An Introduction to Energy Sustainability and Distributed Energy

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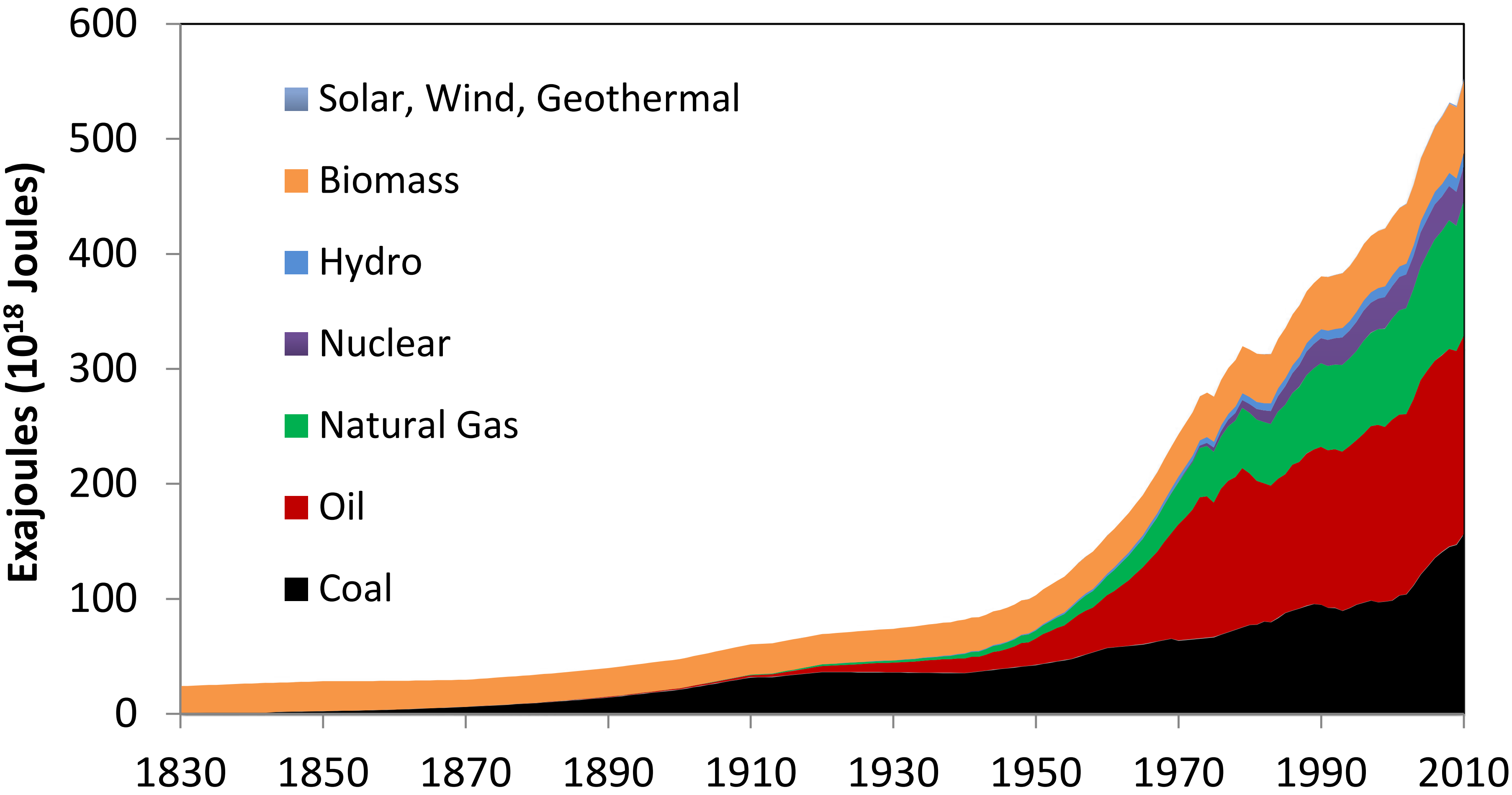
Energy Sustainability

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"
– UN, Our Common Future, 1987

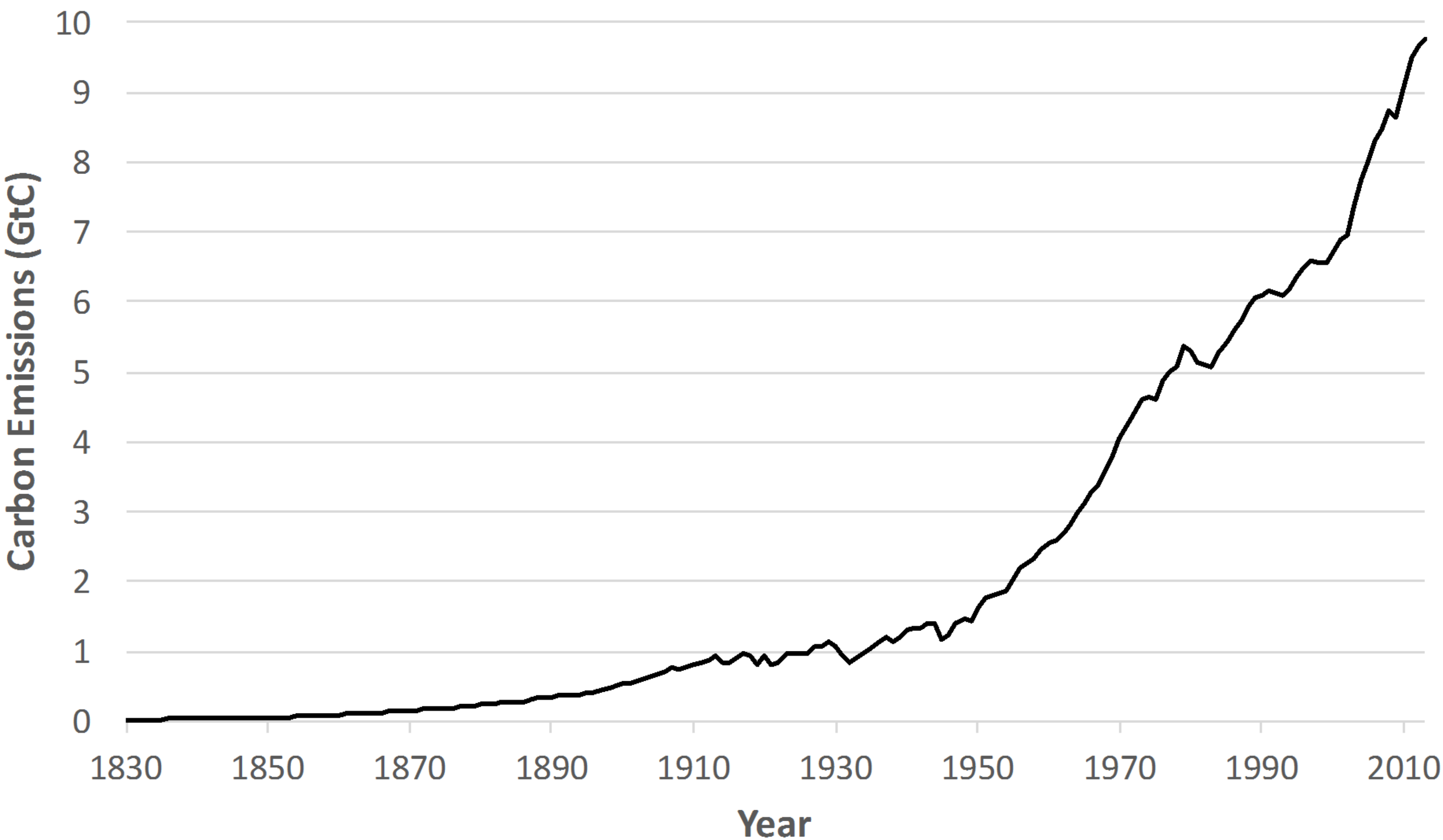
Energy sustainability challenges:

- Economic development
- Resource availability
- Air pollution
- Mining and drilling
- Water consumption
- **Climate change**

Global Primary Energy Consumption 1830 - 2010

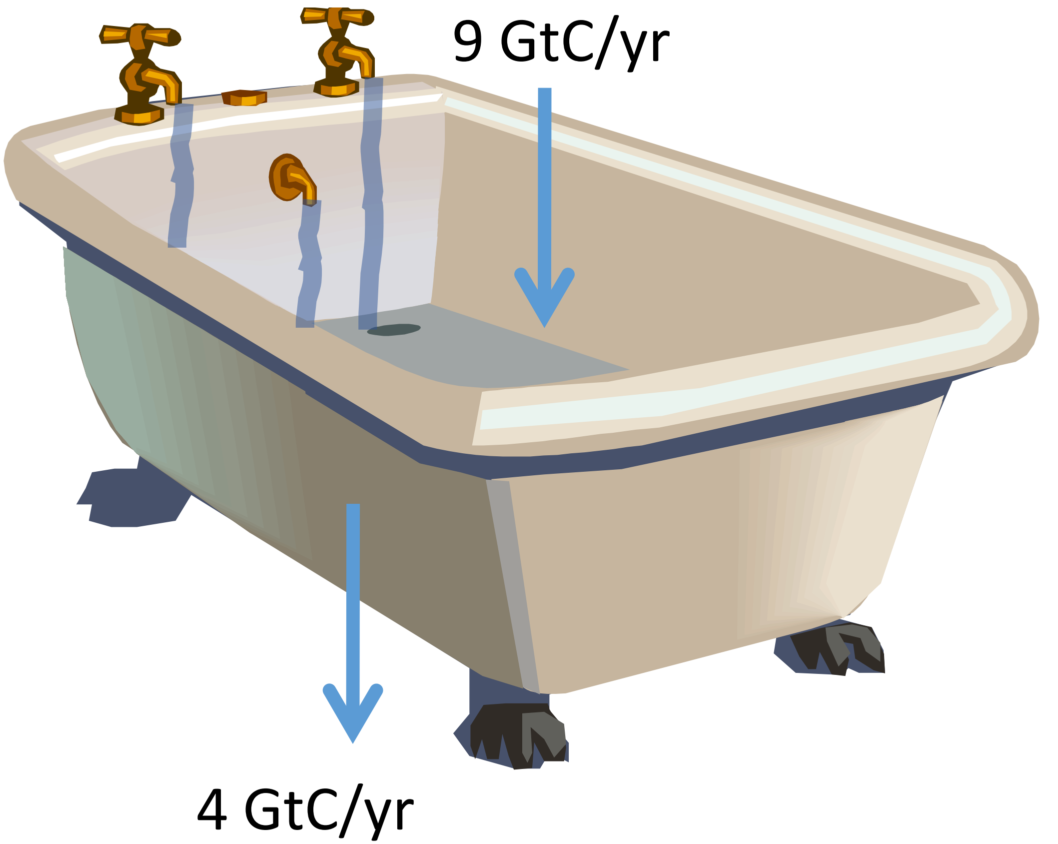


Global Carbon Emissions



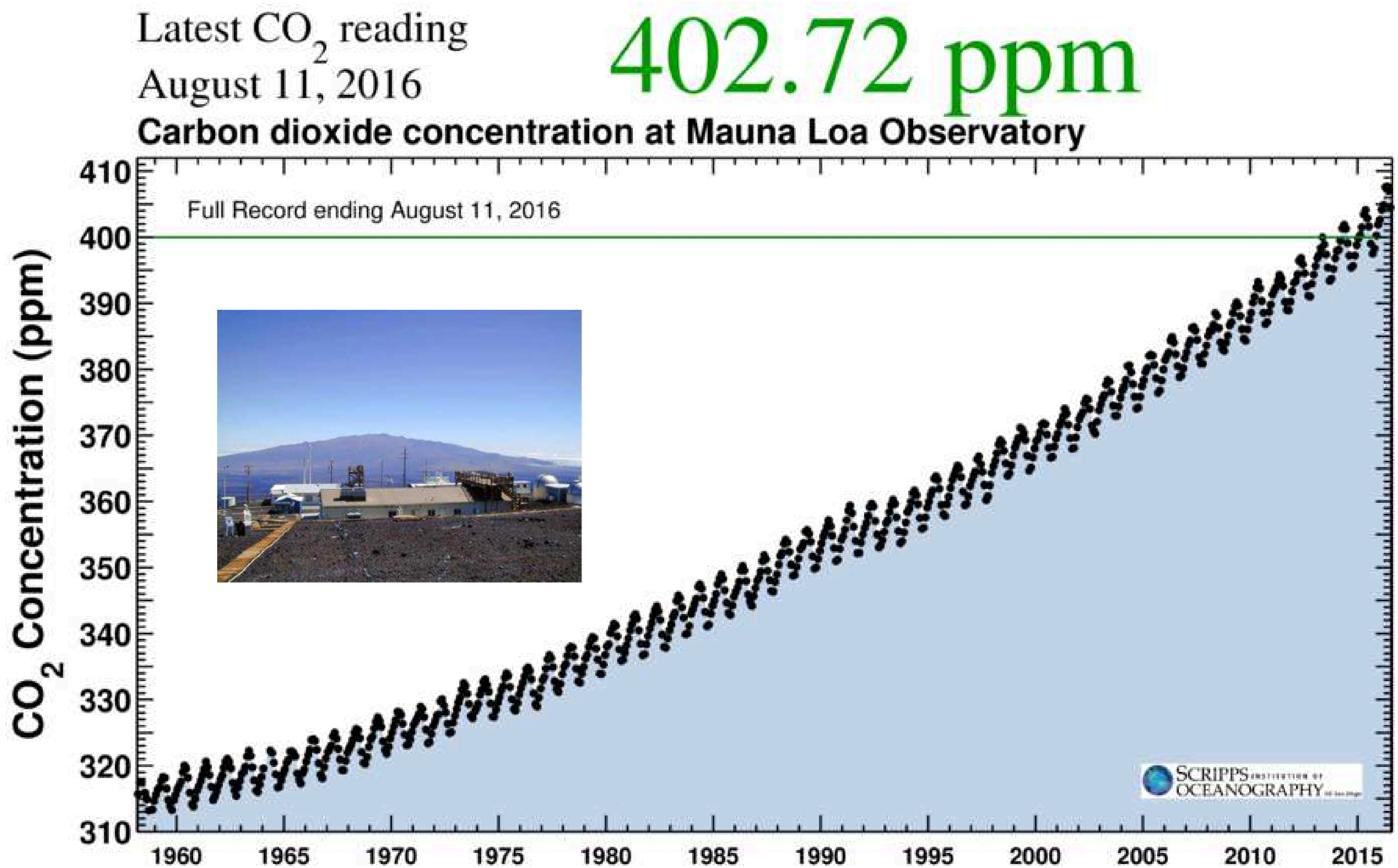
Source: cdiac.ornl.org

The Atmospheric Bathtub



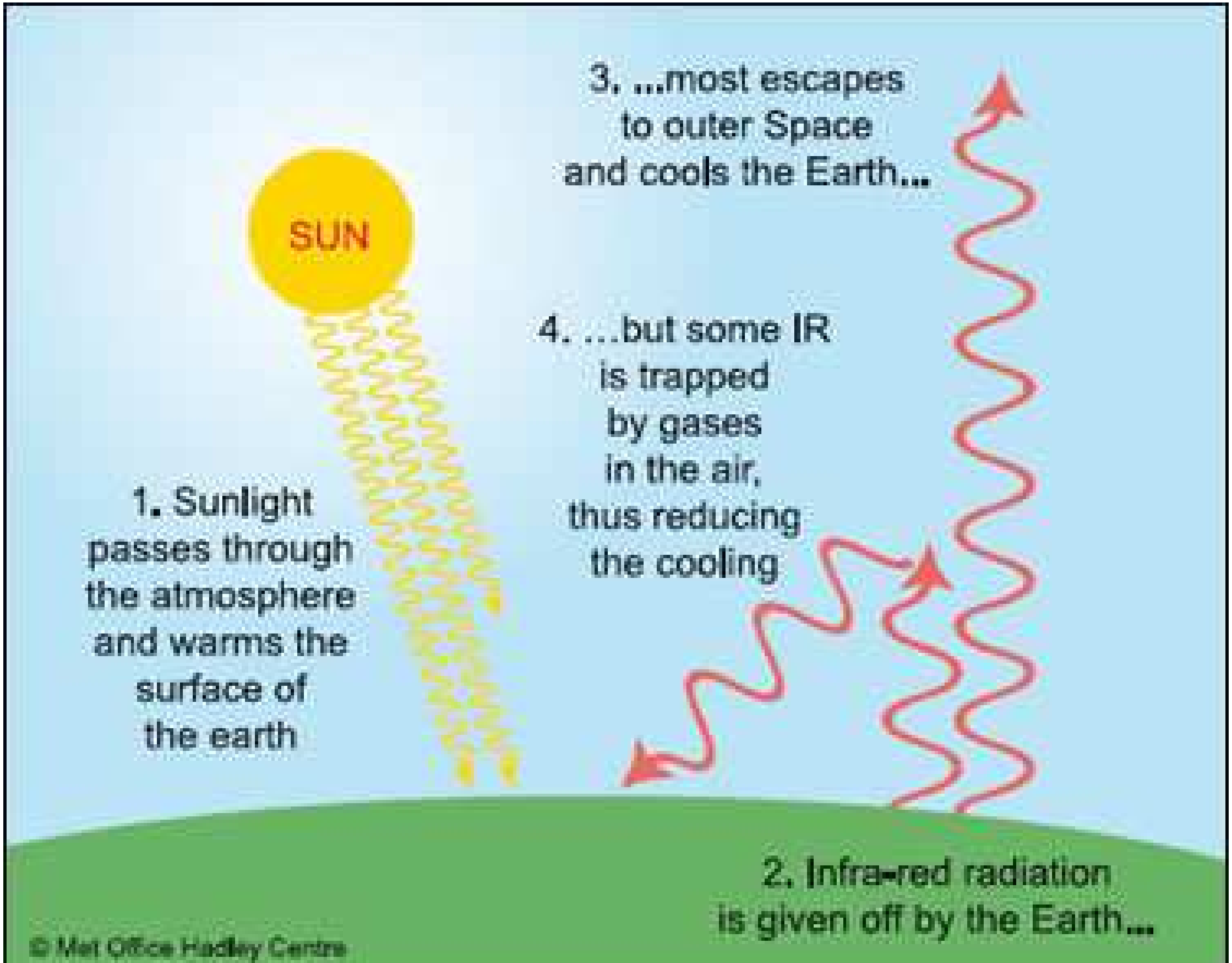
A useful analogy is filling a bathtub at a faster rate than you can drain it.

Keeling Curve: Measured CO_2 Concentration (Mauna Loa, Hawaii)



Source: https://scripps.ucsd.edu/programs/keelingcurve/

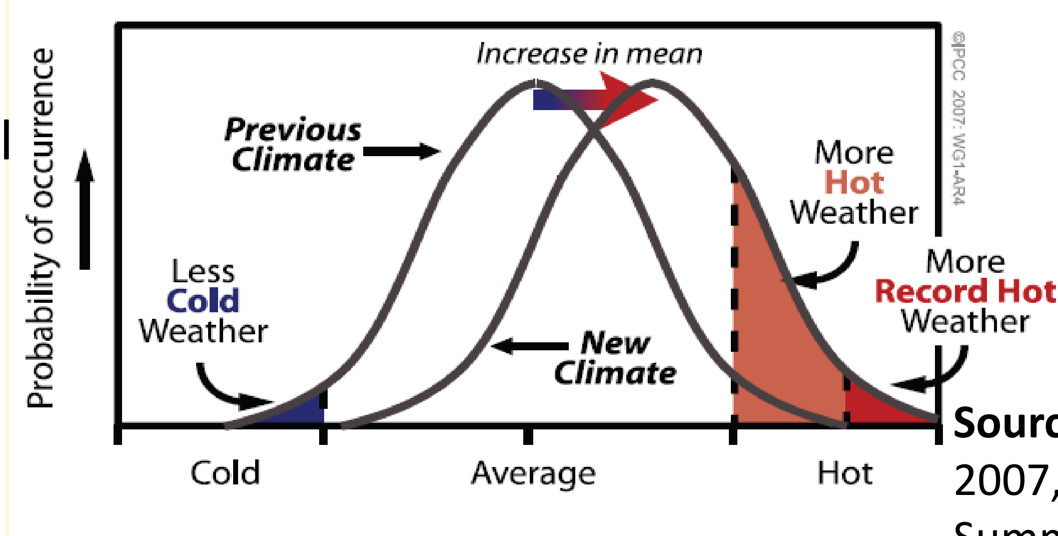
The "greenhouse effect"



Impacts from Climate Change

Average temperature change can be a misleading indicator of impact:

Many ecosystems will have difficulty adapting to climate change, associated disturbances, and other global change drivers.



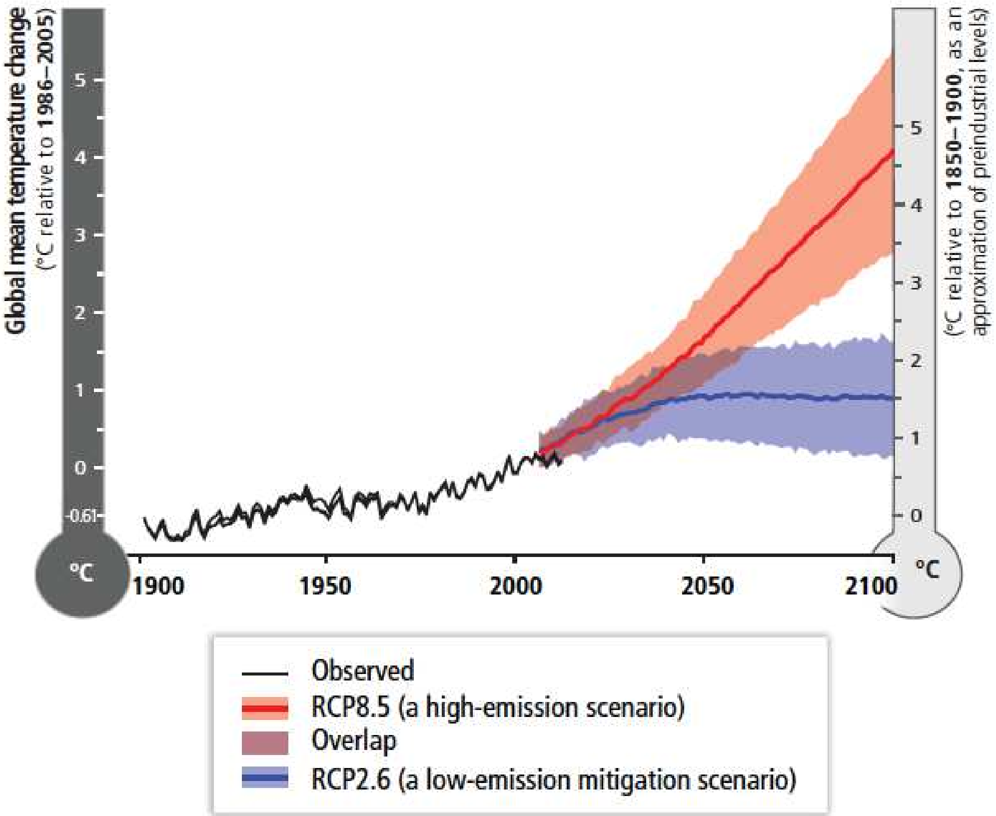
Source: IPCC, WGI, 2007, Technical Summary, p. 53.

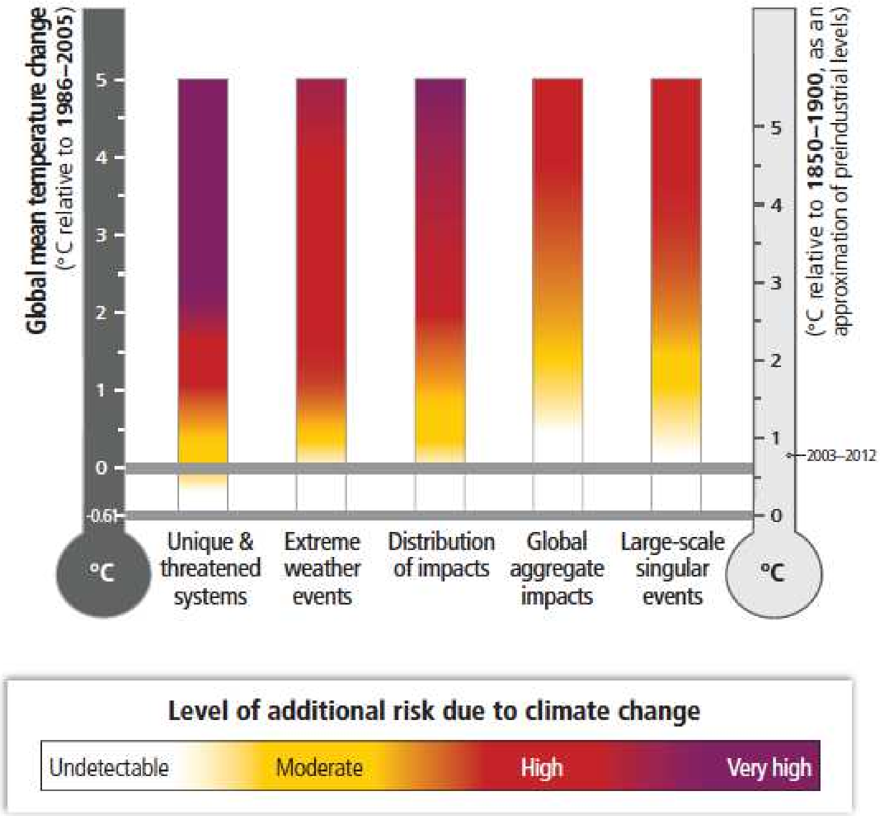
If temperature change exceeds 1.5-2.5°C, approximately 20-30% of known species will be at increasing risk of extinction (IPCC medium confidence).

Populations with low adaptive capacity and/or that live in coastal areas are at greatest risk of climate impacts.

Impacts Versus Temp Change

http://www.met.reading.ac.uk/~ed/spiral_large.gif





Source: IPCC, WGII, 2014, Summary for Policymakers, p. 13.

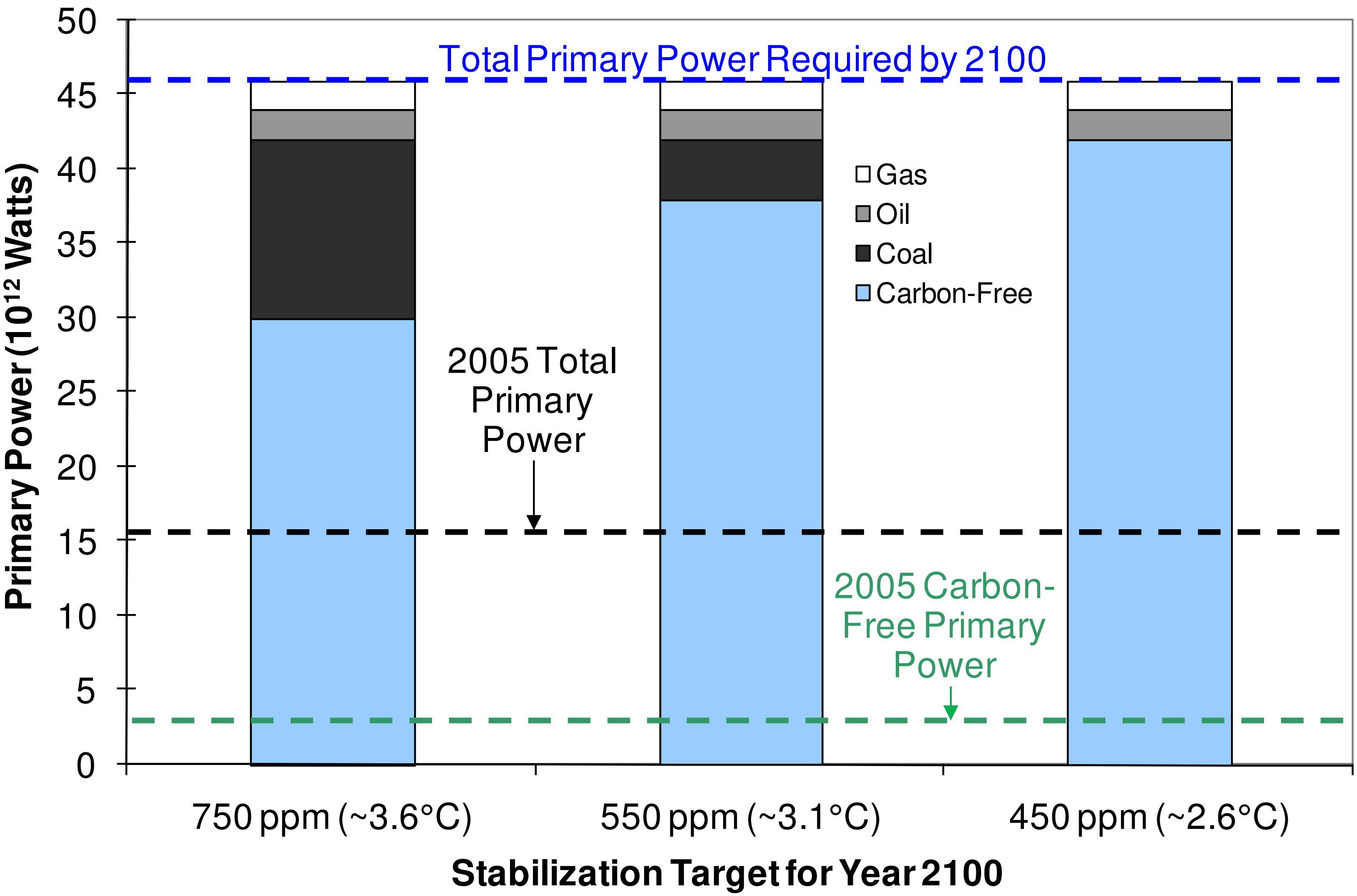
U.S. National Security Implications

Department of Defense, 2015: Report on National Security Implications of Climate-Related Risks and a Changing Climate
http://archive.defense.gov/pubs/150724-congressional-report-on-national-implications-of-climate-change.pdf

"Global climate change will aggravate problems such as poverty, social tensions, environmental degradation, ineffectual leadership and weak political institutions that threaten stability in a number of countries"

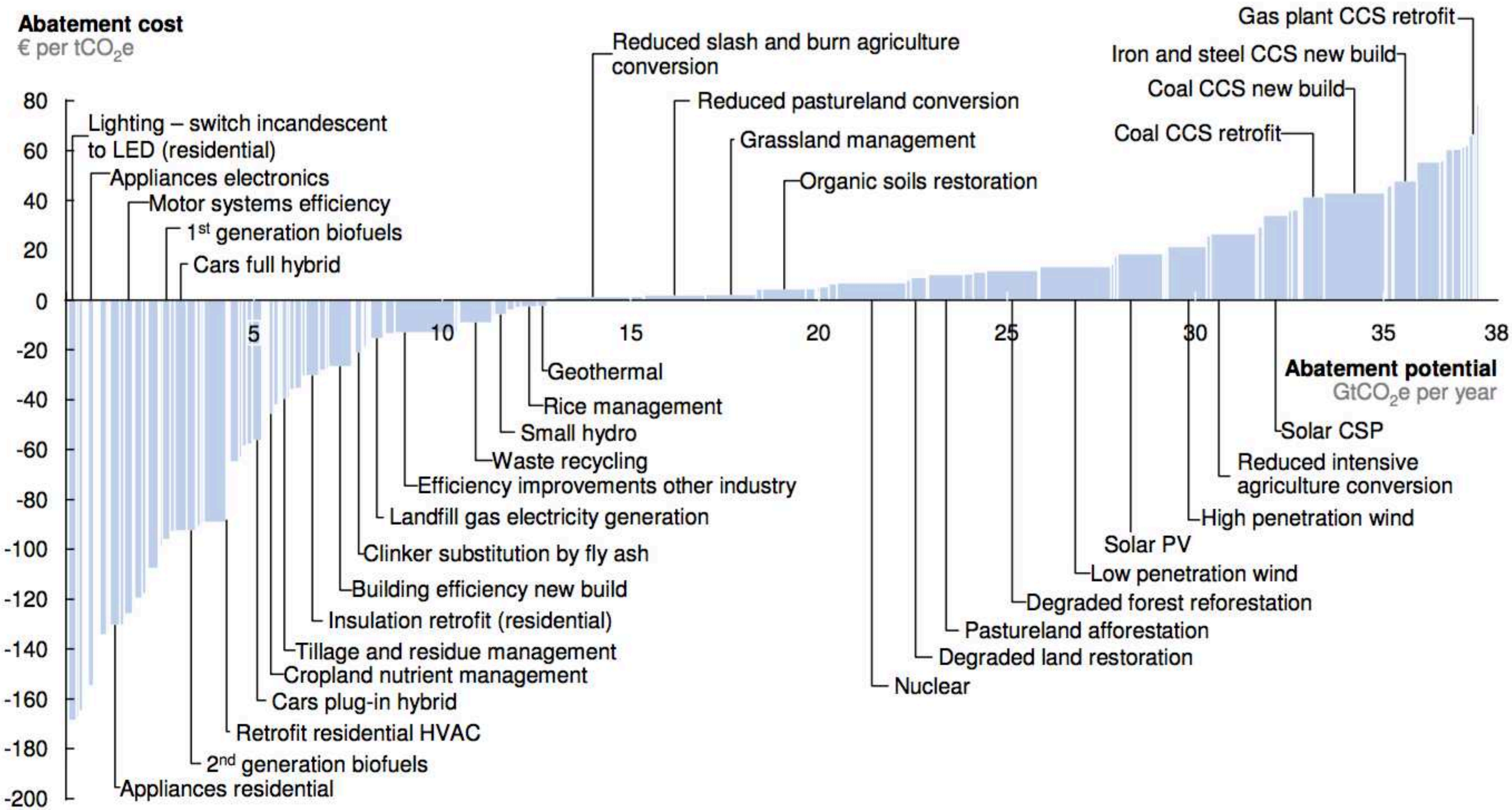
"It is in this context that the department must consider the effects of climate change -- such as sea level rise, shifting climate zones and more frequent and intense severe weather events -- and how these effects could impact national security."

Energy Implications of Climate Change



Based on WRE carbon-cycle model. For details see:
Hoffert et al (1998). "Energy implications of future stabilization of atmospheric CO_2 content." *Nature*, 395: 881-884.

The Cost of Carbon Abatement

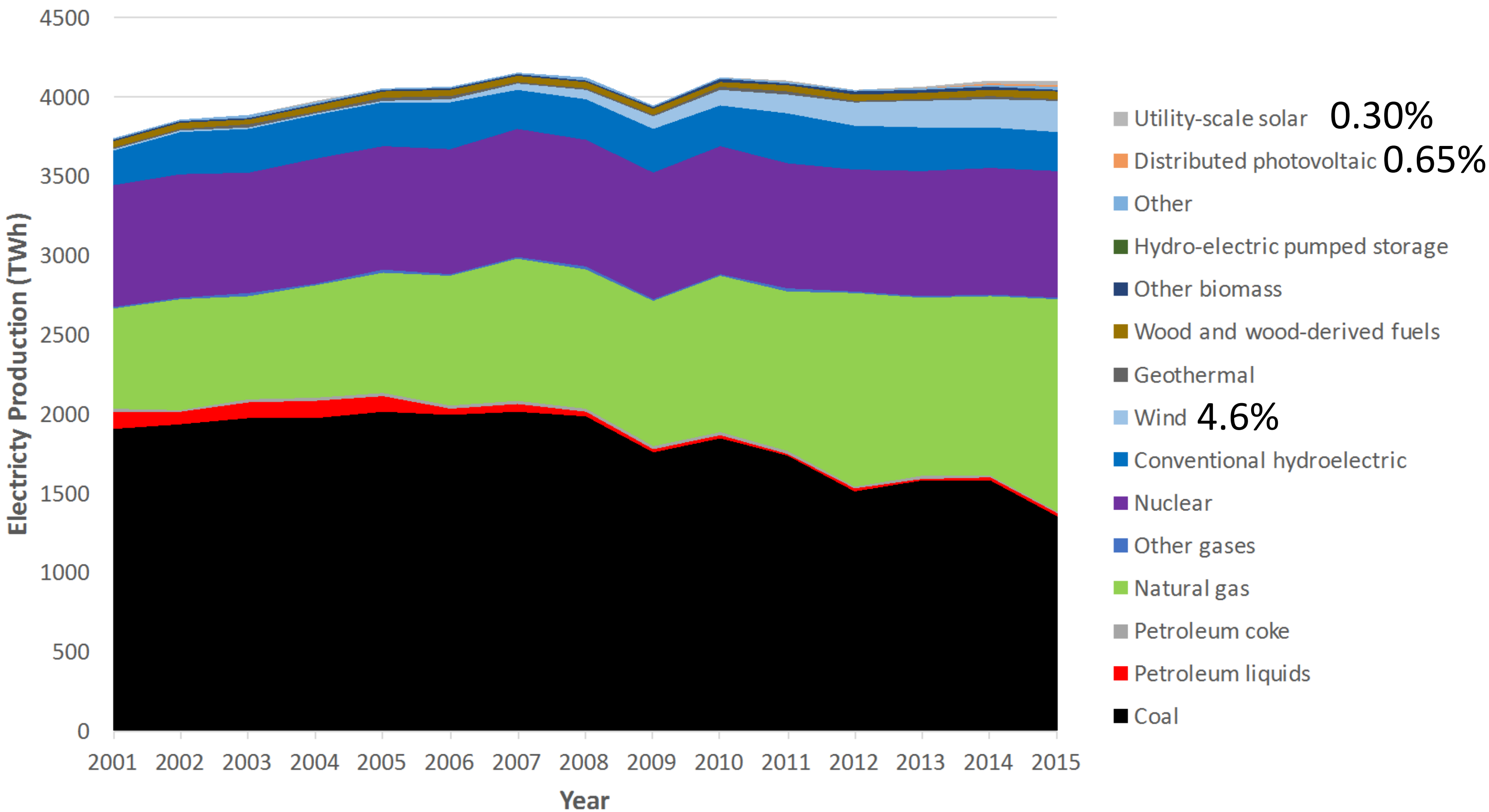


Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: Global GHG Abatement Cost Curve v2.1

Global and U.S. Electricity in 2014

- Global electricity production: 23,816 TWh (P_{avg} = 2.7 TW)
- U.S. electricity production: 4,100 TWh (P_{avg} = 0.47 TW)
- US CO_2 emissions: 5,411 million metric tons
- US CO_2 electricity emissions: 2,050 million metric tons (~40%)



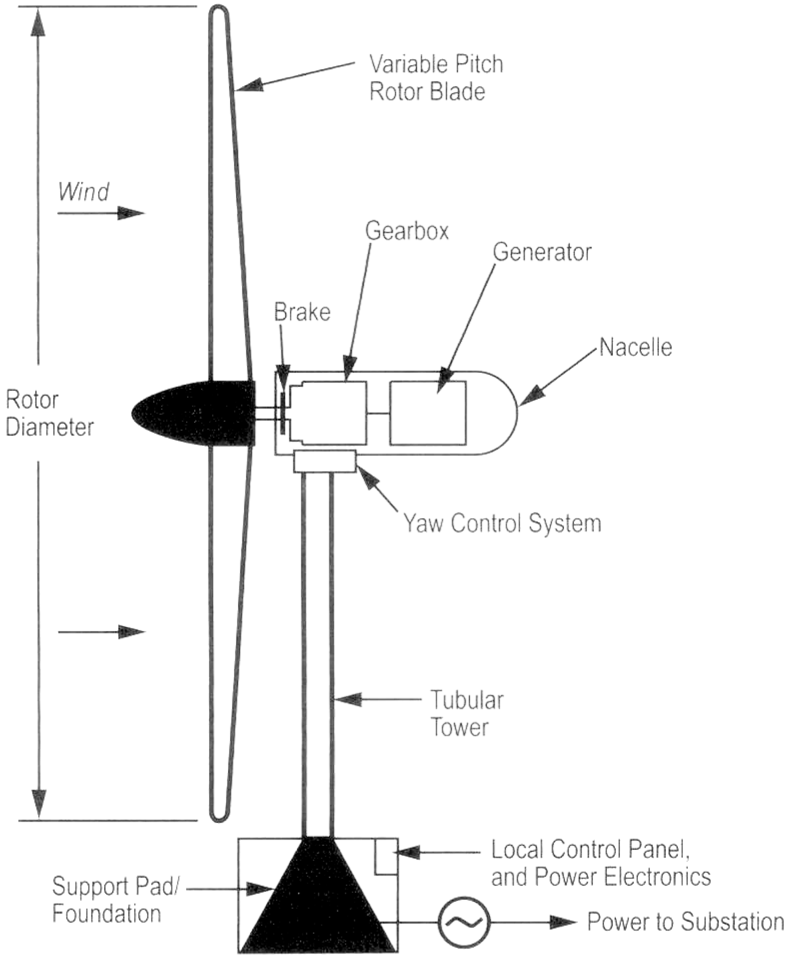
Wind Turbines

More than 1000 55 kW NEG Micon turbines at Palm Springs

Picture: Danish Wind Industry Association

GE 3.6 MW turbine in Spain
Rotor diameter: 104 m
Hub height: ~100 m

Picture: GE



Wind turbine towers are usually one to one-and-a-half the rotor's diameter in height

MIT, *Sustainable Energy*, p. 629

Solar Photovoltaics

Nellis Airforce base, Nevada, 14 MW

GA Tech Aquatic Center, 242 kW

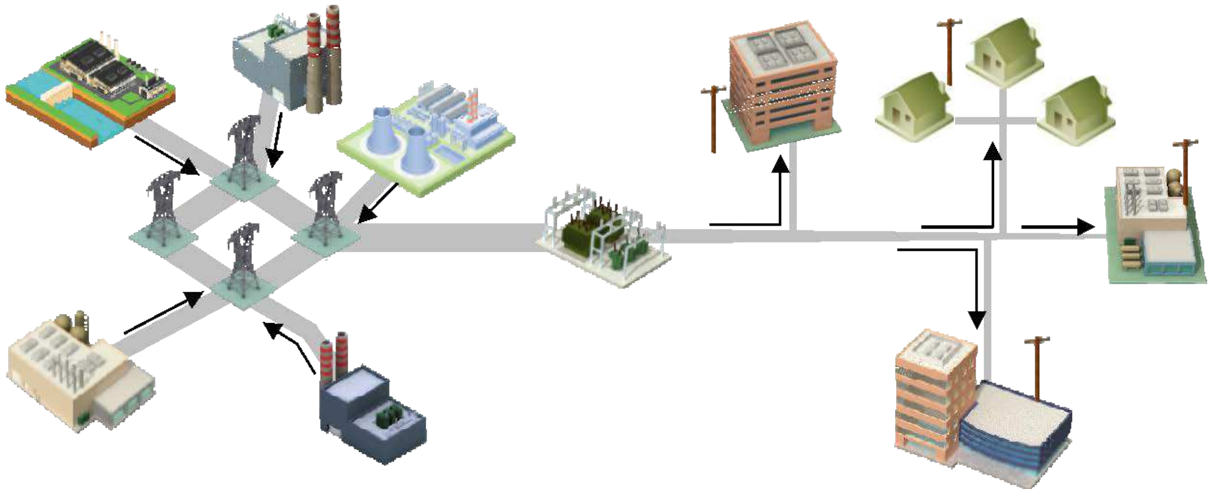
PV windows

Long Island, 1.8 kW rooftop system

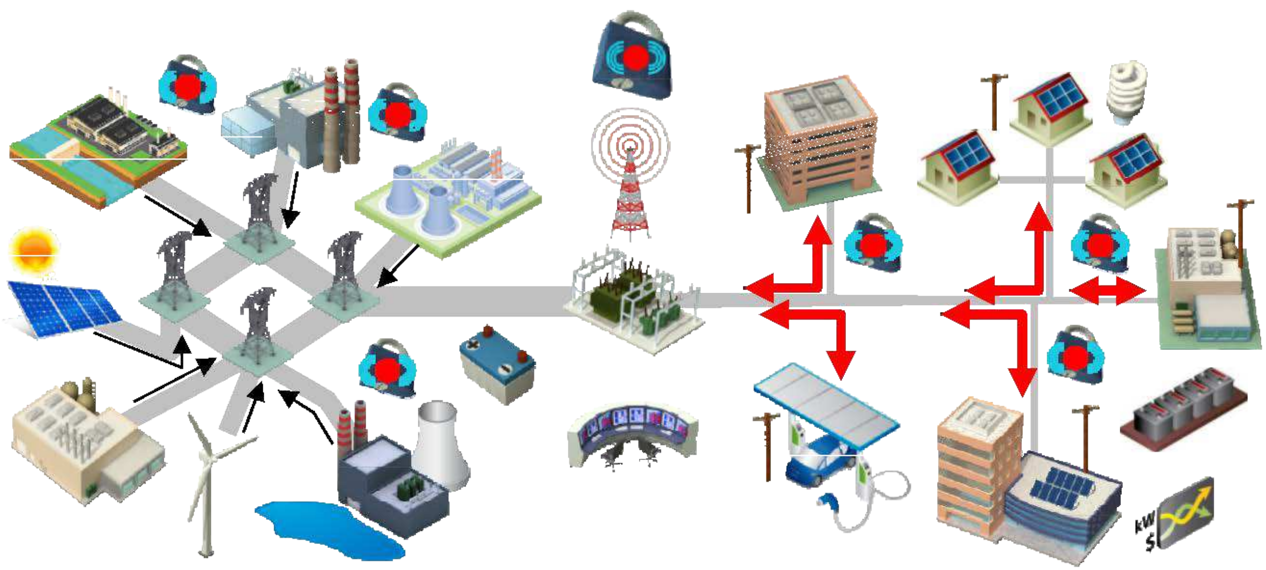
Cells are very modular; 100 cm^2 for typical silicon solar cell

A Shift in Design Paradigm?

Today



Tomorrow?



Source: EPRI (2011) Estimating the Costs and Benefits of the Smart Grid. Palo Alto, CA.

What kind of a system do we want?

Highly Centralized




Advantages

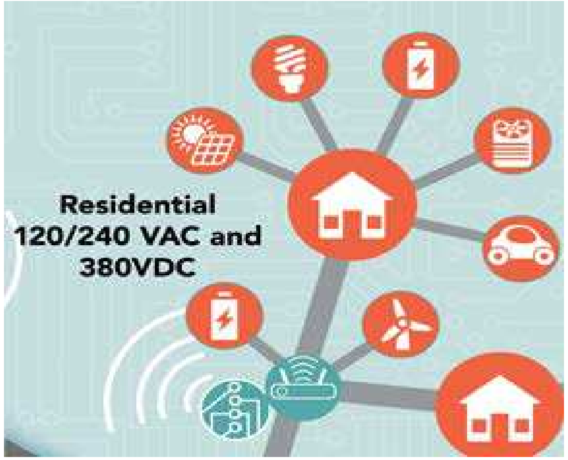
- Wider array of technologies in the portfolio
- Allows for economies of scale, leading to lower levelized cost
- Can reduce NIMBYism by placing in remote areas
- Enable capacity sharing across wide geographic areas

What kind of a system do we want?

Highly Decentralized







Advantages:

- Higher resilience to damage from storms, sabotage, conflict
- Greater consumer control over electricity
- Less dedicated land and water required for generation
- Motivate social capital and cohesion
- Lower financial risks

The Case for Distributed Energy

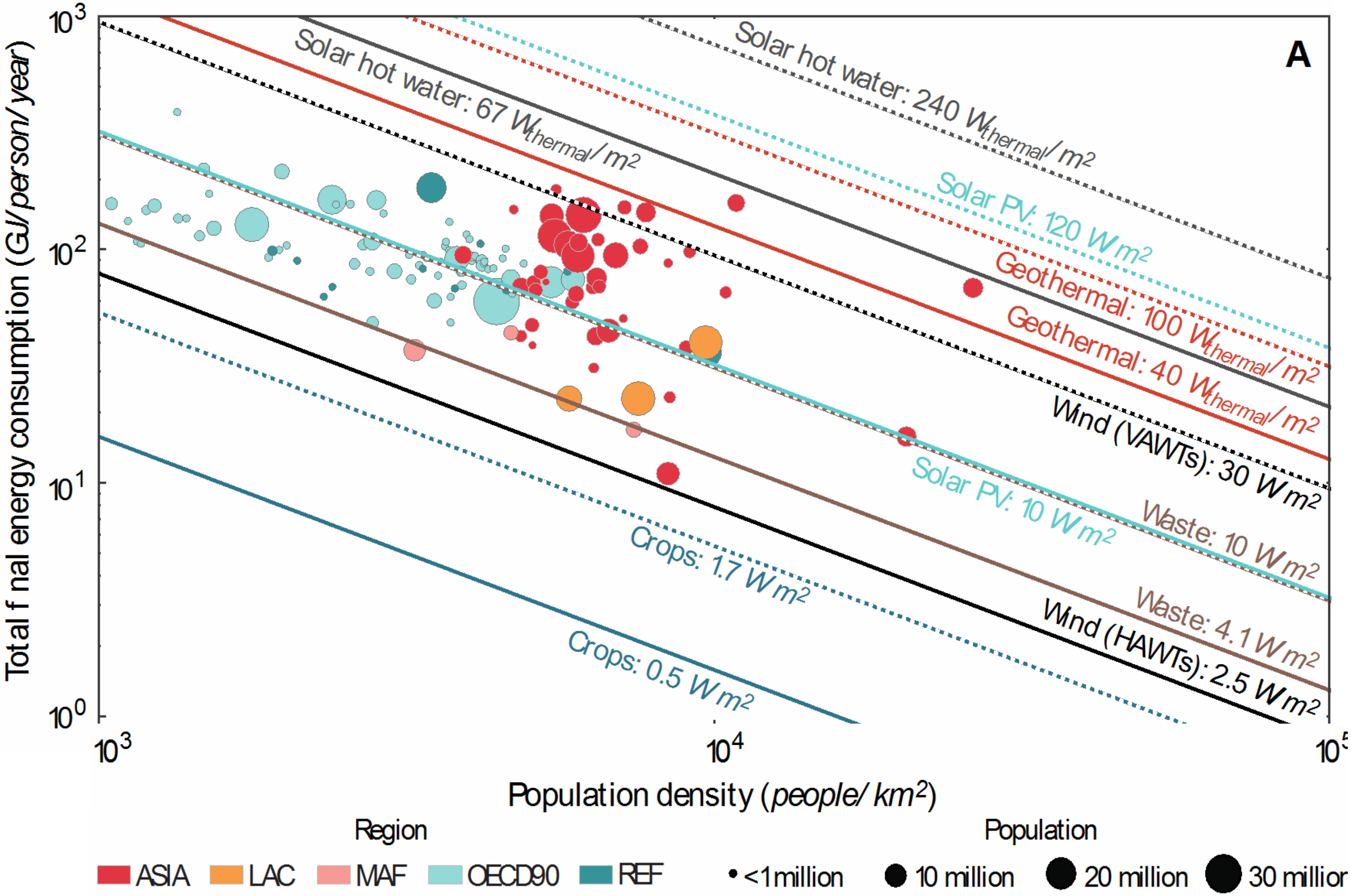
Cities offer an opportunity to rapidly deploy distributed energy resources in dense electricity networks.

- Approximately 54% of global population lives in urban areas
- Cities responsible for 60-70% of anthropogenic greenhouse gas emissions
- Two-thirds of world's population projected to live in urban areas by 2050 → net influx of 2.5 billion people
- Roughly 75% of electricity generated is consumed in cities

But how well do the power densities associated with renewables match power requirements in cities?

Data drawn from: Kammen D, Sunter DA, 2016. City-integrated renewable energy for urban sustainability. *Science*, 352(6288): 922-928.

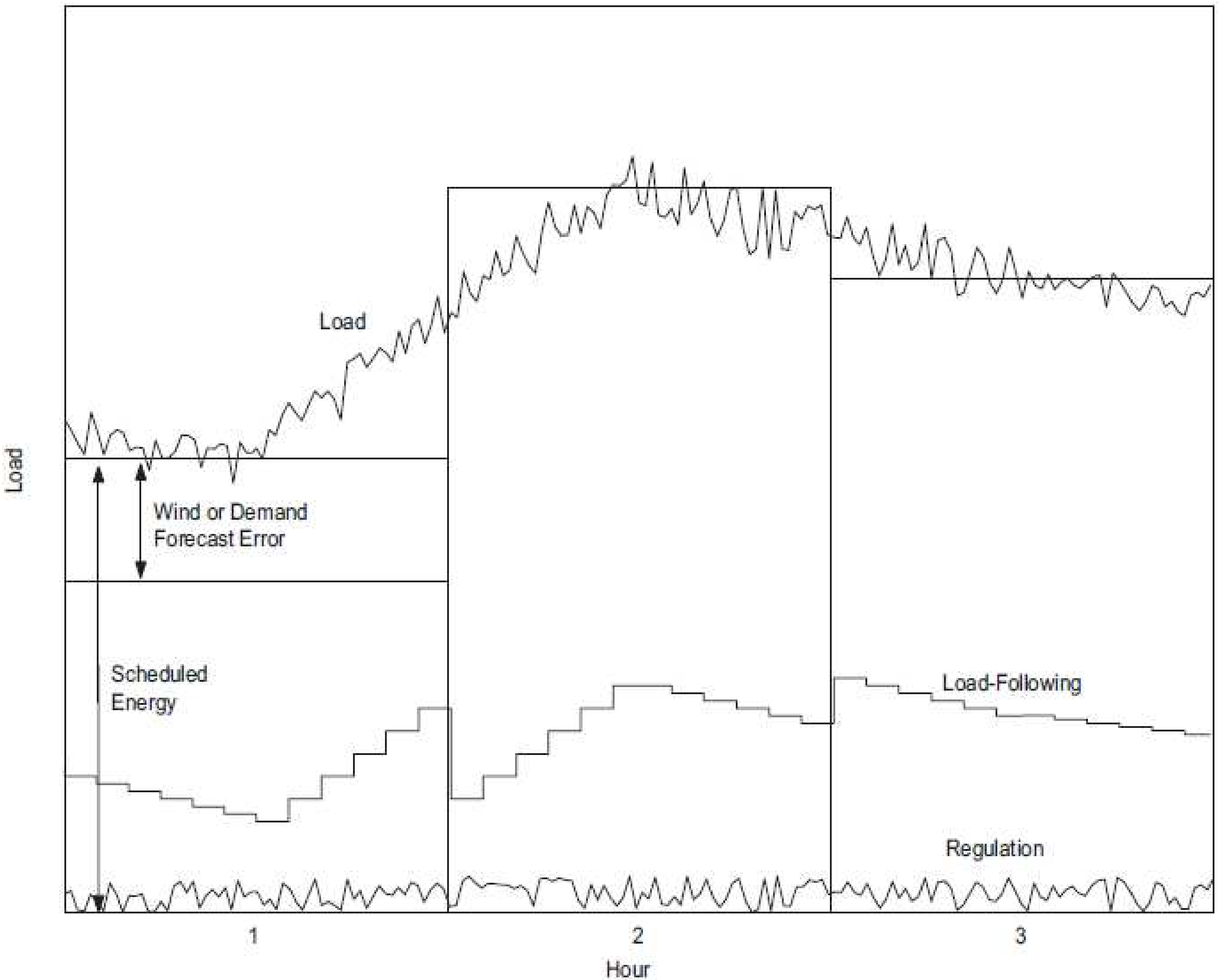
Matching Renewable Supply and Demand



Data drawn from: Kammen D, Sunter DA, 2016. City-integrated renewable energy for urban sustainability. *Science*, 352(6288): 922-928.

The Challenge with Renewable Electricity

System operators must balance supply and demand in real time.



Smart Grids

So not simply a matter of injecting renewable electricity into the grid → requires careful management

Smart Grid integrates traditional upgrades and new grid technologies with renewable generation, storage, increased consumer participation, sensors, communications and computational ability.

Features:

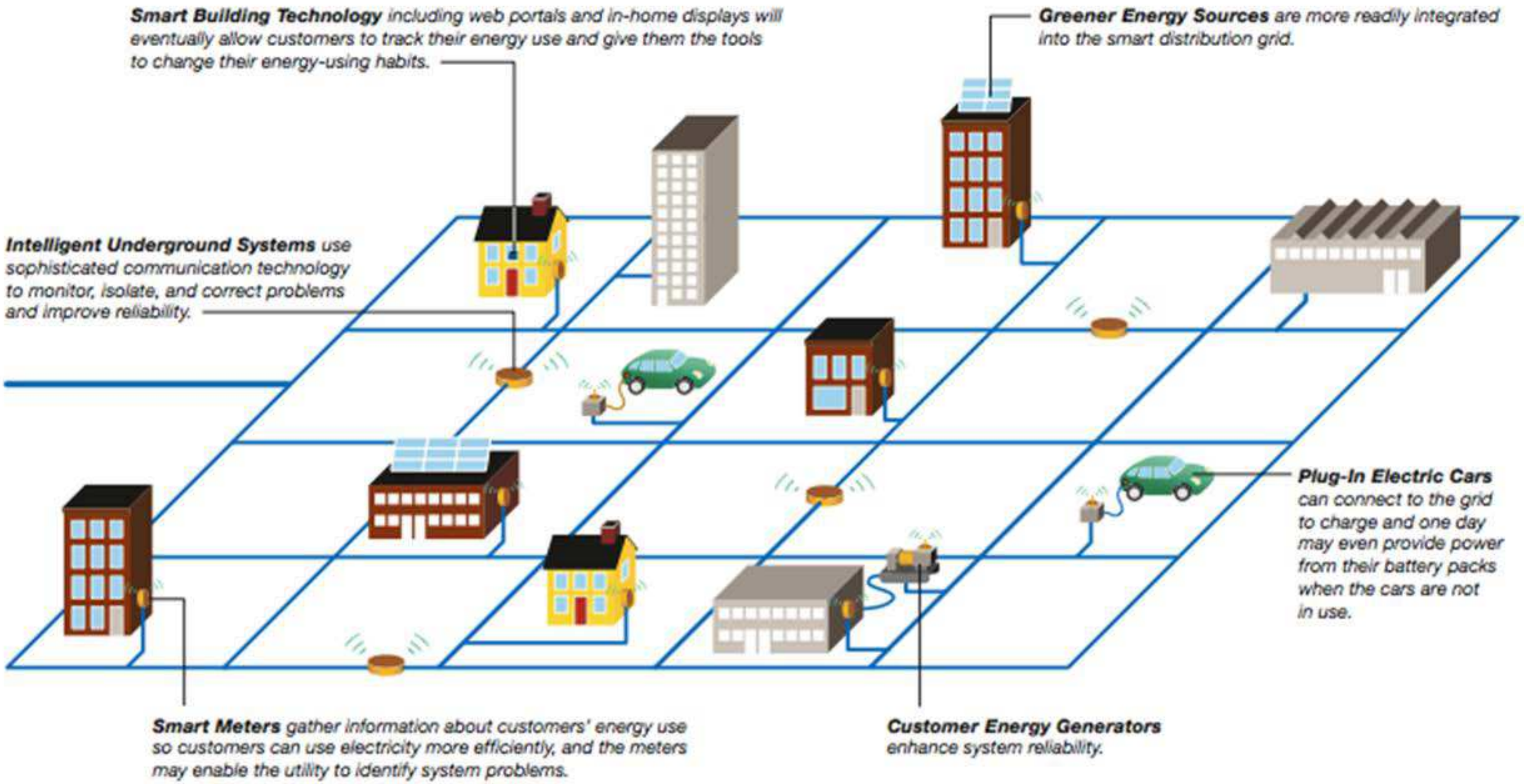
- Two-way flow of electricity and info between utilities and consumers
- Real-time information
- Near-instantaneous balance of supply and demand at the device level

Shift paradigm by using technology to better shape demand to fit variable supply without degrading system performance. Benefits include:

- Greater consumer participation and awareness
- Enhanced system reliability
- Higher deployments of renewables

Source: EPRI (2011): Estimating the Costs and Benefits of the Smart Grid. Palo Alto, CA.

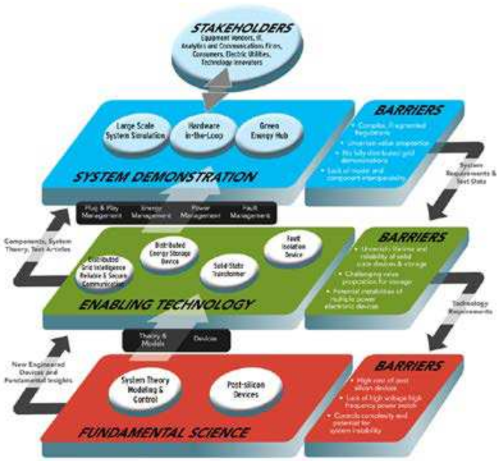
Smart Grid Elements



Where does the FREEDM Center come in?

We need enabling technology to make it work.

Vision is to build an internet for energy: a network of distributed energy resources that intelligently manages power using secure communications and advanced power electronics.



Research priorities:

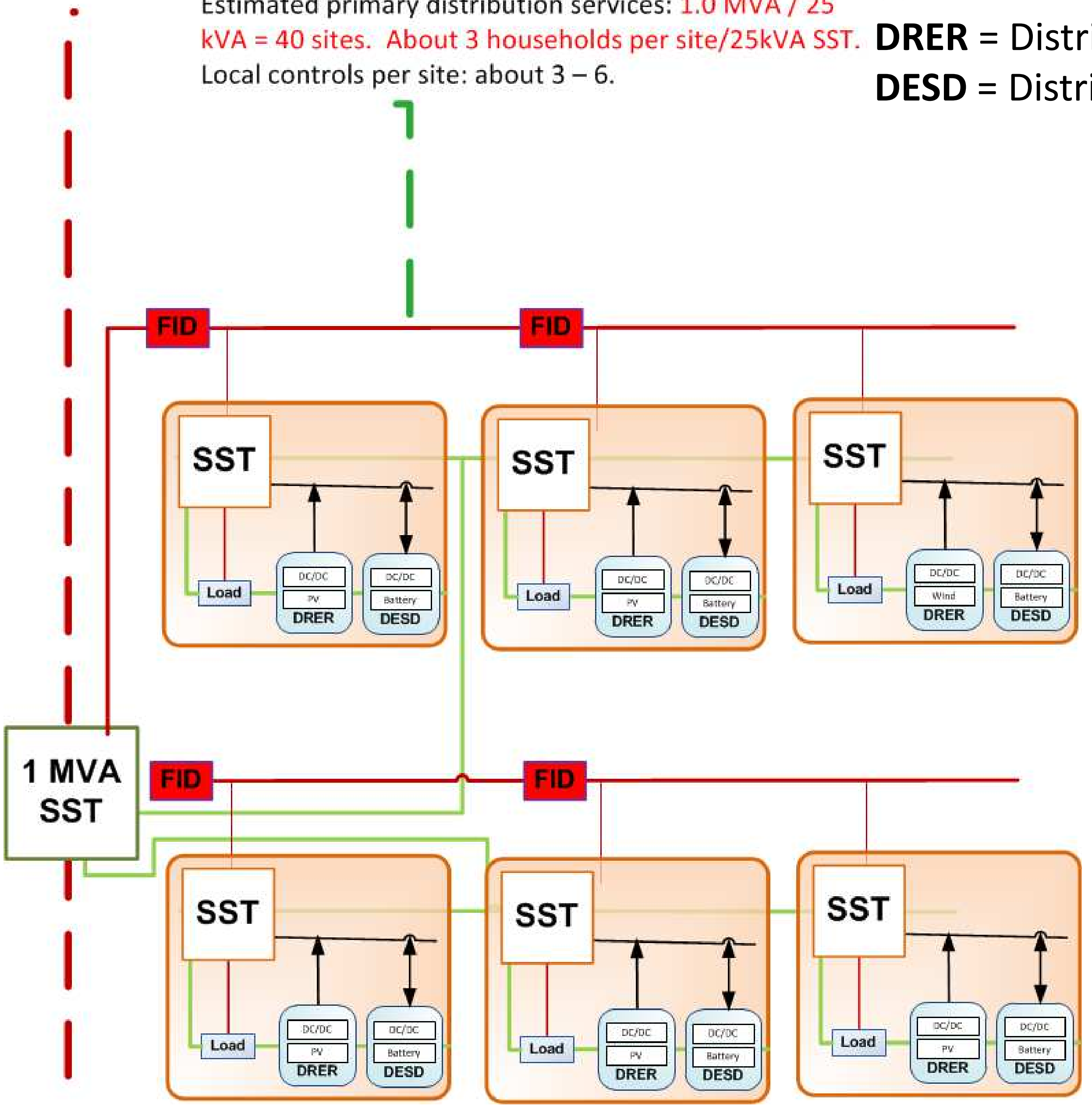
- Power electronics packaging
- Solid state transformers
- Fault isolation devices
- Controls theory
- Power systems simulation and demonstration

Many other technologies will play a supporting role including battery storage, smart thermostats, real-time use monitors and apps.

NCSU FREEDM Center

FID = Fault Interruption Device
SST = Solid State Transformer
DRER = Distributed Renewable Energy Device
DESD = Distributed Energy Storage Device

Estimated primary distribution services: 1.0 MVA / 25 kVA = 40 sites. About 3 households per site/25kVA SST. Local controls per site: about 3 – 6.



Capable of operation with energy from the grid supply, or in islanded mode using only stored energy and distributed resources.

Summary

- Fundamental changes will be required in global electricity supply to mitigate climate change
- Key tradeoffs between centralized and decentralized systems
- Solutions will likely differ by geographically
- Long-term viability of smart grid will be determined by its cost and performance relative to different alternatives
- Future smart grids integrated into urban environments are compelling, but are by no means guaranteed → it will take innovation to make it happen!