

The value of Energy Storage

the good, the bad, and the ugly

Mark O'Malley

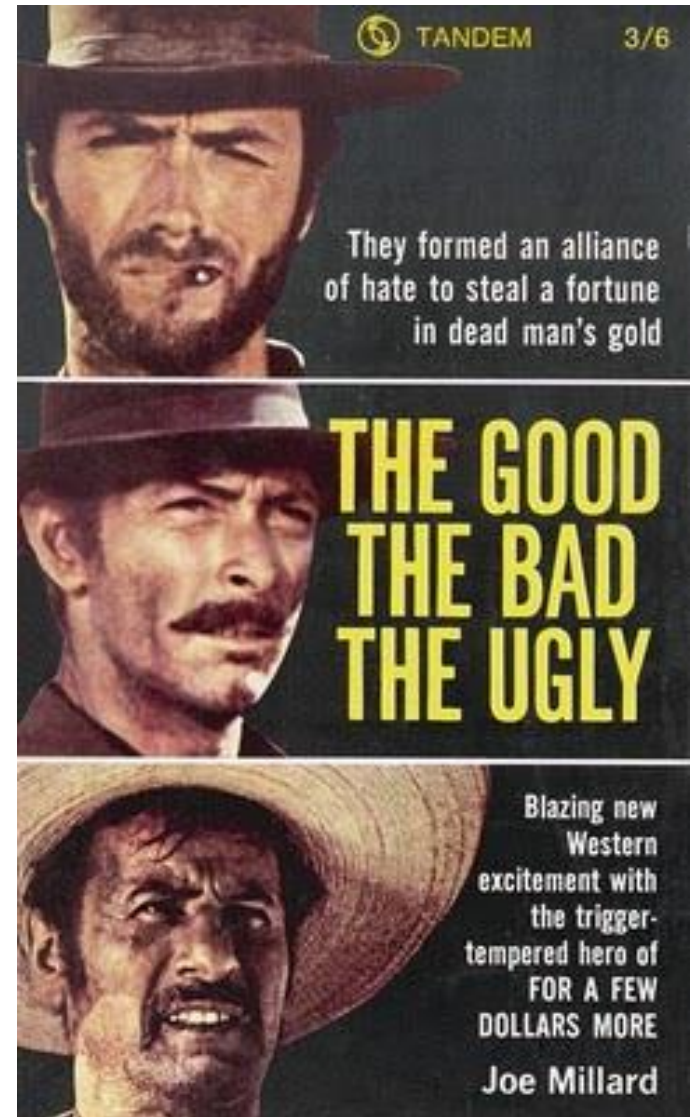
mark.omalley@ucd.ie

EASAC Electricity Storage Study

‘Valuing Dedicated Storage on Electrical Power Systems’

Mark O’Malley, University College Dublin
4th Symposium of the SCCER 24/10/2016

Methodology



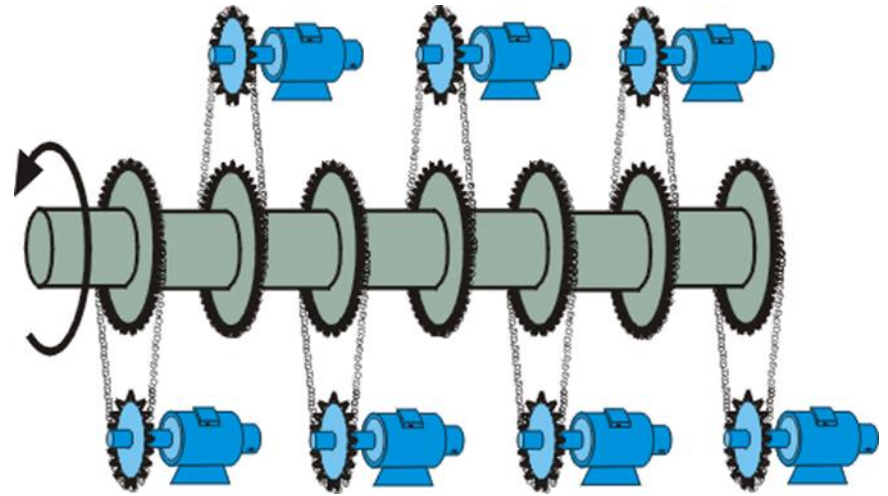
Outline

- Power System engineering 101
- The good – what storage has done and can do
- The ugly – competition is stiff
- The bad – what storage cannot do no matter what some people say
- Conclusions

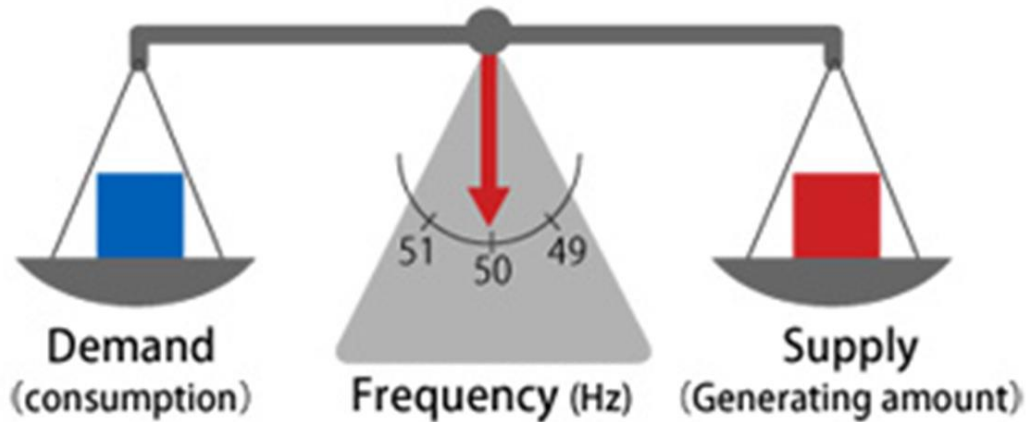


Power Systems Engineering 101

Synchronous Grid

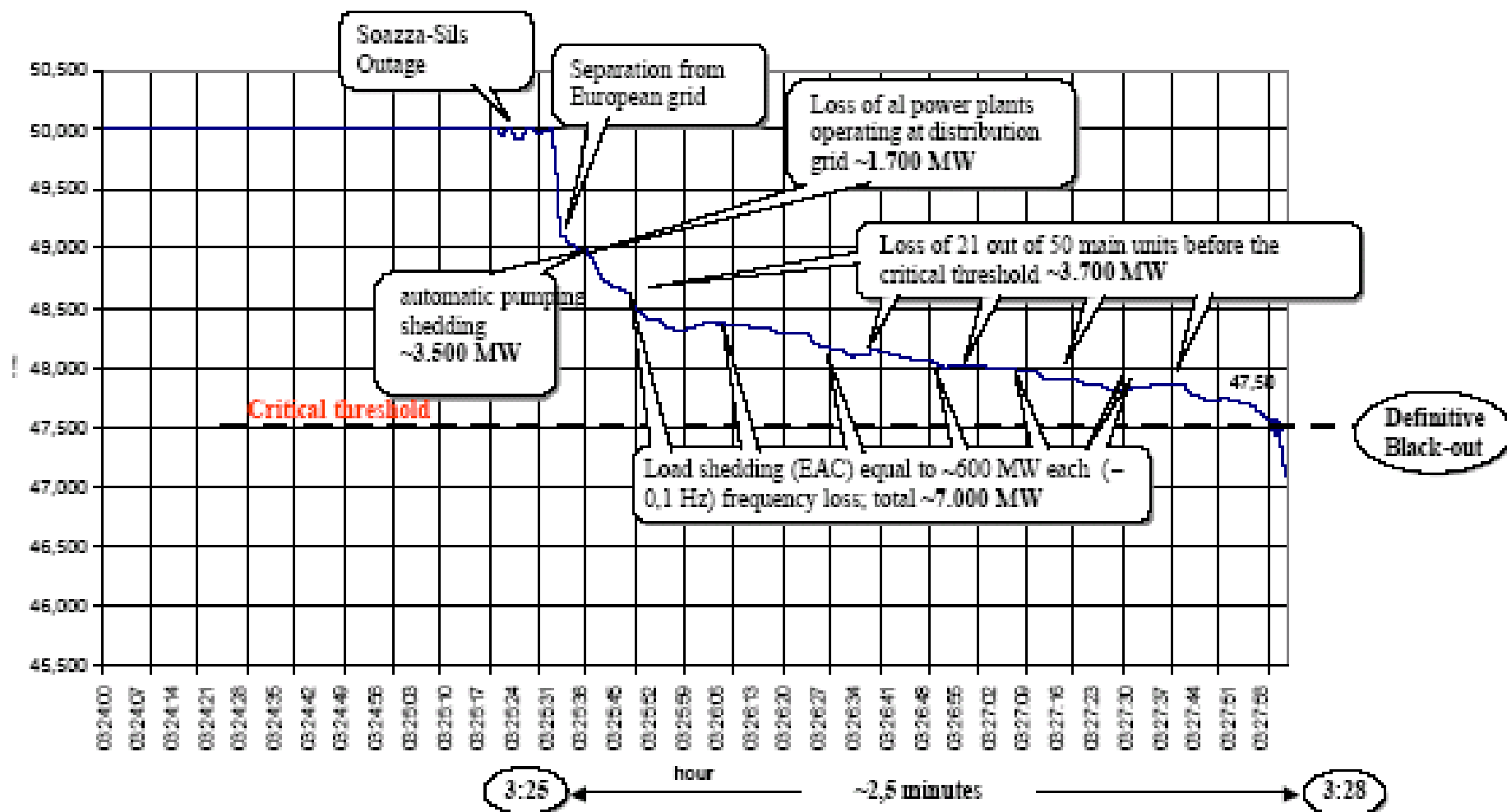


Important to keep balance



Italian blackout 28th September 2003

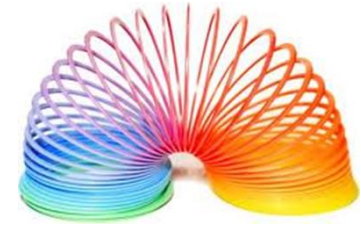
Frequency behaviour in the transitory period



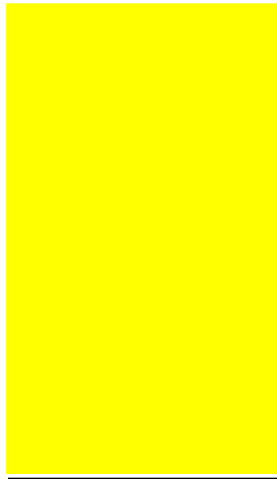
Italy in the dark



Time frames for electricity grids



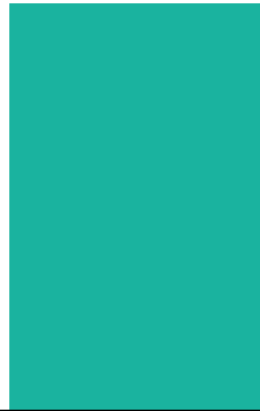
Planning



Years



Unit Commitment (on/off)



Operations

Economic Dispatch (power level)



Weeks - Hours

Minutes

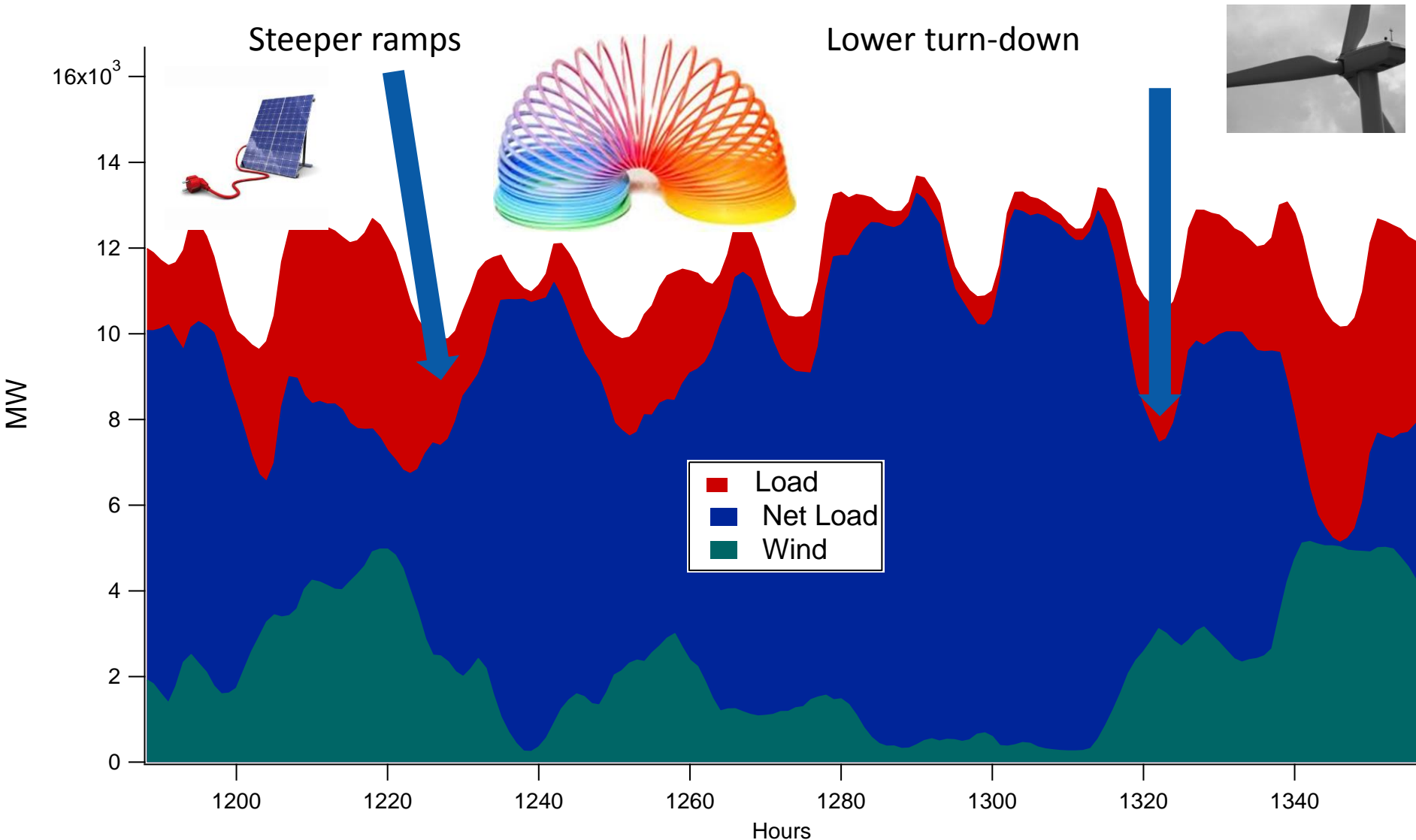
Time



Real Time



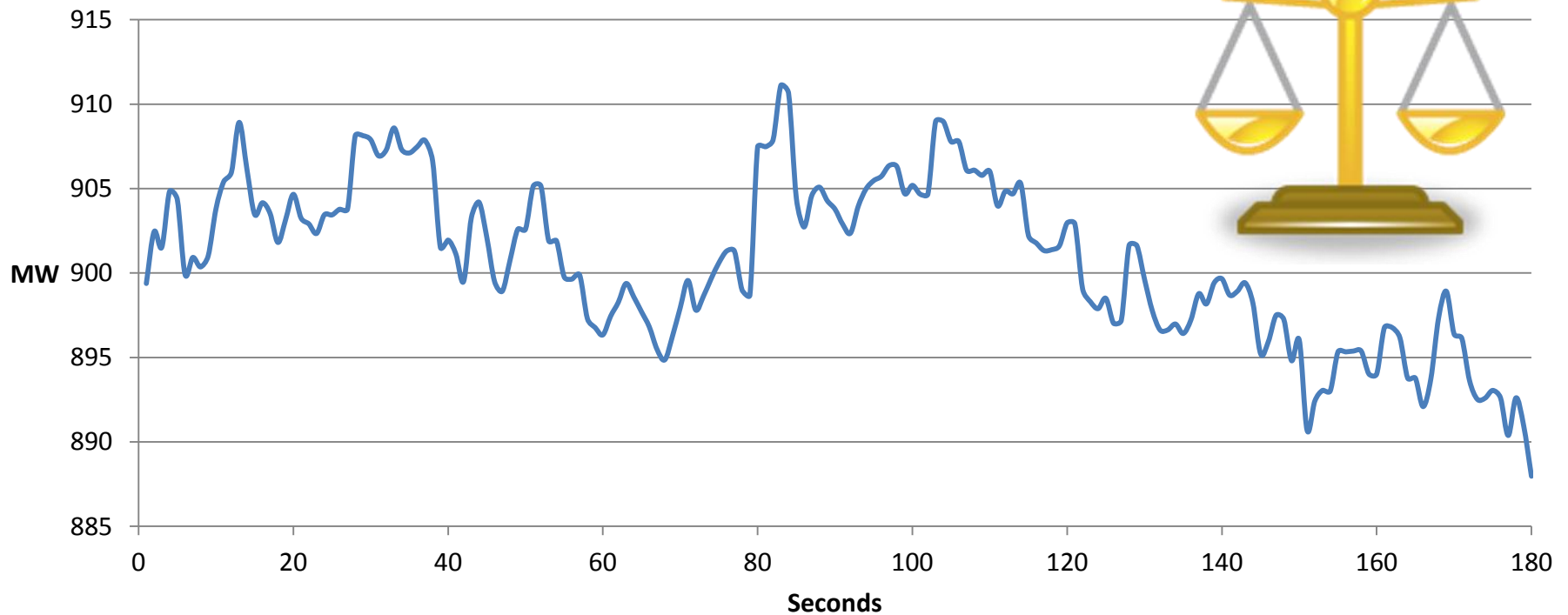
With Variable Renewables More Flexibility is Needed



Short Time Scale Variability

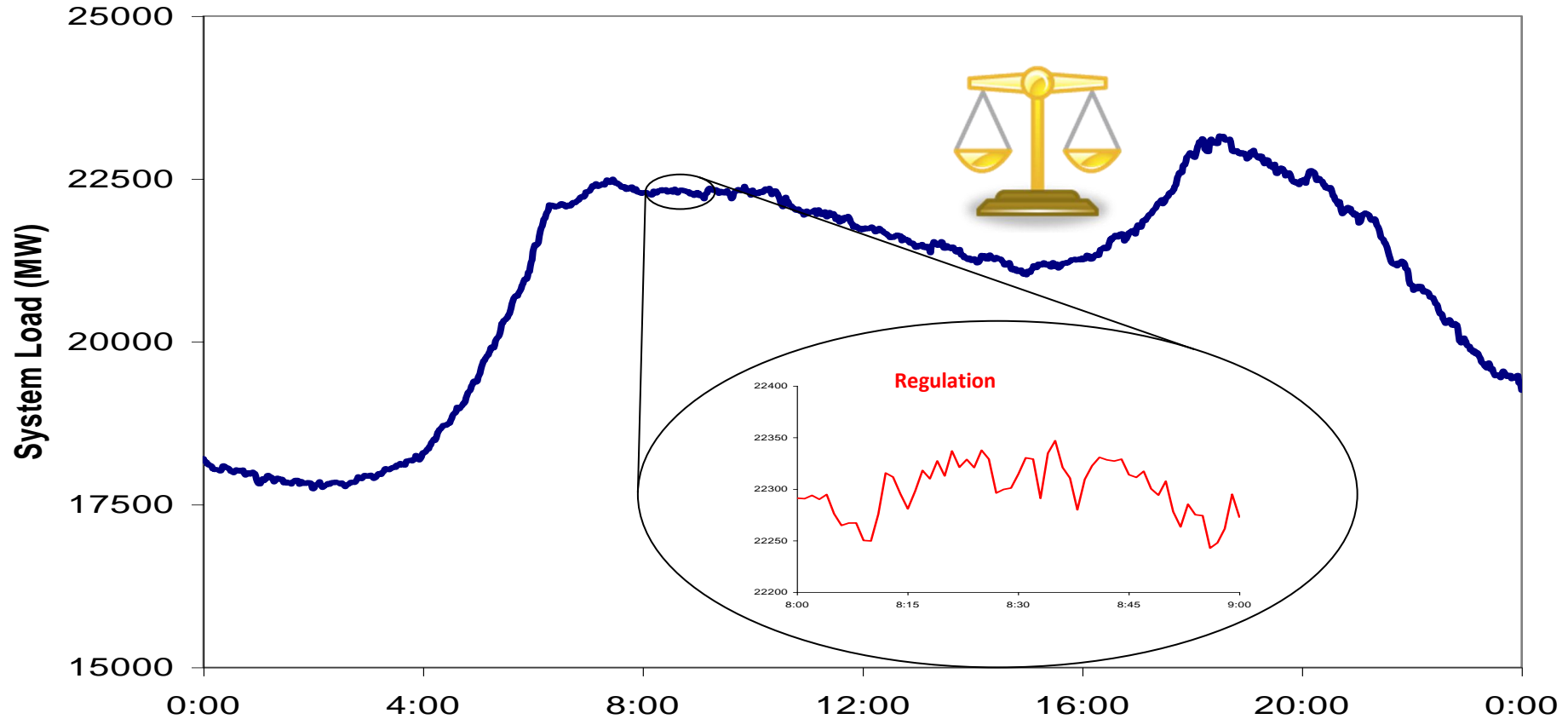


3 Mins Wind 1 Second resolution



Source: EirGrid data 29th October 2010

Frequency control - regulation



- Minute-to-minute regulation helps maintain frequency close to 50/60 Hz i.e. reliability (Brendan Kirby, kirbyconsulting.com)



The good



Storage Applications

		Discharge Time / Duration	Storage Application by Response Timeframe									
			Hours					Minutes			Seconds	
			Energy Arbitrage	Generation Capacity Deferral	(T &D) Investment Deferral	Congestion Management	Voltage Support	Black Start	Spinning Reserve	Renewable Ramp Reduction	Regulation	Power Quality
Storage Technologies	Pumped Hydro	Hours	M	M	M	M	M	M	M	M	M	
	CAES	Hours	C	C	C	C	C	C	C	C		
	Flywheel	Minutes						D	D	D	D	D
	Super Capacitor	Seconds										D
	Lead Acid Battery	Hours										C
	Advanced Lead Acid Battery	Hours						D	D	D	D	C
	NaS Battery	Hours						C		C	C	C
	NiCd Battery	Minutes									D	C
	Flow Battery	Hours					R	R	R	R	R	R
	Li-Ion Battery	Minutes									D	D

Technology Maturity Key : M Mature C Commercial D Demonstration R R & D

Elzinga, D., Dillon, J., O'Malley, M.J., Lampreia, J., "The role electricity storage in providing electricity system flexibility", in Electricity in a climate constrained world. International Energy Agency, Paris, 2012.

Electricity storage technologies

Technology	TRL level	Typical power capacity per plant (MW)	Installed power capacity (MW) worldwide	Installed energy capacity (MWh) worldwide	Installed power capacity (MW) in EU	Installed energy capacity (MWh) in EU	Number of grid connected systems working in EU	Typical Duration at rated power	Speed of response	Cycle life	efficiency
Pumped hydro (PHS)	9	100's MW	164,629	*	48,324	1,313,000	157	Hours	Seconds to minutes	n/a	70 - 80%
Compressed air (CAES)**	8	100's MW	437	4,013	322	646	3	Hours	Minutes	10,000	~ 50%***
Flywheels	8	10's MW	931	28	864	12	14	Seconds - minutes	milliseconds to seconds	1,000,000	90%
Li-Ion batteries	9	Up to 10's MW	1,134	1,321	186	343	104	Minutes - hours	milliseconds to seconds	100,000	85 - 90%
Na-S batteries	9	Up to 10's MW	189	1,273	38	296	6	Hours	milliseconds to seconds	5,000	70 - 85%
Lead acid batteries	9	Up to 10's MW	110	131	7	8	15	Minutes	milliseconds to seconds	1,000	75 - 90%
Flow batteries	7	Up to 10 MW	74	256	1	5	16	Hours	milliseconds to seconds	100,000	70-85%
Power to gas (to power)	7	100's MW	n/a	n/a	n/a	n/a	n/a	days	Seconds to minutes	n/a	~50%

Electricity storage technologies

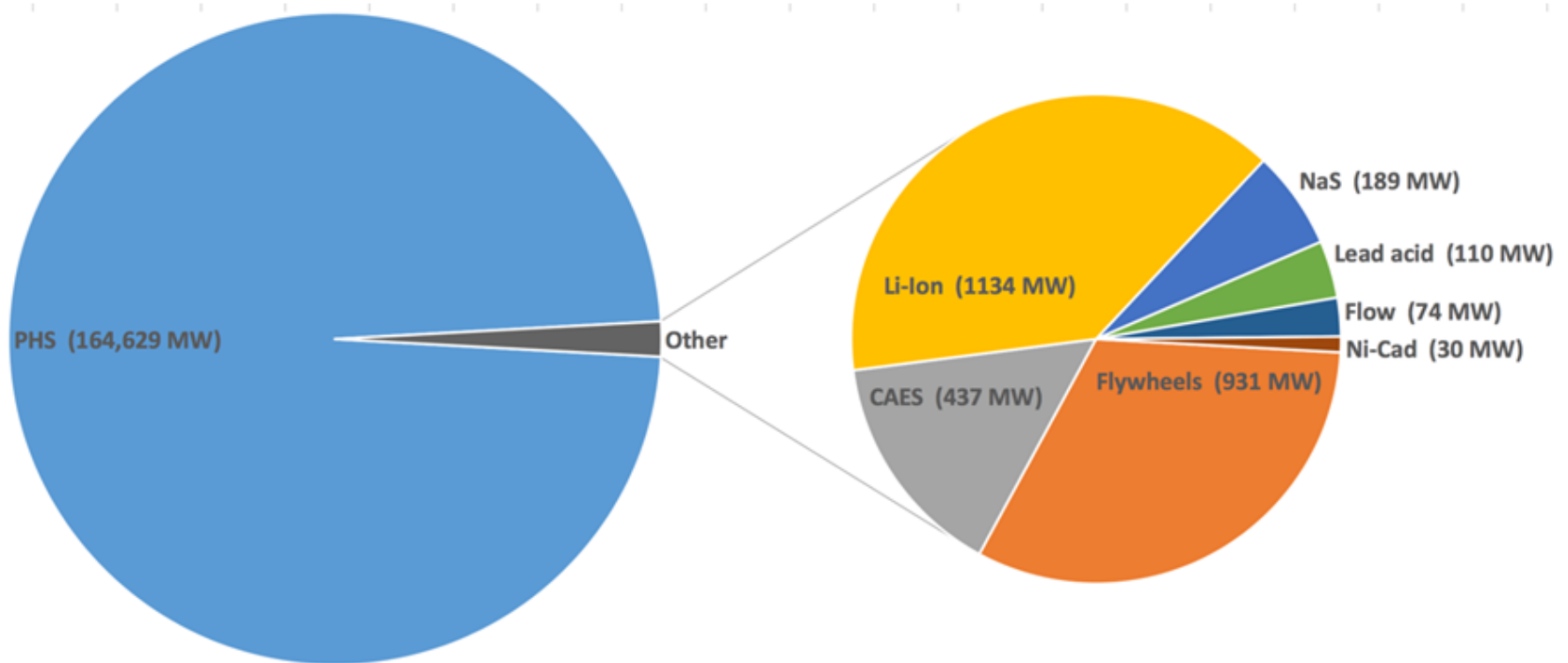
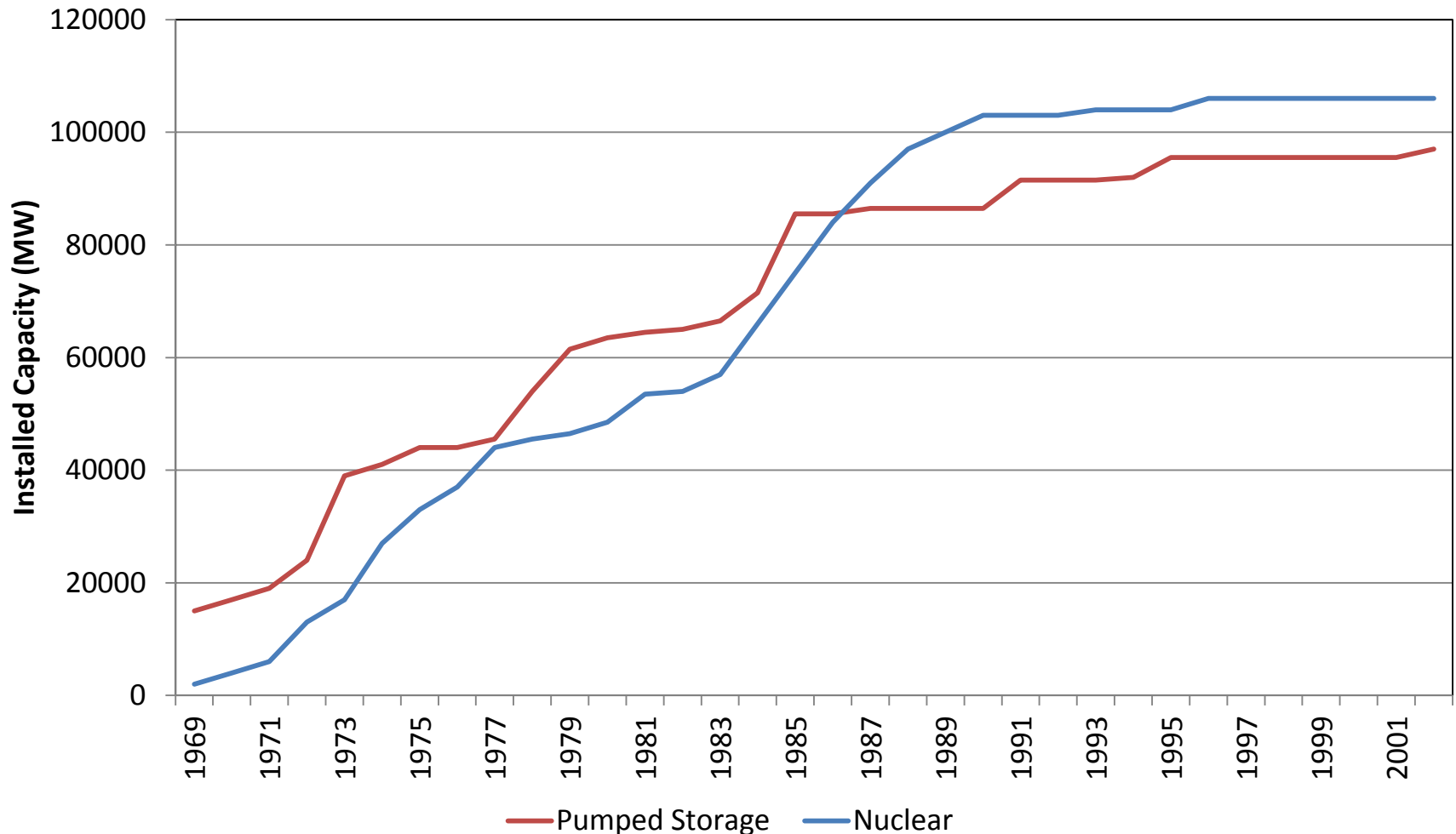


FIGURE 1 CURRENT GLOBAL GRID CONNECTED ELECTRICITY STORAGE CAPACITY (OPERATIONAL) (MW)

Historical Storage Drivers

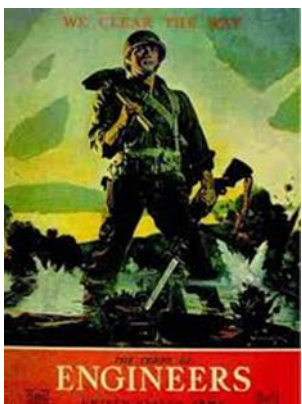


Data From OECD Countries only

Repeal of fuel use act in US:

http://www.eia.gov/oil_gas/natural_gas/analysis_publications/ngmajorleg/repeal.html

Boys and toys pumped storage in Ireland



Island Applications

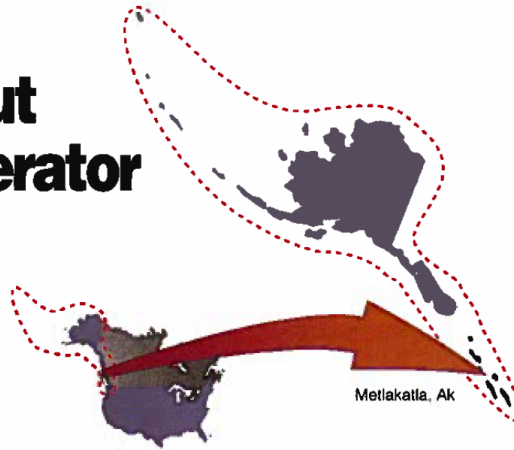
DISTRIBUTION

Battery storage all but eliminates diesel generator

Battery storage has some surprising benefits for island utilities—and it's not just peak shaving. A recently installed battery energy-storage system on the remote island of Metlakatla, Alaska (Fig1), provides rapid spinning reserve, frequency control, and better power quality. What's more, the island's main diesel generator—which once consumed more than 475,000 gal/yr of fuel oil—is now relegated to reserve duty. Hydro units now

electric generation, located at Purple Lake and Chester Lake. However, as times have changed, so have load demands and MP&L's ability to respond to them.

Before 1986, the Annette Hemlock Mill, the largest electric customer on the island, used about one-



1. **Metlakatla** is an island community on the Annette Island Reserve at the southern tip of Alaska

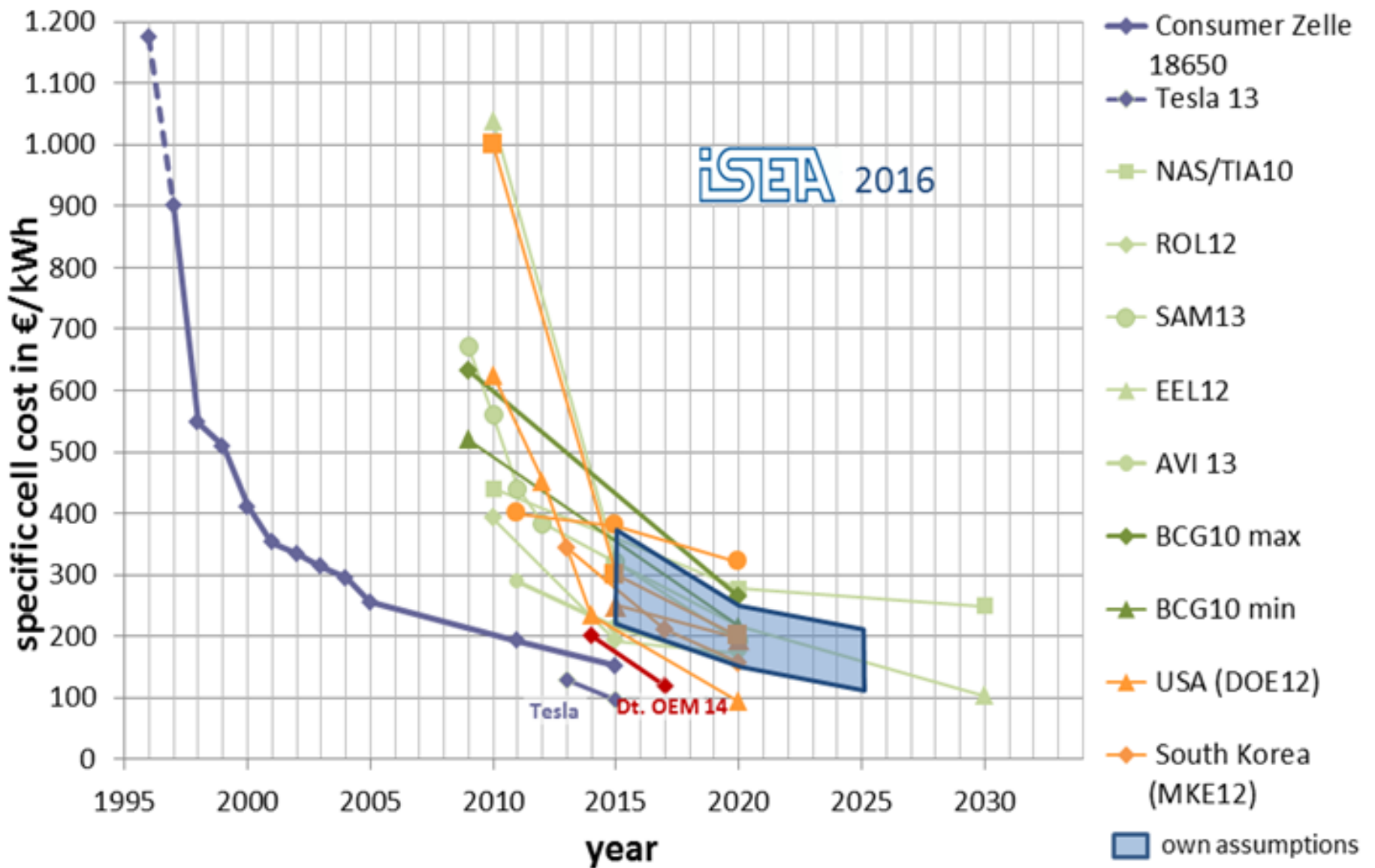
DEMAREST, M.,
TAYLOR, P.,
ACHENBACH, H. and
AKHIL, A., 1997.
Battery storage all but eliminates diesel generator.
Electrical world,
211(6), pp.39-41.

Manz, D.; Piwko, R; Miller, N ,
“Look Before You Leap: The Role of Energy Storage in the Grid”, IEEE Power and Energy Magazine, pp. 75-84, July/August, 2012.



Storage technology costs

Technology	Potential for future cost reductions
PHS	Low
Compressed air energy storage	Medium
Flywheels	Medium
Lead acid batteries	Low
Li-ion batteries	High
Sodium ion batteries	High
Redox flow batteries	Medium / High
Sodium sulphur batteries	Medium
Super capacitors	Medium
Power to gas to power	Medium

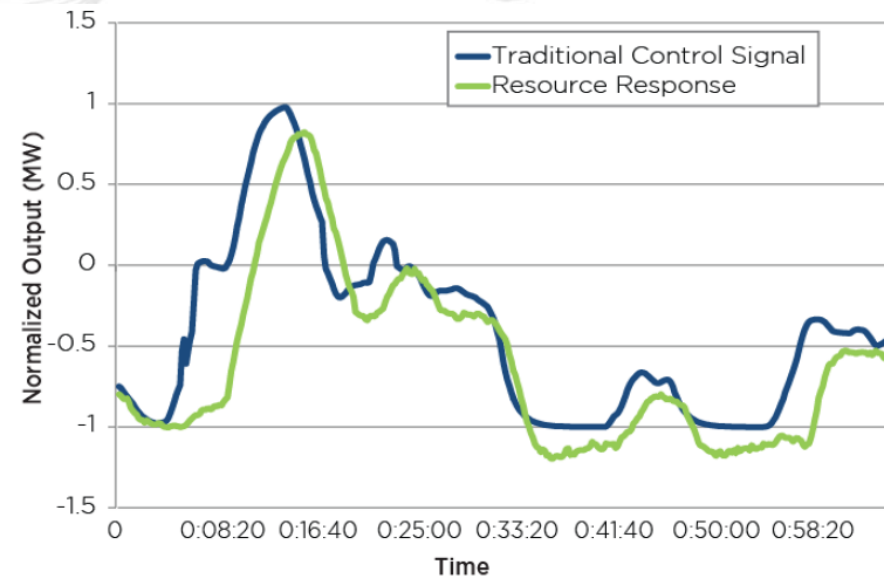
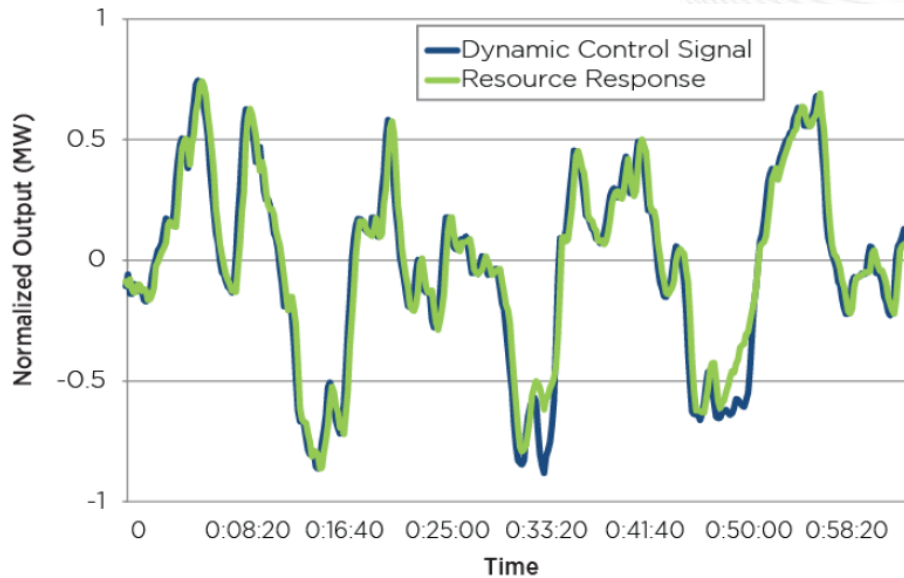


Pay-for-Performance Regulation Market



Scott Baker, Energy Storage: Balancing the 21st Century Grid, UVIG, Oct. 2015

Not All Megawatts are Created Equal



Energy Storage

Scott Baker, Energy Storage: Balancing the 21st Century Grid, UVIG, Oct 2015.



Steam Unit



Storage & regulation play that went wrong



Mark O'Malley, Chet Lyons,
Brendan McGrath, Keith
McGrane, NY, July 2011

Flywheel Energy Storage Lives On at Beacon Power



An update on
Beacon, emerging
from bankruptcy to
work the frequency
regulation markets

Eric Wesoff
May 31, 2013

The DOE loan program had its obvious big losers (Solyndra), its seemingly big winners (Tesla), and firms like Beacon Power, which are still works in



The ugly

Storage Applications & Competitors



Elzinga, D., Dillon, J., O'Malley, M.J., Lampreia, J., "The role electricity storage in providing electricity system flexibility", in Electricity in a climate constrained world. International Energy Agency, Paris, 2012.

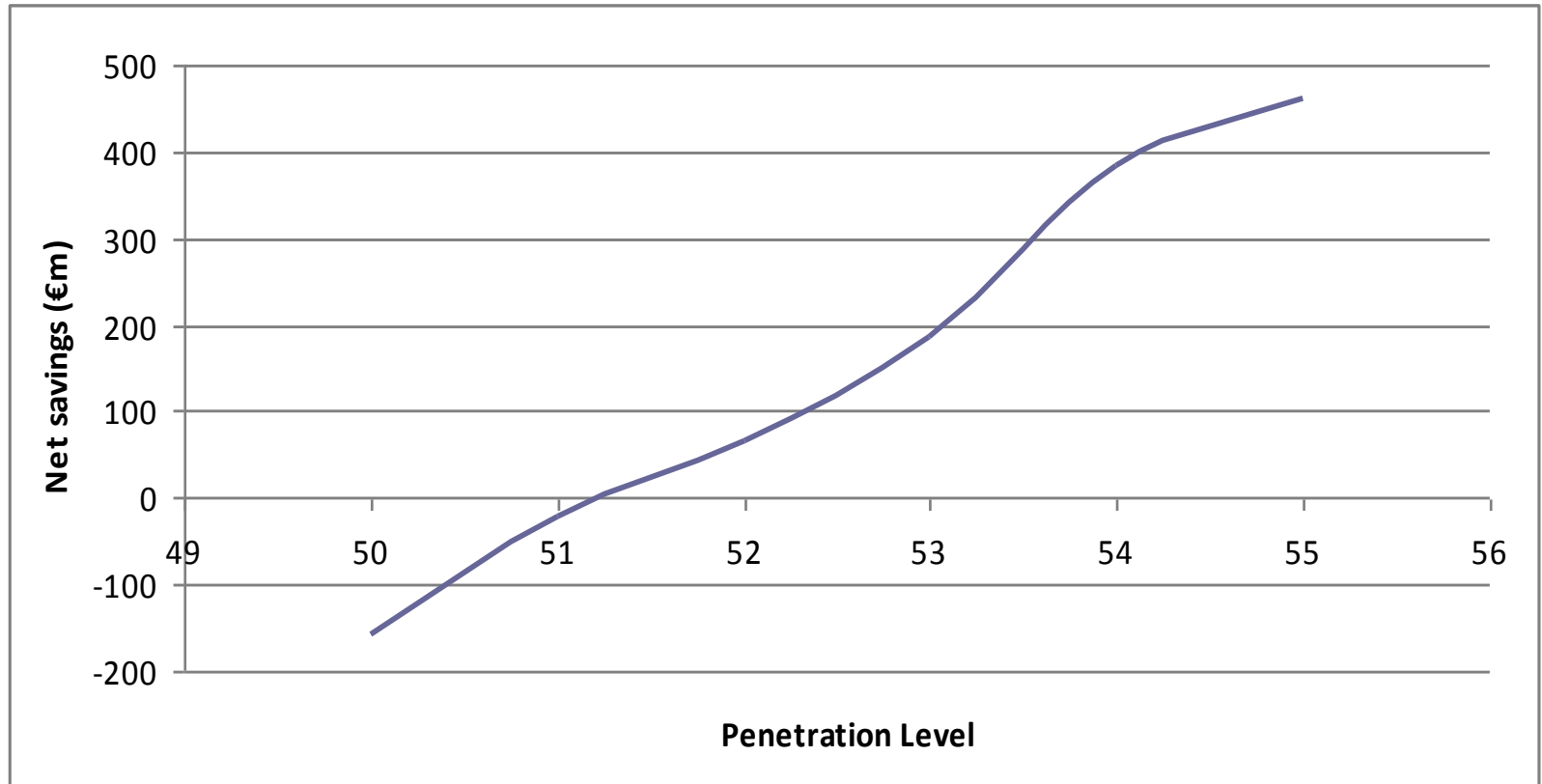
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	CAES	Hours	C	C	C	C	C	C	C	C		
	Flywheel	Minutes						D	D	D	D	D
	Super Capacitor	Seconds										D
	Lead Acid Battery	Hours										C
	Advanced Lead Acid Battery	Hours						D	D	D	D	C
	NaS Battery	Hours						C		C	C	C
	NiCd Battery	Minutes									D	C
	Flow Battery	Hours					R	R	R	R	R	R
	Li-Ion Battery	Minutes									D	D
Competing Technologies	Generation	Conventional Generation		M	M		M	M	M	M	M	
		Generation Re-dispatch			M	M						
		Hydro Generation			M	M	M	M	M	M	M	
	Demand Response ²		M	M					M			
	Transmission / Interconnection	Interconnection	M	M	M	M		M	M	M		
		Transmission	M	M	M	M	M	M			M	M
		Static Comp. Devices			M		M					
		Power Electronics										M
	Operational Measures	Protection Measures			M	M						
		Dynamic Line Rating			C	C						
		Forecasting	M									

Technology Maturity Key : M Mature C Commercial D Demonstration R R & D

Some analysis

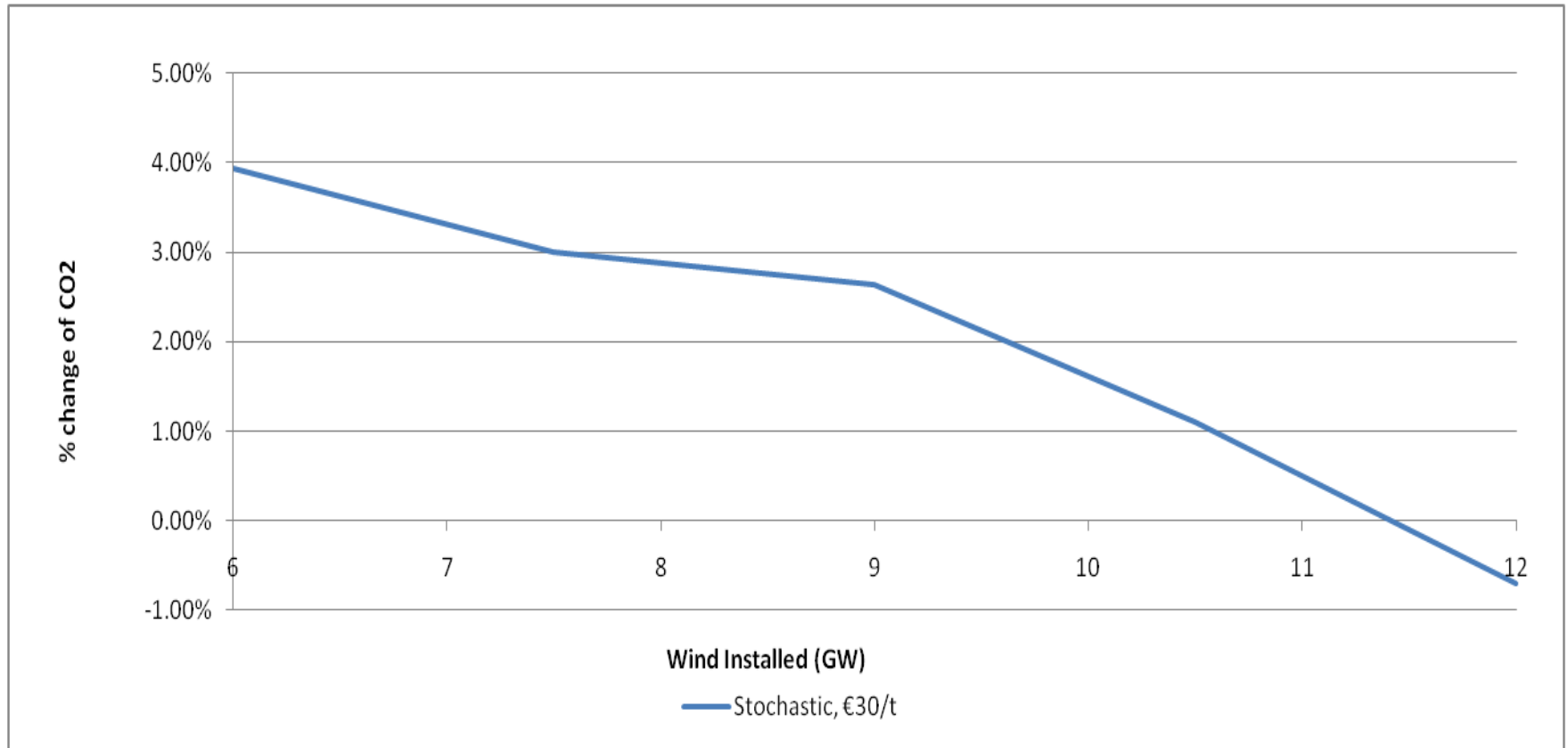


Net Savings with storage



Tuohy, A. and O'Malley, M.J., "Pumped Storage in Systems with Very High Wind Penetration", *Energy Policy*, Vol. 39, pp. 1965-1974, 2011.

Emissions with storage



Tuohy, A. and O'Malley, M.J., "Pumped Storage in Systems with Very High Wind Penetration", *Energy Policy*, Vol. 39, pp. 1965-1974, 2011.

Low value and declines rapidly

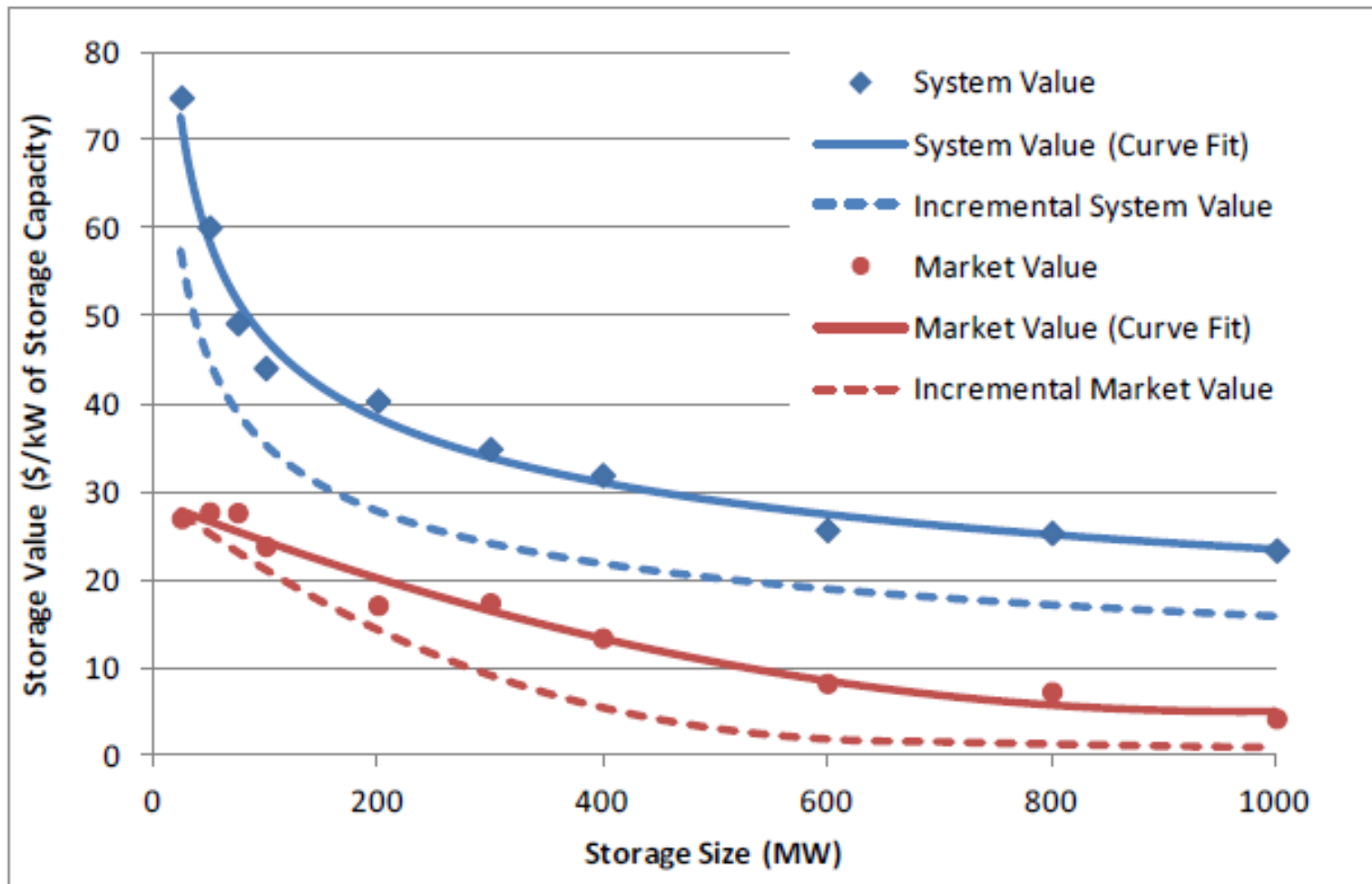


Figure 4-7. Storage operational value as a function of size for an energy-only device

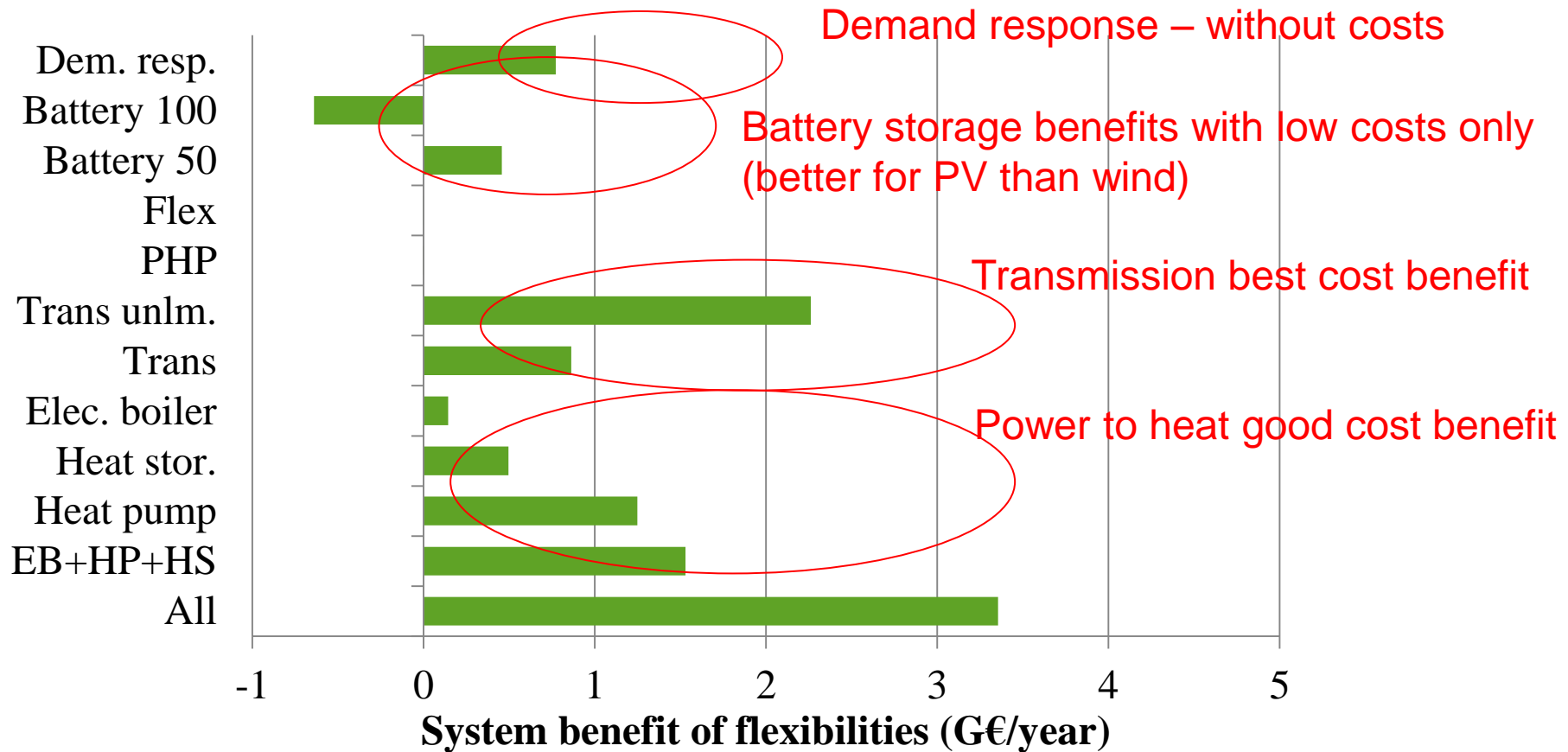
Denholm, P., Jorgenson, J., Hummon, M., Jenkin, T., Palchak, D., Kirby, B., Ma, O. and O'Malley, M.J., "The Value of Energy Storage for Grid Applications", National Renewable Energy Laboratory, Technical Paper NREL/TP -6A20-58465, May 2013.

<http://www.nrel.gov/docs/fy13osti/58465.pdf>

The competition



Comparing the flexibility options



- Relative value of new flexibility options for Northern Europe, scenarios with lot of wind power: 42-55% of energy
- For wind, transmission, heat sector flexibility and demand response most important

(Source: Kiviluoma et al, VTT)

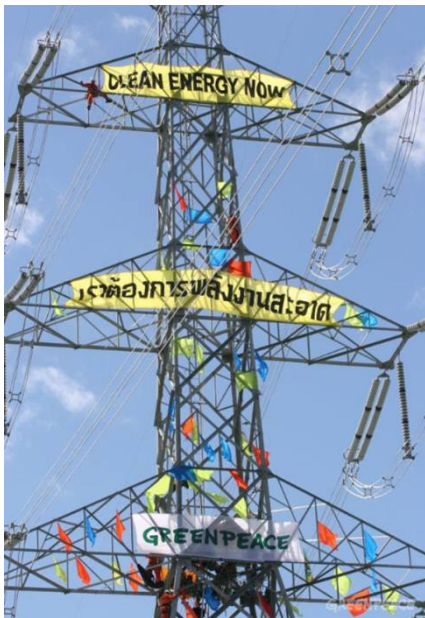


happytoast

Enter the “consumer”



“Engineers (and economists) tend to be ignorant and arrogant about customers”, Janusz Bialek



‘Engineers and economists are ignoring people and miscasting decision making and action’, Sovacool, B.K. (2014) *Nature* 511, 529-530



Masai women from Kenya take a course on solar energy in India.

Energy studies need social science



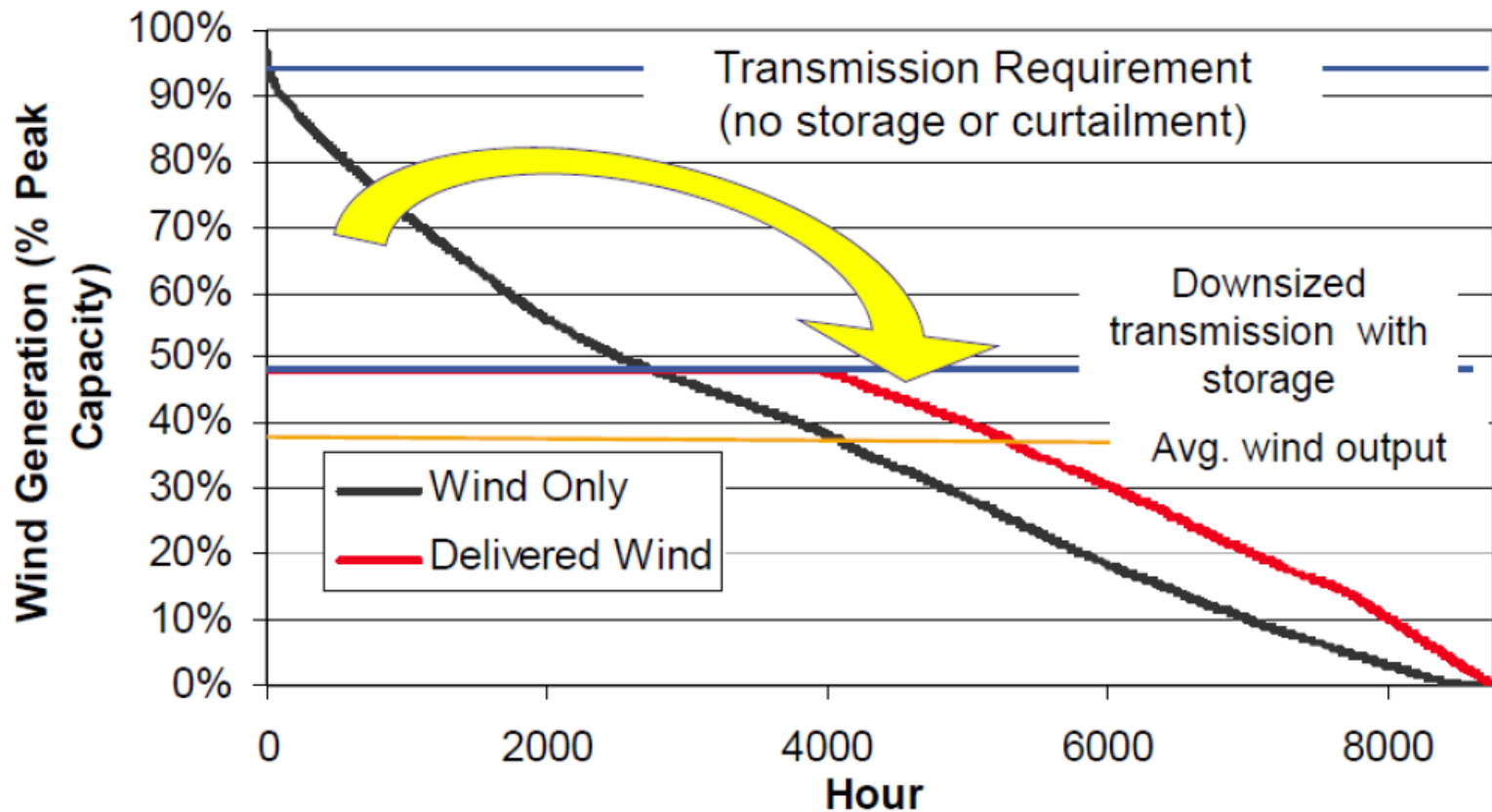


Fig. 10 Effect of storage on transmission capacity required

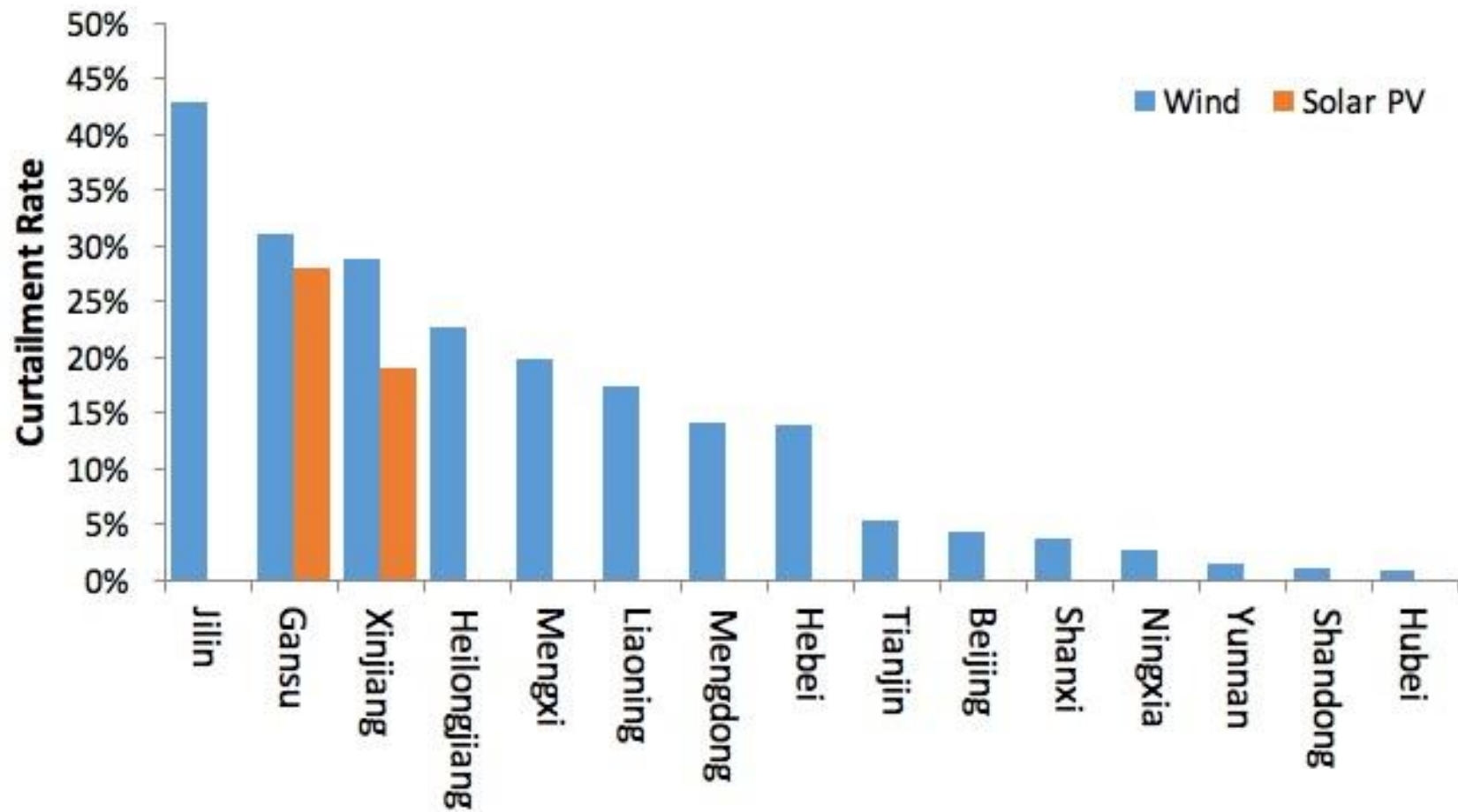


Virtual storage
not dedicated



Wind & solar PV curtailment in China

Wind and Solar Energy Curtailment Rates by Province in China, First Six Months of 2015



Centralised thermal storage in China

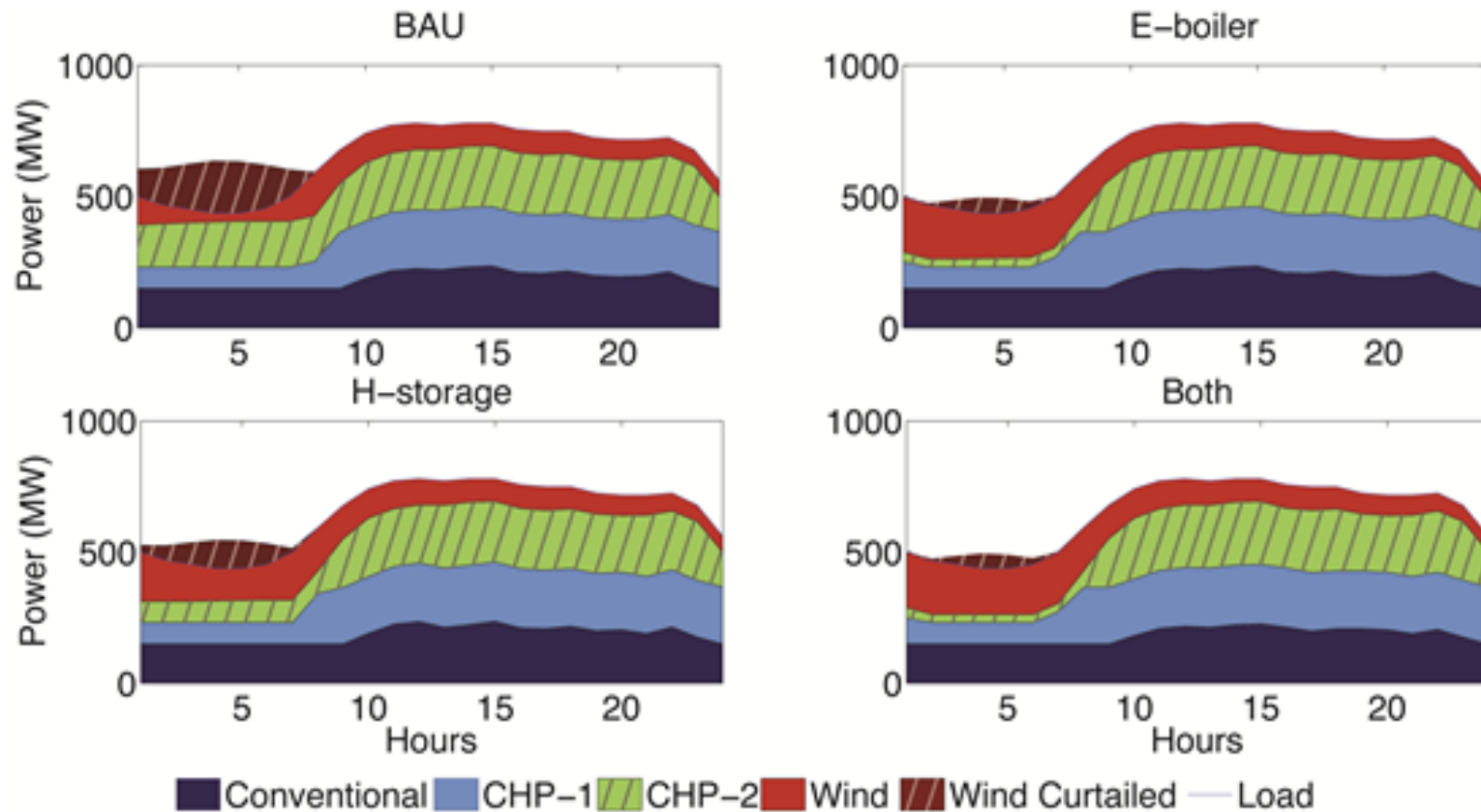


- Established in Inner Mongolia, 2014, with 20 electric boilers
- 500,000 m³ heat supply
- 75 GWh wind power annually, equivalent to 19,000t coal
- Decrease CO₂ emission by 68,000t



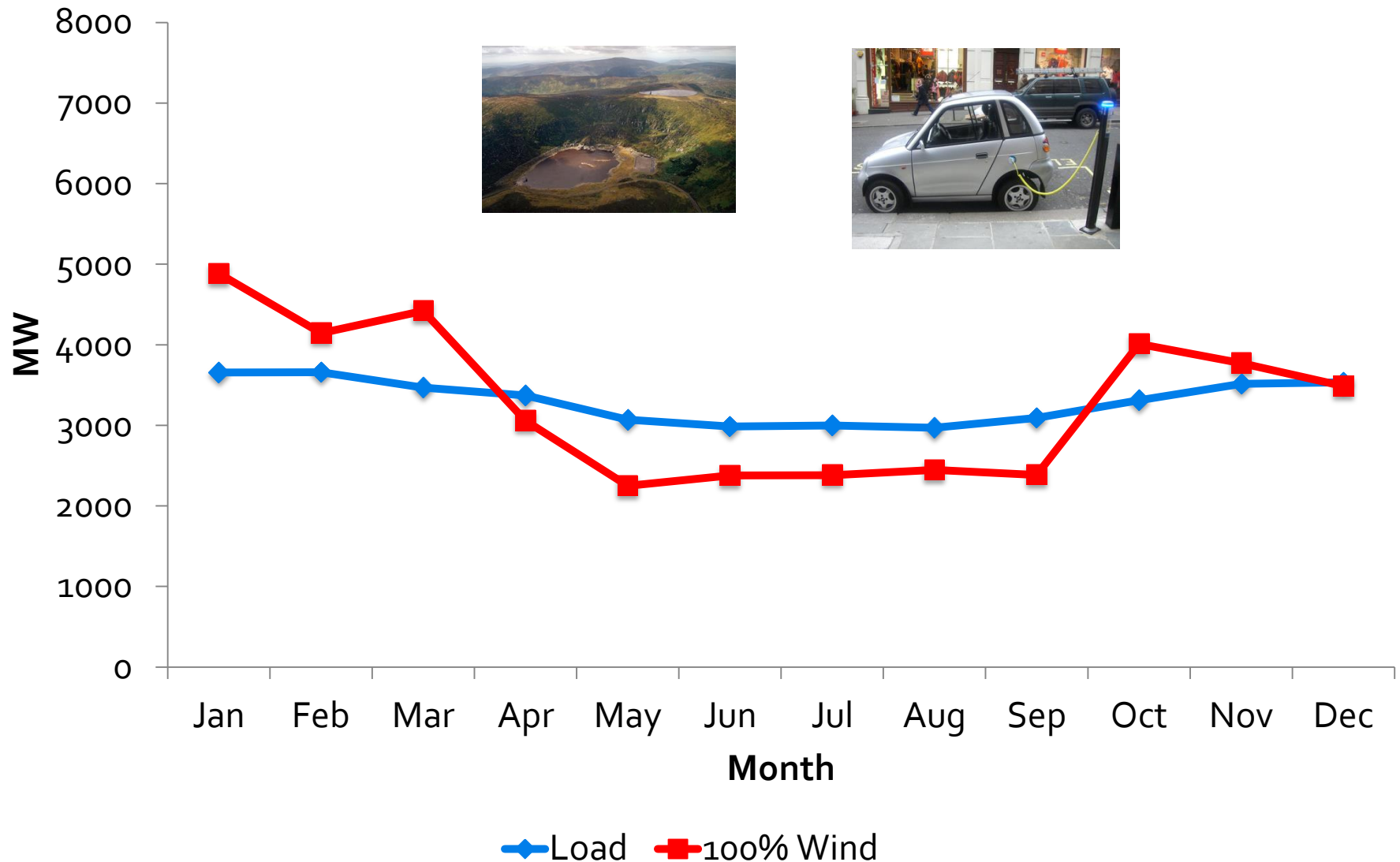
Source: Chongqing Kang, Tsinghua University

Flexible CHP can reduce wind curtailment



Chen, X., Kang, C., O'Malley, M.J., Xia, Q., Bai, J., Liu, C., Sun, R., Wang, W. and Hui, L., "Increasing the Flexibility of Combined Heat and Power for Wind Power Integration in China: Modeling and Implications", IEEE Transactions on Power Systems, Vol. 30, pp.1848-1857, 2015.

Seasonal Storage: we will have to change how we live





The bad

Wind Power Myths Debunked

THE RAPID GROWTH OF WIND POWER IN THE UNITED STATES AND

Does Wind Need Storage?

an inexpensive and conventional energy source and delivers a variable level of power depending on the wind speed. Wind is primarily an energy resource and not a capacity resource. Its primary value is to offset fuel consumption and the resulting emissions, including carbon. Only a relatively small fraction of wind energy is typically delivered during peak and high-risk time periods; therefore, wind generators have limited capacity value. This leads to concerns about the impacts of wind power on maintaining reliability and the balance between load and generation.

This article presents answers to commonly asked questions concerning wind power. It begins by addressing the variability of wind and then discusses whether wind has capacity credit. The article addresses whether wind can stop blowing everywhere at once, the uncertainty of predicting wind generation, whether it is expensive to integrate wind

Common Questions and Misconceptions

*By Michael Milligan, Kevin Porter,
Edgar DeMeo, Paul Denholm,
Hannele Holttinen, Brendan Kirby,
Nicholas Miller, Andrew Mills,
Mark O'Malley, Matthew Schuerger,
and Lennart Soder*

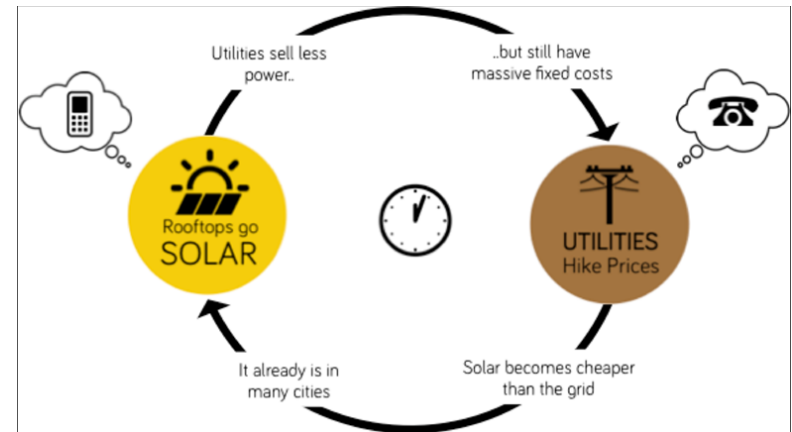
Beware of snake oil salesmen



**Does your laptop keep running out of power?
No longer! Use the natural power of your
own laptop to recharge itself!**

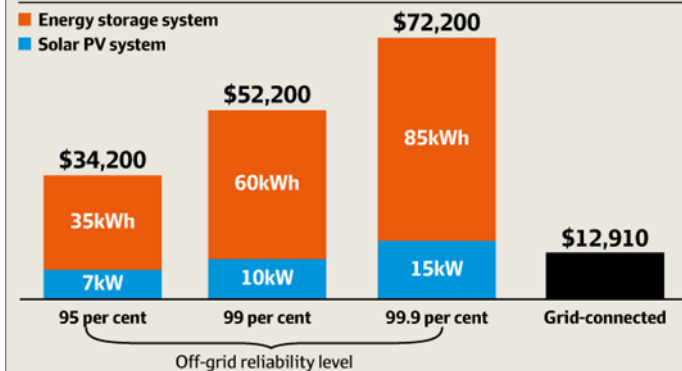


**Use the USB
Laptop self-
charger cable
and never run out of power again!**



Going off the grid

Upfront cost of an off-grid system by reliability level v
present net cost of remaining connected to the grid,
typical Sydney household, 2015



SOURCE: GRATTAN INSTITUTE



EUROPEAN COMMISSION
DIRECTORATE-GENERAL FOR ENERGY

DG ENER Working Paper

The future role and challenges of Energy Storage

Energy storage will play a key role in enabling the EU to develop a low-carbon electricity system. Energy storage can supply more flexibility and balancing to the grid, providing a back-up to intermittent renewable energy. Locally, it can improve the management of

Vinois, J., 2012. DG ENER Working Paper: The future role and challenges of Energy Storage. *European Commission, Director-General for Energy.*

An April fool joke



English (en)



European Commission > The Commissioners > Maroš Šefčovič > Announcements >

SPEECH | 1 April 2015

Energy Union and smart transition

Speech at InnoGrid2020+ conference (Check Against Delivery)

Thank you Nick for this introduction. And thanks to both you and Joao (Torres) for inviting me to this major event. I would like to use this opportunity to discuss the "smart transition" – some would even say "revolution" – that is unfolding before our very eyes.

Ladies and gentlemen, our children are very much part of a 'smart' generation - the generation for which smart phones and smart appliances are taken for granted. Smart technologies are now surrounding us. The ICT revolution, of citizens and consumer empowerment, entails a fundamental transformation of the way we live our lives and this also has a dramatic impact on how we conceive our

inclusive forums. I read it in your press release yesterday and I completely agree: "Smart grids are a prerequisite to achieving a real Energy Union".

As I have already alluded to, what **shale gas did to the US economy, smart grids can and should do in Europe**. Thus I would like to thank EDSO and ENTSO-E, not only for today but for your daily work; for your



Are there opportunities ?

Energywise | Energy | Renewables

California's First-in-Nation Energy Storage Mandate

By Bill Sweet

Posted 25 Oct 2013 | 17:30 GMT




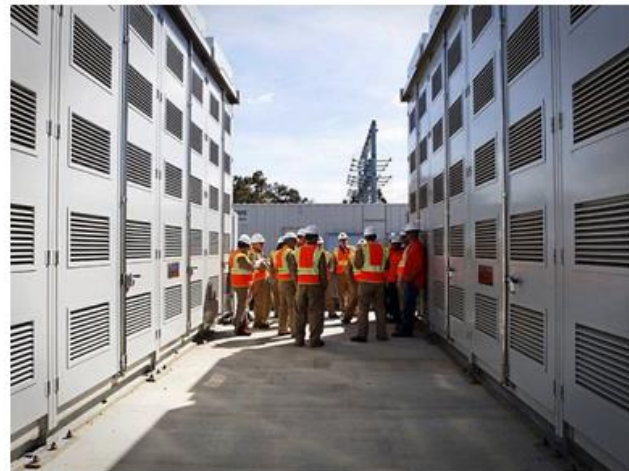
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Photo: PG&E

West Coast Wattage: A 2-megawatt, 14 megawatt-hour battery facility in Vacaville, Calif. could help California meet a new storage mandate.

Relat



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Commissioners



Currently the five commissioners are:

MICHAEL R. PEASEY
PRESIDENT

THOMAS ALAN SANCHEZ
COMMISSIONER

MIKE FLORIO
COMMISSIONER

CATHERINE A.K. SANCHEZ
COMMISSIONER

MARK FERRON
COMMISSIONER

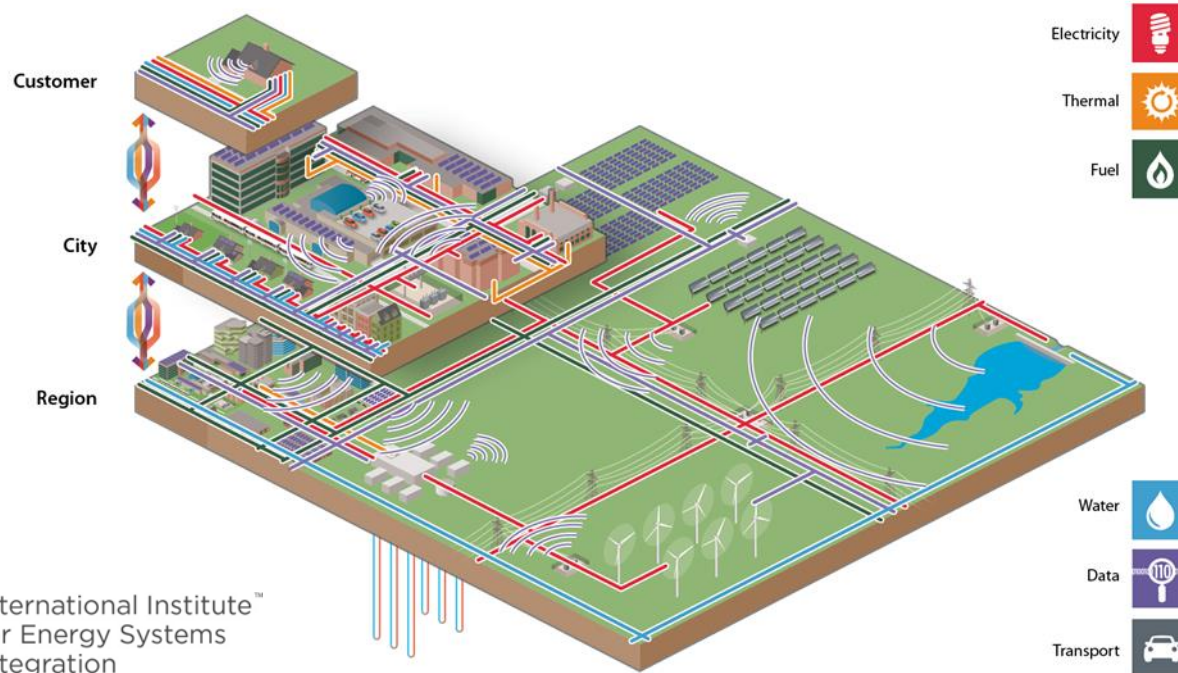


California has adopted the United States' first energy storage mandate, requiring the state's three major power companies to have 1325 MW of electricity storage capacity in place by the end of 2020, and 200 MW by the end of next year. The new rule issued by the California Public Utilities Commission (CPUC) will be key to implementation of the state's ambitious renewable portfolio rules, which calls for 33 percent of delivered electricity to come from renewable sources by 2020 and virtually guarantees that California, along with Germany, will remain in the world vanguard of those aggressively building out wind and solar. By common expert consent, wind and solar can only reach their full potential if storage is provided for, as otherwise little-used generating capacity must be held in reserve for the times the wind does not blow and the sun does not shine. California's landmark rule was written by Commissioner Carla Peterman, newly appointed to the CPUC late last year by Governor Jerry Brown.

"This is transformative," Chet Lyons, an energy storage consultant based in Boston, told the *San Jose Mercury News*, the state's most tech-savvy newspaper. "It's going to have a huge impact on the development of the storage industry, and other state regulators are looking at this as a precedent." Though the new rule was adopted by the five CPUC commissioners unanimously, two expressed concerns about the storage mandate's being achieved at reasonable cost to consumers, especially as large pumped storage (hydraulic) facilities do not qualify. There are a wide range of technologies that do qualify, including batteries and flywheels, but costs are generally high. Pike Research has concluded that the United States as a whole could have as much as 14 GW of electrical storage by 2022, but only if storage costs come down to the vicinity of to about \$700-\$750 kilowatts per hour

<http://spectrum.ieee.org/energywise/energy/renewables/californias-firstinnation-energy-storage-mandate>

Energy Systems Integration



- **optimization** of energy systems across multiple pathways and scales
- increase reliability and performance, and minimise **cost and environmental impacts**
- most valuable at **the interfaces where the coupling** and interactions are strong and represent a challenge and an opportunity
- control variables are **technical economic and regulatory**

Conclusions

- ❑ Storage has many potential roles in future energy systems
- ❑ In electricity dedicated storage is very expensive and has many competitors – only applied in niche applications
- ❑ Virtual storage is more competitive than dedicated storage in many applications
- ❑ Battery technology is declining in cost (and/or improving efficiency) but has a long way to go before it becomes ubiquitous
- ❑ Price distortions can cause perverse incentives and improper deployment of storage technology
- ❑ Great research topic - interdisciplinary is important
- ❑ Sound scientific advice to policy makers is important
- ❑ EASAC report will be published shortly

Acknowledgements

- Thomas Schmidt, Ursula Ludgate-Fucci, et al.
- Hugh Doyle
- My colleagues for many of the slides

