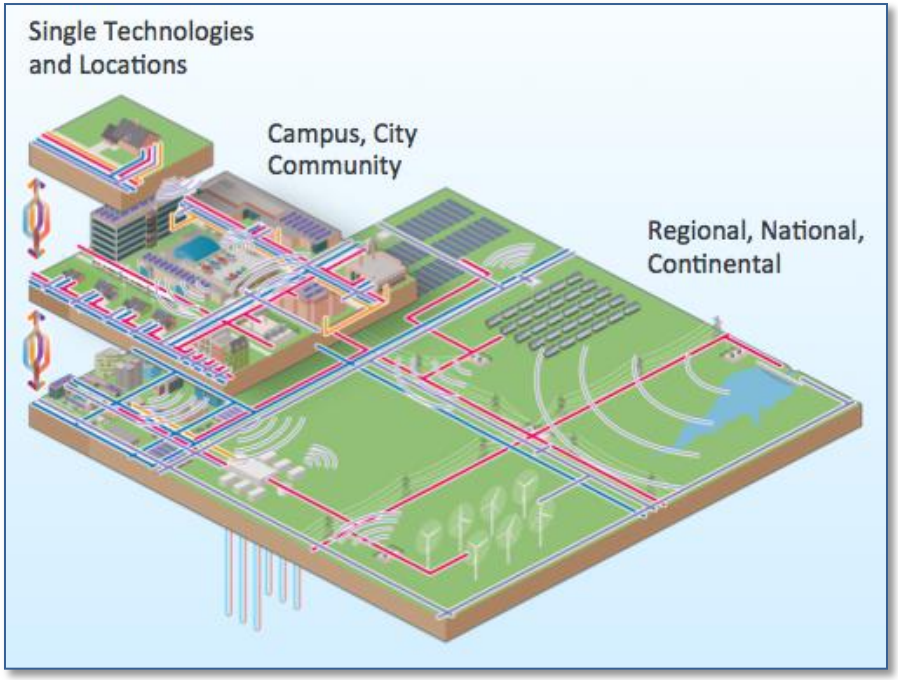
Introduction to Energy Systems Integration (ESI) and Overview of ESI 101

Mark O'Malley

mark.omalley@ucd.ie

21st July 2014

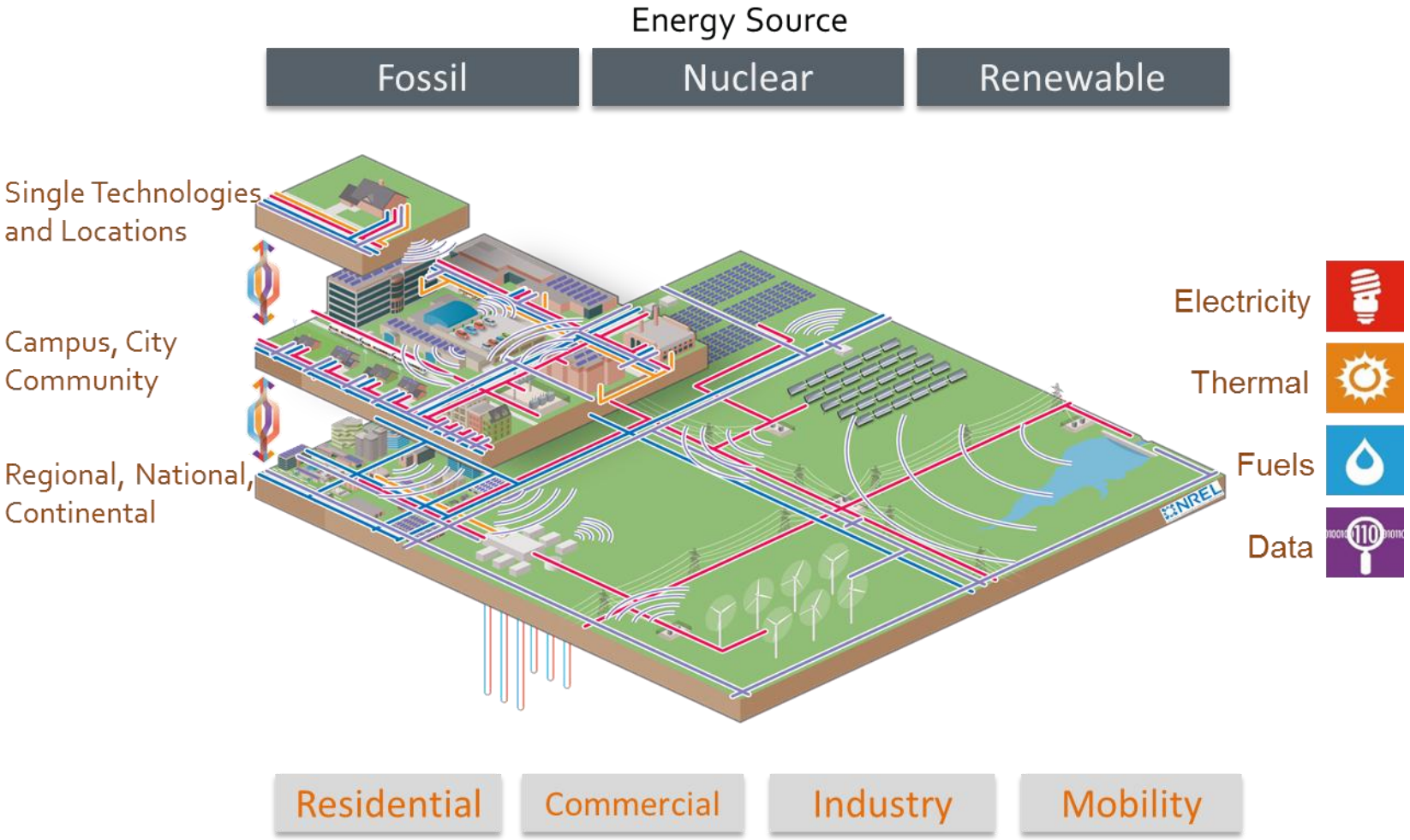


ESI International Institute™ for Energy Systems Integration

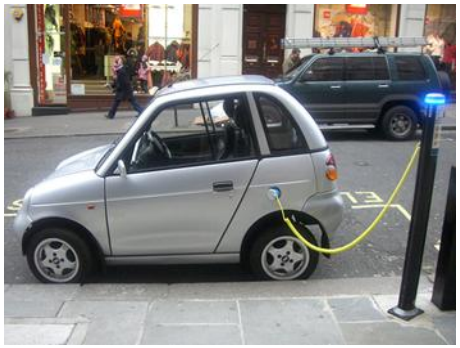
Introduction to ESI

What is Energy Systems Integration?

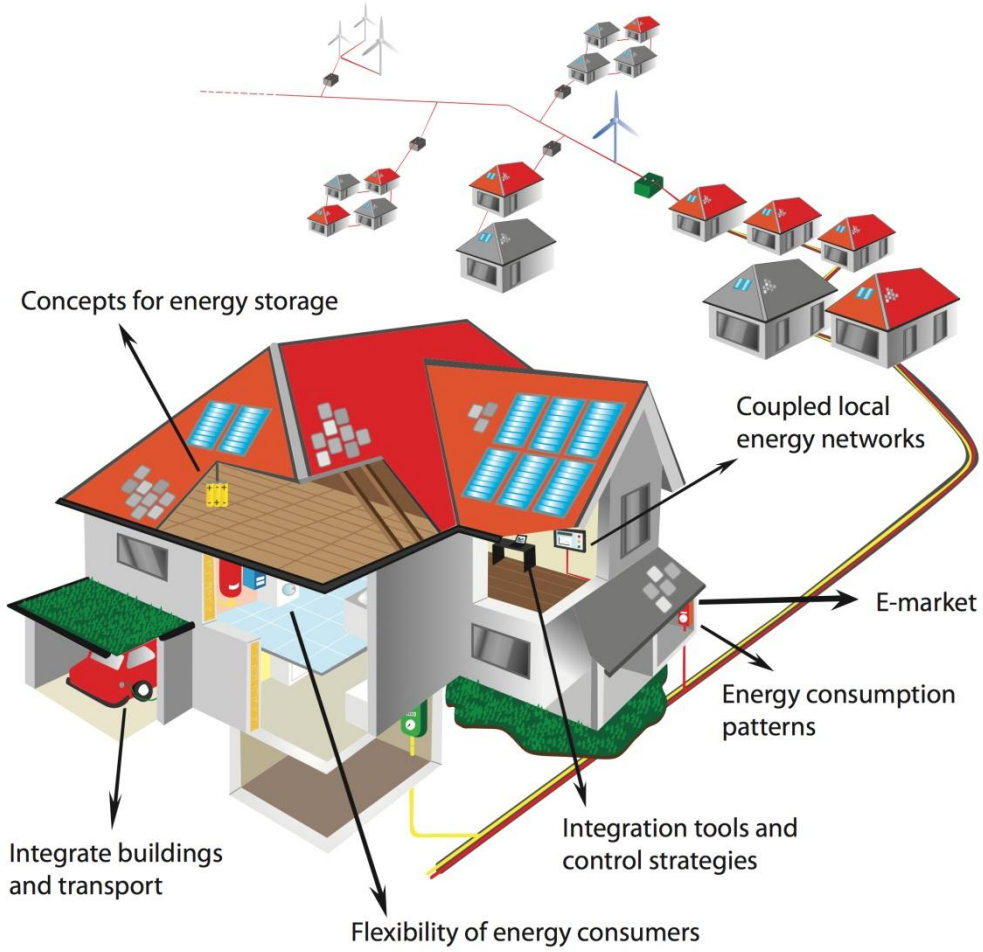
Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways, scales and time horizons



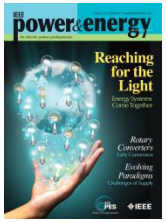
Wider Convergence



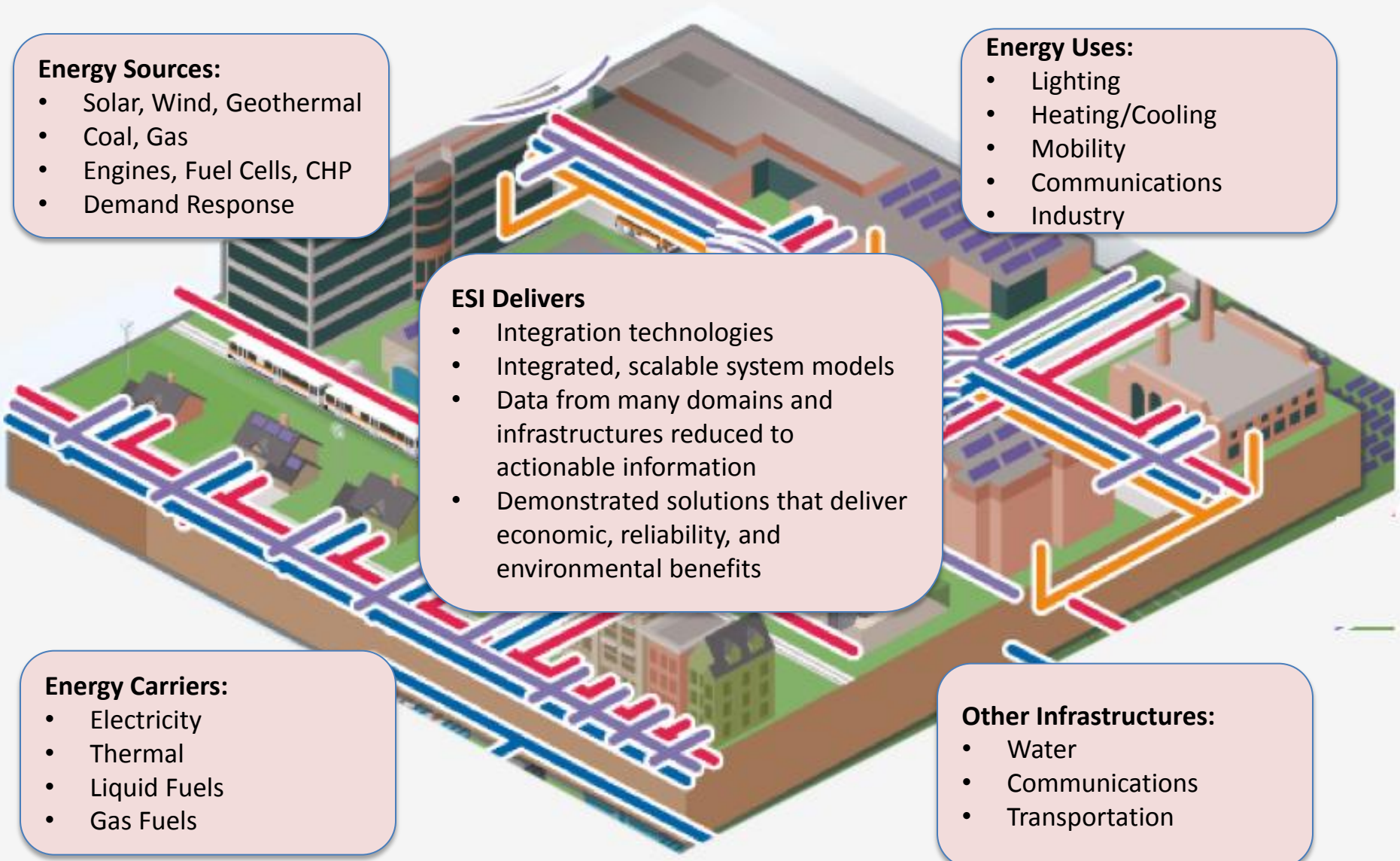
Smart Homes



Van Roy, J.; Verbruggen, B.; Driesen, J., "Ideas for Tomorrow: New Tools for Integrated Building and District Modeling," *Power and Energy Magazine, IEEE* , vol.11, no.5, pp.75,81, Sept. 2013. doi: 10.1109/MPE.2013.2268815



The Smart City



Energy Sources:
- Solar, Wind, Geothermal
- Coal, Gas
- Engines, Fuel Cells, CHP
- Demand Response

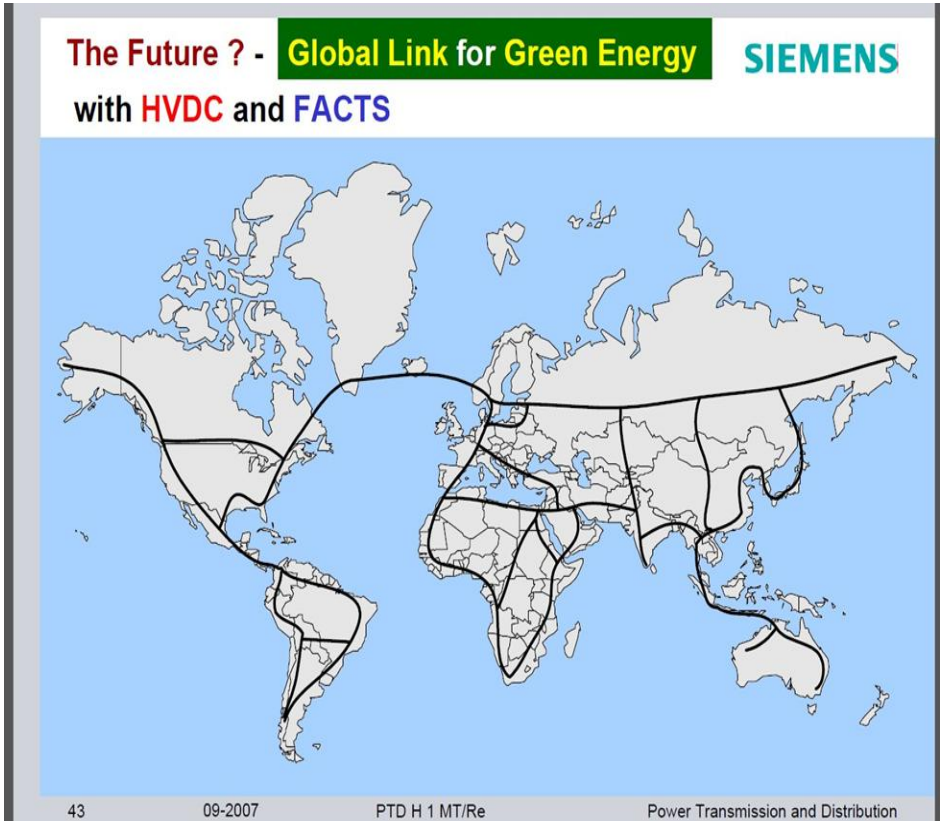
Energy Uses:
- Lighting
- Heating/Cooling
- Mobility
- Communications
- Industry

ESI Delivers
- Integration technologies
- Integrated, scalable system models
- Data from many domains and infrastructures reduced to actionable information
- Demonstrated solutions that deliver economic, reliability, and environmental benefits

Energy Carriers:
- Electricity
- Thermal
- Liquid Fuels
- Gas Fuels

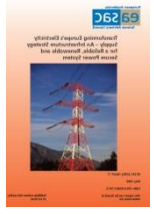
Other Infrastructures:
- Water
- Communications
- Transportation

Continental scale integration



Matthias, C. et al. Security and Sustainability of Power Supply – Benefits of HVDC & FACTS for System Interconnection and Power Transmission Enhancement
http://www.ptd.siemens.de/Presentation_Security%20&%20Sustainability_PowerGrid_08-06_V%201.pdf

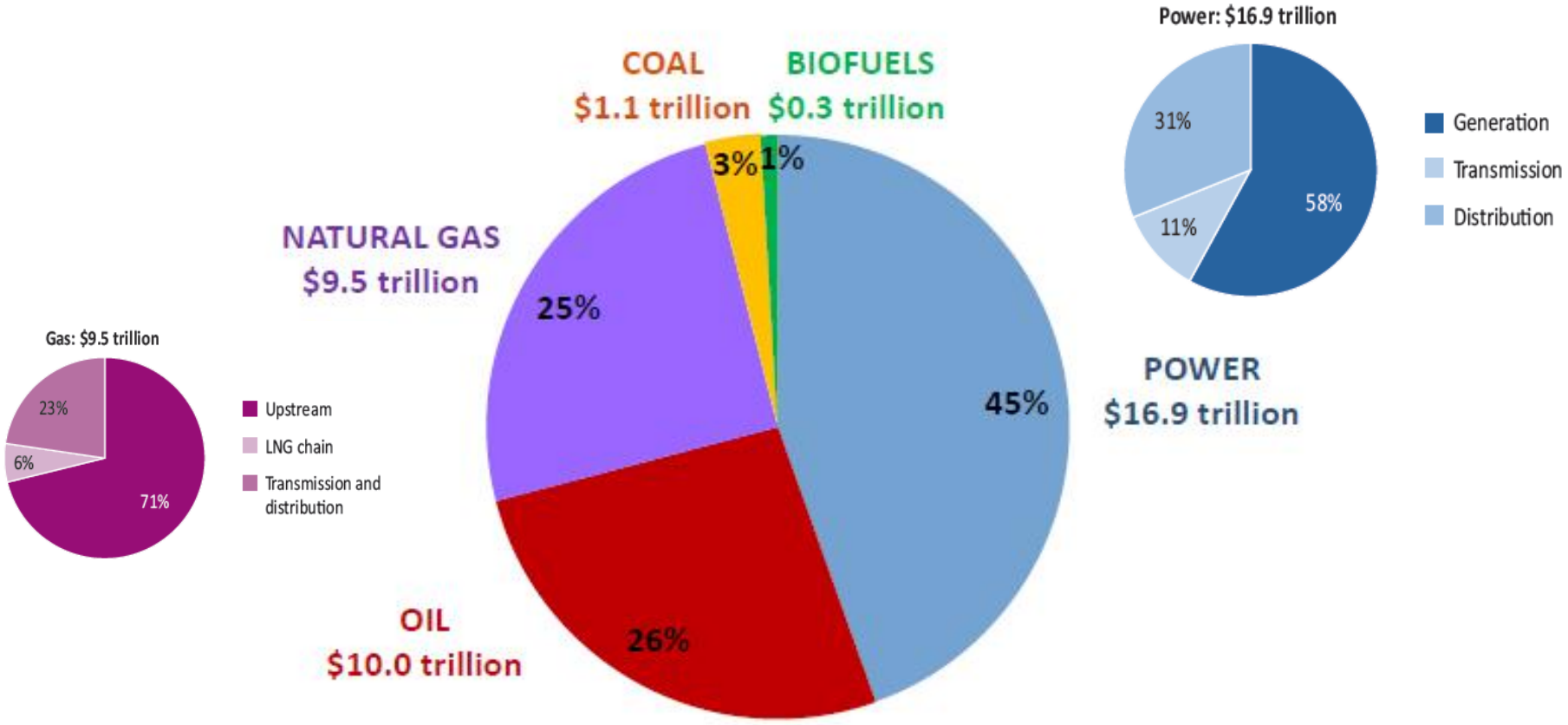
EASAC, "Transforming Europe's Electricity Supply – An Infrastructure Strategy for a Reliable, Renewable and Secure Power System" European Academy of Sciences Advisory Council, May 2009. http://www.easac.org/document.asp?id=96&pageno=&detail=5&parent



Investment: the essence of energy

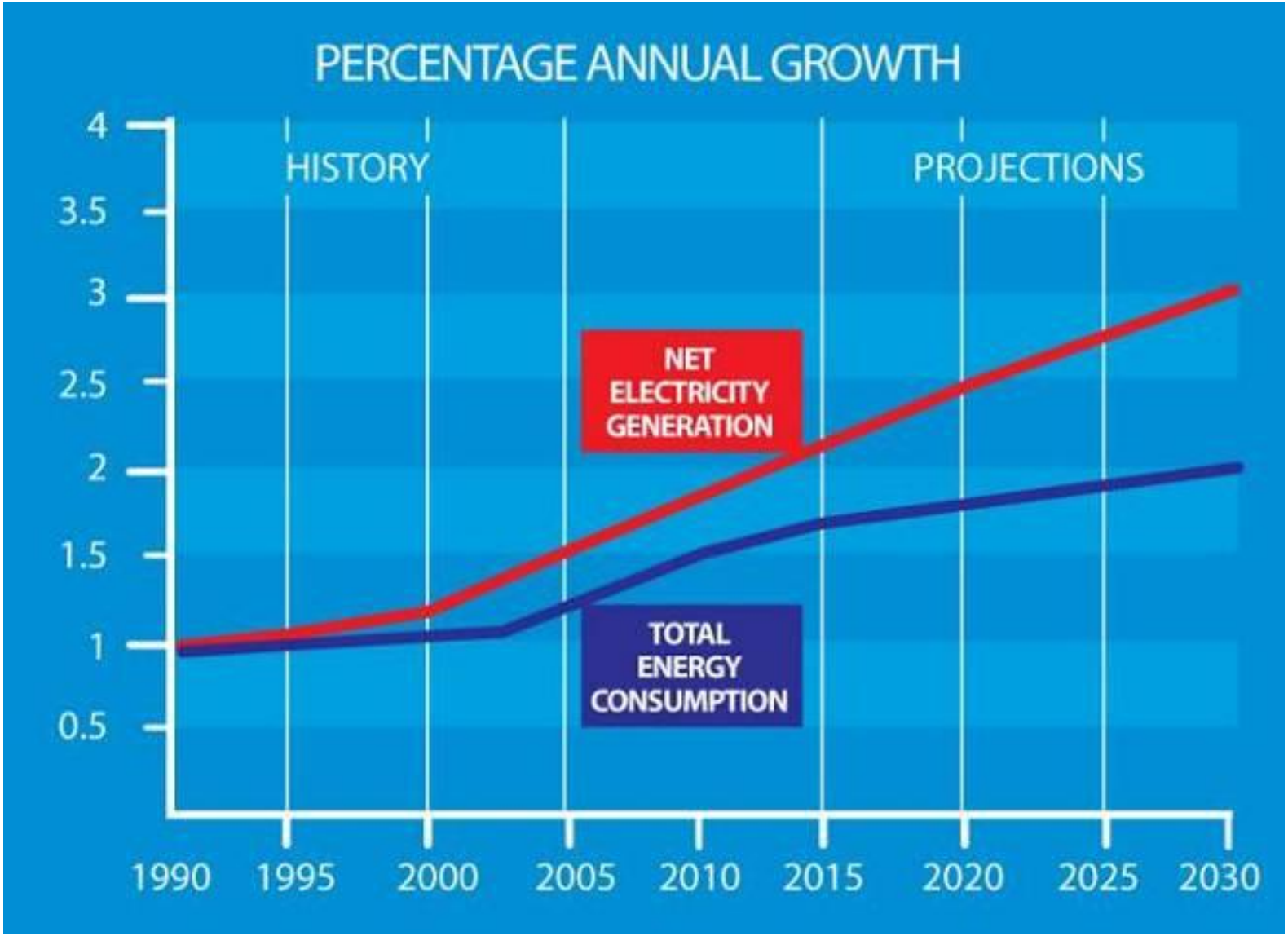
WORLD ENERGY OUTLOOK 2011

Cumulative investment in energy infrastructure, *2011-2035*



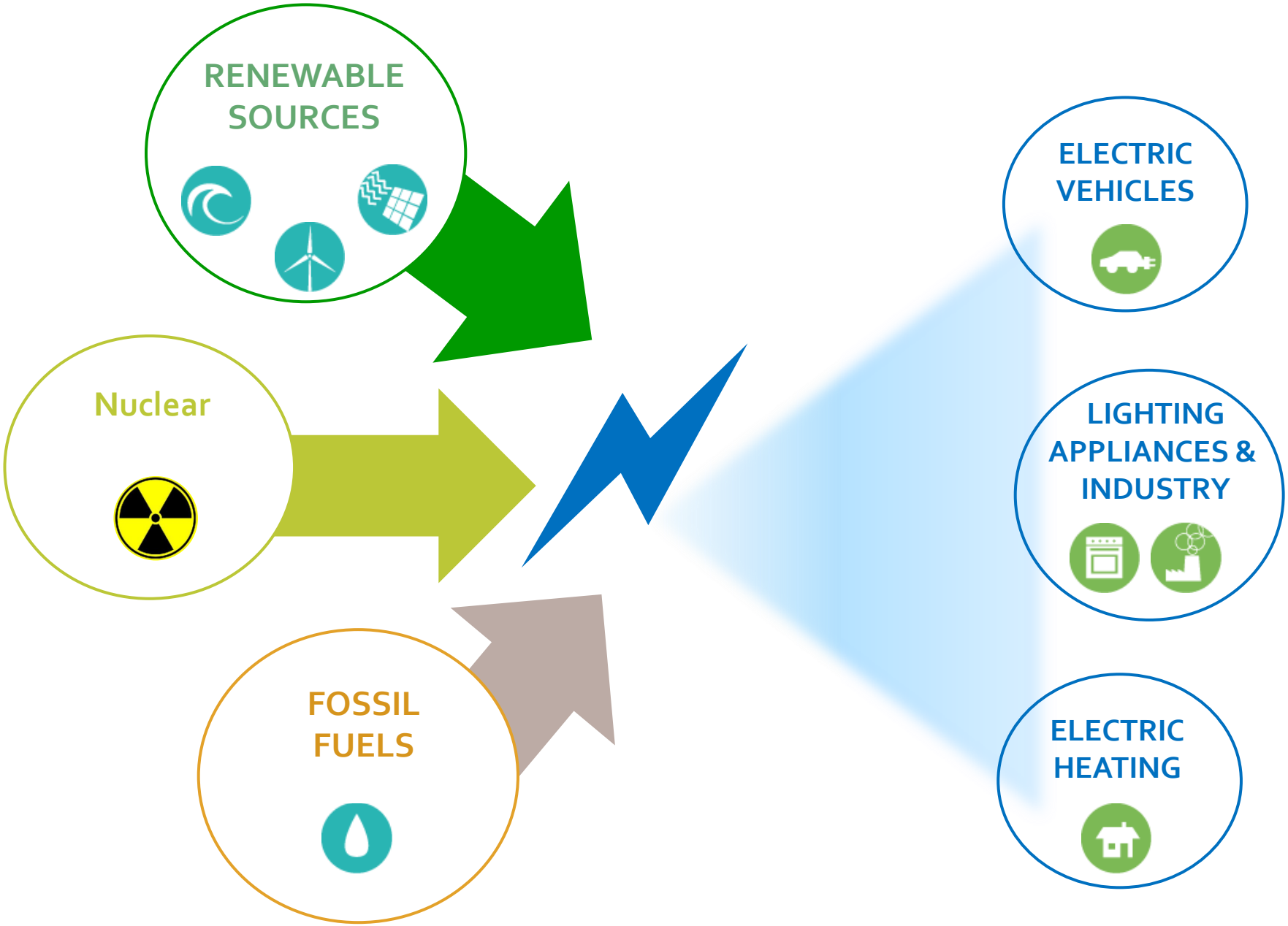
WEO-2011 will show that <u>$38 trillion</u> of investment is required to meet projected energy demand through to 2035 and that investors in energy projects are facing a multitude of risks

The Future is Electric



Source: Energy Information Administration (EIA), 2008.

The Electric Future



ESI across all time domains




Planning

Operations

Unit Commitment (on/off)

Economic Dispatch

(power level)

Real Time

Years

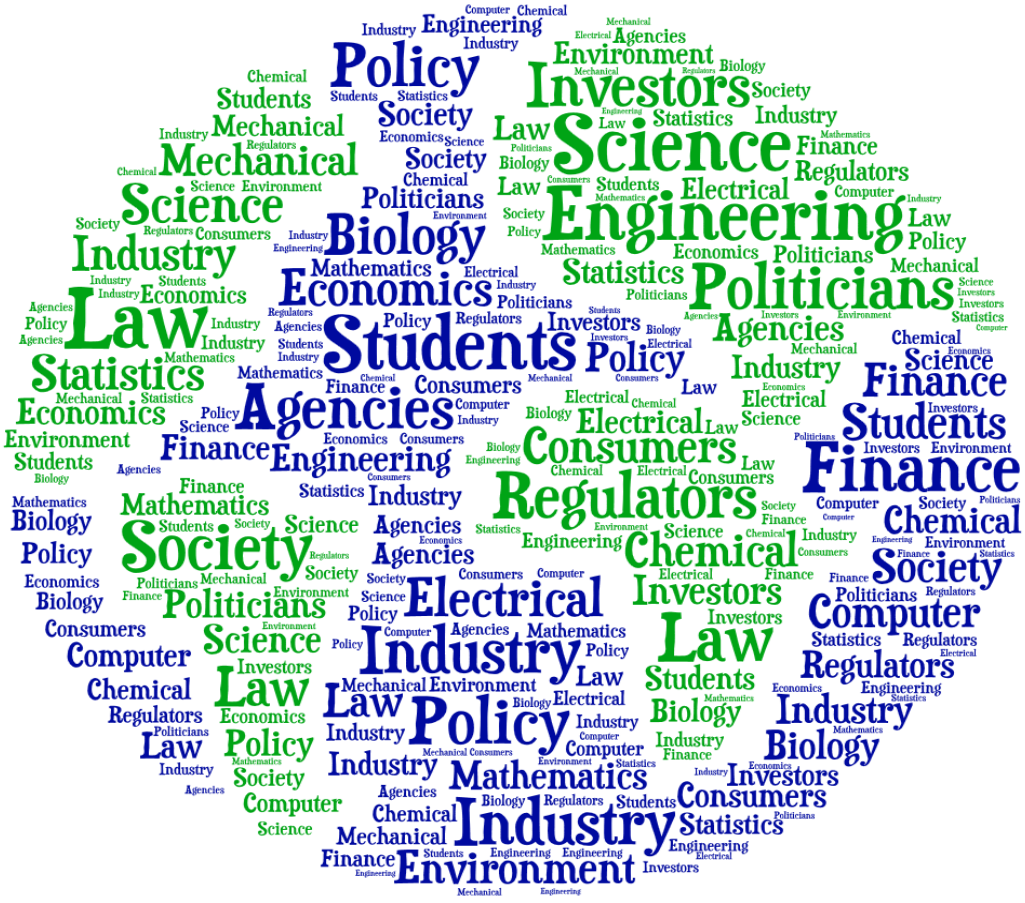
Weeks - Hours

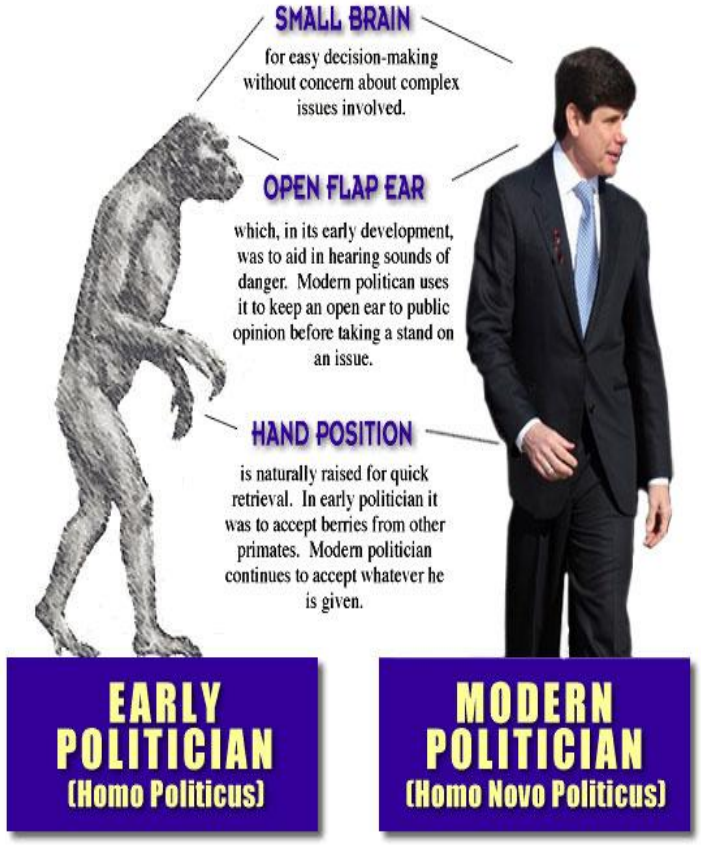
Minutes

Time



Energy Systems Stakeholders

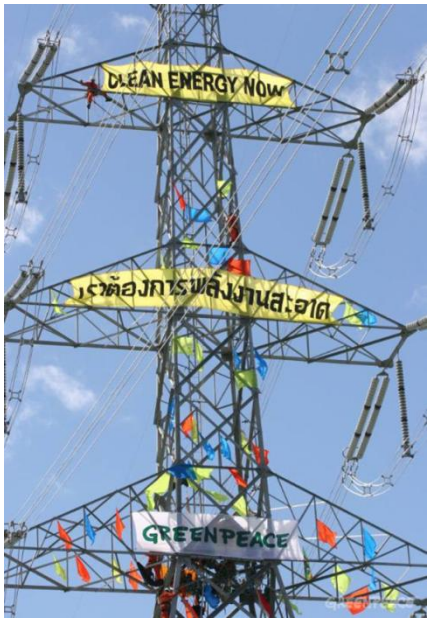


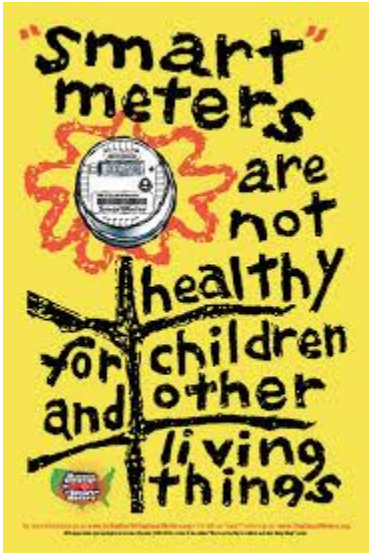


The consumer

"Engineers (and economists) tend to be ignorant and arrogant about customers"

Source: Janusz Bialek, Durham University





ESI built on fundamental laws across may disciplines

Maxwell

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

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

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

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

Daniel Bernoulli

$$\frac{v^2}{2} + gz + \frac{p}{\rho} = \text{constant}$$

Where...

v = fluid flow speed @ a point on a streamline

g = acceleration due to gravity

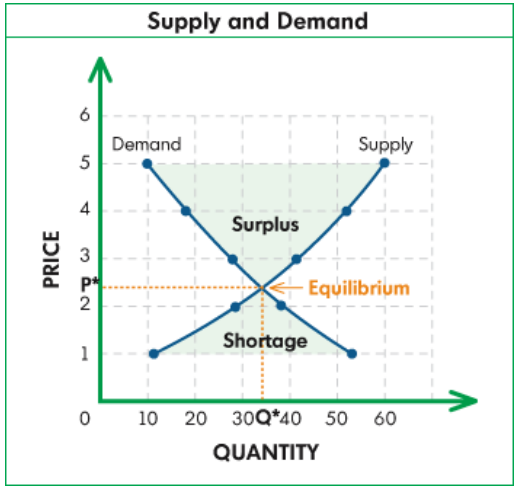
z = height of point

p = pressure at point

ρ = density of fluid

Laws of Thermodynamics

Zeroth: *"You must play the game."*
First: *"You can't win."*
Second: *"You can't break even."*
Third: *"You can't quit the game."*

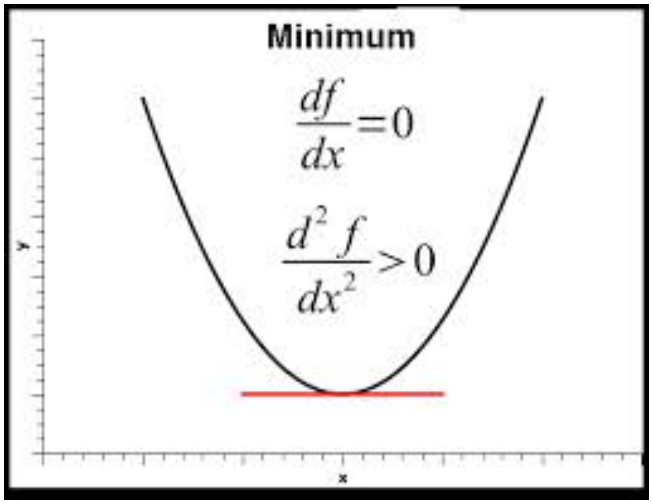


Control

Modelling

Forecasting

Optimisation



ESI is becoming more important globally

European Commission

ESI is central to the forthcoming SET Plan Integrated Roadmap

EERA
European Energy Research Alliance

EERA JP ESI Formal application in process

iiESI International Institute for Energy Systems Integration

Addressing energy challenges through global collaboration www.iiESI.org

Vision: A global community of scholars and practitioners from leading institutes engaged in efforts to enable highly integrated, flexible, clean, and efficient energy systems
Objectives: Share ESI knowledge and Experience: Coordination of R&D activities: Education and Training Resources

Activities 2014

- Feb 18-19 Workshop (Washington)
- May 28-29 Workshop (Copenhagen)
- **July 21 – 25, ESI 101 (Denver)**
- Nov 17th Workshop (Kyoto)

Activities 2015

- Dublin, Hawaii, Brussels, Australia

NREL NATIONAL RENEWABLE ENERGY LABORATORY
Pacific Northwest NATIONAL LABORATORY
EPRI ELECTRIC POWER RESEARCH INSTITUTE
UCD DUBLIN
DTU
KU LEUVEN

ESI Summary

- Energy system integration (ESI) = the process of optimizing energy systems across multiple **pathways, scales and time** horizons
  - lot of money involved
  - dominated by electricity
  - multitude of stakeholders
  - multidisciplinary
  - global issue

Schedule

Mon 21/07/2014		
09:00 - 10:00	Introduction to ESI and Overview of ESI 101	Mark O'Malley
10:00 –11:00	Benefits of ESI	Ben Kroposki
11:00 - 11:30	Coffee	
11:30 - 12:30	Forecasting of Load, Heat, Wind and Solar	Henrik Madsen
12:30-1:30	Lunch	
1:30-5:00	Project Work	

Tues 22/07/2014		
09:00 - 10:00	Energy Infrastructure Expansion Planning	Jim McCalley
10:00 –11:00	Energy-Water Nexus	Pete Thomson
11:00 - 11:30	Coffee	
11:30 - 12:30	Gas – Electricity Nexus	Jim McCalley
12:30-1:30	Lunch	
1:30-2:30	Tour of ESIF	Ben Kroposki
2:30-5:00	Project Work	

Wed 23/07/2014		
09:00 - 11:00	Distributed Energy Systems, DER, CHP and Microgrids	Bob Lasseter
11:00 - 11:30	Coffee	
11:30 - 12:30	Energy – Transport Nexus	Jim McCalley
12:30-1:30	Lunch	
1:30 - 2:30	Regulatory Issues and Business Models In ESI	Jaqueline Cochran
2:30-5:00	Project Work	
5:00-10:00	Social Trip to Mount Evans	

Thurs 24/07/2014		
09:00 – 10:30	Greybox Modeling	Henrik Madsen
10:30 - 11:00	Introduction to Greybox Modeling Exercise	Niamh O'Connell
11:00 - 11:30	Coffee	
11:30 - 12:30	Introduction to Variable Renewables into Electricity Grids	Mark O'Malley
12:30-1:30	Lunch	
1:30-5:00	Grey Box Modeling Exercise	

Fri 25/07/2014		
09:00 – 10:00	Statistical Modeling for ESI	Chris Dent
10:00 - 11:00	Project Report Out	
11:00 - 11:30	Coffee	
10:00 - 11:00	Project Report Out	
12:30-1:30	Lunch	
1:30 - 2:30	Project Report Out	
2:30 – 2:45	Wrap Up	Mark O'Malley


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

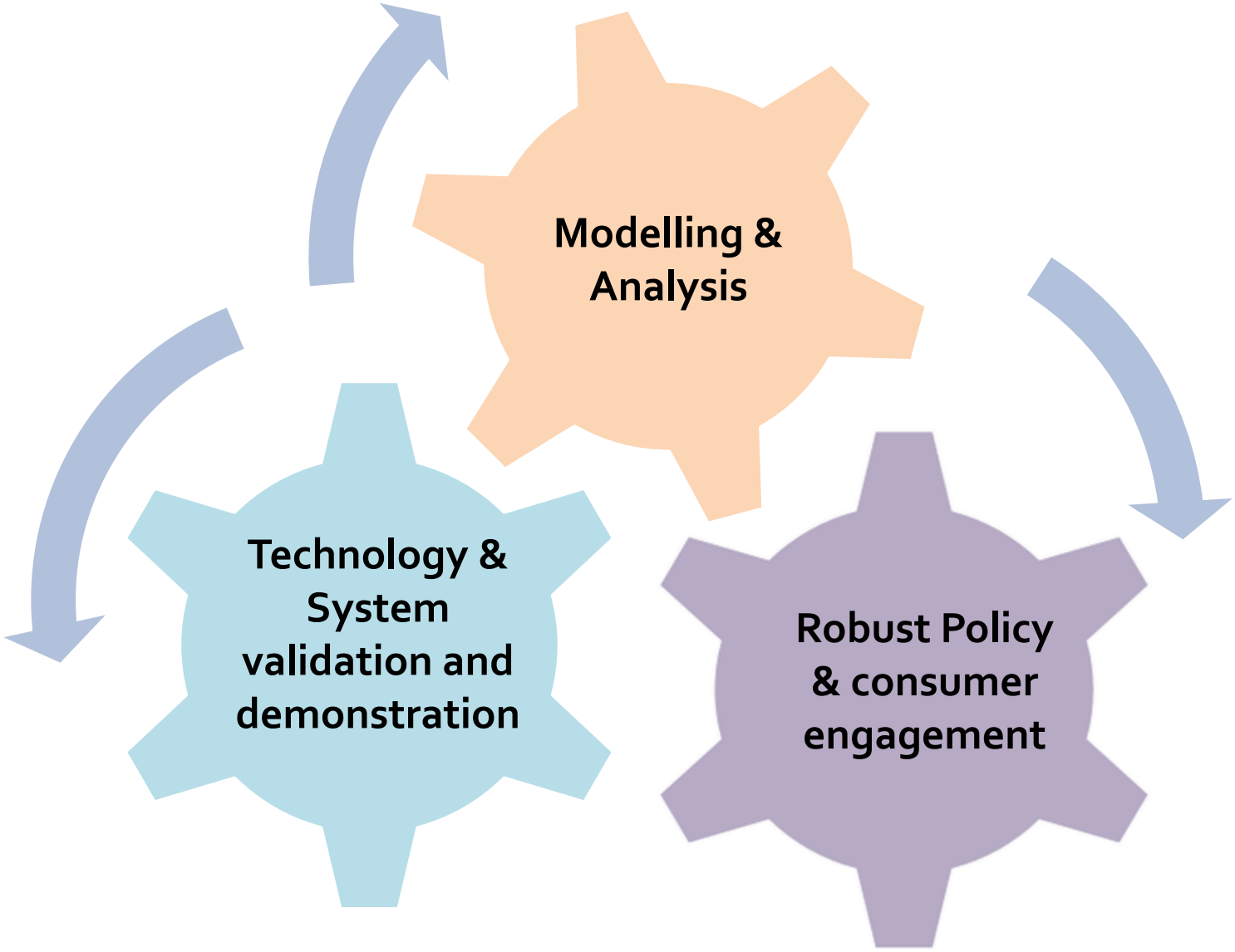

KEEP
CALM
I'M NOT AN
EXPERT


RESEARCH
A+B = C
2
2
Dave Simonds

Ben Kroposki, NREL

Benefits of ESI

ESI research areas working together to deliver solutions




Uncertain
CITY LIMIT
POP.150

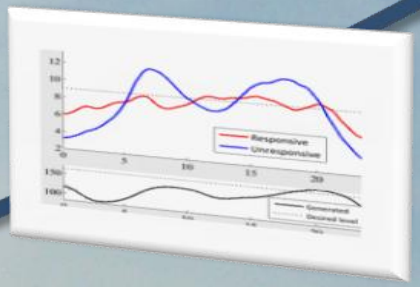
Henrik Madsen, DTU

Forecasting of Load, Heat, Wind and Solar

100% Renewables

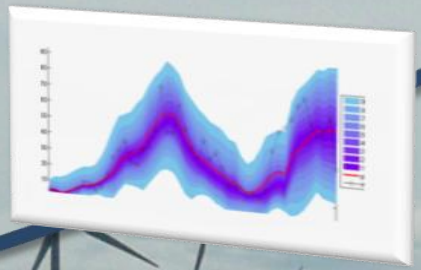
Multiple supply strings

Dynamic tariffs



Biomass

Tax rules reflecting market price



Intelligent consumption

Demand response management

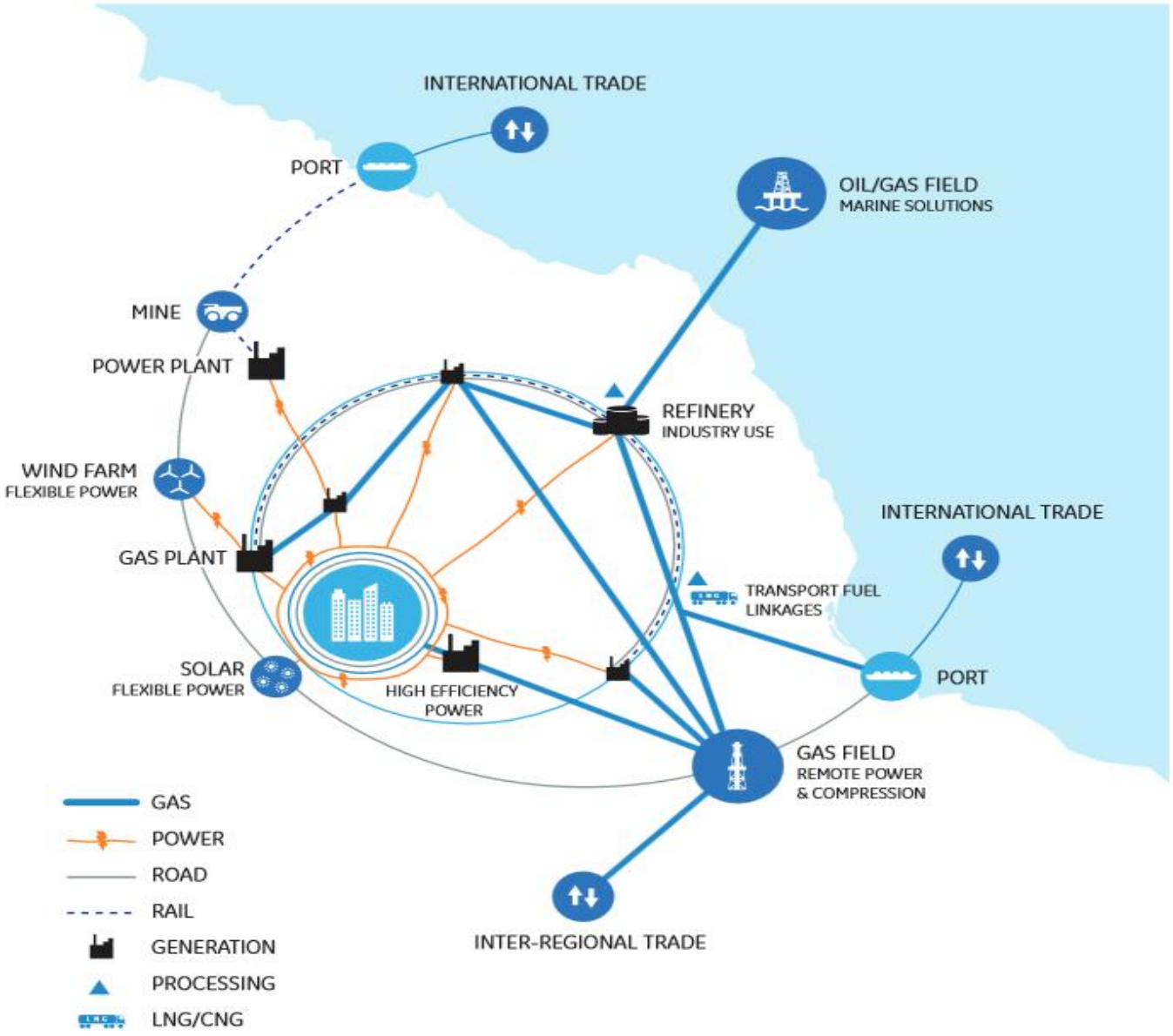
Forecasting of Wind and Solar Power

Jim McCalley, Iowa State University

Infrastructure Expansion Planning

Figure 12. Multi-Network Integration: Gas, Power, Road and Rail

Source: GE Global Strategy and Analytics, 2013



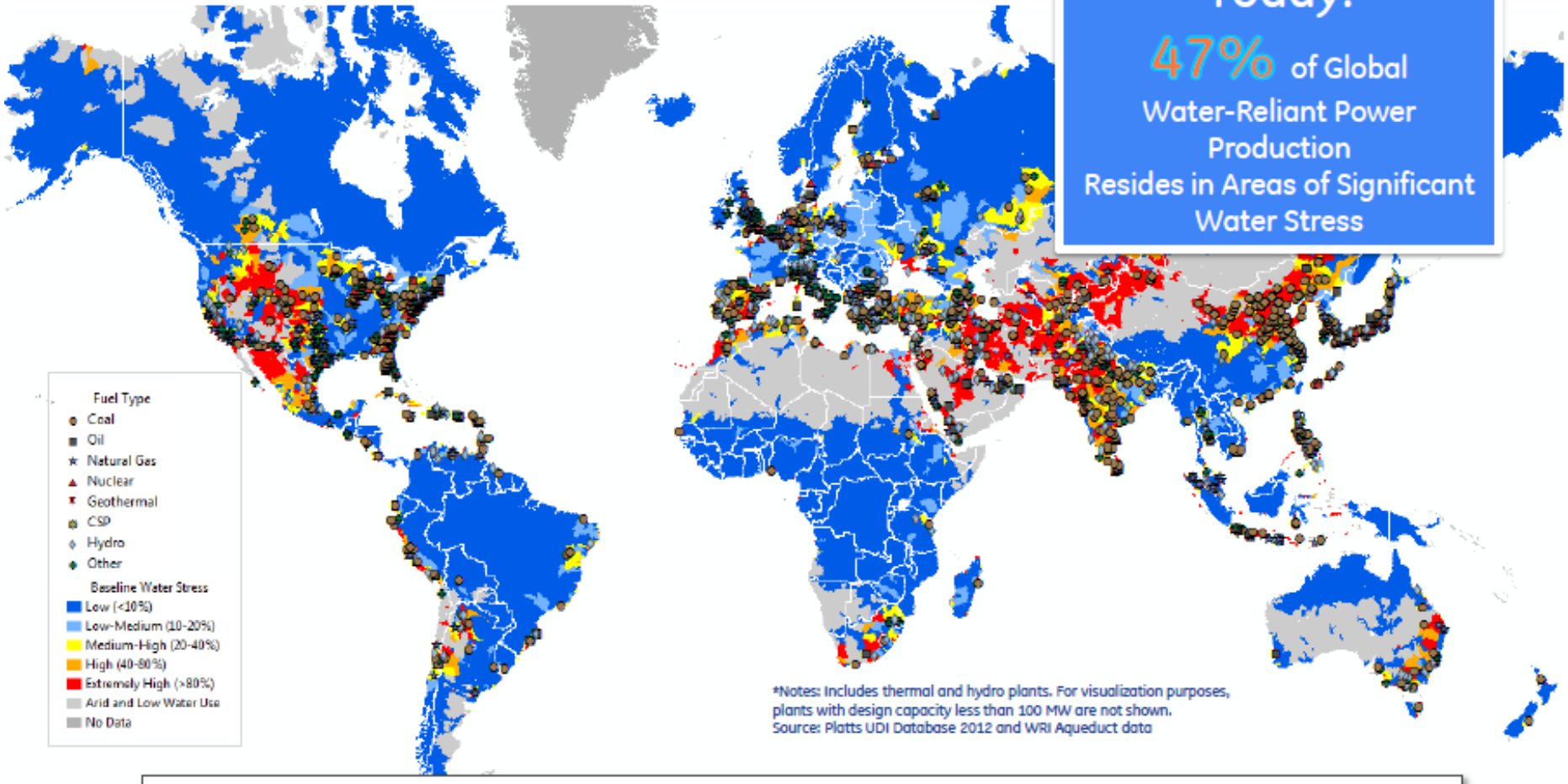
http://www.ge.com/sites/default/files/GE_Age_of_Gas_Whitepaper_20131014v2.pdf

Pete Thompson, Black and Veatch

The Energy – Water Nexus

Global generation units with water stress*

Medium to extremely-high stress



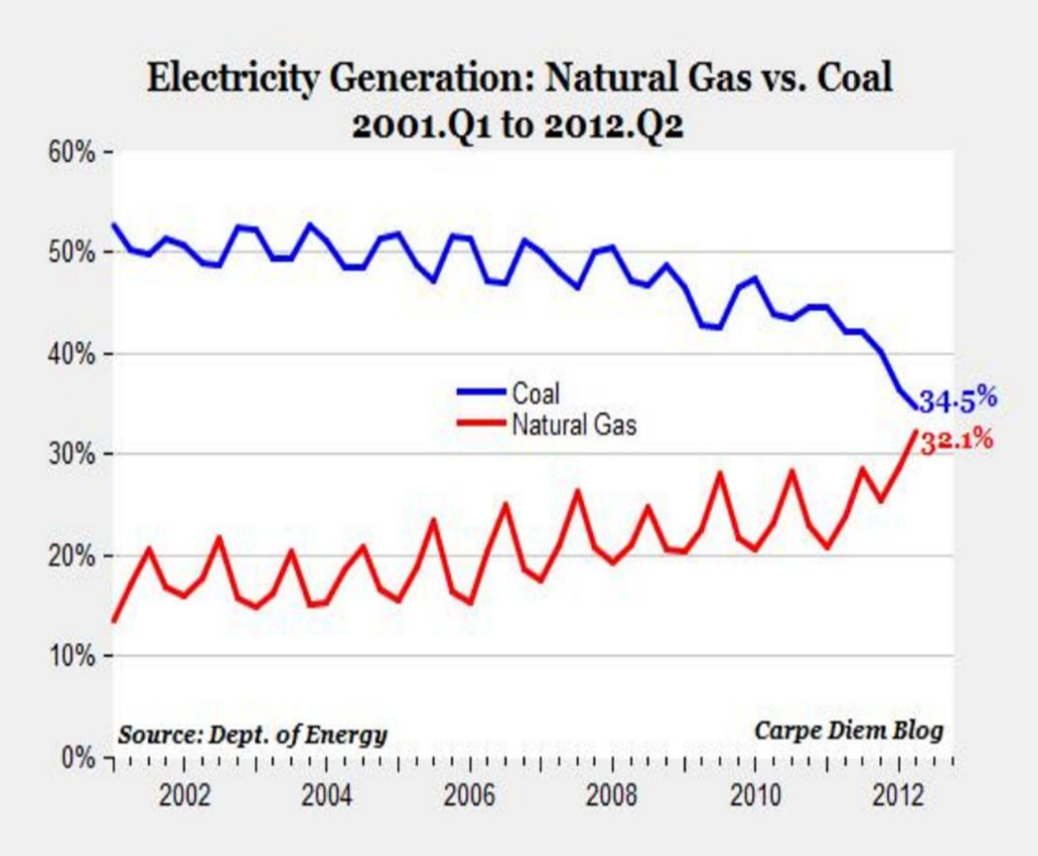
Over 26,000 units are in areas of medium to extremely-high water stress

Used with Permission

Jim McCalley, Iowa State University

The Gas – Electricity Nexus

Gas/Electricity the Global Situation



"This issue of gas-electric interdependence is not a reason to panic, but it's absolutely a reason to plan, and to do so now"

Cheryl A. LaFleur the acting chairman of the Federal Energy Regulatory Commission

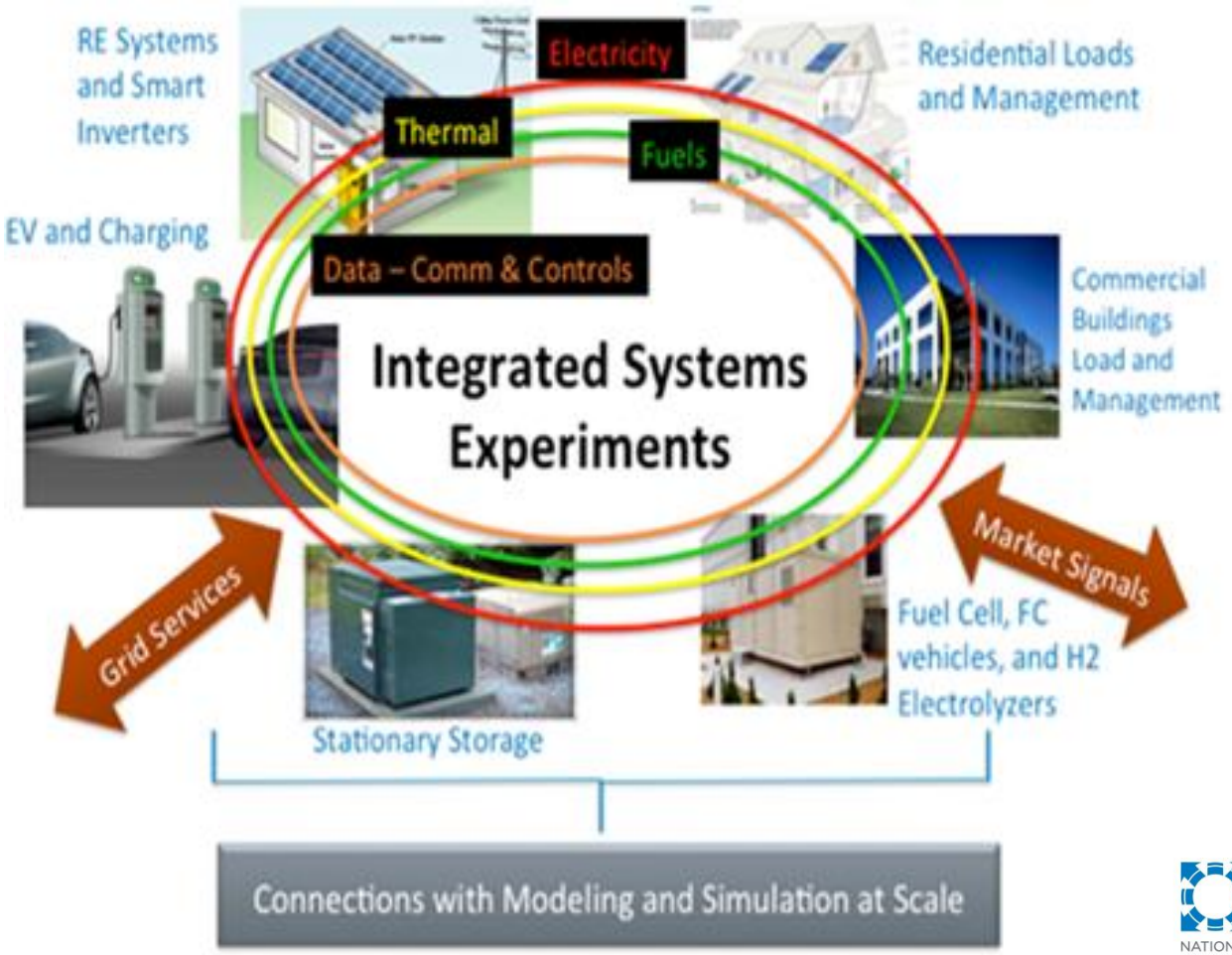
July 15, 2013, 11:49 a.m. ET

E.ON to Mothball Slovak Gas Power Plant Malzenice from October

Tour of ESIF

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

We need to move beyond paper studies and demonstrate solutions at scale



NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Energy Hubs

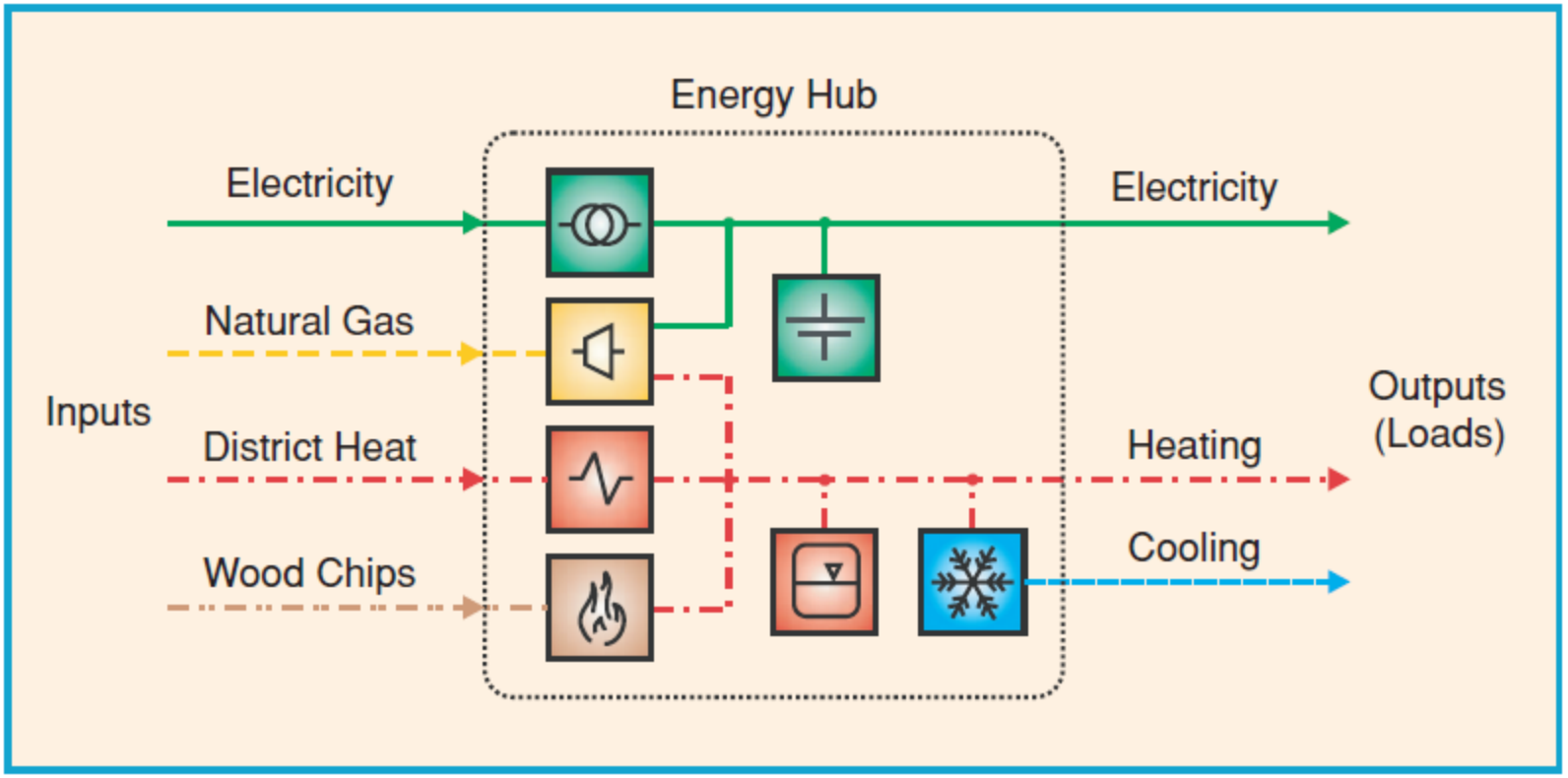


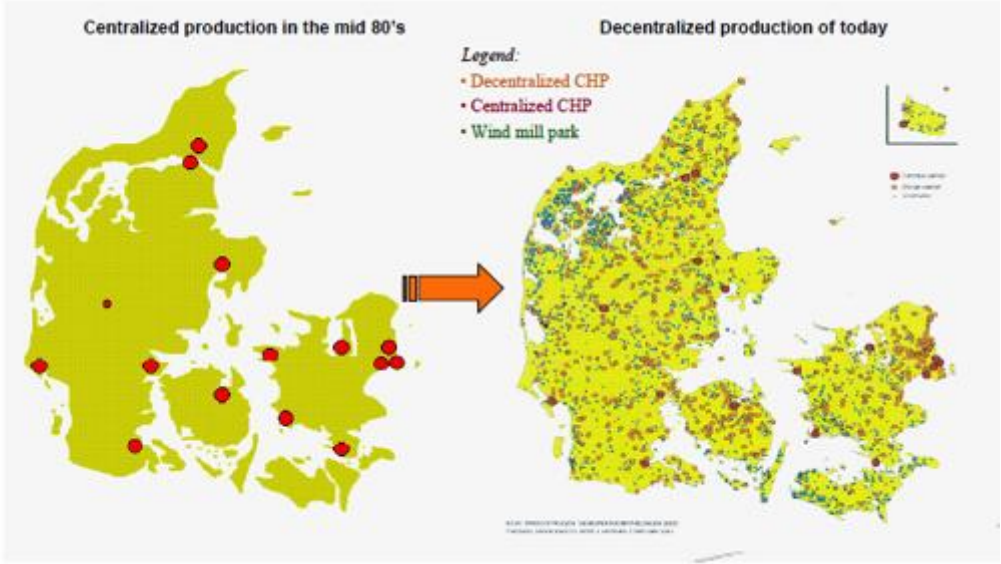
figure 2. Example of an energy hub that contains a transformer, a microturbine, a heat exchanger, a furnace, an absorption chiller, a battery, and a hot water storage.

Geidl, Martin; Koeppel, G.; Favre-Perrod, P.; Klockl, B.; Andersson, G.; Frohlich, K., "Energy hubs for the future," *Power and Energy Magazine, IEEE* , vol.5, no.1, pp.24,30, Jan.-Feb. 2007. doi: 10.1109/MPAE.2007.264850

Bob Lasseter, University of Wisconsin

Distributed Energy Systems, DER, CHP and Microgrids

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

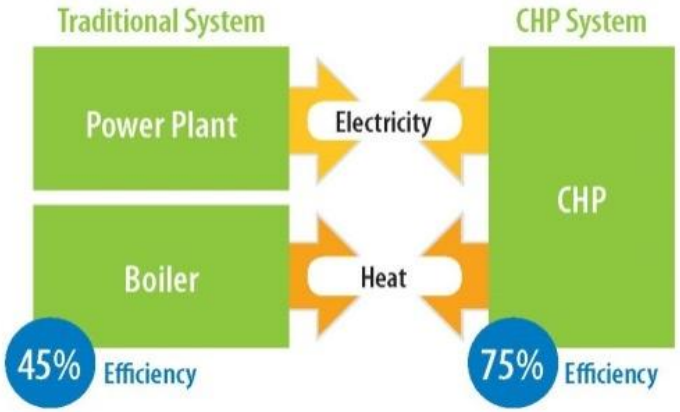
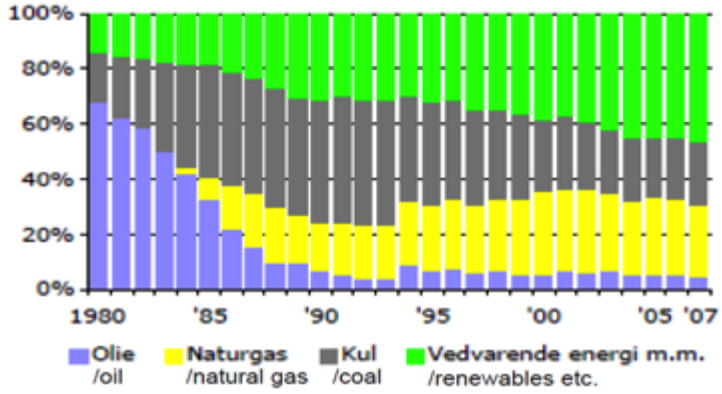


Figure 3: Fuel consumption for district heating production, percentage distribution

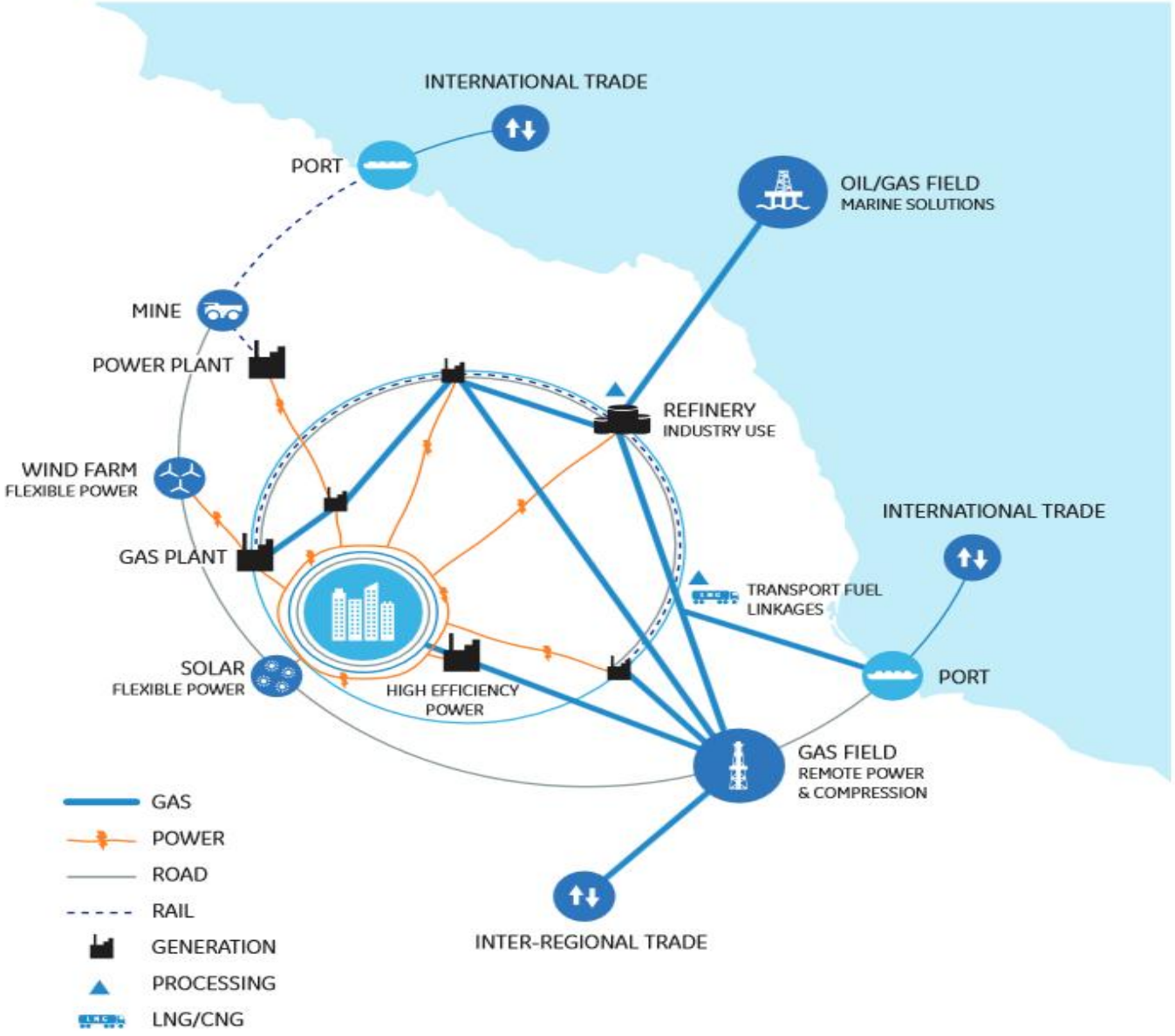


Jim McCalley, Iowa State University

The Energy – Transport Nexus

Figure 12. Multi-Network Integration: Gas, Power, Road and Rail

Source: GE Global Strategy and Analytics, 2013



http://www.ge.com/sites/default/files/GE_Age_of_Gas_Whitepaper_20131014v2.pdf

Jaqueline Cochran, NREL

Regulatory Issues and Business Models in ESI

Policy failures because they are not holistic

Bloomberg Our Company | Professional | Anywhere

HOME QUICK NEWS OPINION MARKET DATA PERSONAL FINANCE TECH POLITICS SUS

Windmills Overload East Europe's Grid Risking Blackout: Energy

By Ladka Bauerova and Tino Andresen - Oct 26, 2012 12:01 AM GMT

15 COMMENTS + QUEUE

Sean Gallup/Getty Images

Germany is dumping electricity on its unwilling neighbors and by wintertime the feud should come to a head.

Germany is dumping electricity on its unwilling neighbors and by wintertime the feud should come to a head.

Borggrefe, F. and Neuhoff K. "Balancing and Intraday Market Design: Options for Wind Integration" Deutsches Institut für Wirtschaftsforschung October 2011

RES-E-NEXT

Next Generation of RES-E Policy Instruments

4 July 2013

RETD

IEA - RENEWABLE ENERGY TECHNOLOGY DEPLOYMENT

M. Miller, L. Bird, J. Cochran, M. Milligan, M. Bazilian
National Renewable Energy Laboratory

E. Denny, J. Dillon, J. Bialek, M. O'Malley
Ecar Limited

K. Neuhoff
DIW Berlin

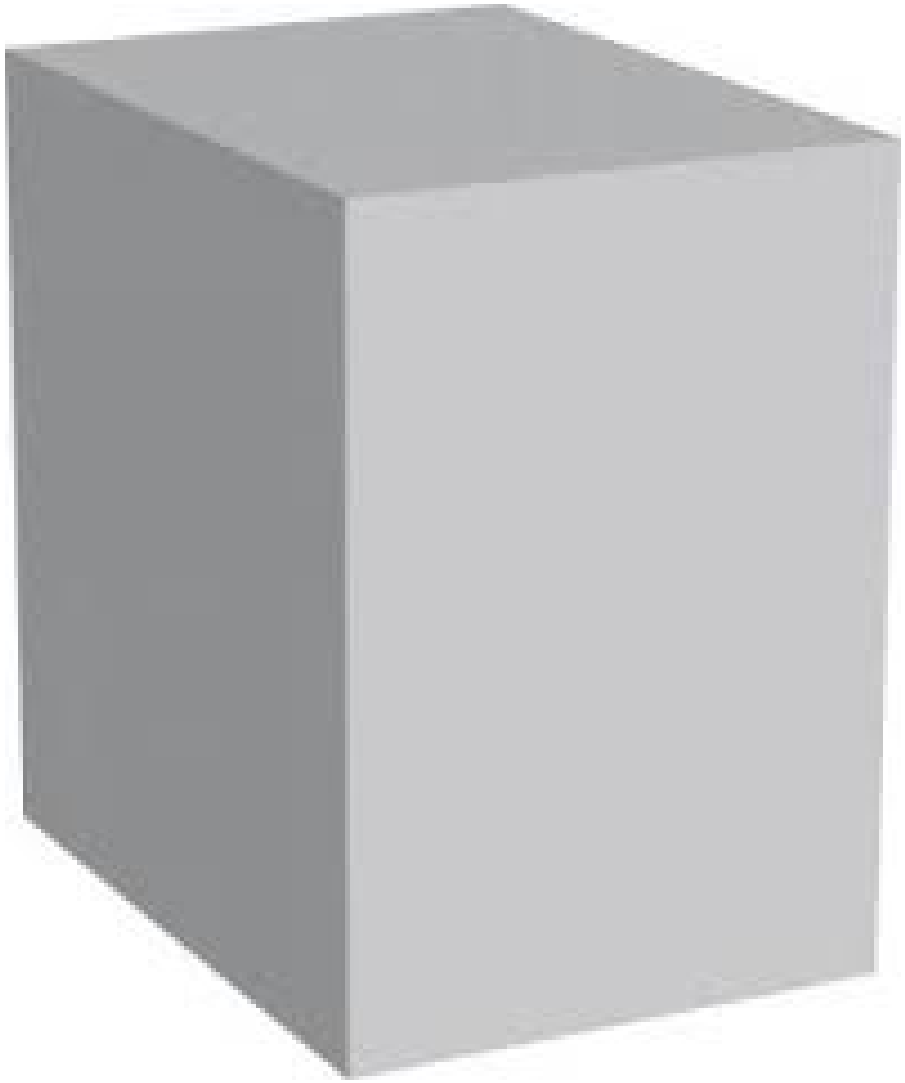
Study commissioned by IEA-RETD
www.iea-retd.org
iea_retd@ecofys.com

Mackay, M., Bird, L., Cochran, J., Milligan, M., Bazilian, M., Neuhoff, K., Denny, E., Dillon, J., Bialek, J. and O'Malley, M.J., "RES-E-NEXT, Next Generation of RES-E Policy Instruments", IEA RETD, July 2013. http://iea-retd.org/wp-content/uploads/2013/07/RES-E-NEXT_IEA-RETD_2013.pdf

Mount Evans

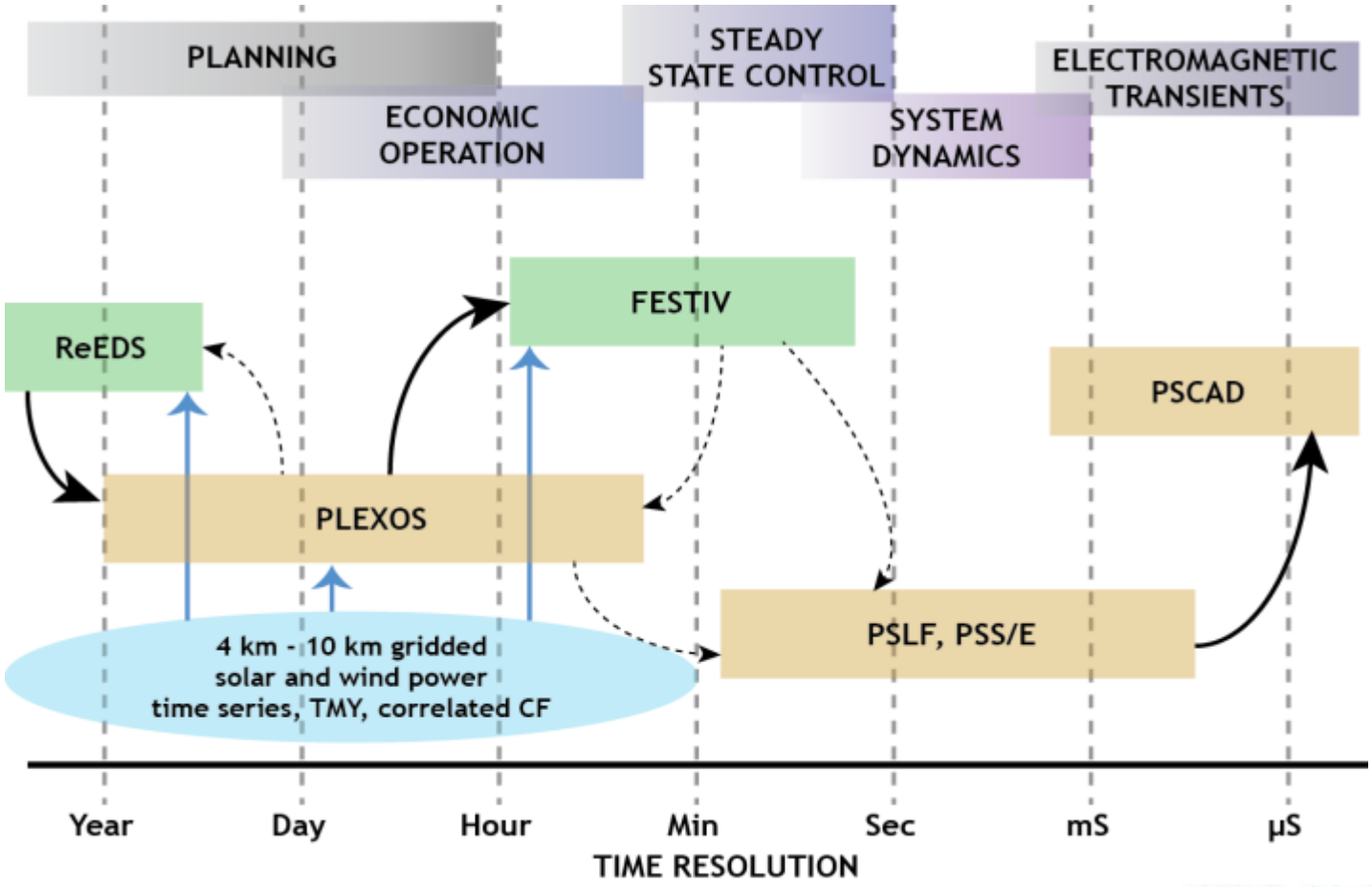
Henrik Madsen, DTU

Greybox Modelling



Models tend to be in one domain

Modeling and Simulation at Multiple Temporal Scales

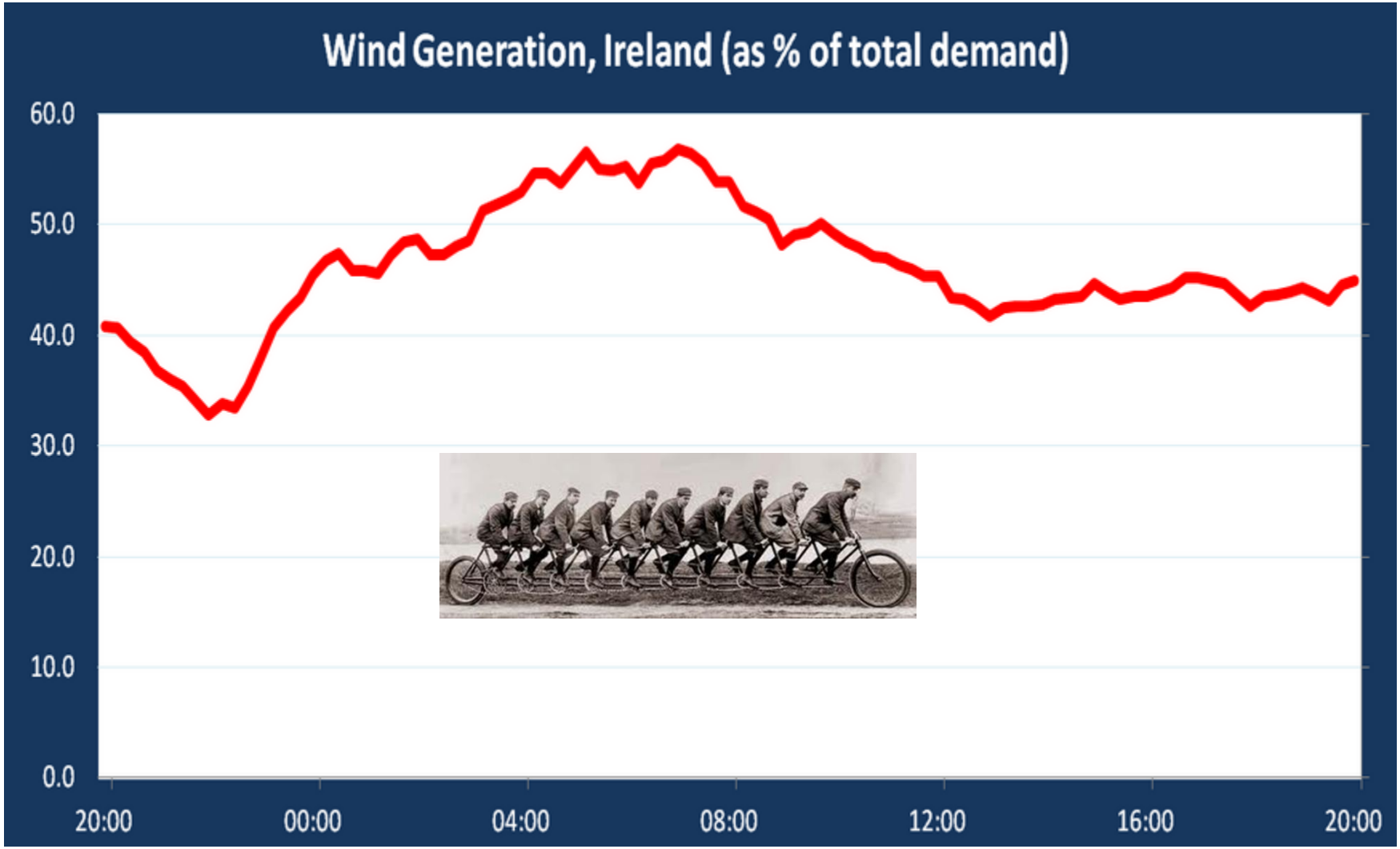


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Mark O’Malley, UCD

Integration of Variable Renewables into Electricity Grids

13/14 Avril 2013 – Record du monde pour un réseau électrique synchrone?



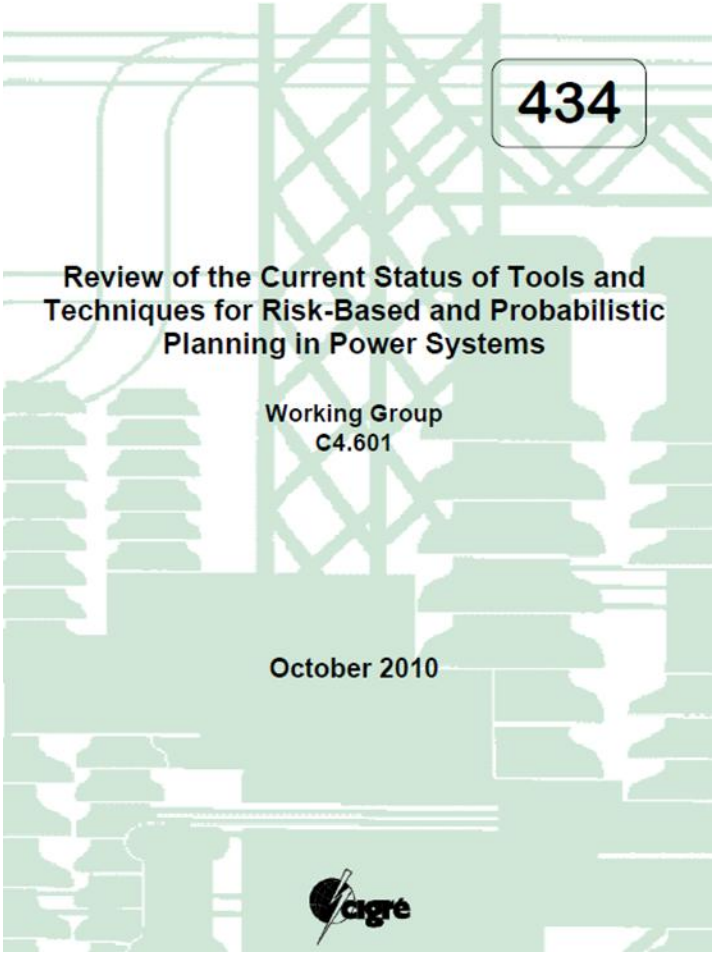
Niamh O’Connell, DTU

Grey Box Modelling Exercise

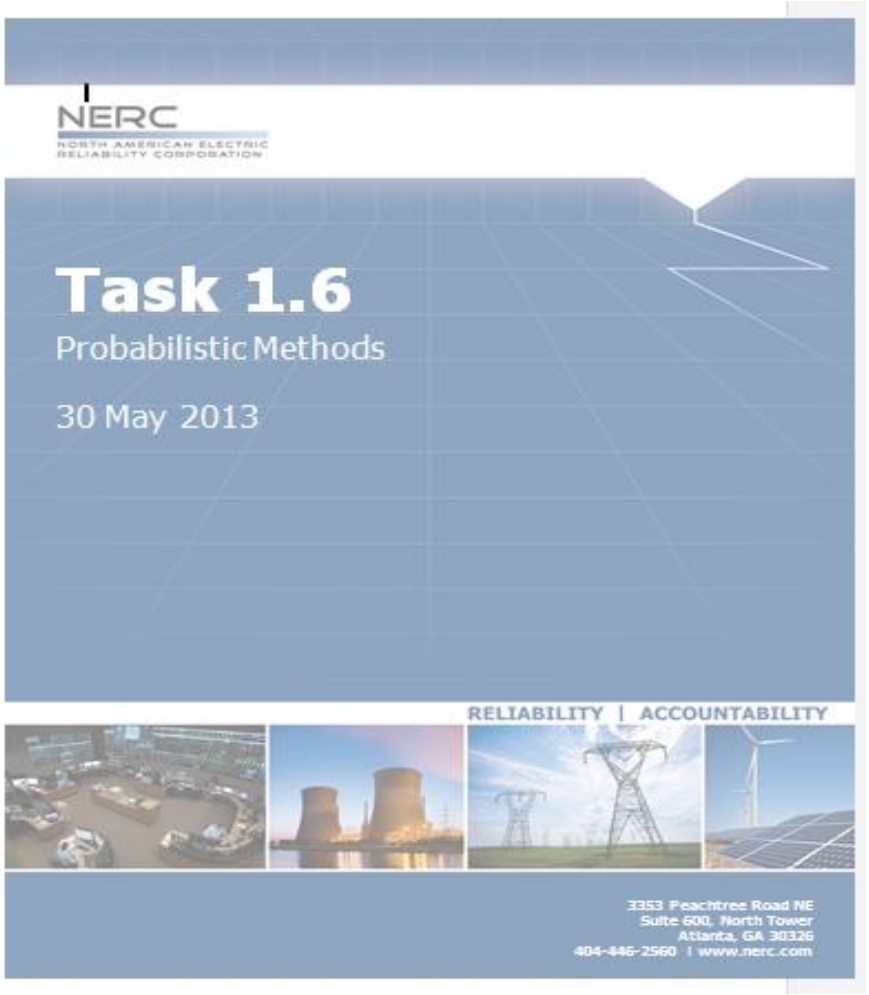
Chris Dent, Durham University

Statistical Modelling For ESI

Managing uncertainty in energy systems



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



NERC, Special Report: IVGTF, Task 1.6, Probabilistic Methods, 2014.

Assignment

Assignment

The students will be allocated to teams of four at the start of the week and will be assigned a country or region. For their assigned country or region they will be asked to prepare a slide deck answering the following questions.

- What will be the energy mix of this region be in 2030 & 2050 ?
- How "integrated" will the energy system be both across domains and scales?
- Give examples of the above and justify them on the basis of their benefits (economically, reliability, security of supply, environmental) e.g. thermal capacity in buildings for grid services.
- Identify technical and/or policy/regulatory innovations required to get to this future energy system.
- What tools techniques will be required to inform this?

Assessment in the form of a 10 minute presentation & 10 minutes for questions) on Friday 25th July.

Assignment Groups

Group:	Name:	Organization:
1	Maria Fernanda Alvarez Mendoza	National Autonomous University of Mexico
	Roland Clarke	Clarke Energy Associates
	Jose Daniel Lara	University of Waterloo
	Asheesh Singh	MN National Institute of Technology Allahabad
	Assigned region/country: Ireland	
2	Juan Andrade	University of Texas
	Alissa Olson	BPA
	Qiao Li	University of Devner
	Venkatesh Thumala Janakiraman	Arizona State University
	Assigned region/country: Denmark	
3	Gurudatta Belavadi	Arizona State University
	Jari Miettinen	VTT
	Roshanak Nateghi	Johns Hopkins University
	Tony Thomas	Natl. Rural Electric Cooperative Assn.
	Assigned region/country: Oahu, Hawaii (USA)	
4	Jose Miguel Carrasco Lopez	University of Colorado, Denver
	Joel Logan	Iowa Association of Municipal Utilities
	Andu Nguyen	UCSD
	Raja Timihiri	UW- Madison
	Assigned region/country: California	
5	David Gao	University of Denver
	Sam Hirsi	BPA
	Sheila Nolan	ERC, UCD
	Miguel Velez-Reyes	UTEP
	Assigned region/country: Japan	

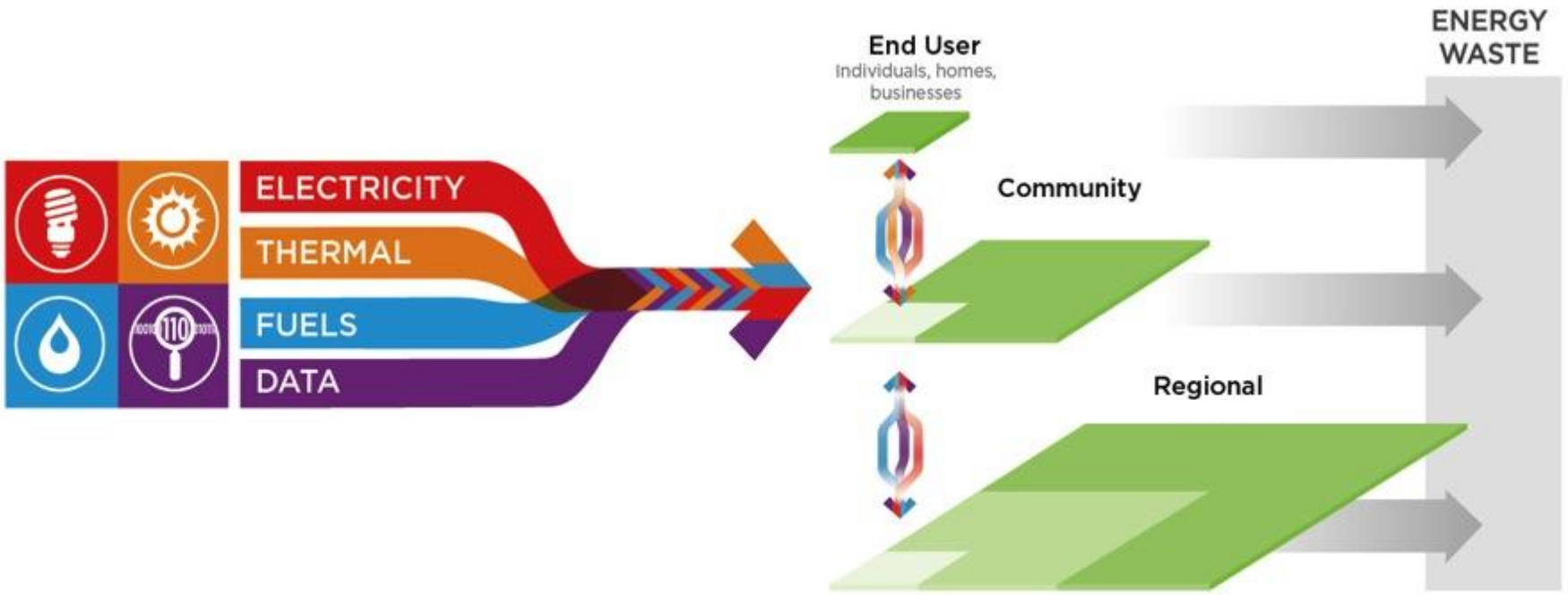
Group:	Name:	Organization:
6	Abdulelah Habib	UCSD
	Samuel Putnam	NREL SULI
	Niamh O' Connell	CITIES, DTU
	Dariush Shirmohammadi	California Wind Energy Association
	Assigned region/country: North Eastern China	
7	Dan Hu	Iowa State Univeristy
	James Briones	US DOE NETI
	Sung Yeul Park	University of Connecticut
	Jesus Alejandro Sotelo-Martinez	UMSNH
	Assigned region/country: Western Australia	
8	Aditya Kelkar	Arizona State University
	Jon Black	ISO New England
	Nadia Maria Salgado Herrera	Universidad Michoacana de San NicolÃ¡s de Hidalgo
	Assigned region/country: New Zealand	
9	Pradeep Kumar	MN National Institute of Technology Allahabad
	Blake Beavers	PEC
	Apurba Sakti	MIT Energy Intiative
	Choices: Finland	

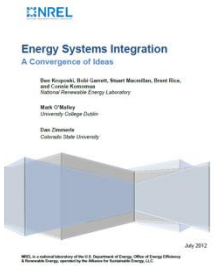
Note: If you wish to chose a city or sub region within the assigned region/country then please consult with Mark O'Malley

Like people all systems are different so each group should have something unique.

Reading/watching material

NREL
NATIONAL RENEWABLE ENERGY LABORATORY




NREL
Energy Systems Integration
A Convergence of Ideas

Kroposki, B., Garrett, B., Macmillan, S., Rice, B., Komomua, C., O'Malley, M., Zimmerle, D. "Energy Systems Integration, A Convergence of Ideas, National Renewable Energy Laboratory, Technical Paper NREL/TP-6A00-55649, July 2012. http://www.nrel.gov/docs/fy12osti/55649.pdf

IEEE Power & Energy Magazine, Sept./Oct. 2013

M. O'Malley and B. Kroposki Guest Editors

- Planning ESI – Jim McCalley *et al.*, Iowa St.
- Hawaii ESI – Dave Corbus, *et al.*, NREL
- EU ESI – John Holms, EASAC & Oxford University
- Danish ESI – Peter Meibom *et al.*, Dansk Energi, DTU
- Tools and modeling for ESI – Juan Van Roy *et al.* KU Leuven
- China ESI – Chongqing Kang *et al.*, Tsinghua University

O'Malley, M.J. and Kroposki B. "Energy comes together the integration of all systems", Editorial, Special issue in Energy Systems Integration, *IEEE Power & Energy Magazine*, Vol. 11, Sept/October, pp. 18 – 23, 2013.

Reading Material # 1

- P. Bacher, H. Madsen, H.Aa. Nielsen: Online Short-term Solar Power Forecasting, Solar Energy, Vol. 83(10), pp. 1772-1783, 2009.
- 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
- CIGRE 2010: Review of the Current Status of Tools and Techniques for Risk-Based and Probabilistic Planning in Power Systems, Working Group.
- 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
- 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
- A. Costa, A. Crespo, J. Navarro, G. Lizcano, H. Madsen, F. Feitosa, A review on the young history of the wind power short-term prediction, Renew. Sustain. Energy Rev., Vol. 12, pp. 1725-1744, 2008.
- EASAC, “Transforming Europe’s Electricity Supply – An Infrastructure Strategy for a Reliable,
- Renewable and Secure Power System” European Academy of Sciences Advisory Council, May 2009. http://www.easac.org/document.asp?id=96&pageno=&detail=5&parent
- Energy Needs Ireland “Participating in Ireland’s Smart Energy Future “ Final Report, September 2013
- Favre – Perrod, P. “Hybrid Energy Transmission for Multi-Energy Networks” PhD thesis submitted to ETH Zurich
- C. Gallego, P. Pinson, H. Madsen, A. Costa, A. Cuerva (2011). Influence of local wind speed and direction on wind power dynamics - Application to offshore very short-term forecasting. Applied Energy, in press
- Geidl, M. “Integrated Modeling and Optimization of Multi-Carrier Energy Systems” PhD thesis submitted to ETH Zurich
- Geidl, Martin; Andersson, G., "Optimal Power Flow of Multiple Energy Carriers," *Power Systems, IEEE Transactions on* , vol.22, no.1, pp.145,155, Feb. 2007 doi: 10.1109/TPWRS.2006.888988
- Geidl, Martin; Koeppel, G.; Favre-Perrod, P.; Klockl, B.; Andersson, G.; Frohlich, K., "Energy hubs for the future," *Power and Energy Magazine, IEEE* , vol.5, no.1, pp.24,30, Jan.-Feb. 2007, doi: 10.1109/MPAE.2007.264850
- G. Giebel, R. Brownsword, G. Kariniotakis, M. Denhard, C. Draxl: The state-of-the-art in short-term prediction of wind power, ANEMOS plus report, 2011.

Reading Material # 2

- Hemmes, JK., .L. Zachariah-Wolf, M. Geidl, G. Andersson, Towards multi-source multi-product energy systems, International Journal of Hydrogen Energy, Volume 32, Issues 10–11, July–August 2007, Pages 1332-1338, ISSN 0360-3199, http://dx.doi.org/10.1016/j.ijhydene.2006.10.013.
- Dag Henning, MODEST—An energy-system optimisation model applicable to local utilities and countries, Energy, Volume 22, Issue 12, December 1997, Pages 1135-1150, ISSN 0360-5442, http://dx.doi.org/10.1016/S0360-5442(97)00052-2.
- Holmes, J., "A More Perfect Union: Energy Systems Integration Studies from Europe," *Power and Energy Magazine, IEEE* , vol.11, no.5, pp.36,45, Sept. 2013 , doi: 10.1109/MPE.2013.2268714
- IEA "World Energy Outlook 2014" www.worldenergyoutlook.com
- T. Jónsson, P. Pinson (2010). On the market impact of wind energy forecasts. Energy Economics, Vol. 32(2), pp. 313-320.
- T. Jónsson, M. Zugno, H. Madsen, P. Pinson (2010). On the Market Impact of Wind Power (Forecasts) - An Overview of the Effects of Large-scale Integration of Wind Power on the Electricity Market. IAEE International Conference, Rio de Janeiro, Brazil.
- Koeppel, G. A. "Reliability Considerations of Future Energy Systems: Muti-Carrier Systems and the Effect of Energy Storage" PhD thesis submitted to Swiss Federal Institute of Technology Zurich
- Kiviluoma, J., Meibom, P.; "Influence of wind power, plug-in electric vehicles, and heat storages on power system investments" Energy, Volume 35, Issue 3, March 2010, Pages 1244-1255
- Krause, T.; Andersson, G.; Fröhlich, K.; Vaccaro, A., "Multiple-Energy Carriers: Modeling of Production, Delivery, and Consumption," *Proceedings of the IEEE* , vol.99, no.1, pp.15,27, Jan. 2011, doi: 10.1109/JPROC.2010.2083610
- Krishnan, V.; Das, T.; Ibanez, E.; Lopez, C.A.; McCalley, J.D., "Modeling Operational Effects of Wind Generation Within National Long-Term Infrastructure Planning Software," *Power Systems, IEEE Transactions on* , vol.28, no.2, pp.1308,1317, May 2013 doi: 10.1109/TPWRS.2012.2216293
- Kroposki, B., Garrett, B., Macmillan, S., Rice, B., Komomua, C., O'Malley, M.J., Zimmerle, D. "Energy Systems Integration, A Convergence of Ideas, National Renewable Energy Laboratory, Technical Paper NREL/TP-6A00-55649, July 2012. http://www.nrel.gov/docs/fy12osti/55649.pdf
- Kroposki, B., Komomua, C. and O'Malley, M., From the Building to the Grid: An Energy Revolution and Modeling Challenge, National Renewable Energy Laboratory, Technical Paper NREL/TP-6A00-56056, January 2013. http://www.nrel.gov/docs/fy13osti/56056.pdf

Reading Material # 3

- Mackay, M., Bird, L., Cochran, J., Milligan, M., Bazilian, M., Neuhoff, K., Denny, E., Dillon, J., Bialek, J. and O'Malley, M.J., "RES-E-NEXT, Next Generation of RES-E Policy Instruments", IEA RETD, July 2013. http://iea-retd.org/wp-content/uploads/2013/07/RES-E-NEXT_IEA-RETD_2013.pdf
- H. Madsen: Time Series Analysis, Chapman and Hall, 392 pp, 2008.
- H. Madsen, P. Pinson, G. Kariniotakis, H.Aa. Nielsen, T.S. Nilsen: Standardizing the performance evaluation of short-term wind prediction models, Wind Engineering, Vol. 29, pp. 475-489, 2005.
- Martinez-Mares, A.; Fuerte-Esquivel, C.R., "A Unified Gas and Power Flow Analysis in Natural Gas and Electricity Coupled Networks," *Power Systems, IEEE Transactions on* , vol.27, no.4, pp.2156,2166, Nov. 2012, doi: 10.1109/TPWRS.2012.2191984
- Matthias, C. et al. Security and Sustainability of Power Supply – Benefits of HVDC & FACTS for System Interconnection and Power Transmission Enhancement http://www.ptd.siemens.de/Presentation_Security%20&%20Sustainability_PowerGrid_08-06_V%201.pdf
- McCalley, J.; Jewell, W.; Mount, T.; Osborn, D.; Fleeman, J., "A Wider Horizon," *Power and Energy Magazine, IEEE* , vol.9, no.3, pp.42,54, May-June 2011, doi: 10.1109/MPE.2011.940576
- McCalley, J.; Krishnan, V.; Gkritza, K.; Brown, R.; Mejia-Giraldo, D., "Planning for the Long Haul: Investment Strategies for National Energy and Transportation Infrastructures," *Power and Energy Magazine, IEEE* , vol.11, no.5, pp.24,35, Sept. 2013, doi: 10.1109/MPE.2013.2268712
- 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, doi: 10.1109/MPE.2013.2268751
- J.K. Møller, H. Madsen, H.Aa. Nielsen: Time Adaptive Quantile Regression, Computational Statistics and Data Analysis, Vol. 52, pp. 1292-1303, 2008.
- J.M. Morales, A.J. Conejo, H. Madsen, P. Pinson, M. Zugno: Integrating Renewables in Electricity Markets, Springer, 430 pp., 2013
- NERC, Special Report: IVGTF, Task 1.6, Probabilistic Methods, 2014.
- T.S. Nielsen, A. Joensen, H. Madsen, L. Landberg, G. Giebel: A New Reference for Predicting Wind Power, Wind Energy, Vol. 1, pp. 29-34, 1999.
- H.A. Nielsen, H. Madsen: A generalization of some classical time series tools, Computational Statistics and Data Analysis, Vol. 37, pp. 13-31, 2001.
- H.A. Nielsen, T.S. Nielsen, H. Madsen, S.I. Pindado, M. Jesus, M. Ignacio: Optimal Combination of Wind Power Forecasts, Wind Energy, Vol. 10, pp. 471-482, 2007.
- O'Malley, M.J. and Kroposki B. "Energy comes together the integration of all systems", Editorial, Special issue in Energy Systems Integration, *IEEE Power & Energy Magazine*, Vol. 11, Sept/October, pp. 18 – 23, 2013.

Reading Material # 4

- Papaefthymiou, G.; Hasche, B.; Nabe, C., "Potential of Heat Pumps for Demand Side Management and Wind Power Integration in the German Electricity Market," *Sustainable Energy, IEEE Transactions on* , vol.3, no.4, pp.636,642, Oct. 2012 doi: 10.1109/TSTE.2012.2202132
- P. Pinson, H. Madsen: Ensemble-based probabilistic forecasting at Horns Rev. Wind Energy, Vol. 12(2), pp. 137-155 (special issue on Offshore Wind Energy), 2009.
- P. Pinson, H. Madsen: Adaptive modeling and forecasting of wind power fluctuations with Markov-switching autoregressive models. Journal of Forecasting, 2010.
- P. Pinson, P. McSharry, H. Madsen. Reliability diagrams for nonparametric density forecasts of continuous variables: accounting for serial correlation. Quarterly Journal of the Royal Meteorological Society, Vol. 136(646), pp. 77-90, 2010.
- P. Pinson, H.Aa. Nielsen, H. Madsen, G. Kariniotakis (2009). Skill forecasting from ensemble predictions of wind power. Applied Energy 86(7-8), pp. 1326-1334.
- P. Pinson, H.Aa. Nielsen, J.K. Moeller, H. Madsen, G. Kariniotakis (2007). Nonparametric probabilistic forecasts of wind power: required properties and evaluation. Wind Energy 10(6), pp.497-516.
- J. Tastu, P. Pinson, E. Kotwa, H.Aa. Nielsen, H. Madsen (2011). Spatio-temporal analysis and modeling of wind power forecast errors. Wind Energy 14(1), pp. 43-60
- F. Thordarson, H.Aa. Nielsen, H. Madsen, P. Pinson (2010). Conditional weighted combination of wind power forecasts. Wind Energy 13(8), pp. 751-763
- Van Roy, J.; Verbruggen, B.; Driesen, J., "Ideas for Tomorrow: New Tools for Integrated Building and District Modeling," *Power and Energy Magazine, IEEE* , vol.11, no.5, pp.75,81, Sept. 2013, doi: 10.1109/MPE.2013.2268815
- C.L. Vincent, G. Giebel, P. Pinson, H. Madsen: Resolving non-stationary spectral signals in wind speed time-series using the Hilbert-Huang transform. Journal of Applied Meteorology and Climatology, Vol. 49(2), pp. 253-267, 2010.
- C.L. Vincent, P. Pinson, G. Giebel (2011). Wind fluctuations over the North Sea. International Journal of Climatology, available online
- Zachary, S. & Dent, C.J. (2014). Estimation of Joint Distribution of Demand and Available Renewables for Generation Adequacy Assessment. Available from http://dro.dur.ac.uk/cgi/

- math.nist.gov/IFIP-UQSC-2011/slides/Goldstein.pdf
- http://www.maths.bris.ac.uk/~mazjcr/climPolUnc.pdf
- http://www.significancemagazine.org/details/magazine/868617/Climate-change.html

Watching material

O'Malley, M.J., "Energy Systems Integration 101", GCEP Research Symposium Stanford University, October 2013.
http://www.youtube.com/watch?v=w4LyN3Or60A

Schedule

Mon 21/07/2014		
09:00 - 10:00	Introduction to ESI and Overview of ESI 101	Mark O'Malley
10:00 –11:00	Benefits of ESI	Ben Kroposki
11:00 - 11:30	Coffee	
11:30 - 12:30	Forecasting of Load, Heat, Wind and Solar	Henrik Madsen
12:30-1:30	Lunch	
1:30-5:00	Project Work	

Tues 22/07/2014		
09:00 - 10:00	Energy Infrastructure Expansion Planning	Jim McCalley
10:00 –11:00	Energy-Water Nexus	Pete Thomson
11:00 - 11:30	Coffee	
11:30 - 12:30	Gas – Electricity Nexus	Jim McCalley
12:30-1:30	Lunch	
1:30-2:30	Tour of ESIF	Ben Kroposki
2:30-5:00	Project Work	

Wed 23/07/2014		
09:00 - 11:00	Distributed Energy Systems, DER, CHP and Microgrids	Bob Lasseter
11:00 - 11:30	Coffee	
11:30 - 12:30	Energy – Transport Nexus	Jim McCalley
12:30-1:30	Lunch	
1:30 - 2:30	Regulatory Issues and Business Models In ESI	Jaqueline Cochran
2:30-5:00	Project Work	
5:00-10:00	Social Trip to Mount Evans	

Thurs 24/07/2014		
09:00 – 10:30	Greybox Modeling	Henrik Madsen
10:30 - 11:00	Introduction to Greybox Modeling Exercise	Niamh O'Connell
11:00 - 11:30	Coffee	
11:30 - 12:30	Introduction to Variable Renewables into Electricity Grids	Mark O'Malley
12:30-1:30	Lunch	
1:30-5:00	Grey Box Modeling Exercise	

Fri 25/07/2014		
09:00 – 10:00	Statistical Modeling for ESI	Chris Dent
10:00 - 11:00	Project Report Out	
11:00 - 11:30	Coffee	
10:00 - 11:00	Project Report Out	
12:30-1:30	Lunch	
1:30 - 2:30	Project Report Out	
2:30 – 2:45	Wrap Up	Mark O'Malley

Note: Slides will be emailed in advance by Sheila or Niamh. Final set of slides will be made available on www.iiesi.org