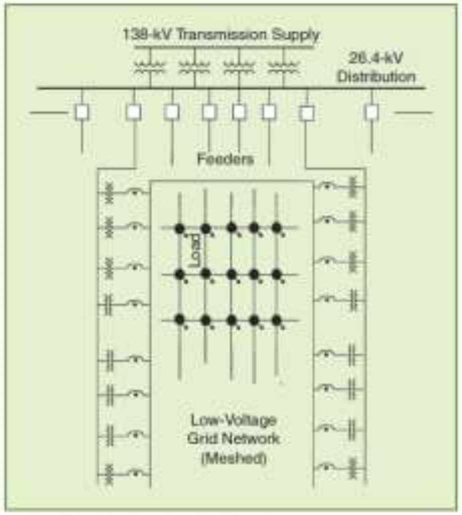
Source: A Framework for Determining The Costs and Benefits of Renewable Resources in Georgia

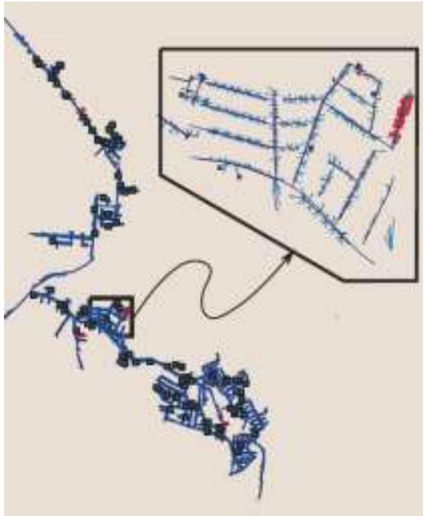
Q: IF WE AGREE ON ALL THAT WILL WE KNOW THE VALUE OF SOLAR?

A: Well… It still depends.

- Where is the solar being installed (geographically and electrically)?
- How much solar is already installed?
- Do the solar installations use smart inverters?
- What other DERs does the solar interact with it?
- How's the weather?
- What time is it?







Smith, Jeff, et al. "Time and Location: What Matters Most When Valuing Distributed Energy Resources." *IEEE Power and Energy Magazine* 15.2 (2017): 29-39.

COST-REFLECTIVE RATES

An Economist's Dream:

"Implement efficient rates which reflect both short- and long-run marginal costs and provide clear and separate price signals for the electricity commodity and delivery services, which have very different cost structures. Ensuring that customers receive price signals that reflect the costs that their use imposes on the different parts of the system will result in more optimal use patterns. More cost-reflective rates reduce system costs: Having electricity prices reflect costs gives customers the ability to reduce their electricity bills by changing their use patterns and investing in DERs. These responses will decrease overall costs in the long run."

Convery, Frank J., Kristina Mohlin, and Elisheba Spiller. "Policy Brief—Designing Electric Utility Rates: Insights on Achieving Efficiency, Equity, and Environmental Goals." *Review of Environmental Economics and Policy* 11.1 (2017): 156-164.

BARRIERS

- **Path Dependence –** Particularly in regulated markets pricing for service would be a huge transition.
- **Technology** – need near complete deployment of AMI before wide-spread opt-out cost-of-service rates
- **Computational and Communication Capacity** – do all utilities have the capacity to manage data flows, information storage, and cyber security concerns
- **Residential Acceptance** – historically, consumers aren't great at understanding electricity rates or responding to price signals
- **Political** – Can rate redesign get through the public service commissions?
  - Competing interest groups include large utility lobbies, solar installers, environmental groups, solar adopters…
- **Institutional** – How to address legacy plants such as nuclear which may no longer be cost competitive in the services they provide

GOING FORWARD

Georgia Tech

Recommendations:

- Better data collection and sharing practices
- Holistic approach to electric sector changes
- Pilot programs
- Local policy variability
- Align utility incentives with customer and societal needs

Drivers of new utility business models. (source: AEEI)

CONCLUSIONS

Georgia Tech

- More questions than answers
- This is an area in which interdisciplinary collaboration is crucial. The issue is technically complex, involves many disciplines, and engenders concerns for both efficiency and equity.
- The IGERT program at Georgia Tech provided the resources and opportunities to work on these issues.
- There remains a lot of work to do.
- Questions?

DISCUSSION OF MORNING TALKS

Mike Bush
Manager, Generation Planning and Development
Southern Company

Lunch with Table Topics and Leaders

"Fast-tracking the Energy Transition"

Dr. Benjamin Sovacool
University of Sussex

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

Benjamin K. Sovacool, Ph.D

Professor of Energy Policy

Director of the Sussex Energy Group

Director of the Center on Innovation and Energy Demand

Roadmap

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

Data sources

Centre on Innovation and Energy Demand

ELSEVIER

Volume 13, March 2016

CONTENTS

Special Issue

Energy Transitions in Europe: Emerging Challenges, Innovative Approaches, and Possible Solutions

Guest Editors

Mauro Sarrica, Sonia Brondi and Paolo Cottone

(Contents continued on inside back cover)

Data sources

Centre on Innovation and Energy Demand

Energy Research & Social Science 13 (2016) 202–215

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

ELSEVIER

Original research article

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

Benjamin K. Sovacool[a,b,*]

Conceptualizing energy transitions

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

Table 1
Five definitions of energy transitions.

Definition	Source
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)	Hirsh and Jones [22]
Shifts in the fuel source for energy production and the technologies used to exploit that fuel	Miller et al. [23]
A particularly significant set of changes to the patterns of energy use in a society, potentially affecting resources, carriers, converters, and services	O'Connor [24]
The switch from an economic system dependent on one or a series of energy sources and technologies to another	Fouquet and Pearson [25]
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	Smil [26]

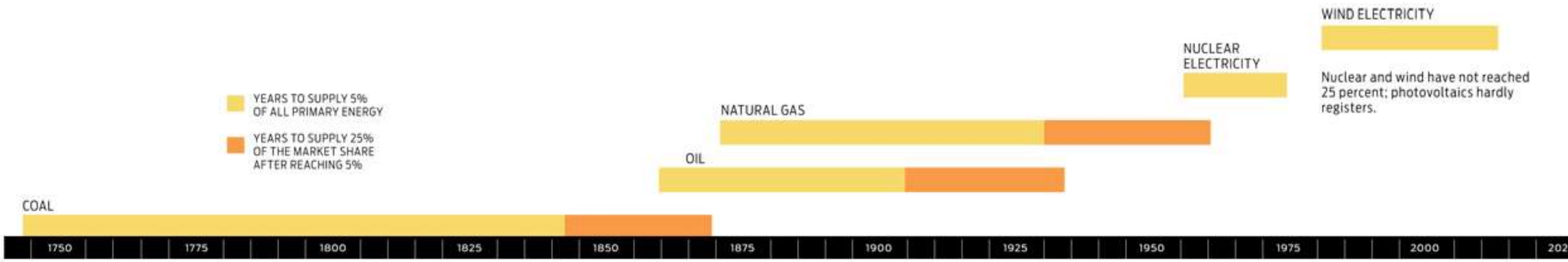
Conceptualizing energy transitions

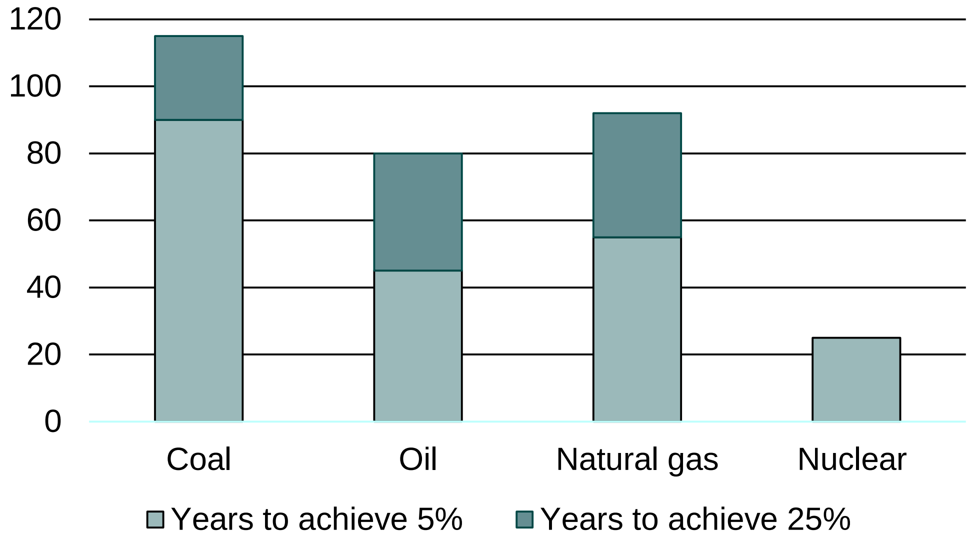
- What does the academic literature say?
- *"Energy transitions have been, and will continue to be, inherently prolonged affairs, particularly so in large nations whose high levels of per capita energy use and whose massive an expensive infrastructures make it impossible to greatl accelerate their progress even if we were to resort to some highly effective interventions …"*

Table 2
The differences in timing and speed of energy transitions in Europe.

Phase-out traditional renewables phase-in coal:		Diffusion midpoint	Diffusion speed
Core	England	1736	160
Rim	Germany	1857	102
	France	1870	107
	Netherlands	1873	105
Periphery	Spain	1919	111
	Sweden	1922	96
	Italy	1919	98
	Portugal	1949	135
Phase-out coal phase-in oil/gas/electricity:			
Core	Portugal	1966	47
	Italy	1960	65
	Sweden	1963	67
Rim	Spain	1975	69
	Netherlands	1962	62
	France	1972	65
Periphery	Germany	1984	50
	England	1979	67

Conceptualizing energy transitions





Conceptualizing energy transitions

Energy Research & Social Science 22 (2016) 18–25

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Short communication

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

Arnulf Grubler[a,b,*], Charlie Wilson[a,c], Gregory Nemet[d]

Conceptualizing energy transitions

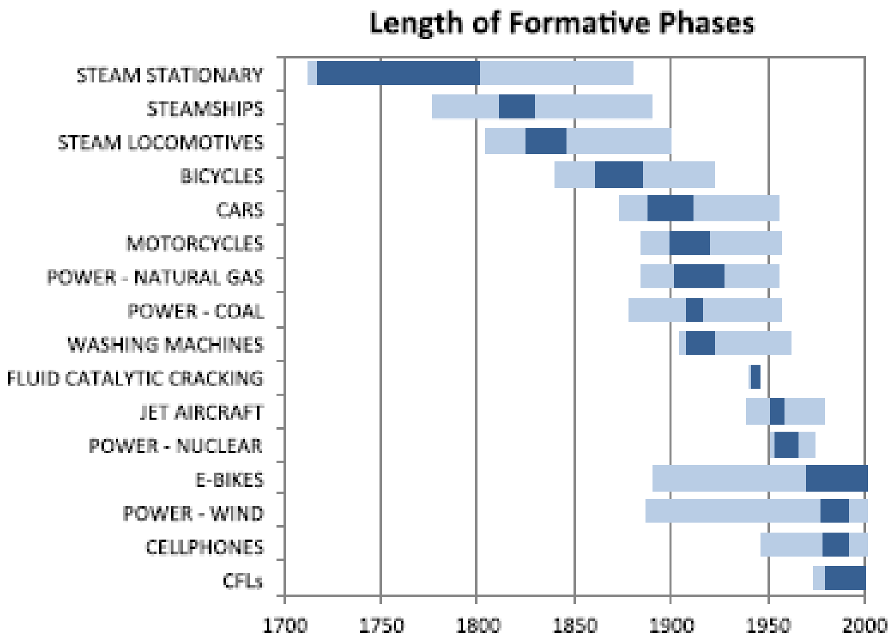


Fig. 1. Durations of formative phases for energy technologies are at a decadal scale [4]. Note: Ranges refer to alternative definitions for the start and end points of formative phases, and so capture measurement uncertainties.

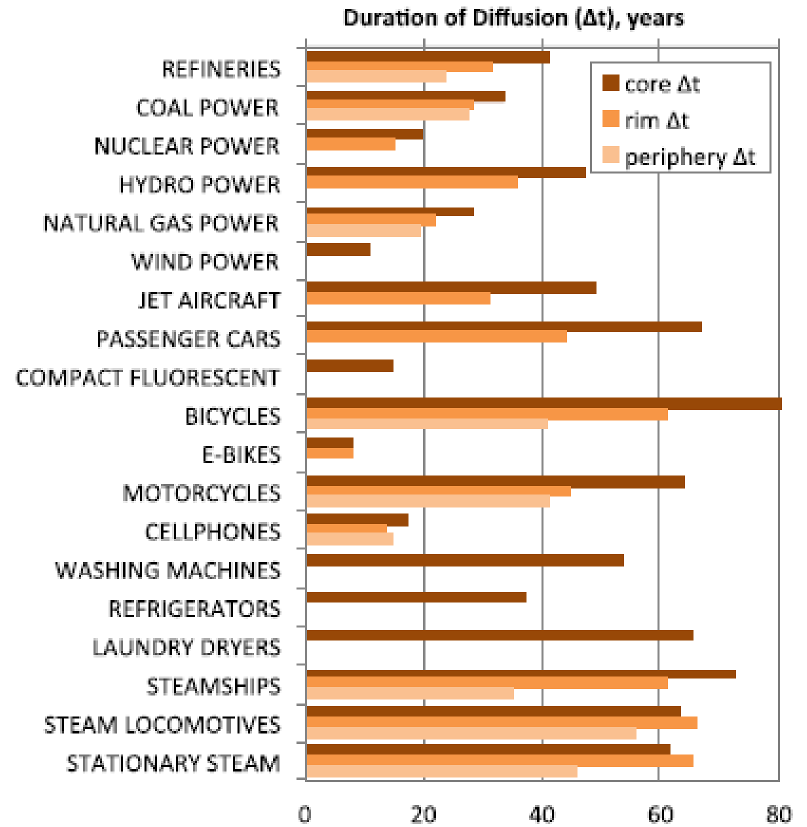


Fig. 2. Diffusion speeds accelerate as technologies diffuse spatially. Notes: Bars show durations of diffusion measured by cumulative total capacity installed, with historical data fitted via a logistic growth curve and the diffusion duration expressed as Δ t in years. 'Core' is typically within the OECD; 'Rim' is typically Asian countries; 'Periphery' is typically other world regions. For details and data, see: [42,3].

Conceptualizing energy transitions

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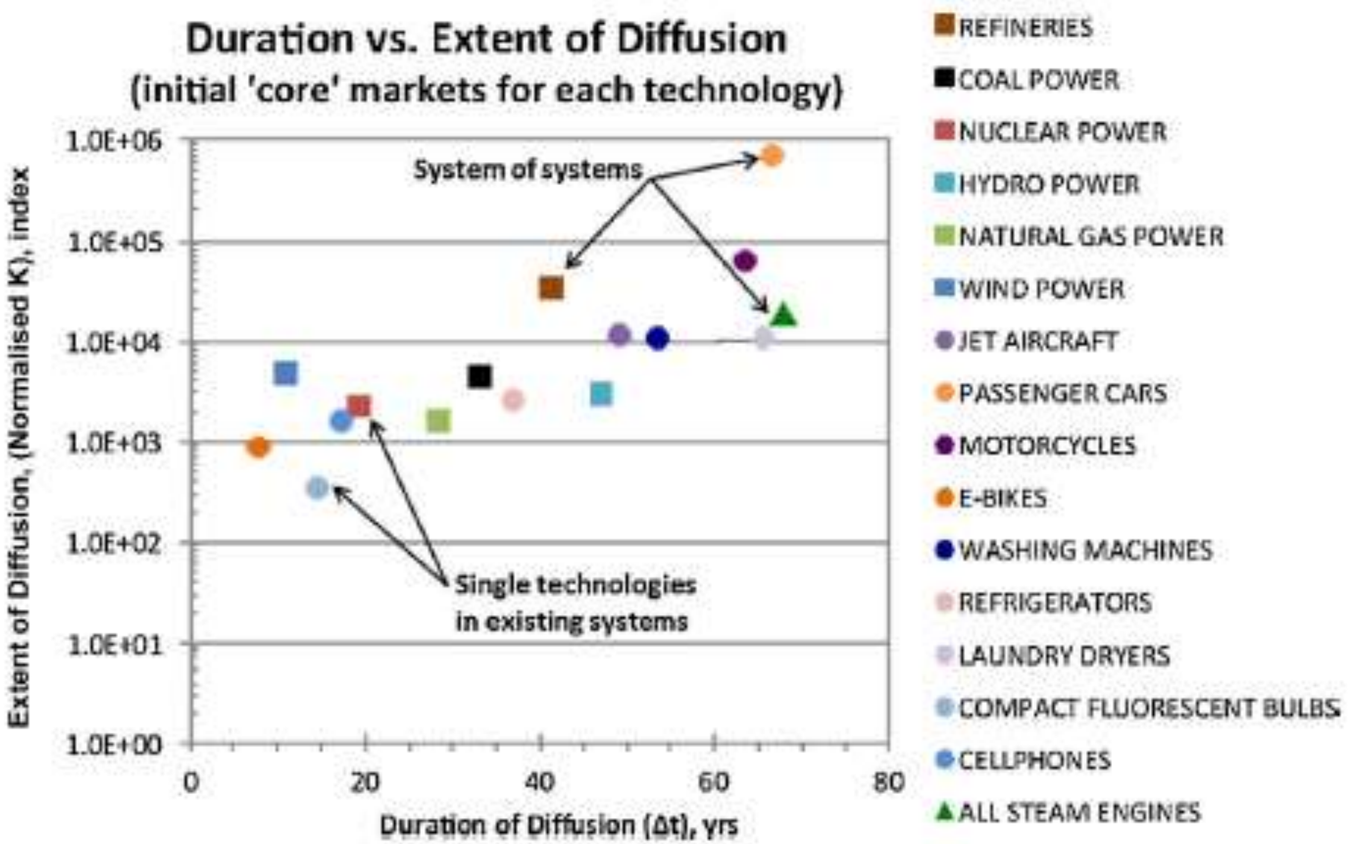


Diffusion durations scale with market size. Notes: X-axis shows duration of diffusion (t) measured in time to grow from 10% to 90% of cumulative total capacity; y-axis shows extent of diffusion normalized for growth in system size. All data are for ‘core’ innovator markets. Round symbols denote end-use 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)?

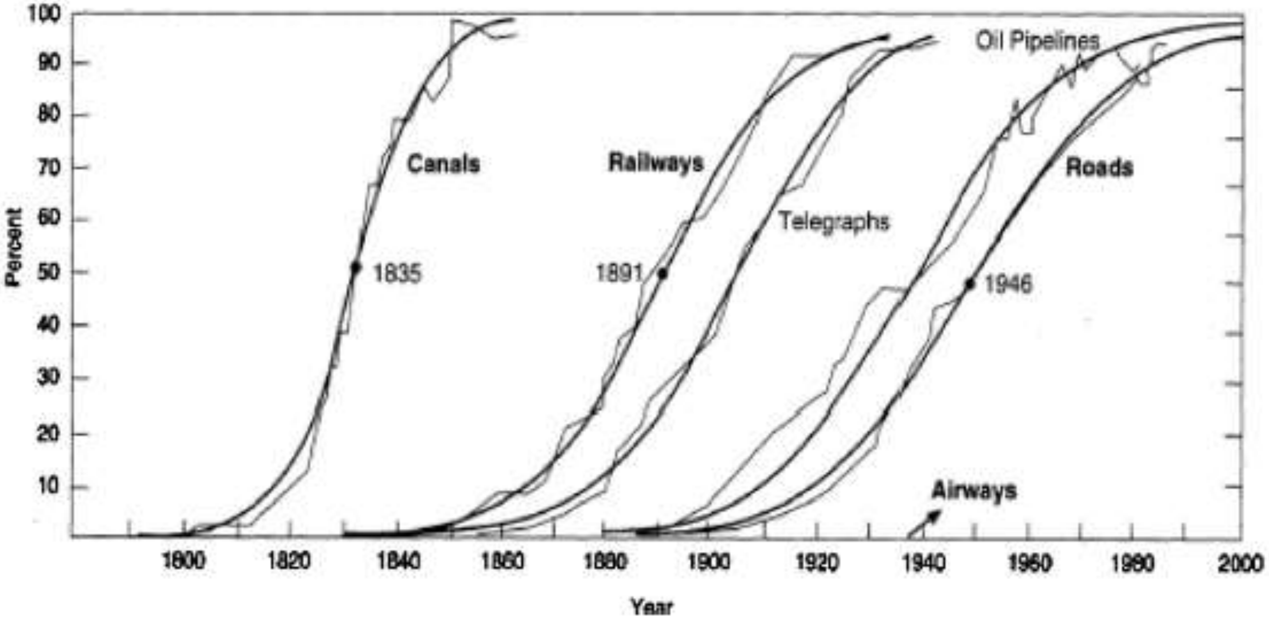


Fig. 1. Growth of Infrastructures in the United States as a Percentage of their Maximum Network Size.

- *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?

Centre on Innovation and Energy Demand

- 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 4
Overview of rapid energy transitions.

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

[a] The Ontario case study is the inverse, showing how quickly a province went from 25% coal supply to zero.

Rethinking transitions

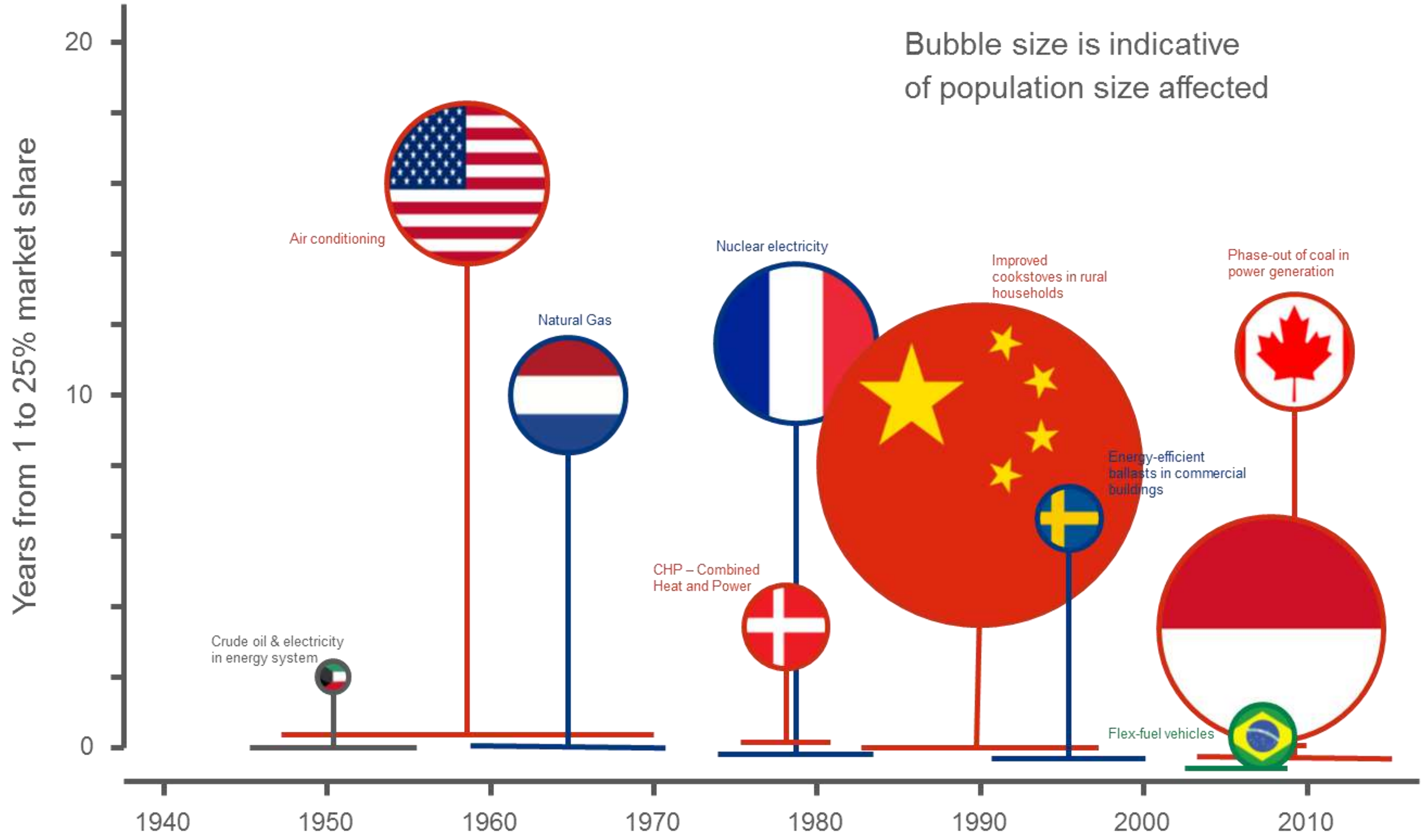


Figure designed by Gert Jan Kramer, used with permission

Rethinking transitions

Centre on Innovation and Energy Demand

Energy Research & Social Science 22 (2016) 13–17

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

ELSEVIER

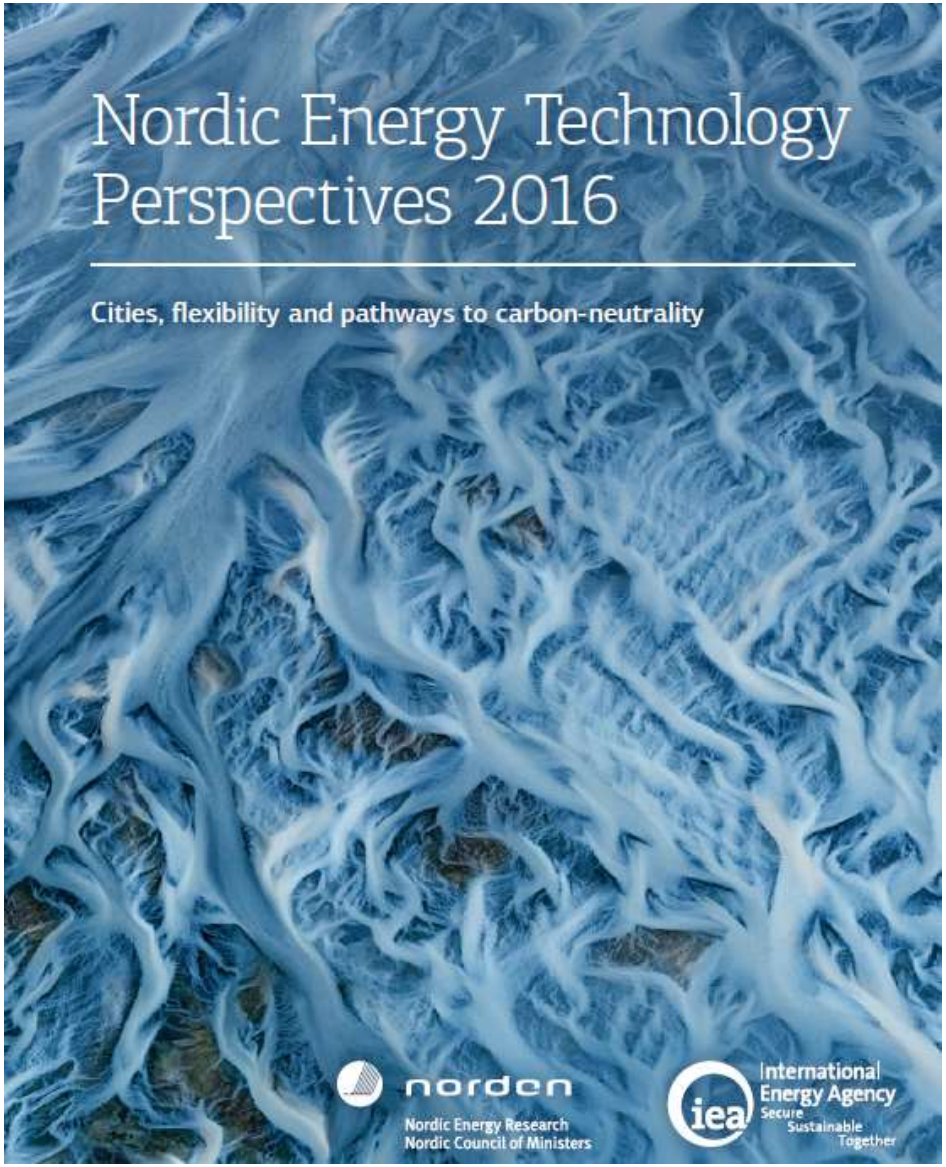
Short communication

The pace of governed energy transitions: Agency, international dynamics and the global Paris agreement accelerating decarbonisation processes?

Florian Kern [a,*], Karoline S. Rogge [a,b]

- 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

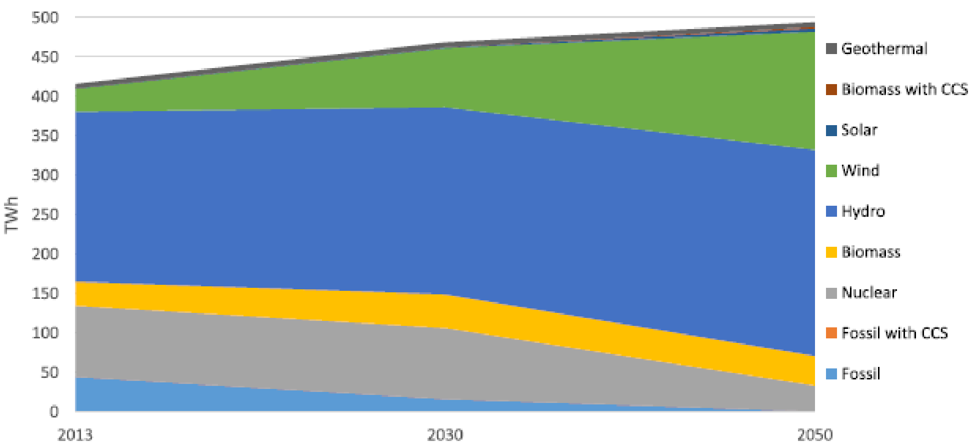
Rethinking transitions



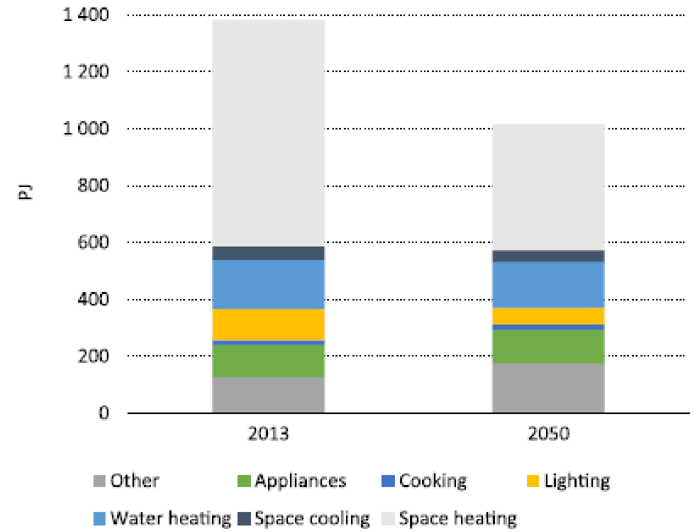
Rethinking transitions: electricity, heat, and buildings

Centre on Innovation and Energy Demand

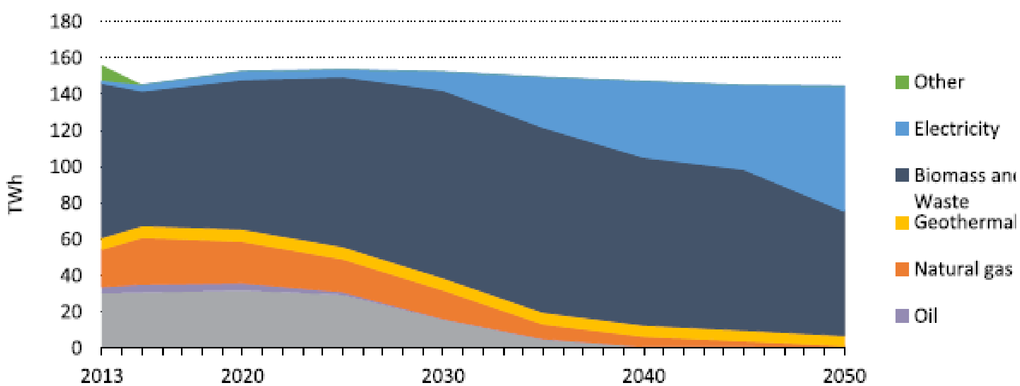
a. Top panel: Electricity generation



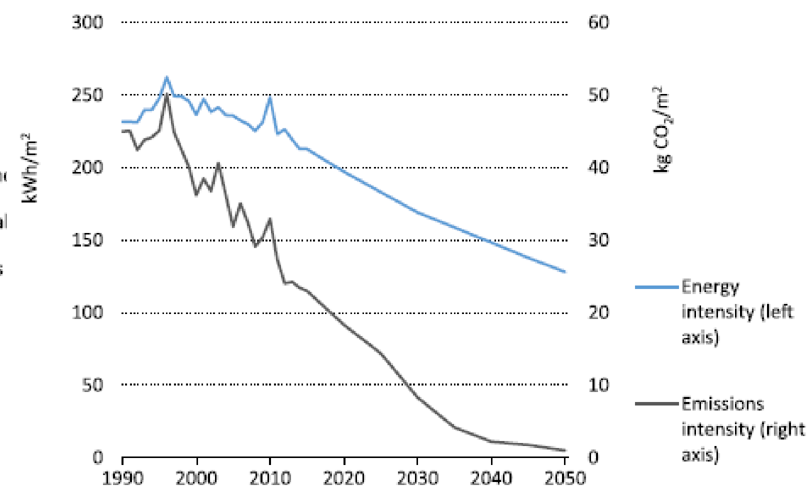
a. Top panel: Buildings energy consumption, 2013 and 2050



b. Bottom panel: heat supply



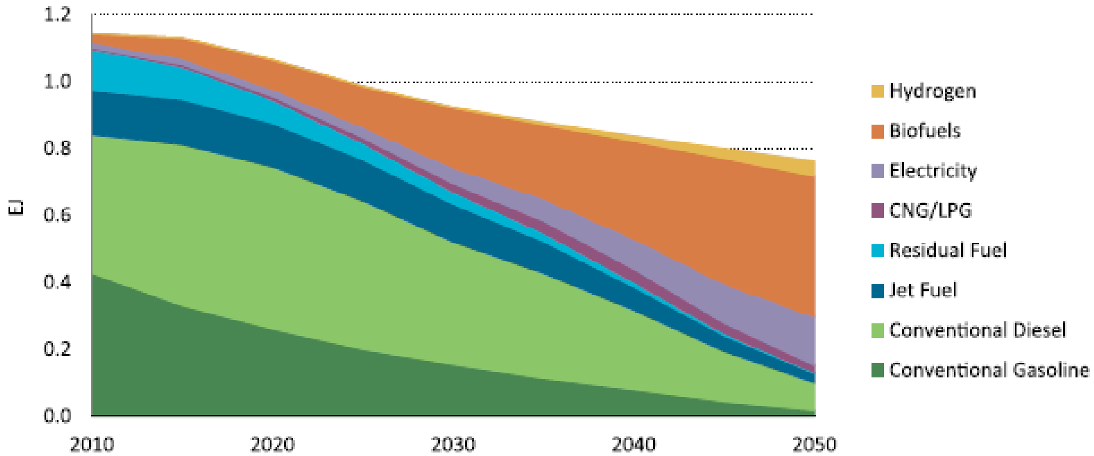
b. Bottom panel: Energy intensity and emission intensity, 1990 to 2050



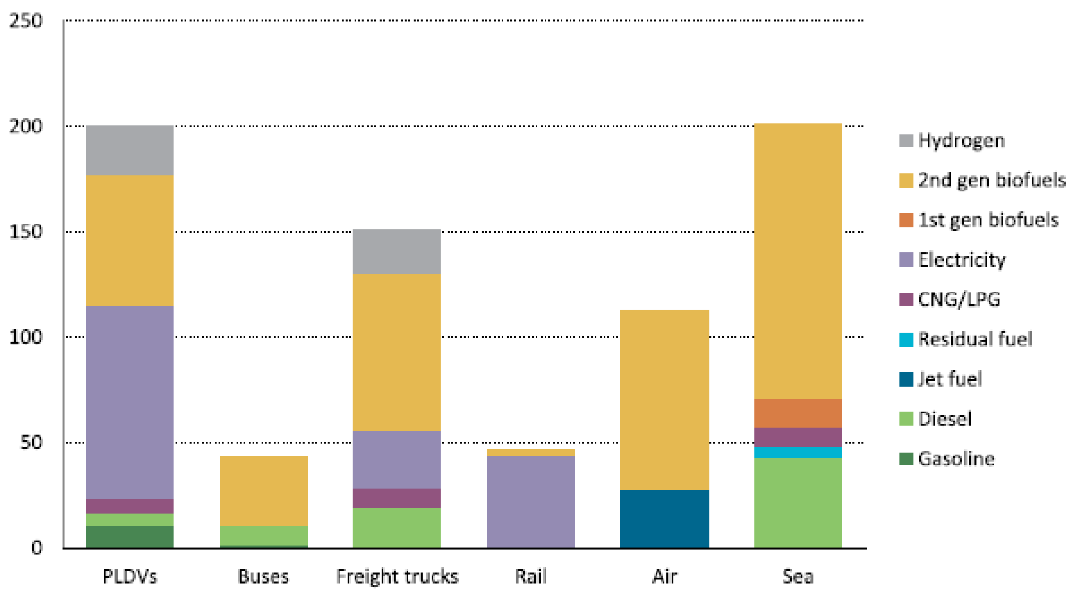
Rethinking transitions: transport fuel

Centre on Innovation and Energy Demand

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



b. Bottom panel: by transportation mode, 2050



Rethinking transitions: industrial emissions

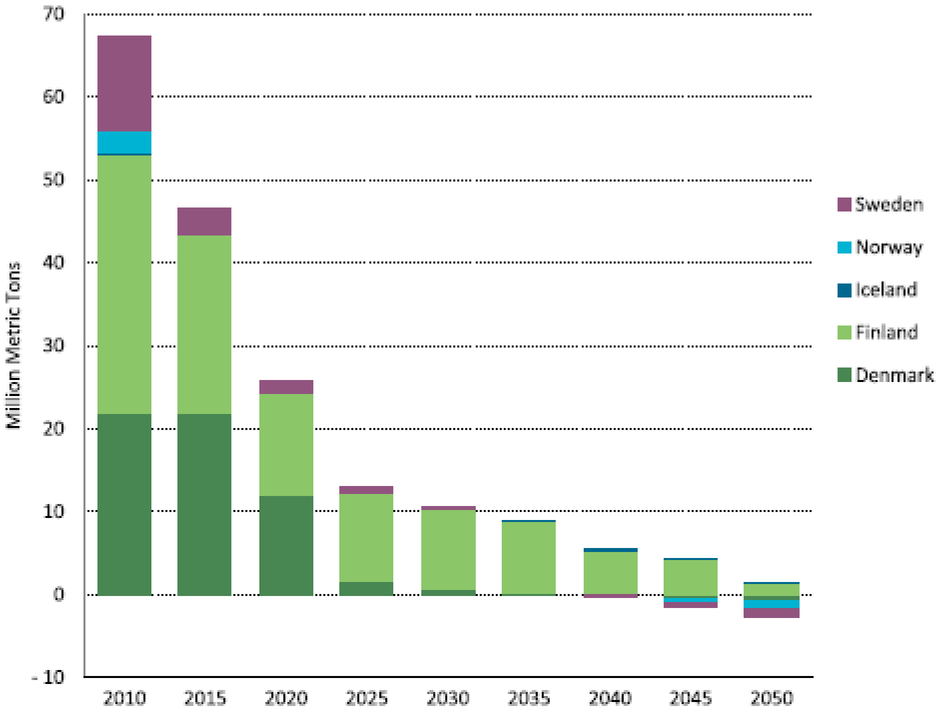
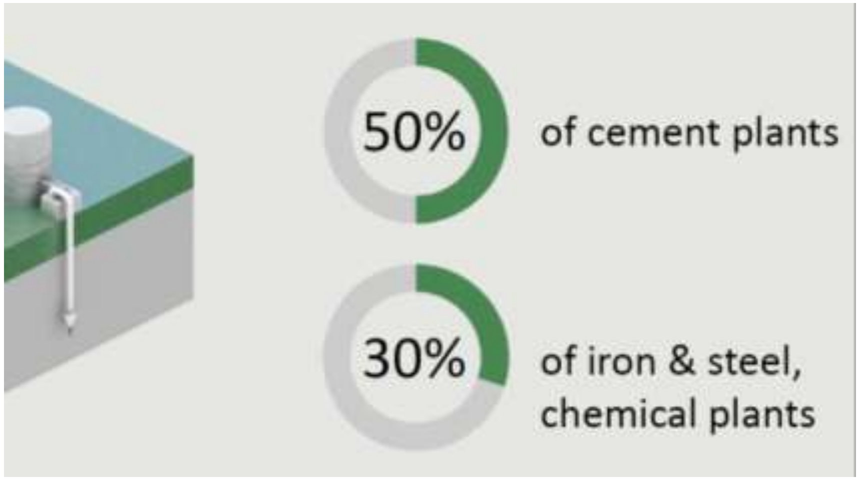


Fig. 11. Nordic Carbon Dioxide Emissions by Country, 2010–2050.

CCS utilization by 2050:



Rethinking transitions

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Energy Policy 102 (2017) 569–582

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Energy Policy

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ENERGY POLICY

Contestation, contingency, and justice in the Nordic low-carbon energy transition

Benjamin K. Sovacool[a,b,*]

Table 3
Cumulative Nordic Investments for Decarbonization by Sector, 2016–2050.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives 2016 (Paris: OECD, 2016). Assumes the Carbon Neutral Scenario.

Sector	$ (USD Billion)
Energy-related investments in buildings	326
Industry	103
Transport: vehicles	1,674
Transport: infrastructure	1,121
Power: generation	197
Power: infrastructure	151
Total	3,572

- 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?

Centre on Innovation and Energy Demand

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?"

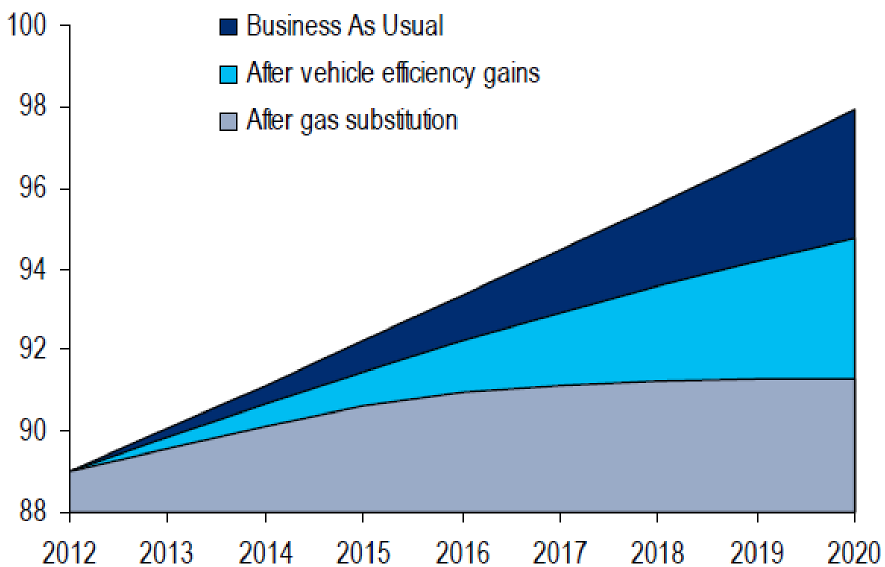
Centre on Innovation and Energy Demand

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

Citi Research

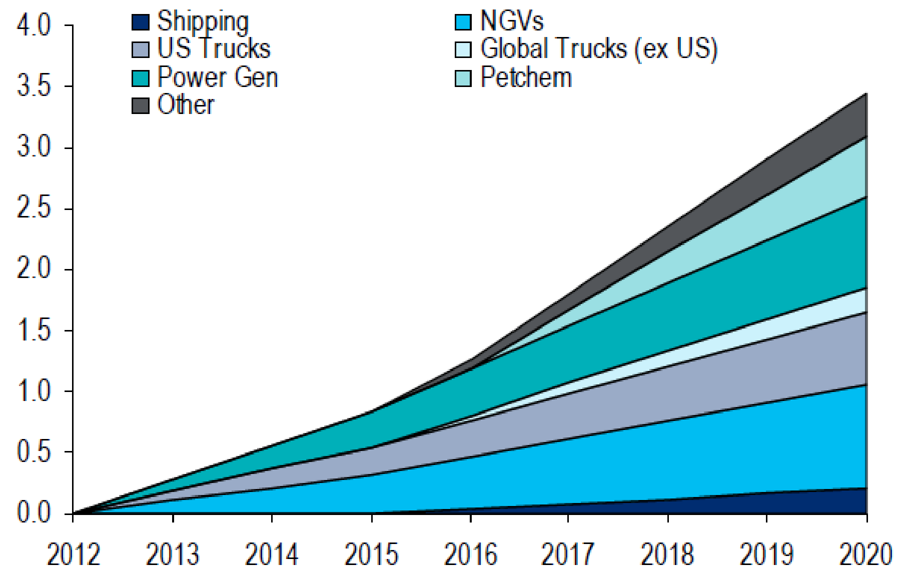
Global Oil Demand Growth – The End Is Nigh

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



Source: Citi Research

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



Source: Citi Research

A perspective from utilities and incumbents?

Centre on Innovation and Energy Demand

The energy transition is already happening?

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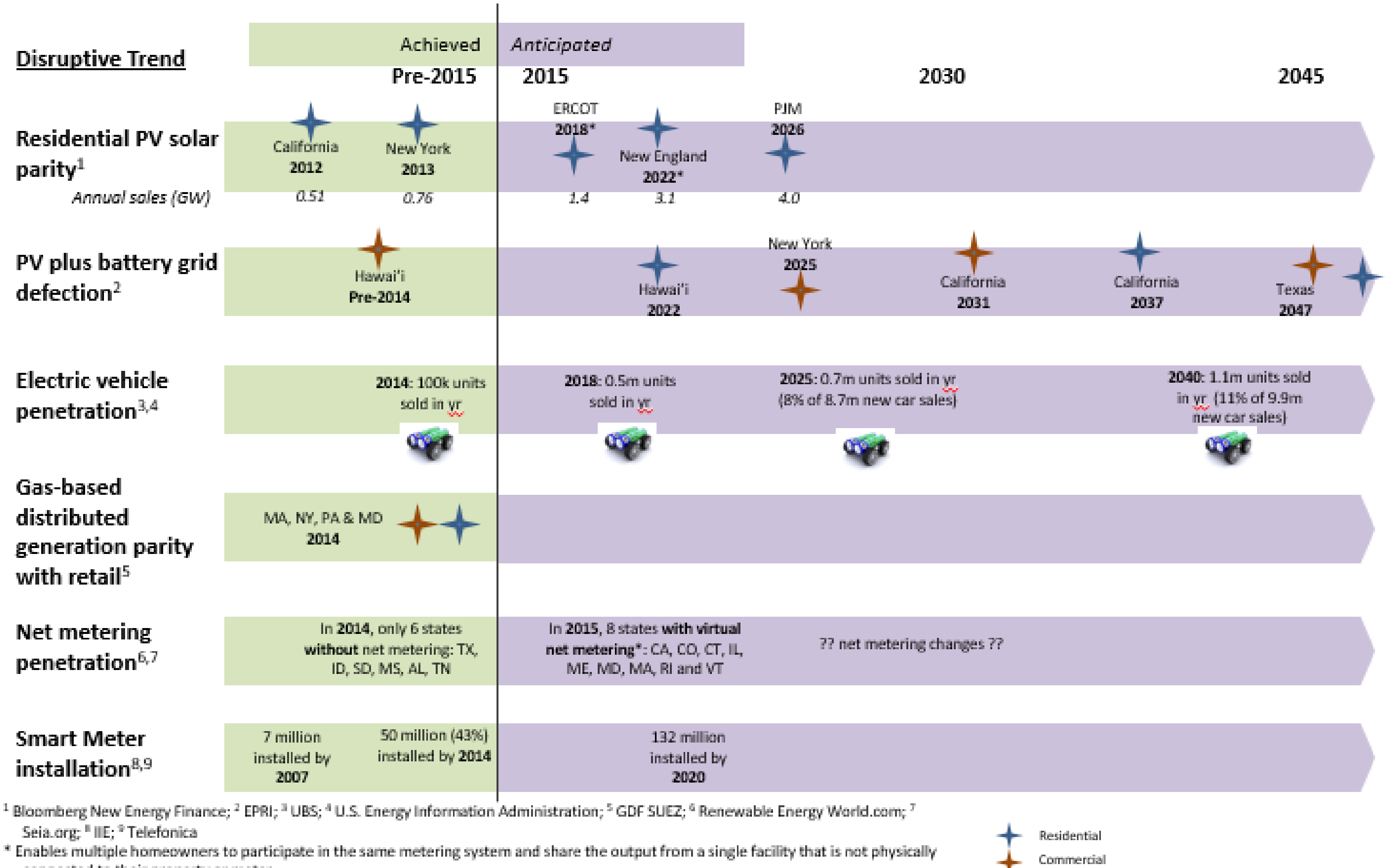


[1] Bloomberg New Energy Finance; [2] EPRI; [3] UBS; [4] U.S. Energy Information Administration; [5] GDF SUEZ; [6] Renewable Energy World.com; [7] Seia.org; [8] IIE; [9] Telefonica

* 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

APPLIANCES & AUDIO DEVICES
hiku, INDEPENDA, innit, SONOS, SECTORQUBE, KITU SYSTEMS, MUSAIC

LIGHTING
LUMETRIC LIGHTING, plum, switchmate, emberlight, LIFX

MISCELLANEOUS
KAMARQ, notion

SAFETY & SECURITY
leeo, BeONhome, SimpliSafe, roost, MY ALARM CENTER, myfox, august, Lockitron, canary, ring, LATCH, audio analytic, cocoon, Glue

ENERGY & UTILITIES
Ecoisme, sense, thinkeco, rachio, ecobee, there., tado°

iStock.com/skypicsstudio

DEVICE CONTROLLERS
SENTRI, Fluent, NINJA BLOCKS, muzzley, wigwag, ivee, peel, avi-on, iRule

HEALTH & WELLNESS
beddit, hello, MedMinder

GENERAL SMART HOME SOLUTIONS
ecovent, netatmo, KEEN home, vivint.SmartHome

HOME ROBOTS
jibo, Rokid, 小鱼在家, robart, neato robotics

GARDENING
grove, NIWA, EDYN

CBINSIGHTS

Shifts in business models and value creation alongside technology

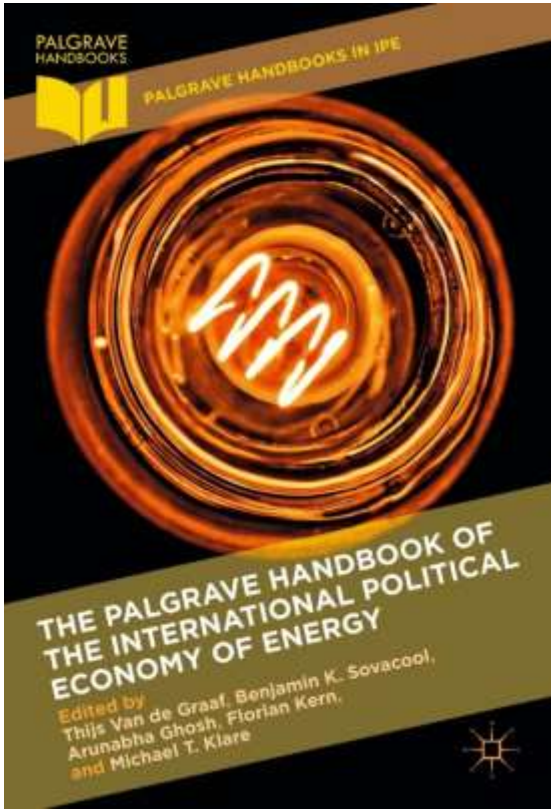
Centre on Innovation and Energy Demand

Trends pushing down the cost of solar, other renewables and energy efficiency	Examples
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

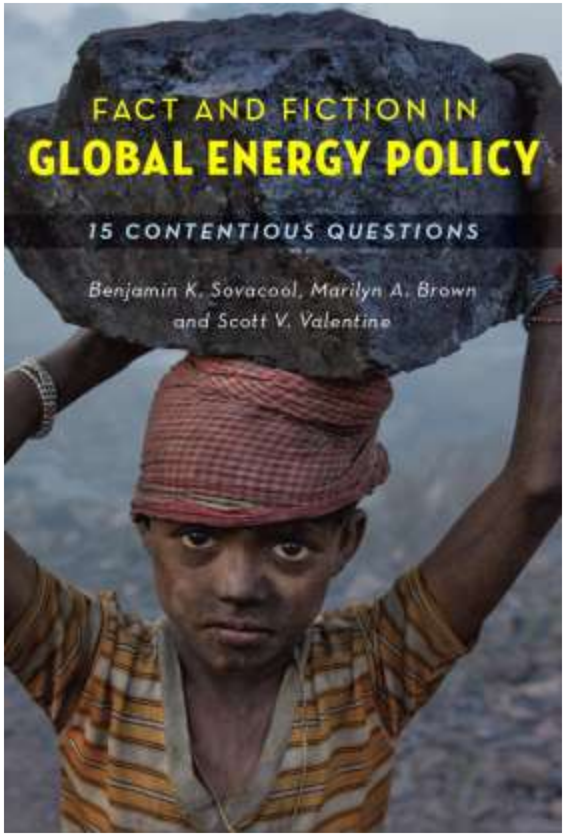
Concluding remarks

- 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

Contact Information



Benjamin K. Sovacool, Ph.D
Professor of Energy Policy
University of Sussex
Jubilee Building, Room 367
Falmer, East Sussex, BN1 9SL
+44 1273 877128
B.Sovacool@sussex.ac.uk



ENERGY STORAGE FOR PV AND EV SYSTEMS

Setting the stage by Georgia Tech NSF IGERT Faculty:
--Steve Usselman, *History, Technology and Society*
--Matthew McDowell, *Mechanical Engineering*
Research results presented by Georgia Tech NSF Fellows:
Materials and Systems
--Eric Tervo, *Mechanical Engineering*
Policy and Economics
--Wale Odukomaiya, *Mechanical Engineering*
--Caroline Golin, *Vote Solar*

An Economic Analysis of Residential Photovoltaic Systems with Battery Storage in the United States

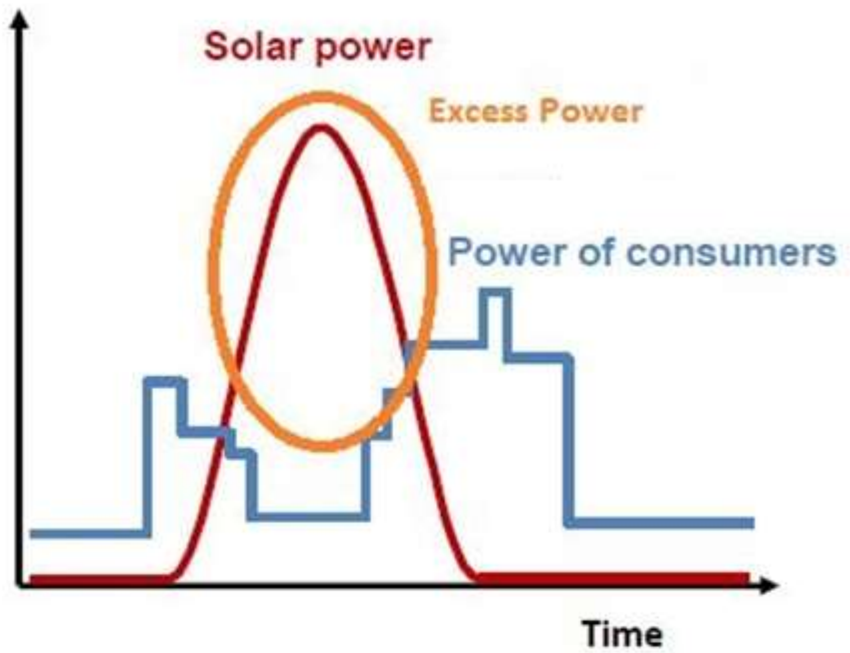
Presented by

Eric Tervo
Ph.D. Candidate, G.W.W. School of Mechanical Engineering
eric.tervo@gatech.edu
July 25, 2017

In collaboration with

Kenechi Agbim, Alfred DeAngelis, Jeffrey Hernandez, Hye Kyung Kim, and Wale Odukomaiya

Motivation



http://www.neutek-energy.com.au/energy-management/platinum-battery

Excess PV generation during the day must be utilized to achieve low LCOEs

- **Net or Bi-Directional Metering**
- **Battery Storage**

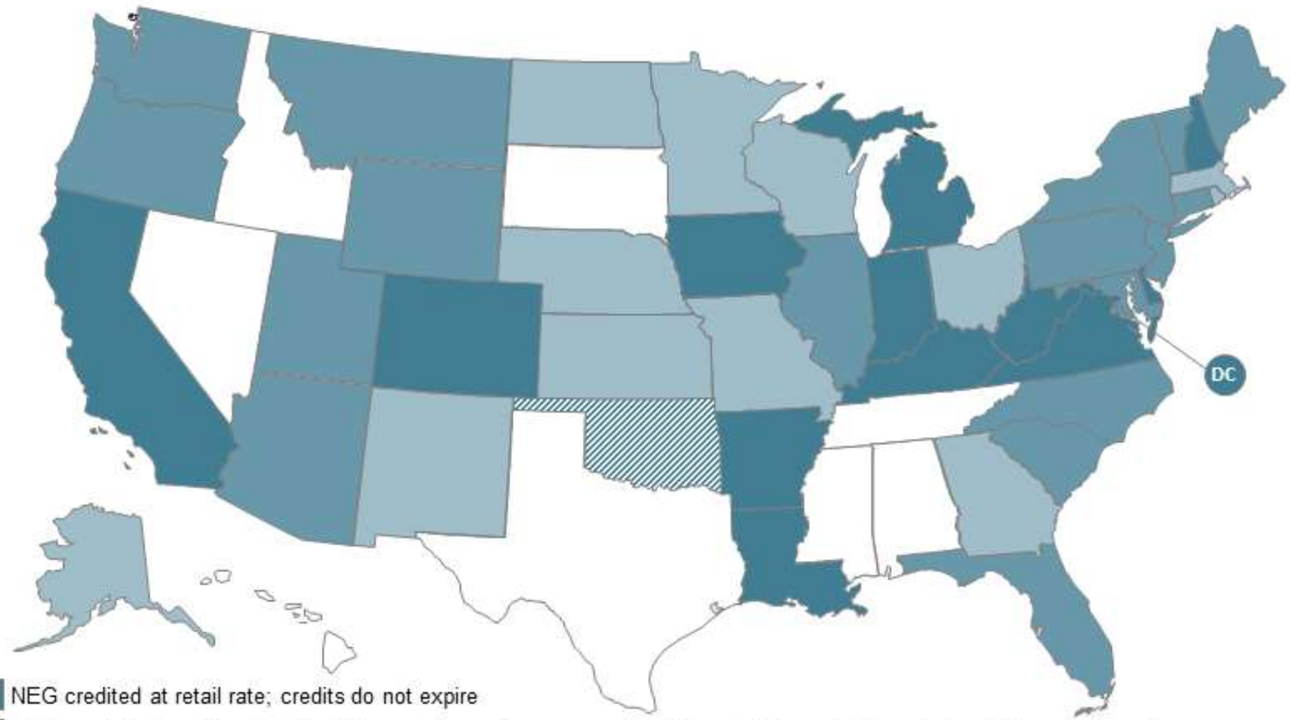
DSIRE®

NC CLEAN ENERGY TECHNOLOGY CENTER

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Customer Credits for Monthly Net Excess Generation (NEG) Under Net Metering

www.dsireusa.org / July 2016



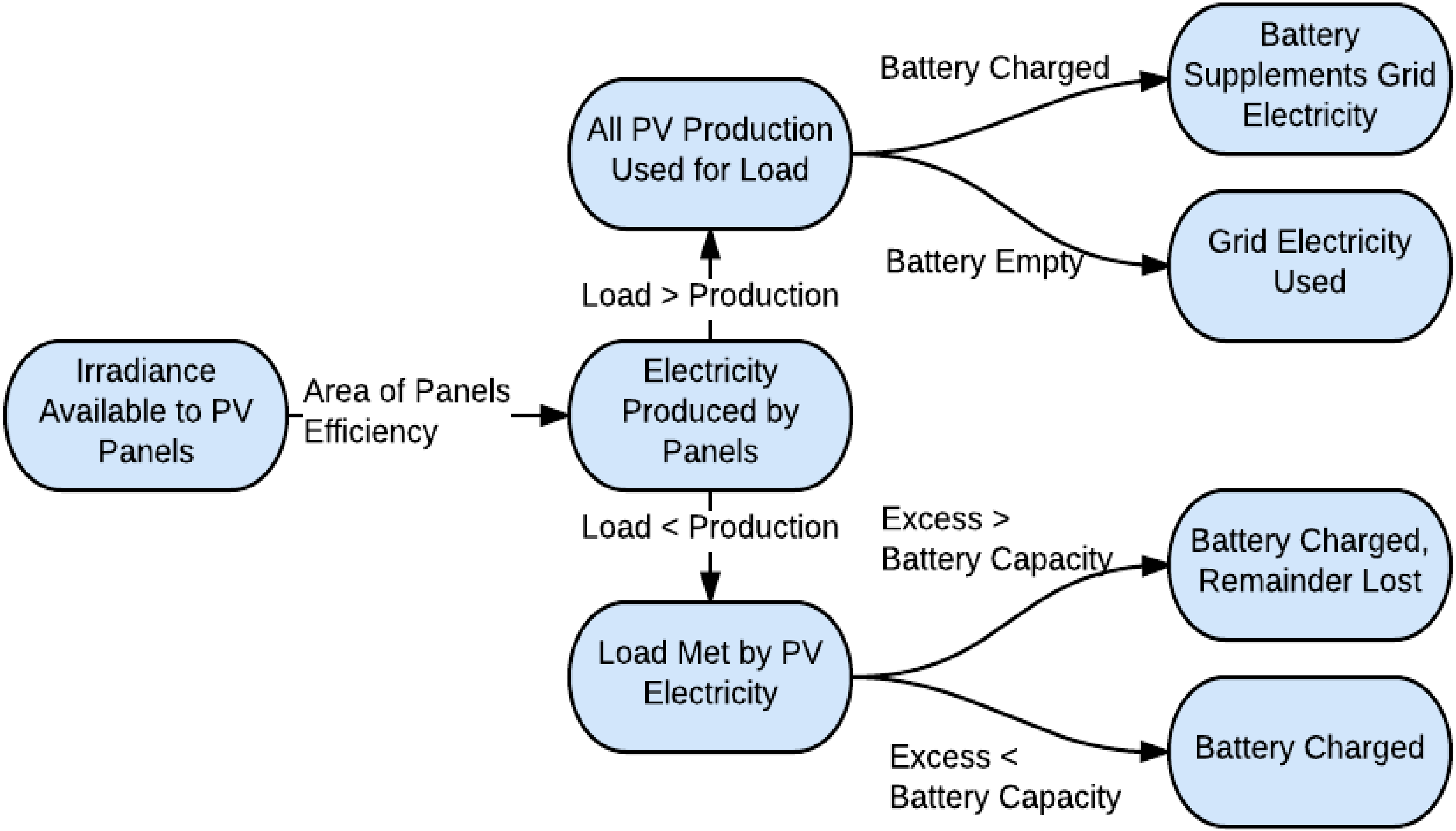
- NEG credited at retail rate; credits do not expire
- NEG credited at retail rate at first, then credits expire or are reduced (e.g., to the avoided cost rate at the end of year)
- NEG credited at less than retail rate (e.g., avoided cost rate)
- NEG is not compensated
- No statewide mandatory net metering rules

***NOTE:** The map shows NEG credits under statewide policies for investor-owned utilities (IOUs); other utilities may offer different NEG credit amounts. IOUs in HI, NV, MS, and GA have other policies for compensating self-generators. Some IOUs in TX and ID offer net metering, but there is no statewide policy. IOUs in WI differ in their treatment of NEG.*

Objectives

- Develop model to predict cost/performance of residential PV with battery storage – without bi-directional metering
  - Capture geographical variation in solar insolation and household load profiles
  - Define and predict a battery LCOE that can be compared against net- or bi-directional metering schemes

Model: System Performance

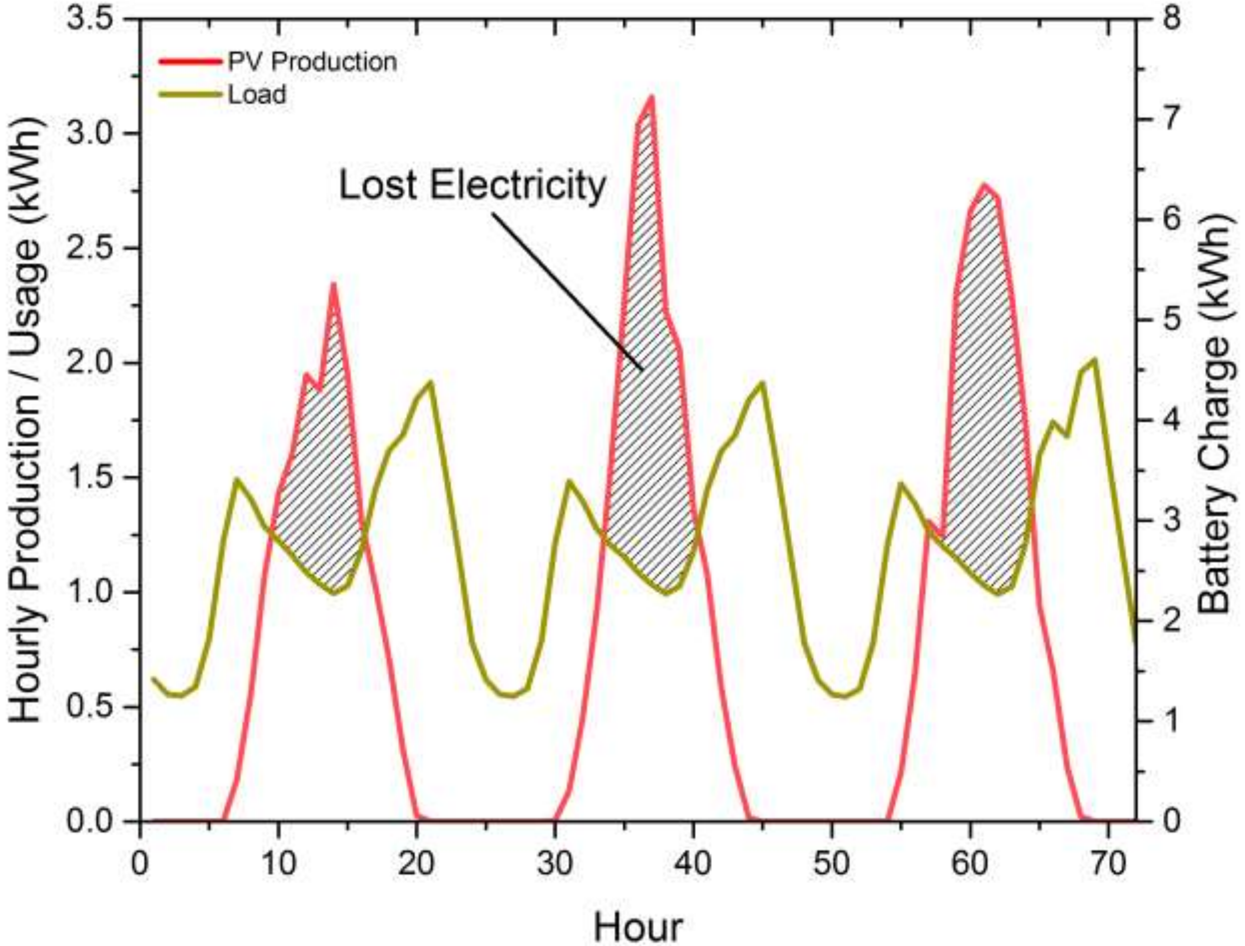


Model: System Finances

- Financing
  - 4%, 30 year home-equity loan
  - 20% down payment
- Taxes
  - Exempt (or negligible) property tax
  - Interest payments are tax-deductible (25% federal)
- Levelized Costs
  - 6% discount rate
  - 2% inflation
- Incentives
  - 30% investment tax credit

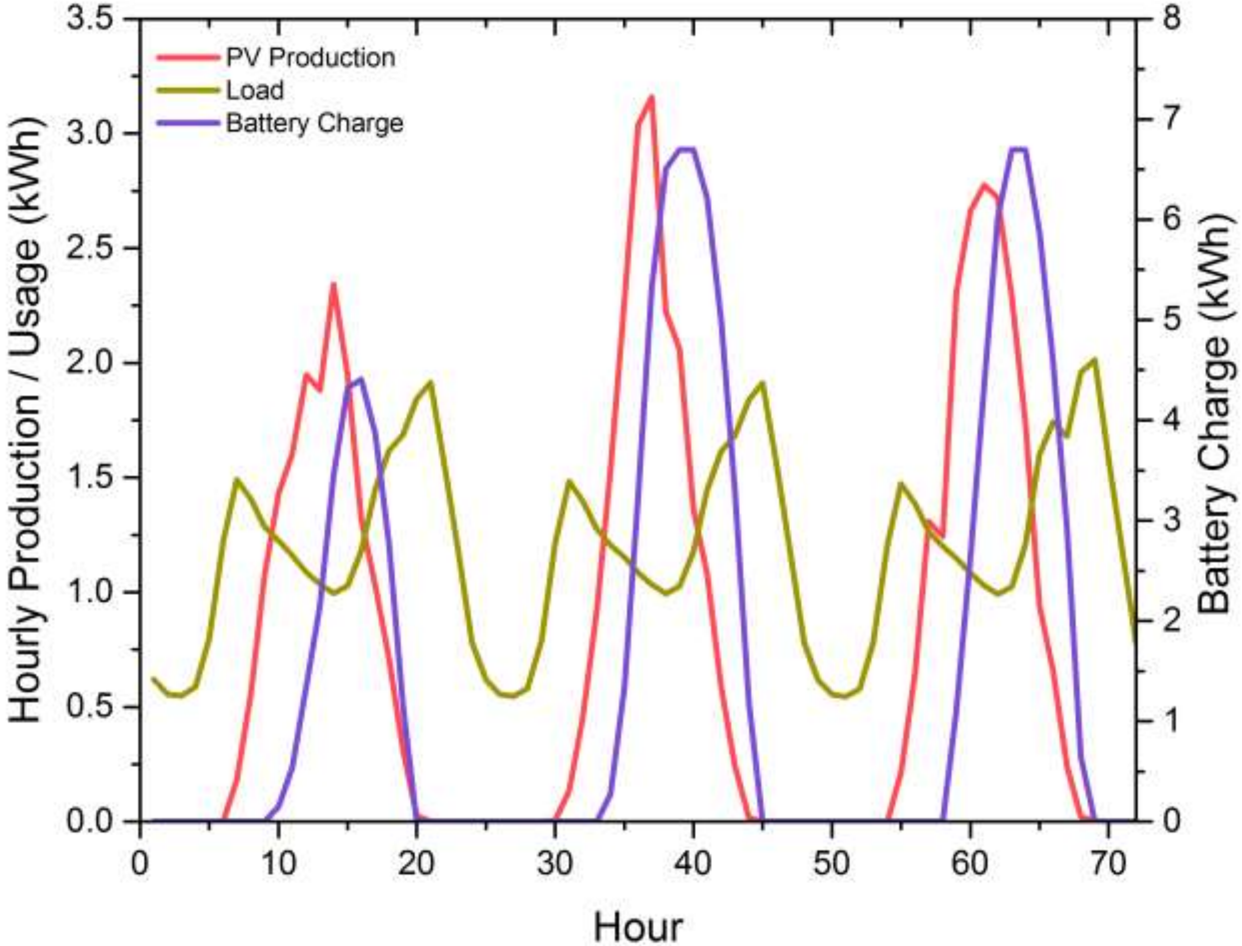
Results: Impact of Using Batteries

For Atlanta, GA with 5 kW PV system and no battery

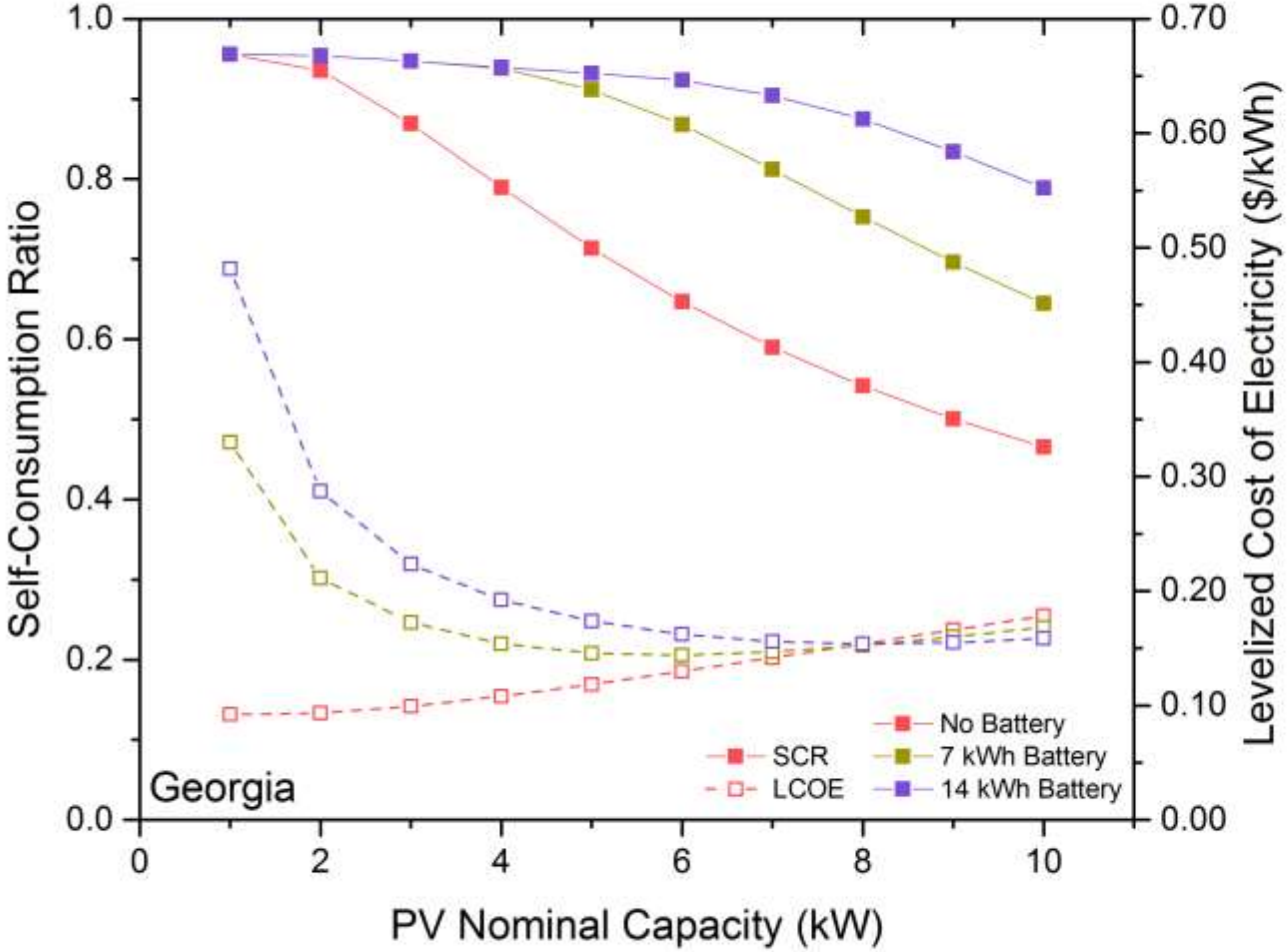


Results: Impact of Using Batteries

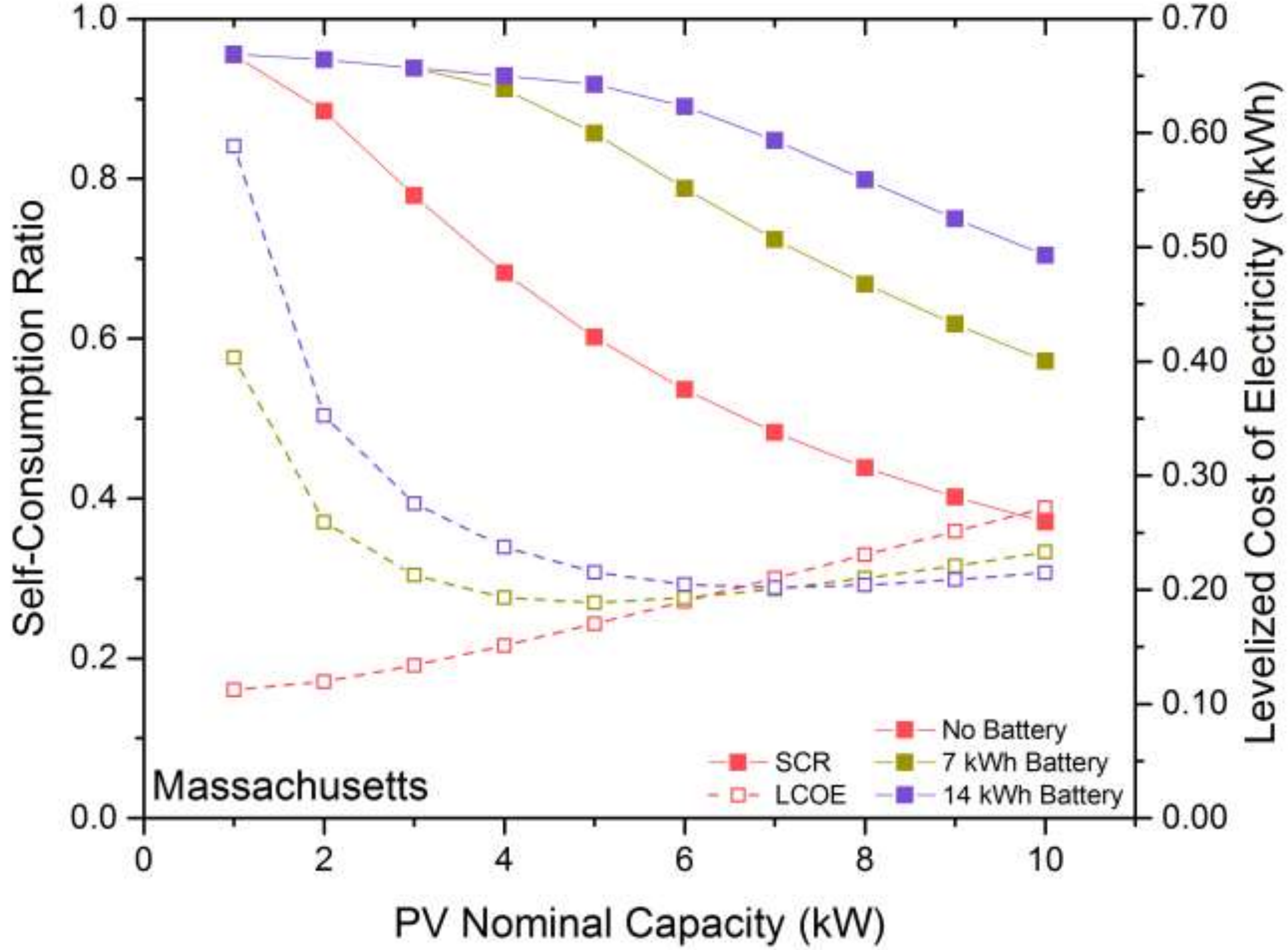
For Atlanta, GA with 5 kW PV system and 7 kWh battery



Results: LCOE & Self-Consumption Ratio



Results: LCOE & Self-Consumption Ratio



Results: LCOE for Batteries Alone

- 5 kW PV system, 7 kWh battery system
- LCOE above PV "production cost" can be compared to costs in net-metering schemes

- Georgia
  - 0.054 $/kWh raises SCR from 71% to 91%

- Massachussetts
  - 0.076 $/kWh raises SCR from 60% to 85%

Conclusions

- Created detailed, flexible model to analyze residential PV and battery systems
- Batteries can effectively utilize excess PV generation
- For larger PV installations (> 6 kW), battery systems can lower the LCOE
- Created cost metric to compare to net-metering policies
- Caveat: Despite promise, not grid competitive yet

Thank you!

Drs. Marilyn Brown, Samuel Graham, and Valerie Thomas

My Co-Authors





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--Caroline Golin, *Vote Solar*
--Wale Odukomaiya, *Mechanical Engineering*

The Value of Energy Storage in Buildings

Wale Odukomaiya
PhD Candidate
G.W. Woodruff School of Mechanical Engineering
Energy and Transportation Science Division, Oak Ridge National Laboratory

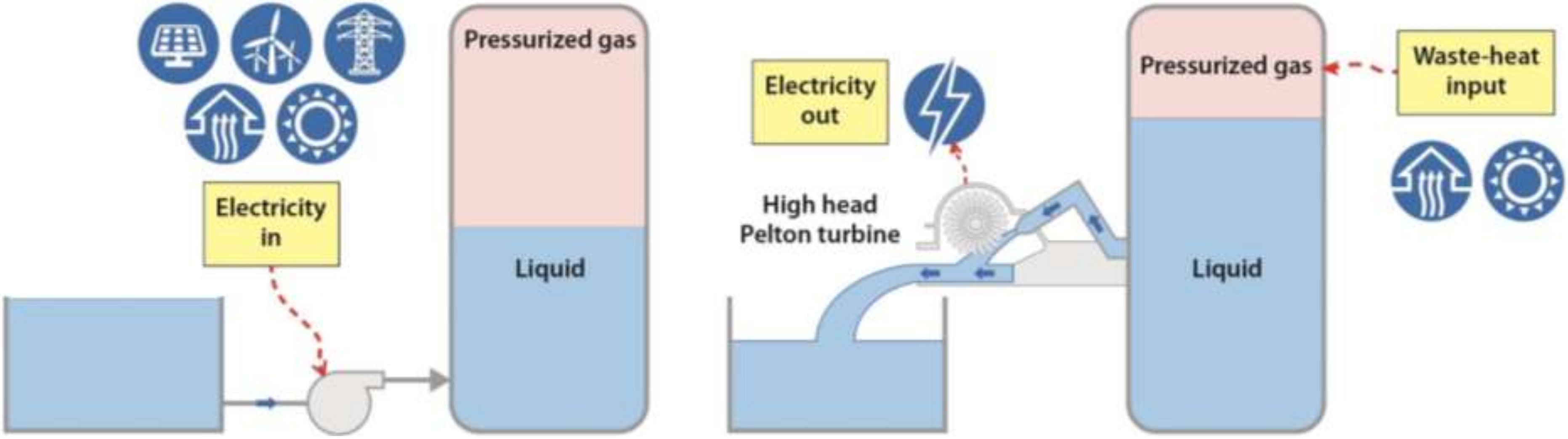
07/25/2017

Talk Outline

- Overview of the GLIDES energy storage technology
- Motivation for this work
- Cost model (buildings use-case)
- Results
- Conclusions and future work

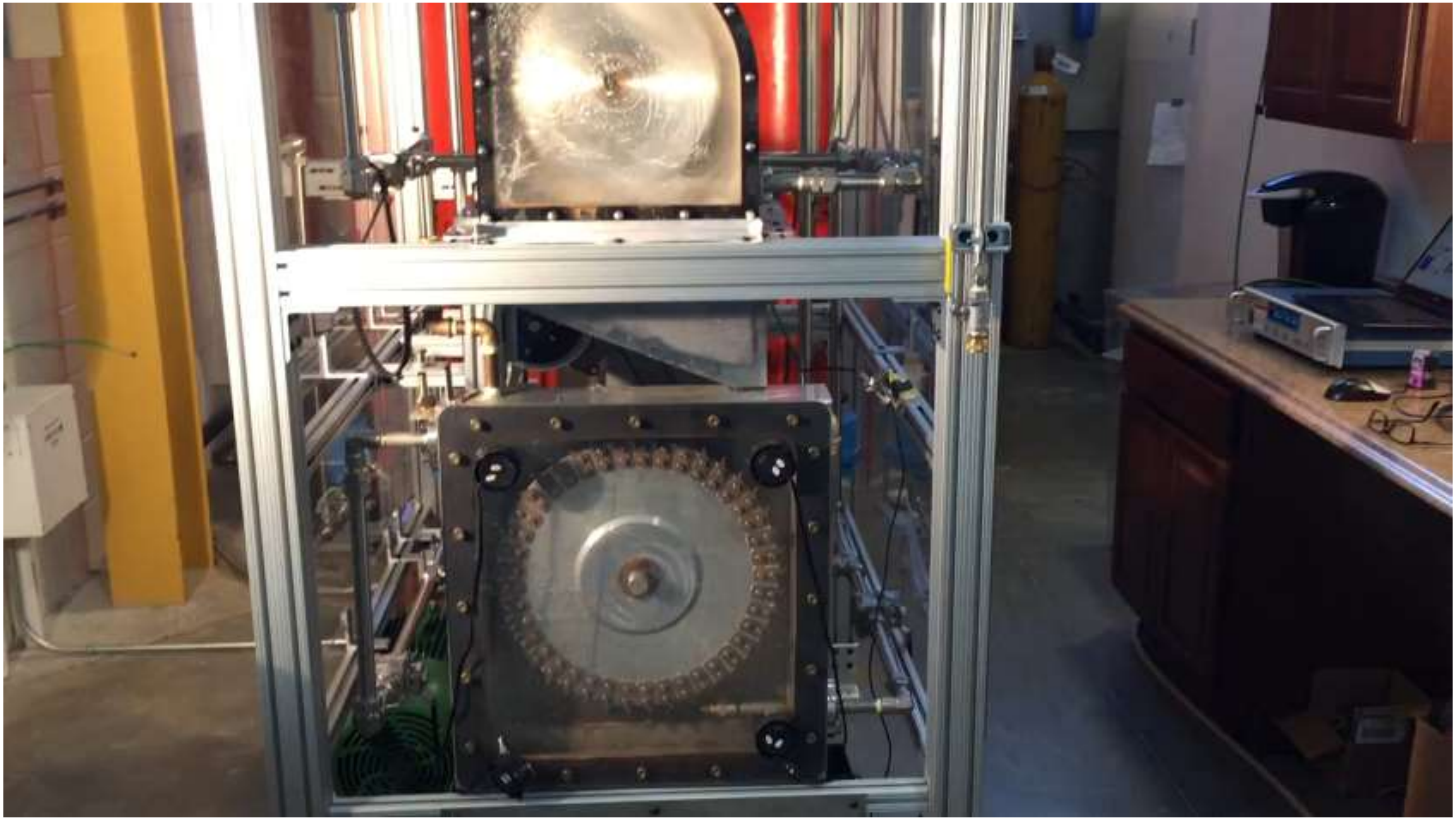
The GLIDES concept

Objective: Develop a unique, low-cost, high round trip efficiency storage technology for a) small scale building applications b) large scale modular pump hydro storage.



Key advantages	
Simple, low cost	Dispatchable, scaleable
Accepts heat and/or electricity as inputs	Decouples power/energy storage capacity
High round-trip efficiency	Terrain independent

The GLIDES concept

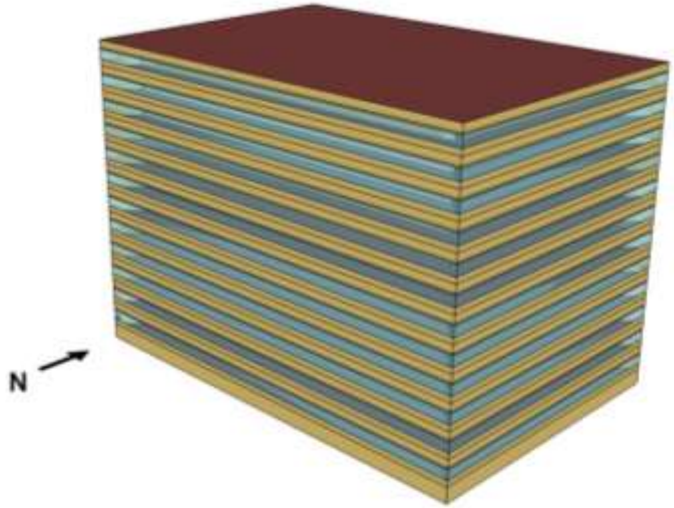


ES for Buildings

- Utility companies charge buildings with high power draws a monthly demand charge (based on the highest draw sustained for a certain length of time, usually 15 minutes).
- Demand charge and energy charge vary throughout the day (highest during peak periods).
- Storage can provide value by reducing peak draw and shifting time of use.
- Question: At what storage cost ($/kWh) does investment make sense, based on resulting savings?

ES for Buildings

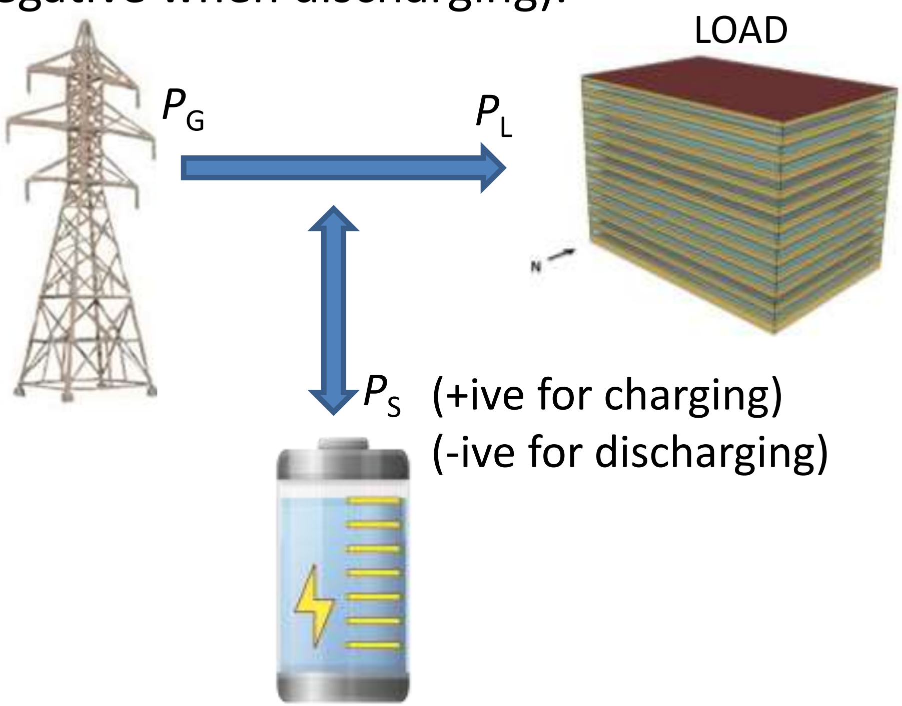
- Study:
  - Determine target storage system cost ($/kWh) based on electric utility bill savings resulting from peak reduction and time-of-use shifting.
  - Use EnergyPlus and DOE Large Office reference building as case study.
  - Optimization model to determine when to charge/discharge storage to maximize savings.



DOE E+ Large Office reference building (498, 600 ft^2)

ES for Buildings

- Optimization model:
  - Built using MATLAB optimization toolbox
  - Building load in 15 minute timesteps (output from E+) is fed in.
  - Storage is modeled as a load additional to building load (positive when charging, negative when discharging).

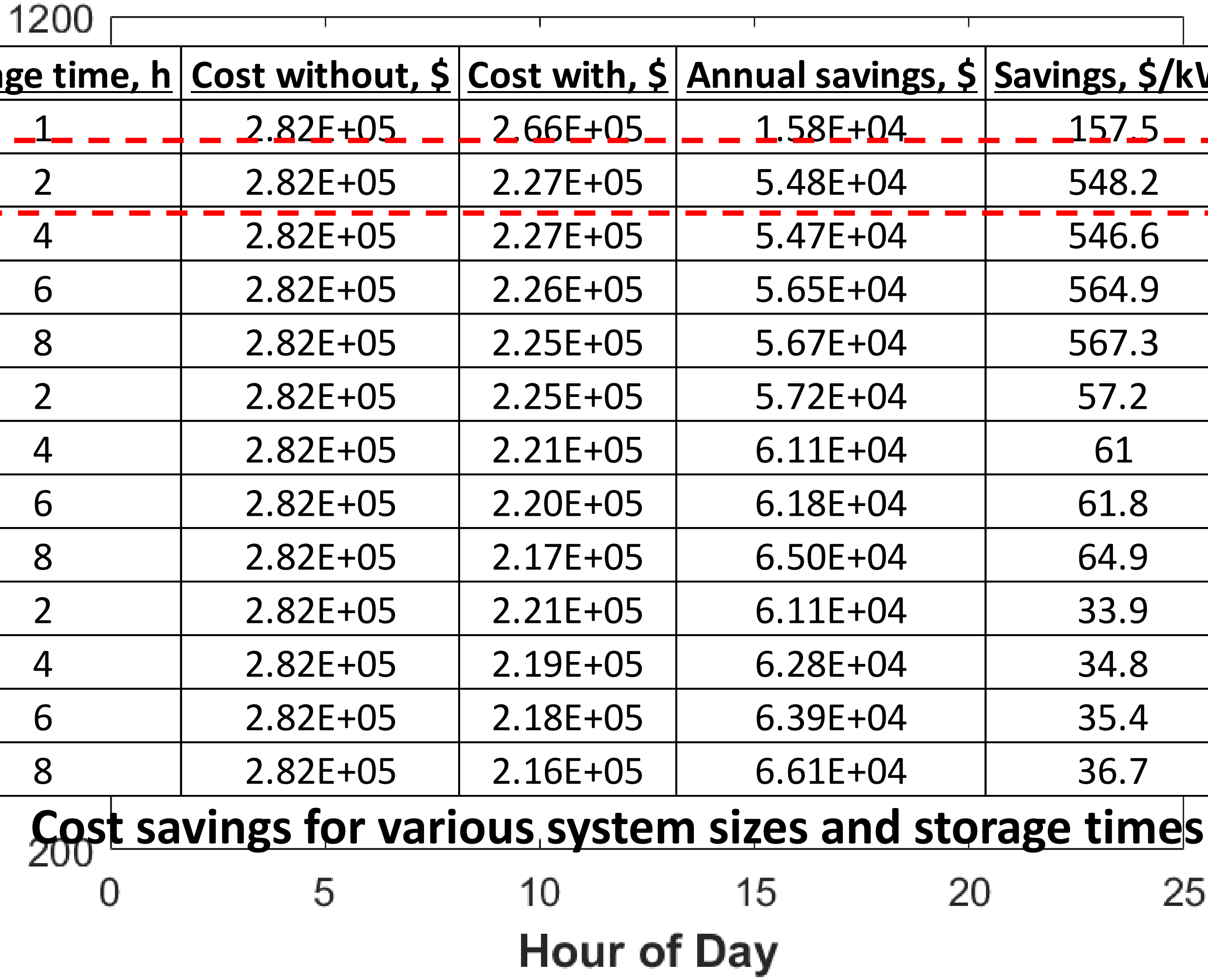


Total consumption = storage consumption · η + building consumption

Cost = energy charge · total kWh + demand charge · maximum power draw

Case Study – Los Angeles

Sample daily power demand profile



Power, kW	Storage time, h	Cost without, $	Cost with, $	Annual savings, $	Savings, $/kW	Savings, $/kWh
100	1	2.82E+05	2.66E+05	1.58E+04	157.5	157.5
100	2	2.82E+05	2.27E+05	5.48E+04	548.2	274.1
100	4	2.82E+05	2.27E+05	5.47E+04	546.6	136.6
100	6	2.82E+05	2.26E+05	5.65E+04	564.9	94.1
100	8	2.82E+05	2.25E+05	5.67E+04	567.3	70.9
1000	2	2.82E+05	2.25E+05	5.72E+04	57.2	28.6
1000	4	2.82E+05	2.21E+05	6.11E+04	61	15.2
1000	6	2.82E+05	2.20E+05	6.18E+04	61.8	10.3
1000	8	2.82E+05	2.17E+05	6.50E+04	64.9	8.1
1800	2	2.82E+05	2.21E+05	6.11E+04	33.9	16.9
1800	4	2.82E+05	2.19E+05	6.28E+04	34.8	8.7
1800	6	2.82E+05	2.18E+05	6.39E+04	35.4	5.9
1800	8	2.82E+05	2.16E+05	6.61E+04	36.7	4.5

Cost savings for various system sizes and storage times

Case Study – Los Angeles

- Estimating target initial capital cost:
  - Calculate present value of annual savings over target payback period

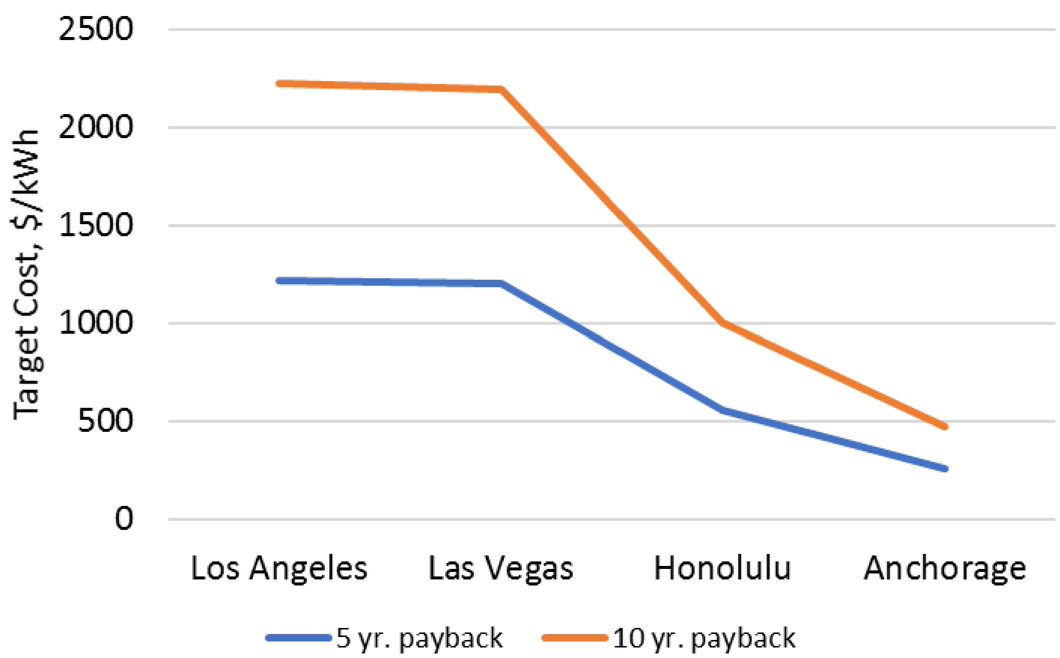
$$PV = C\left[\frac{1-(1+i)^{-n}}{i}\right]$$

Payback time, yrs	Target cost, $/kWh
1	263.56
2	516.98
5	1220.24
10	2223.20

* i = 4% interest rate assumed

Other U.S. Locations

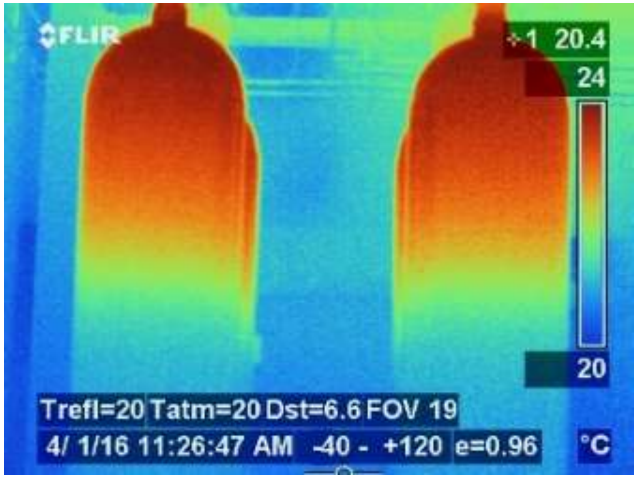
	Capacity, kW	Capacity factor, kW/kW	Storage time, h	Annual savings, $/kWh
Los Angeles	100	0.057	2	274.1
Las Vegas	100	0.051	1	270.9
Honolulu	100	0.052	1	123.9
Anchorage	50	0.033	1	57.8



Conclusions

- Stand-alone, ‘behind the meter’ storage can provide value in certain markets.
- Can afford to spend generous amounts on storage in some cases, depending on desired payback period.
- Small storage capacity (relative to peak building load) and storage times provide highest value.
- Next steps:
  - Expand study to include more locations, building sizes, and building types.

Thank You



Infrared thermal image of GLIDES prototype storage vessels during charging

GLIDES first- generation proof-of-concept prototype

OAK RIDGE National Laboratory

NSF

IGERT INTEGRATIVE GRADUATE EDUCATION AND RESEARCH TRAINEESHIP

The Future of Solar + Storage is Non-Wires Alternatives

Forum and Celebration of Energy Transitions

VOTE SOLAR

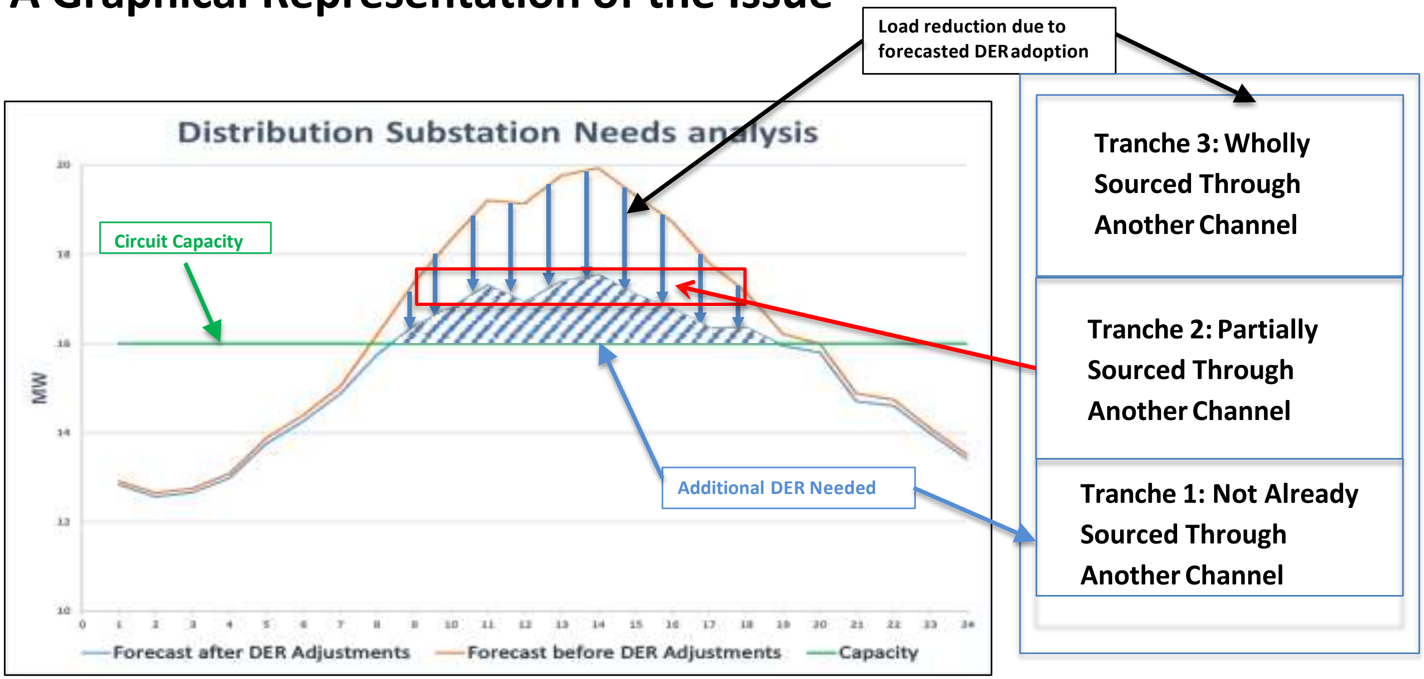
Caroline Golin, Regulatory Director

Distributed Energy Resources (DER) as Non-Wire Alternatives (NWAs)

VOTE SOLAR

- **Using DERs as non-traditional investments to defer or replace the need for specific equipment upgrades or replacements in the Transmission and Distribution (T&D) system.**
- Recognizing the current and **future role of DERs** in the distribution planning process.
- Not just including DER growth in Distributed Resource Planning but **utilizing DERs to serve grid needs**
- Determining the '**right' business and regulatory model**

A Graphical Representation of the Issue



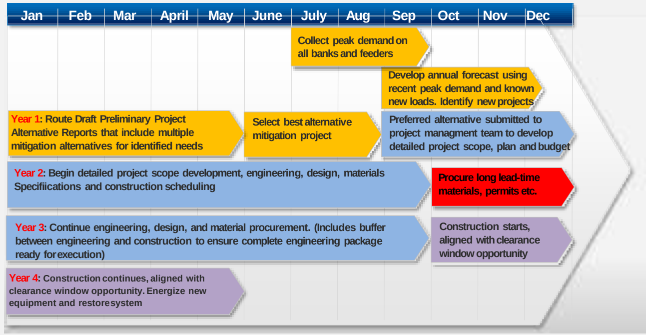
VOTE SOLAR

Forecasted DER Adoptions Include:

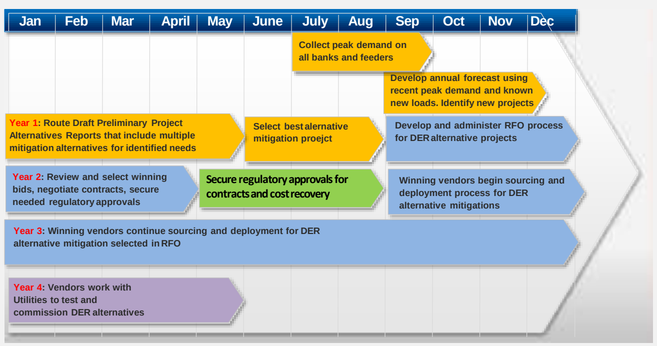
- impacts of future energy efficiency programs , codes and standards
- impacts of future time dependent rates (load modifying demand response)
- impacts of future behind the meter distributed generation (primarily PV)
- impacts of future electric vehicle adoption

PG&E, SDGE, SoCal Edison. IDER Incentive Pilots DPAG Meeting # 4. Joint IOU Presentation. Double Counting / Incrementality. March 30, 2017

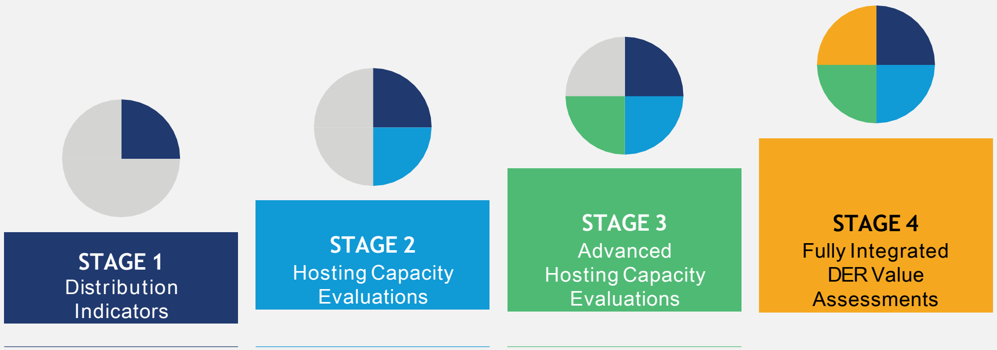
Illustrative: 'Wires' Project Timeline



Illustrative: 'Non-Wires' Project Timeline



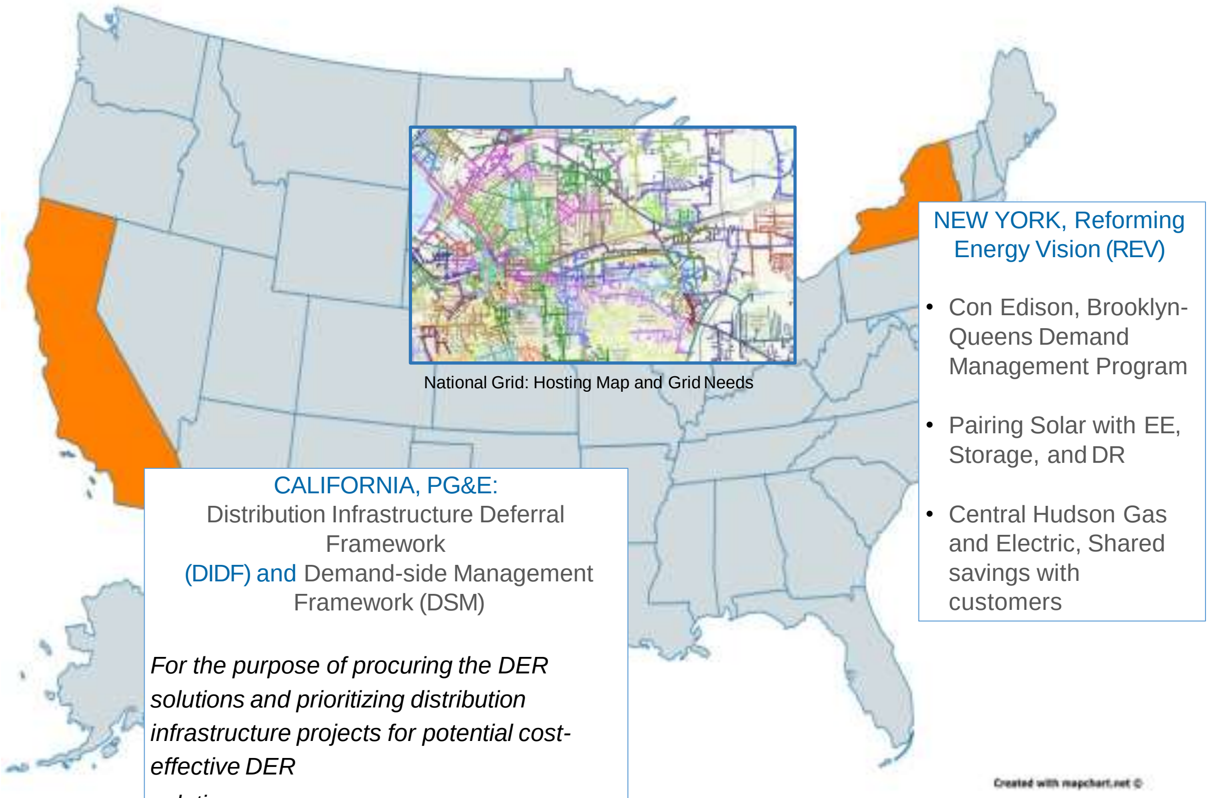
VOTE SOLAR



- Data is imperative at every stage
- Getting the Value Right will set a better market and outcome for utility

3.Joint Utilities of New York, Supplemental Distributed System Implementation Plans (SDSIP) Final, 2016. http://jointutilitiesofny.org/wp-content/uploads/2016/10/3A80BFC9-CBD4-4DFD-AE62-831271013816.pdf
4.PG&E, SDGE, SoCal Edison. IDER Incentive Pilots DPAG Meeting # 2. Joint IOU Presentation Distribution Planning Process & Proposed Distribution Investment Deferral Framework March 16, 2017

Two Case Studies: DERs as NWAs



National Grid: Hosting Map and Grid Needs

NEW YORK, Reforming Energy Vision (REV)

- Con Edison, Brooklyn-Queens Demand Management Program
- Pairing Solar with EE, Storage, and DR
- Central Hudson Gas and Electric, Shared savings with customers

CALIFORNIA, PG&E:
Distribution Infrastructure Deferral Framework
(DIDF) and Demand-side Management Framework (DSM)

For the purpose of procuring the DER solutions and prioritizing distribution infrastructure projects for potential cost-effective DER solutions.

VOTE SOLAR

Pairing Solar + Storage to serve as a grid asset.

Critical in advancing the market!

http://ngrid.maps.arcgis.com/apps/MapSeries/index.html?appid=4c8cfd75800b469abb8febca4d5dab59&folderid=8a8a74bf834613a04c19a68eefb43b.

What do we need to utilize DERs as NWAs?

VOTE SOLAR

- **Strong Distributed Resource Planning (DRP) Process**, including third-party providers and detailed forecasting/mapping of DERs on the system

- Develop integrated distribution resource planning **framework wherein distributed energy resources are explicitly considered as resource options** in the T&D Planning Process.

- Evaluation of **DER locational net benefits** versus traditional infrastructure upgrades or resources

- **Strong Request for Proposal Process** (RFP) that allows for all technologies to compete to service a specific grid need

Questions

ENERGY EFFICIENCY AND SOLID STATE LIGHTING

Setting the stage by Georgia Tech NSF IGERT Faculty:
--Professor Bernard Kippelen, Electrical and Computer Engineering
--Professor Valerie Thomas, Industrial and Systems Engineering

Research results presented by Georgia Tech NSF Fellows:
Materials and Systems
--Ryan Murphy, Materials Science and Engineering,
Policy and Economics
--Mallory Flowers, School of Public Policy

Energy Efficiency and Solid-State Lighting: An introduction

Bernard Kippelen

Joseph M. Pettit Professor in Electrical and Computer Engineering
Director, Center for Organic Photonics and Electronics

kippelen@gatech.edu
404 385-5163

Legacy technology

- ❑ 60 Watts
- ❑ 900 lumens
- ❑ 15 lm/W
- ❑ 1,500 h

…see you in the museum.

Innovation

INORGANIC SEMICONDUCTORS

Novel compound semiconductors grown by MOVCD or MBE (e.g. GaN)

INSTITUTLAFAYETTE

OLEDs

ORGANIC SEMICONDUCTORS

Processed over large area at room temperature. The future is flexible.

Performance comparison

Table 5-1. Performance Parameters for Lamps Considered in this Analysis

Characteristics	Incandescent	CFL	LED lamp – 2012	LED lamp – 2017
Power Consumption	60 watts	15 watts	12.5 watts	6.1 watts
Lumen Output	900 lumens	825 lumens	812 lumens	824 lumens
Efficacy	15 lm/W	55 lm/W	65 lm/W	134 lm/W
Lamp Lifetime	1500 hours	8000 hours	25,000 hours	40,000 hours
Total Lifetime Light Output	1.35 Mlm-hr	6.6 Mlm-hr	20.3 Mlm-hr*	33.0 Mlm-hr
Impacts Scalar	15.04	3.08	1.00	0.61

* In Part 1 of DOE's study (*Review of the Lifecycle Energy Consumption of Incandescent, Compact Fluorescent and LED Lamps*), 20 megalumen-hours was selected as the functional unit for comparison of the energy use. In this study (Part 2), we use the same functional unit as a normalizing scalar to ensure the impacts are comparable.

Solid State Lighting (SSL)

"Solid-state lighting has contributed to more than $2.8 billion in U.S. energy cost savings over the past 15 years, and further SSL technology advances will increase those savings even more in the years to come. By 2035, SSL could reduce national lighting electricity use by 75% -- which would equate to the total energy consumed by 45 million American homes today and could save American families and businesses $50 billion annually, not to mention add jobs and boost the economy."

U.S. DEPARTMENT OF ENERGY

Beyond energy savings

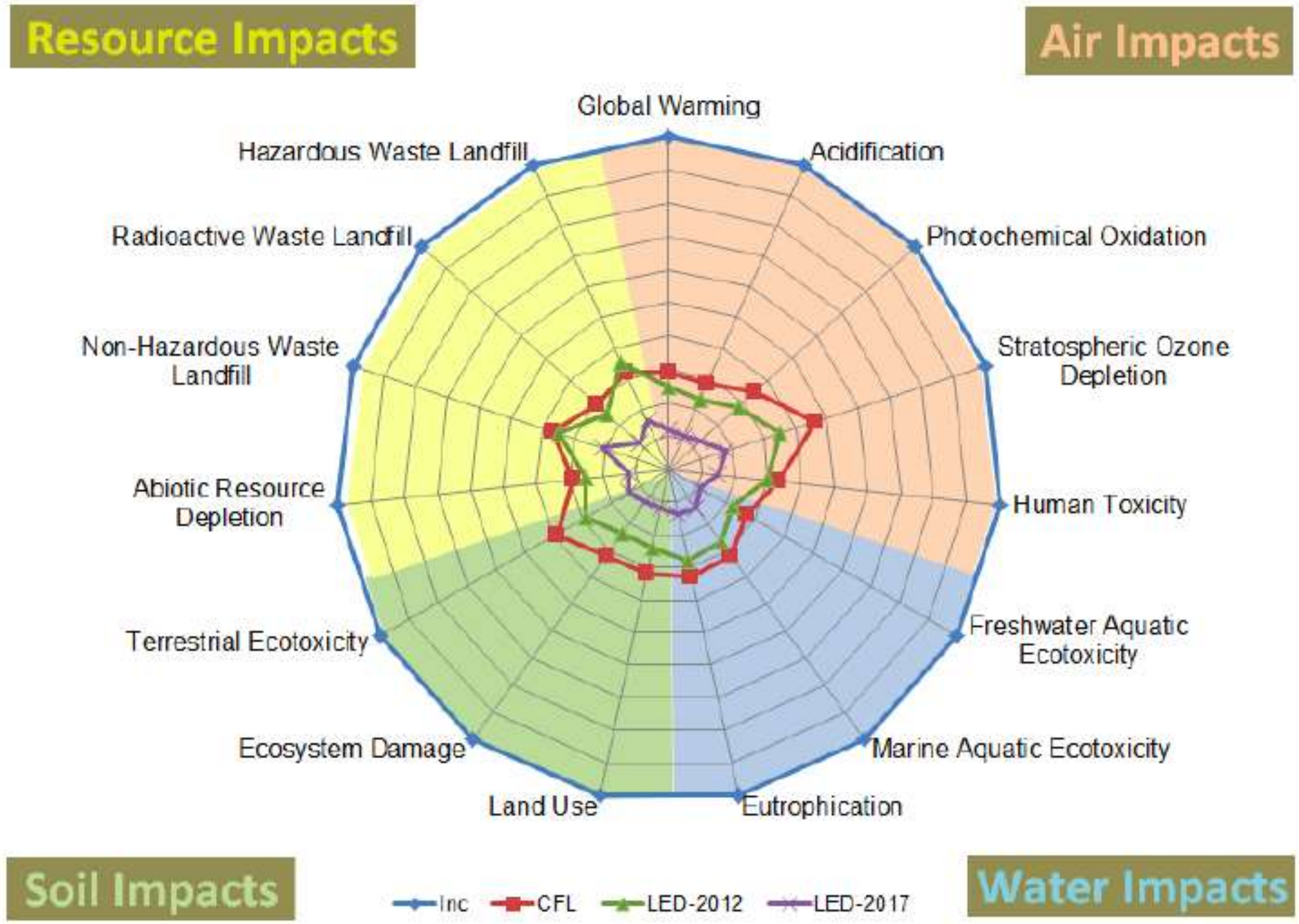


Figure 1-1. Life-Cycle Assessment Impacts of the Lamps Analyzed Relative to Incandescent

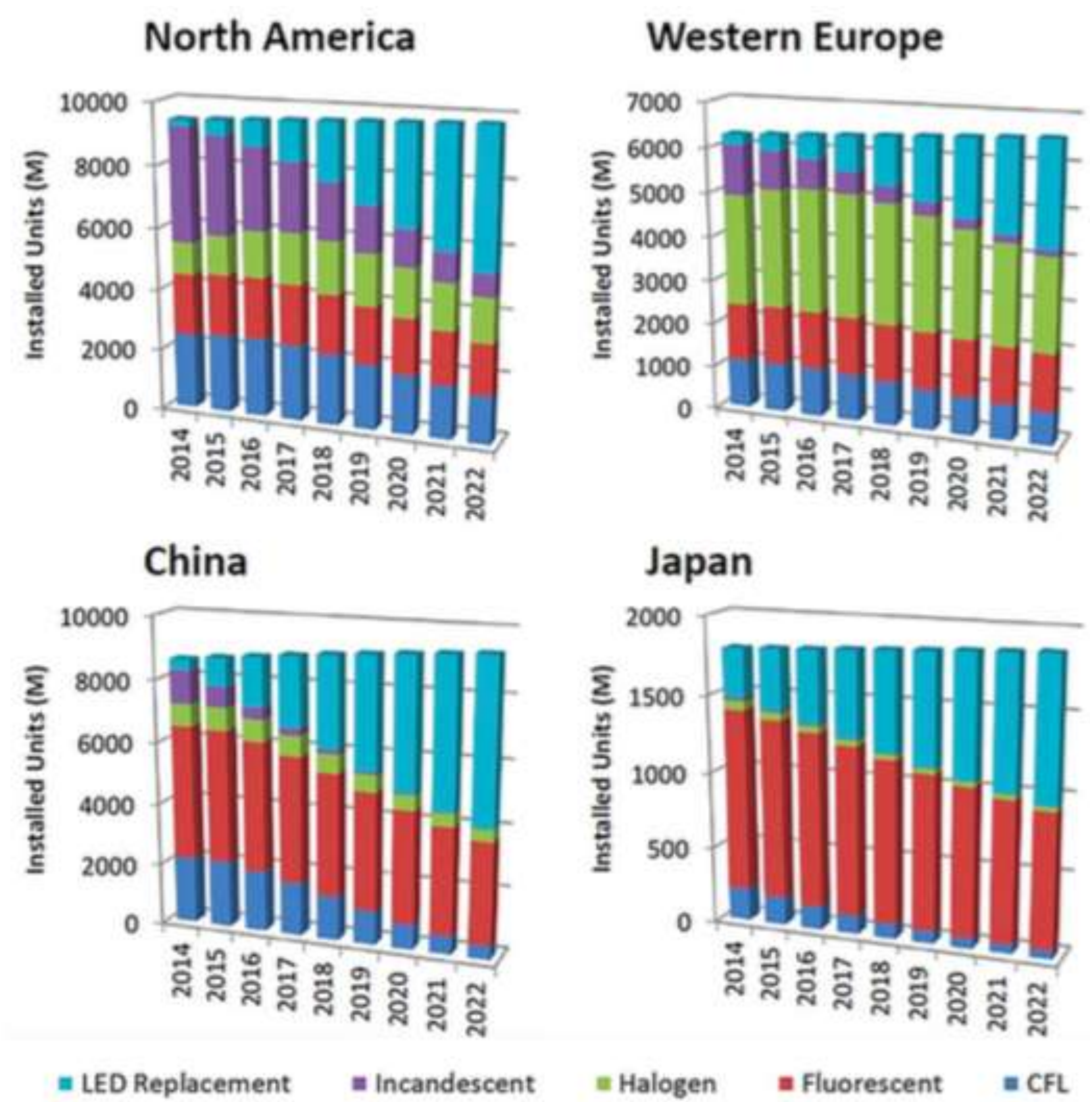
Energy Efficiency and Solid-State Lighting: An introduction

Valerie Thomas

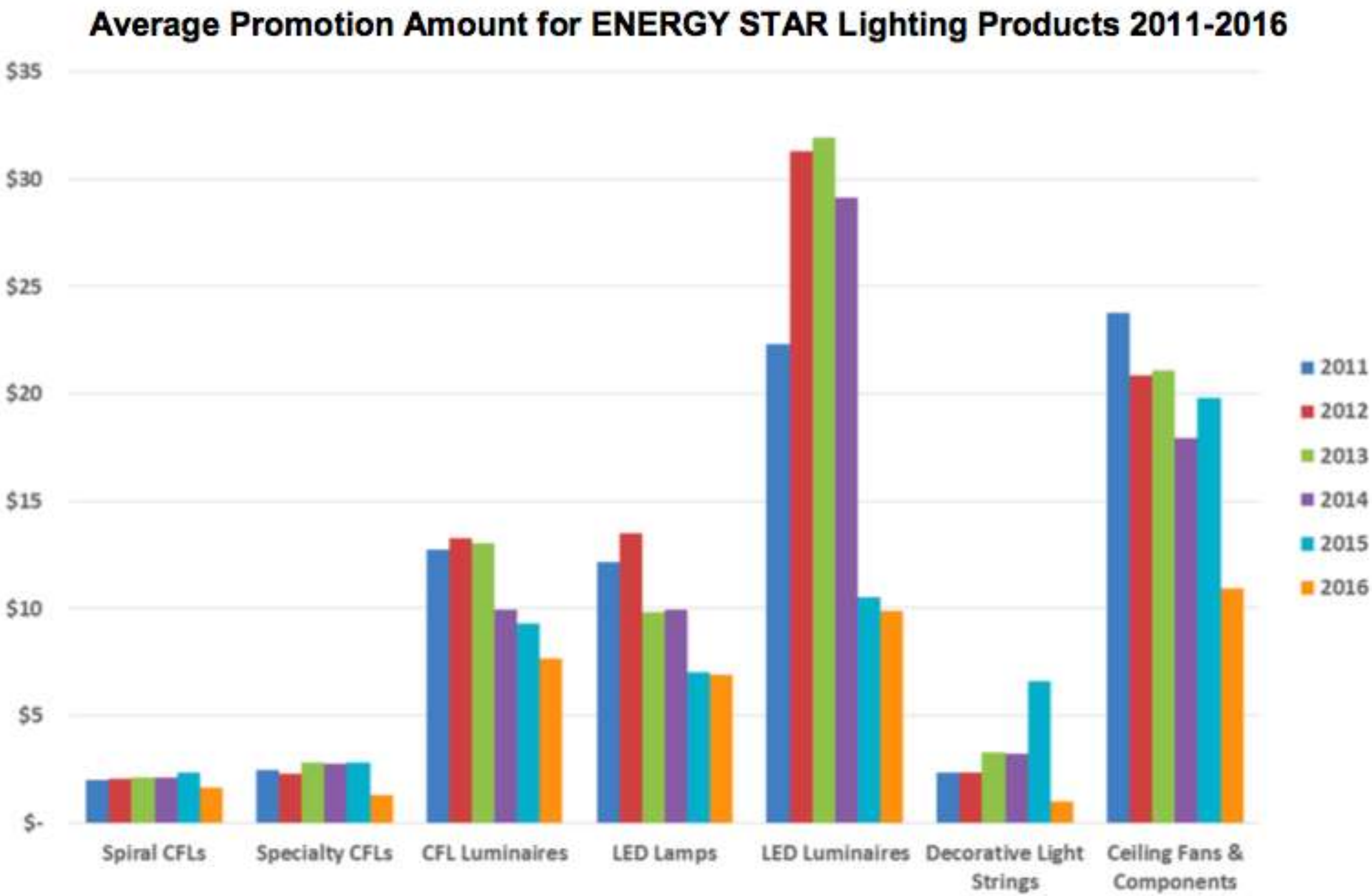
Anderson Interface Professor
in Industrial and Systems Engineering and Public Policy

vt34@gatech.edu
404 385-7254

Japan Led Early Adoption
Due to Prioritizing Energy Savings after Fukushima

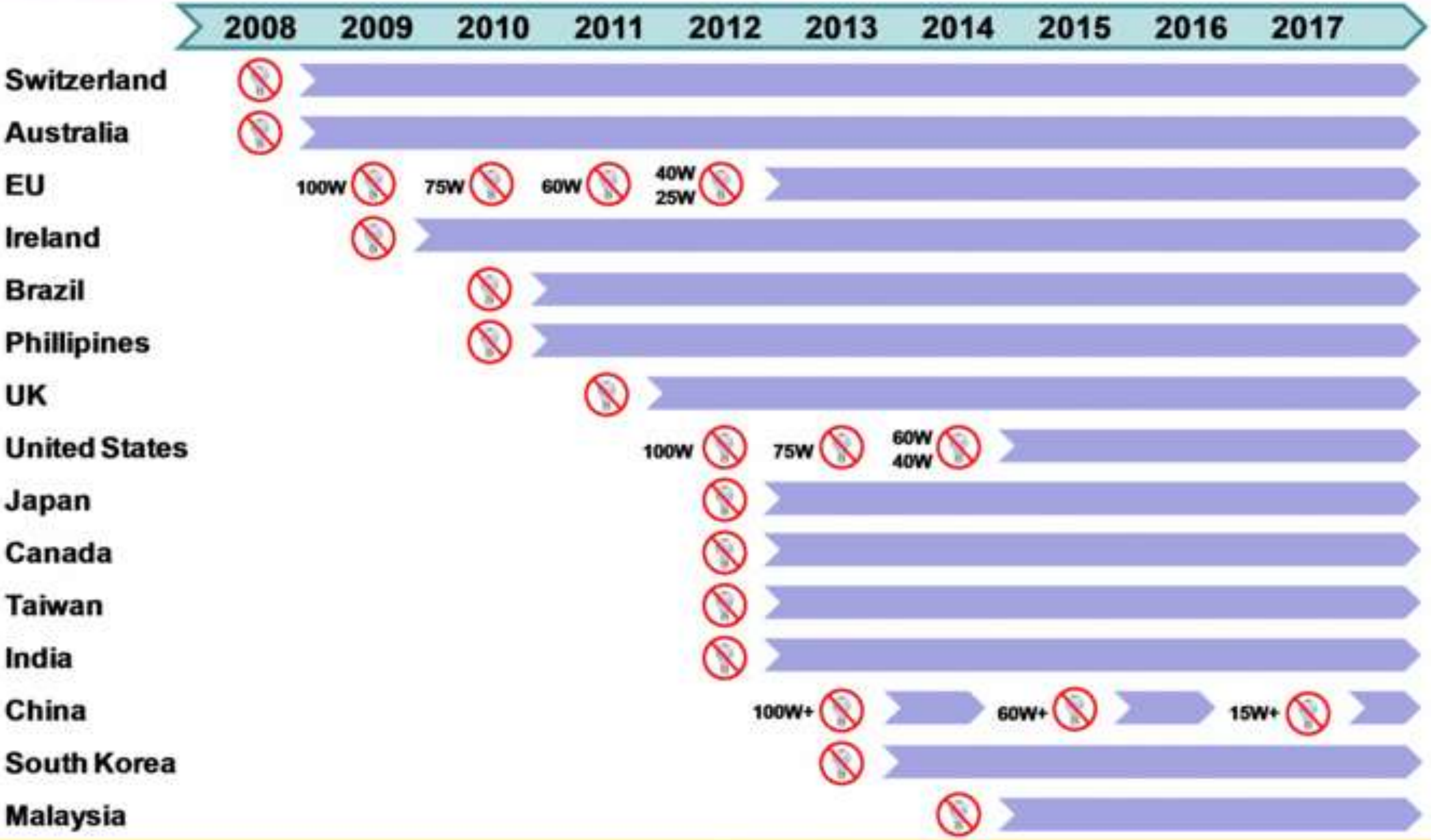


EIA, 2016, Energy Star Summary of Lighting Programs




GENERAL PURPOSE & DECORATIVE BULBS
(MEDIUM SCREW BASE)
PHASE OUT
BY 1/1/2012
REPLACE WITH
100 Watt A19
72 Watt
Halogen
OR
23 Watt
Compact
Fluorescent
PHASE OUT
BY 1/1/2013
REPLACE WITH
75 Watt A19
43 Watt
Halogen
OR
19 Watt
Compact
Fluorescent
PHASE OUT
BY 1/1/2014
REPLACE WITH
60 Watt A19
43 Watt
Halogen
OR
13 Watt
Compact
Fluorescent
OR
12 Watt
LED

Incandescent Light Bulb Phase Outs Occurring Now



Global Phase Out of Incandescent Bulbs, Combined with Declining LED Prices Will Trigger Next Phase of LED Lighting Adoption

Source: LEDinside, PiperJaffray 10/2011, Morgan Stanley 9/14/2011

"Challenges of Solid State Lighting Adoption"

Ryan Murphy

School of Materials Science and Engineering

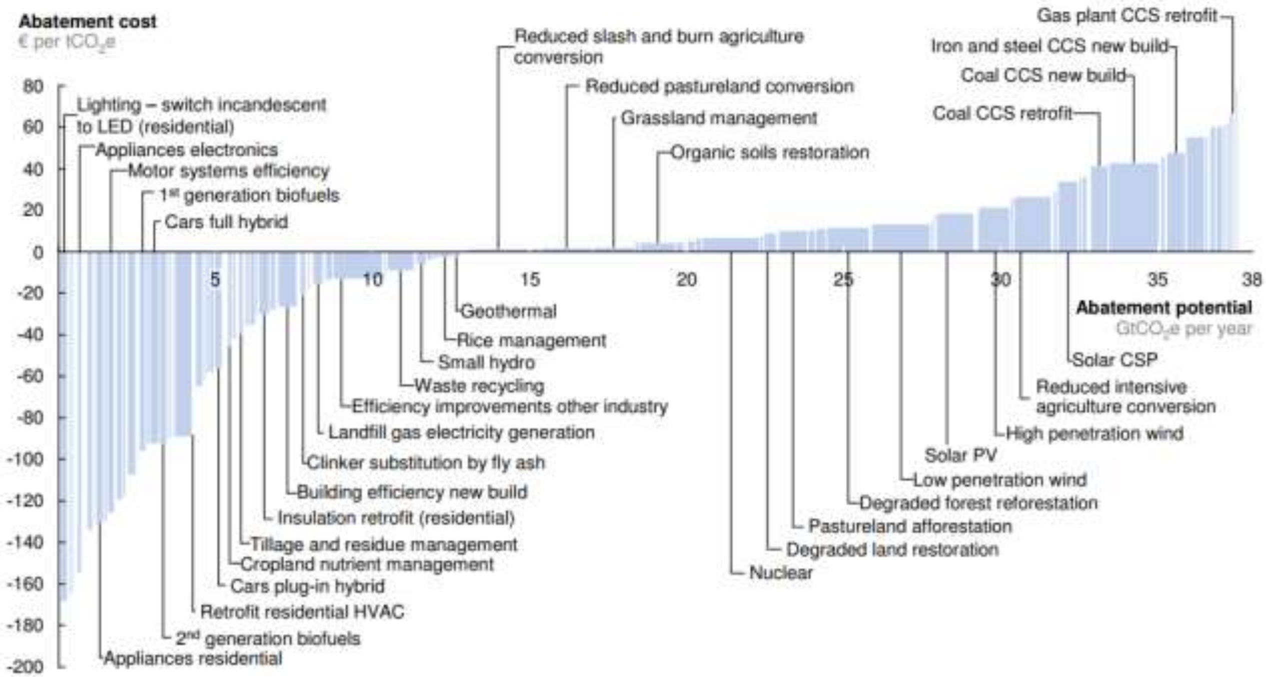
rjmurphy@gatech.edu

Outline

- Advantages of LEDs
- Challenges of LEDs and LED Adoption
- New Technologies and Policies to Improve LED Adoption

A Reduction in Energy Consumption Does not Have to Cost the Economy!

V2.1 Global GHG abatement cost curve beyond BAU – 2030



McKinsey & Company, *Version 2.1 of the Global Greenhouse Gas Abatement Cost Curve*, 2010

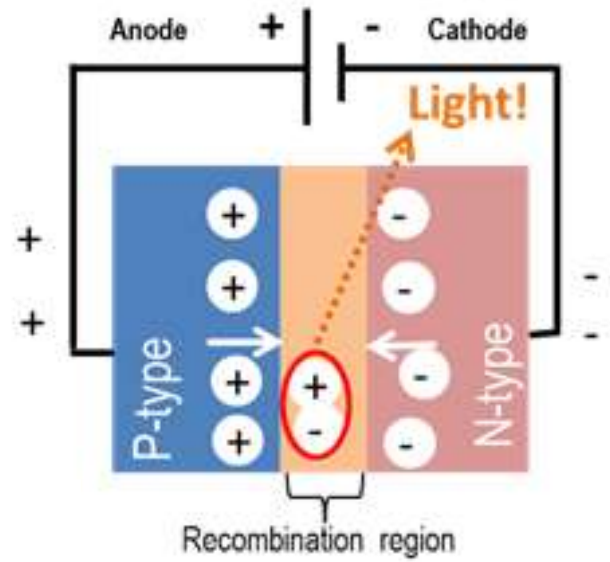
Simple Estimations Show Huge Savings Over Traditional Incandescent Bulbs

	LED	Incandescent
Upfront cost	$8	$1
Energy	11 watts	60 watts
Lifetime	50,000	1,200
Power @ 6 hours per day	66 Wh/day	360 Wh/day
Cost per day @ 7 ₵ per kWh	0.46 ₵	2.52 ₵
Cost per year @ 7 ₵ per kWh	$1.69	$9.20

Assuming you have to replace the incandescent bulb at least once in the first year (avg lifetime 200 days), you break even after 291 days

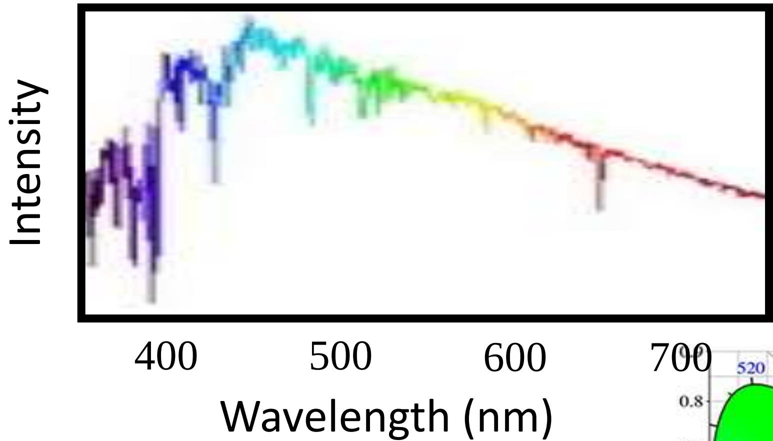
Over the lifetime of a LED (~23 years) you save $205

Lighting has Become More Efficient but Also More Complicated

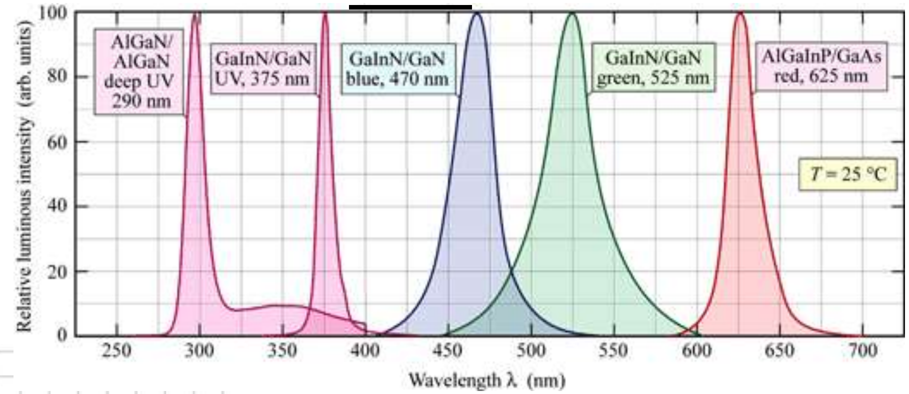


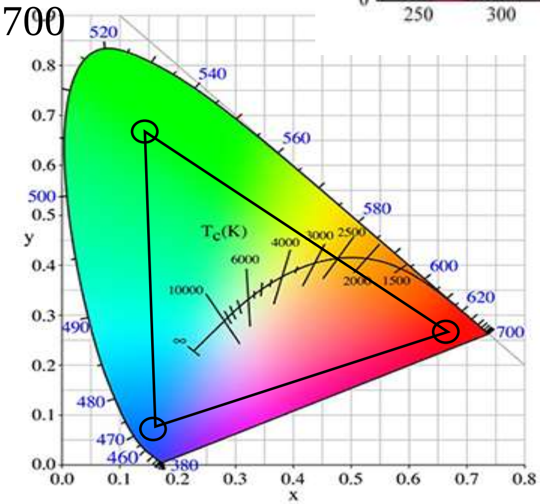
...And to Create Natural Looking Light is Even More Difficult

Sunlight



LEDs



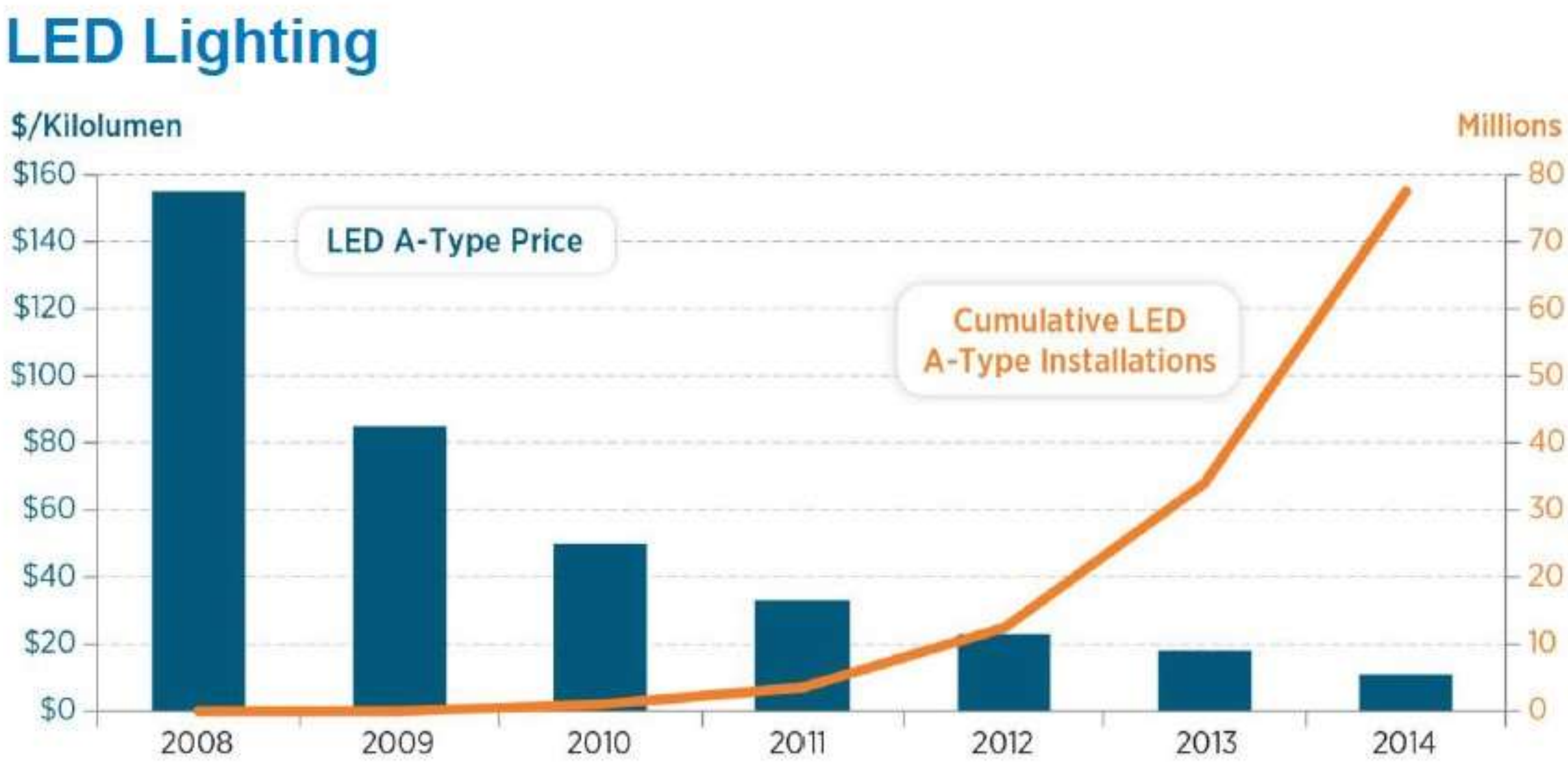


Kirk-Othmer Encyclopedia of Chemical Technology (John Wiley & Sons, Inc., Hoboken, NJ, USA, 2000).
S. Keeping, How the CIE Color Space is Used to Design Better LEDs. *Digi-Key Artic. Libr.*

Despite Their Low Overall Cost, LEDs have not Been as Widely Adopted as Expected

- High Up-Front Costs
- Lack of Clear Information
  - Lumens
  - Equivalent Watts vs. Watts Consumed
  - Color Temperature
- Color Stigmatization

As With Most Electronics, LED Cost will Decline as Demand and Production Increases



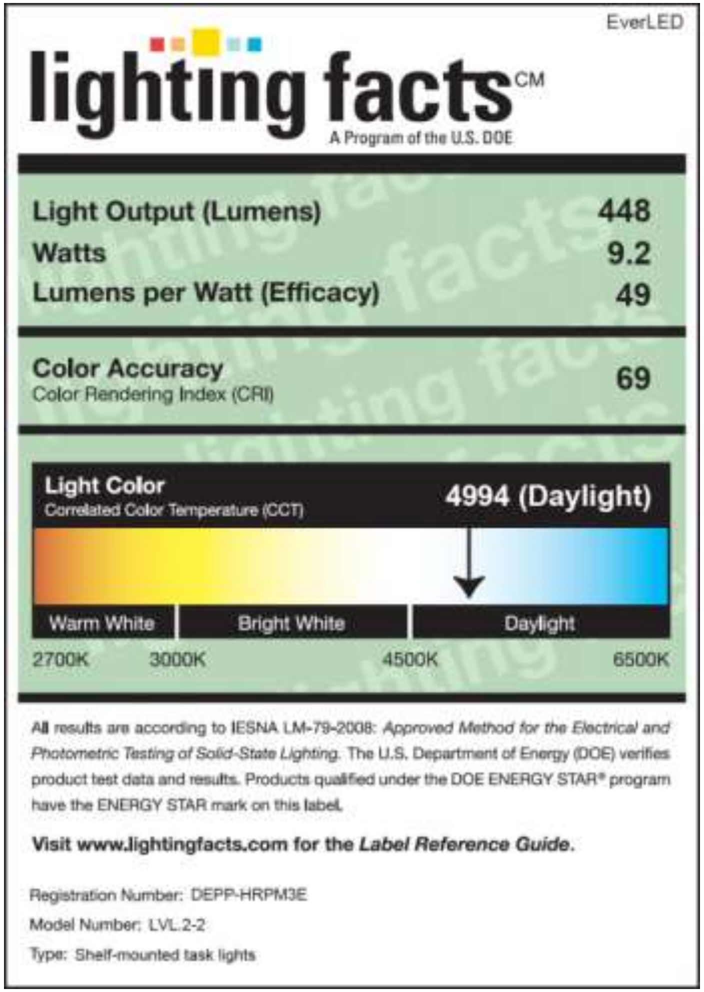
Source: DOE

Setting Standards for Lightbulb Efficiencies can Increase LED Demand

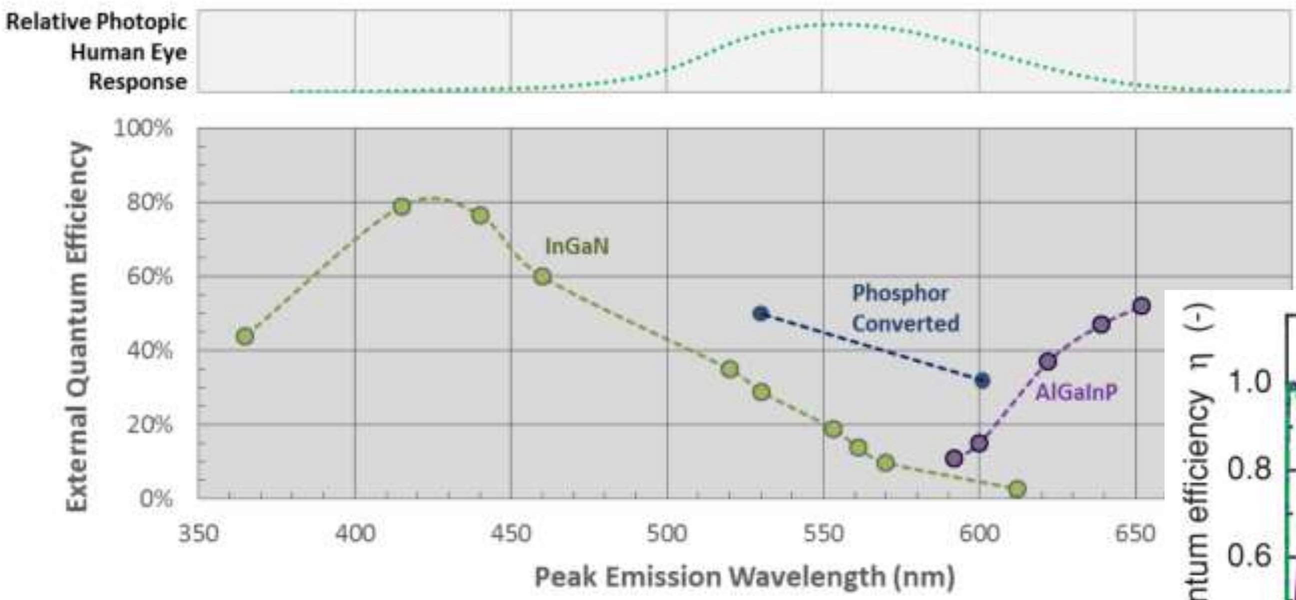
- In 2012, the *Energy Independence and Security Act of 2007* began to require all light bulbs be at least 25% more efficient than traditional incandescent bulbs

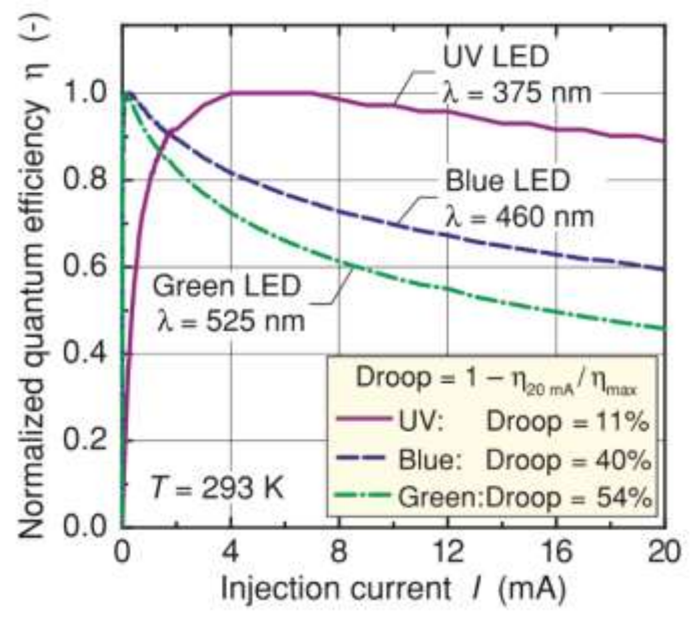
Source: DOE

Clear Information is Key to Removing Stigma

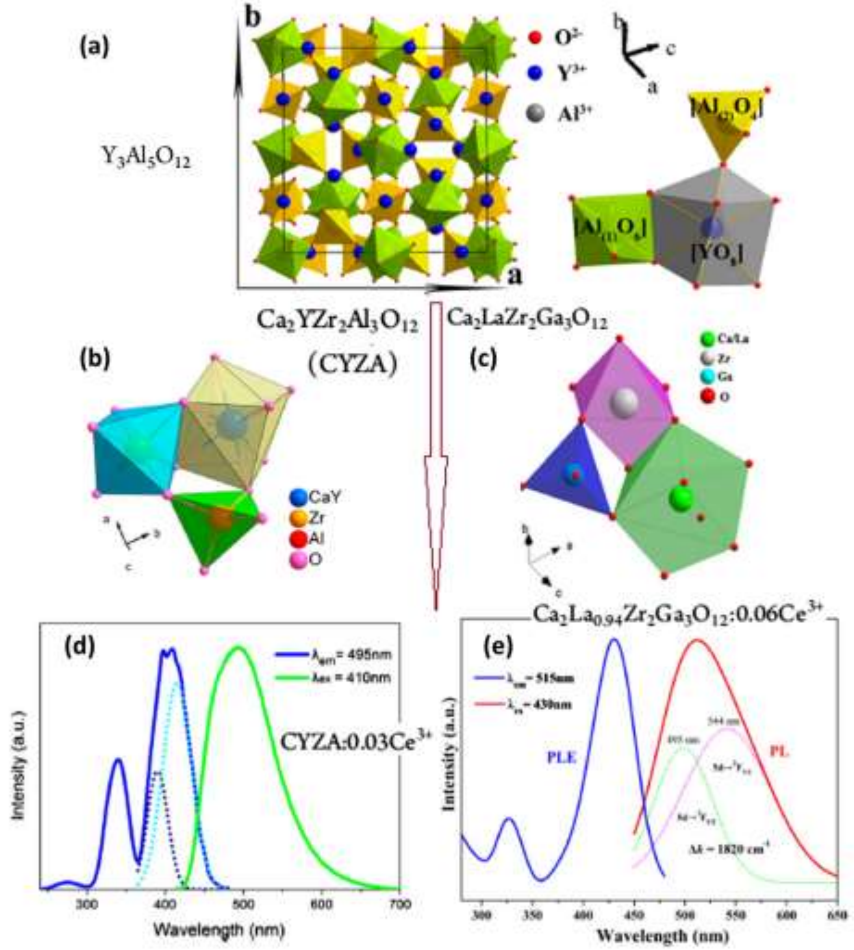


The Difficulty of Improving the Color Accuracy of LEDs is Green Light





Improving Phosphor Efficiency

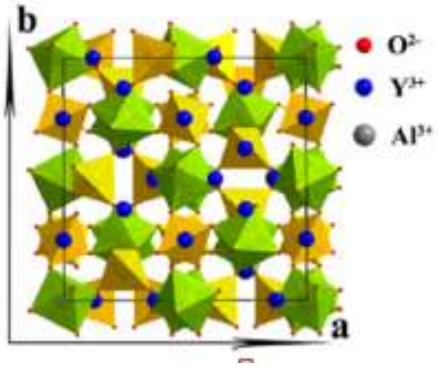


Z. Xia, Q. Liu / Progress in Materials Science 84 (2016) 59–117

Smart Bulbs Can Help Displace Stigma and Further Reduce Energy Usage

Policy, New Materials, and Smart Devices Togeather Can Address the Challenges of Solid State Lighting

$Y_3Al_5O_{12}$



Acknowledgements

- Kera Allen, School of Public Policy
- Usayd Casewit, School of Public Policy
- Carolyn Buckley, School of Chemistry and Biochemistry

- NSF IGERT Program

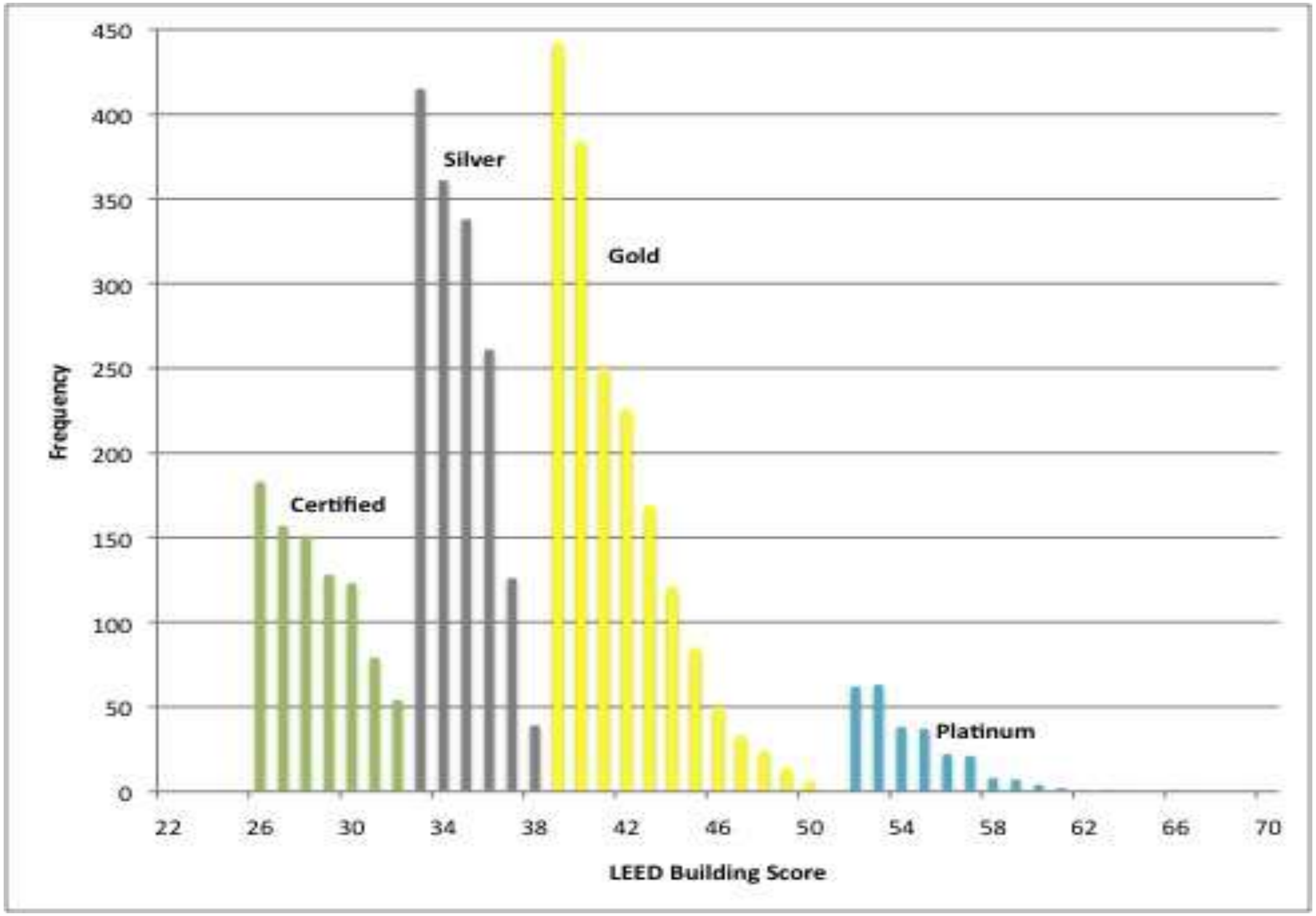
Energy Efficiency & SSL in the Built Environment

- Traditional Policy Approaches
- Market-based Approaches

Theory: Why Volunteer for Certification?

- Market premiums from signaling green
- Improved employee/occupant experience
- Reduced utility bills

Practice: What is the Market Signal Worth?



Findings

- Certification incentivizes:

  Energy & Water Efficiency

- But is more limited at promoting:

  Indoor Environmental Quality

  (Low-VOC materials, Improved Ventilation, etc)

  Provision of Public Goods

  (Habitat Protection, Stormwater Controls, Albedo Effects, etc)

Break

- Restrooms
- Snacks/Drinks
- 15 minutes

"The Third Industrial Revolution"

How it Might "Future-Proof" the Economy and Make It Much More Sustainable than Imagined *

John A. "Skip" Laitner

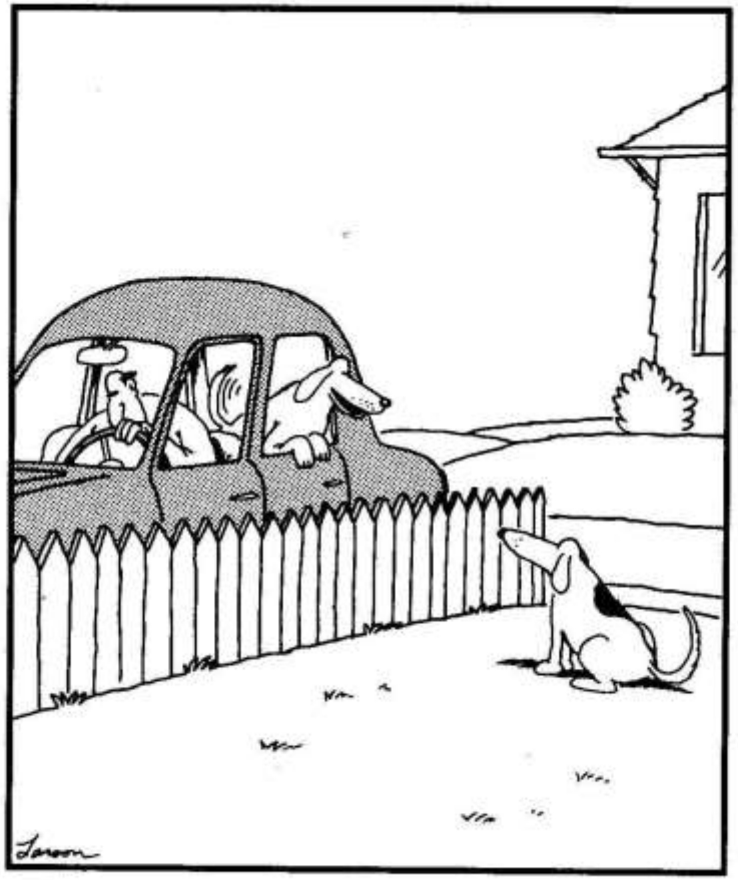
Economic and Human Dimensions Research Associates

and

Russian Presidential Academy of National Economy

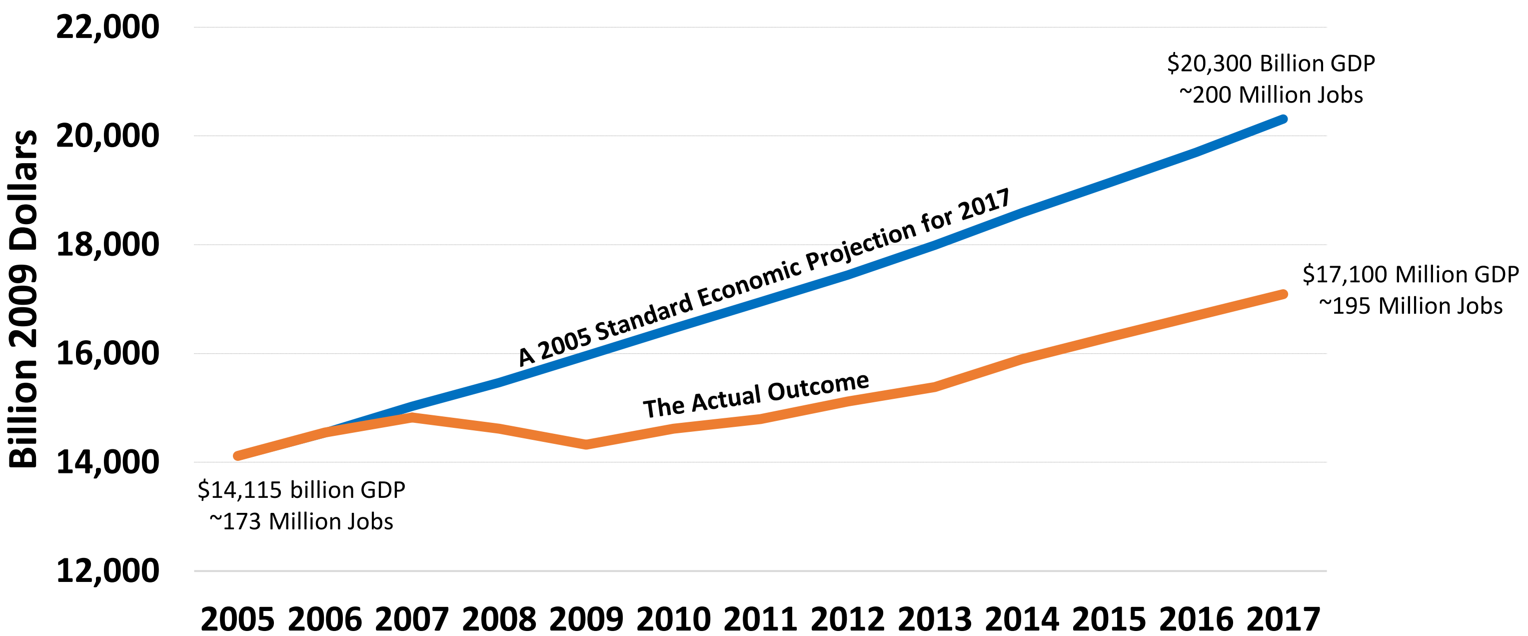
*** In the spirit and tradition of Nobel Laureate and former Caltech physicist Richard Feynman, in his 1959 visionary talk, "There's Plenty of Room at the Bottom." See, http://www.its.caltech.edu/~feynman/plenty.html.**

Not a Frivolous Assertion: Small Differences in Assumptions Can Make a Very Real Difference in Outcomes



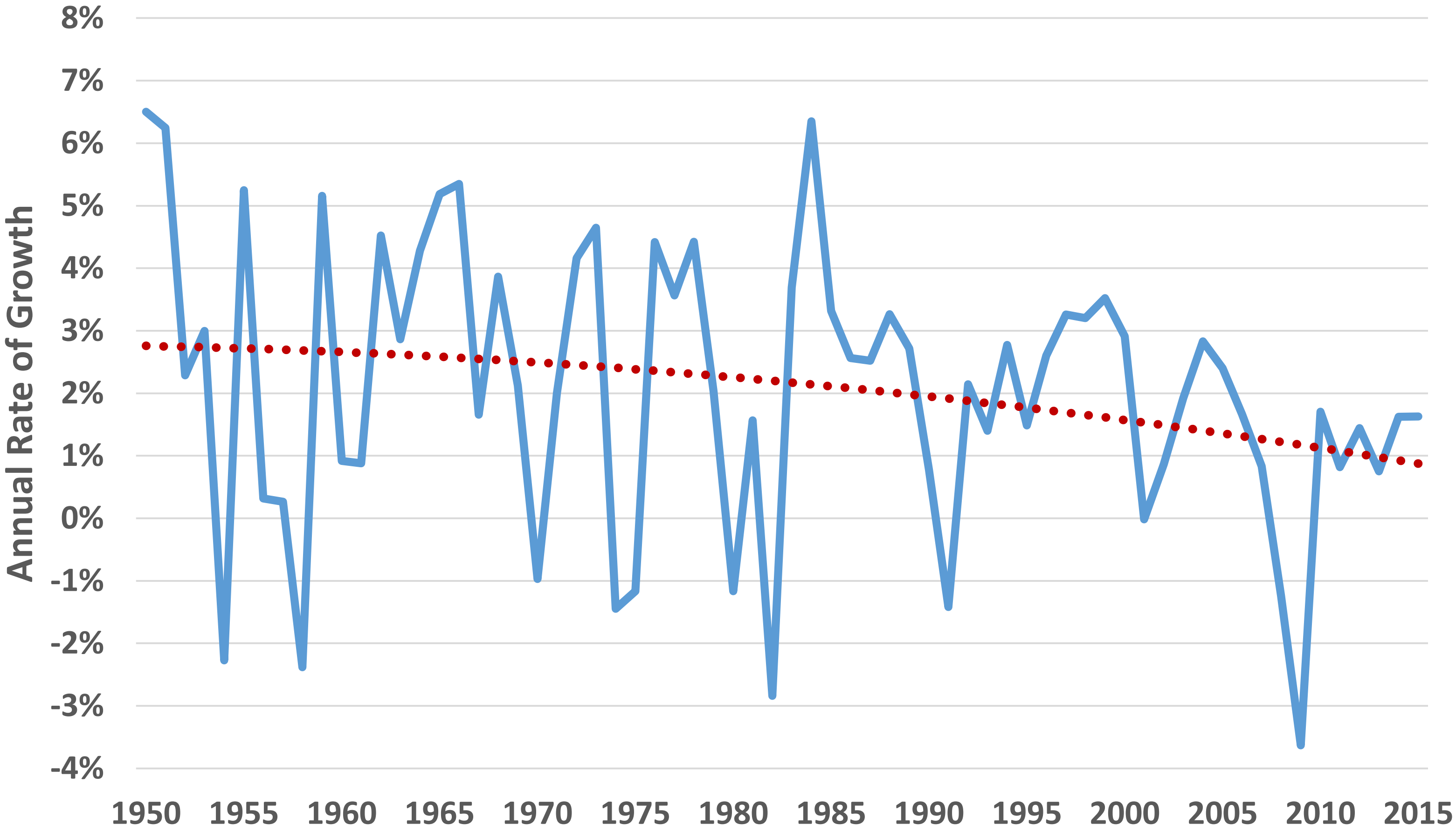
"Ha ha ha, Biff. Guess what? After we go to the drugstore and the post office, I'm going to the vet's to get tutored."

Comparing Economic Projections and Actual Outcomes: United States 2005 to 2017



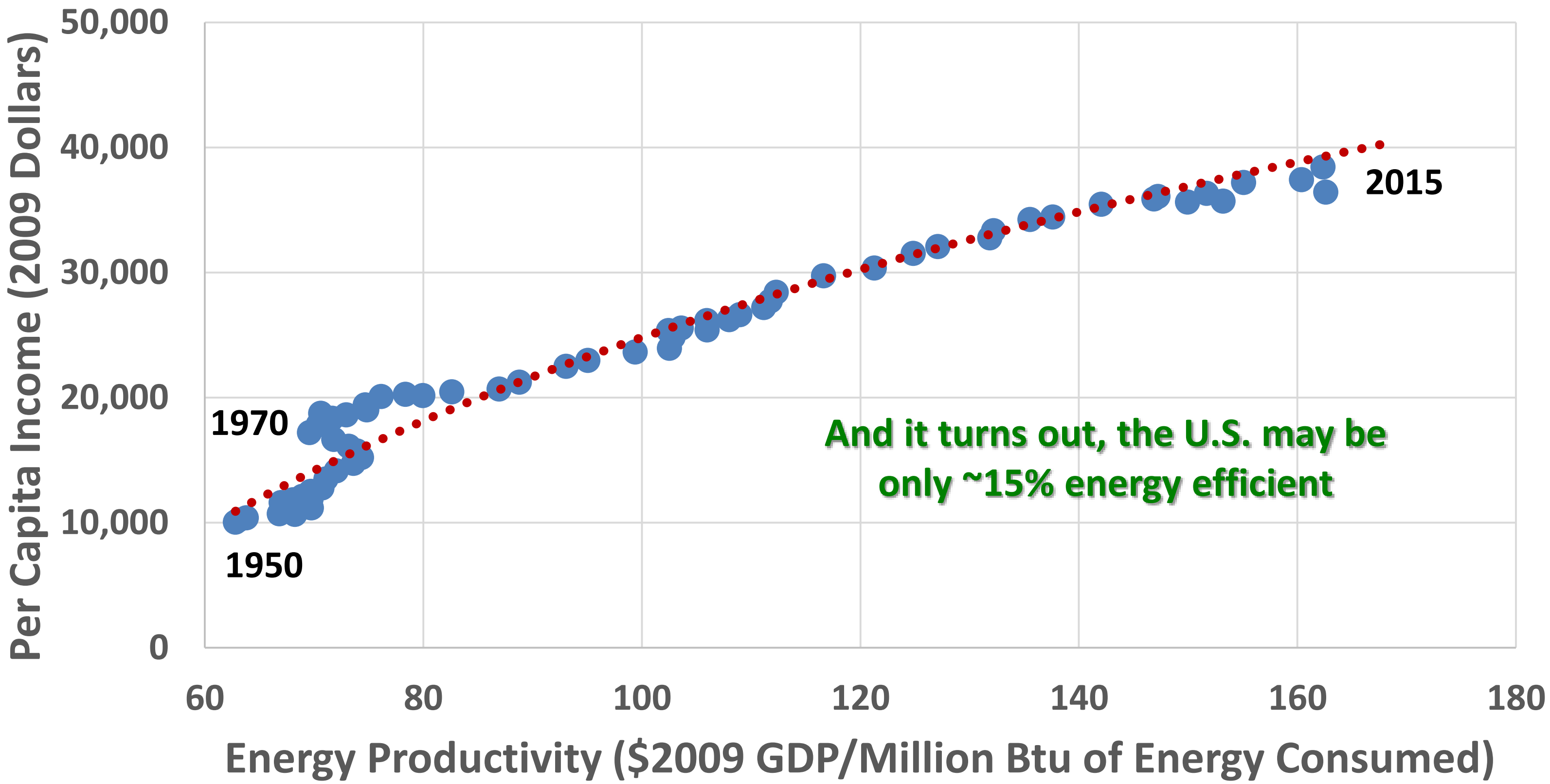
Source: Calculations by Laitner, using projections from the U.S. Energy Information Administration and other sources, May 2017.

Long-Term Trend in U.S. Real GDP Per Capita 1950-2015



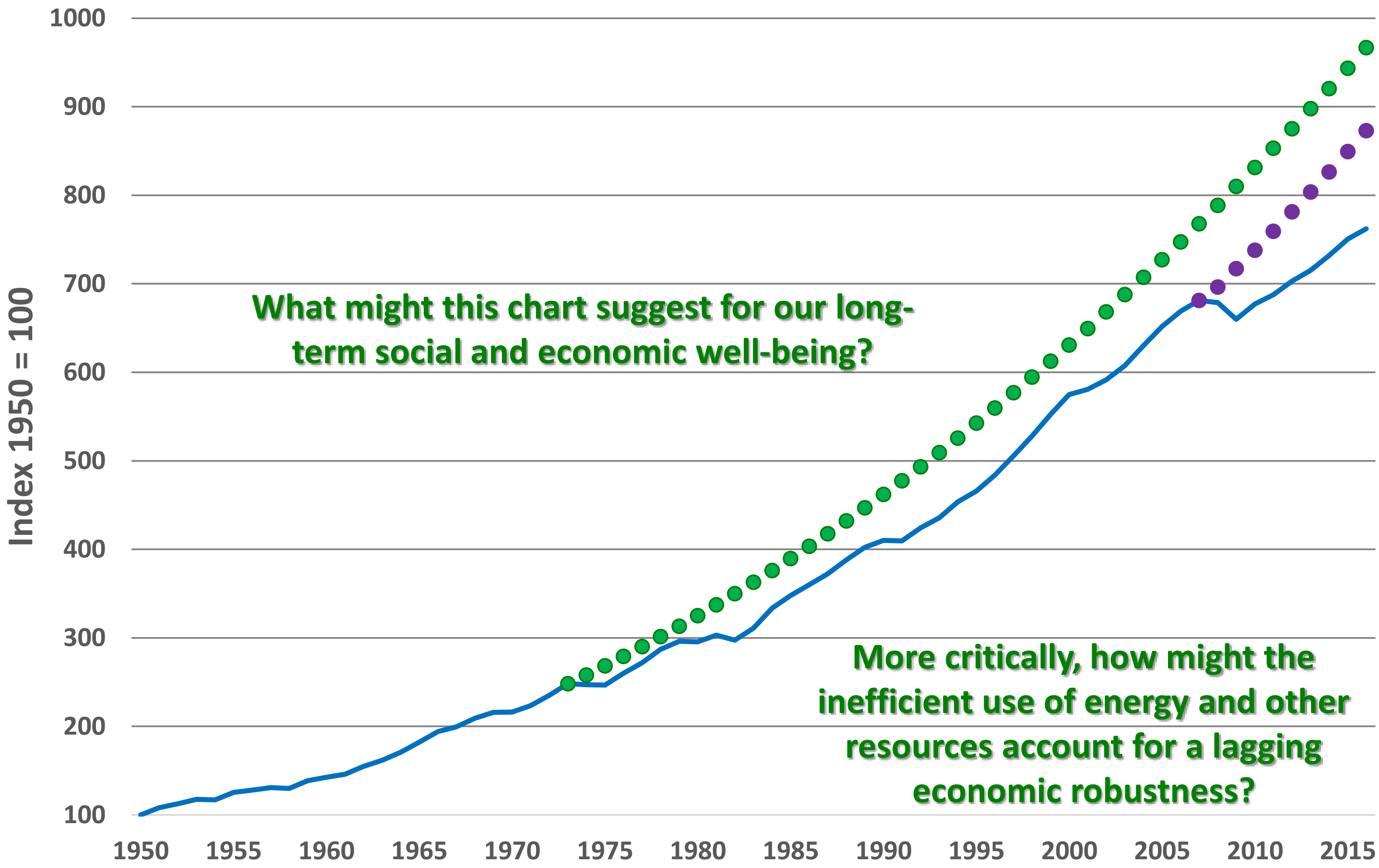
Source: John A. "Skip" Laitner based on U.S. Energy Information Administration Data, May 2017

The Connection Between U.S. Energy Productivity and Per Capita Income (1950-2015)

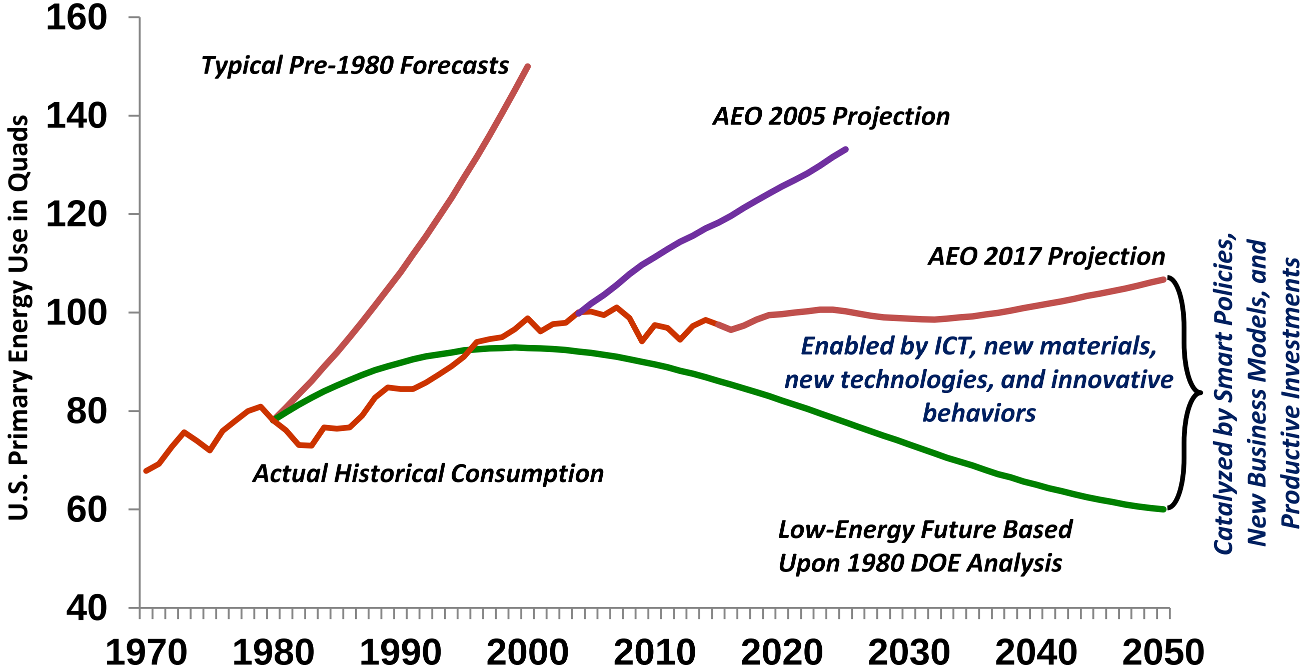


Source: Calculations by John A. "Skip" Laitner using data from the U.S. Energy Information Administration

Exploring U.S. GDP Trends 1950-2015



Key Insight: The Energy Efficiency Resource Is Larger than Generally Believed or Understood



Sources: DOE 1980 Policy Analysis, AEO 2005, AEO 2017, and Laitner Estimates 2017.

Emerging evidence and insights from Europe

With a Bit of Added Context

In his best-selling books, my colleague Jeremy Rifkin notes that any time you have a coming together of a new form of communication with a new form of energy, you've laid the foundation for an industrial revolution:

- ***The First Industrial Revolution*** – roughly corresponding to use of print media and coal/steam energy
- ***The Second Industrial Revolution*** – telegraph and telephone coupled with the internal combustion engine and electricity generation
- ***And the emerging (but not at all guaranteed) Third Industrial Revolution? A buildout of infrastructure that relies on interactive communications and distributed clean energy technologies anchored by large-scale energy productivity***

And Some Further Insights

- The economy-wide benefits and returns on the "Second Industrial Revolution" technologies and the larger public infrastructure are diminishing.
- A social and economic transformation is clearly needed – driven by purposeful effort that includes both directed actions and targeted investments.
- Hence, the development of ***Third Industrial Revolution (TIR) Strategic Plans*** by Team Rifkin.
- And the more productive and efficient use of all resources, especially energy, must underpin this transformation over the next three decades.

Who Is Acting How on These Ideas?

- Both Luxembourg (population 576,000) and MRDH (Metropolitan Region Rotterdam/Den Haag 2.3 million). . .
- Working with Rifkin, and our partners at Navigant Consulting and Fraunhofer Institute, we crafted strategic plans (Roadmap Next Economy) that propose to double the regional rate of energy productivity by 2050. All remaining energy needs are to be provided by renewable resources, also by 2050.
- With significant upgrades to public infrastructure, energy efficiency upgrades, and the deployment of renewable energy technologies, by 2050 the plans anticipate a cumulative total investment roughly equal to one year's GDP. For the State of Georgia, that might equal ~$525 billion.
- The result will be a more resilient, robust and sustainable economy that also increases the net gains in jobs.

The 7 Ways Energy Productivity Can Improve the Robustness of a National or Regional Economy

- It can save money and lower dependence on imported oil and reduce the potential of other supply disruptions.
- It can minimize the volatility of energy and other prices.
- It will both lessen the threat of climate change and increase the opportunities for adaptation to shifts in climate patterns.
- It can boost overall economic productivity and job creation.
- It will lessen health and other environmental impacts.
- It will likely stimulate a higher level of innovation across all sectors—increasing the prospect for a resilient, a more durable, and a more vigorous economy.
- It will demonstrate a very real leadership that, in turn, may catalyze other regions to develop a similar roadmap, with synergies that amplify benefits and further reduce the risks.

MRDH and Luxembourg: Elevating to a Higher Level of Economic Performance

*'Our world is in transition. We no longer live in an era of change, but are witnessing the change of an era. We are on the verge of the greatest social and economic challenge since the 19th century. Global trends like climate change, geopolitical changes, increasing migration, growing inequality, natural resource depletion (lagging rates of resource productivity) and the emergence of disruptive technological innovations are driving the transition to a systemic change. We need to anticipate this change that will **fundamentally alter the way we manage, power and move our society.'***

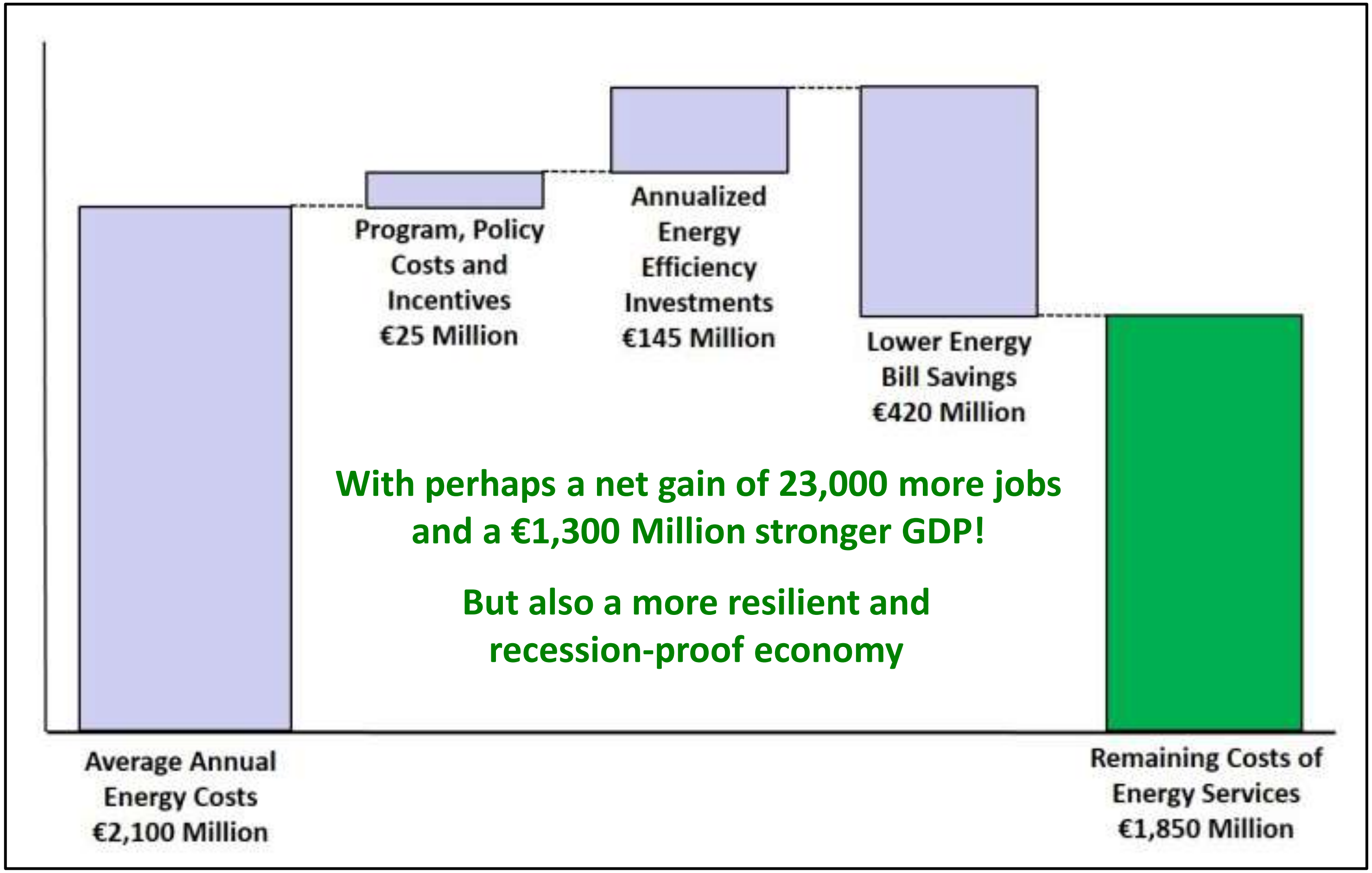
MRDH Roadmap Next Economy, February 2017

*'Today, a transition toward the Third Industrial Revolution is underway, and Luxembourg is the first country to get prepared at the national level. During the forum, different parts of the Grand Duchy's national strategy will allow you to discover **how the country enrolls in the co-construction of this new sustainable economic model.'***

IMS Luxembourg, November 2016

The Luxembourg Future Cost of Energy Services

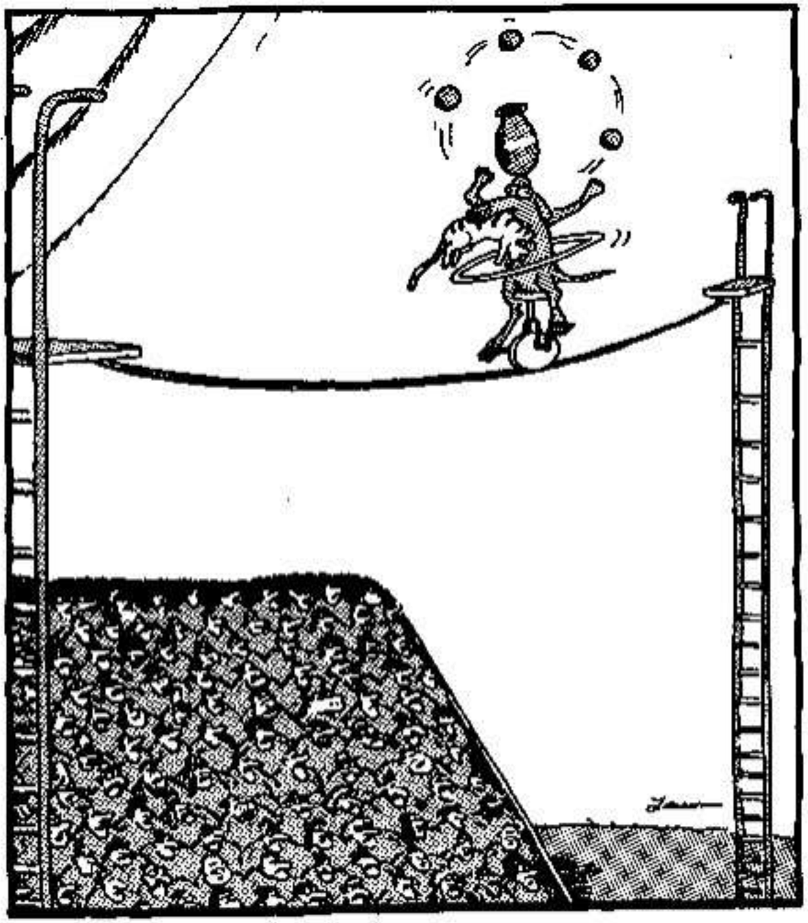
Figure 3. The Average Annual Payments for Energy Services, 2016 through 2050



Source: John A. "Skip" Laitner (September 2016).

Perhaps Our Ultimate Economic and Energy Efficiency Resource?

- Recalling the comment of early Twentieth Century UK essayist, Lionel Strachey, who remarked: *"Americans guess because they are in too great a hurry to think."*
- Jerry Hirschberg, founder and former CEO of Nissan Design, who noted that: *"Creativity is not an escape from disciplined thinking. It is an escape with disciplined thinking."*
- And Henry Ford once said, *"Thinking is the hardest work there is which is the probable reason why so few engage in it."*



High above the hushed crowd, Rex tried
to remain focused. Still, he couldn't shake one
nagging thought: He was an old dog and
this was a new trick.

Contact Information

John A. "Skip" Laitner (@EconSkip)
Principal Economist and Consultant
Economic and Human Dimensions Research Associates
https://theresourceimperative.com/

Tucson, Arizona 85750
c: (571) 332-9434
Email: EconSkip@gmail.com

“Policy Pathways to an Advanced Energy Economy”

Professor Marilyn Brown
Georgia Tech, School of Public Policy

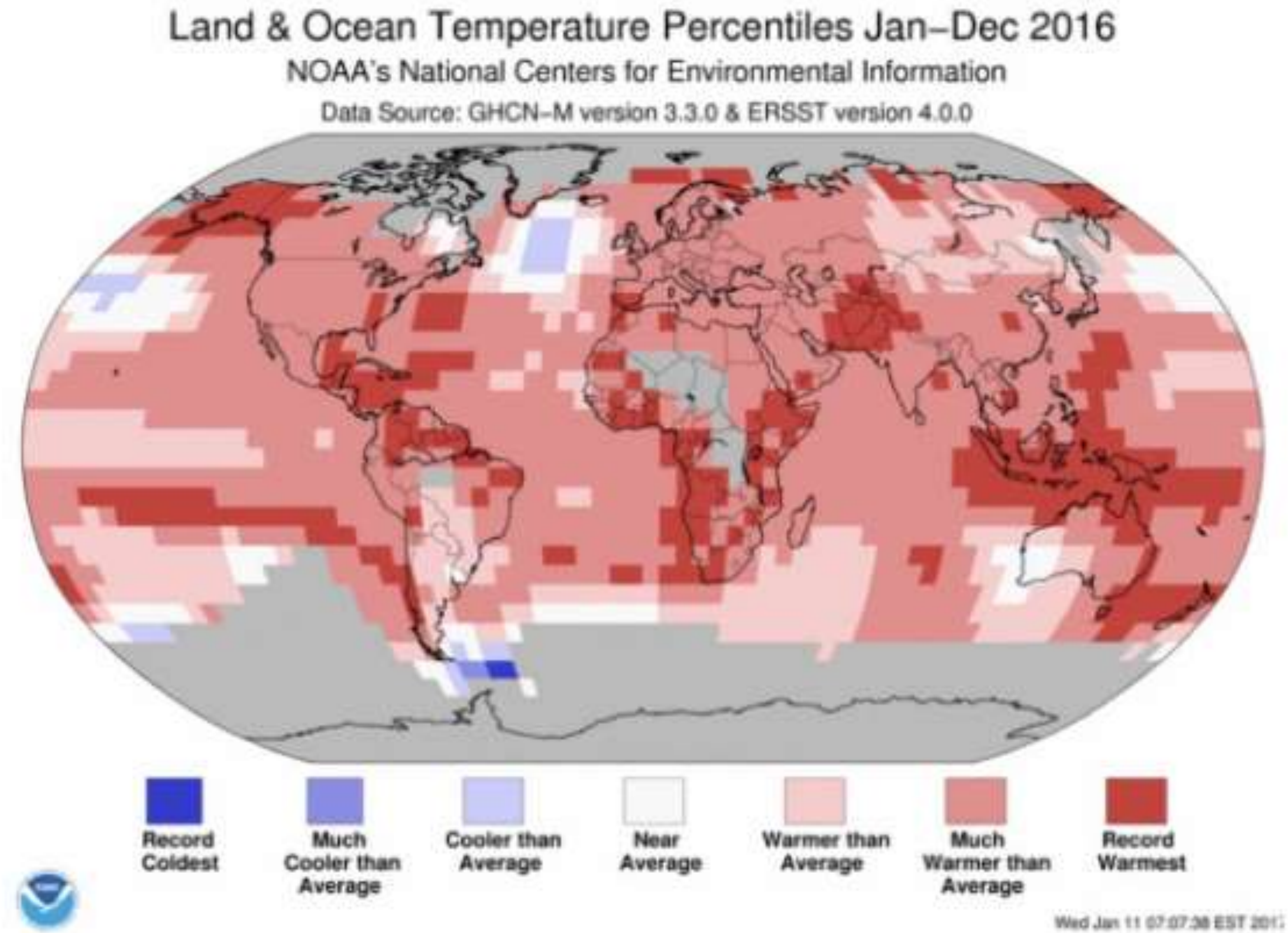
Policy Pathways to an Advanced Energy Economy

Marilyn A. Brown
Brook Byers Professor of Sustainable Systems,
School of Public Policy, Georgia Institute of Technology

Energy Transitions Forum

July 25, 2017

2016: Hottest Year on Record



2016 temperatures compared to normal around the globe. (NOAA)

The Southeastern U.S. is no longer an "anomaly".

Marilyn Brown
@Marilyn_Brown1

$180 billion of new power plants to meet this load, or can we better manage our demand?

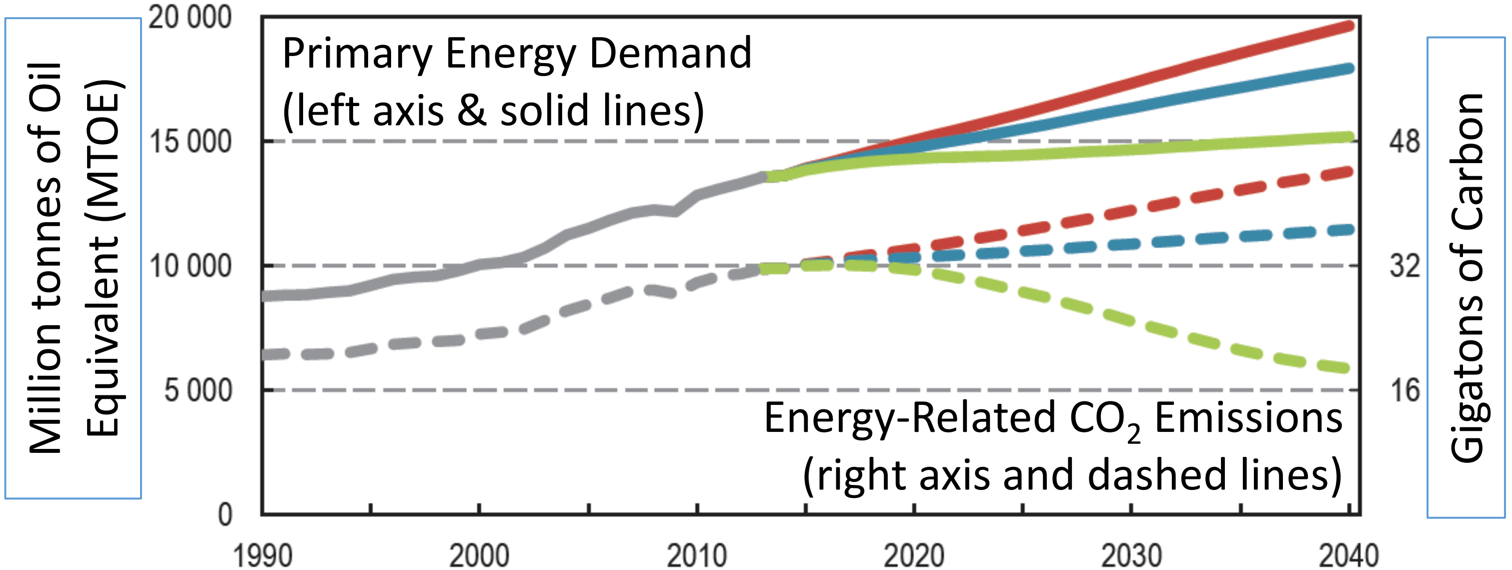
Peak Temperatures Will Push Electric Grid to the Brink in an Ever-Warming W...
Rising temperature could cost U.S. utilities as much as $180 billion this century due to greater electricity demand.
seeker.com

Meeting the 2°C Goal

Red ~ Current Policies

Blue ~ The Paris Accord – The "First Pivot"

Green ~ The 2ºC Goal – The "Second Pivot"



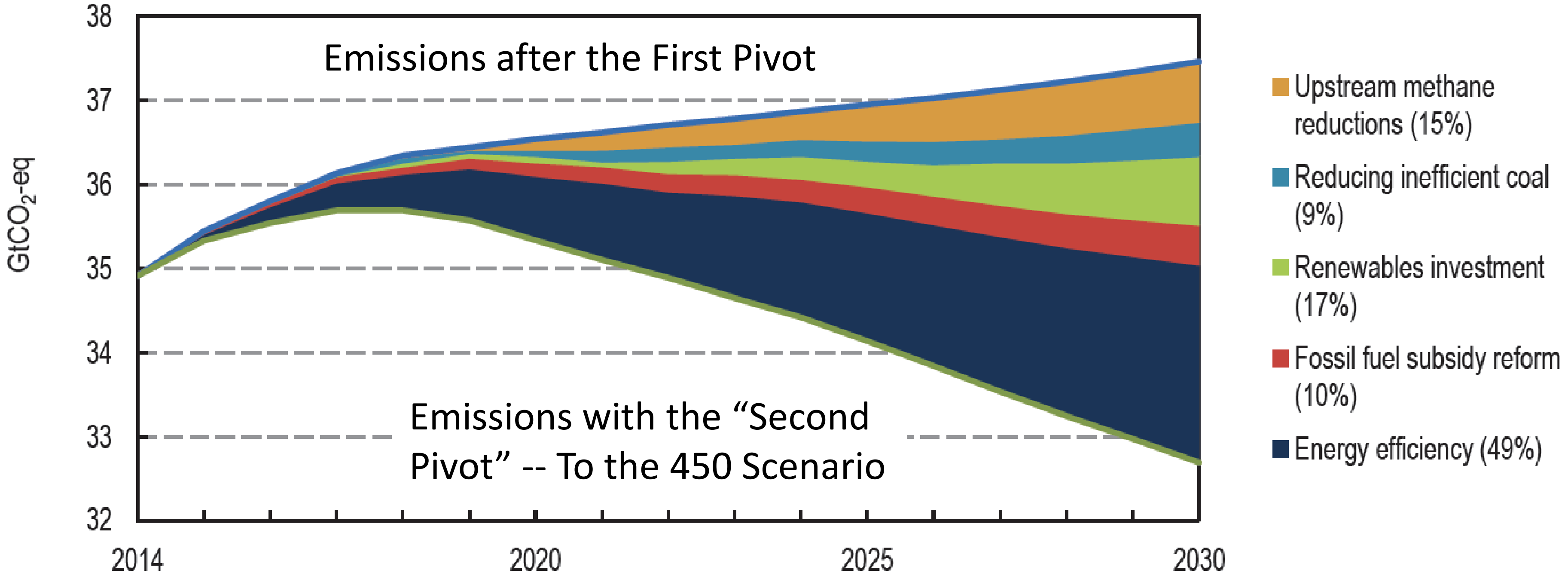
The Paris Accord is an important first step, but it is not strong enough to limit the global temperature increase to 2°C above the pre-industrial revolution.

Source: Adapted from the International Energy Agency's *World Energy Outlook*

The Least-Cost Second Pivot

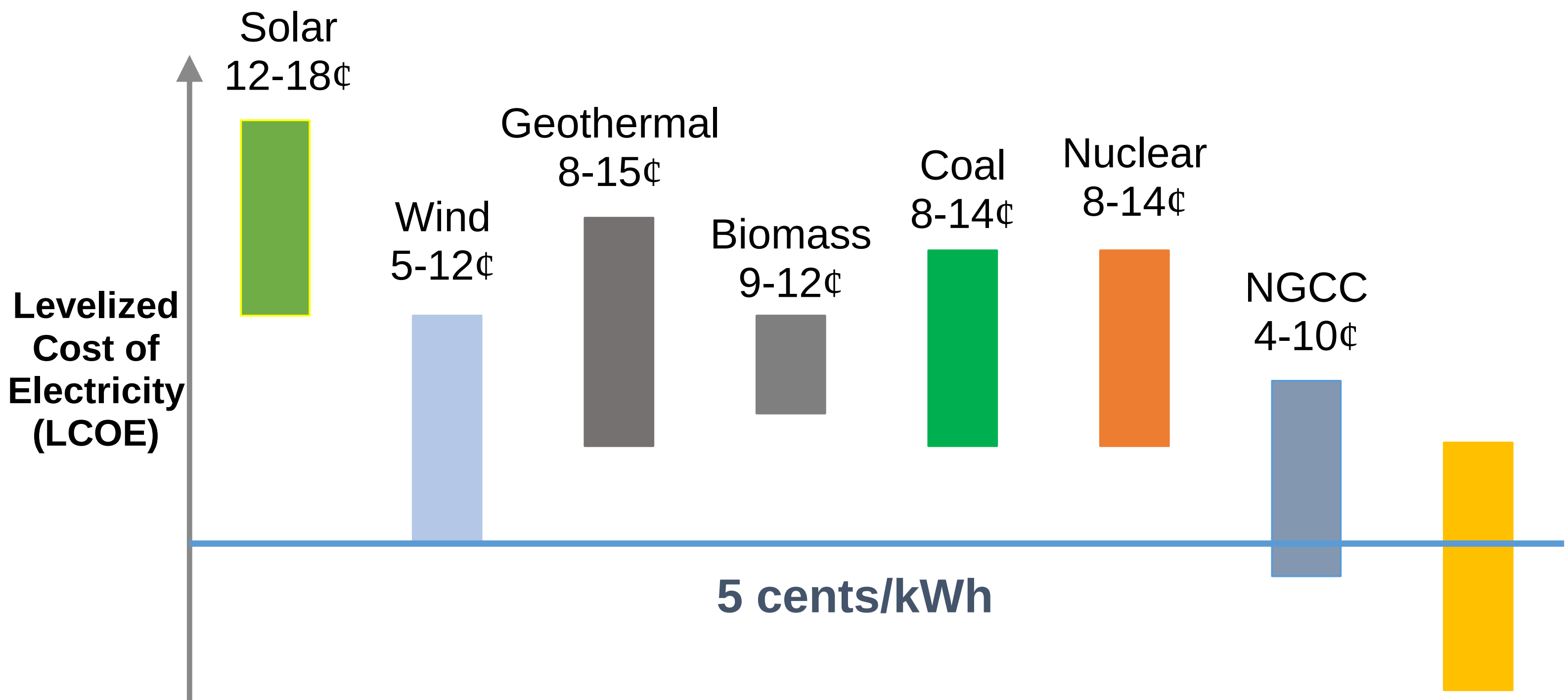
- IEA: Energy efficiency and renewables will likely dominate the "Second Pivot"

Estimated Least-Cost "Second Pivot"



Adapted from: IEA (2015) *Energy and Climate Change: A Special Report*

The "LCOE" Metric

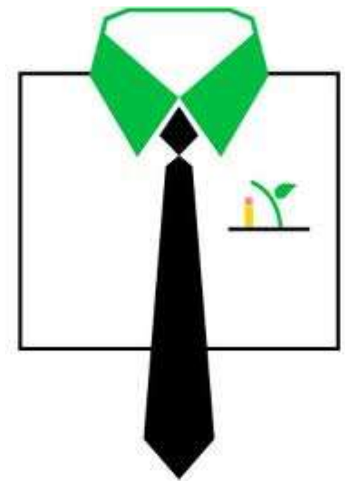


How can the answer not be energy efficiency & renewables?

The LCOE metric is incomplete:
--the hourly shape of supply and demand,
--the need for frequency and voltage control and support,
--reactive power planning and other locationally variable resource issues.

Source: *Green Savings*, Figure 2.10

Changing the Narrative



The U.S. has about 75,000 jobs in coal mining. Automation has had a major impact on this workforce: autonomous trucks work the Powder River Basin….

See: 30-minute CNN discussion: 175,000 live "hits"

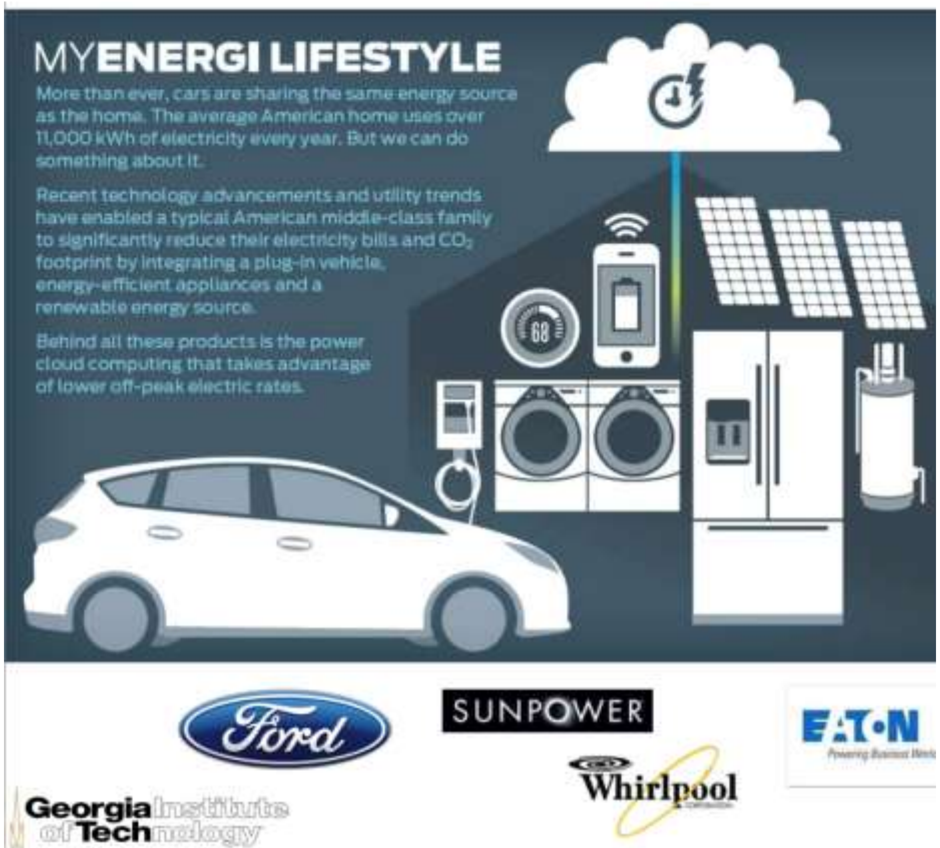
https://www.facebook.com/cnn/videos/10156318782866509/?hc_ref=NEWSFEED

Energy Efficiency Jobs

Nearly 1 million U.S. workers spend a majority of their time installing energy-efficient equipment and services.

Technologies include:

- Advanced windows & insulation
- High efficiency HVAC
- Smart thermostats
- Efficient lighting and controls
- Energy Star appliances, etc.



Source: Environmental Entrepreneurs (E2) and E4 The Future. 2016. *Energy Efficiency Jobs in America*.

Solar Jobs

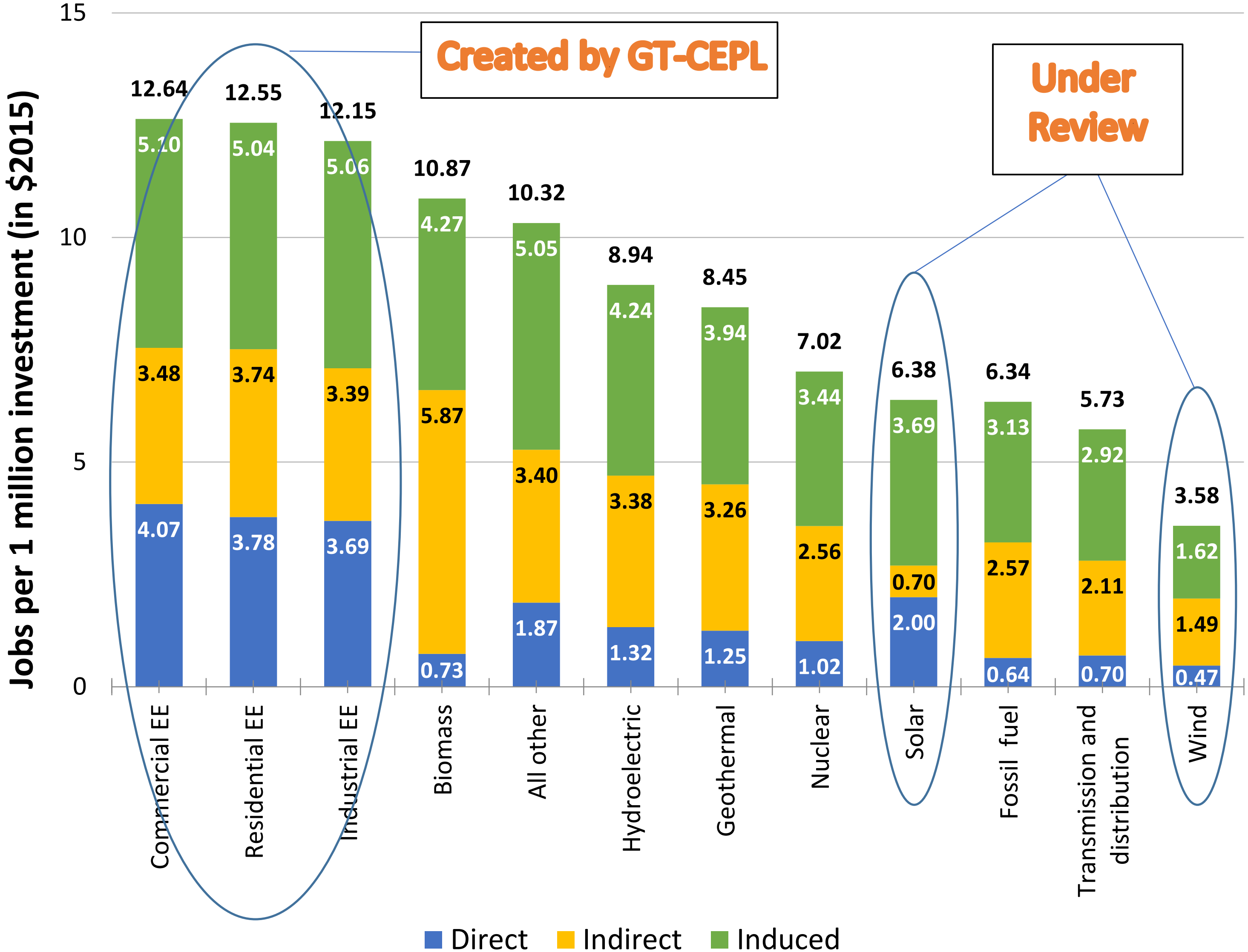
- The U.S. has about 250,000 workers in the solar industry.
- One out of every 50 new jobs added in the U.S. in 2016 was created by the solar industry.

Source: The Solar Foundation. 2017. *National Solar Jobs Census 2016*, available at: SolarJobsCensus.org.

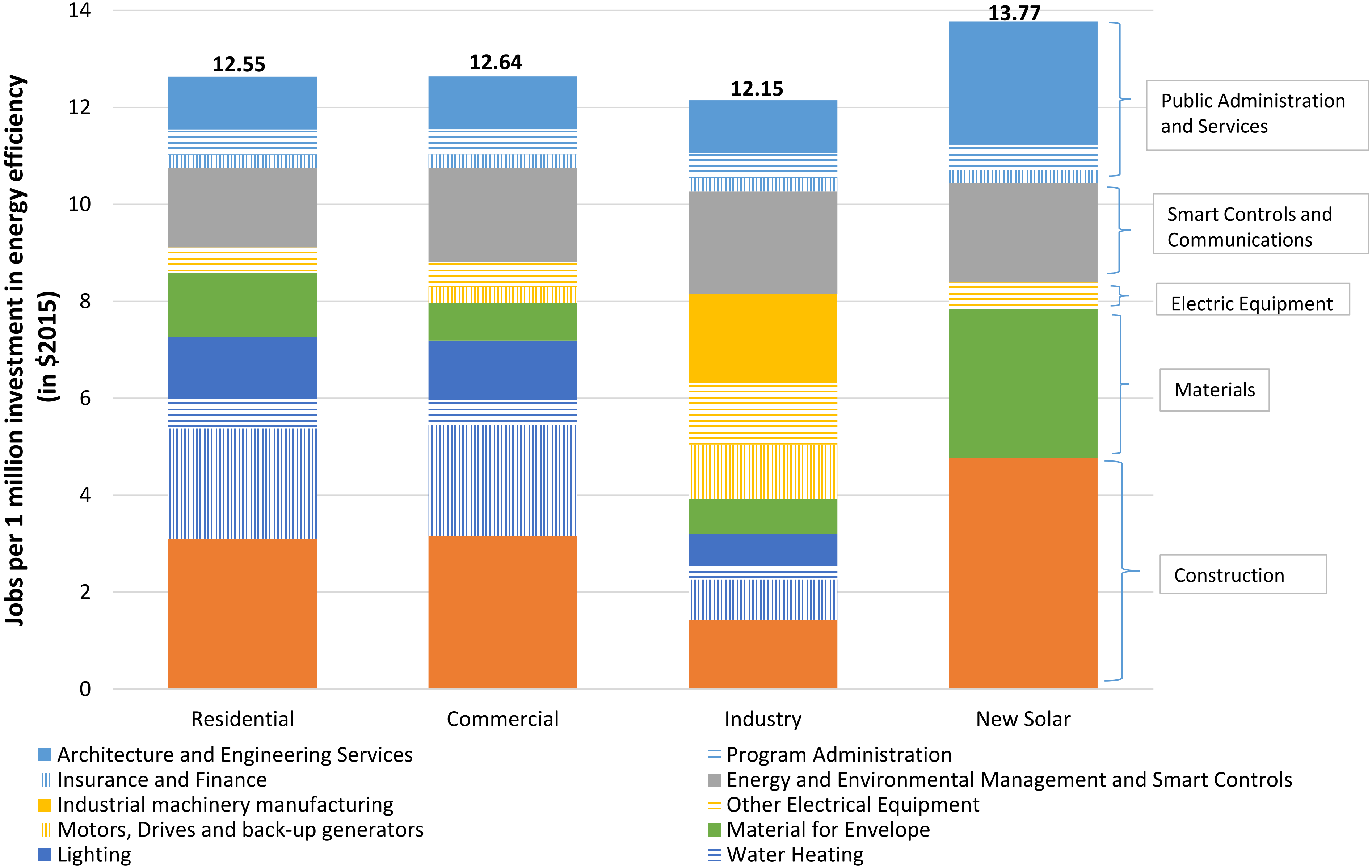
Georgia Tech

Job Coefficients for Different Types of Energy Investments

IGERT
Energy Materials & Policy

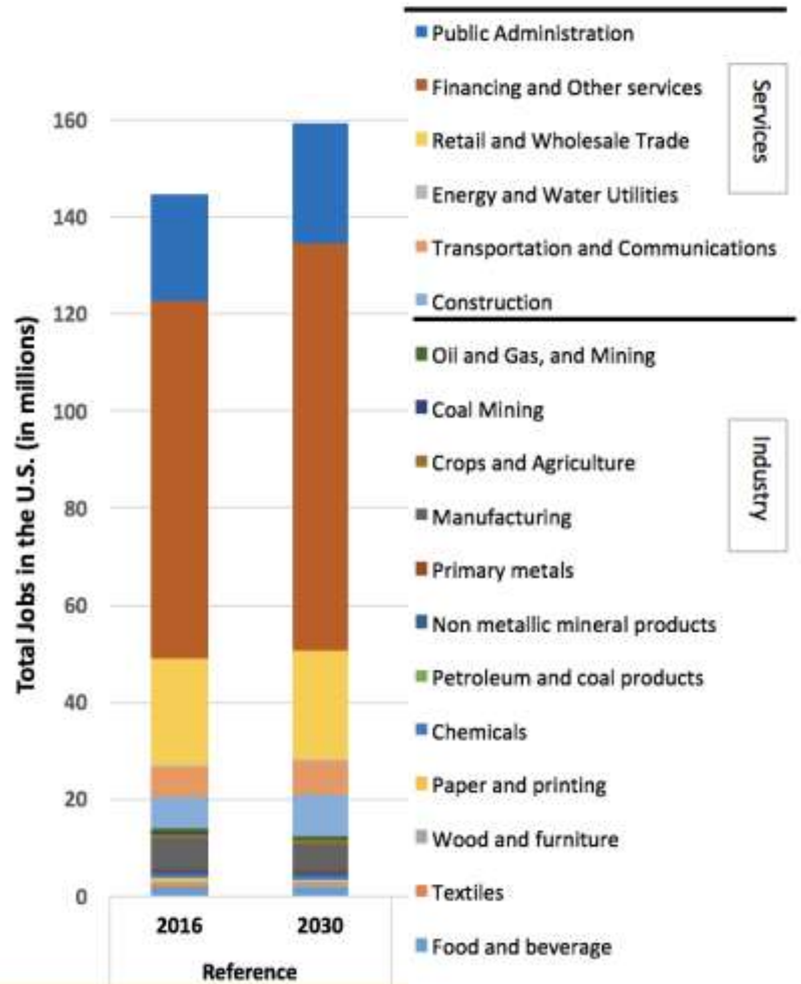


Types of Jobs Generated by Investments in Energy Efficiency and New Solar

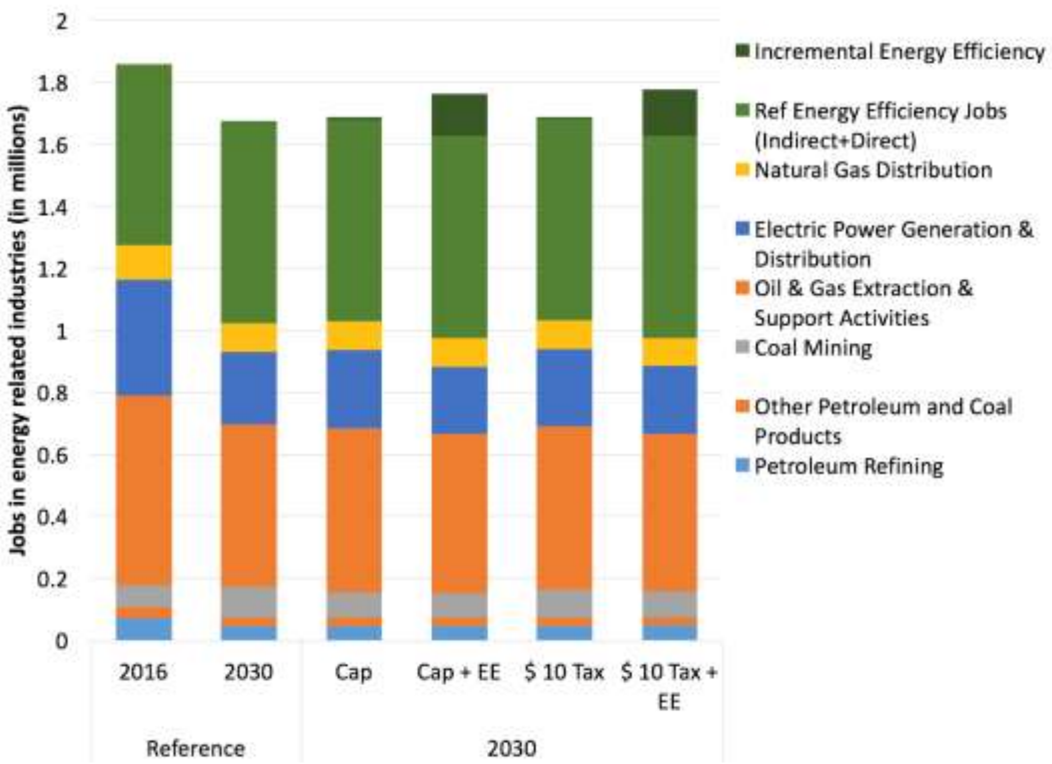


Conventional Energy Jobs are Shrinking

Jobs in the U.S. are forecast to continue to grow, especially service sectors:



Conventional energy jobs are forecast to shrink, but jobs In the new energy economy will grow:



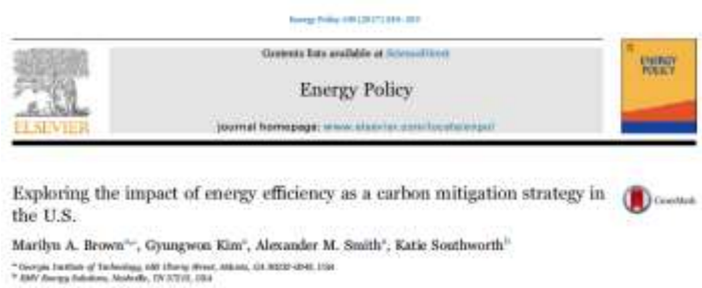
Source: GT-NEMS modeling results

Co-optimizing demand- and supply-side resources can produce "negative" carbon mitigation costs.

+ **lower** electricity bills.

Smart climate policies are needed:

- Carbon caps: the "Clean Power Plan")
- Carbon taxes: the "Carbon Dividends Plan"
  - redistribute taxes on a per capita basis vs
  - redistribute per source of CO_2.


Energy Policy

Exploring the impact of energy efficiency as a carbon mitigation strategy in the U.S.

Marilyn A. Brown, Gyungwon Kim, Alexander M. Smith, Katie Southworth

Cost of climate policy in 2030
(in billions $2013)

Climate Policy:	Electric Utility Resource Costs	Costs Including Energy-Efficiency Investments
Carbon Cap	5.4	6.5
Carbon Cap + EE	-9.6	-2.9
$10 Carbon Tax	5.4	6.5
$10 Carbon Tax + EE	-9.6	-2.9

Cost of climate policy = utility resource cost + EE costs + administrative costs – carbon tax recycling (net present value @7% discount rate)

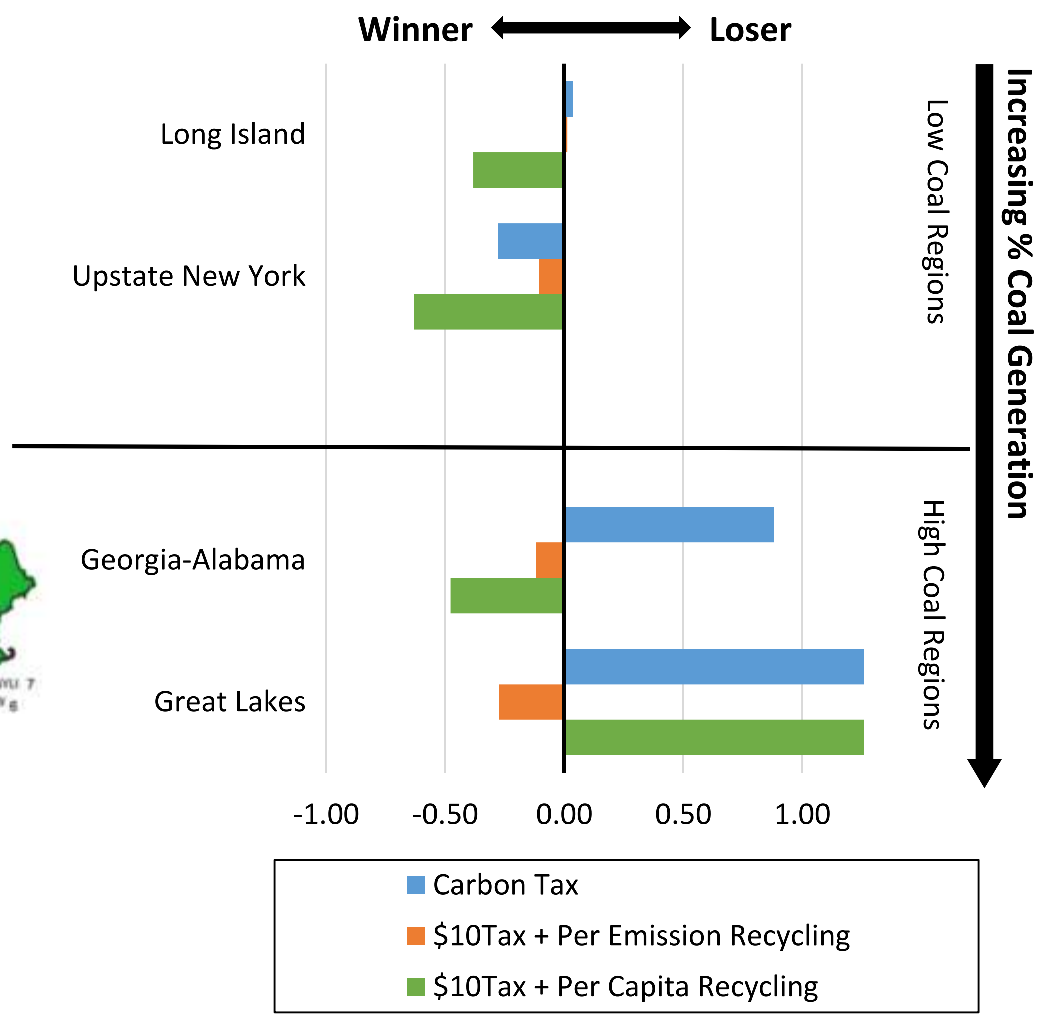
Winners and Losers

Policy design matters!

- How carbon tax revenues are recycled creates different regional winners and losers.

Electricity Market Module Regions

Cost of Climate Policy in 2030*



*Net present value (in $2013) using a 7% discounte rate

Conclusions

The clean power transformation can grow the economy, create jobs with livable wages, improve human health, and protect the environment.

A great deal is at stake, and policy design matters.

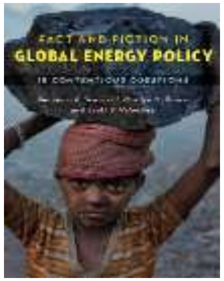
Winners and losers are inevitable at all geographic scales.

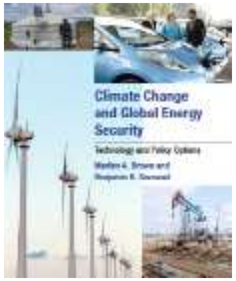
Blending the engineering and natural sciences with economics, social sciences, and policy analysis can reveal new possibilities and avoid unwanted futures.

For More Information

Dr. Marilyn A. Brown
Brook Byers Professor of Sustainable Systems
School of Public Policy
Georgia Institute of Technology
Atlanta, GA 30332-0345
Marilyn.Brown@gatech.edu
Climate and Energy Policy Lab:
www.cepl.gatech.edu

CLIMATE AND ENERGY POLICY LABORATORY
SCHOOL OF PUBLIC POLICY





DISCUSSION OF AFTERNOON TALKS

Charles Rossmann
Forecasting and Model Development Manager
Southern Company

CLOSING REMARKS

Elsa Reichmanis
Chemistry and Biochemistry
Georgia Institute of Technology

THANK YOU!

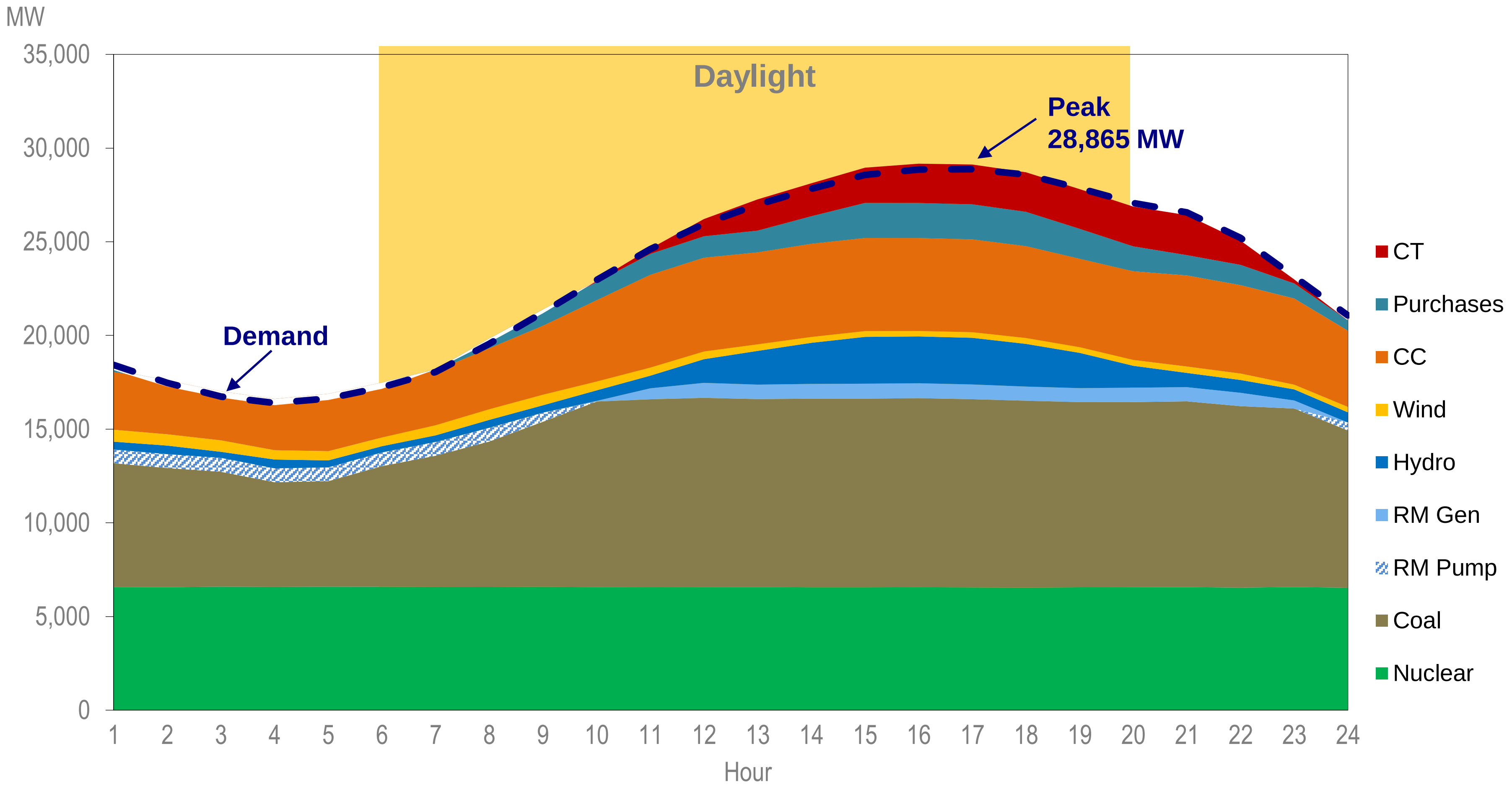
APPENDIX

“Envisioning Future Energy Technologies”

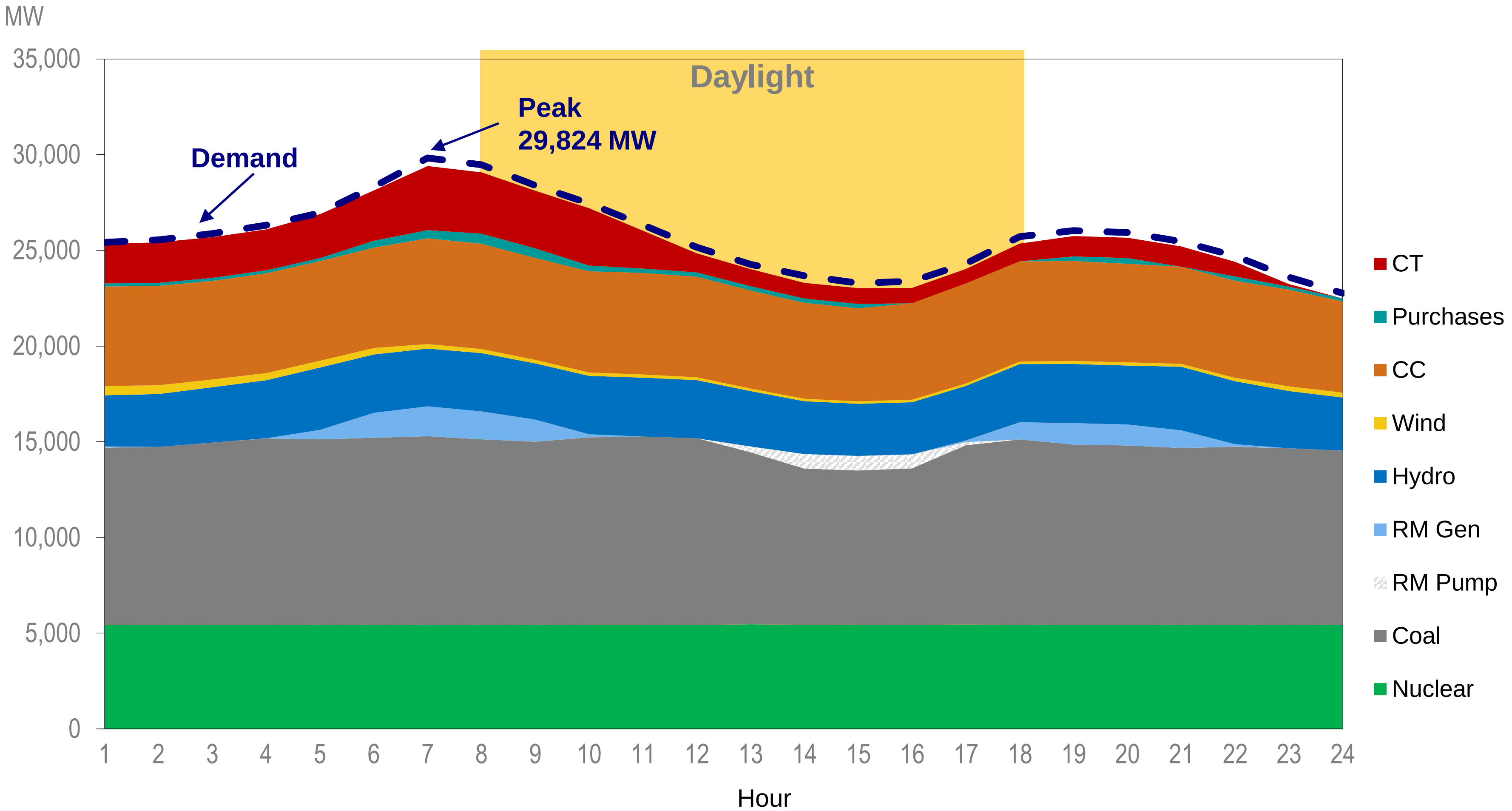
Aaron Melda
Tennessee Valley Authority

Appendix (Other Slide Options)

Load Dispatch on Typical Summer Day



Load Dispatch on Typical Winter Day



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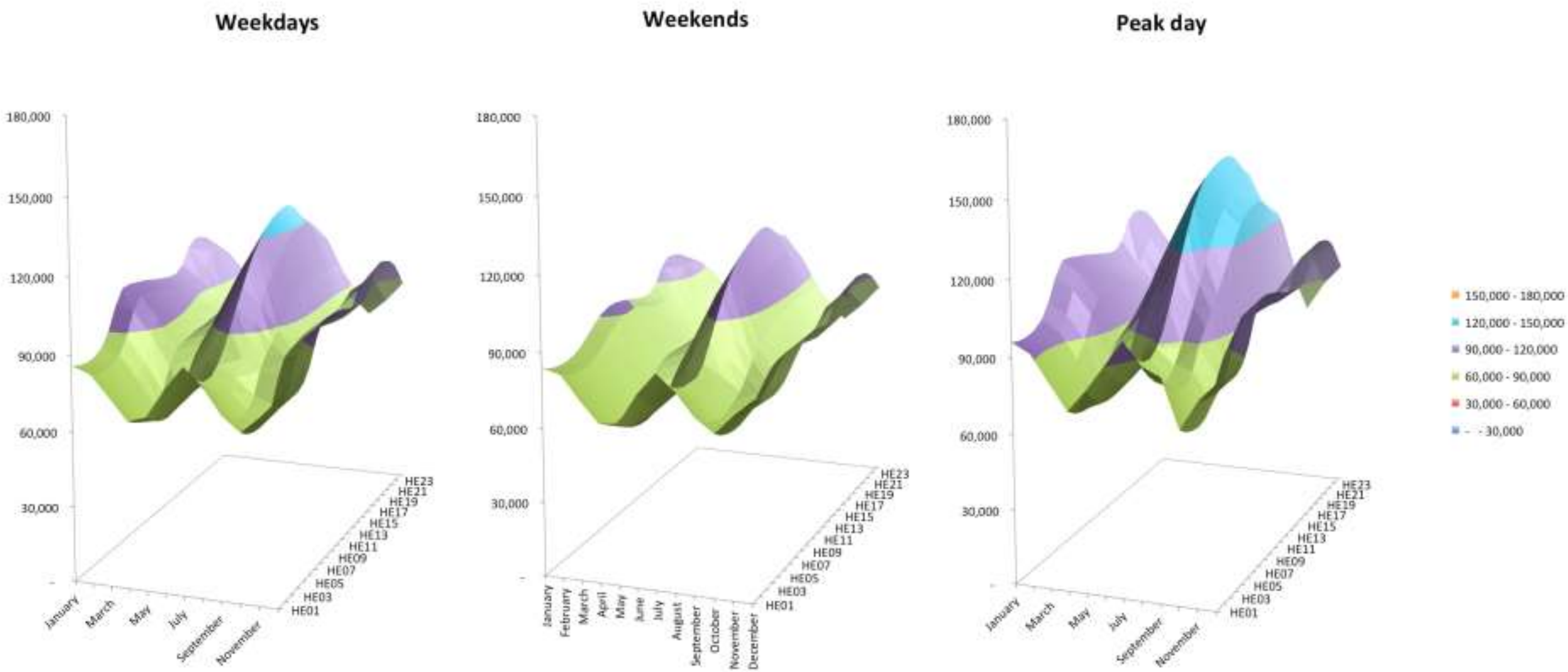
THE POLICY IMPLICATIONS OF SOLAR PENETRATION

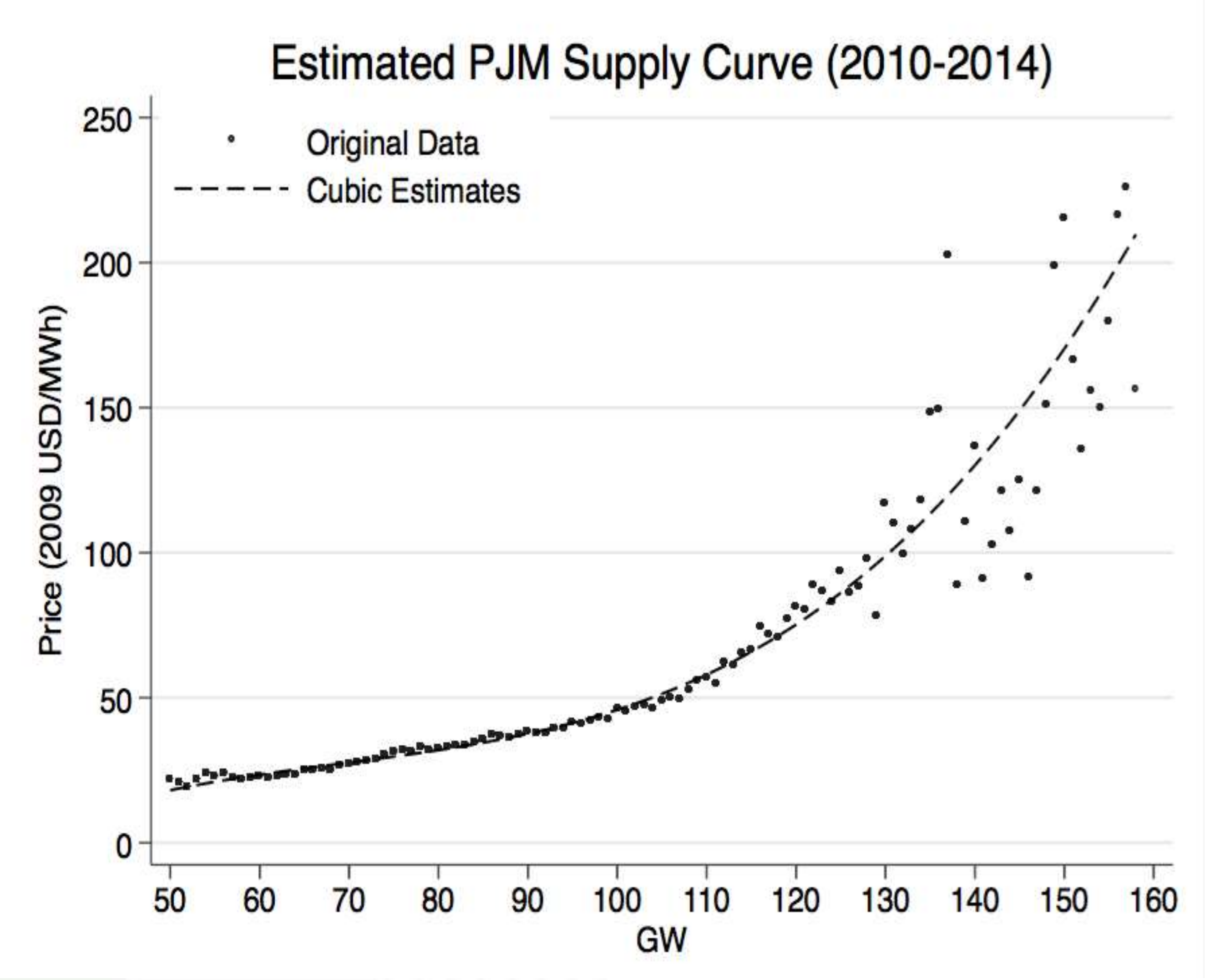
Ross Beppler

IGERT Fellow – Public Policy

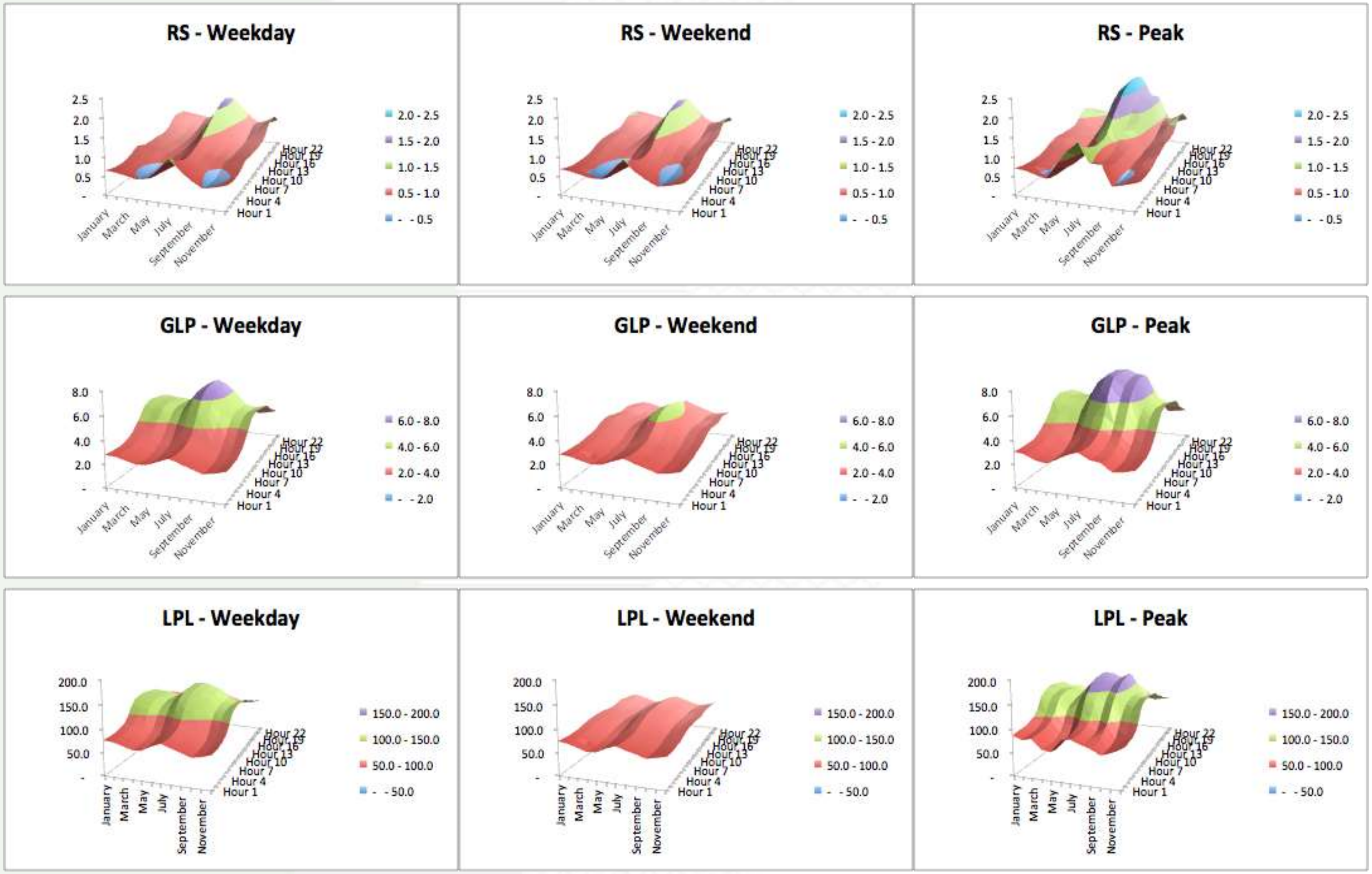
MODEL, DATA, METHODOLOGY – PJM DEMAND



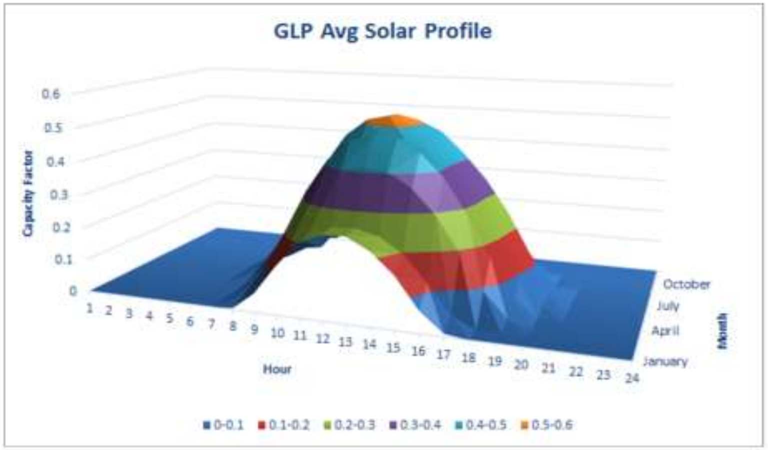
MODEL, DATA, METHODOLOGY – PJM SUPPLY CURVE

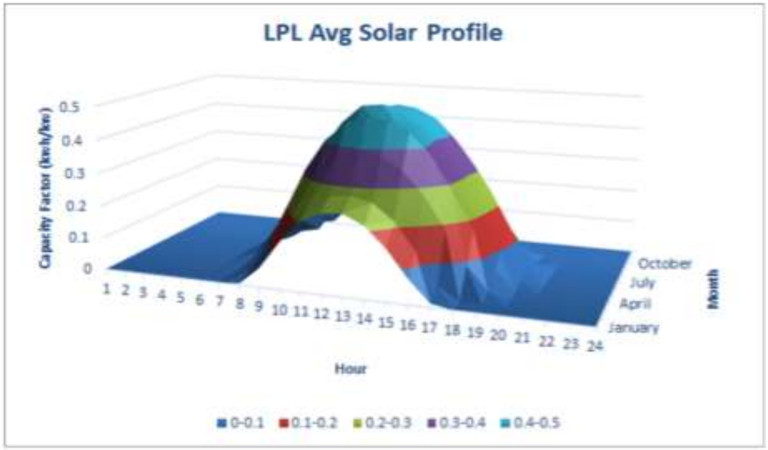


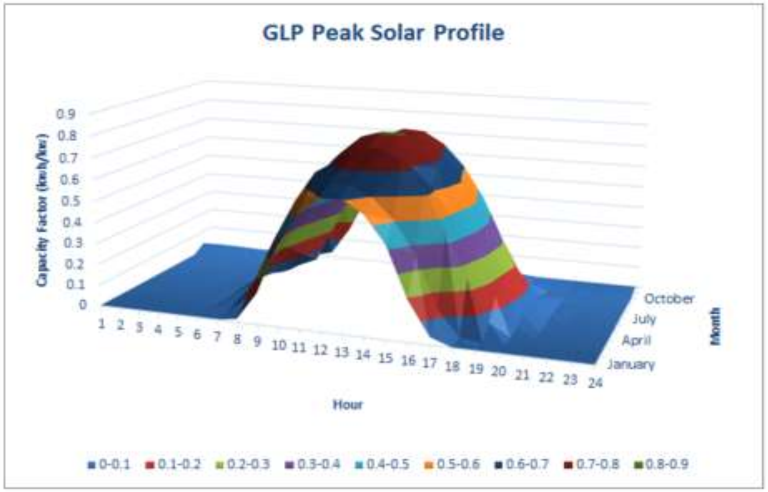
MODEL, DATA, METHODOLOGY – CUSTOMER LOAD PROFILES

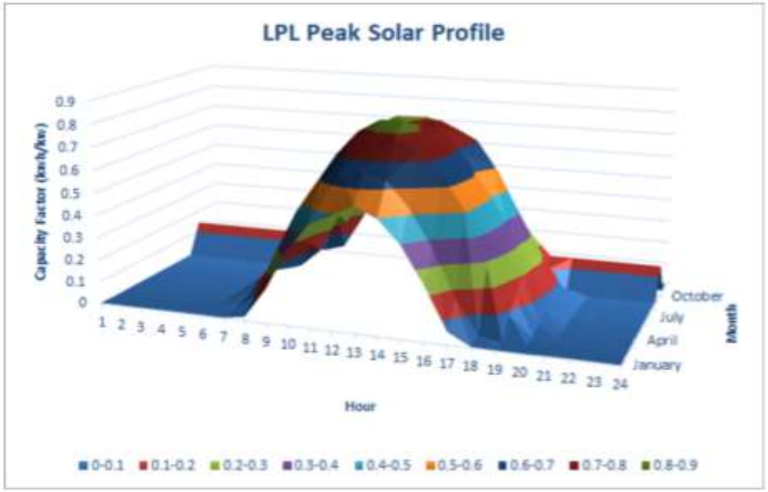


MODEL, DATA, METHODOLOGY – SOLAR GENERATION









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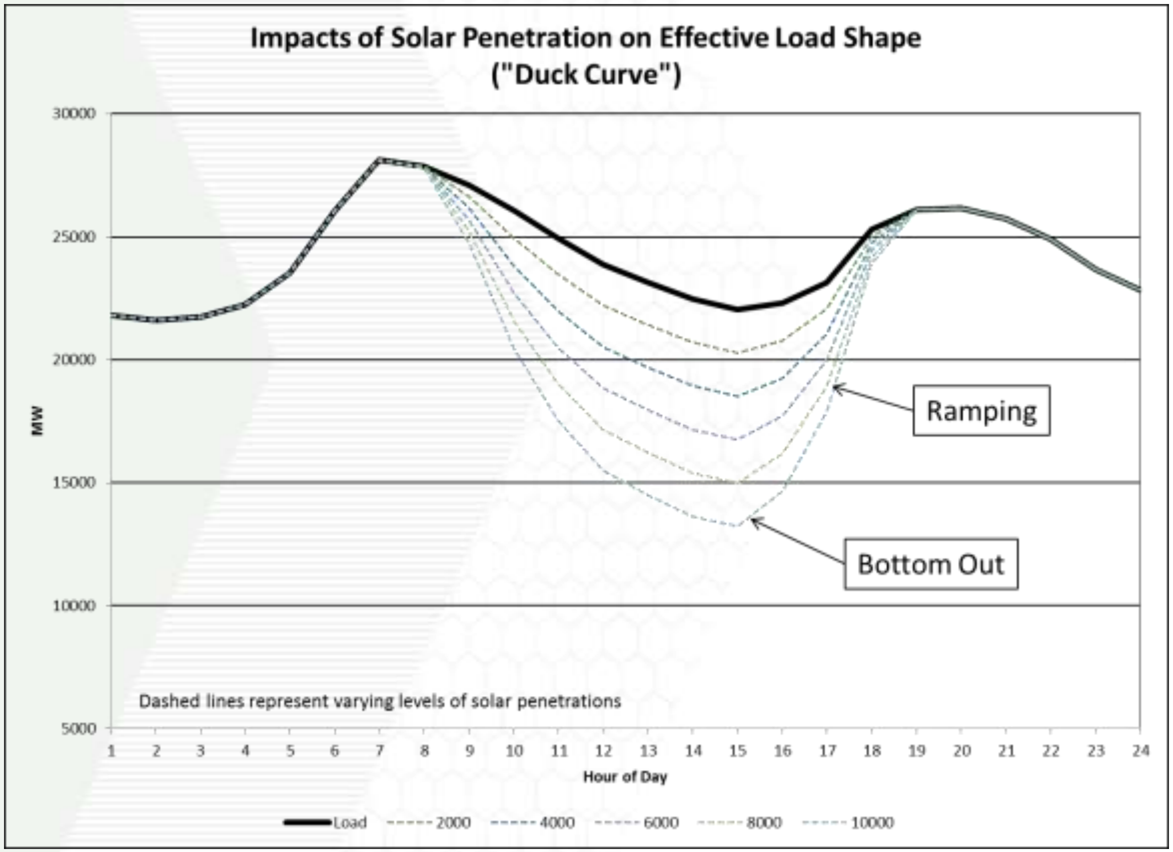
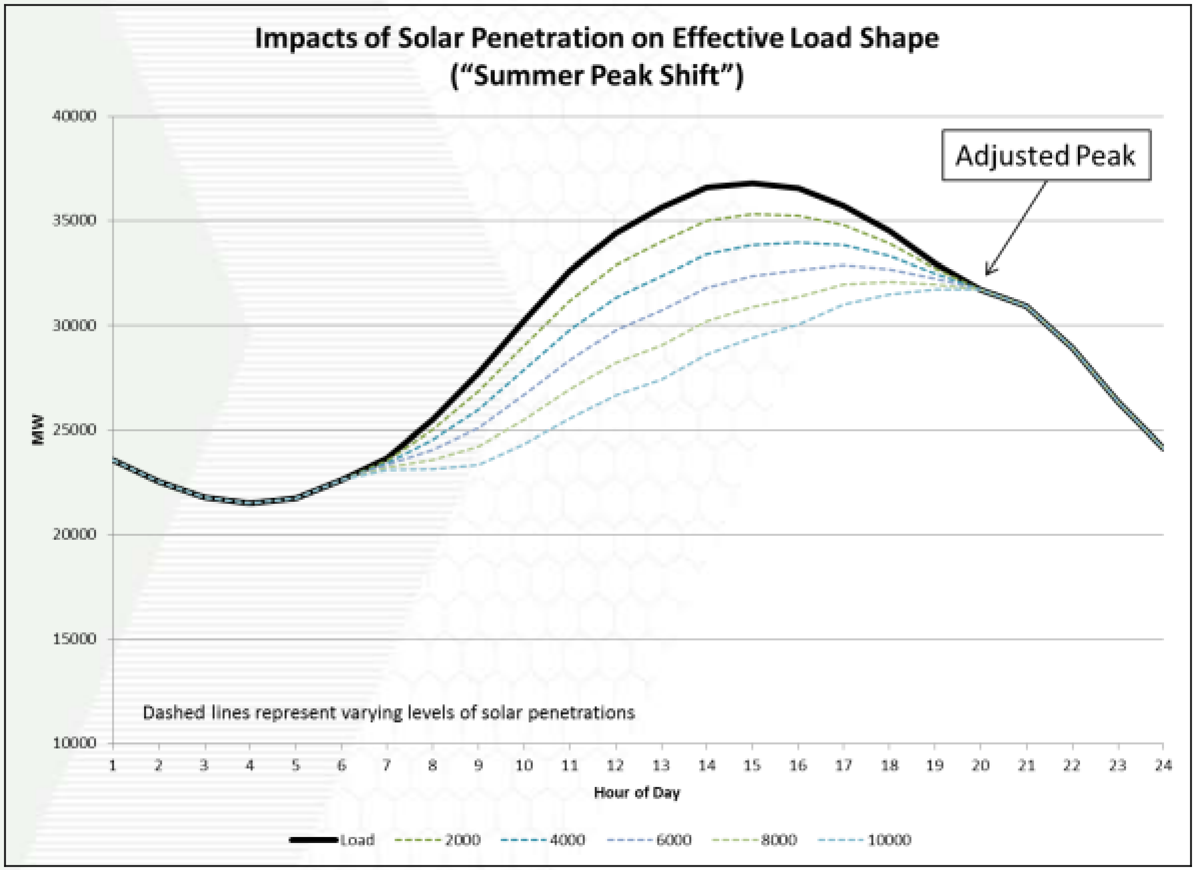


Georgia Tech



MODEL, DATA, METHODOLOGY – SCENARIOS

- Base Case – Designed to imitate current policy
  - 5% solar by 2030
  - New capacity installations in each rate class match 2015 levels
  - 70% distributed solar (of that ½ C&I and 1/3 residential)
- High Case -
  - 15% solar by 2030
- High Grid –
  - 70% grid scale installations
- High Res –
  - 2/3 of distributed is residential

MODEL, DATA, METHODOLOGY – OTHER ASSUMPTIONS

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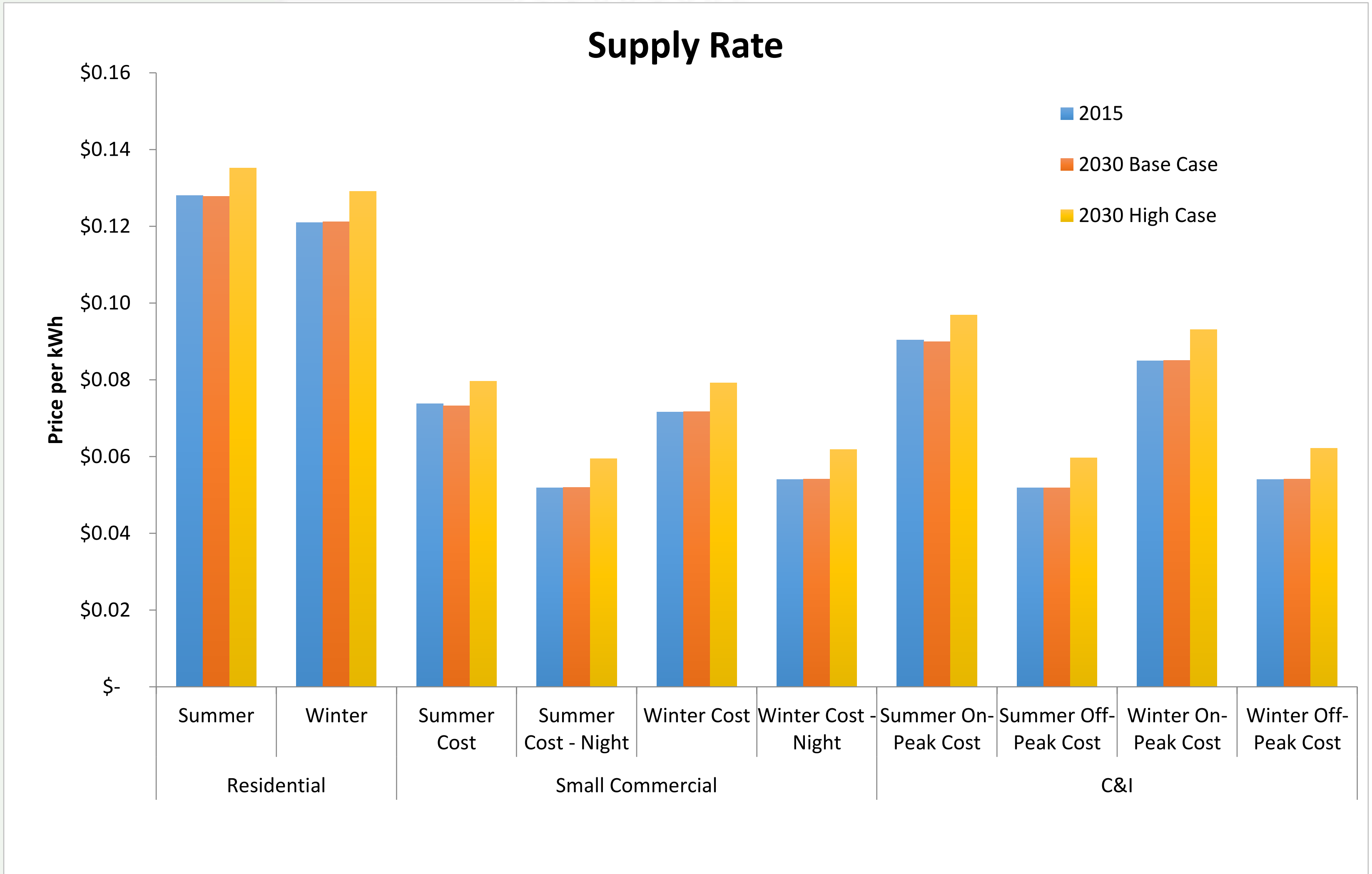
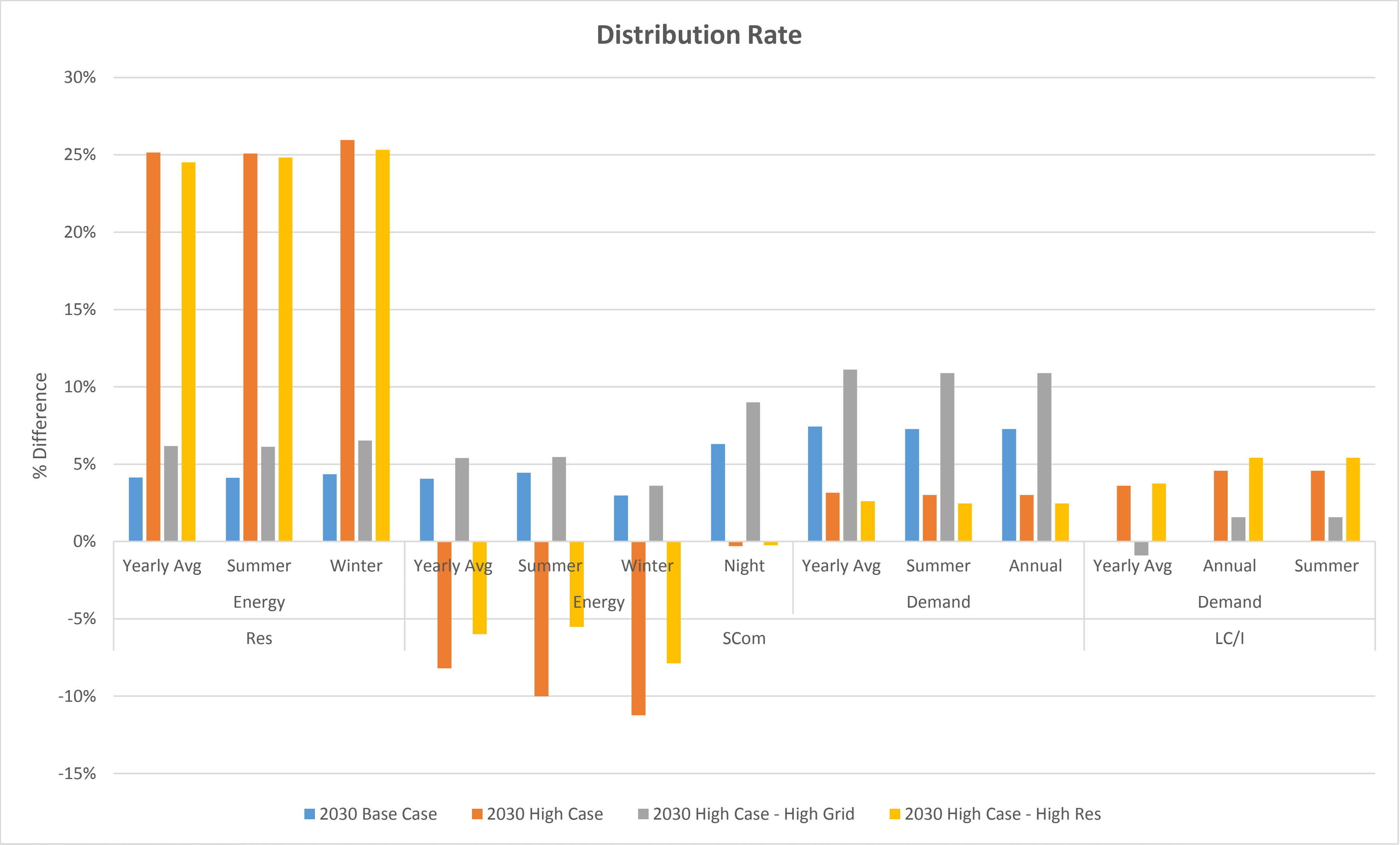
- Energy demand is inelastic
- Energy demand is constant over time
- Natural gas prices are constant
- Future SREC prices are 50% of the SACP
- Average System Size Remains Constant
  - Residential 5kW
  - Small Commercial 40 kW
  - C&I 750 kW
- Rate structure doesn't change

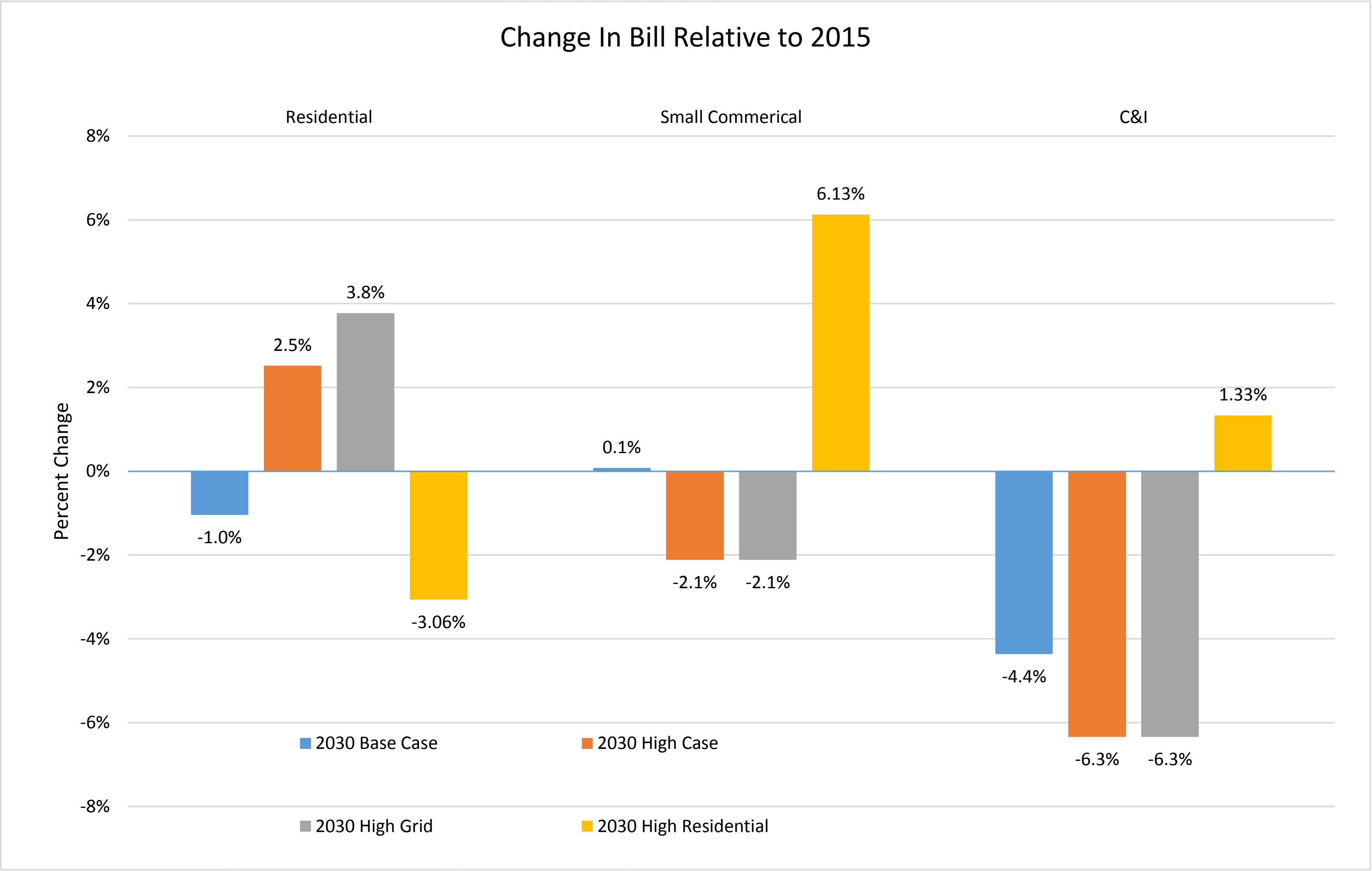
RESULTS – SUPPLY RATES



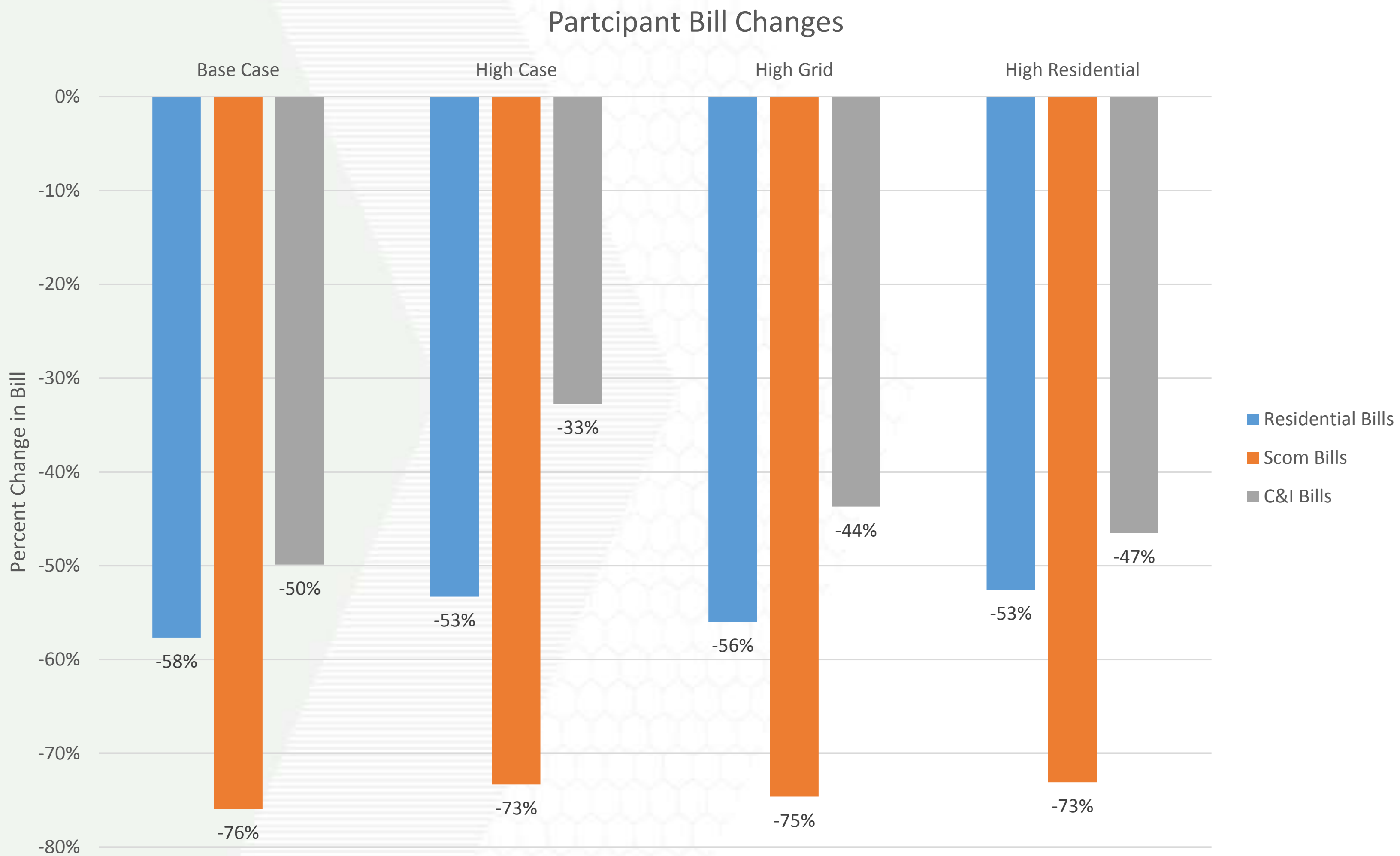
RESULTS – DISTRIBUTION RATES



RESULTS – AVERAGE BILLS

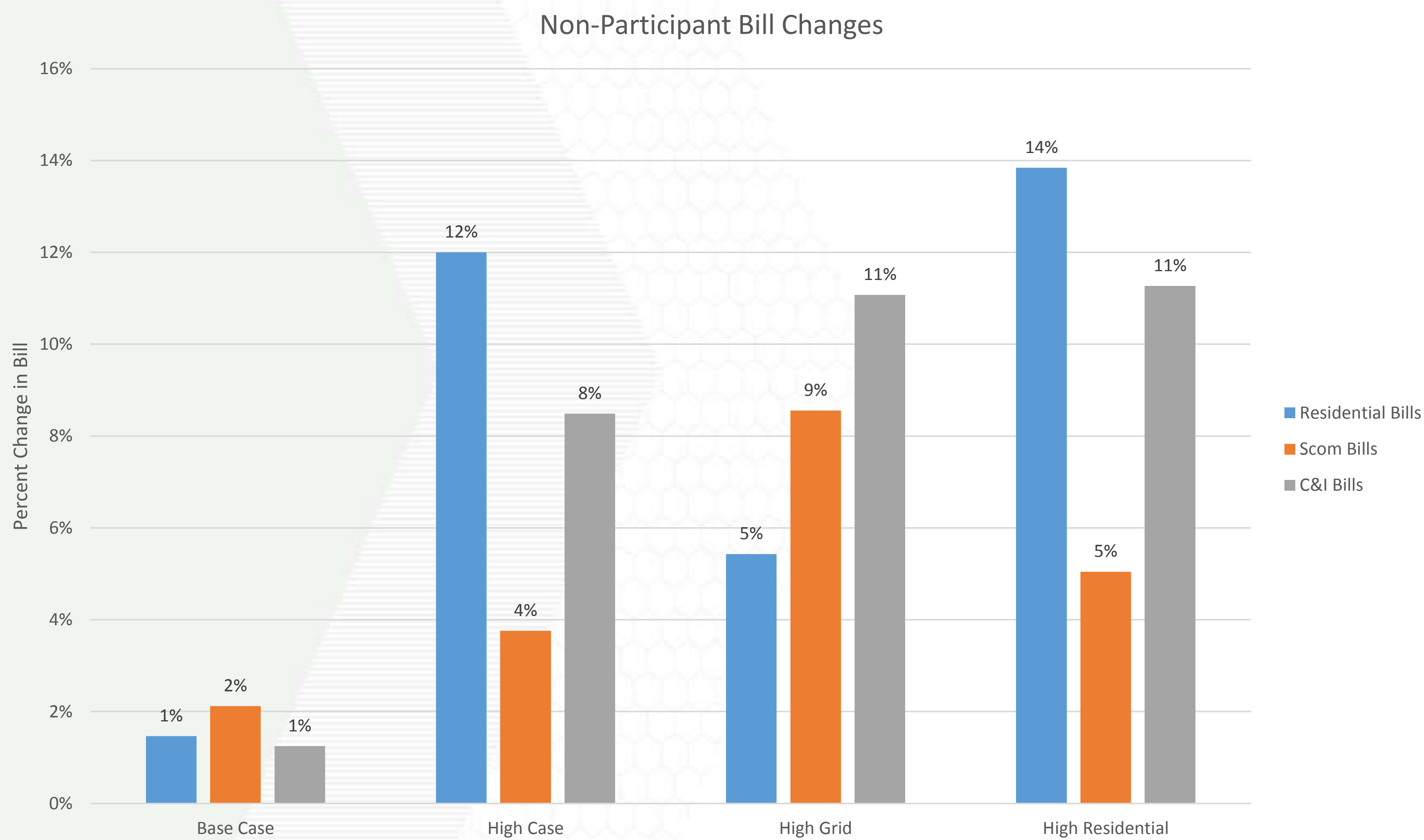


RESULTS –PARTICIPANT BILLS

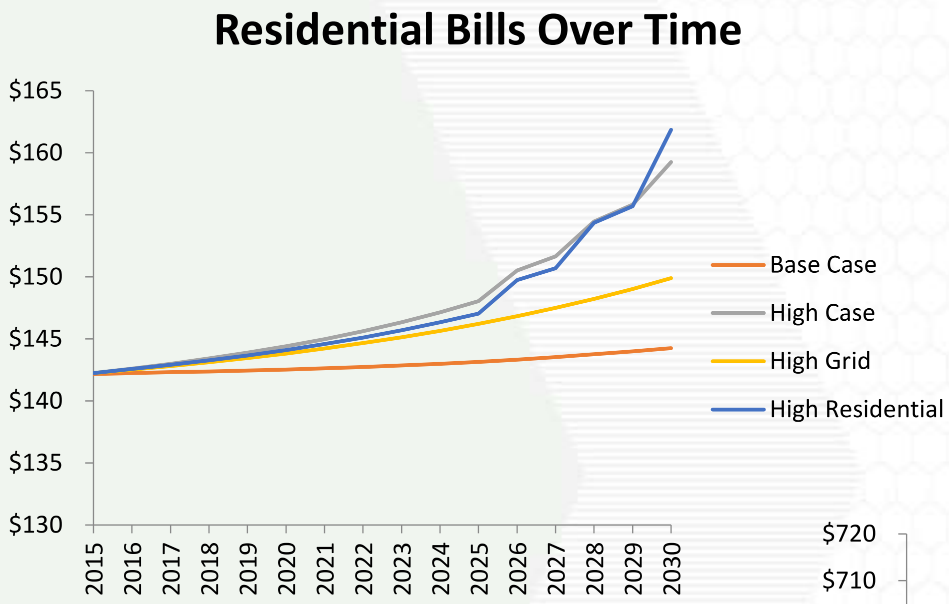


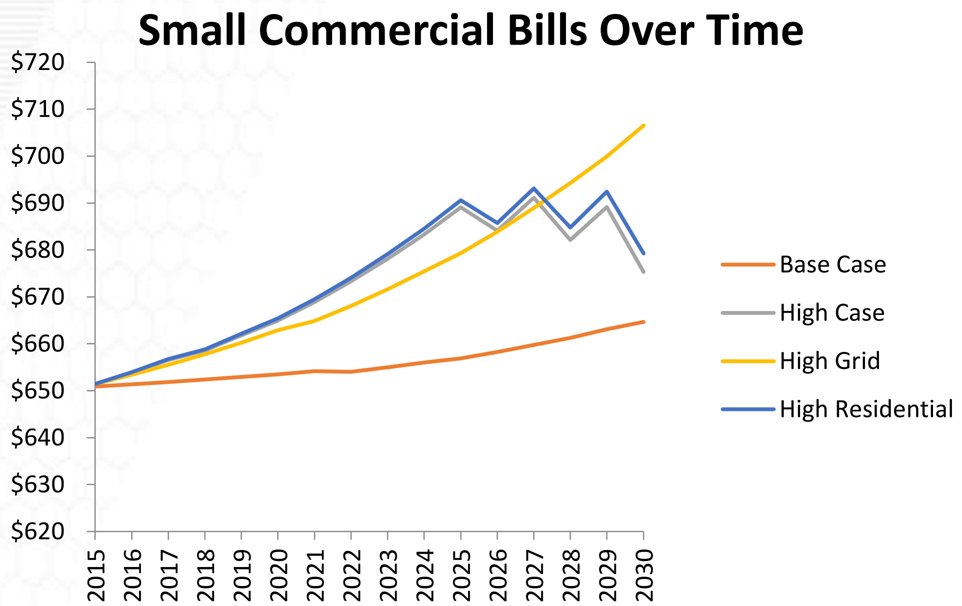
CREATING THE NEXT®

RESULTS – NON PARTICIPANT BILLS



RESULTS – BILLS OVER TIME





CONCLUSIONS

- Fears of "Death Spiral" may be exaggerated
  - In the Base Case, non-participant bills only increase by 2%
- Who installs solar (which rate class or grid scale) matters
- Non-adopters subsidize solar participants
- Coincident Peak Hour changes lead to rate class cross-subsidization

POLICY IMPLICATIONS

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- There are distributional and equity consequences of non-participants subsidizing solar adopters
- Do different policy attract different adopters?
- Cost Causality
  - How do utilities attribute fixed costs
  - What is the value of solar?
- Will technology facilitate alternative rate designs?
  - Rate designs are the product of a political process
  - Concentrated vs. diffuse interests
- Political Nature of PUCs

NEXT STEPS AND FUTURE RESEARCH

- Sensitivity Analysis
- Locational Consequences
- Introduce variable demand
- Alternative Rate Structures
- Customer "Profiles"