International Institute for Energy Systems Integration

European Energy Research Alliance

Energy Systems Integration

a megatrend or just business as usual ?

Mark O'Malley

Energy Systems Integration Partnership Programme

UCD, October 28th 2016

electricity research centre

ENERGY INSTITUTE UCD

Outline

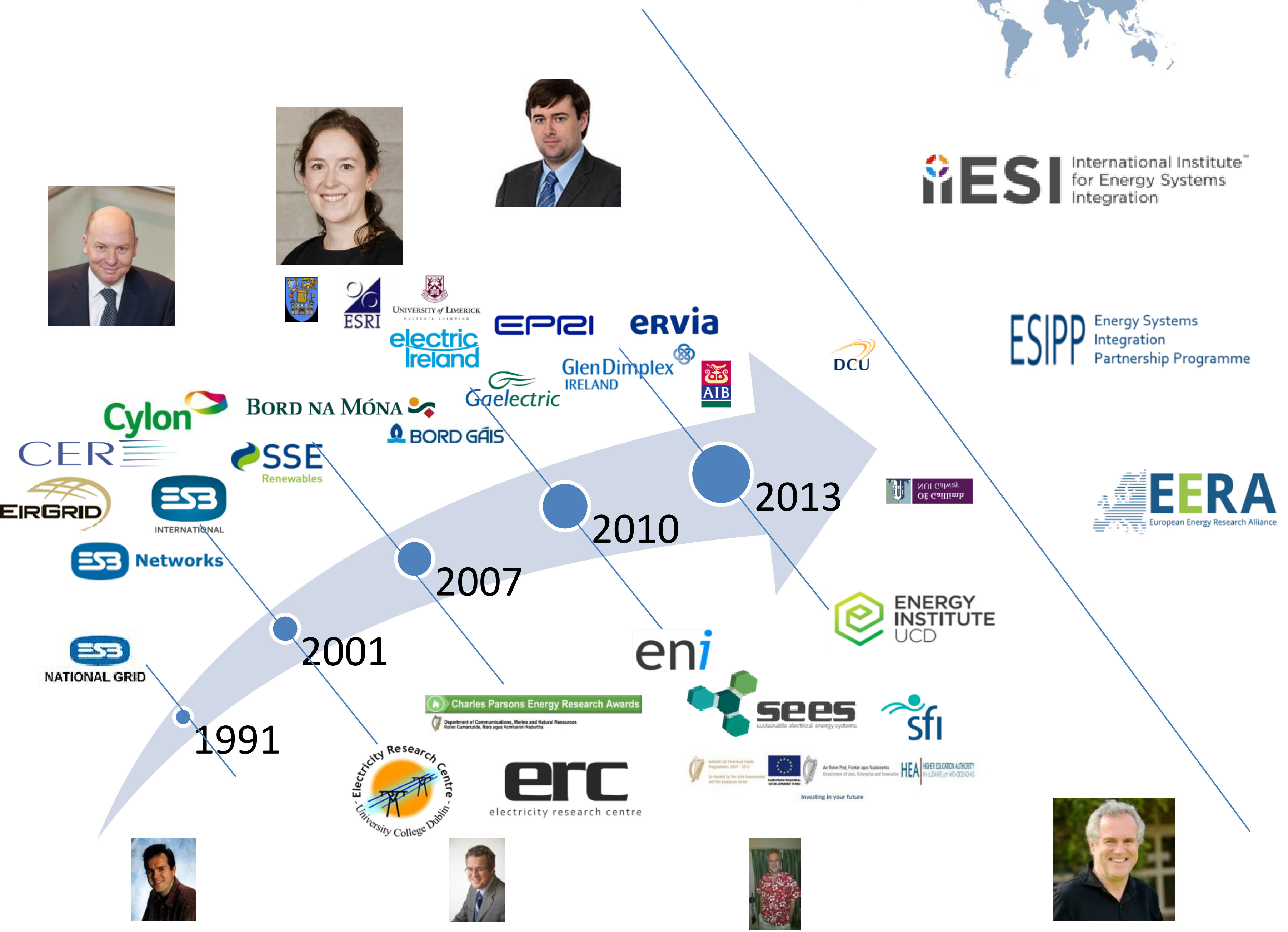
- Your responses
- Learning from the past
- What is Energy System Integration (ESI) ?
- ESI and the low carbon agenda, including renewable integration
- Examples Ireland, Denmark, (China etc.)
- Conclusion

Responses

‘I am especially interested in understanding differences between centralised and decentralised renewable energy systems. It is often emphasized that decentralised approaches suffer from a problem of upscaling. I would like to hear arguments of experts in engineering, economics, psychology, public policy and other relevant disciplines on this issue. I'm certain this topic could initiate a fruitful discussion.

the role of companies in energy transition

A little history



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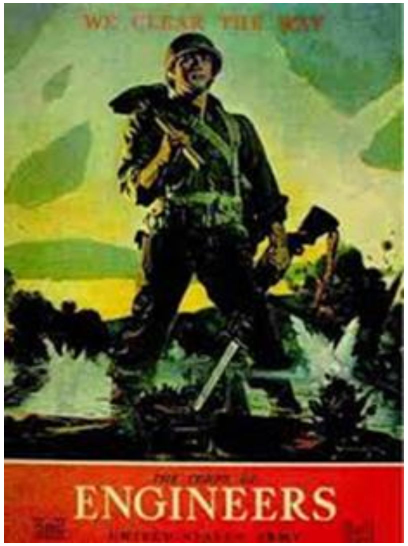
Smart Grids

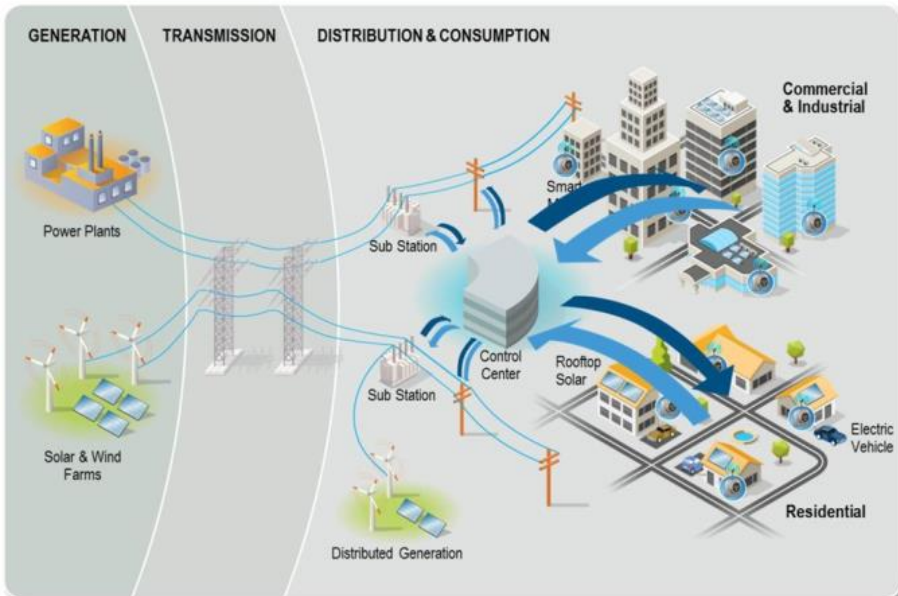
a megatrend or just business as usual ?

Mark O’Malley, UCD, Ireland

UCD, October 28th 1996

Smart Grid and the unholy Trinity

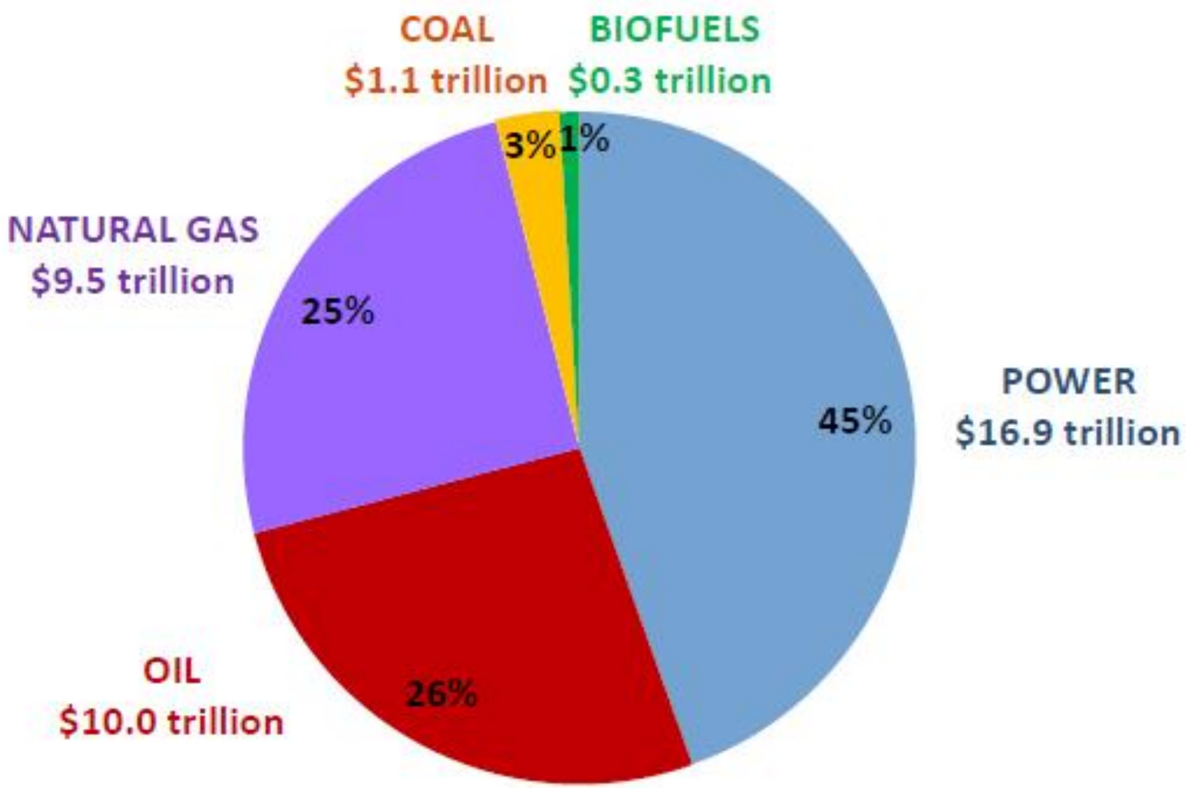




Investment: the essence of energy

WORLD ENERGY OUTLOOK 2011

Cumulative investment in energy infrastructure, *2011-2035*



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

The digital utility of the future captures opportunities all along the value chain.

McKinsey&Company

The digital utility of the future captures opportunities all along the value chain.

McKinsey&Company

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)

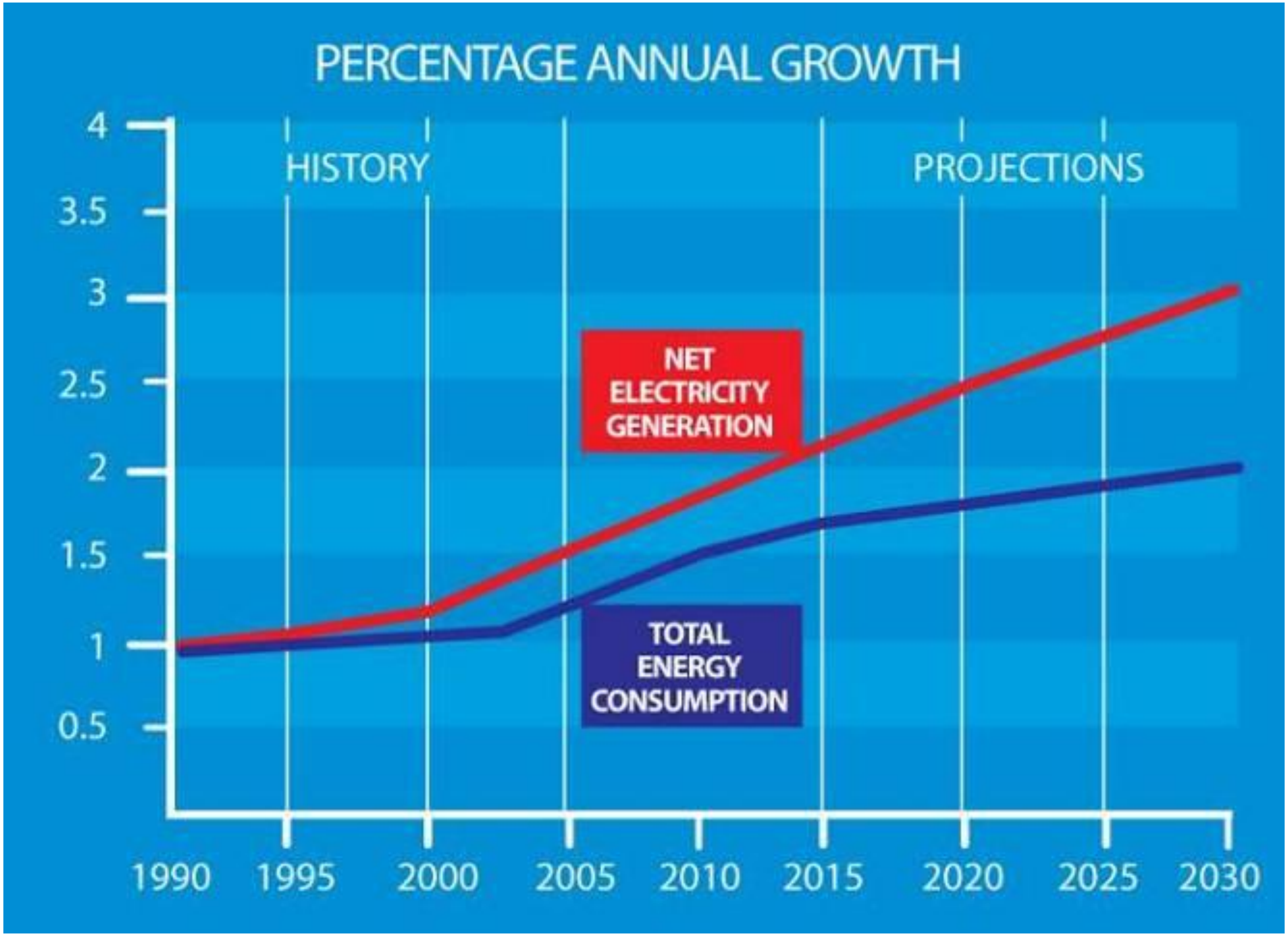
Thank you Nick for this introduction. And thanks to both you and Joao (Torres) for inviting me to this major event. I would like to use this opportunity to discuss the "smart transition" – some would even say "revolution" – that is unfolding before our very eyes.

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".

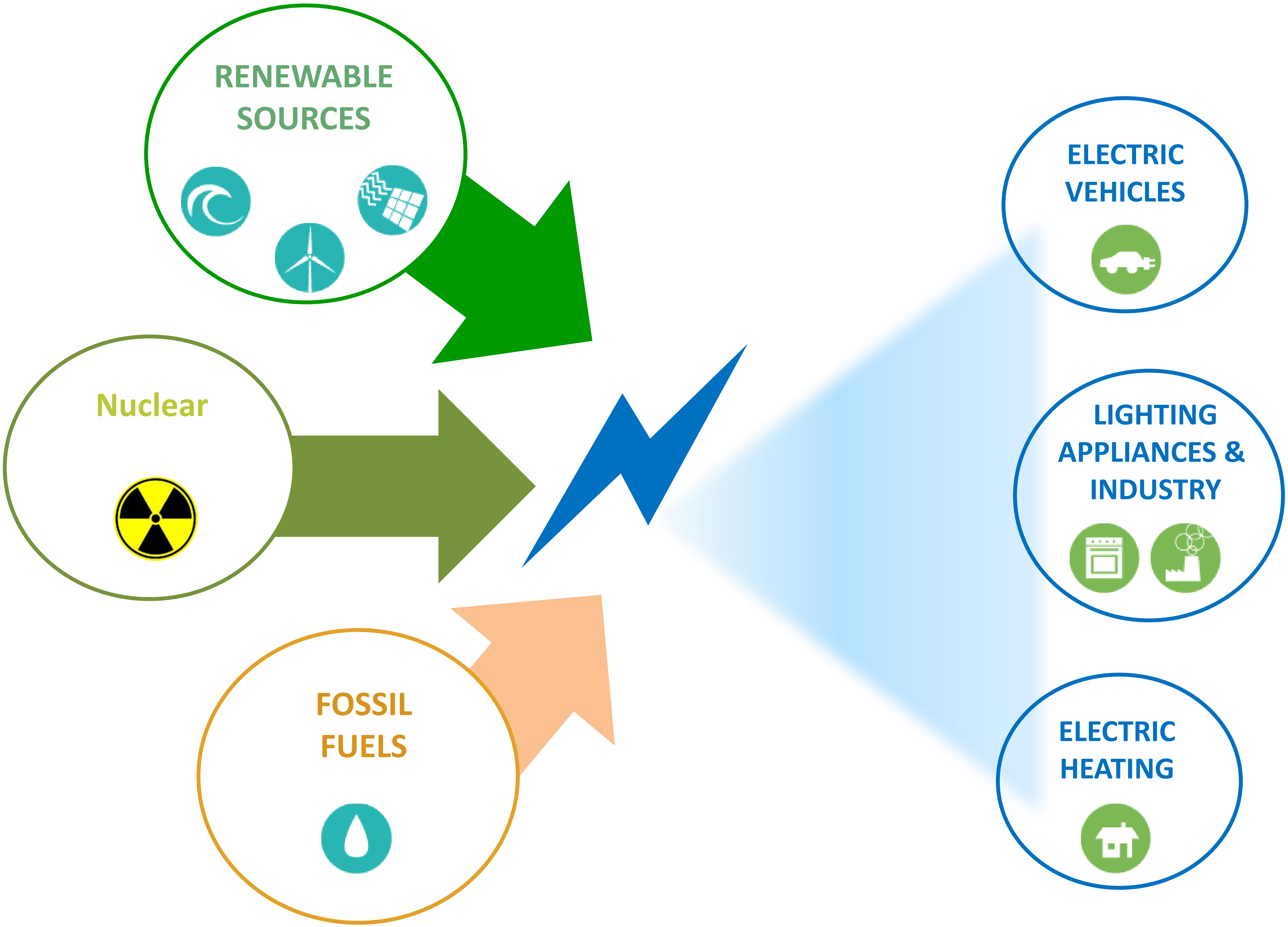
As I have already alluded to, what **shale gas did to the US economy, smart grids can and should do in Europe**. Thus I would like to thank EDSO and ENTSO-E, not only for today but for your daily work; for your

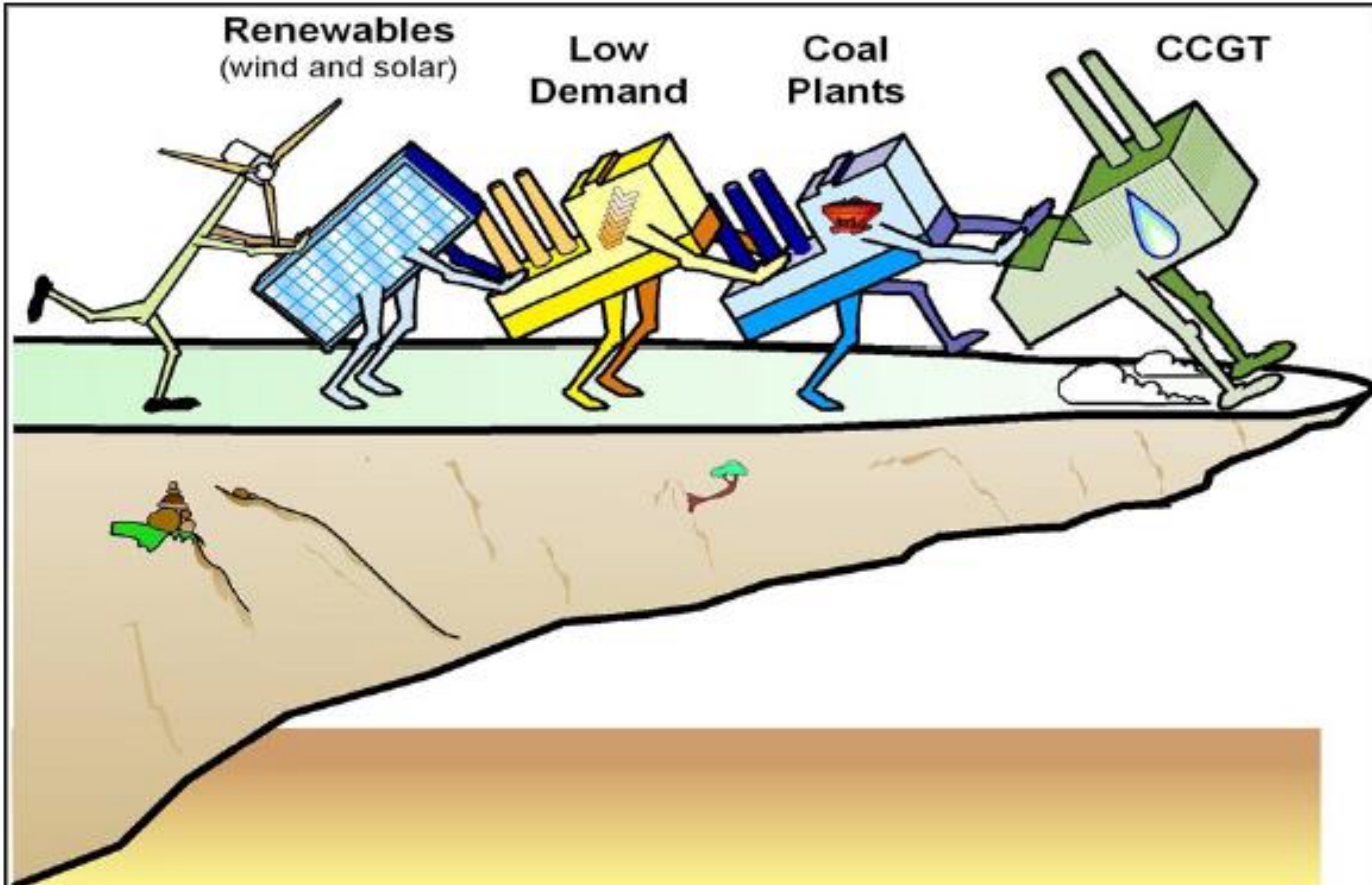
The future is electric



Source: Energy Information Administration (EIA), 2008.

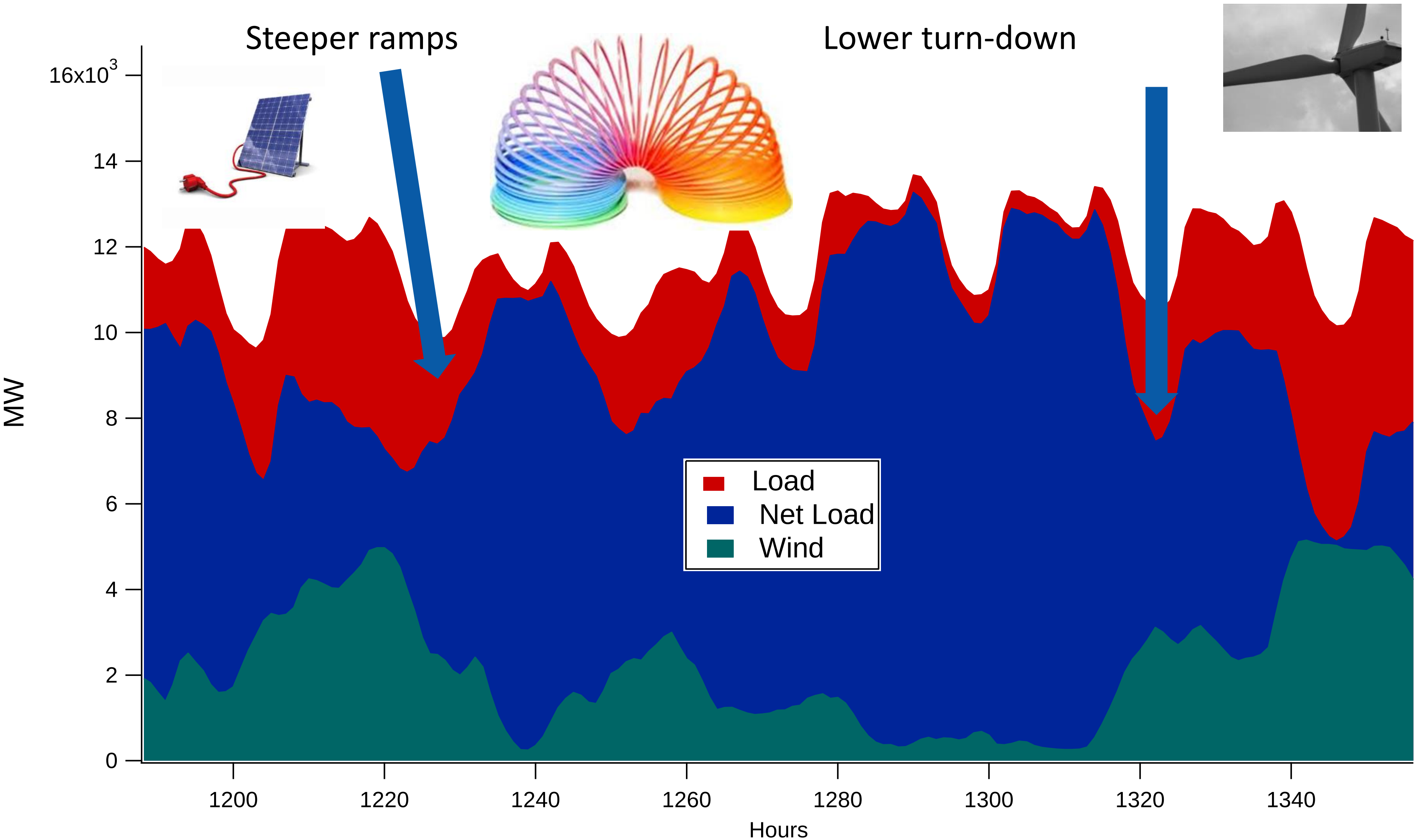
The Electric Future





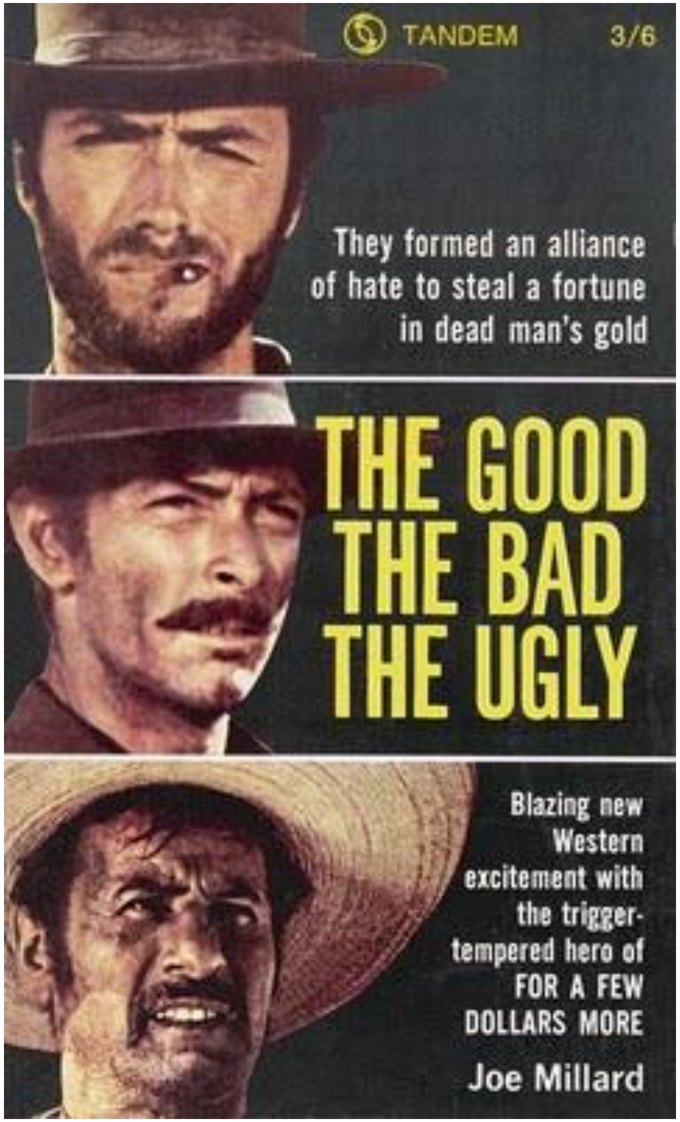
Renewables
(wind and solar)
Low
Demand
Coal
Plants
CCGT

With Variable Renewables More Flexibility is Needed

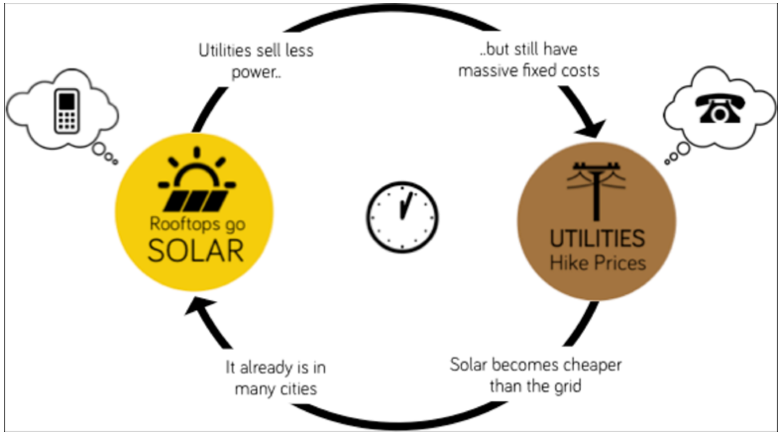


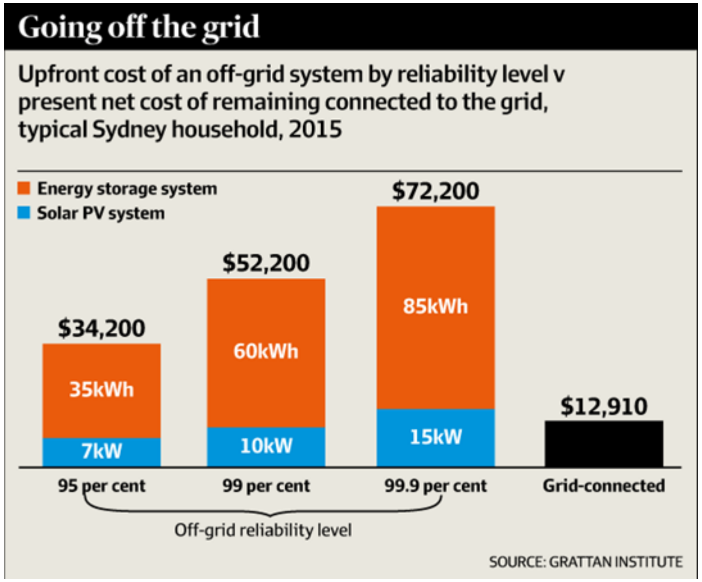
Source: Michael Milligan , NREL

Beware + Methodology

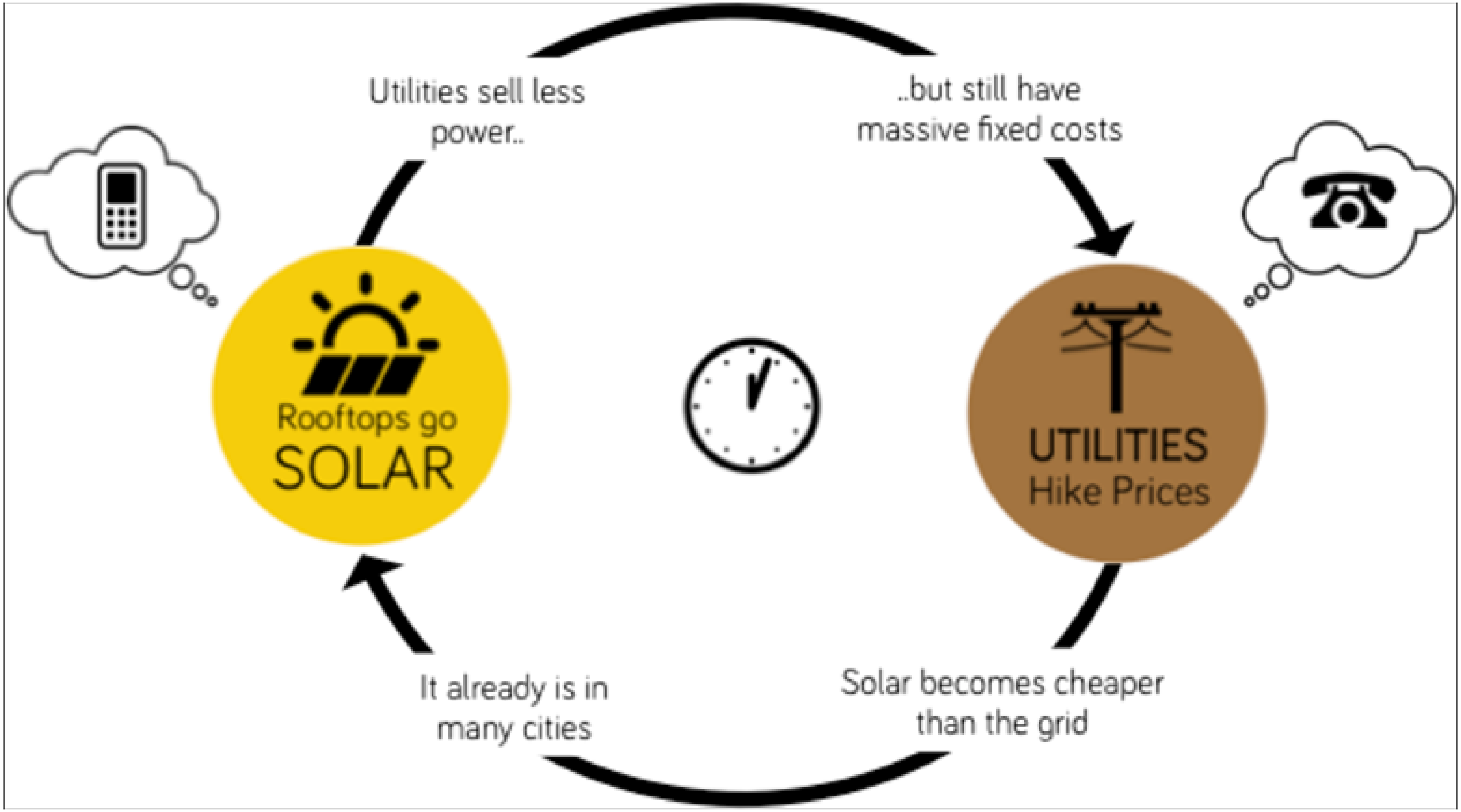


Beware of snake oil salesmen

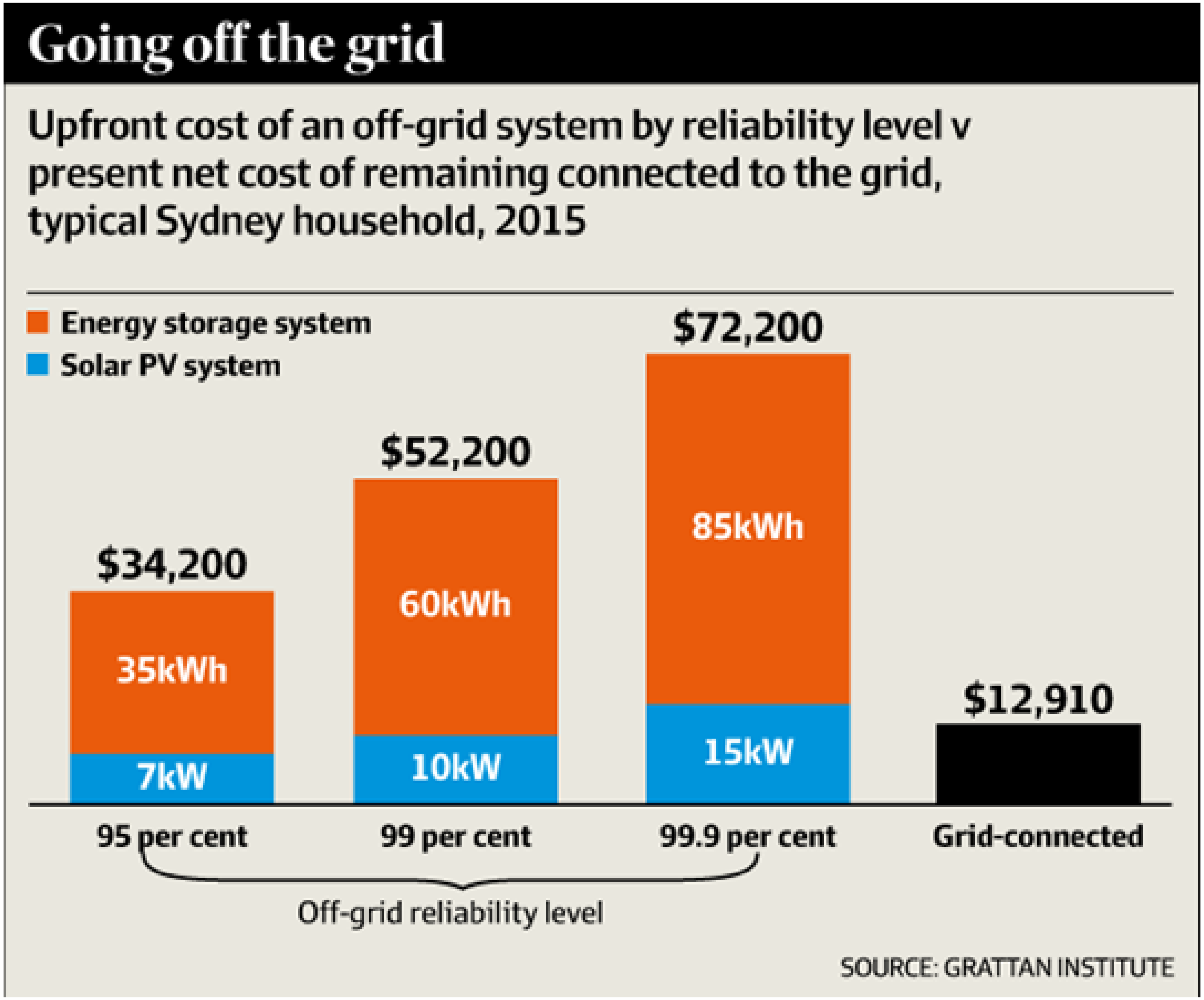




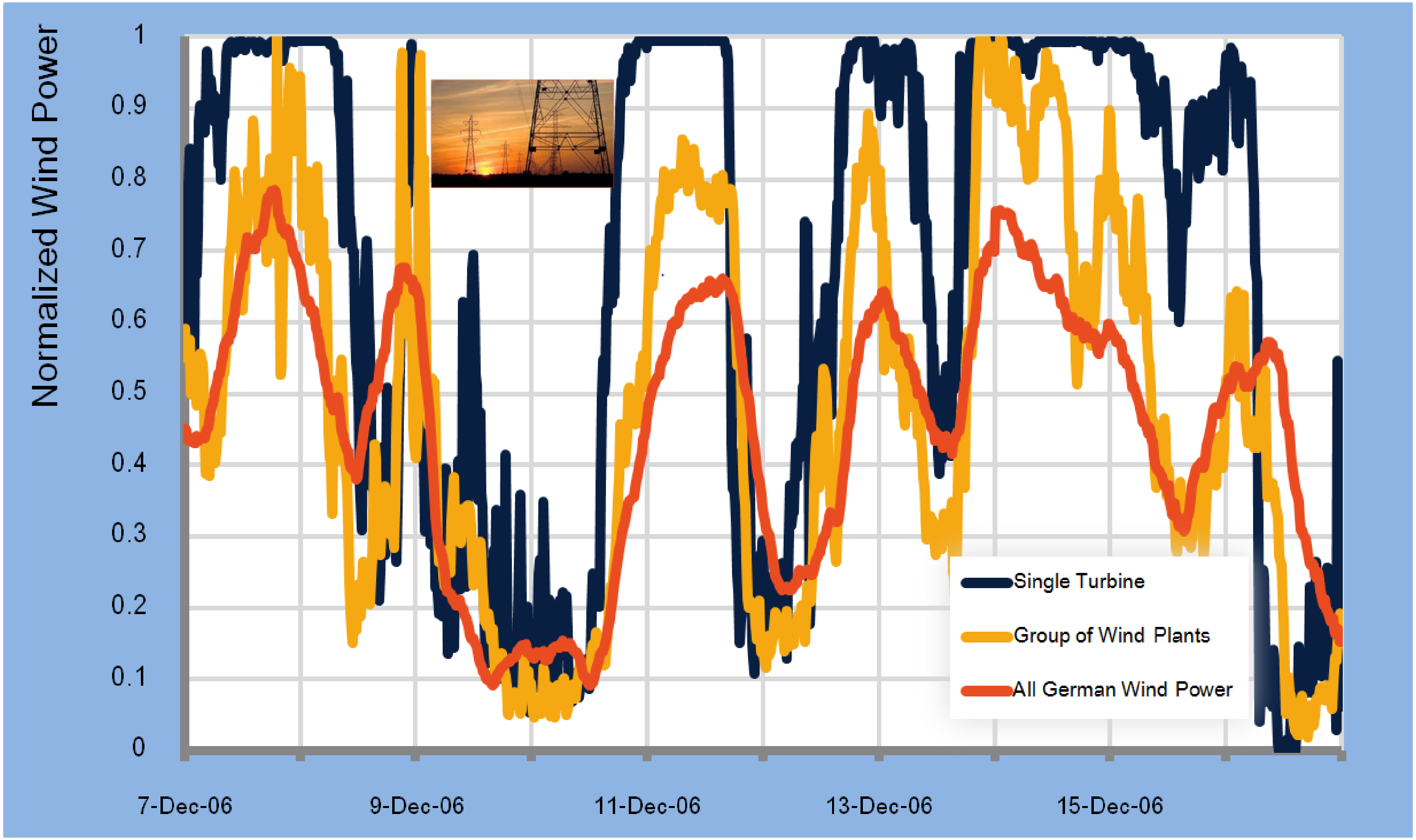
The spiral of death



Going off grid is very expensive

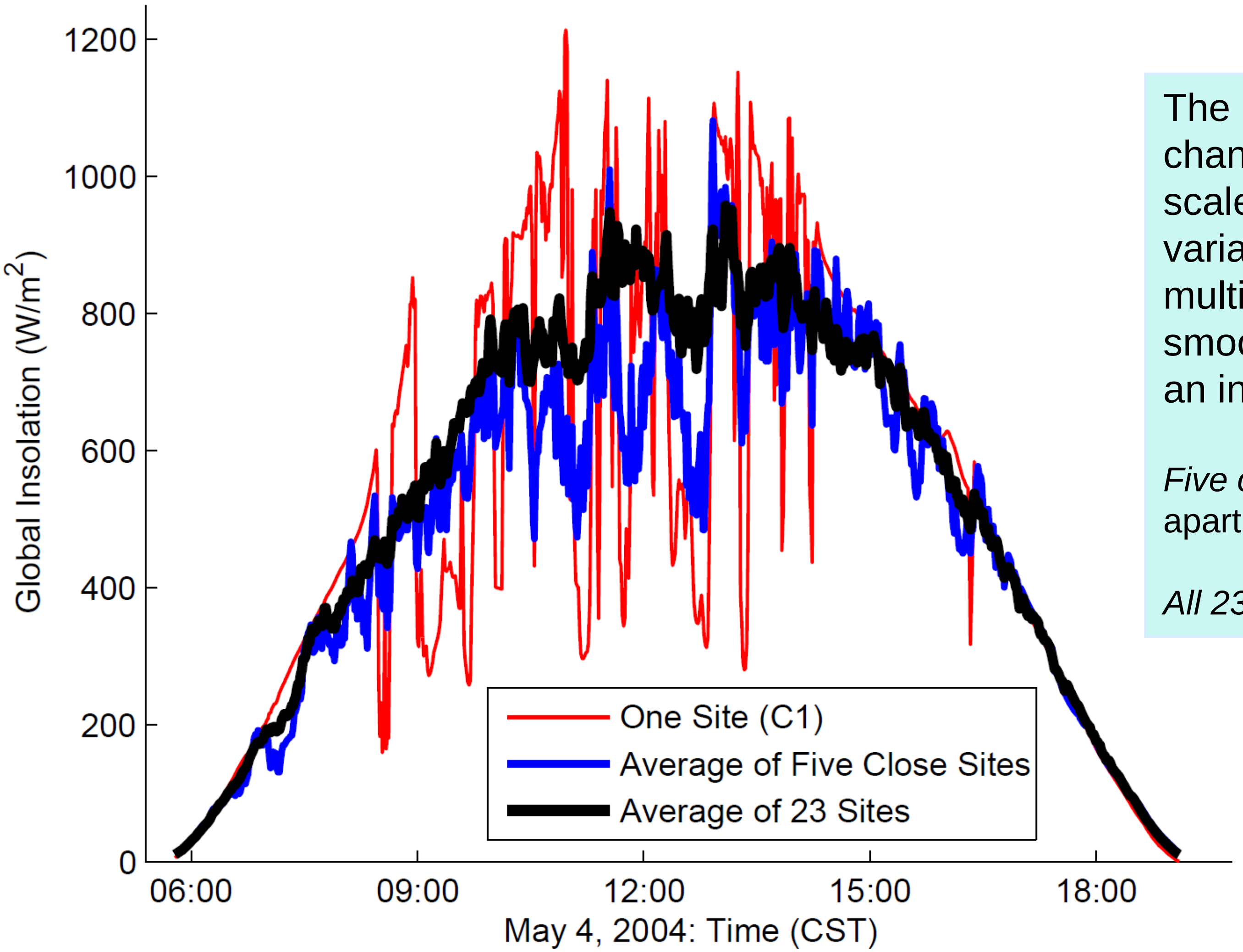


Aggregation of wind with transmission



Krewitt, W. et al. Integration of Renewable Energy into Present and Future Energy Systems. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2011.

Aggregation of solar



The lack of correlation in changes solar over short time scales means that the variability of the aggregated multiple sites is significantly smoother than the variability of an individual site.

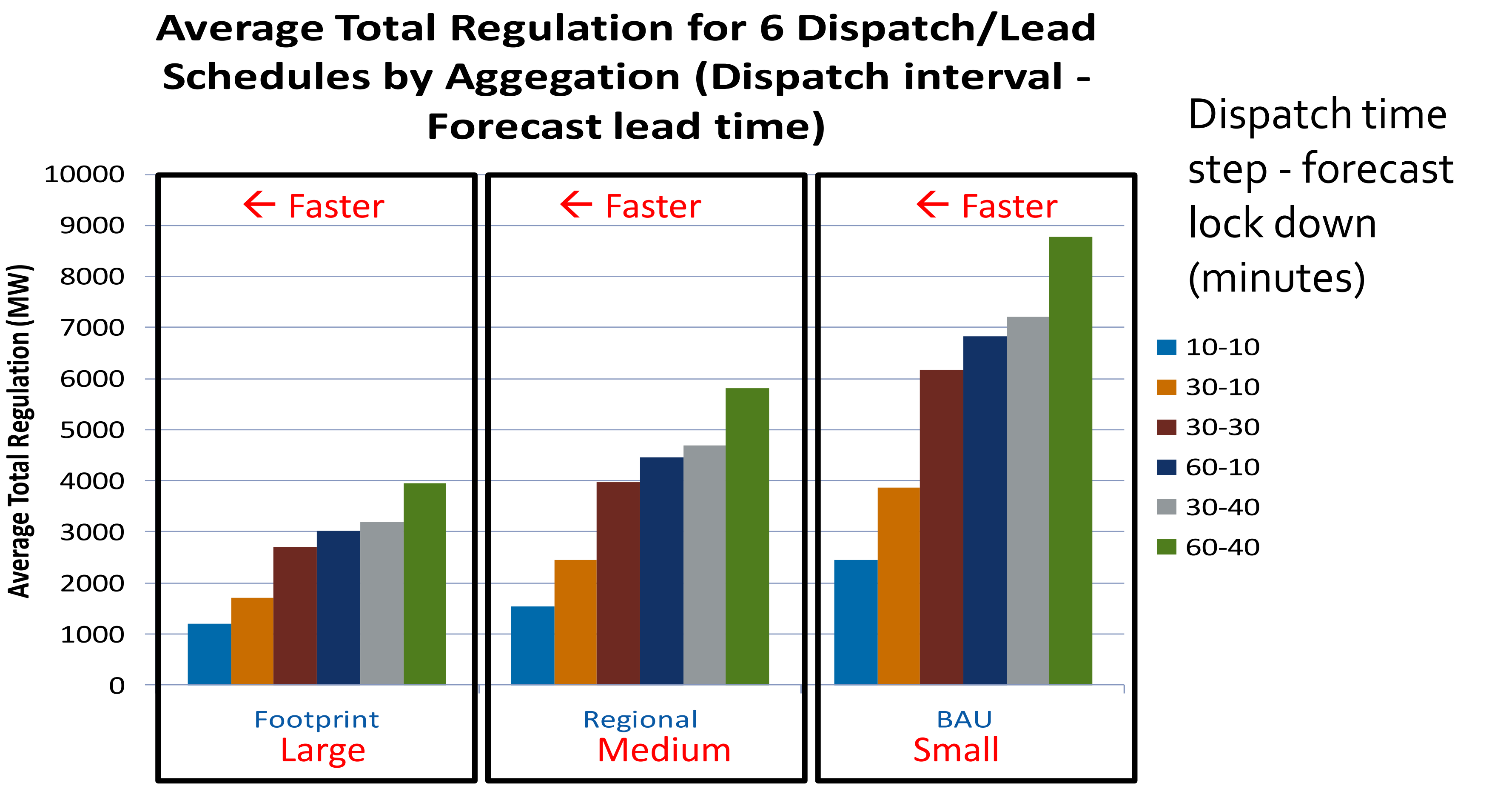
Five closest sites: 50 – 170 km apart

All 23 sites: 20 – 440 km apart

Mills, A. D, and R. H. Wiser. 2011. Implications of geographic diversity for short-term variability and predictability of solar power. In 2011 IEEE Power and Energy Society General Meeting, 1-9. IEEE, July 24. doi:10.1109/PES.2011.6039888.

Source: Andrew Mills, LBL

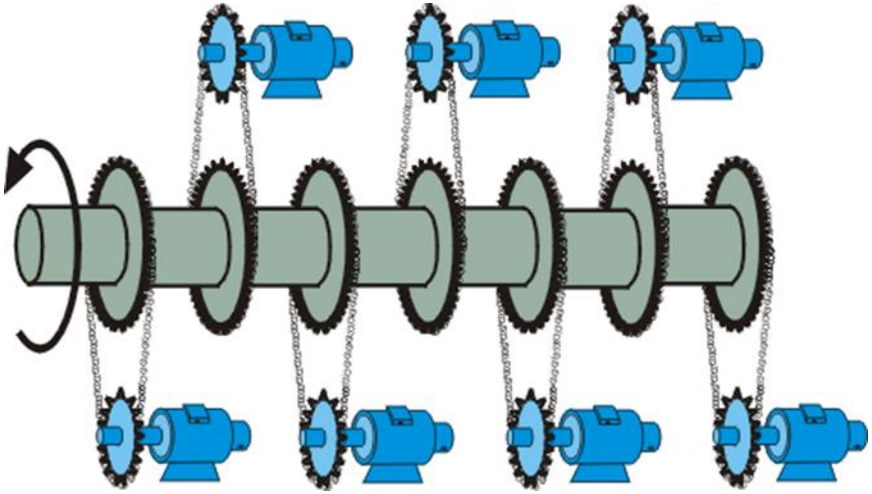
Bigger is better; faster is better

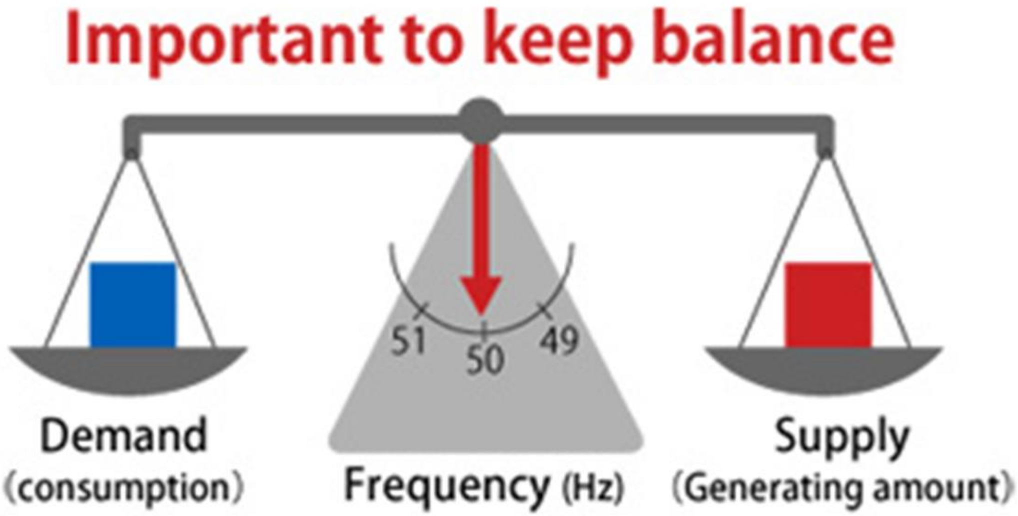


Milligan, Kirby, King, Beuning (2011), The Impact of Alternative Dispatch Intervals on Operating Reserve Requirements for Variable Generation. Presented at 10th International Workshop on Large-Scale Integration of Wind (and Solar) Power into Power Systems, Aarhus, Denmark. October

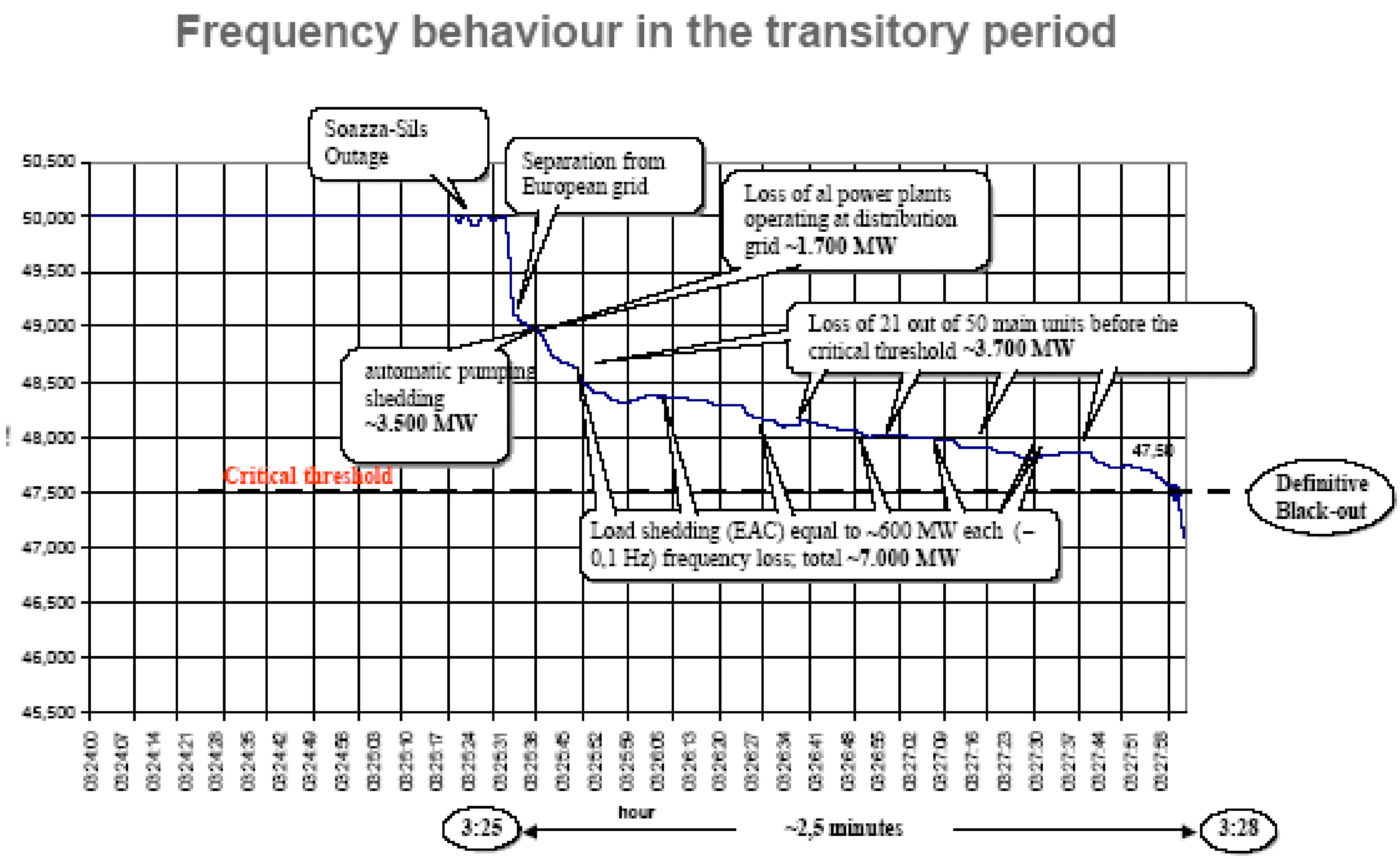
Source: Michael Milligan, NREL

Synchronous Grid





Italian blackout 28th September 2003



Vandenberghe, F., et al. "FINAL REPORT of the Investigation Committee on the 28 September 2003 Blackout in Italy." (2004).

Italy in the dark

MY Responses

~~'I am especially interested in understanding differences between centralised and decentralised renewable energy systems. It is often emphasized that decentralised approaches suffer from a problem of upscaling. I would like to hear arguments of experts in engineering, economics, psychology, public policy and other relevant disciplines on this issue. I'm certain this topic could initiate a fruitful discussion.~~

the role of companies in energy transition

Are there opportunities ?

Greatest Engineering Achievements OF THE 20TH CENTURY

- About
- Timeline
- The Book

Welcome!

How many of the 20th century's greatest engineering achievements will you use today? A car? Computer? Telephone? Explore our list of the top 20 achievements and learn how engineering shaped a century and changed the world.

1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. Petroleum and Petrochemical Technologies
18. Laser and Fiber Optics
19. Nuclear Technologies
20. High-performance Materials

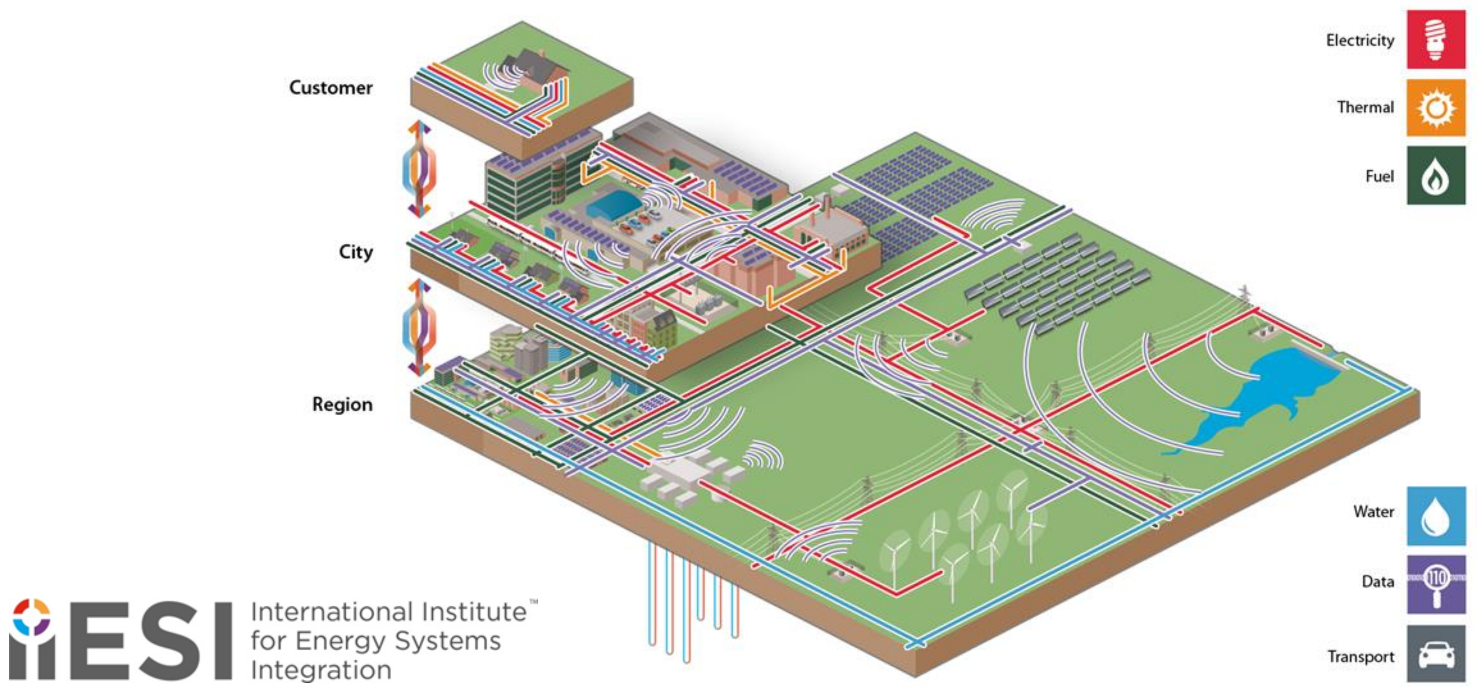
21st Century Innovation Topics

1. Energy conservation
2. Resource protection
3. Food and water production and distribution
4. Waste management
5. Education and learning
6. Medicine and prolonging life
7. Security and counter-terrorism
8. New technology
9. Genetics and cloning
10. Global communication
11. Traffic and population logistics
12. Knowledge sharing
13. Integrated electronic environment
14. Globalization
15. AI, interfaces and robotics
16. Weather prediction and control
17. Sustainable development
18. Entertainment
19. Space exploration
20. "Virtualization" and VR
21. Preservation of history
22. Preservation of species

Greatest Achievements

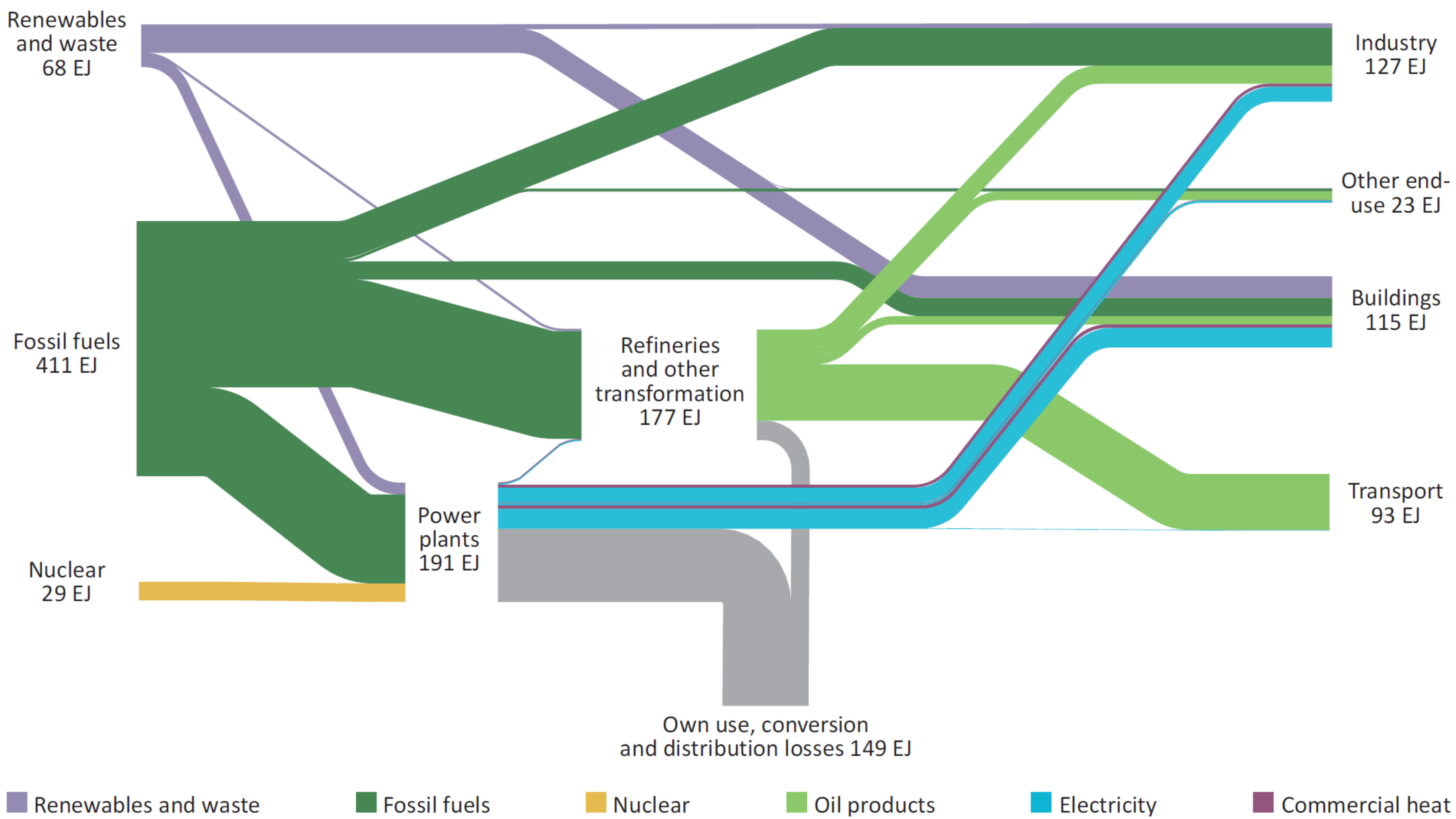
 Printer-Friendly Version. Text-Only Version. Contact Us.

Energy Systems Integration



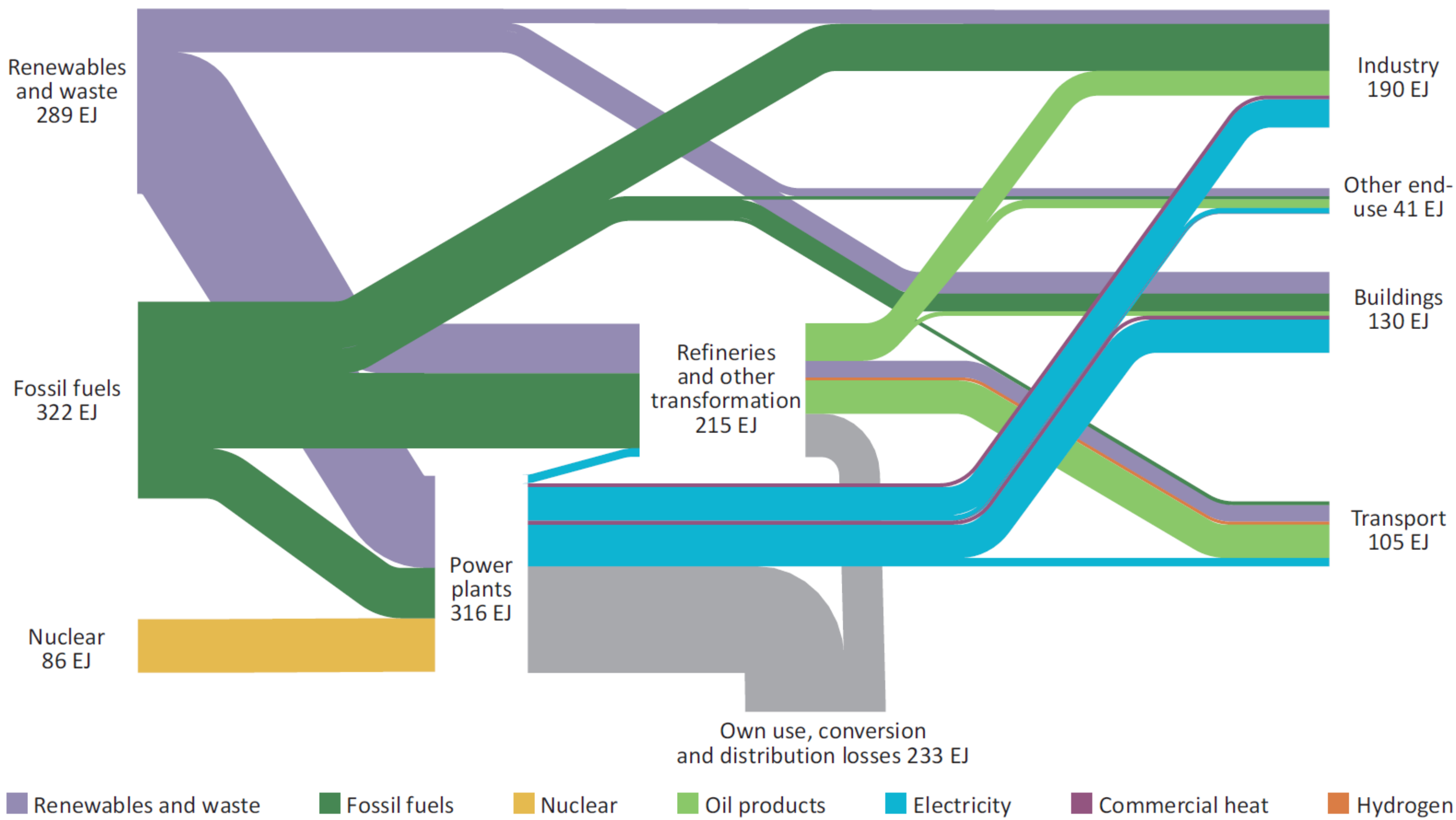
- **optimization** of energy systems across multiple pathways and scales
- increase reliability and performance, and minimise **cost and environmental impacts**
- most valuable at **the interfaces where the coupling** and interactions are strong and represent a challenge and an opportunity
- control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

The global energy system today



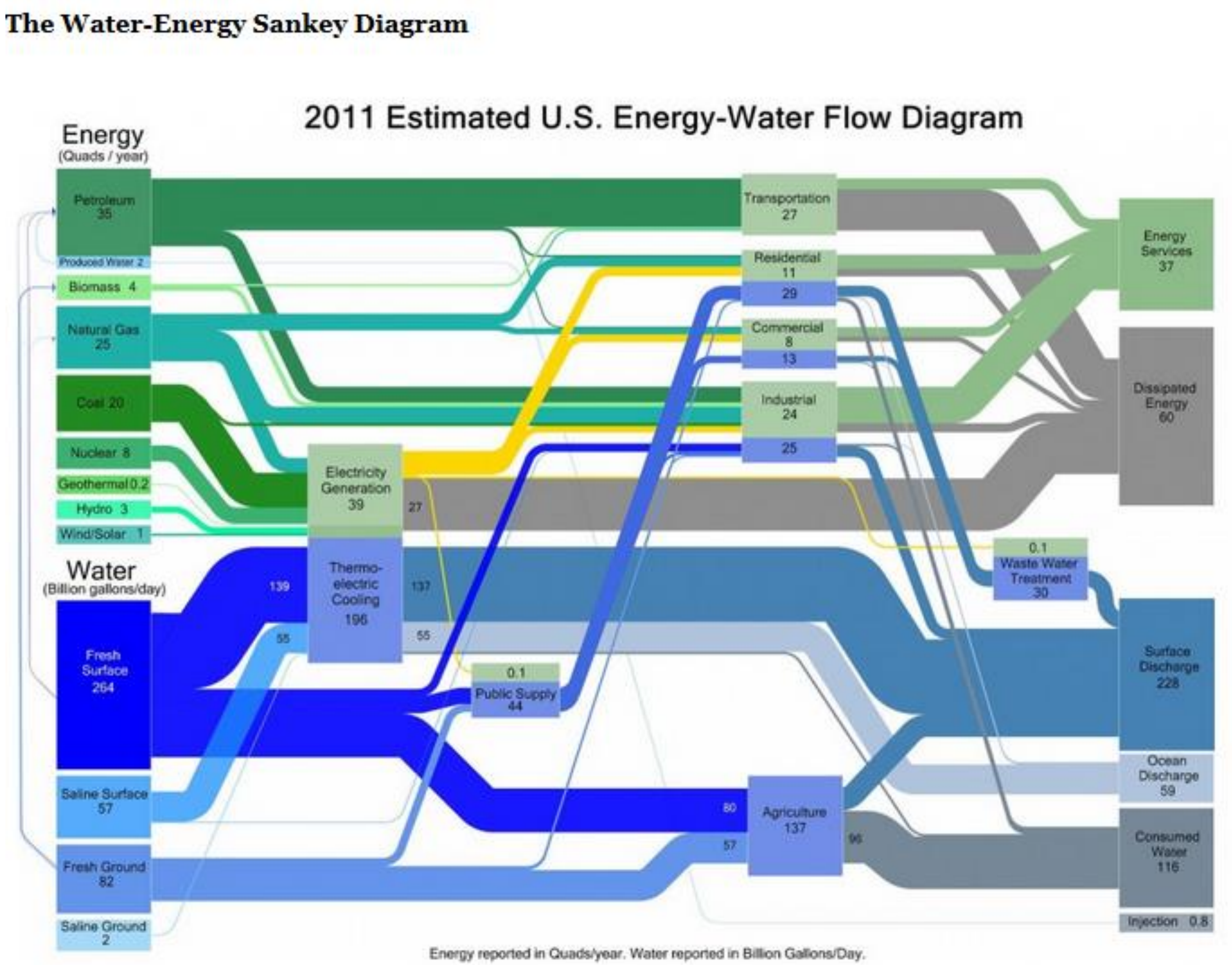
Dominated by fossil fuels in all sectors: (Source IEA)

The future low-carbon energy system



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

Water Energy Nexus



K. Zerrenner, "New graphic from DOE illustrates the energy-water-land nexus," http://blogs.edf.org/energyexchange/2014/07/24/new-graphics-from-doe-illustrate-the-energy-water-land-nexus/.

- Teaching Water
- Post-2015 Water and Sanitation
- Water, Sanitation and Hygiene
- Water and urbanization
- Water resources management
- Water quality
- Transboundary waters

WATER, FOOD AND ENERGY NEXUS

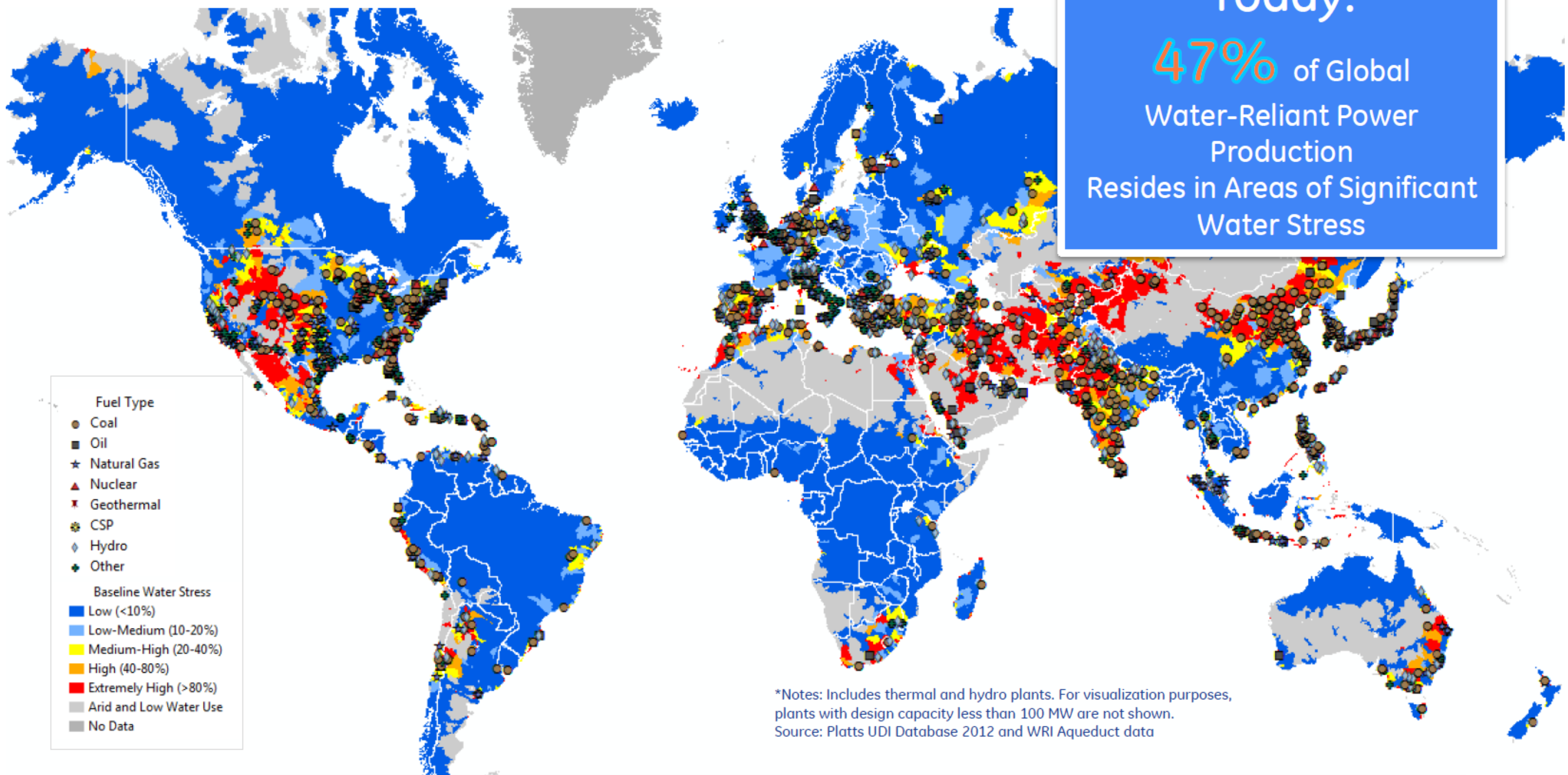
Water, energy and food are inextricably linked. Water is an input for producing agricultural goods in the fields and along the entire agro-food supply chain. Energy is required to produce and distribute water and food: to pump water from groundwater or surface water sources, to power tractors and irrigation machinery, and to process and transport agricultural goods.

Agriculture is currently the largest user of water at the global level, accounting for 70% of total withdrawal. The food production and supply chain accounts for about 30% of total global energy consumption.

Global generation units with water stress*

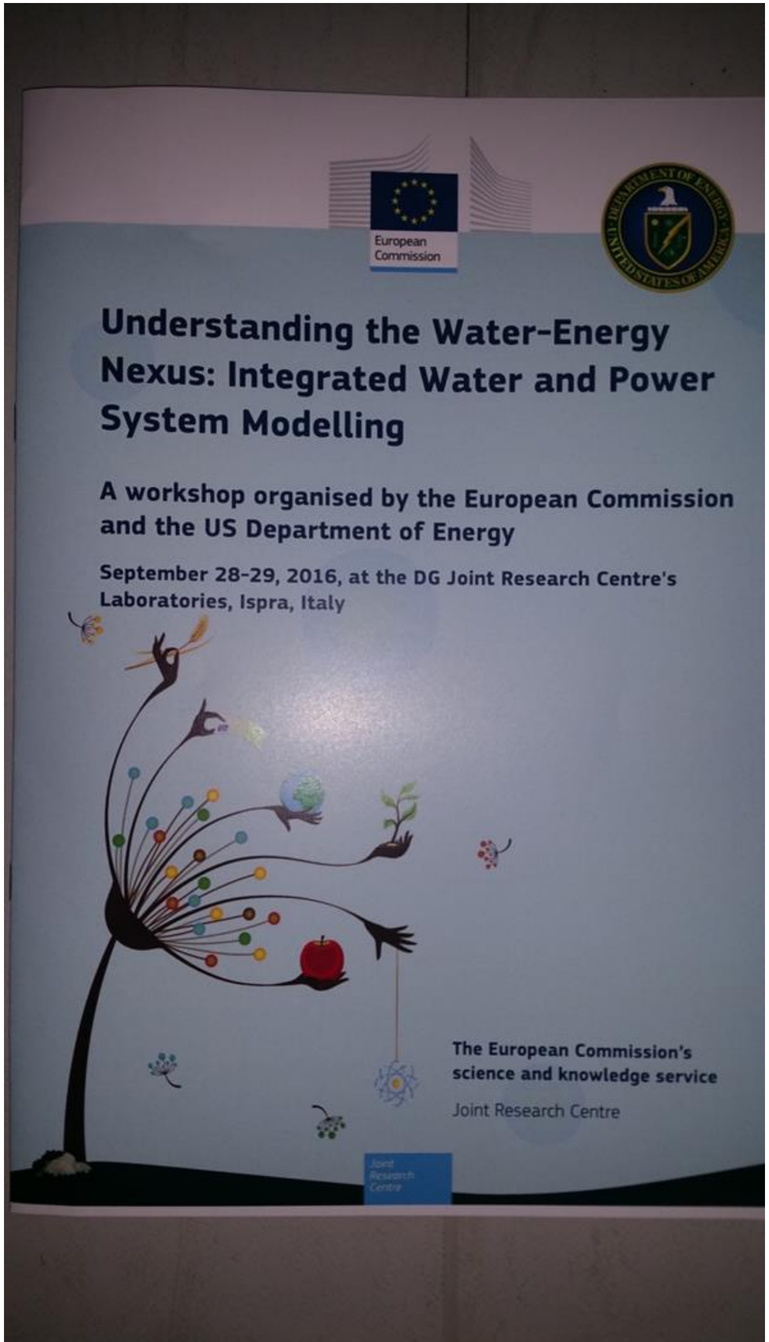
Medium to extremely-high stress

Today:
47% of Global Water-Reliant Power Production Resides in Areas of Significant Water Stress



*Notes: Includes thermal and hydro plants. For visualization purposes, plants with design capacity less than 100 MW are not shown.
Source: Platts UDI Database 2012 and WRI Aqueduct data

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



COMMENTARY:

The global groundwater crisis

J. S. Famiglietti

Groundwater depletion the world over poses a far greater threat to global water security than is currently acknowledged.

Groundwater — the water stored beneath Earth's surface in soil and porous rock aquifers — accounts for as much as 33% of total water withdrawals worldwide[1]. Over two billion people rely on groundwater as their primary water source[2], while half or more of the irrigation water used to grow the world's food is supplied from underground sources[1].

Groundwater also acts as the key strategic reserve in times of drought[3], in particular during prolonged events such as those in progress across the western United States (Fig. 1), northeastern Brazil and Australia. Like money in the bank, groundwater sustains societies through the lean times of little incoming rain and snow. Hence, without a sustainable groundwater

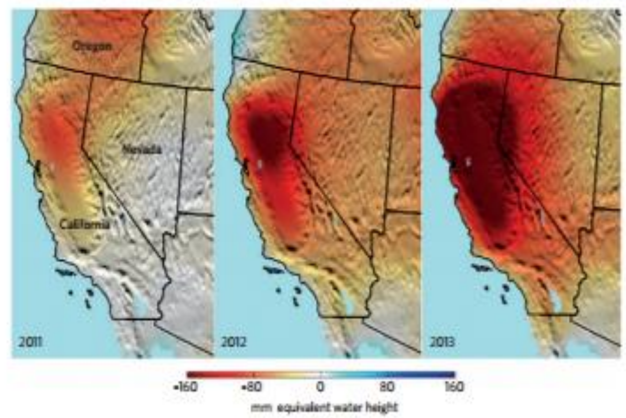


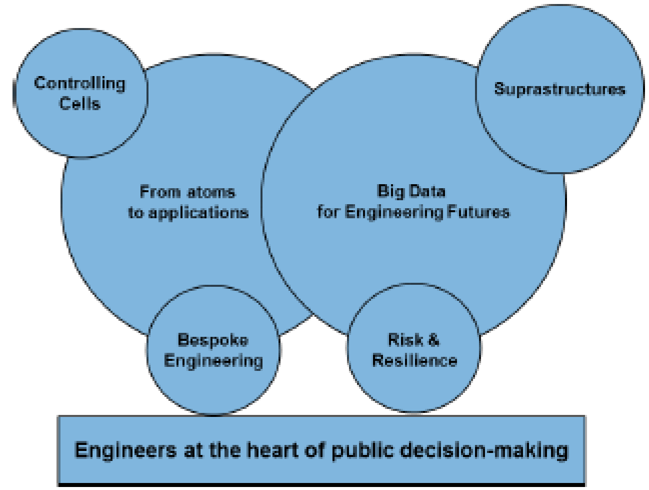
Figure 1 | NASA's Gravity Recovery and Climate Experiment (GRACE) satellite mission is providing new, space-based insights into the global nature of groundwater depletion[3–6]. The ongoing California drought is evident in these maps of dry season (September–November) total water storage anomalies (in mm equivalent water height; anomalies with respect to 2005–2010) in the western United States. The maps were constructed using GRACE Mascons solutions from NASA's Jet Propulsion Laboratory (M. M. Watkins, D. N. Wiese, D.-N. Yuan, C. Boening and F. W. Landerer, unpublished results). California's Sacramento and San Joaquin river basins have lost roughly 15 km^3 of total water per year since 2011 — more water than all 38 million Californians use for domestic and municipal supplies annually — over half of which is due to groundwater pumping in the Central Valley[4,8]. Image: Felix W. Landerer, NASA Jet Propulsion Laboratory, California Institute of Technology, USA.

are being mined, their precious contents never to be returned. These include the North China Plain[10], Australia's Canning Basin, the Northwest Sahara Aquifer System, the Guarani Aquifer in South America, the High Plains[11] and Central Valley[3] aquifers of the United States, and the aquifers beneath northwestern India[4] and the Middle East[12] (Fig. 2). Nearly all of these underlie the word's great agricultural regions and are primarily responsible for their high productivity.

Climate change and associated changes to the water cycle vastly complicate the challenge of sustaining groundwater supplies for the foreseeable future. Changing patterns of precipitation and groundwater recharge, and increasing extremes of flooding and drought[13] are among the most palpable impacts of global change, and underscore the need to rethink stationarity in current water management strategies[14]. As the wet, high- and low-latitude areas of the world become wetter, and the dry areas in between become drier[15] (and already limited groundwater recharge decreases), the 'haves' and 'have nots' of the future water landscape are emerging.

Moreover, because the natural human response to drought is to pump more groundwater[3,5,12], continued groundwater

Engineering and Physical Sciences Research Council



Engineering Grand Challenges

Report on outcomes of a retreat – 07 and 08 May 2014

Ettington Chase, Stratford-upon-Avon

4.6 Suprastructures – Integrating Resource Infrastructures under Constraints

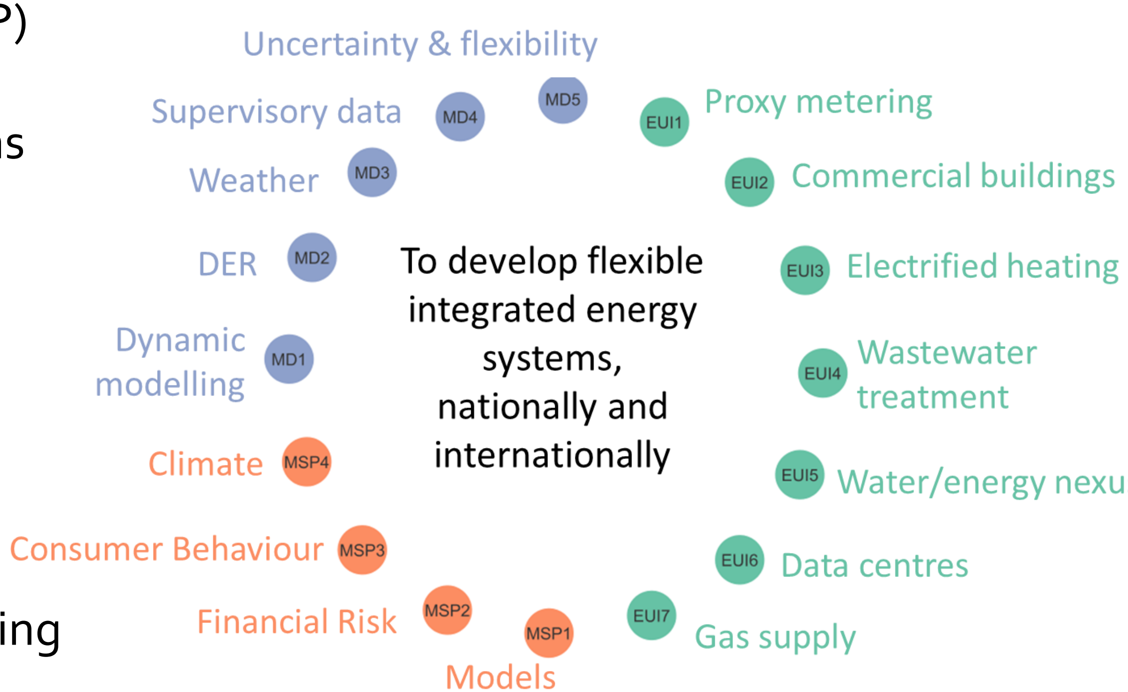
Description

Design the development and operation of optimised integrated infrastructures - both the physical and organisational structures/facilities - for an uncertain but sustainable future.

As we move to uncertain but increasingly tight resource constraints, how should we design, operate and bring about connected, integrated and holistic infrastructures for communications and information, water, energy, food, material and people to achieve resilience against environmental change, demand variation and technology evolution?

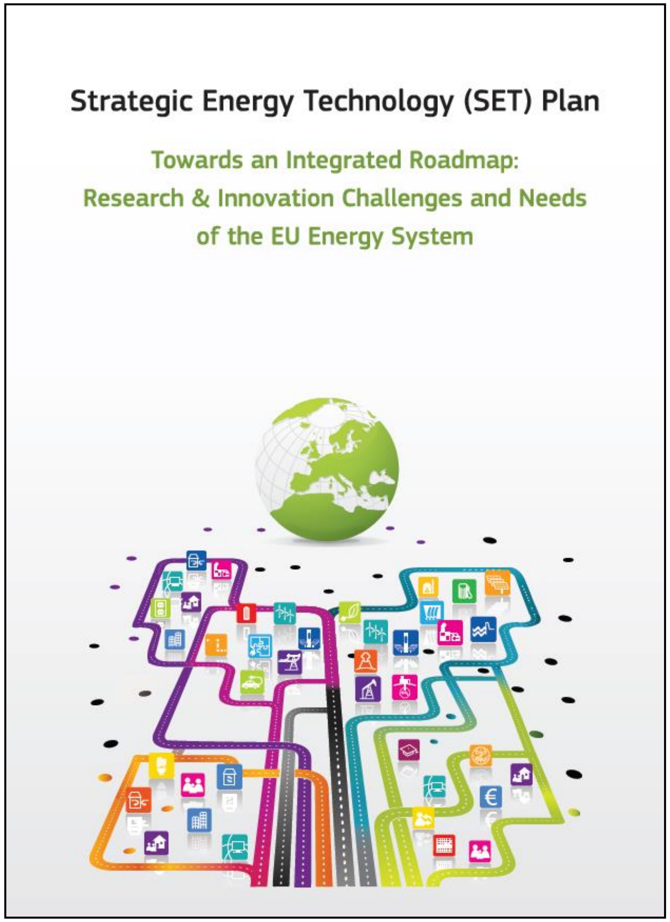
ESI is Multidisciplinary

- Energy Systems Integration Partnership Programme (ESIPP)
- 23 academics from 7 institutions
- 5 Industry Partners, 17 Industry Collaborators
- Three strands:
  - Modelling & Data
  - End Use
  - Markets & Strategic Planning
- Funding €11.0M (SFI, philanthropic donation & industry funding)
- Officially launched, 24th November 2015



Global

International Context



https://setis.ec.europa.eu/system/files/Towards%20an%20Integrated%20Roadmap_0.pdf

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

CATAPULT Energy Systems

https://es.catapult.org.uk/

EERA JP in ESI

You are here » EERA Joint Programmes (JPs)

JOINT PROGRAMMES

About JPs

- How does a Joint Programme operate
- What is the outcome of a Joint Programme
- Integrated Research Programmes
- Collaborating with industry
- International Cooperation
- National Alignment

List of JPS

- AMPEA
- Bioenergy
- Carbon Capture and Storage
- Concentrated Solar Power (CSP)
- Economic, environmental and social impacts (JP e3s)
- Energy Efficiency in Industrial Processes
- Energy Storage
- Energy Systems Integration
- Fuel Cells and Hydrogen
- Geothermal
- Nuclear Materials
- Ocean Energy
- Photovoltaic Solar Energy
- Shale Gas
- Smart Cities
- Smart Grids
- Wind Energy

Energy Systems Integration

The EERA Joint Programme in Energy Systems Integration

This Joint Programme in Energy Systems Integration seeks to bring together research strengths across Europe to optimize our energy system, in particular by benefiting from the synergies between heating, cooling, electricity, renewable energy and fuel pathways at all scales. The energy elements of the water and transport system are also included as is the enabling data and control network that enables the optimization.

The Joint Programme in Energy Systems Integration is designed to develop the technical and economic framework that government and industries will need to build the future efficient and sustainable European energy system. It is fully aligned with the recently published SET Plan Integrated Roadmap and potential impact include increased reliability and performance, minimisation of cost and environmental impacts and, in particular, increased penetration of renewable energy sources.

The Joint Programme is organised in 5 Sub-Programmes (SP) that target different aspects of Energy Systems Integration. Given the nature of Energy Systems Integration, the SPs are strongly interlinked.

SP1: Modelling, coordinated by Dr. Juha Kiviluoma, VTT (FI)

SP2: Forecasting, aggregation & control, coordinated by Prof. Henrik Madsen, DTU (DK)

SP3: Technology, coordinated by Prof. William D'haeseleer, KU Leuven (BE)

SP4: Consumer, coordinated by Mr. Didier Van den Abeele, CEA (FR)

SP5: Finance & regulation, coordinated by Dr.ir. Laurens J. De Vries, TU Delft (NL)

The Description of Work (DoW) for the Joint Programme in Energy Systems Integration is available here.

News of this program

Useful documents

EERA intranet

Coordinator

Prof. Mark O'Malley
e-mail

Claire Cullen
e-mail

Contact at EERA

Maria Oksa
e-mail

iiESI.org

iiESI International Institute™ for Energy Systems Integration

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Imperial College London

NREL NATIONAL RENEWABLE ENERGY LABORATORY

한국에너지기술연구원 KIER KOREA INSTITUTE OF ENERGY RESEARCH

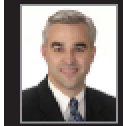
EPRI ELECTRIC POWER RESEARCH INSTITUTE

DTU

KU LEUVEN

iiESI Leadership

Mark O'Malley
iiESI Director
(University College Dublin)



Bryan Hannegan
iiESI Executive Director
(National Renewable Energy Laboratory)

Solving complex global energy challenges requires changing the way we THINK about energy systems, providing opportunities to SHARE knowledge, and helping nations EVOLVE by informing the discussions that are guiding energy investments and policy decisions.

GE

International Institute for Energy Systems Integration

Energy Systems Integration: Defining and Describing the Value Proposition

Mark O'Malley
University College Dublin

Benjamin Kroposki and Bryan Hannegan
National Renewable Energy Laboratory

Henrik Madsen and Mattias Andersson
Technical University of Denmark

William D'haeseleer
KU Leuven

Mark F. McGranaghan
Electric Power Research Institute

Chris Dent
Durham University

Goran Strbac
Imperial College London

Suresh Baskaran and Michael Rinker
Pacific Northwest National Laboratory

Technical Report
NREL/TP-5D00-66616
June 2016

DOI link: http://dx.doi.org/10.2172/1257674

Contract No. DE-AC36-08GO28308

Energy Systems Integration 102 – Research Challenges

National Renewable Energy Laboratory (NREL)
Energy Systems Integration Facility (ESIF) – Maxwell Conference Room
15013 Denver West Parkway, Golden, Colorado, USA
August 3rd to 7th, 2015

The International Institute of Energy Systems Integration presents a course on Energy Systems Integration (ESI). The course is informed by a recent workshop held in Imperial College London that identified key research challenges in ESI, hence this course is particularly suited for those with an interest in the future research challenges. The course also builds on previous courses held at NREL (ESI 101) and KU Leuven, but are not deemed to be prerequisites.

The course will cover the research challenges of ESI at all scales (from residential to continental) across multiple energy (and non-energy) domains from a technical, market, regulatory and consumer standpoint. The course is

Call for Papers – IEEE Transactions on Smart Grid

Special section on

Energy Systems Integration

Energy Systems Integration (ESI) is 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. Energy systems have evolved from individual systems with little or no dependencies into a complex set of integrated systems at scales that include customers, cities, and regions. This evolution has been driven by political, economic, and environmental objectives. As we try to meet the globally recognized imperative to reduce carbon emissions through the deployment of large renewable energy capacities while also maintaining reliability and competiveness, flexible energy systems are required. This flexibility can be attained through integrating various systems: by physically linking energy vectors, namely electricity, heat, and fuels; by coordinating these vectors across other infrastructures, namely water, data, and transport; by institutionally coordinating energy markets; and, spatially, by increasing market footprint with granularity all the way down to the customer level. Smart grids and ESI have overlaps in particular the interaction between electricity, consumers, data and transport. This special issue therefore focusses on the aspects of ESI where electricity is coupled to water, heat and fuels and where this coupling brings challenges and/or opportunities. Topics of interest include, but are not limited to:

- Multi energy system modelling
- Integrated energy markets
- Combined heat and power
- Electricity water nexus
- Electricity gas coupling
- Planning of integrated energy systems
- Operating integrated energy systems
- Case studies of integrated energy systems

This special section solicits original work that is not under consideration for publication in other venues. Extended abstracts of up to two pages are requested for the first round of reviews. Authors of selected extended abstracts will be invited to submit full papers, of up to eight pages, in a second round of reviews. Prospective authors should refer to http://www.ieee-pes.org/publications/information-for-authors for guidelines on content and formatting of submissions. Please submit a PDF version of the extended abstract, including a cover letter with the authors' contact information, via e-mail to ieeetsgesi@ucd.ie. Full papers should be submitted to: https://mc.manuscriptcentral.com/tsg-pes

Important Dates

- January 15th, 2017: Deadline for extended abstract submission
- February 15th, 2017: Decision notification for inviting full paper submissions
- July 1st, 2017: Deadline for full paper submission
- Jan 1st, 2018: Notification of final decisions
- Feb 1st, 2018: Publication materials due

Guest Editorial Board

- Dr. Janusz Bialek, Skoltech
- Dr. Gabriela Hug, Swiss Federal Institute of Technology
- Dr. Suyong Chae, Korean Institute of Energy Research
- Dr. Juha Kiviluoma, VTT
- Dr. Benjamin Kroposki (Guest Editor-in-Chief), NREL
- Dr. Pierluigi Mancarella, University of Melbourne and Manchester
- Dr. Jim McCalley, Iowa State University
- Dr. Mark O'Malley (Guest Editor-in-Chief), University College Dublin
- Dr. Aidan Tuohy, Electric Power Research Institute
- Dr.Laurens de Vries, TU Delft

Editor-in-Chief of IEEE Transactions on Smart Grid: Dr. Jianhui Wang, Argonne National Laboratory, USA

Recent Journal Publications

- Ye, X., Lu, Z., Qiao, Y., Min Y. and O'Malley, M.J., "Identification and Correction of Outliers in Wind Farm Time Series Power Data", *IEEE Transactions on Power Systems*, in press, 2016.

- O'Connell, N., Pinson, P., Madsen, H., and O'Malley, M.J., "Economic Dispatch of Demand Response Balancing through Asymmetric Block Offers", *IEEE Transactions on Power Systems*, Vol. 31, pp.2999-3007, 2016.

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- Lannoye, E., Tuohy, A., Daly, P., Flynn, D. and O'Malley, M.J., "Assessing Power System Flexibility for Variable Renewable Integration: A Flexibility Metric for Long-Term System Planning", *CIGRE Science and Engineering*, Iss. 3, pp. 26 – 39, 2015.

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Energy Systems Integration

Backbone Model

Juha Kiviluoma

ESIPP Energy Systems Integration Partnership Programme

Backbone: Generalised model for energy systems and energy resources

- The core model offers energy conversions and energy transfers that are applicable to any conceivable energy transformation
  - Minimize equations to keep the code tractable
- Input data drives what forms of energy are actually modelled
- Allows stochastics for short-term forecasts and for long-term statistics (e.g. reservoir hydro power)
- Different models can directly re-use each others results (e.g. investments and operations)
- New models are defined through model definition files: allows to build new implementations on top of the core engine as needed

The best approach for particular problem is not known: Backbone makes the model structure easily modifiable

- Temporal structure of the model can be changed without changing underlying data:
  - Optimization horizon
  - Looping structure
  - Temporal aggregation of later periods
- Flexible constraints that can be relaxed for later periods
  - Presentation of reserves
  - Unit commitment constraints (SOS1 and SOS2 MIP, LP)
  - Unit and geographical aggregation
- Can do both energy blocks and power/ramp scheduling

Sceleton: Python interface for any model (including Backbone)

- Keeps input data in order
  - Stores things only once, project-based
  - Can handle multiple input data sources: Excel, databases, binary files, etc.
- Calls data conversion tools and models
  - Possible to chain input data, tools and models
- Shows what scenarios have been run
- Can display and process results
- Fast and reliable creation of sensitivities with a spreadsheet program
  - Possible to use ’recipes’ where one can do Cartesian products or other set theory based scenario combinations
  - Sceleton will distribute the scenario tasks to available computation units (in future)

The Epiphron Tool

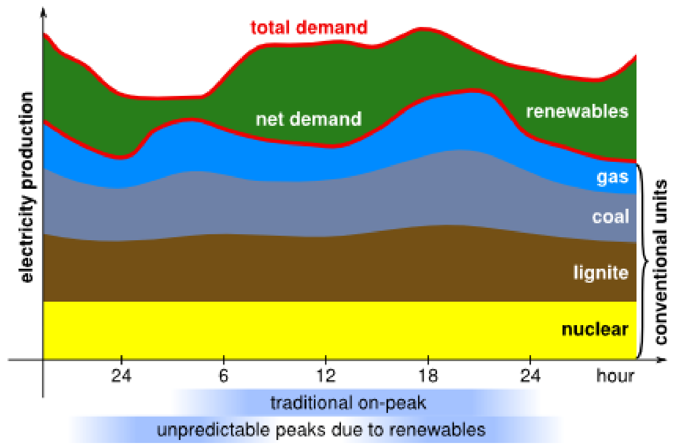
A useable, flexible, research focussed state of the art unit commitment model

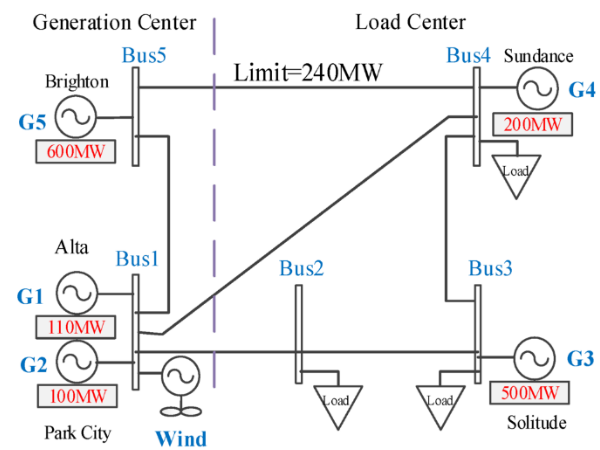
Joseph Dillon

ESIPP Energy Systems Integration Partnership Programme

What is the Epiphron Tool?

- A flexible unit commitment/economic dispatch optimization model with rolling planning and stochastic capabilities
- Simulates and optimizes time sequential operation of generating resources to meet demand forecasts
- Produces estimates of
  - total system production costs including fuel, consumption, unit start up costs and more
  - emissions production and abatelement
  - energy prices
  - unit energy and reserve schedules
  - renewable production and curtailment
  - network load flows and congestion
  - new generation investments
  - Capacity value of new technologies





Defining features

- State of the art implementation (tight MIP formulation)
- Comprehensive features
  - DC Load flow and security constrained unit commitment
  - Maintenance and forced outage simulation
  - Two-stage rolling planning
  - Stochastic representation of uncertainty
  - Stochastic scenario generation
- User interface to create and manage model elements
- Unrestricted access “under the hood” for customisation, expansion and for advanced users
- Designed from the ground up to be used in a research environment
  - Intuitive objected oriented data driven model structure
  - Low effort expandability via data rather than code
  - Arbitrary user defined linear constraints via data model
- Library of available models actively maintained
- Implemented in GAMs with MS Access front end