# Energy Systems Integration (ESI)


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UVIG, Tucson, Arizona

March 12th 2018

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# Charlie's instructions

9:00 a.m. – 12:00 p.m.
**ESI Tutorial – Energy Systems Integration – An Introduction**
Location: Kiva A
Chair: **Mark O'Malley,** Chief Scientist for ESI, NREL

As the penetration levels of variable renewable energy increase in electricity systems, coupling with other energy vectors (e.g. fuels, heating/cooling) and energy infrastructures (e.g. transport, water) becomes increasingly important and necessary. This integration across the wider energy system is known as energy systems integration (ESI). The ESI Tutorial will briefly introduce the topic of energy systems integration, and further examine two aspects in greater detail. The tutorial will conclude with an outlook for the future, followed by a discussion period.

- Introduction and Overview of Energy Systems Integration – **Mark O'Malley**, NREL (35 min)
- Planning in an Integrated Energy System – **Jim McCalley**, Iowa State University (50 min)
- Transport in an Integrated Energy System – **Johan Driesen**, KU Leuven, Belgium (50 min)
- Outlook for Energy Systems Integration – **Mark O'Malley**, NREL (15 min)
- Open Discussion (15 min)

10:15 a.m. – 10:30 a.m.
**Break**
Location: Kiva Patio

# Initial Comments

- Why now
- Focus on where it matters – not an academic exercise
- Every system is different
- Not just about systems – devices and people with make up the energy system
- It is about coordination NOT optimisation
- Collaboration is key
- Working Group on Research and Education

# Overview

- What, why, who etc.
- Role of electricity
- Examples
  - energy vectors
  - scales
  - other infrastructures
  - institutional
- Conclusion


# What, why, who etc.

# What is Energy Systems Integration (ESI) ?

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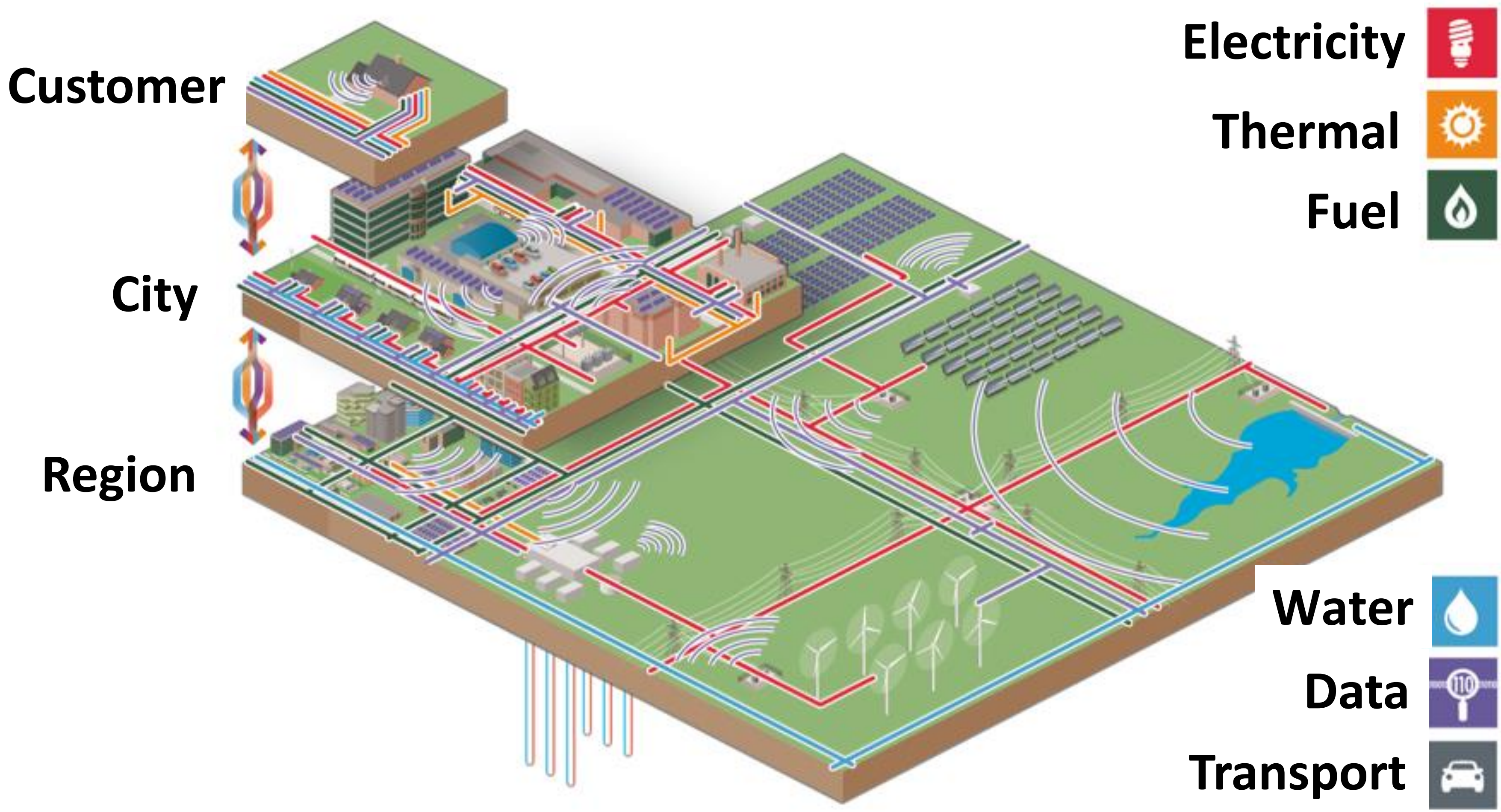
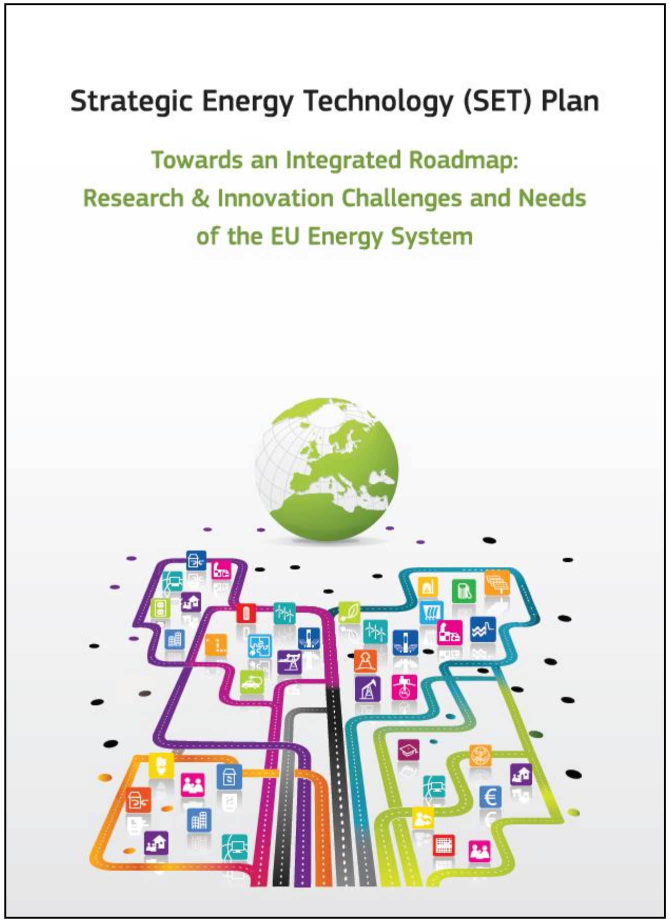
**Energy system integration (ESI)** = the process of coordinating the operation and planning of energy systems across multiple pathways and/or geographical scales to deliver reliable, cost-effective energy services with minimal impact on the environment.



# European/US context





http://www.nrel.gov/esi/esif.html

EERA European Energy Research Alliance

New Joint Programme in Energy Systems Integration

iESI International Institute for Energy Systems Integration

# Why is Energy Systems Integration Important ?

The value of ESI is in **coordinating** the energy system to deliver reliable, cost-effective energy services to the energy consumer and society, with minimal impact on the environment.

ESI, therefore, is a strategically important area to achieve mankind’s goals of achieving a sustainable energy future.

# Where is Energy Systems Integration Valuable ?

ESI is only of interest at the interfaces between the energy vectors, scales and institutional mechanisms, where the coupling and interactions are **strong**.

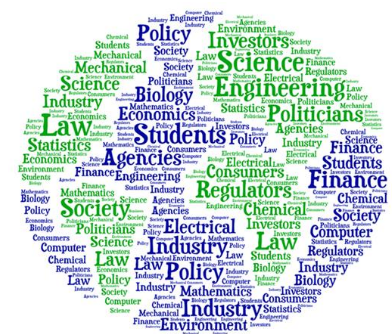
It is important that ESI is focussed on the interfaces where significant reliability, and/or economic, and/or environmental **benefits** can be achieved.

# Why is Energy Systems Integration Valuable

- ESI is not new but recent trends are increasing the challenges and opportunities at the interfaces.
- The biggest trend driving ESI is the global trend to decarbonise the energy system.
- The increasing penetration of variable renewable energy resources, in particular wind and solar Photovoltaics, or PV, in electricity systems is resulting in ESI opportunities.
- Variable renewable energy is growing rapidly and presenting integration challenges where it may have to be **curtailed** if the rest of the system is not flexible enough.
- Flexibility can be improved by **coordinating** energy vectors and institutional mechanisms across scales.



# Who needs to understand ?




# What do they need to understand ?

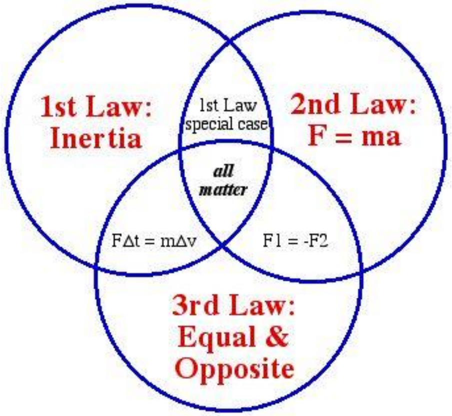
**Maxwell**

$$\oint \mathbf{E}\cdot d\mathbf{A} = \frac{q_{enc}}{\varepsilon_0}$$

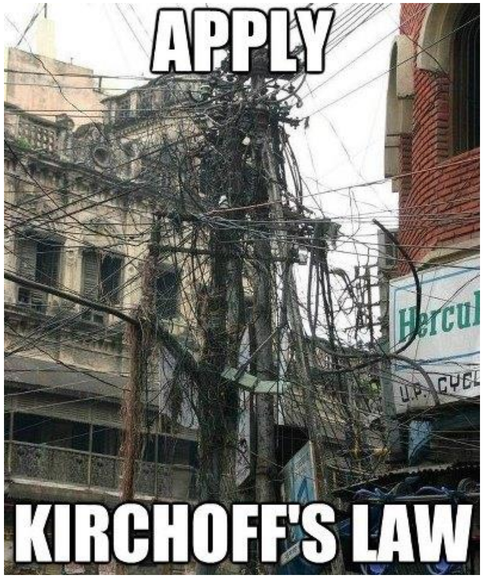
$$\oint \mathbf{B}\cdot d\mathbf{A} = 0$$

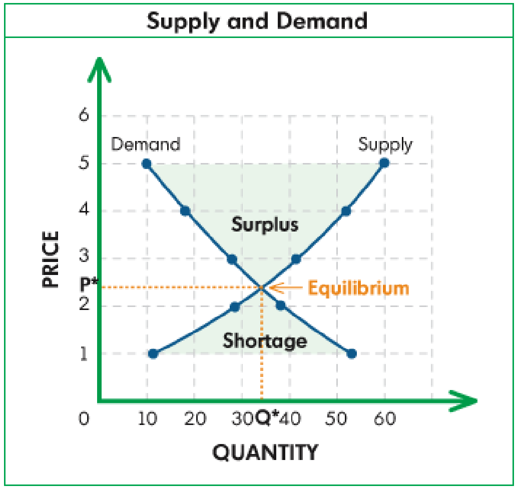
$$\oint \mathbf{E}\cdot d\mathbf{s} = -\frac{d\Phi_B}{dt}$$

$$\oint \mathbf{B}\cdot d\mathbf{s} = \mu_0\varepsilon_0\frac{d\Phi_E}{dt} + \mu_0 i_{enc}$$




Newton's Laws



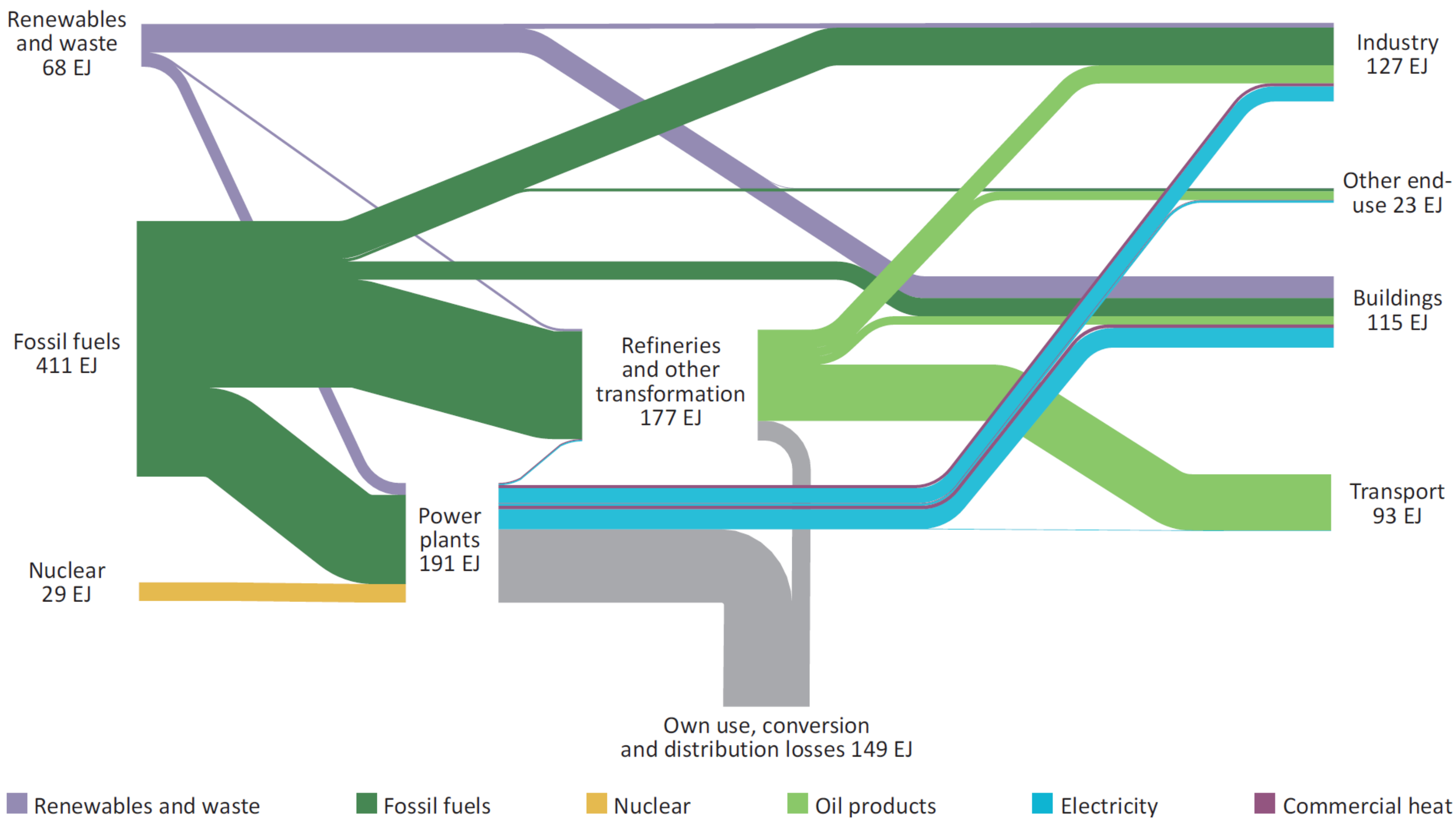

The Breadth of Knowledge Test
You have a general awareness across a range of IT topics
BREADTH
DEPTH
Skills assessment interview
You have a depth of knowledge in a specific area of IT
You are an expert in your field


KEEP CALM
I'M NOT AN EXPERT


education
is the

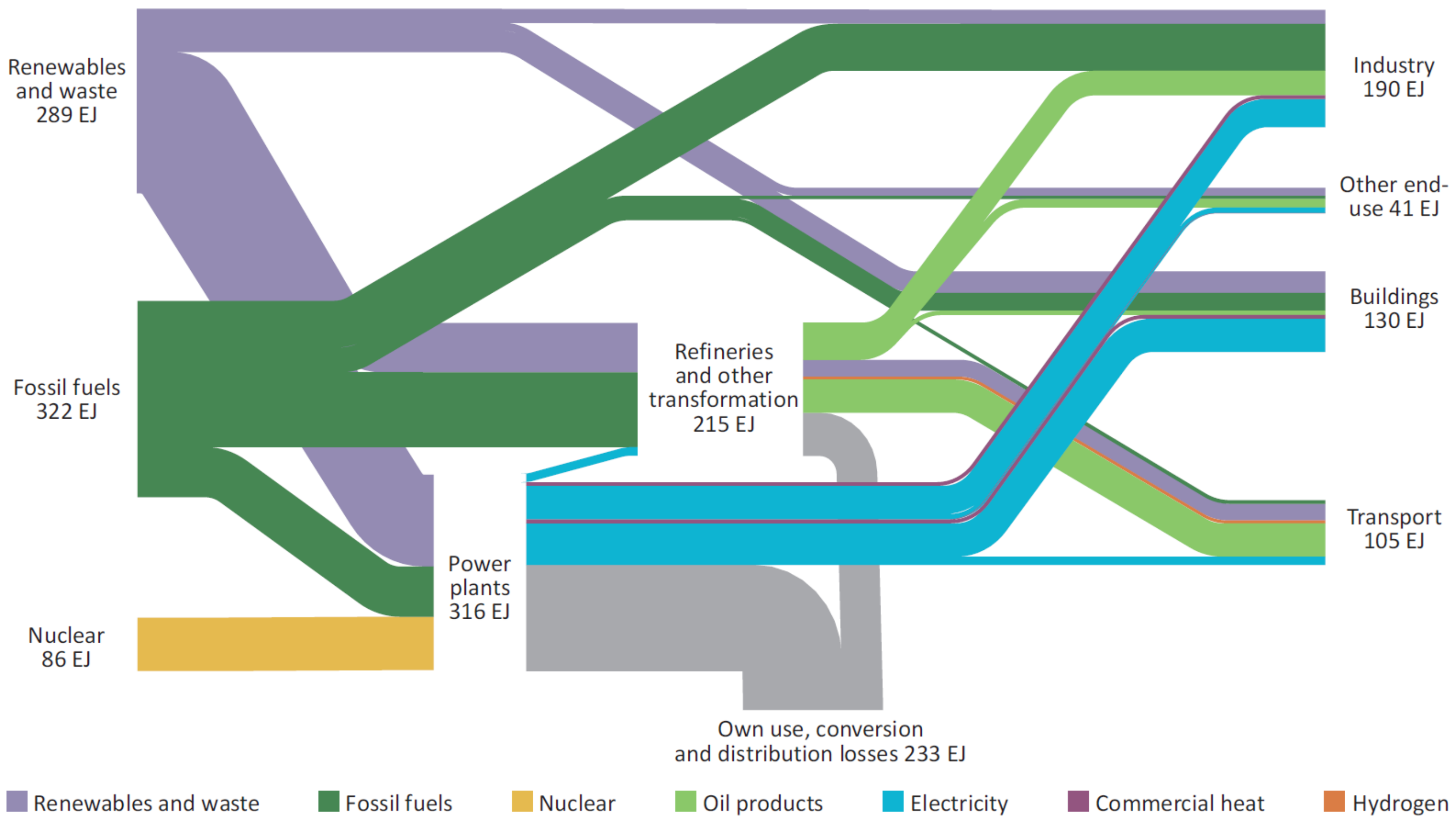
# The Importance of Electricity in ESI

# The global energy system today



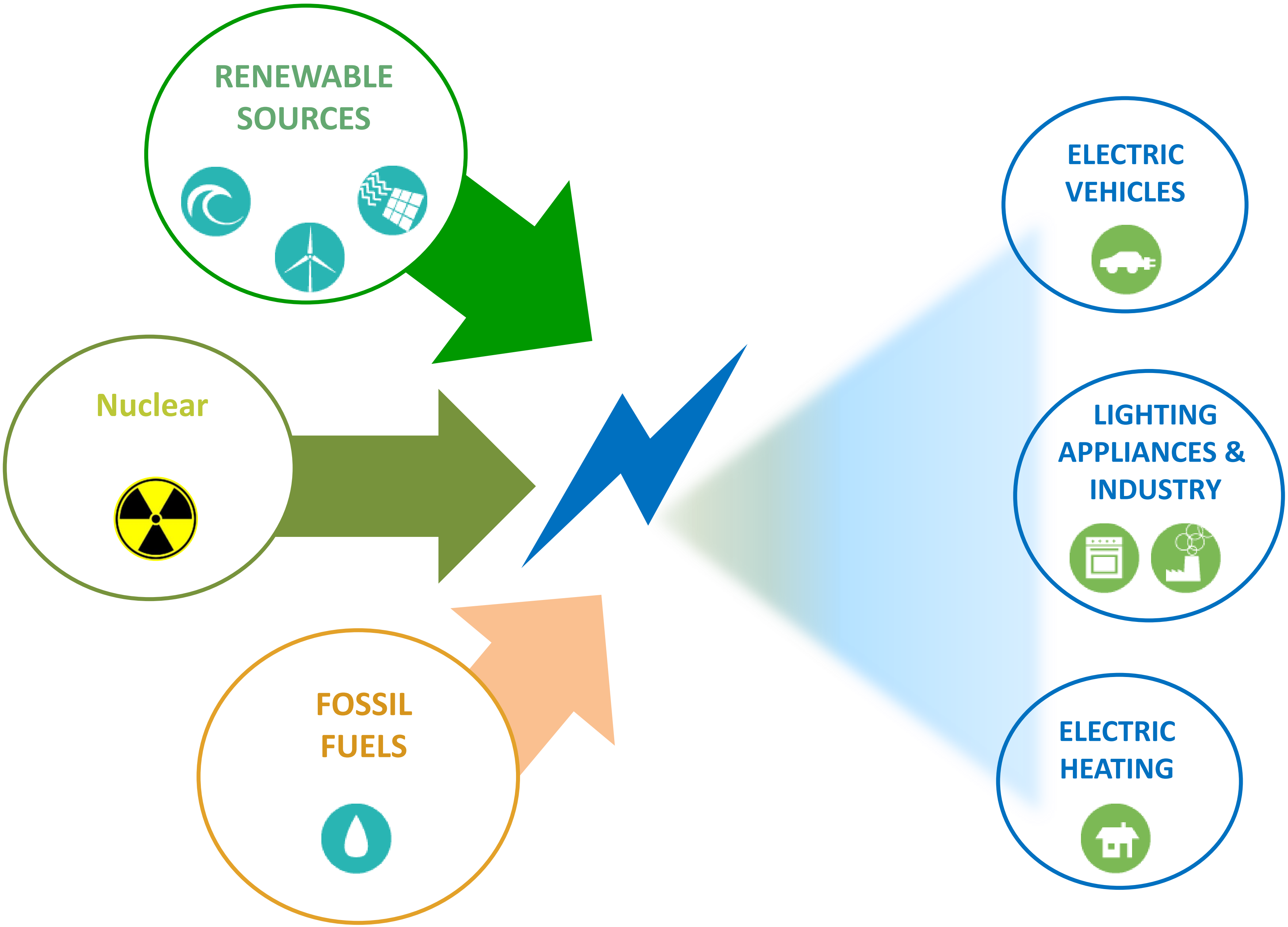

*Dominated by fossil fuels in all sectors: (Source IEA)*

# The future low-carbon energy system

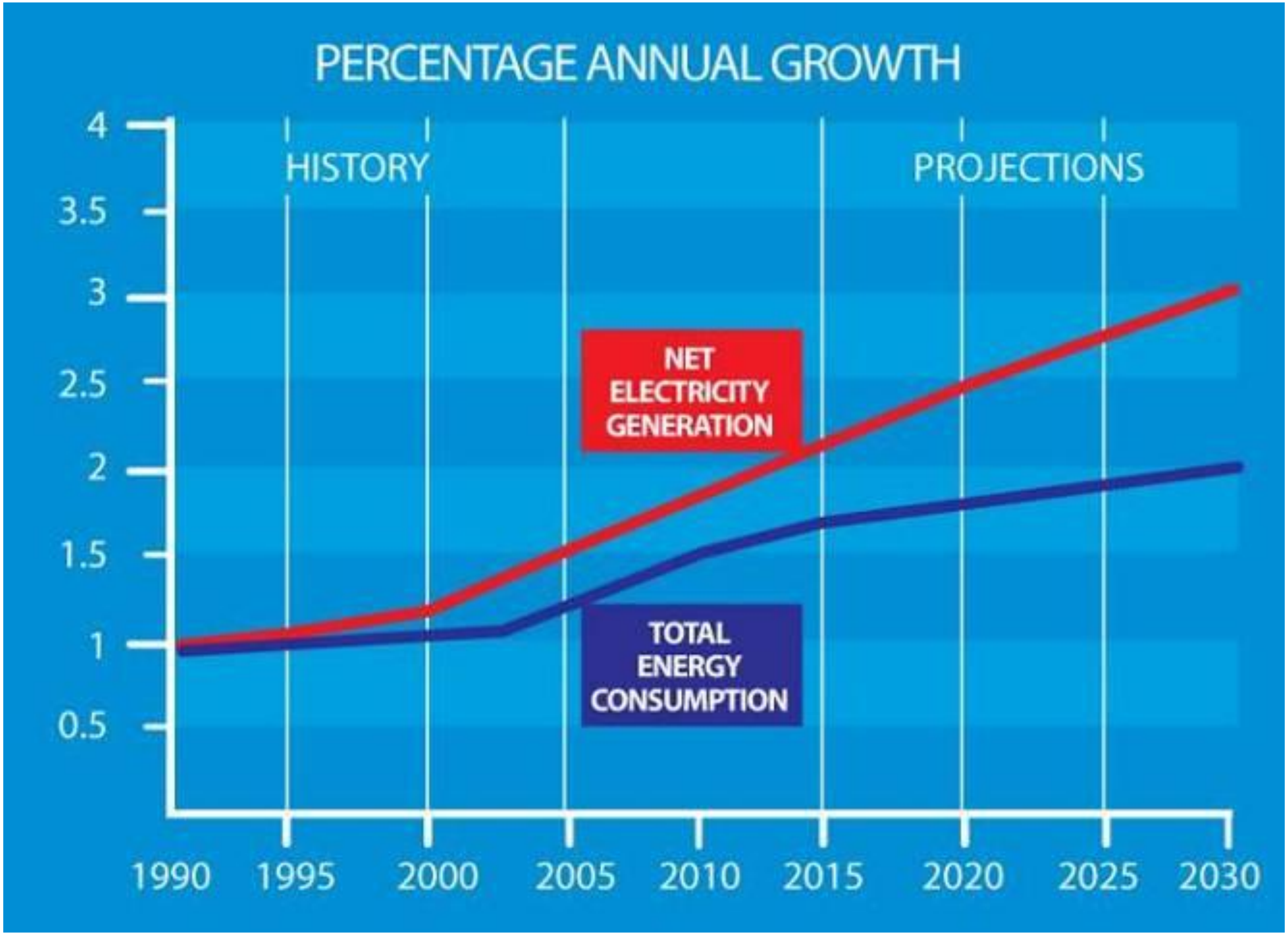



*The 2DS in 2050 shows a dramatic shift in energy sources and demands: (Source IEA)*

# The Electric Future



# The Future is Electric

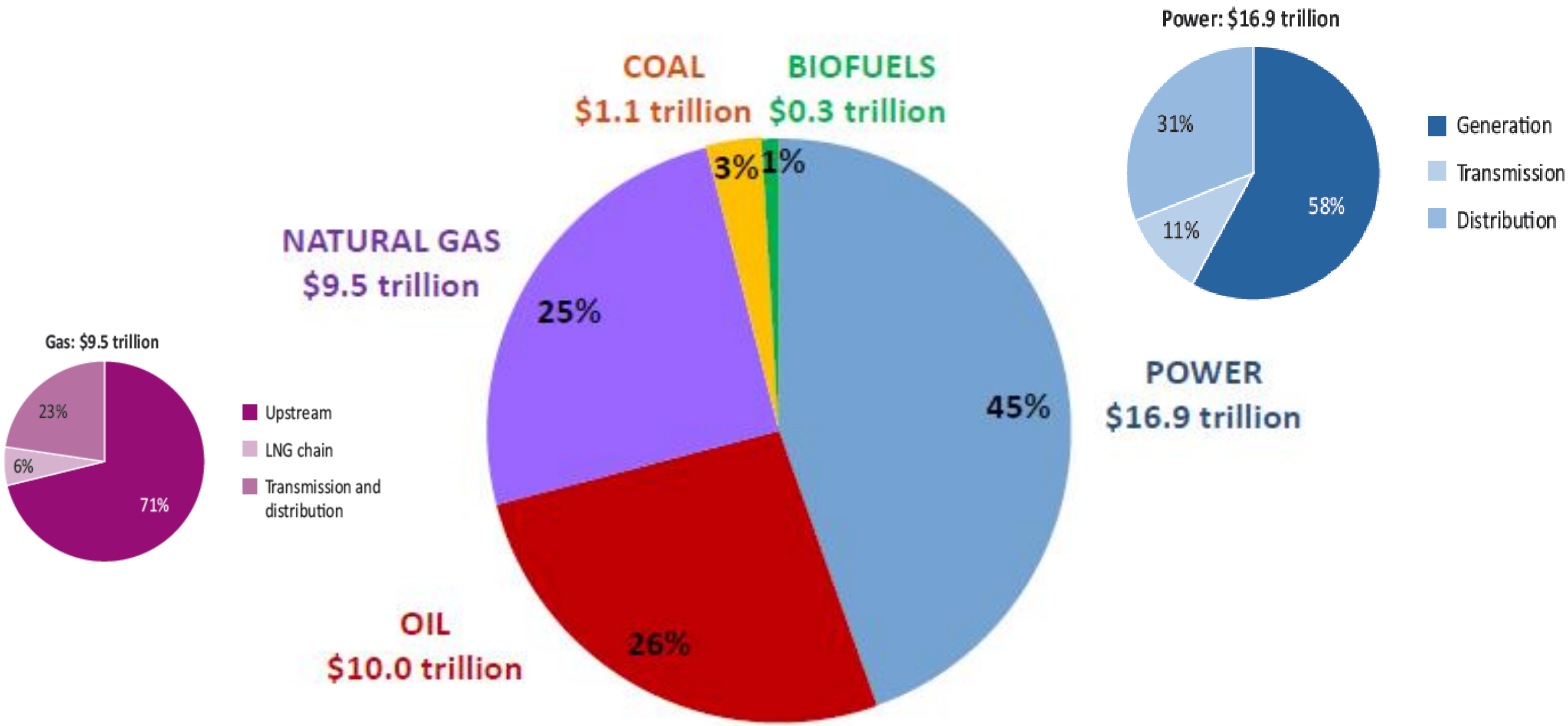



Source: Energy Information Administration (EIA), 2008.

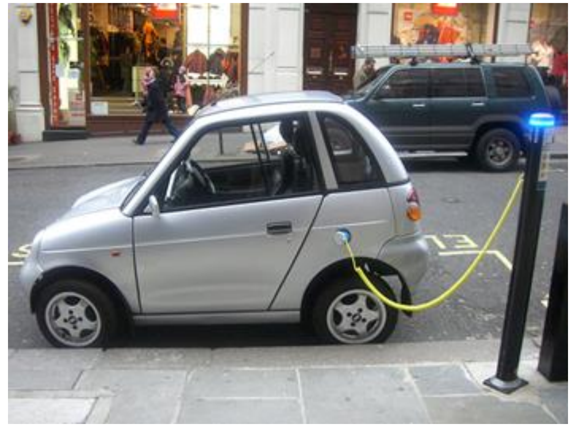
# *Investment: the essence of energy*

WORLD ENERGY OUTLOOK 2011

## Cumulative investment in energy infrastructure, *2011-2035*

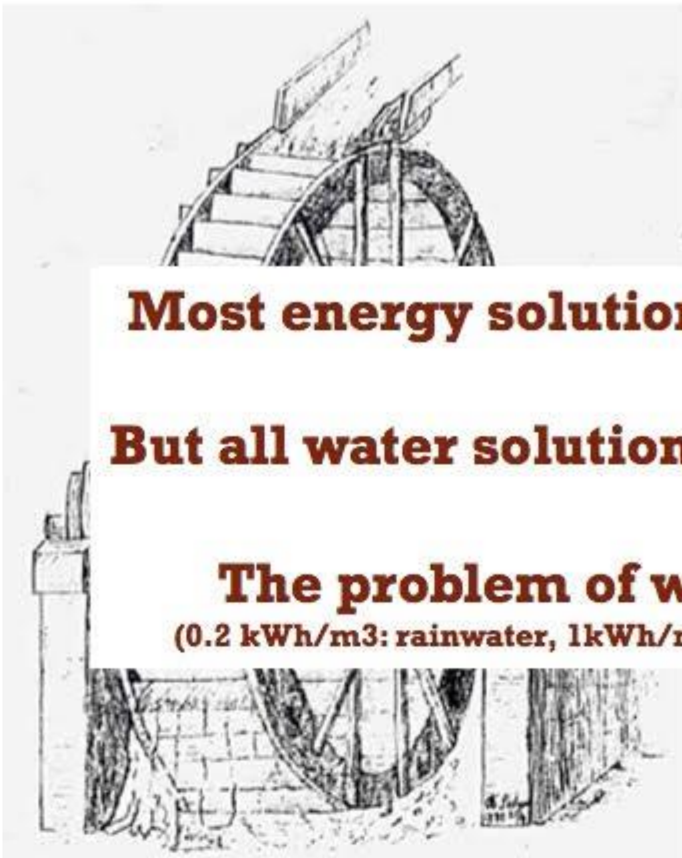
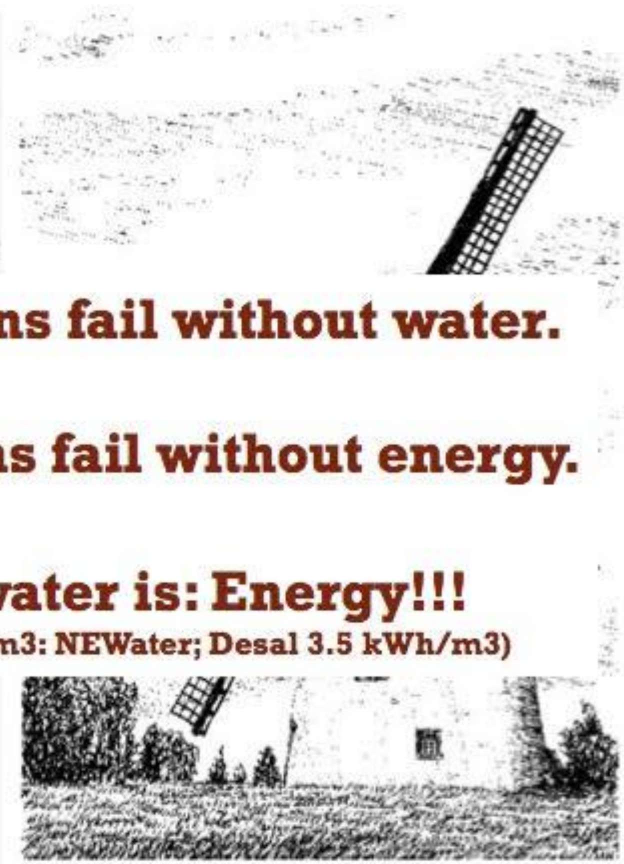



***WEO-2011 will show that <u>$38 trillion</u> of investment is required to meet projected energy demand through to 2035 and that investors in energy projects are facing a multitude of risks***



# Wider Convergence

## Energy or Water?

**Most energy solutions fail without water.**

**But all water solutions fail without energy.**

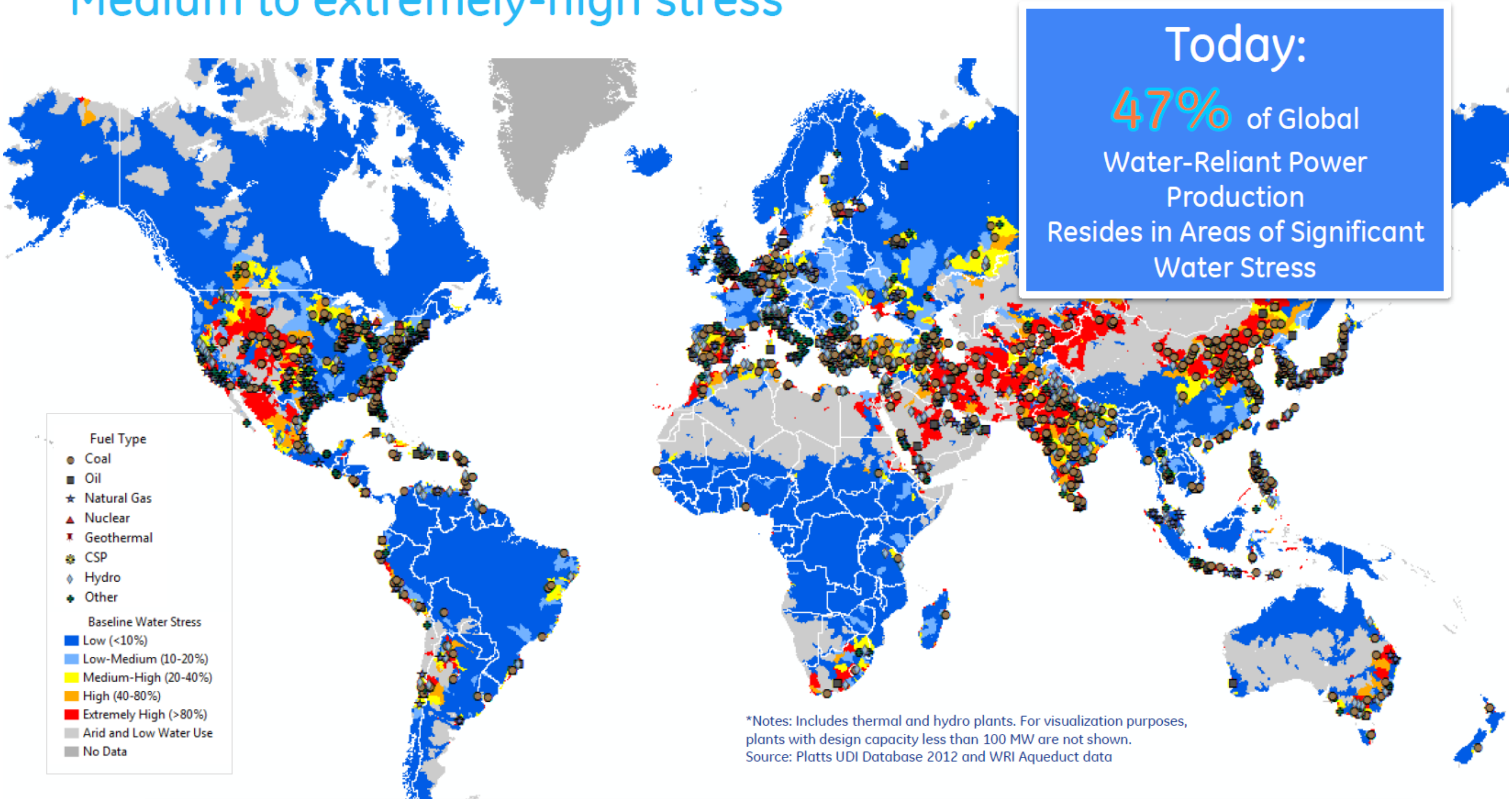
**The problem of water is: Energy!!!**

**(0.2 kWh/m3: rainwater, 1kWh/m3: NEWater; Desal 3.5 kWh/m3)**

Nick Hodge, in Energy and Capital, June 9th 2008

# Global generation units with water stress*

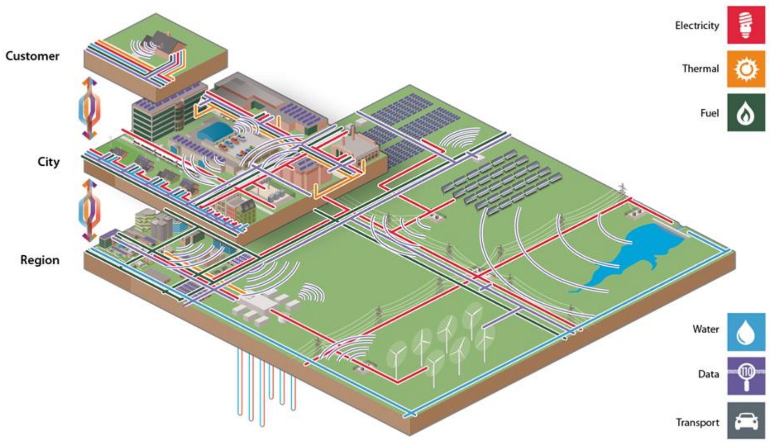
## Medium to extremely-high stress




**Over 26,000 units are in areas of medium to extremely-high water stress**



## Trilemma plus the “consumer” a Quadrilemma




# At different scales

# ESI at all Scales

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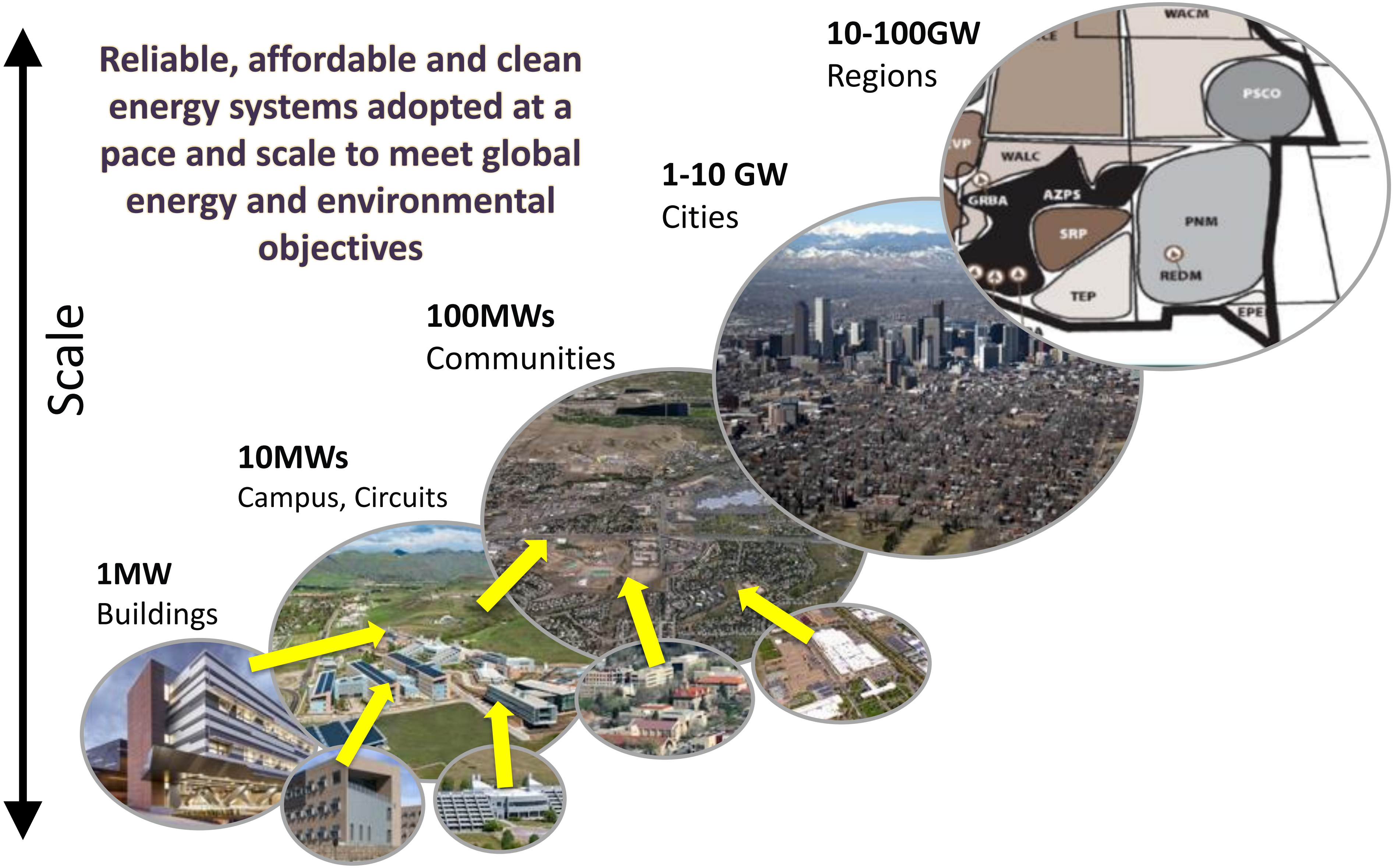
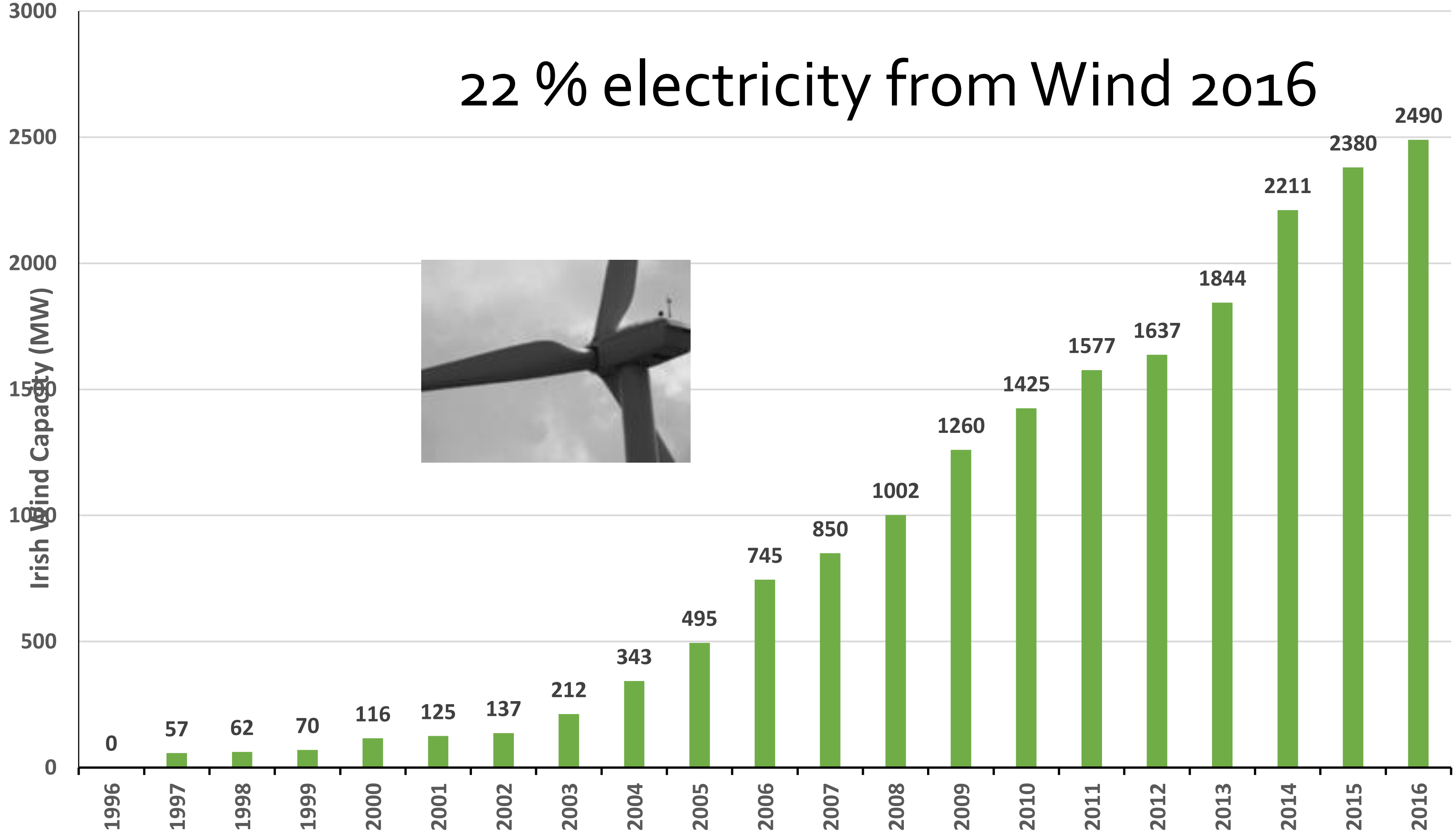
**Reliable, affordable and clean energy systems adopted at a pace and scale to meet global energy and environmental objectives**



# Gas Electricity Interface

# Wind installed in Ireland




Sources: EirGrid http://www.eirgridgroup.com/site-files/library/EirGrid/4289_EirGrid_GenCapStatement_v9_web.pdf
Eirgrid Generation Capacity Statement 2017-2026 and Irish Wind Energy Association

# System Generation: All Island

Last updated: 29 April 2017, 23:45

| LATEST SYSTEM GENERATION | THERMAL GENERATION (COAL, GAS, OTHER) | RENEWABLE GENERATION | NET IMPORT |
|---|---|---|---|
| 3,624 MW | 59.14 % | 48.09 % | -7.23 % |

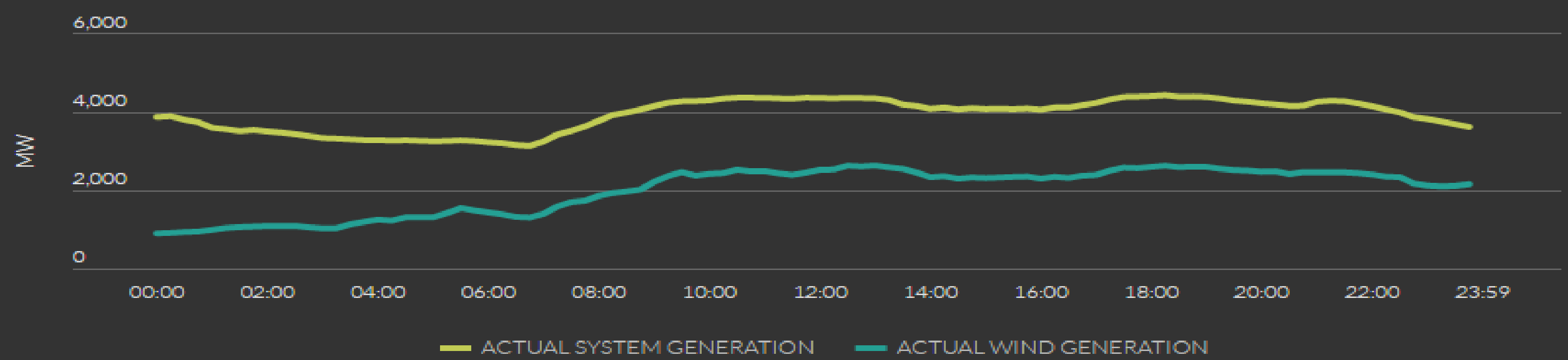
## Actual System Generation

System Generation represents the total electricity production on the system, including system losses, but net of generators' requirements. System Generation is shown in 15 minute intervals.

DAY | WEEK | MONTH

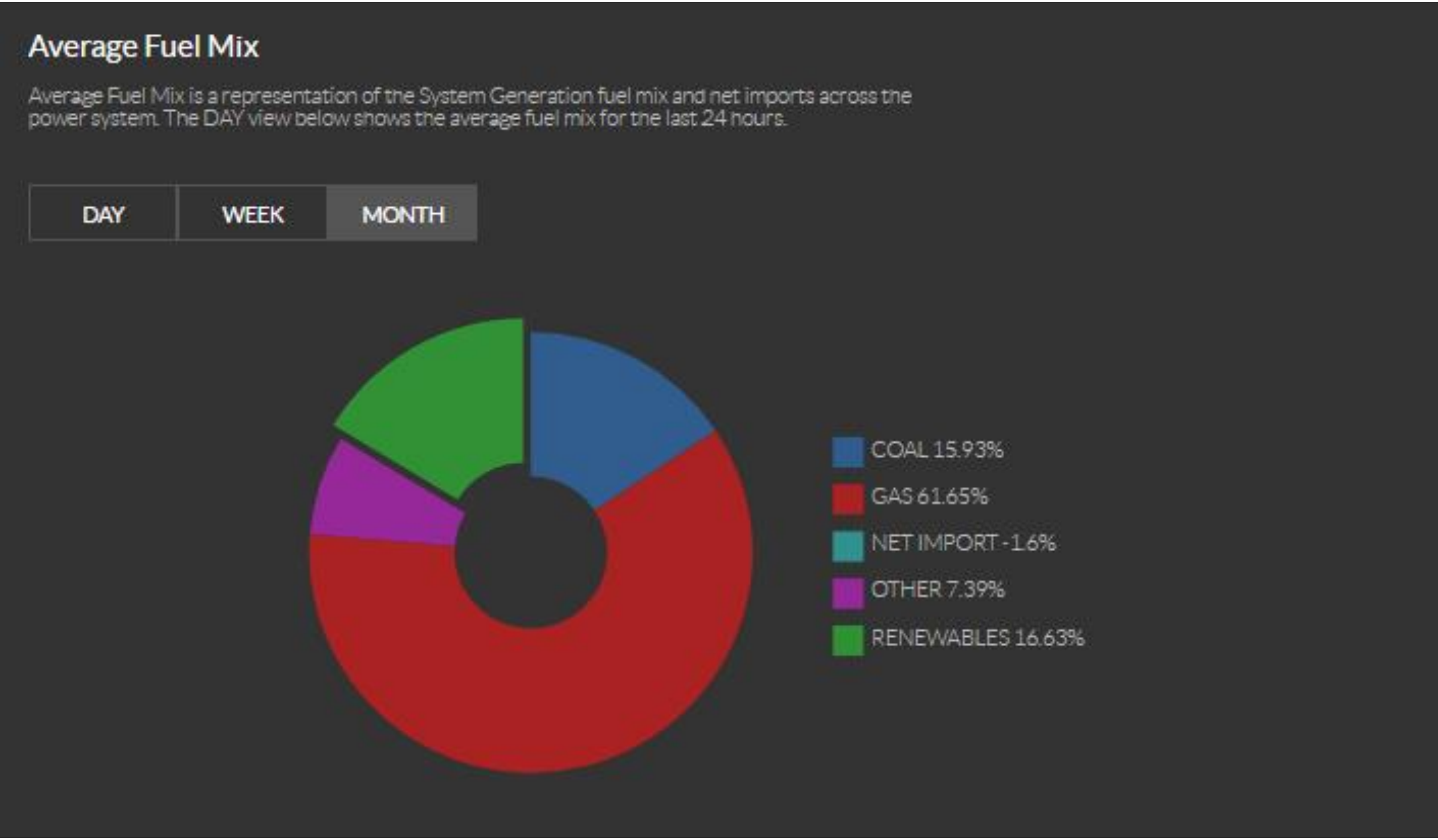
COMPARE WITH OTHER DATA

< Today (29/04/2017) >




http://smartgriddashboard.eirgrid.com/

# April 2017 fuel mix (Ireland)



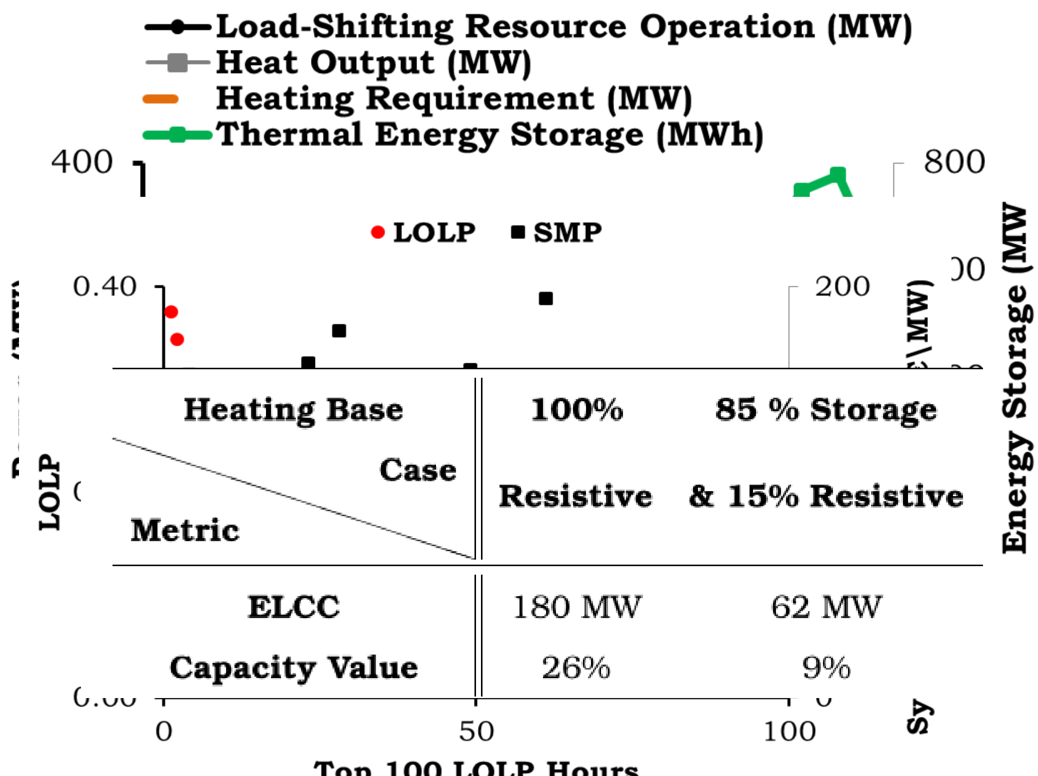

http://smartgriddashboard.eirgrid.com/

# Heat and integrating the consumer

# Load shifting (thermal electric storage) in Ireland

- Capacity value of resource is limited because:

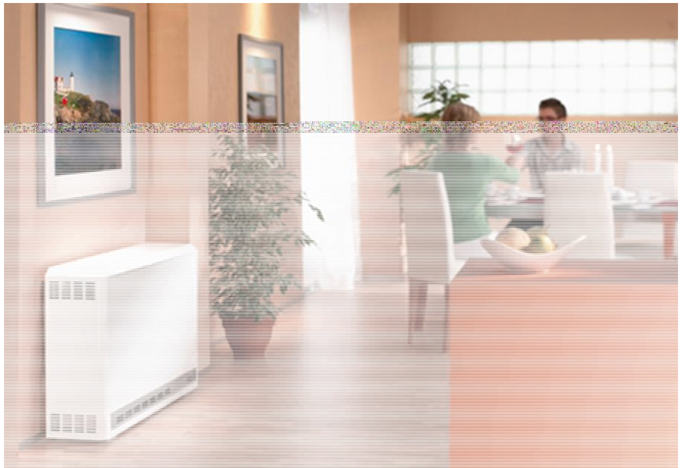
- Consumer requirements




| Heating Base Case / Metric | 100% Resistive | 85 % Storage & 15% Resistive |
|---|---|---|
| ELCC | 180 MW | 62 MW |
| Capacity Value | 26% | 9% |

S Nolan, O Neu, M O'Malley. ``Capacity Value Estimation of a Load-Shifting Resource using a Coupled Building and Power System Model", Applied Energy, Vol. 192, pp. 71 – 82, 2017.

# How they do it in China

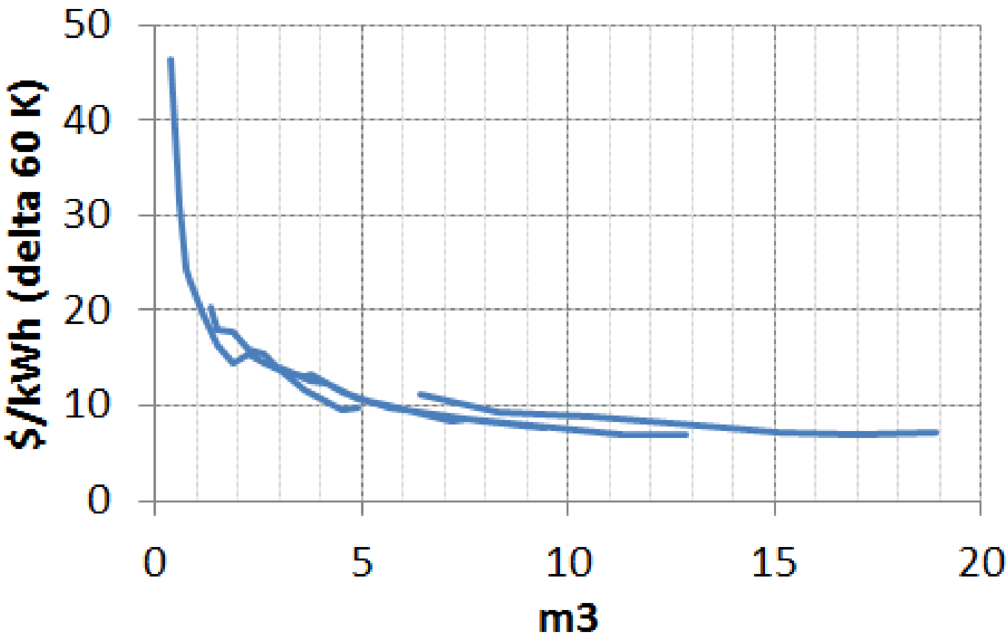


- Established in Inner Mongolia, 2014, with 20 electric boilers
- 500,000 $m^3$ heat supply
- 75 GWh wind power annually, equivalent to 19,000t coal
- Decrease $CO_2$ emission by 68,000t


Source: Chongqing Kang, Tsinghua University

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.

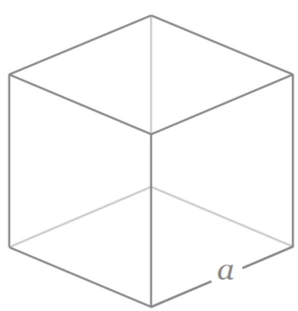
# Cost of heat storage is all about scale

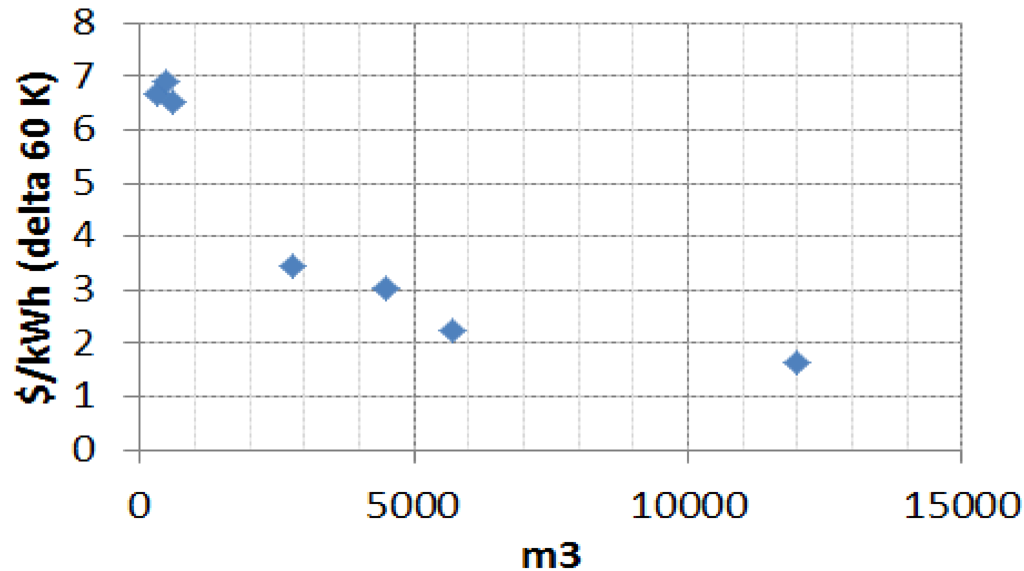



$$V = a^3$$

$$A = 6a^2$$

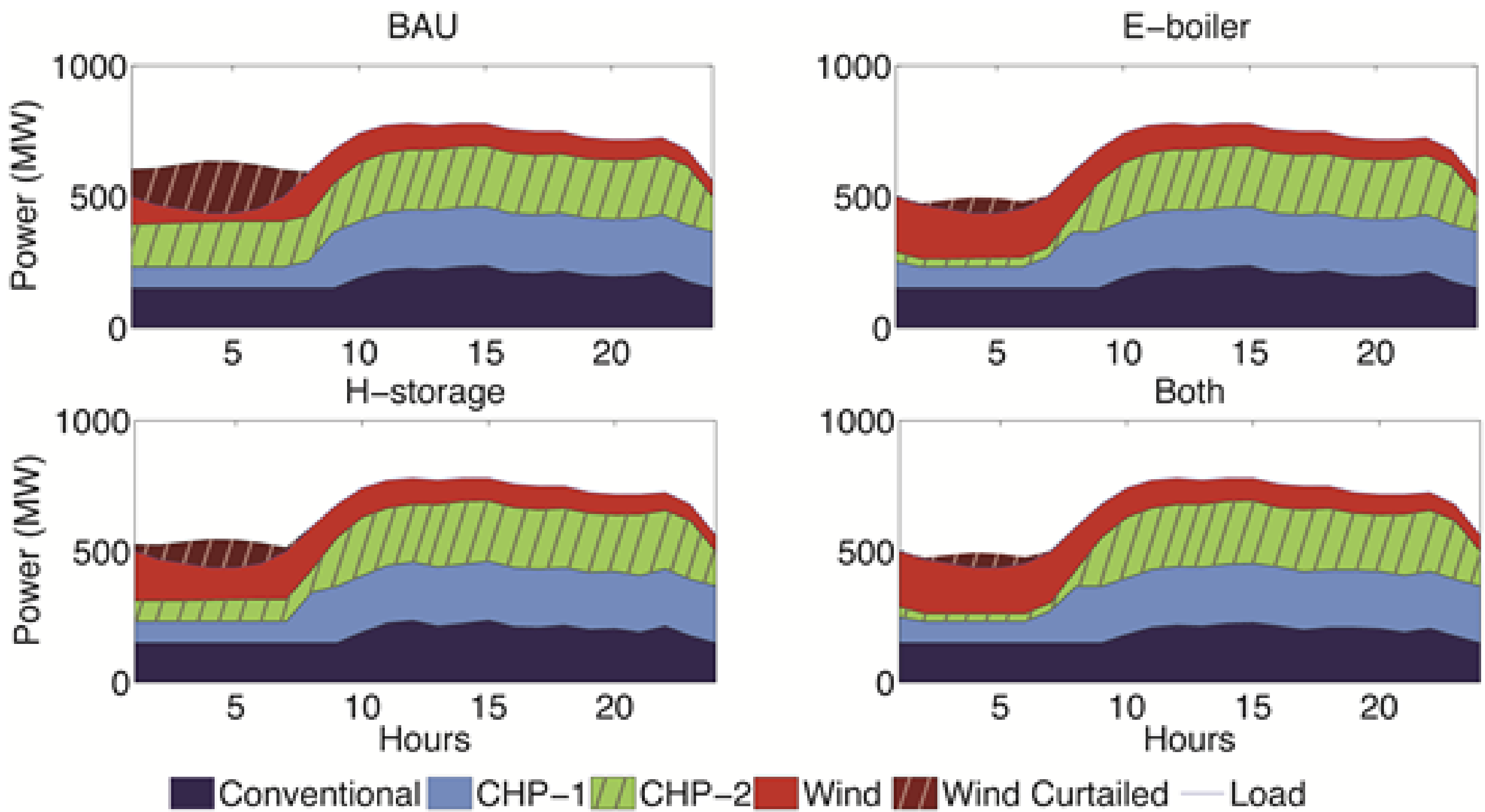
Source: Market data




Source: Juha Kiviluoma

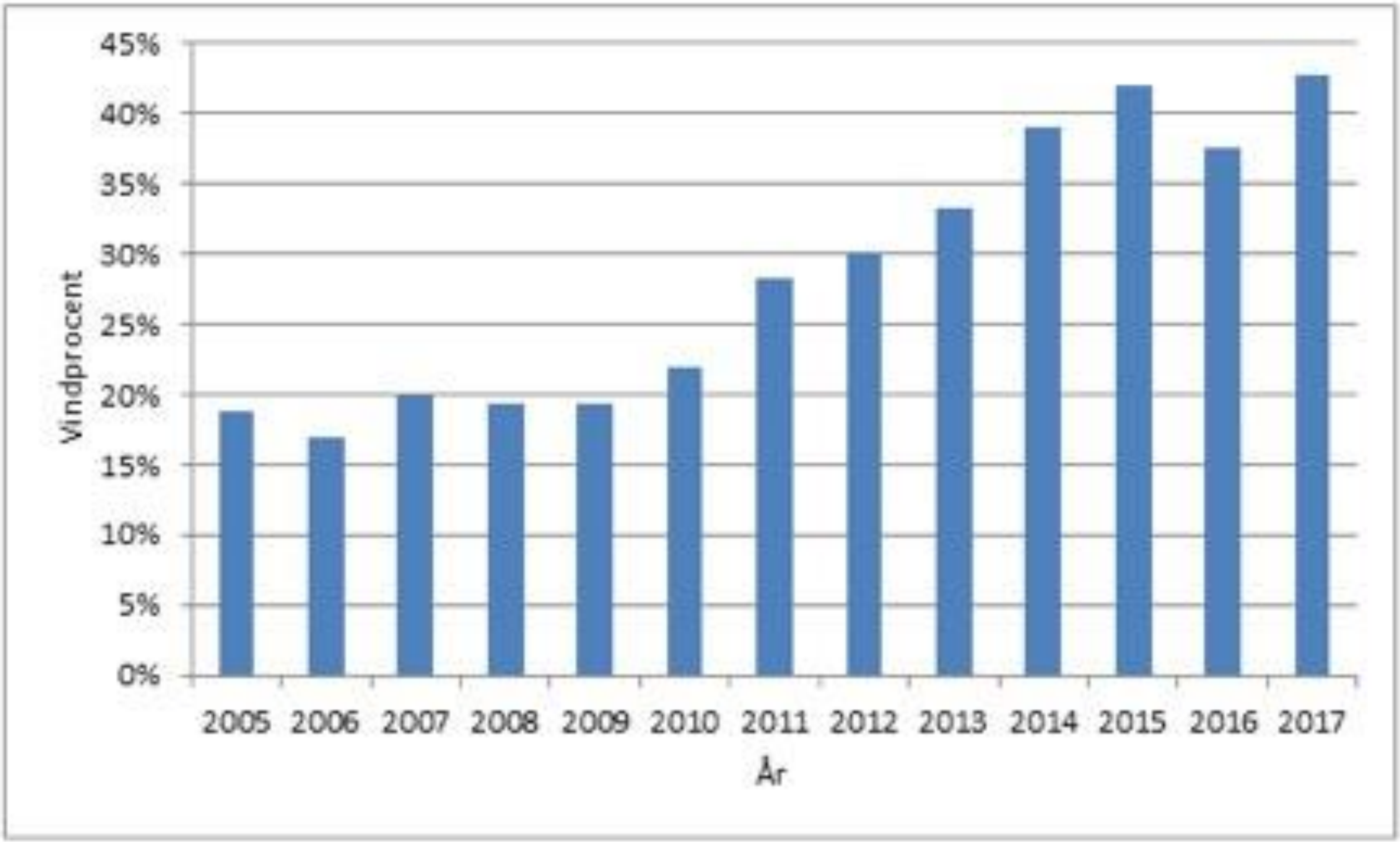
# Flexible CHP can reduce wind curtailment

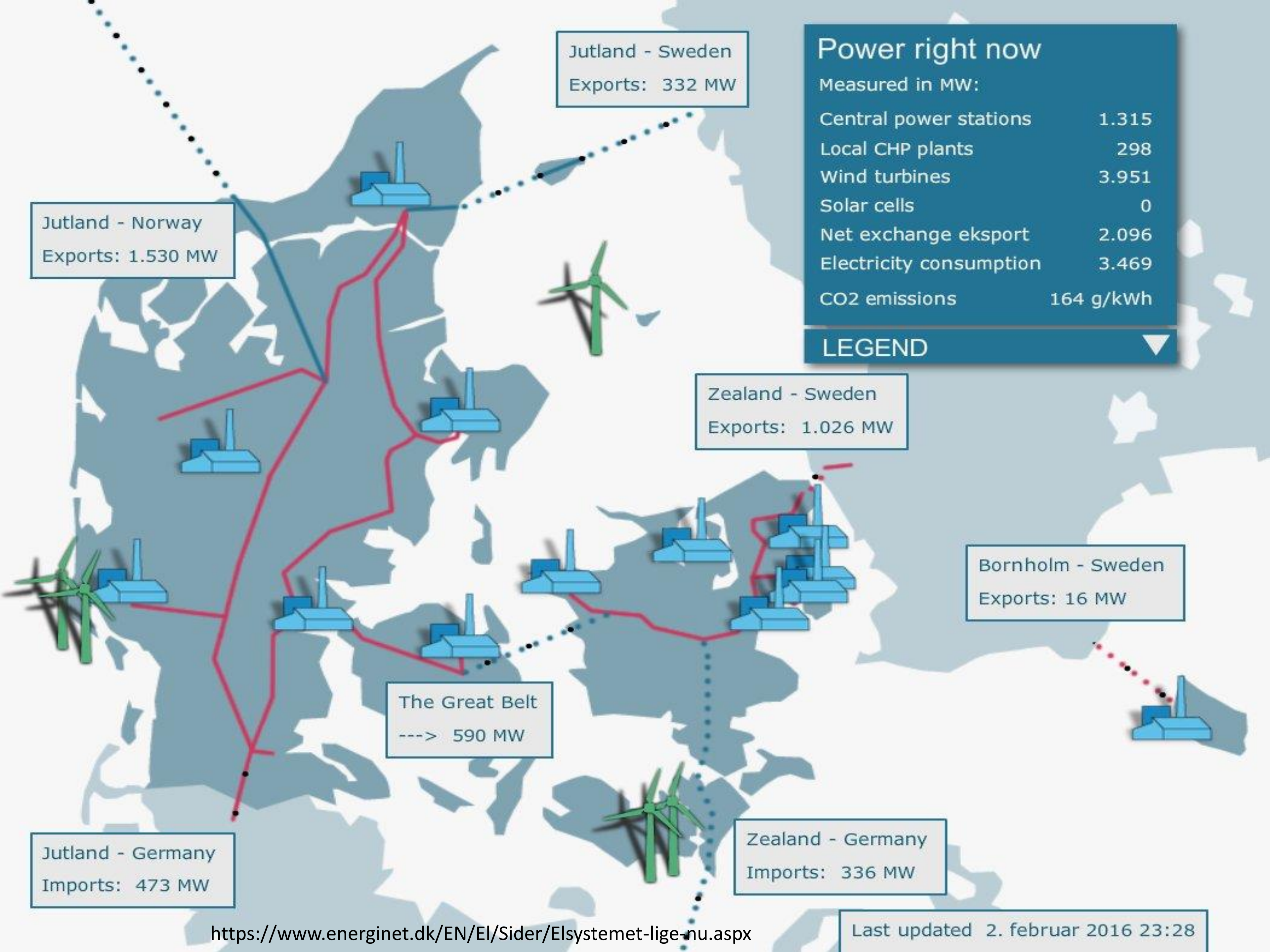



Chen, X., Kang, C., O'Malley, M.J., Xia, Q., Bai, J., Liu, C., Sun, R., Wang, W. and Hui, L., "Increasing the Flexibility of Combined Heat and Power for Wind Power Integration in China: Modeling and Implications", IEEE Transactions on Power Systems, Vol. 30, pp.1848-1857, 2015.


# Denmark ahead of the rest

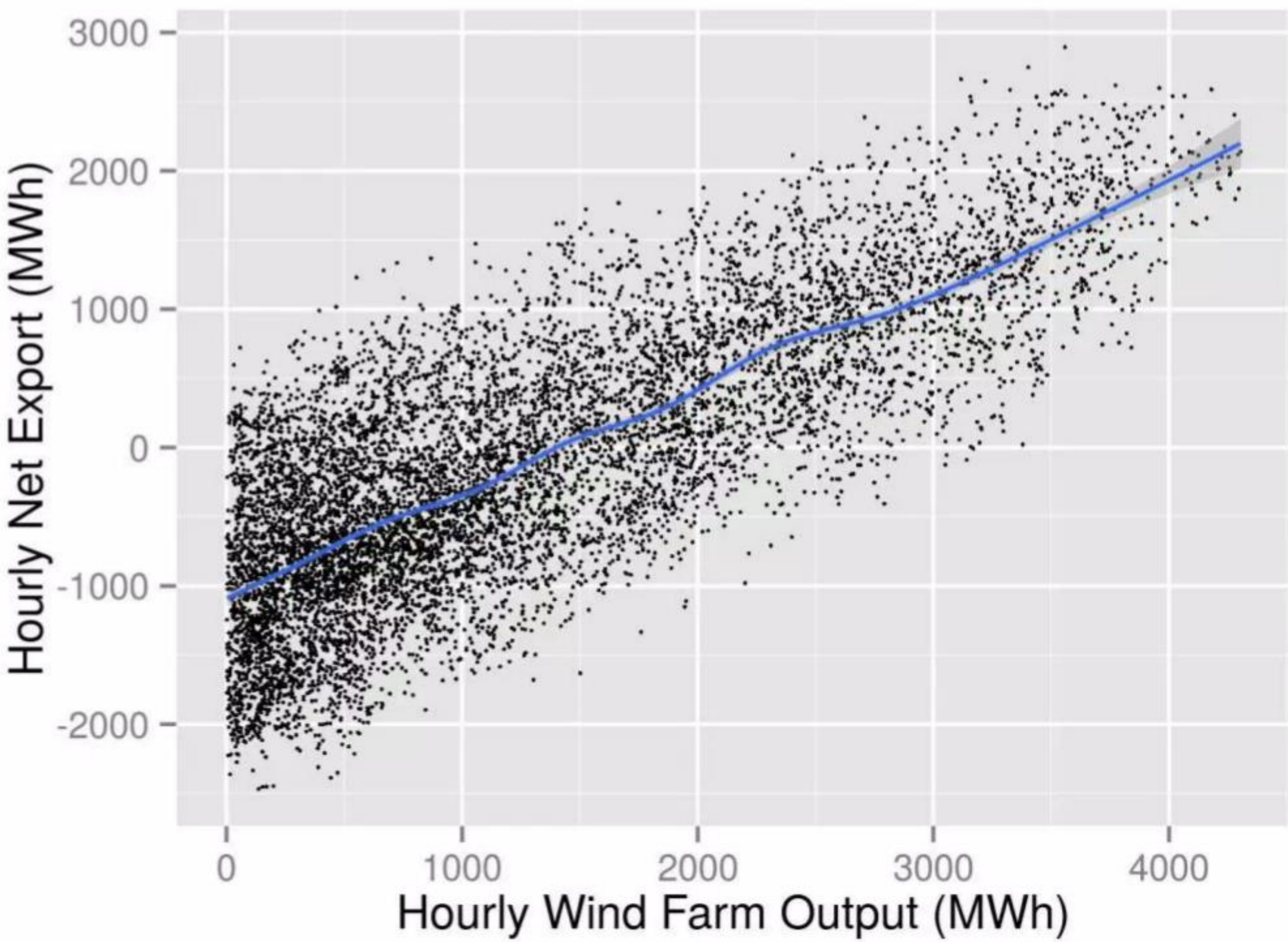
# Wind energy %, electricity, Denmark

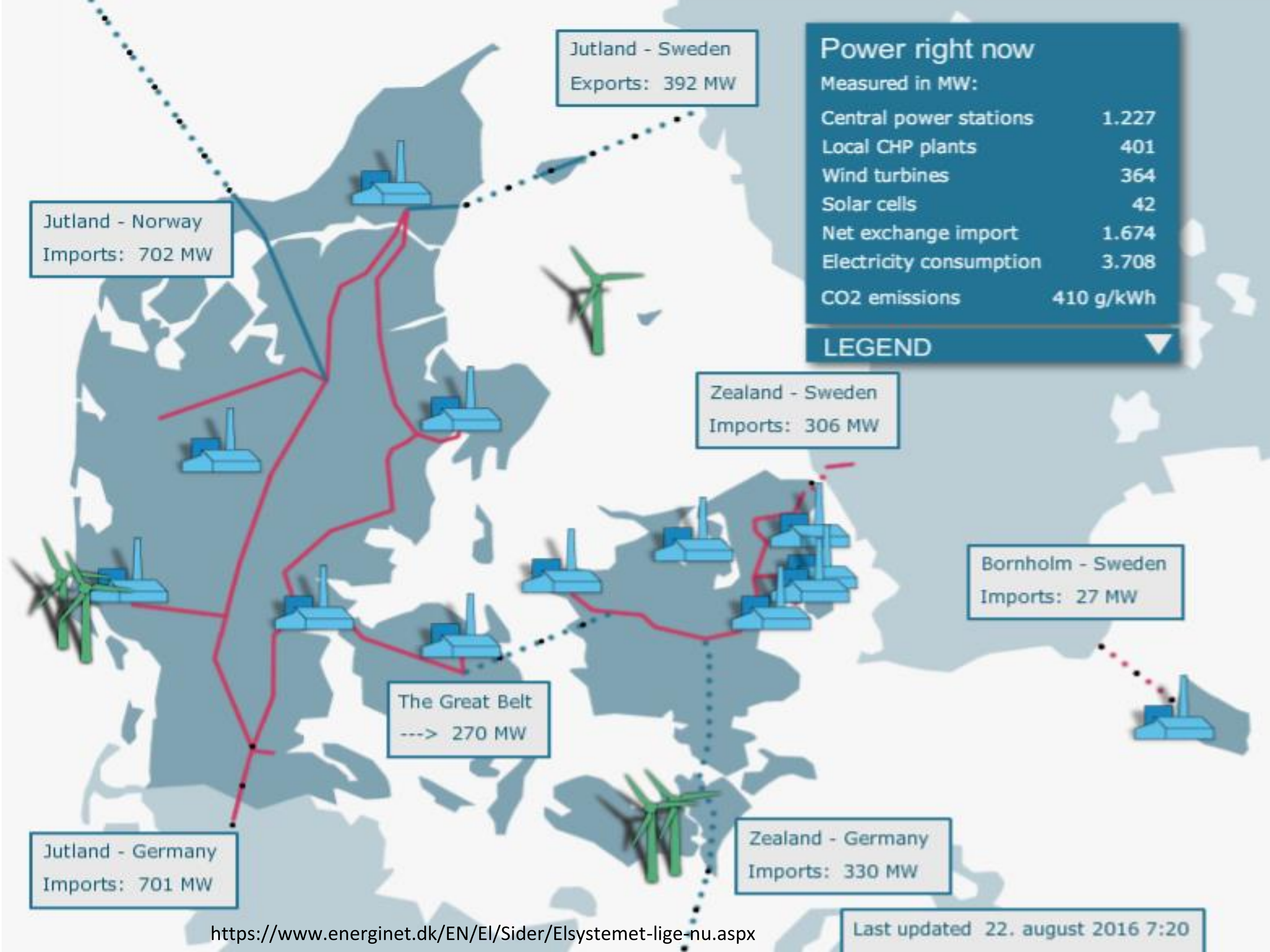





https://www.energinet.dk/EN/El/Sider/Elsystemet-lige-nu.aspx

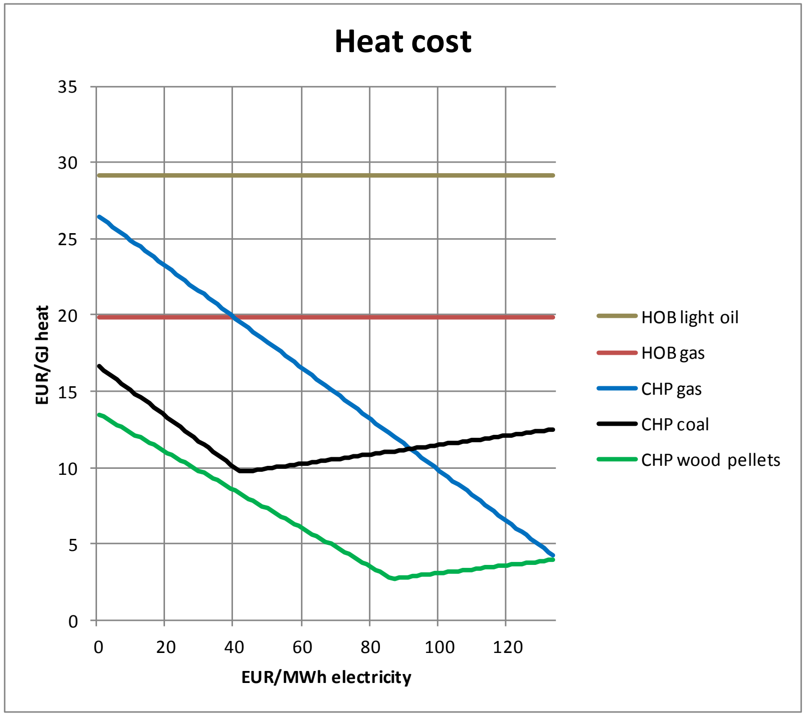
# Denmark integration of wind: The role of interconnection

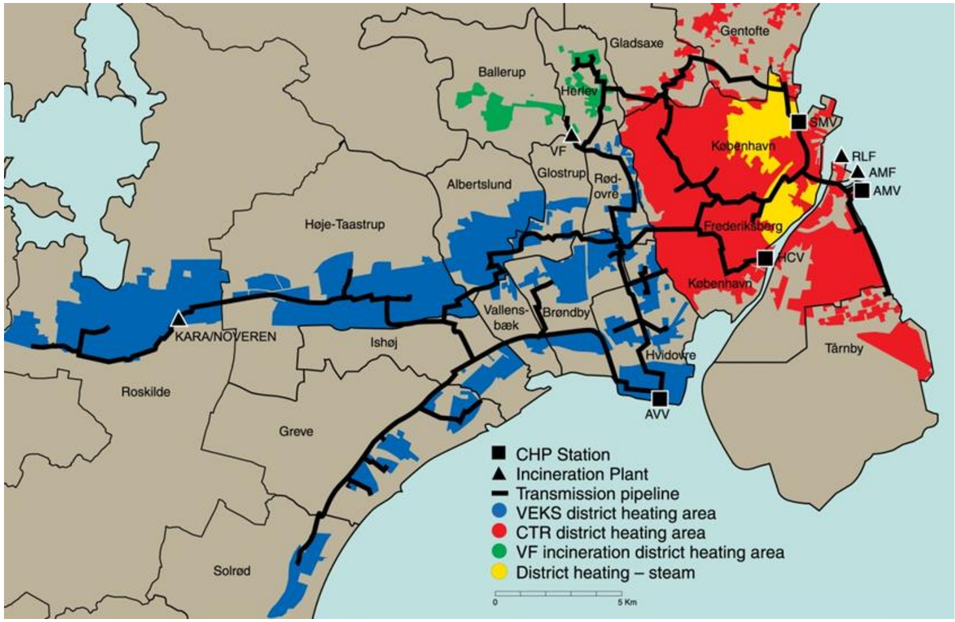


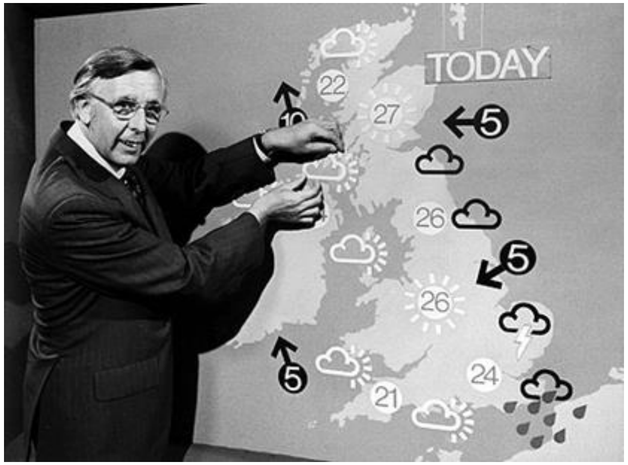



https://www.energinet.dk/EN/El/Sider/Elsystemet-lige-nu.aspx

# Co optimization of heat and electricity at scale

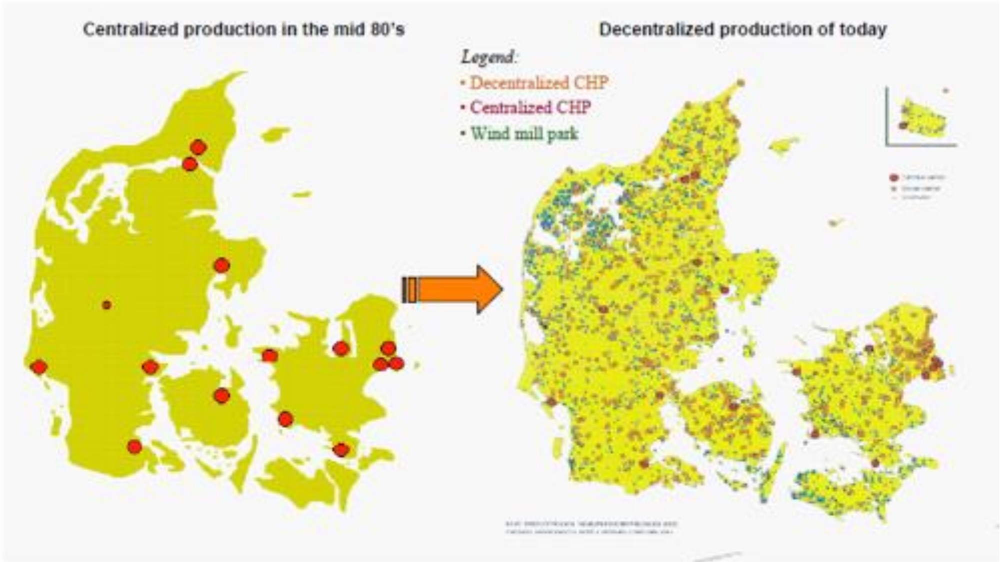



Source: Lars Bregnbæk, EAEA

# CHP with District Heating in Denmark




- Integrated combined heat and power has:
  - dramatically increased efficiency (30 %)
  - allowed 10 % of electricity from biomass
  - Reduced CO2 emissions by 20 %
  - Increasing the opportunity for natural gas

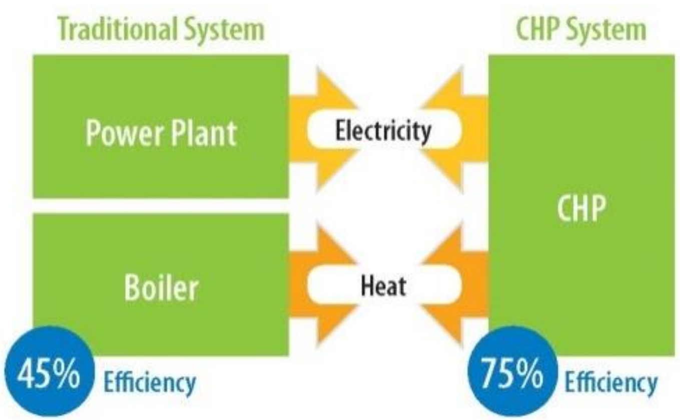
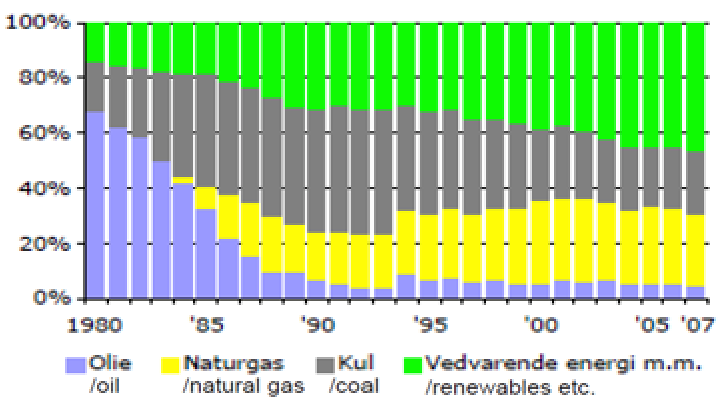
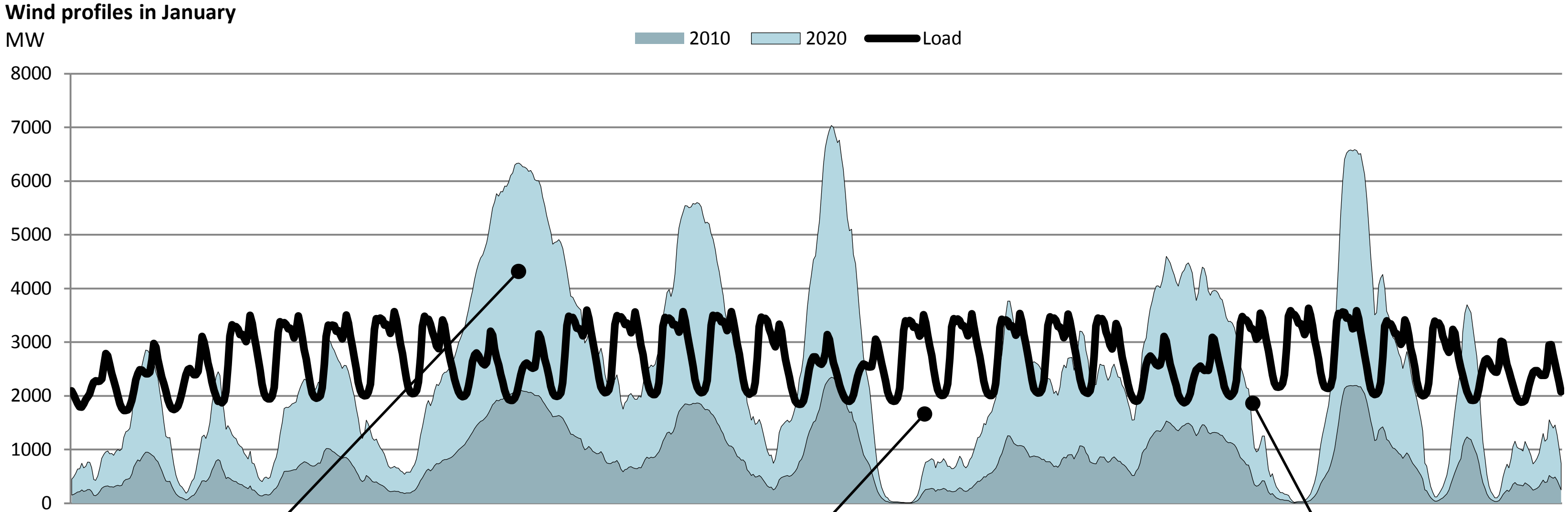



Figure 3: Fuel consumption for district heating production, percentage distribution



# How to balance large penetratons of electricity from variable renewables like wind?




1 Periods with **surplus** of power

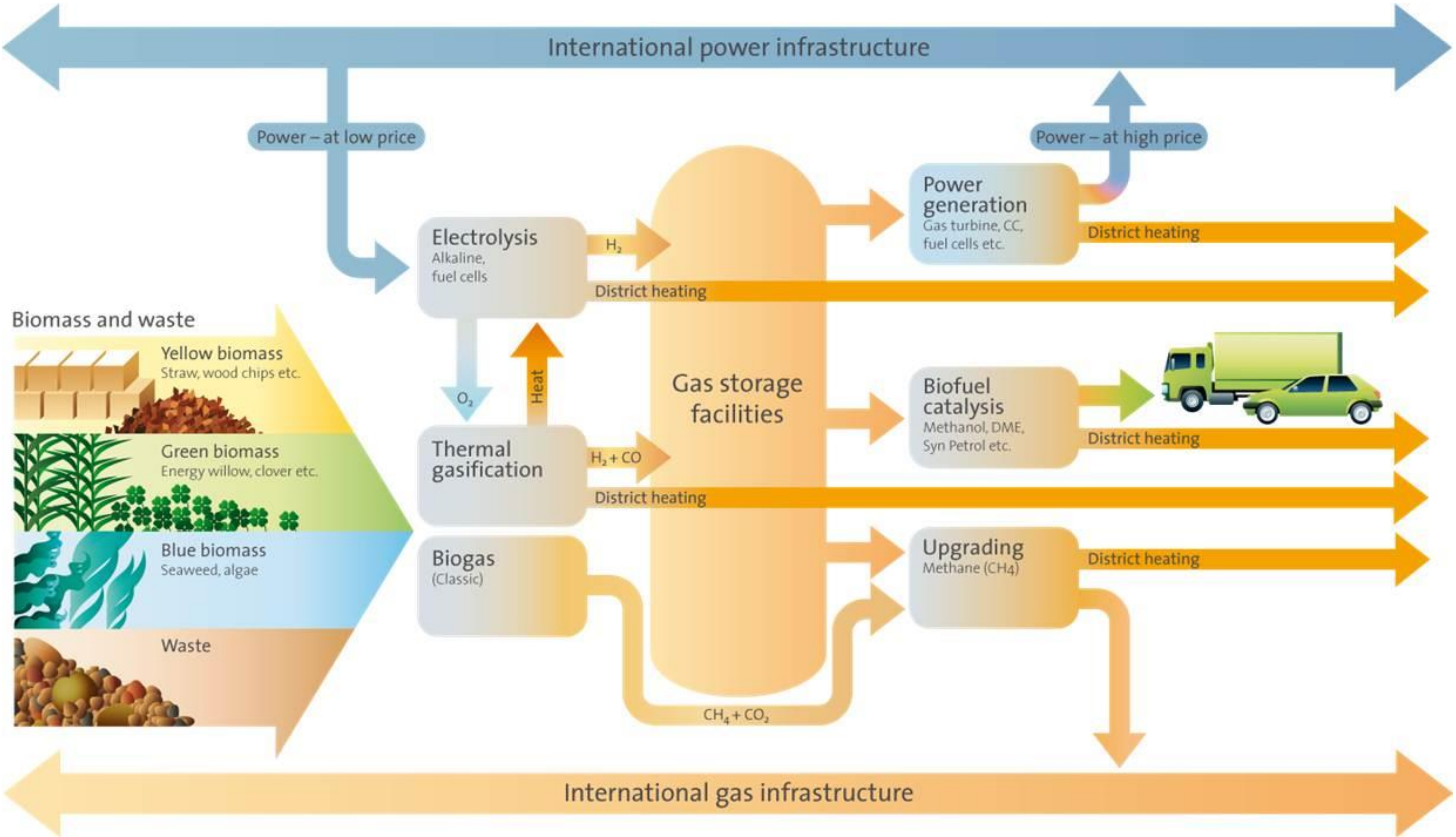
2 Periods with **deficit** of power

3 Periods requiring fast **ramping** of back-up capacity

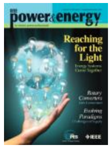
4 Alternatives to **grid support*** from conventional power plants must be identified

*Voltage and frequency control etc.

# ESI in Denmark




Meibom, P.; Hilger, K.B.; Madsen, H.; Vinther, D., "Energy Comes Together in Denmark: The Key to a Future Fossil-Free Danish Power System," *Power and Energy Magazine, IEEE* , vol.11, no.5, pp.46,55, Sept. 2013.

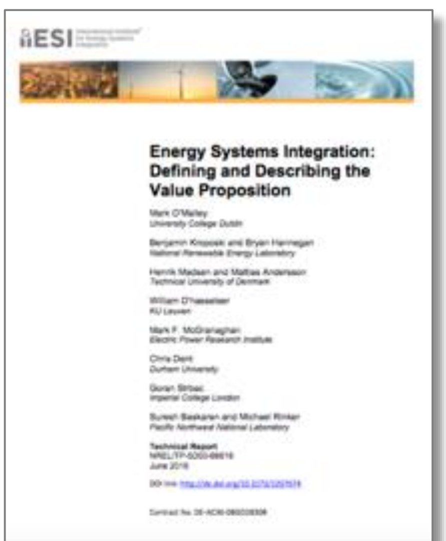


# Reading Material

# Additional Information

ESI practitioners take a holistic view of the energy systems we use today—focusing on the combined strength of our electricity, heat, and fuels systems. Tapping into the combined strength of energy systems maximizes the value of every unit of energy we use in our water, power, and transportation infrastructures.


**IEEE Power & Energy Magazine** – Sept. 2013


Energy Systems Integration:
Defining and Describing the
Value Proposition

Technical Report

**Energy Systems Integration:** Defining and Describing the Value Proposition – June 2016


**IEEE Power & Energy Magazine** – January 2017

# For Further Reading

International Institute for Energy Systems Integration


- *"Energy Systems Integration - A Convergence of Ideas"*, B. Kroposki, B. Garrett, S. Macmillan, B. Rice, C. Komomua, M. O'Malley, D. Zimmerle, NREL/TP-6A00-55649, July 2012, http://www.nrel.gov/esi/pdfs/55649.pdf
- *"Energy Comes Together – The Integration of All Systems"*, M. O'Malley and B. Kroposki, *IEEE Power & Energy Magazine*, Sept/Oct 2013, pp. 18-23, http://ieeexplore.ieee.org/document/6582607/
- *"Energy Systems Integration: An Evolving Energy Paradigm"*, M. Ruth and B. Kroposki, *The Electricity Journal*, 2014, http://www.sciencedirect.com/science/article/pii/S1040619014001195
- *"Renewable Electricity Futures Study" (Entire Report) National Renewable Energy Laboratory. (2012). Renewable Electricity Futures Study. Hand, M.M.; Baldwin, S.; DeMeo, E.; Reilly, J.M.; Mai, T.; Arent, D.; Porro, G.; Meshek, M.; Sandor, D. eds. 4 vols. NREL/TP-6A20-52409. Golden, CO: National Renewable Energy Laboratory.* *http://www.nrel.gov/analysis/re_futures/*
- *"Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues"*, M. Melaina, O. Antonia, and M. Penev, NREL/TP-5600-51995, March 2013, http://www.nrel.gov/docs/fy13osti/51995.pdf
- "Multiple-energy carriers: modeling of production, delivery, and consumption", Krause, T., Andersson, G., Fröhlich, K. and Vaccaro, A. (2011, *IEEE Proceedings*, 99 (1), pp. 15–27. http://ieeexplore.ieee.org/document/5638594/
- "Unleashing the Flexibility of Gas: Innovating Gas Systems to Meet the Electricity System's Flexibility Requirements", S. Heinen, C. Hewicker, N. Jenkins, J. McCalley, M. O'Malley, S. Pasini, S. Simoncini, IEEE Power & Energy Magazine, Jan/Feb 2017,http://ieeexplore.ieee.org/document/7845750/
- "Harnessing Flexibility from Hot and Cold: Heat Storage and Hybrid Systems Can Play a Major Role", J. Kiviluoma, S. Heinen, H. Qazi, H. Madsen, G.Strbac, C. Kang, N. Zhang, D. Patteeuw, T. Naegler, IEEE Power & Energy Magazine, Jan/Feb 2017, http://ieeexplore.ieee.org/document/7842783/

# Reading Material # 1


- CIGRE 2012; Technical Brochure on Coping with Limits for Very High Penetrations of Renewable Energy, Joint Working Group C1/C2/C6.18 of Study Committee C6, August 2012, International Conference on Large High Voltage Electric Systems
- Chongqing Kang; Xinyu Chen; Qianyao Xu; Dongming Ren; Yuehui Huang; Qing Xia; Weisheng Wang; Changming Jiang; Ji Liang; Jianbo Xin; Xu Chen; Bo Peng; Kun Men; Zheng Chen; Xiaoming Jin; Hui Li; Junhui Huang, "Balance of Power: Toward a More Environmentally Friendly, Efficient, and Effective Integration of Energy Systems in China," *Power and Energy Magazine, IEEE* , vol.11, no.5, pp.56,64, Sept. 2013, doi: 10.1109/MPE.2013.2268752
- X. Chen, C. Kang, M.J. O'Malley, Q. Xia, J. Bai, C. Liu, R. Sun, W. Wang and L. Hui, *"*Increasing the Flexibility of Combined Heat and Power for Wind Power Integration in China: Modeling and Implications*"*, *IEEE Transactions on Power Systems*, in press, 2015. [10.1109/TPWRS.2014.2356723]
- Corbus, D.; Kuss, M.; Piwko, D.; Hinkle, G.; Matsuura, M.; McNeff, M.; Roose, L.; Brooks, A., "All Options on the Table: Energy Systems Integration on the Island of Maui," *Power and Energy Magazine, IEEE* , vol.11, no.5, pp.65,74, Sept. 2013
  doi: 10.1109/MPE.2013.2268814
- EASAC, "Transforming Europe's Electricity Supply – An Infrastructure Strategy for a Reliable,
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