The Next 100 Years of Global Energy: Part II
Global Population, Energy Demand, and Future Technology

Steven E. Koonin[1]

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[1]NYU CUSP Director, NYU Stern School of Business, Tandon School of Engineering (steven.koonin@ynu.edu)

Contexts to 2050

Demographic

Growing population
"Older" Developed World, "Younger" Developing world
Urbanization

Economic

Development of MOW
Growing demand for resources (energy demand + 50%)
Leveling of the playing field (U.S. out-of-wack by factor of 4)
Greater regulation, globalization of people, goods, ideas, capital

Energy

Fossil fuels are most common (80%), most reliable, cheapest form of energy
Once in place, the energy system changes slowly

Environmental

Growing environmental impacts ("The only humans who don't pollute …")
Push to reduce human influences on climate (GHG emissions)

Technology Progress

Energy: Abundant, Affordable, Available, Reliable, Clean

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Global Population, Energy Demand, and Future Technology

The Next Hundred Years of Global Energy

AAPG Forum, Houston, 04/04/17

Dr. Steven E. Koonin, NYU CUSP Director
NYU University Professor
Stern School of Business
Tandon School of Engineering School
steven.koonin@nyu.edu
http://cusp.nyu.edu

Contexts to 2050

- **Demographic**
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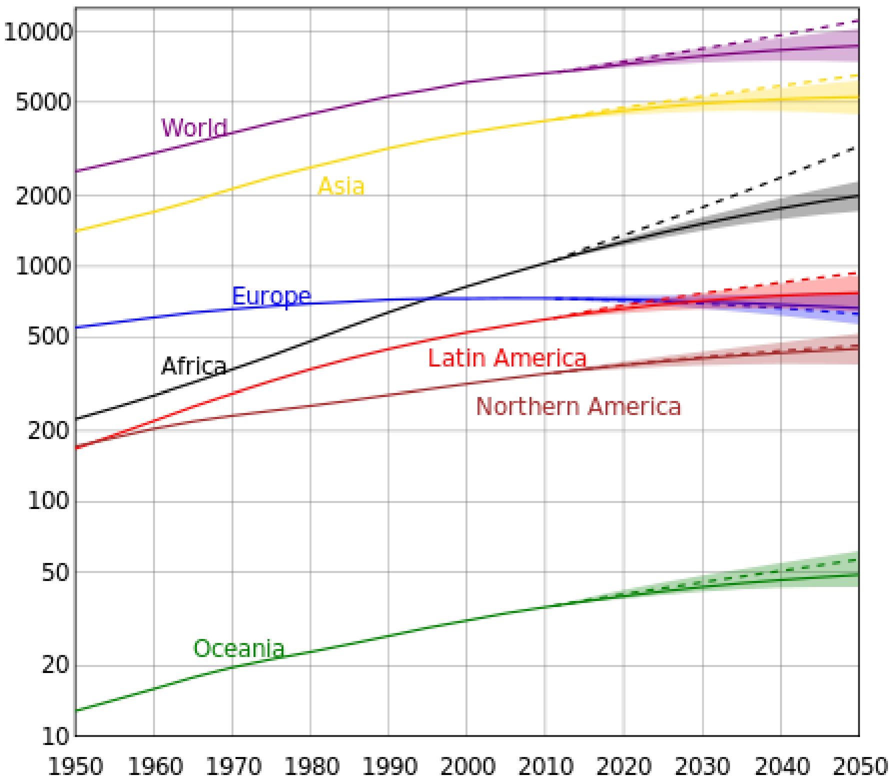
Demography is destiny

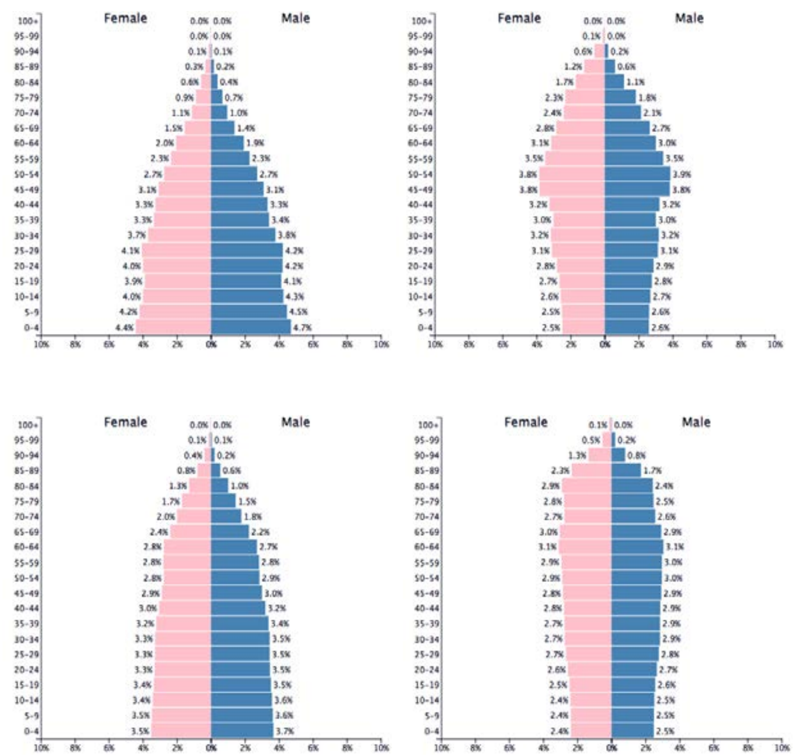
Population Growth



Age pyramids

Global

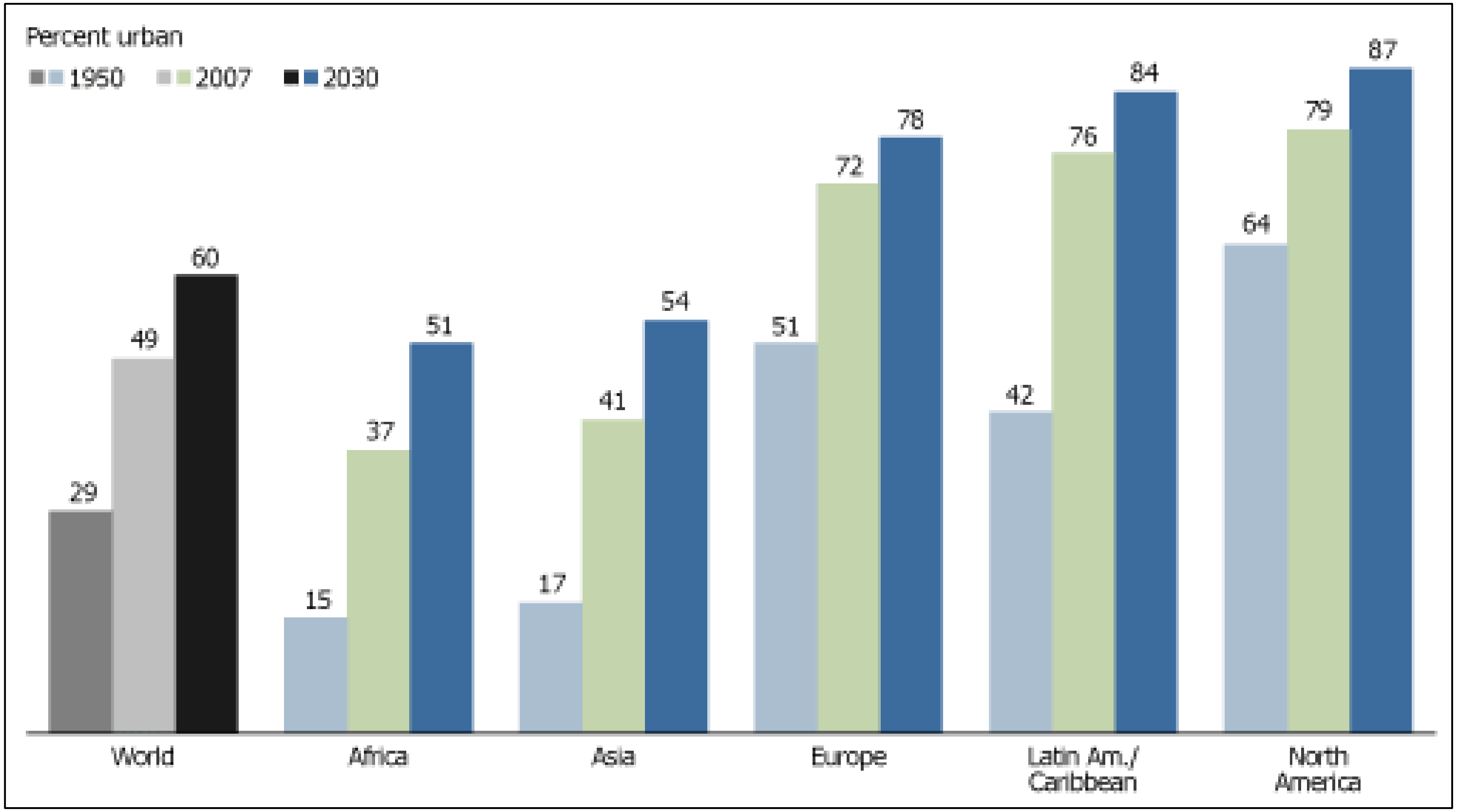
Western Europe



2015

2050

Rapid urbanization



Cities are the loci of consumption, economic activity, and innovation

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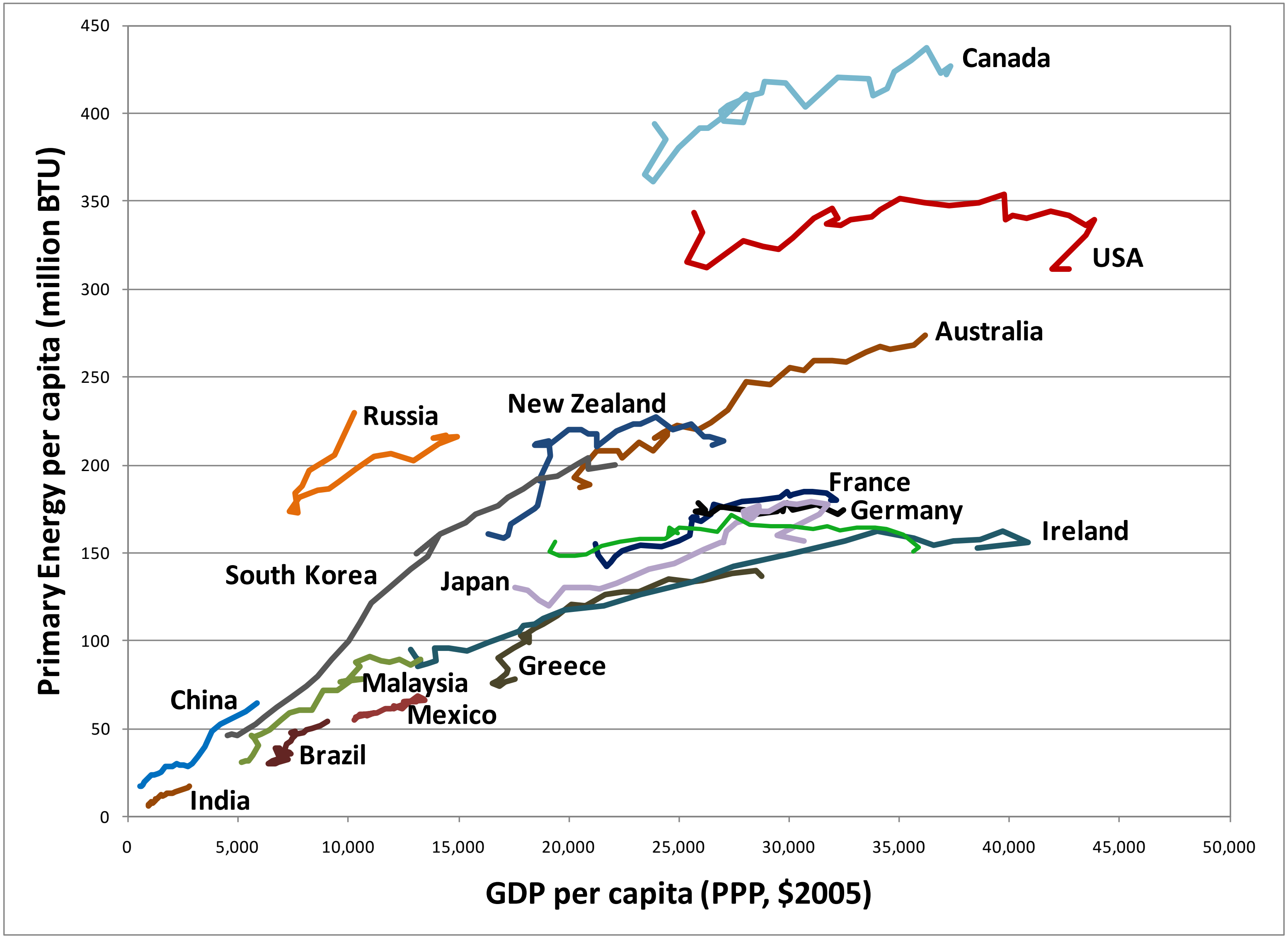
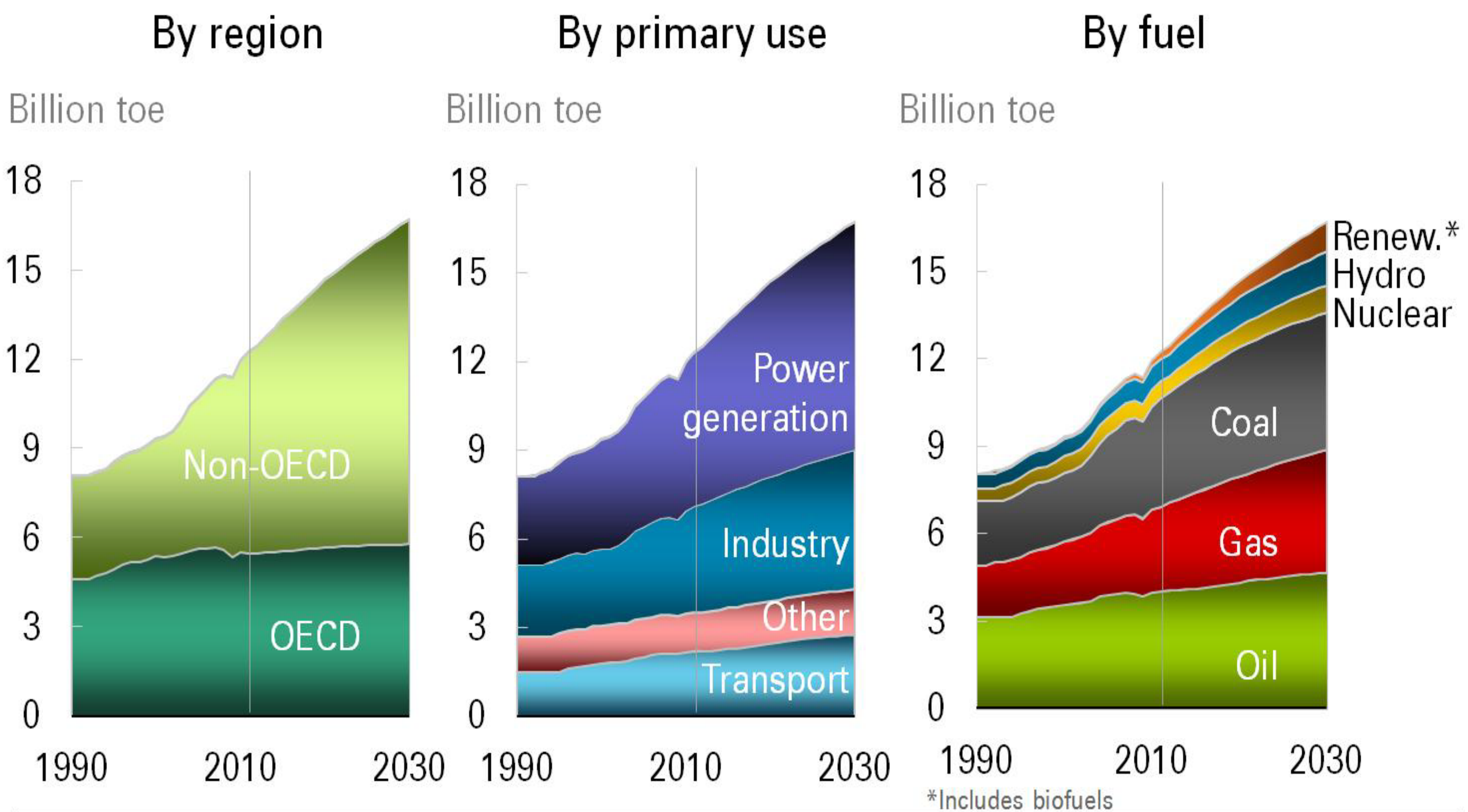
  - Greater regulation, globalization of people, goods, ideas, capital

Energy Use vs. GDP, both per capita (1980-2010)



Source: EIA

Energy demand is rising



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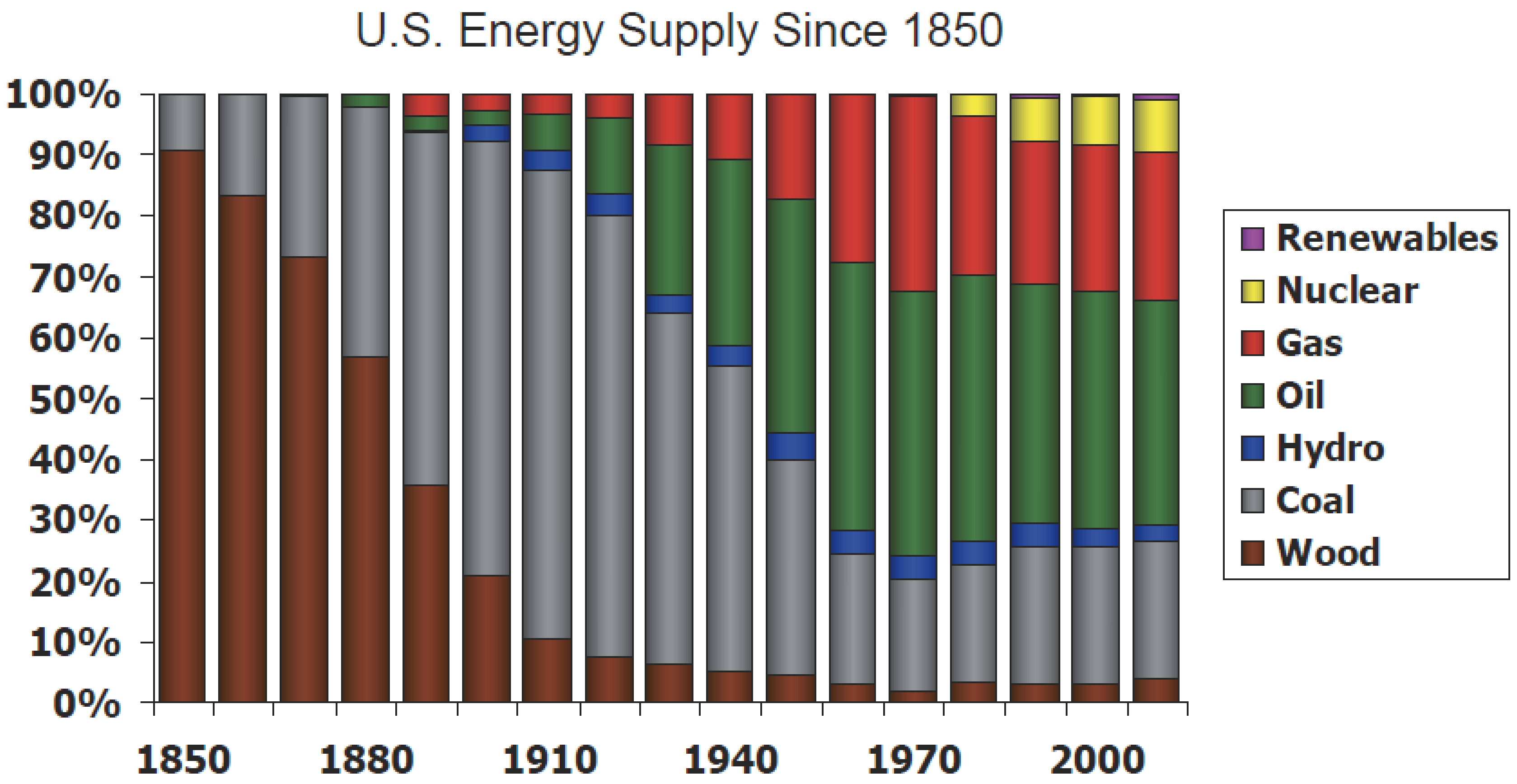
Energy supply has changed on decadal scales



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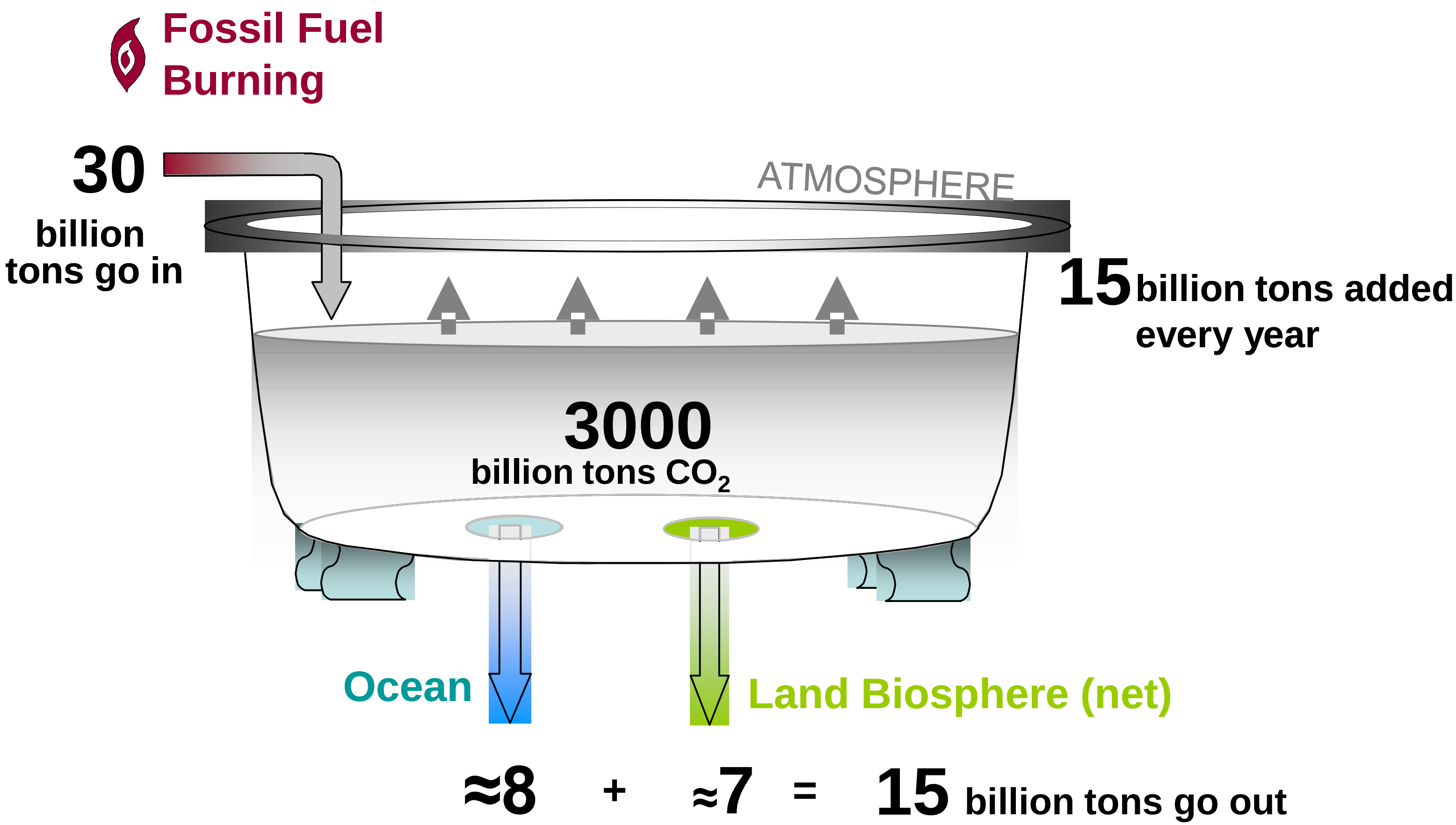
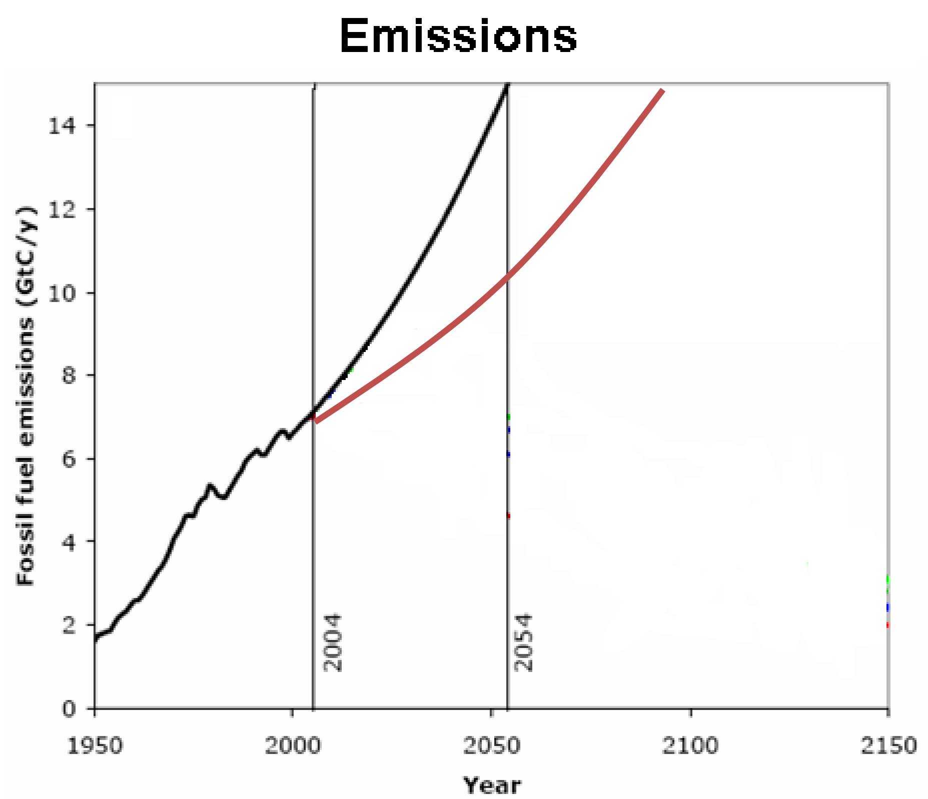
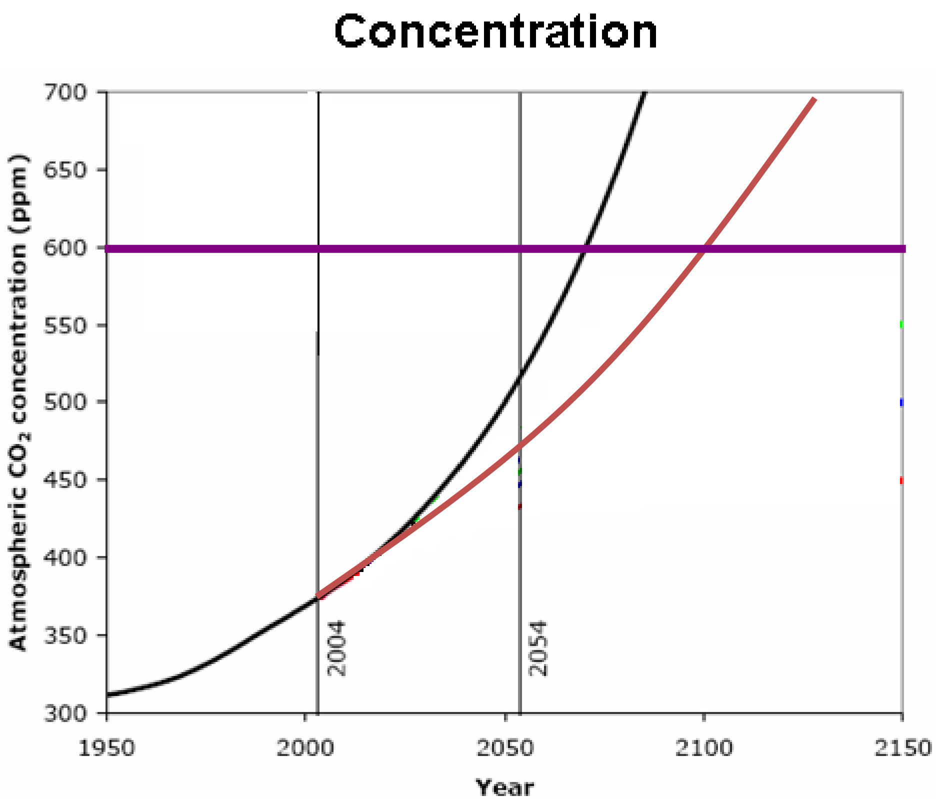
Half of the carbon we emit stays in the atmosphere for centuries



The long CO_2 lifetime is highly problematic





Carbon constraints are severe

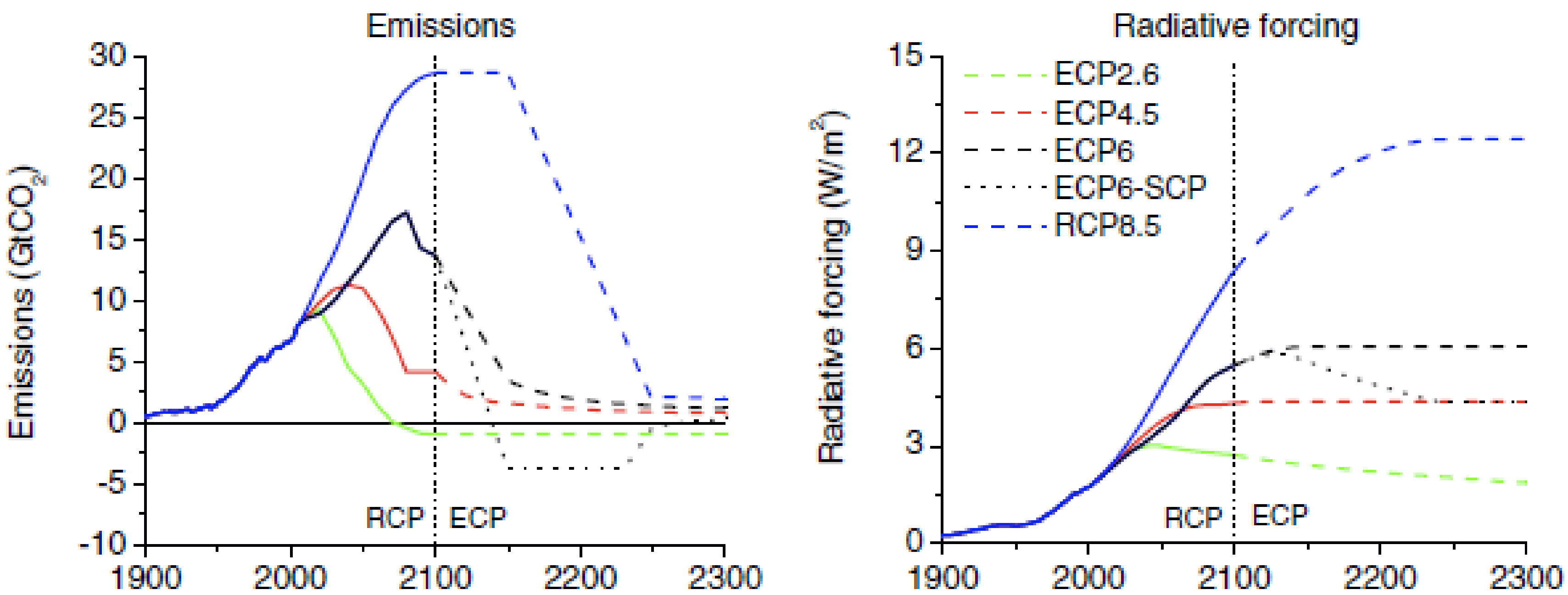
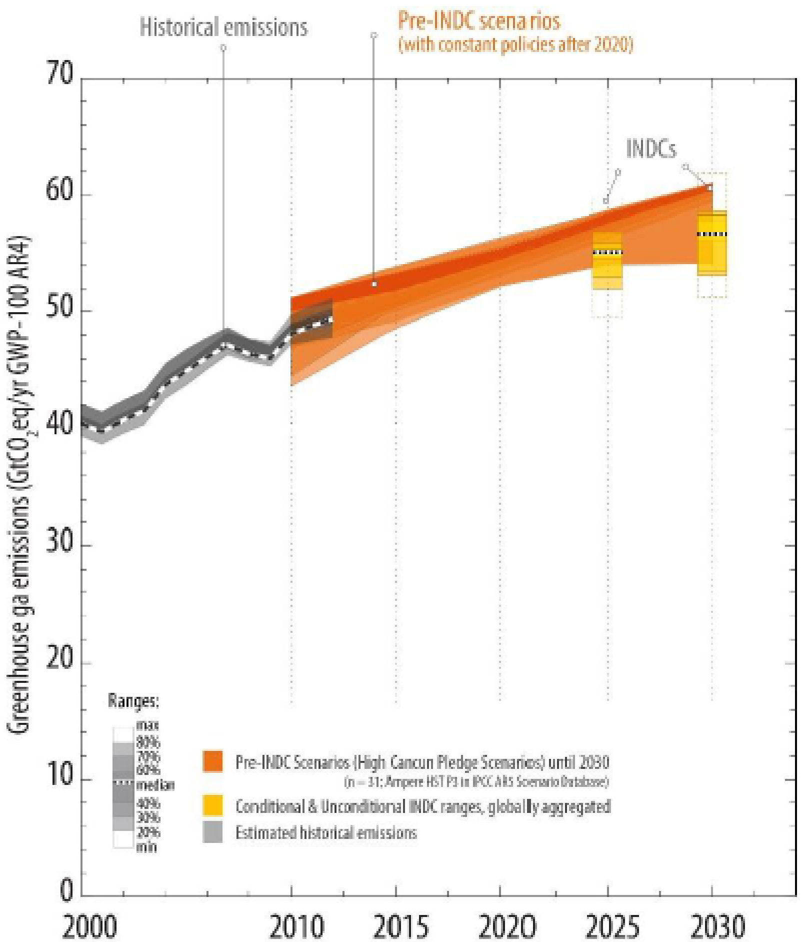
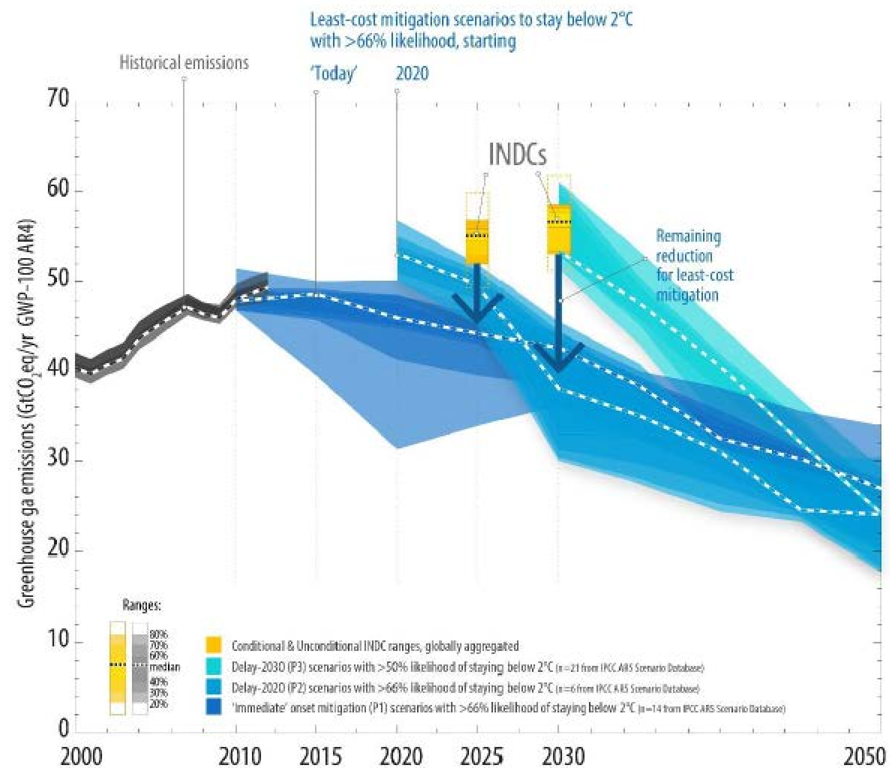


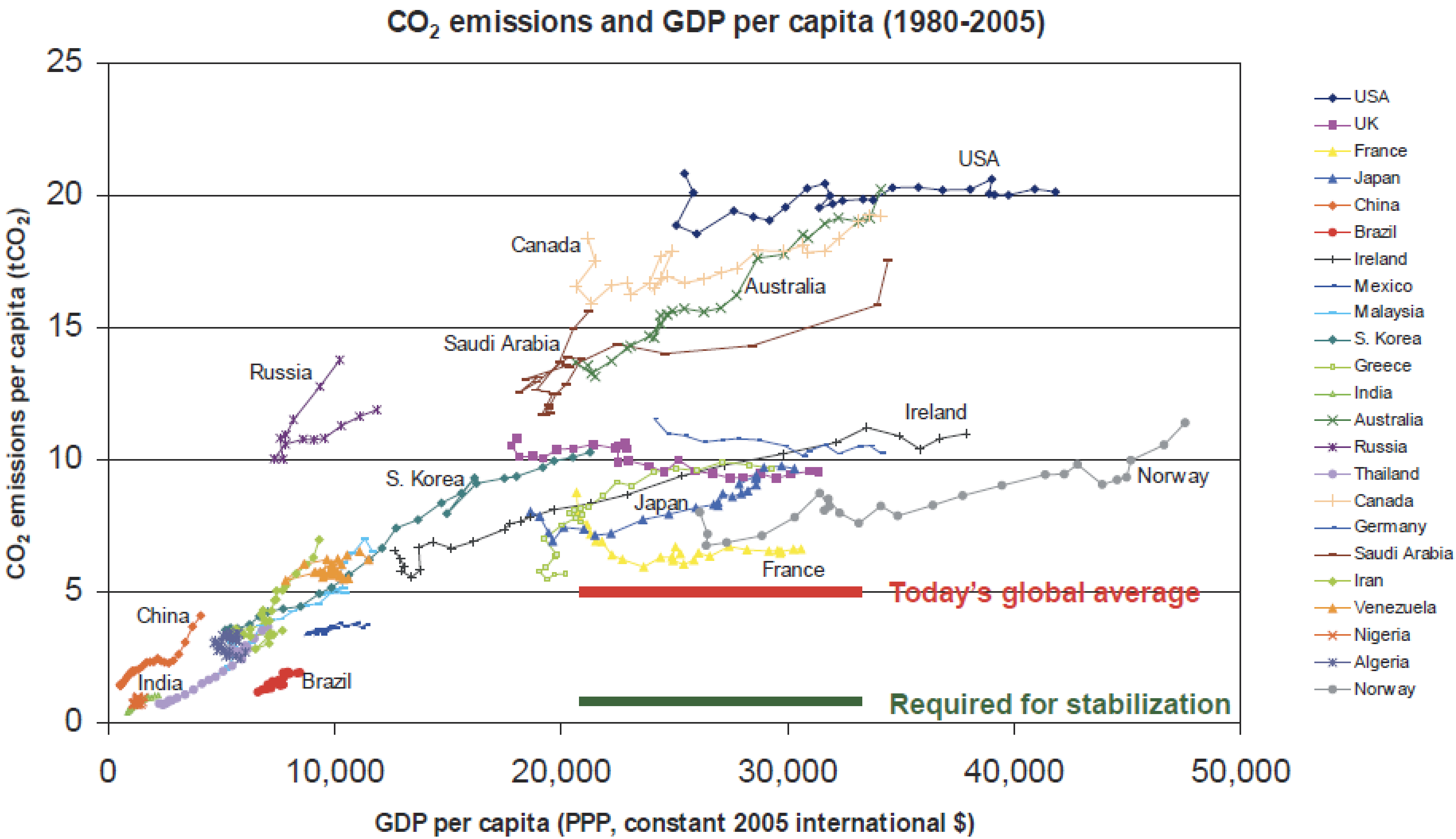
Fig. 11 Extension of the RCPs (radiative forcing and associated CO_2 emissions). ECP is extended concentration pathway. The SCP6to4.5 (supplementary concentration pathway) shows an alternative extension for RCP6 (see main text) (Meinshausen et al. 2011b)

And we’re not making much progress





CO_2 emissions and GDP per capita



Source: DOE EIA database (2008)
Russia data 1992-2005, Germany data 1991-2005

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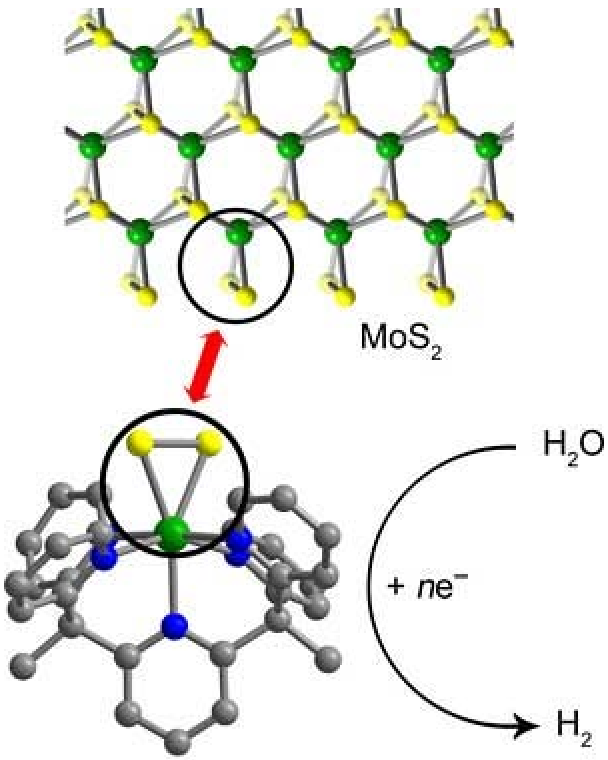
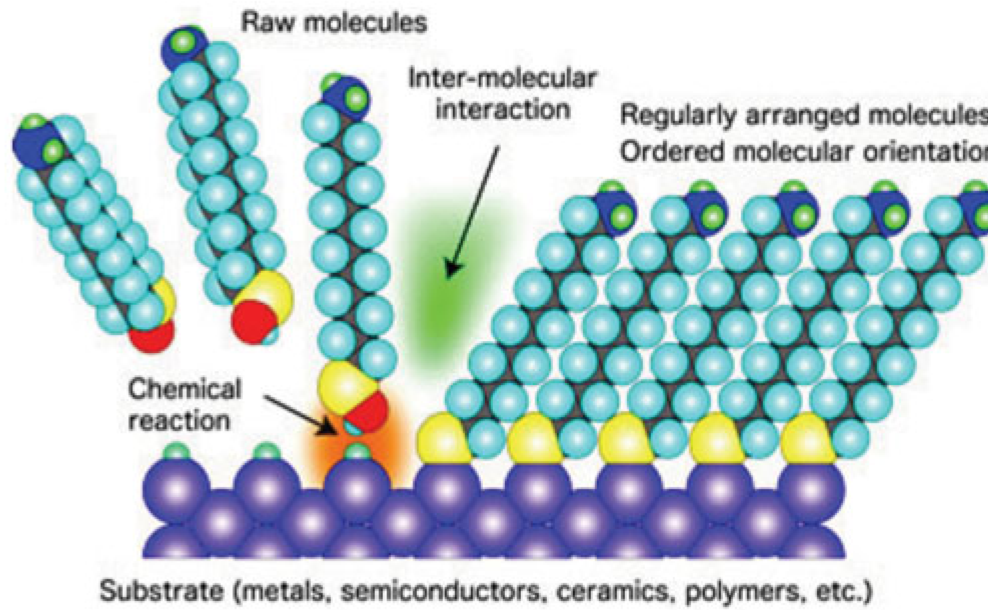
- **Technology progress**

Energy: Abundant, Affordable, Available, Reliable, Clean

FOUNDATIONAL TECHNOLOGIES TO WATCH

Molecular/materials design





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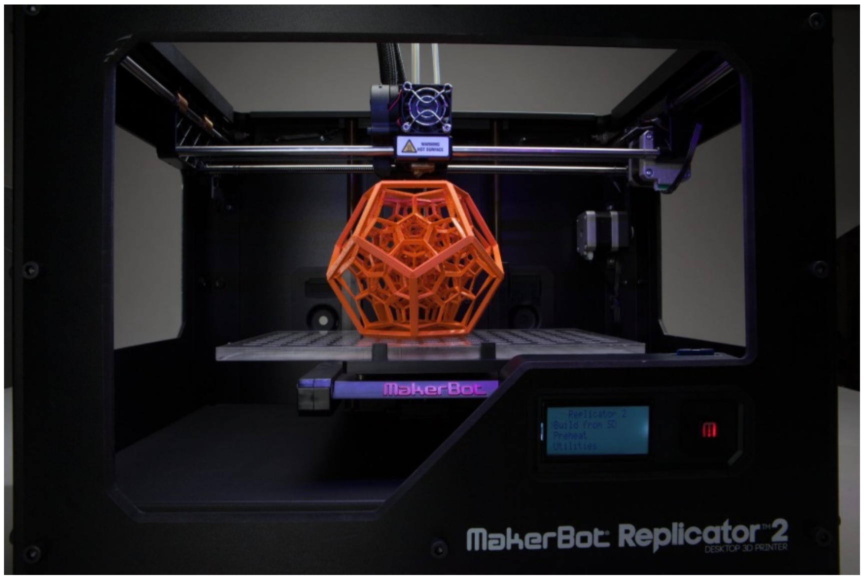
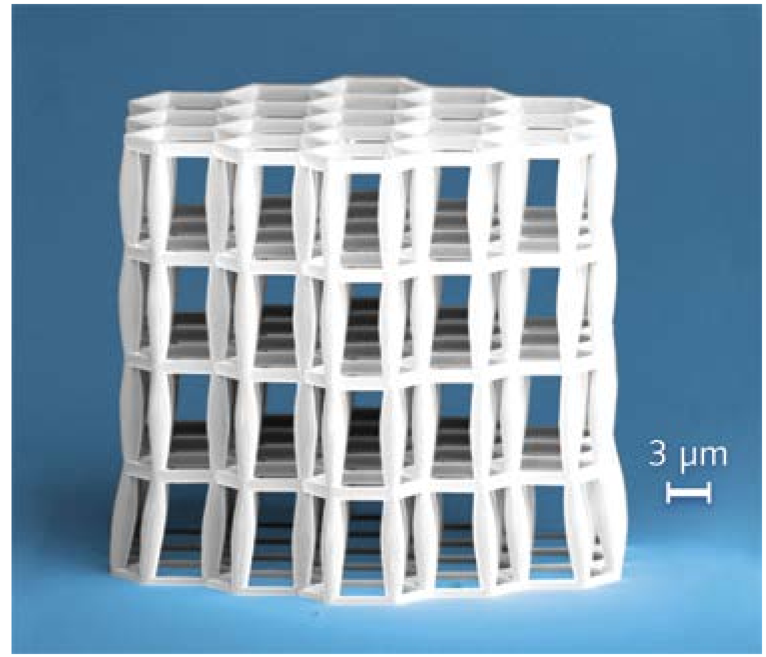
Additive manufacturing

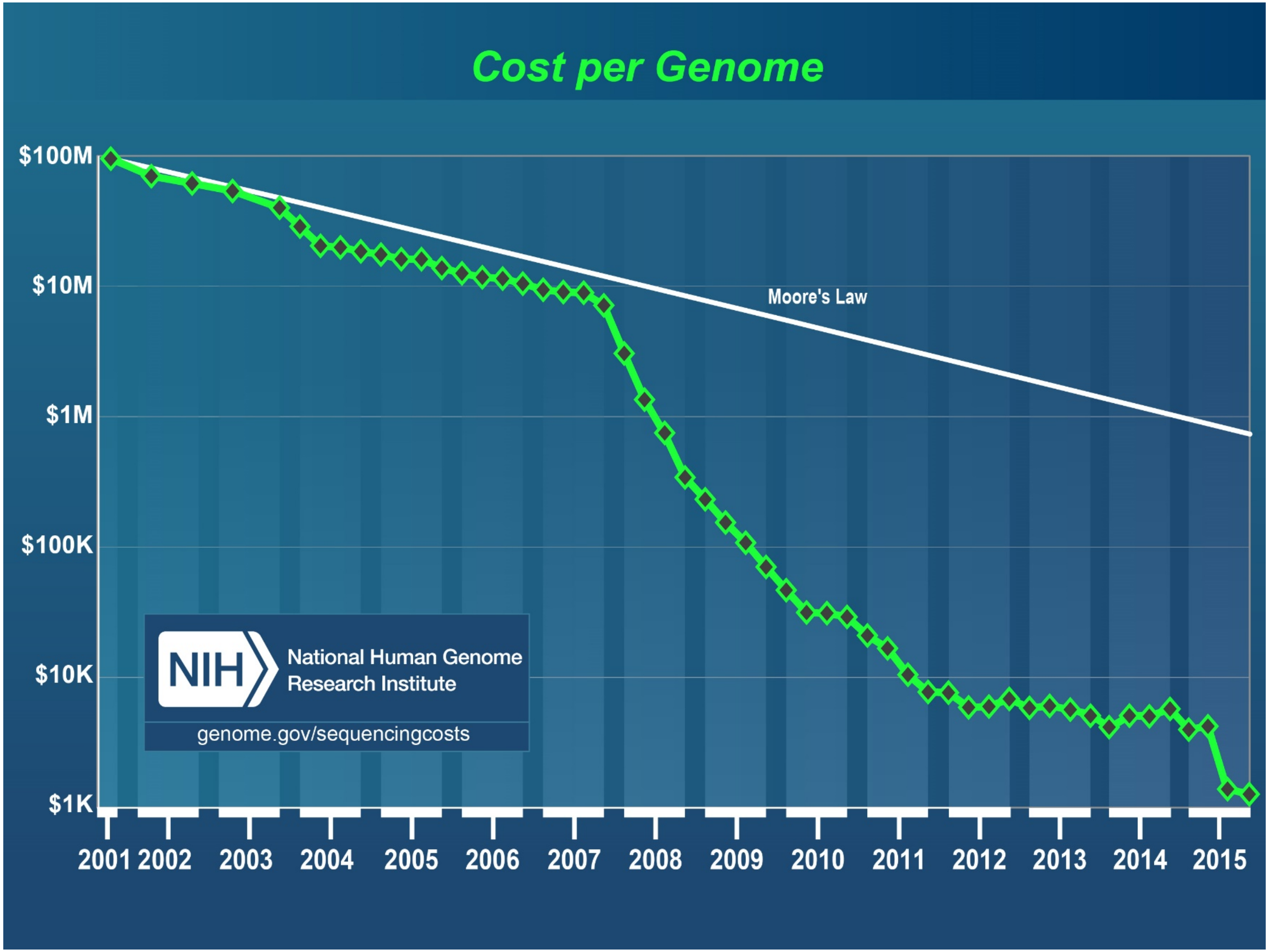




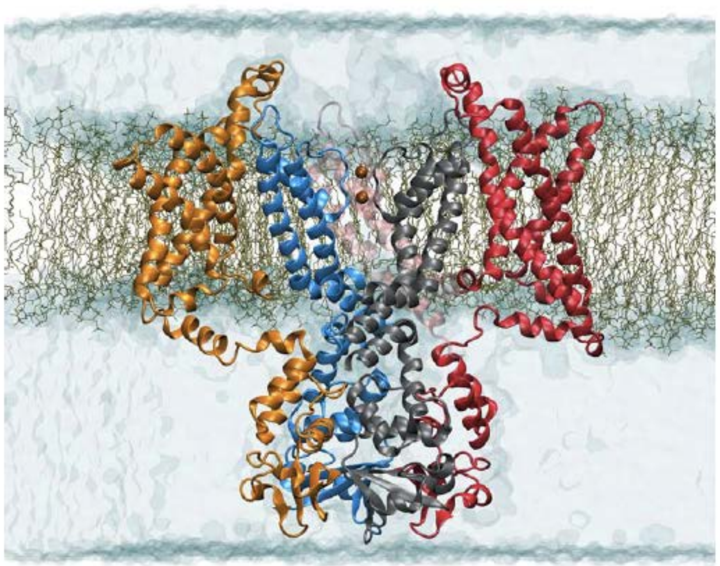
http://www.laserfocusworld.com/articles/print/volume-50/issue-08/features/lasers-for-3d-printing-additive-manufacturing-with-nir-lasers-forms-micro-sized-parts.html

BIO technologies

Sequencing costs have come down



Biomolecular structure/function

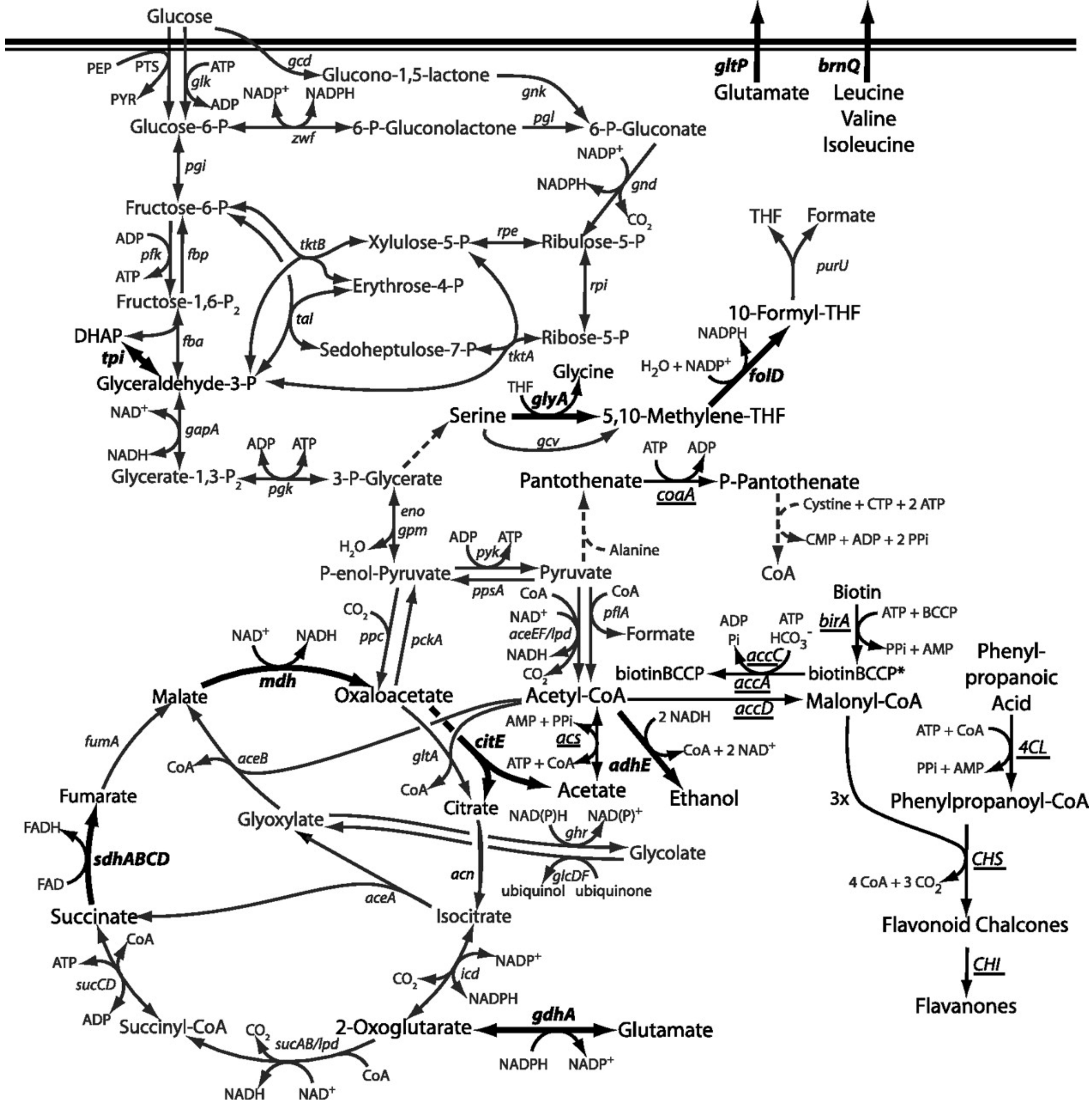


Motivating Example: Large-scale Simulation of Ion Channels

Voltage-gated ion channels, or Kv channels, are involved in the generation and spread of electrical signals in neurons, muscle, and other excitable cells. In order to open the gate of a channel, the electric field across the cellular membrane acts on specific charged amino acids that are strategically placed in the protein in a region called the voltage sensor. In humans, malfunction of these proteins, sometimes owing to the misbehavior of only a few atoms, can result in neurological diseases. A wealth of experimental data exists from a wide range of approaches, but its interpretation is complex. One must ultimately be able to visualize atom-by-atom how these tiny mechanical devices move and change their shape as a function of time while they perform. Researchers are using a tight integration of experiment, modeling, and simulation to gain insights into Kv channels. Their studies serve as a roadmap for simulating, visualizing, and elucidating the inner workings of these nanoscale molecular machines. Because these channels are functional electromechanical devices, they could be used in the design of artificial switches in various nanotechnologies. The practical applications of this work are significant. For example, the research in ion channel mechanisms may help identify strategies for treating cardiovascular disorders such as long-QT syndrome, which causes irregular heart rhythms and is associated with more than 3,000 sudden deaths each year in children and young adults in the United States. Moreover, the studies may help researchers find a way to switch or block the action of toxins – such as those emitted by scorpions and bees – that plug the ion channel pores in humans.

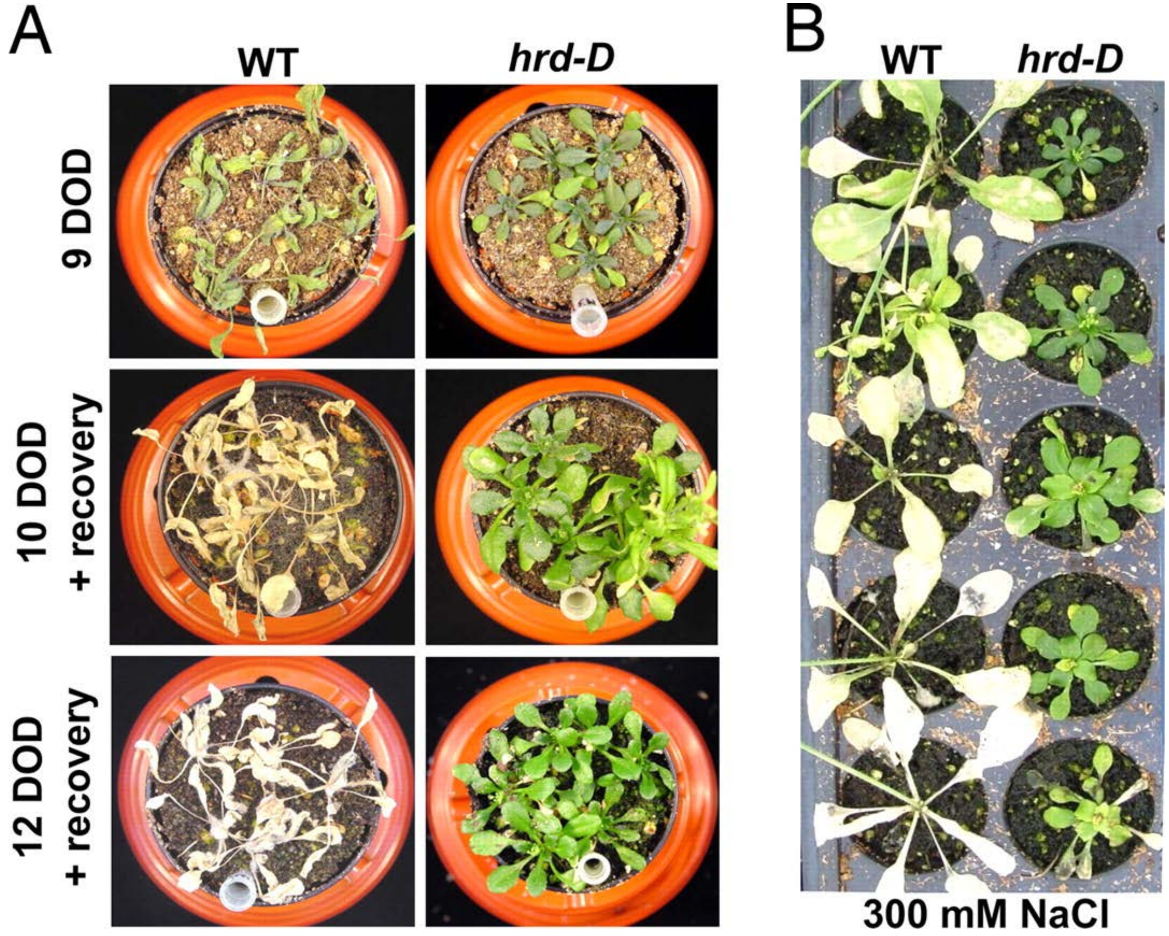
Figure 9: Complete model of the Kv1.2 channel assembled using the Rosetta method. The atomic model comprises 1,560 amino acids, 645 lipid molecules, 80,850 water molecules and ~300K+ and Cl- ion pairs. In total, there are more than 350,000 atoms in the system. The simulations were generated by using NAMD on the Cray X-T (Jaguar) at Oak Ridge National Laboratory and the Blue Gene/P at Argonne National Laboratory. Image courtesy of Benoit Roux, Argonne National Laboratory and University of Chicago

E. coli metabolic network



http://aem.asm.org/content/75/18/5831/F2.expansion.html

We can do amazing things with plants

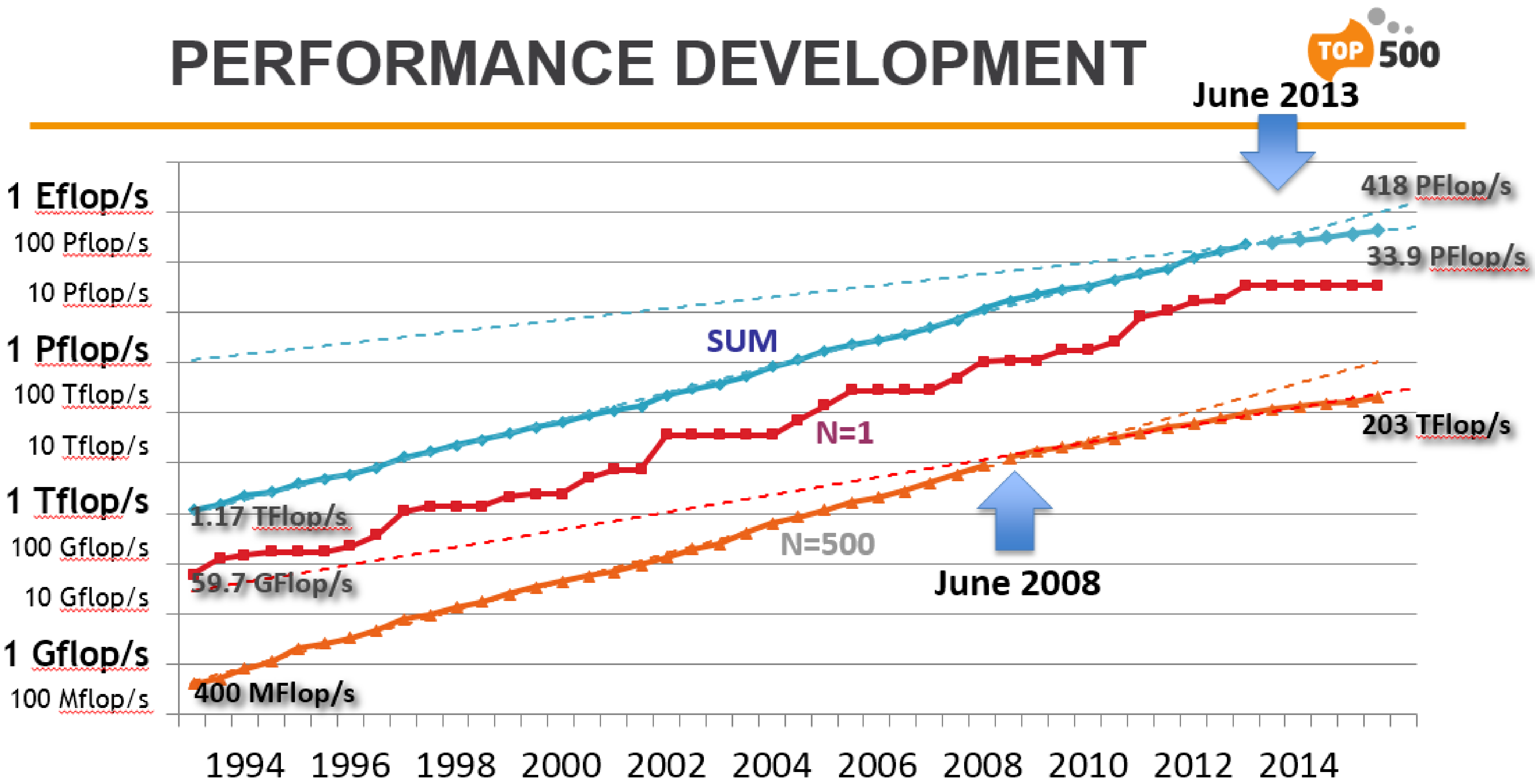


Stress tolerance/resistance by overexpression of *HRD* in *Arabidopsis*. (*A*) Drought-resistance tests of *Arabidopsis* WT and the *hrd-D* mutant line, treated for 9–12 days without water. The first row is at 9 days of dehydration (DOD), followed by plants treated for 11 and 12 DOD that were subsequently watered to reveal surviving plants. (*B*) Mutant *hrd-D* and WT *Arabidopsis* treated at 300 mM NaCl concentrations, showing bleached/dead plants and surviving *hrd-D* plants.

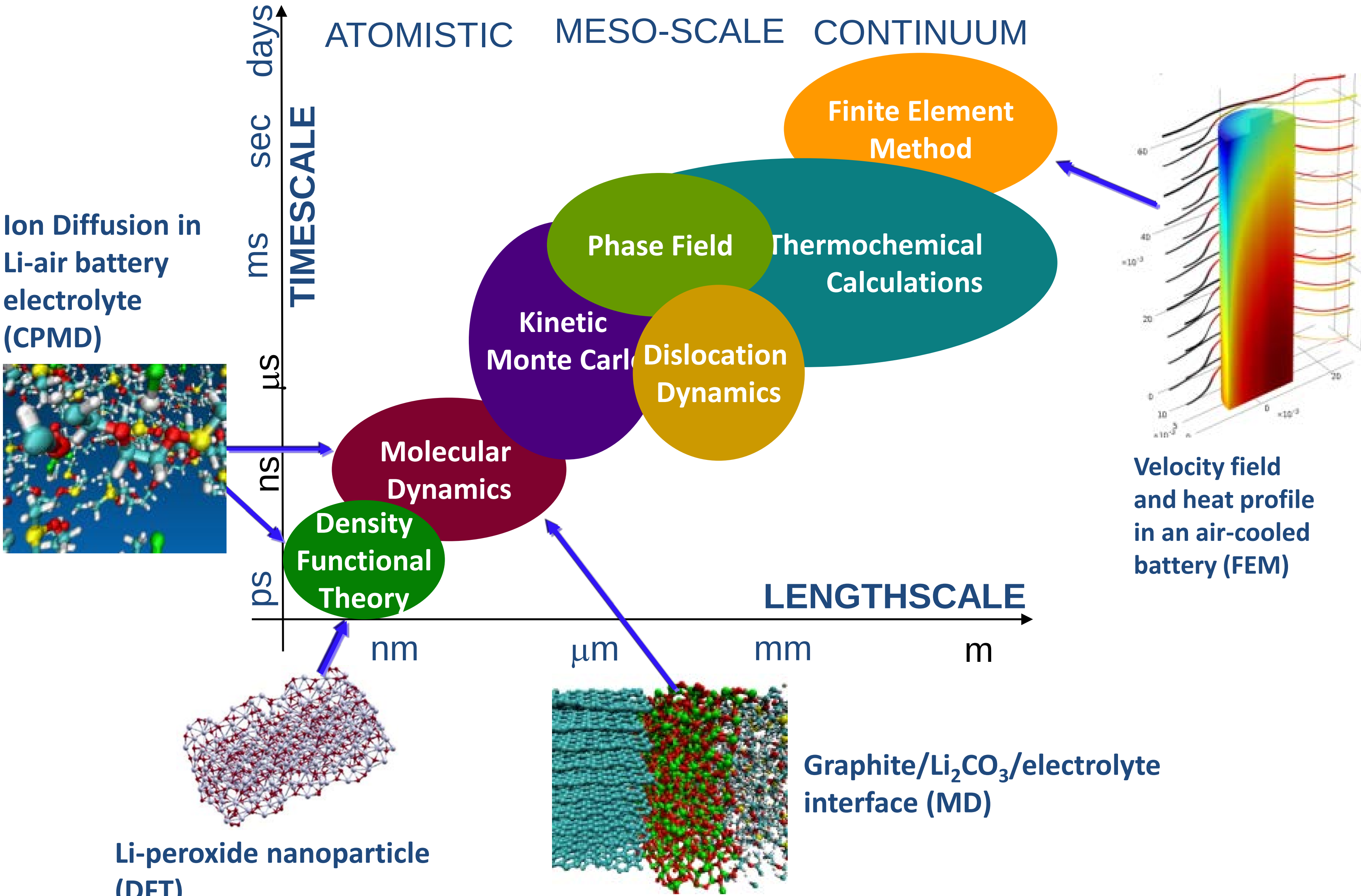
http://www.pnas.org/content/104/39/15270/F3.expansion.html

INFO technologies

Top 500 computer systems



Multi-scale Theory and Computation – "Battery Computer Simulator"



Adaptive Control of Subsurface Fractures, Reactions & Flow

Wellbore Integrity & Drilling Technology

- Materials: adaptive cements, muds, casings
- Real time, in-situ data acquisition and transmission system
- Diagnostics tools, remediation tools and techniques
- Quantification of material/seal fatigue and failure
- Advanced drilling and completion tools (e.g. centralizers)
- Well abandonment analysis/ R&D

Subsurface Stress & Induced Seismicity

- Stress state beyond the borehole
- Signal acquisition and processing and inversion
- Localized manipulation of subsurface stress
- Risk assessment

Fracture & Flow Control

- Physicochemical rock physics , including fluid-rock interactions
- New approaches to remotely characterize in-situ fractures and to monitor fracture initiation/branching and fluid flow.
- Manipulating (enhancing, reducing and eliminating) flow paths
- Novel stimulation methods

New Subsurface Signals

- Diagnostic signatures of system behavior and critical thresholds
- Autonomous acquisition, processing and assimilation approaches
- Approaches to integrate different measurements collected over various support scales to quantify critical parameters and improve spatial and temporal resolutions

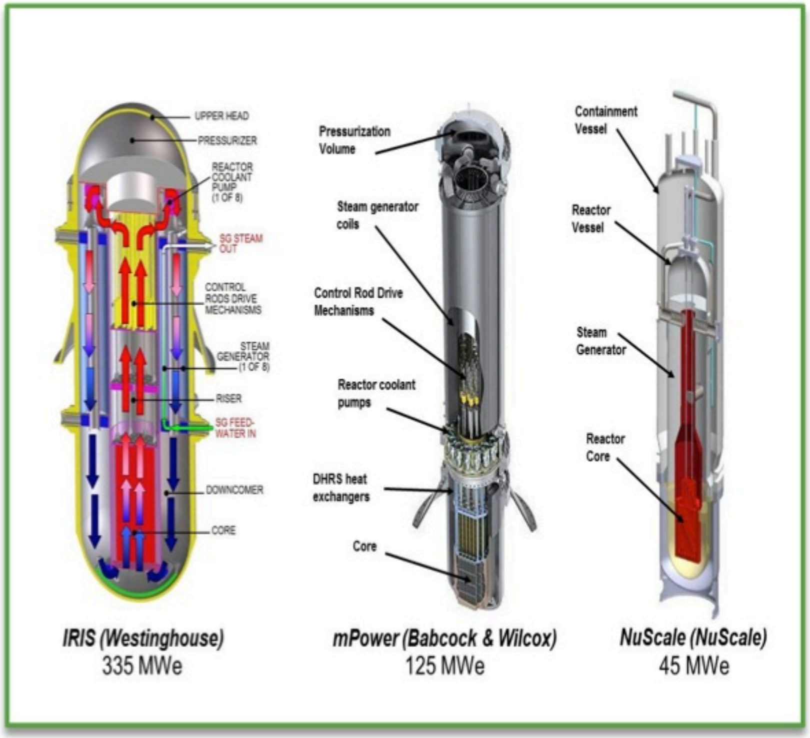
Fit For Purpose Simulation Capabilities

- Simulation of multi-scale T-H-M-C processes and dynamic fracture propagation
- Decision support
- Adaptive control strategies
- Joint inversion of multiple data streams

Energy technologies

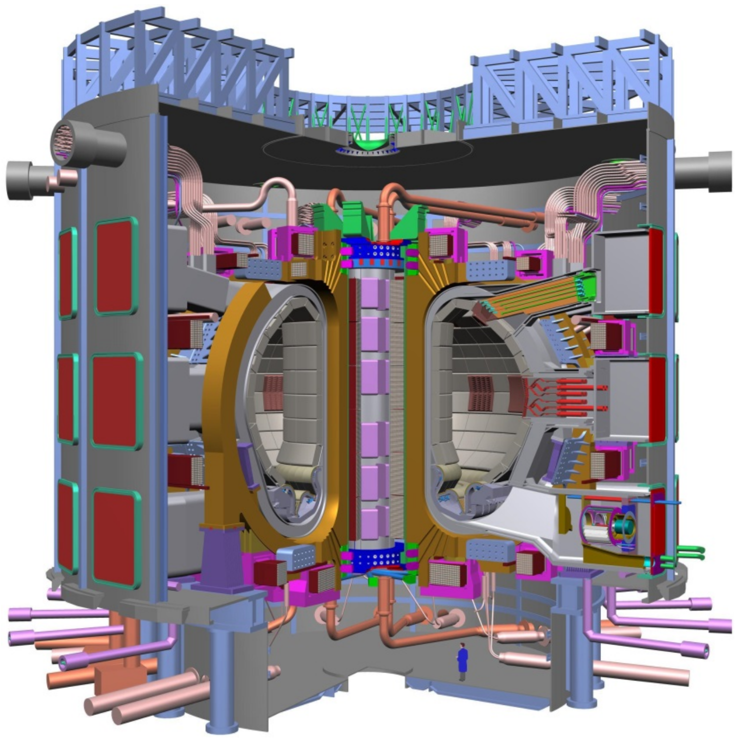
Fission

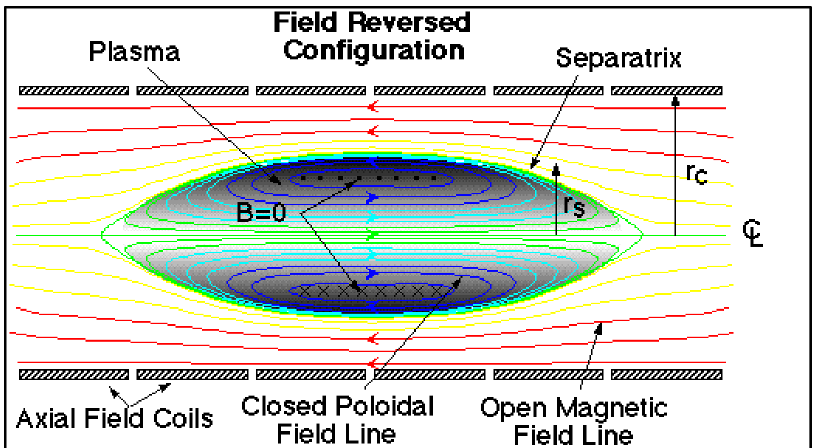
- Existing
  - LWR life extension (materials)
  - Waste management (science + politics; Yucca)
- New
  - $7 gas constraint
  - Small modular reactors
  - Advanced designs (thorium, HTGR, travelling wave, …) all questionable

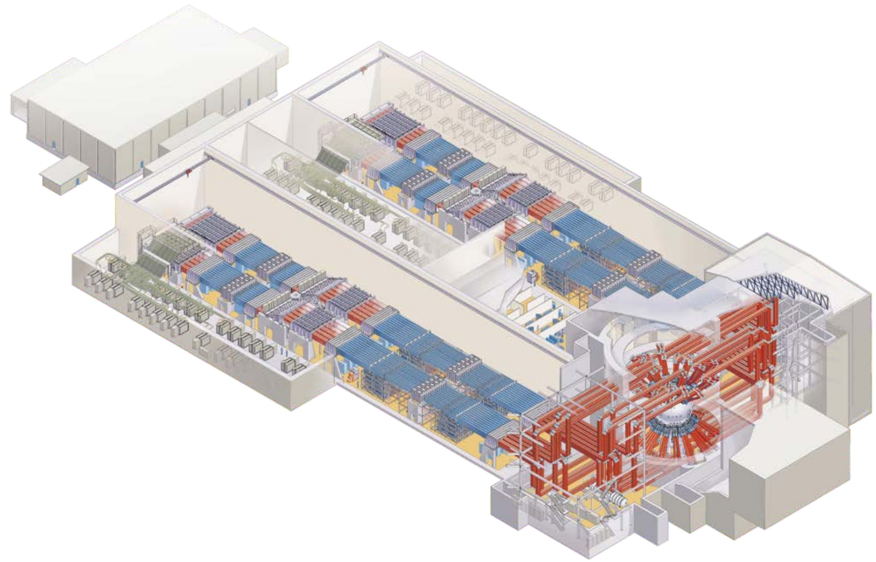


Fusion Energy Concepts

Tokomak - ITER







Inertial Confinement Fusion - NIF

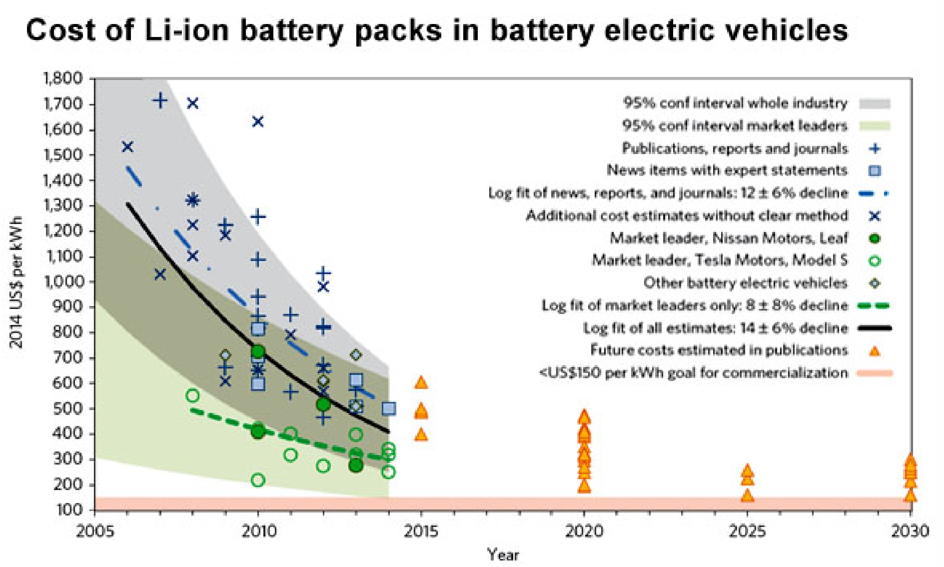
LDV electrification is incipient

Electric vehicles

The year 2015 saw the global threshold of 1 million electric cars[1] on the road exceeded, closing at 1.26 million. In 2014, only about half of today's electric car stock existed. In 2005, electric cars were still measured in hundreds. 2015 also saw more than 200 million electric two wheelers on the road, and 170 000 buses, primarily in China.

Evolution of the global electric car stock, 2010-15

Key point: The uptake of electric cars has been growing since 2010, with a BEV uptake slightly ahead of PHEV uptake. 80% of the electric cars on road worldwide are located in the United States, China, Japan, the Netherlands and Norway.



"Rapidly Falling Costs of Battery Packs for Electric Vehicles," *Nature Climate Change*, 2015

Fleet penetration of plug-ins

- <1% now
- <10% by 2030
- ~50% by 2050

\+ autonomy + connectivity

THANK YOU