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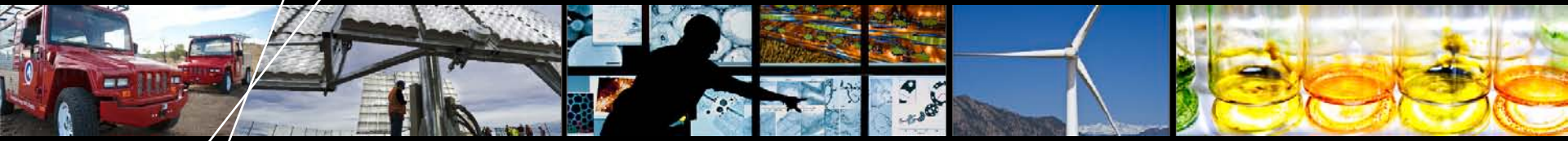
NATIONAL RENEWABLE ENERGY LABORATORY

Realizing a Clean Energy Future

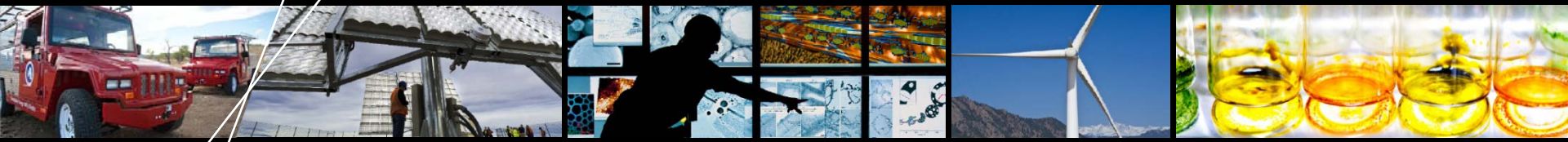


World Renewable Energy Forum 2012

Dr. Dan E. Arvizu

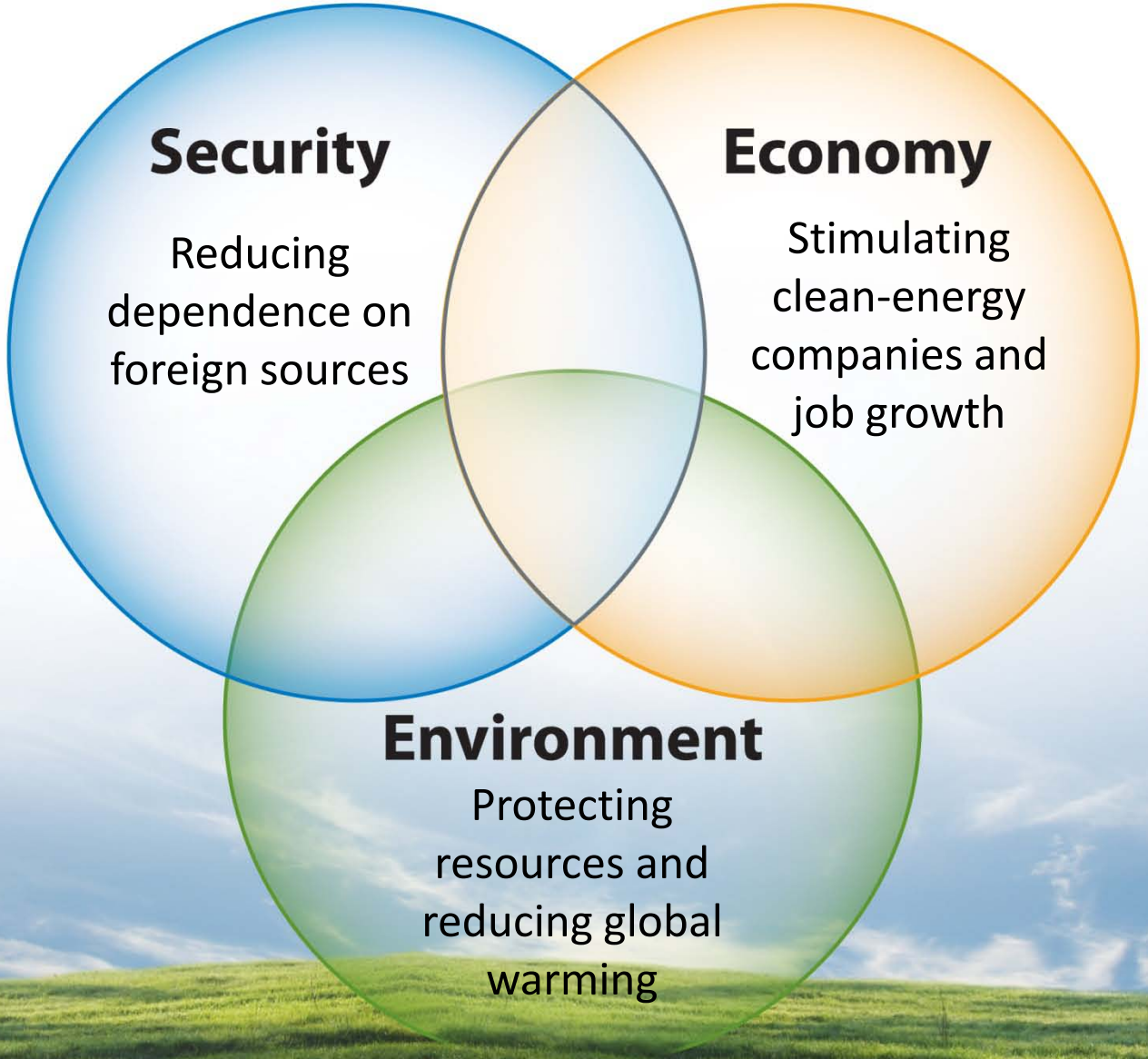
Laboratory Director

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

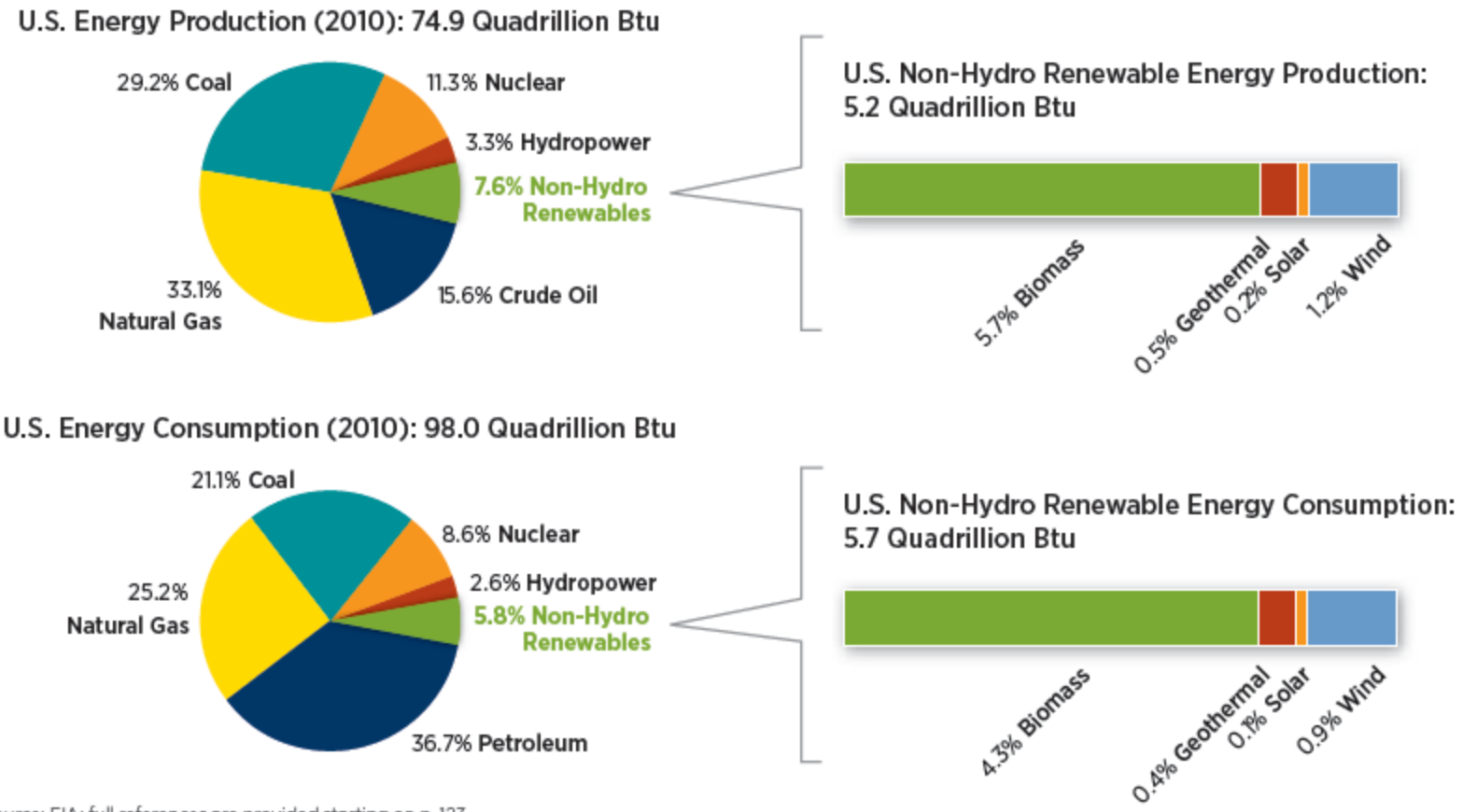


Energy Context

National Energy Imperatives



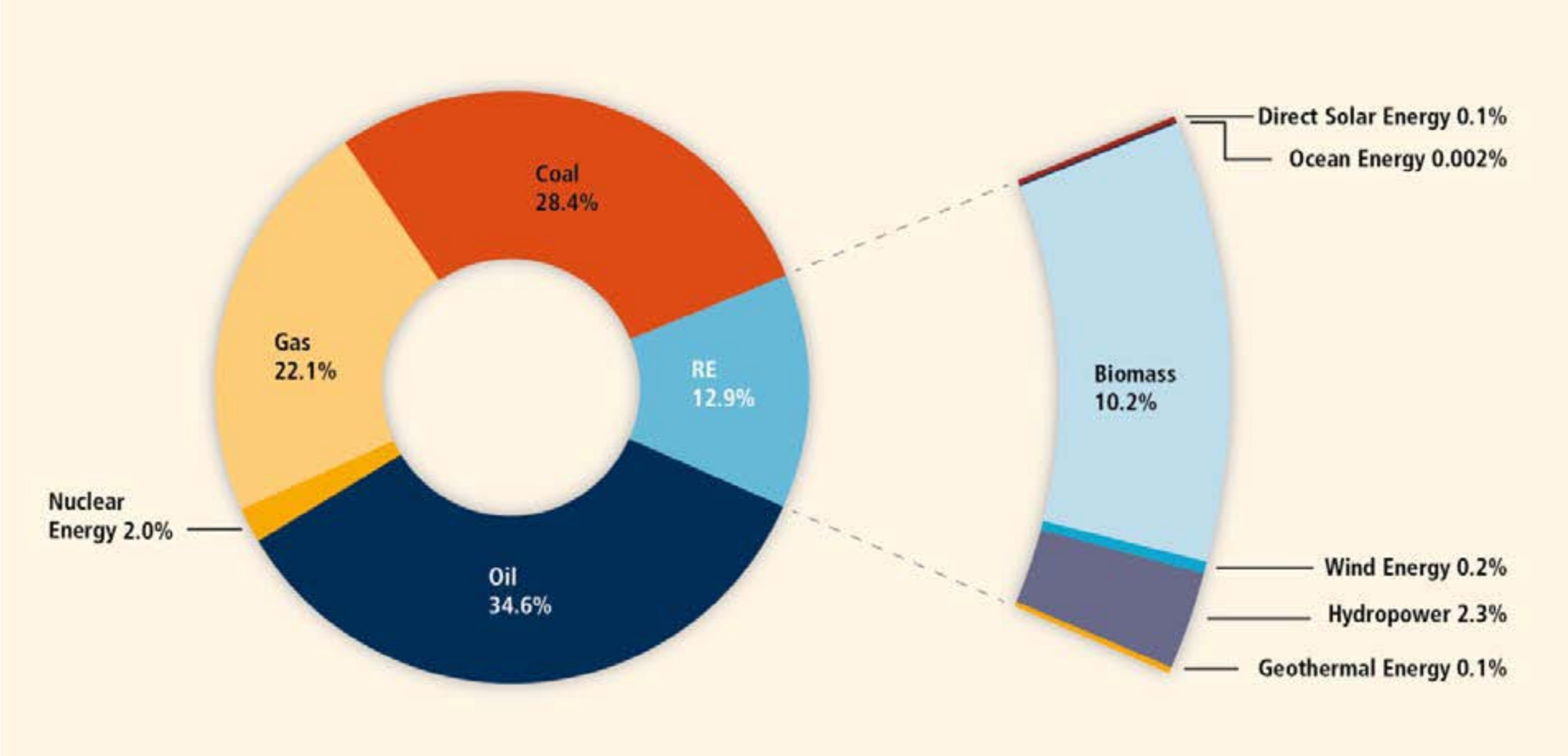
U.S. Energy Production and Consumption (2010)



Source: EIA; full references are provided starting on p. 123.

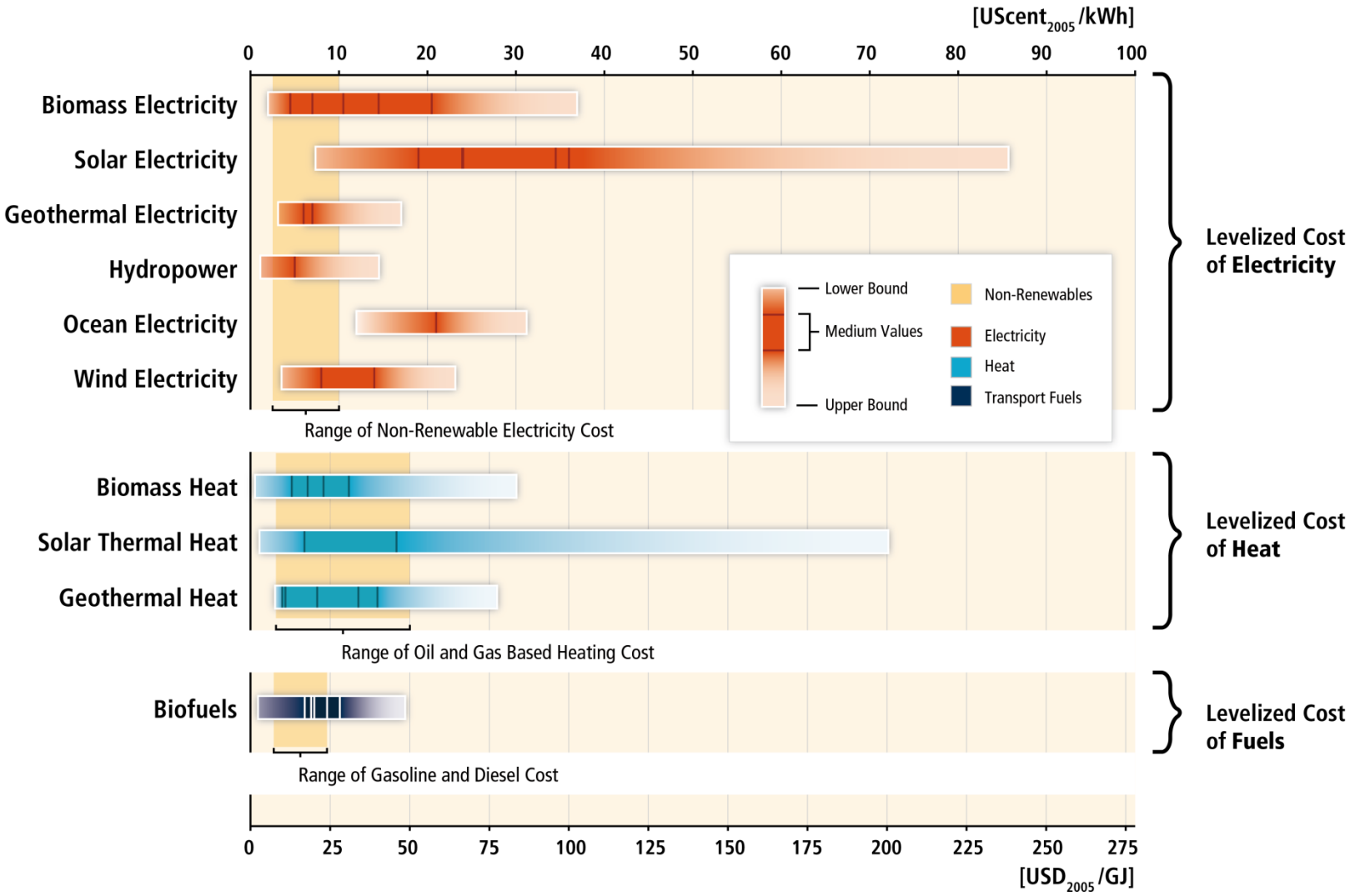
Note: Because hydropower is considered a conventional source of energy, it is accounted for separate from other new renewable sources of energy. Energy consumption is higher than energy production due to oil imports.

Shares of renewable energy sources in total global primary energy supply is still small

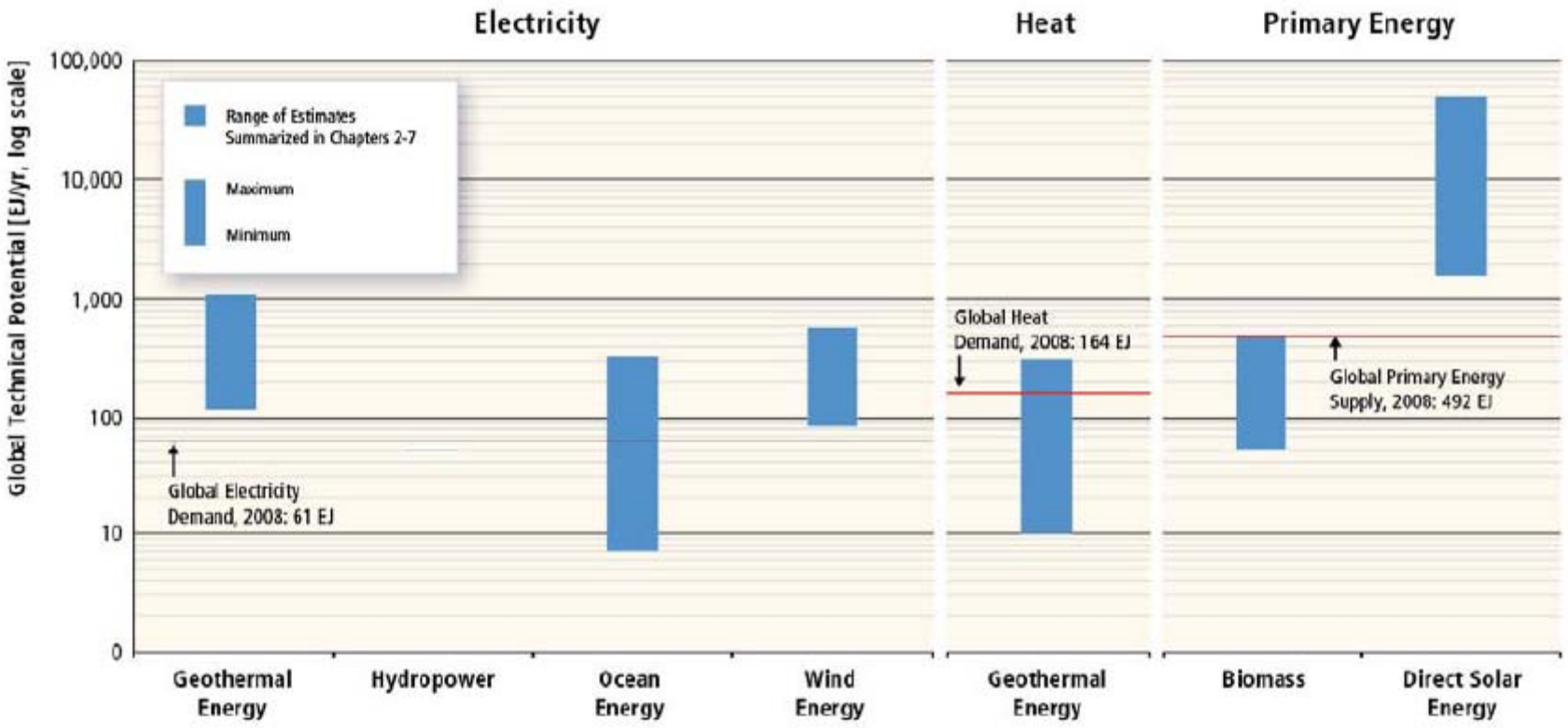


Source: IPCC Special Report Renewable Energy Sources (SRREN)

Renewable energy costs are still higher than existing energy prices, but in various settings renewable energy is getting competitive



Ranges of global technical potentials of renewable energy sources is enormous

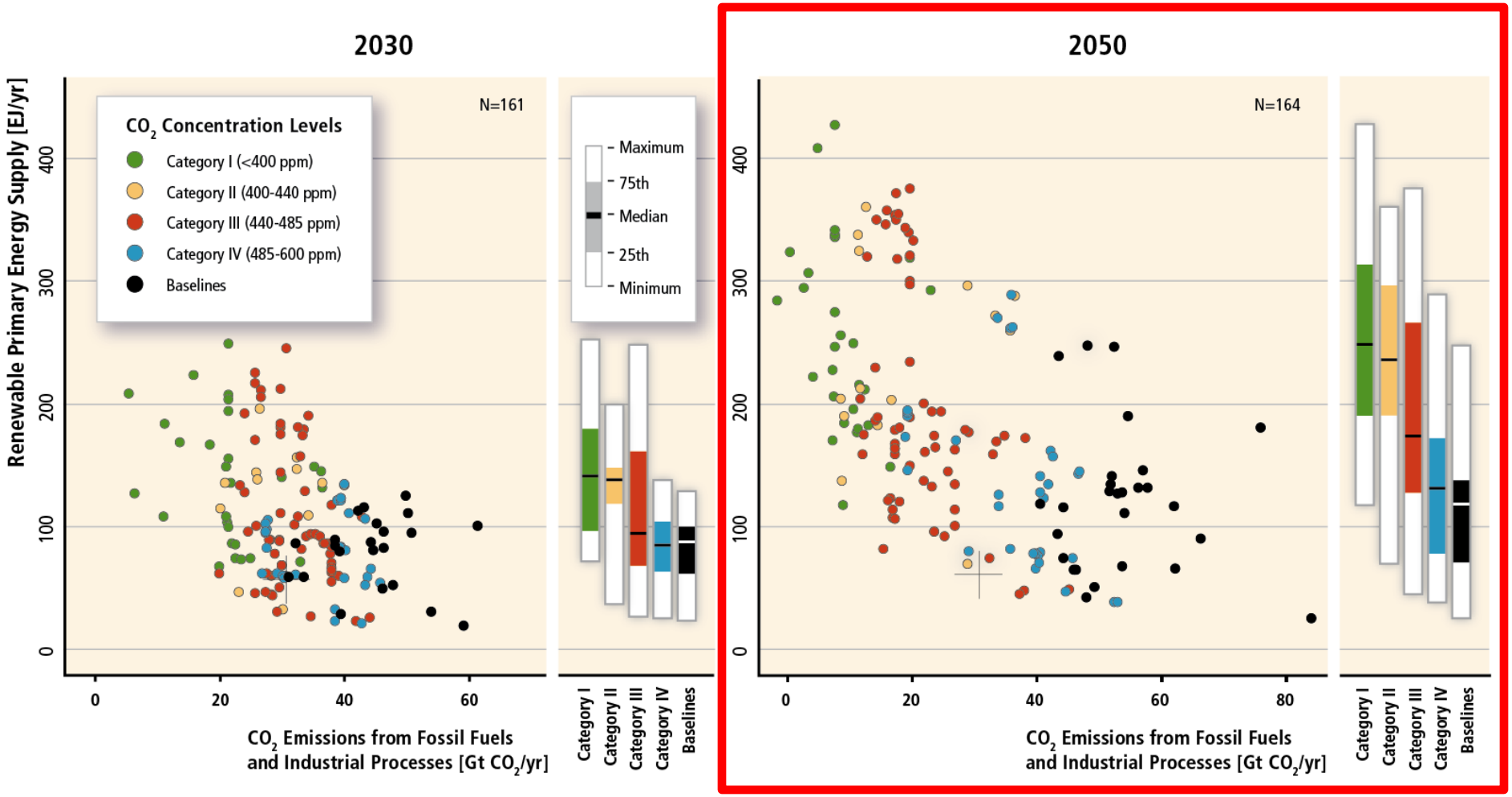


Range of Estimates of Global Technical Potentials

Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

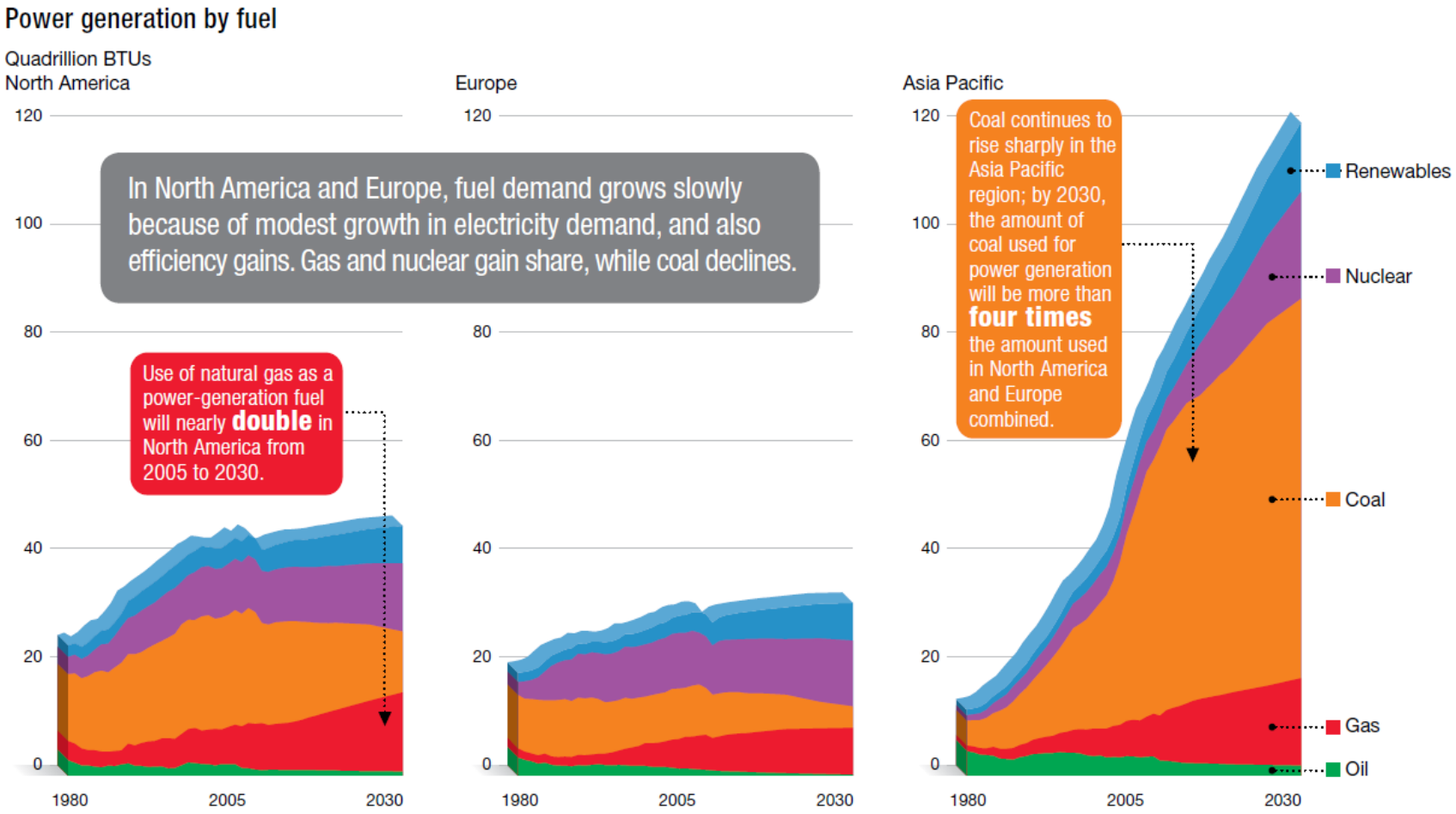
Source: IPCC Special Report Renewable Energy Sources (SRREN)

Global renewable energy primary energy supply from 164 long-term scenarios versus fossil and industrial CO_2 emissions. Modeling suggests many outcomes.



Source: SRREN SPM, Figure SPM.9

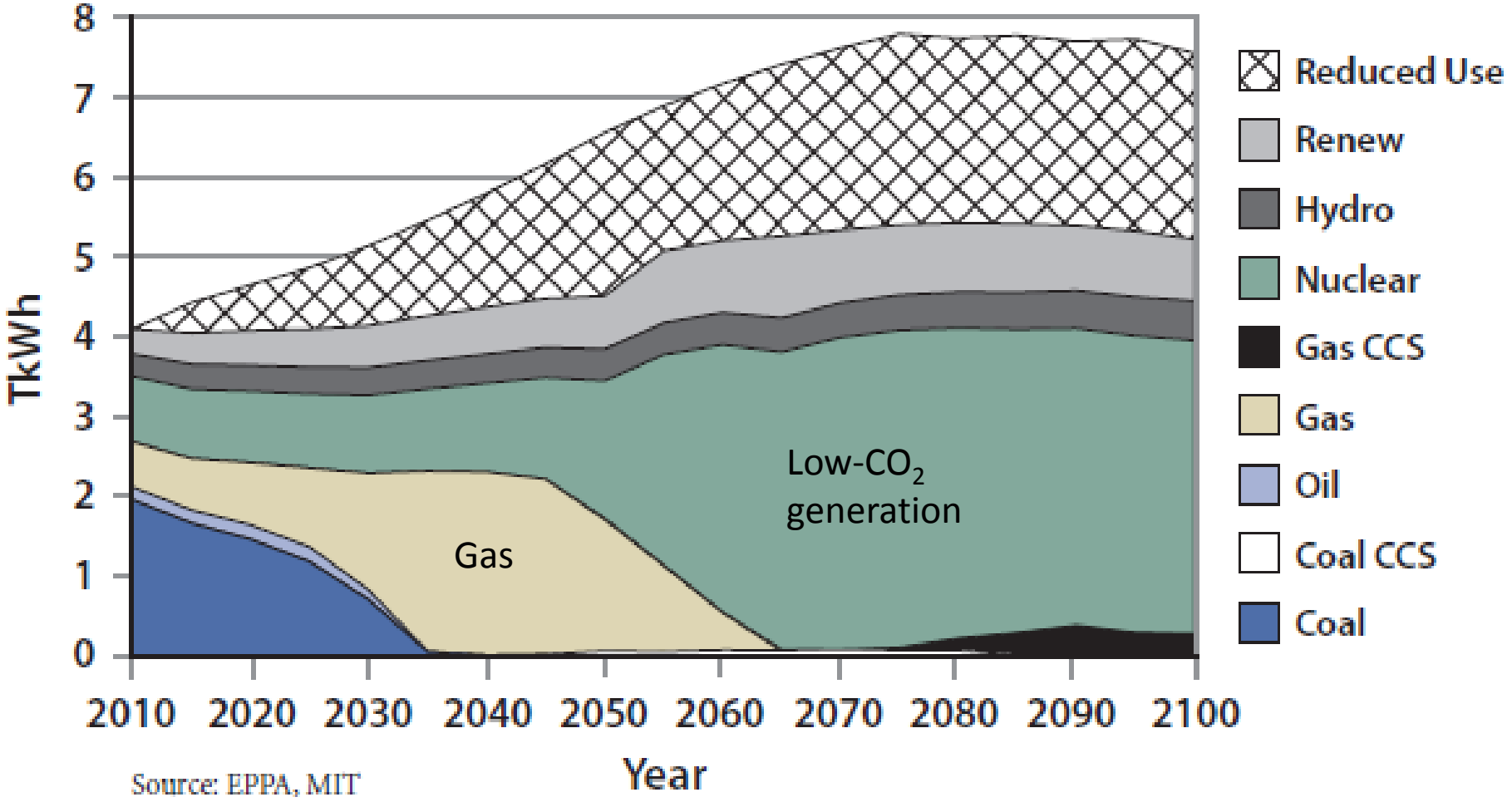
Many expect electricity demand to grow faster than renewable energy generation



Source: ExxonMobile
http://www.exxonmobil.com/corporate/files/news_pub_eo_2010.pdf

The Outlook for Energy: A View to 2030 31

MIT's *Future of Natural Gas* Study



A Profound Transformation is Required

Today's Energy System

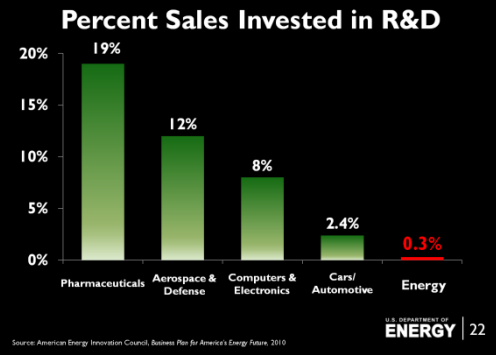
- Dependent on non-domestic sources
- Subject to price volatility
- Increasingly vulnerable energy delivery systems
- 2/3 of source energy is wasted
- Significant carbon emissions
- Role of electricity increasing

Sustainable Energy System

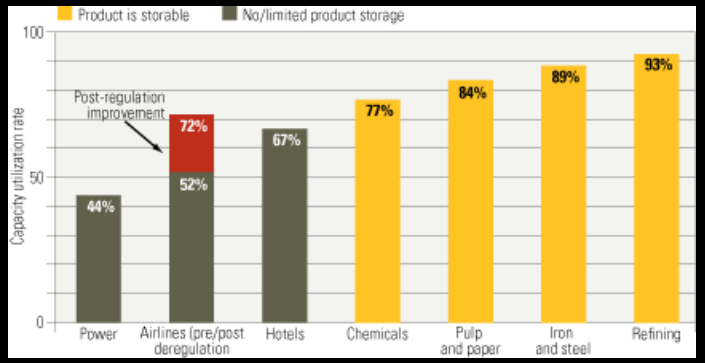
- Carbon neutral
- Efficient
- Diverse supply options
- Sustainable use of natural resources
- Creates economic development
- Accessible, affordable and secure

TRANSFORMATION

Energy Sector Challenges



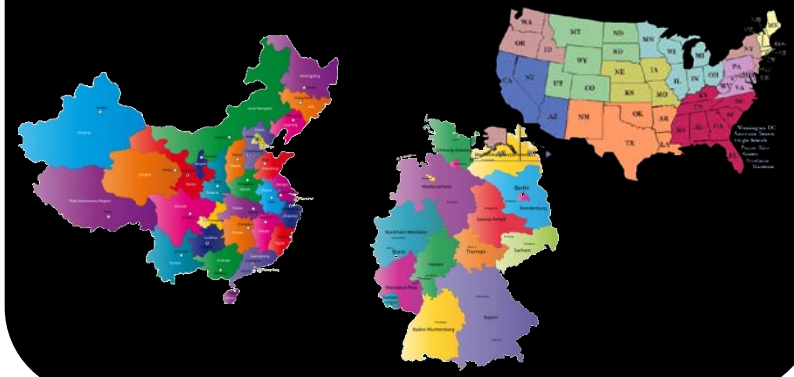
R&D Investment Drives Innovation



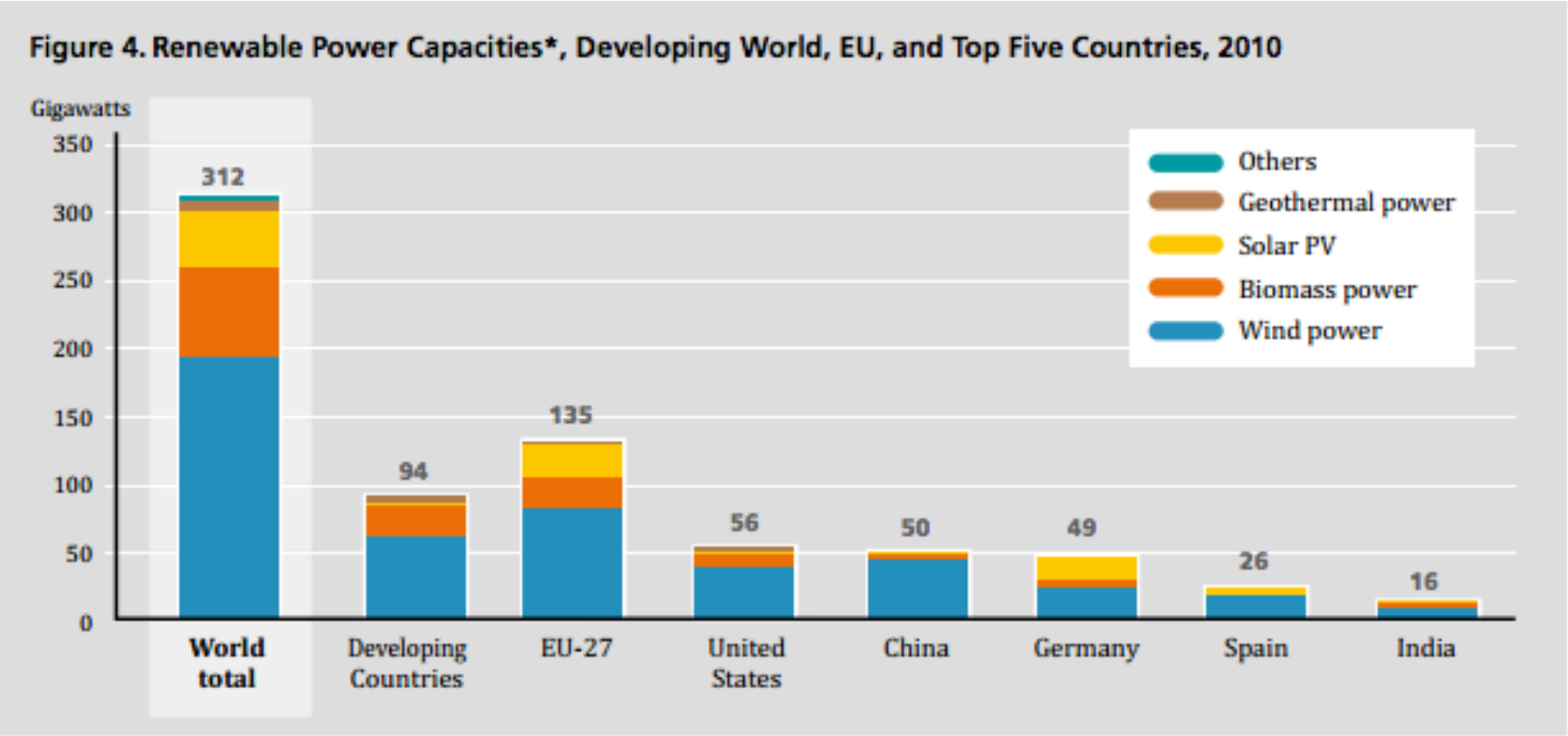
Asset Utilization

Capital Intensive with Long Life Cycles

National Strategies Driving Energy Market



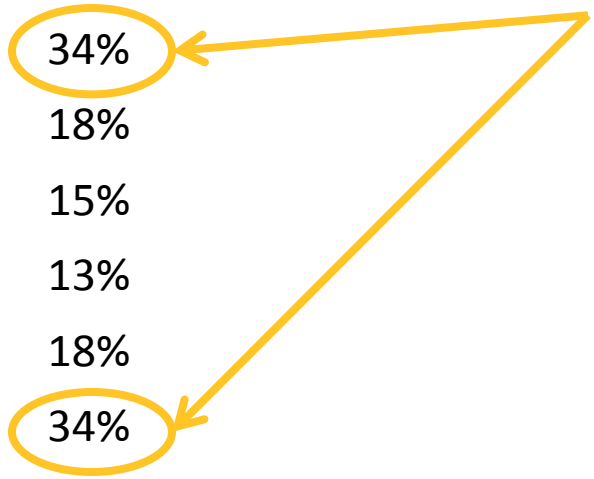
RE Sector Capacities Vary by Region



Source: REN21 (2011)

RE has achieved varying degrees of penetration

Country	% Renewable Generation (2010)
Australia	8%
China	19%
Denmark	34%
Germany	18%
India	15%
Ireland	13%
Mexico	18%
Spain	34%
Thailand	8%
United Kingdom	7%
United States	11%

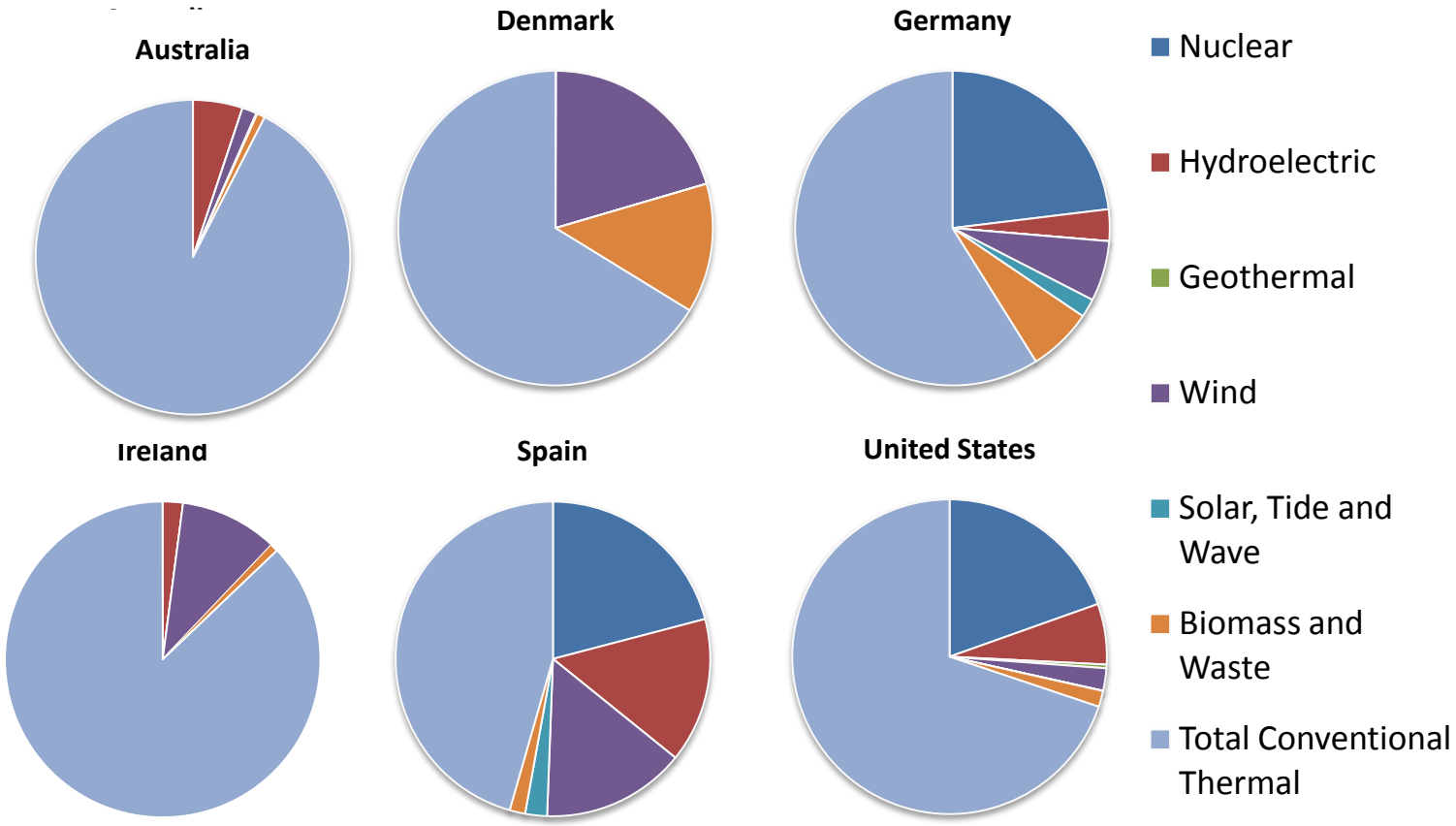


Highest penetration on annual basis

Source: U.S. EIA, International Energy Statistics

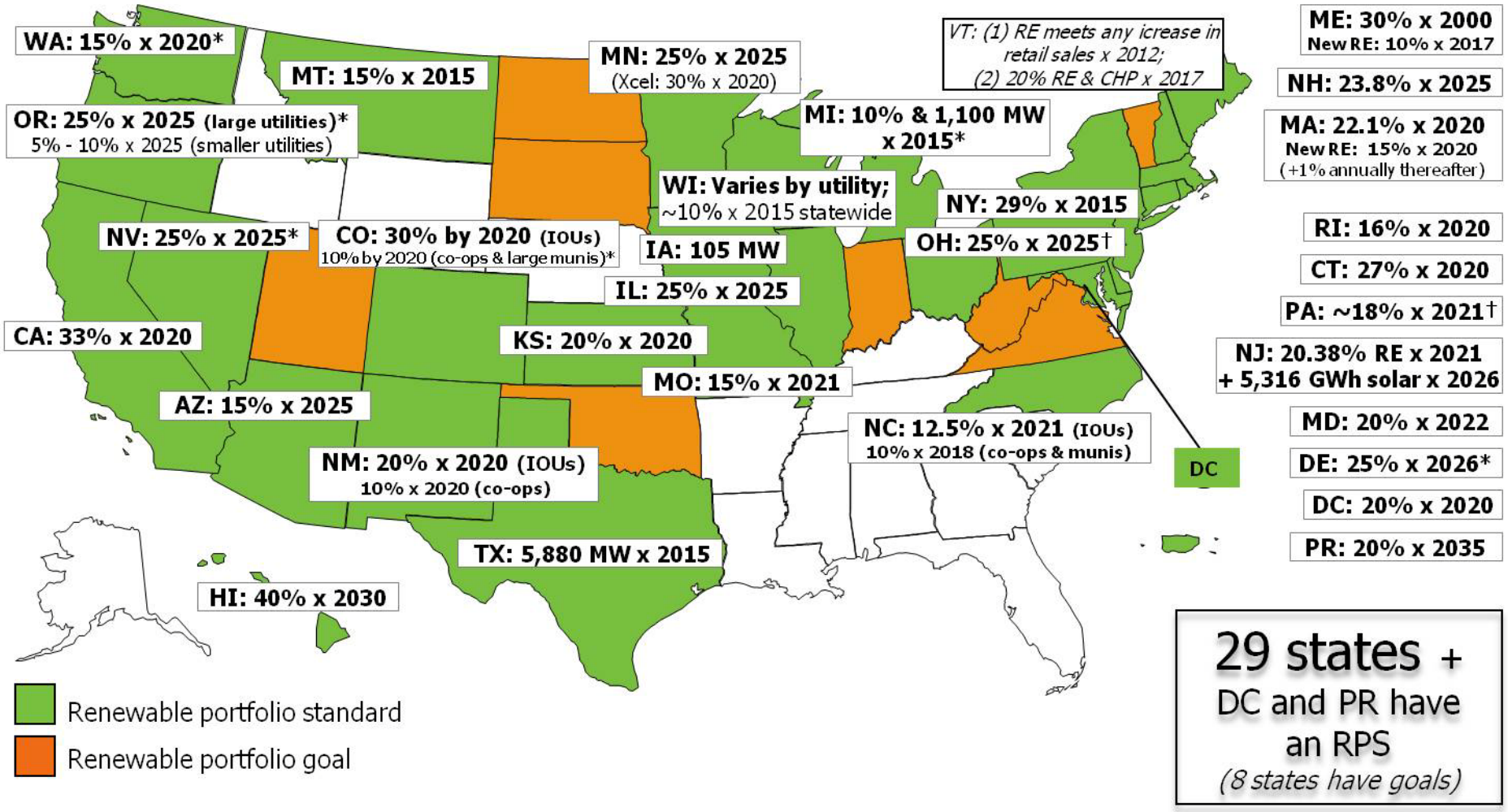
As a result, different settings for RE integration

Percentage of Electricity Generation by Type, 2010



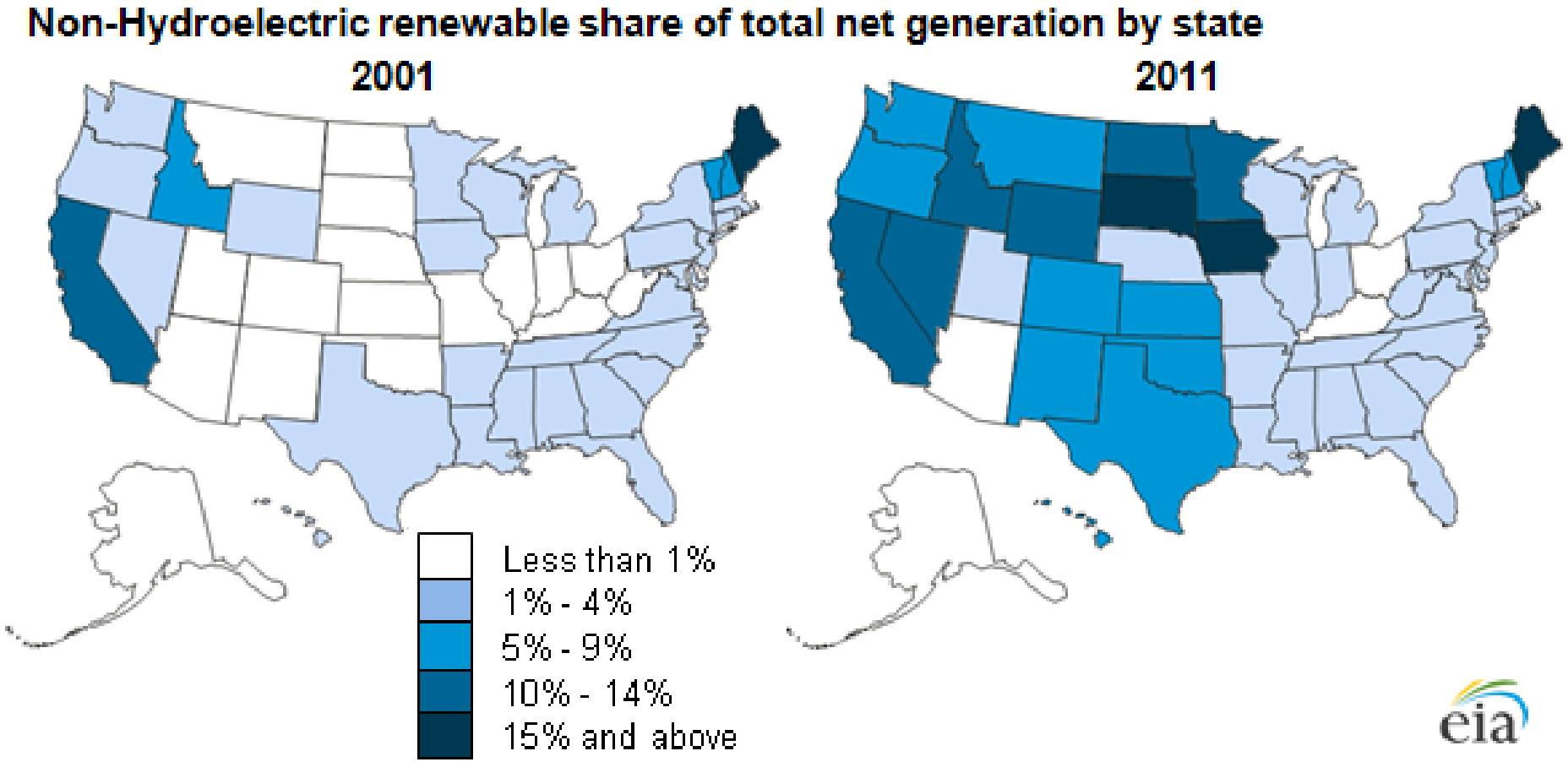
Source: U.S. EIA, International Energy Statistics

Renewable Portfolio Standards



April 2012
Source: DSIRE http://www.dsireusa.org/summarymaps/index.cfm?ee=1&RE=1

Renewable Share of Total Generation by State Up Across the United States

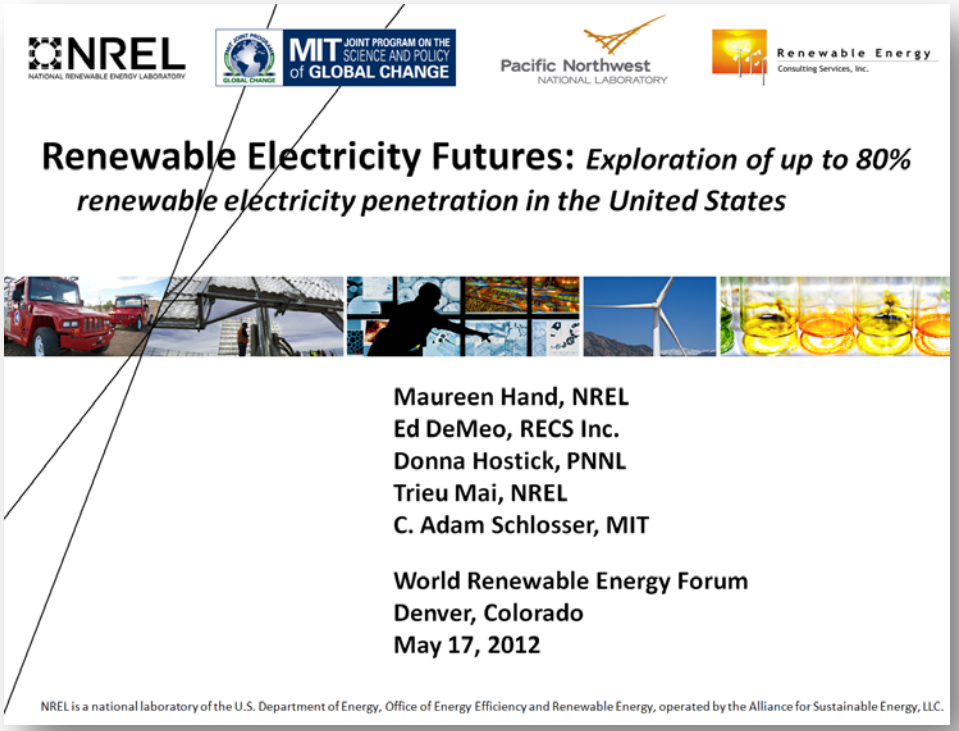


Source: U.S. Energy Information Administration, Form EIA-923, Power Plant Operations Report.
Notes: Non-hydroelectric renewables include generation from wind, solar, geothermal, and other renewable sources such as wood and wood wastes, municipal solid wastes, landfill gas, etc. Data for 2011 are preliminary.

Specific Implementation Challenges

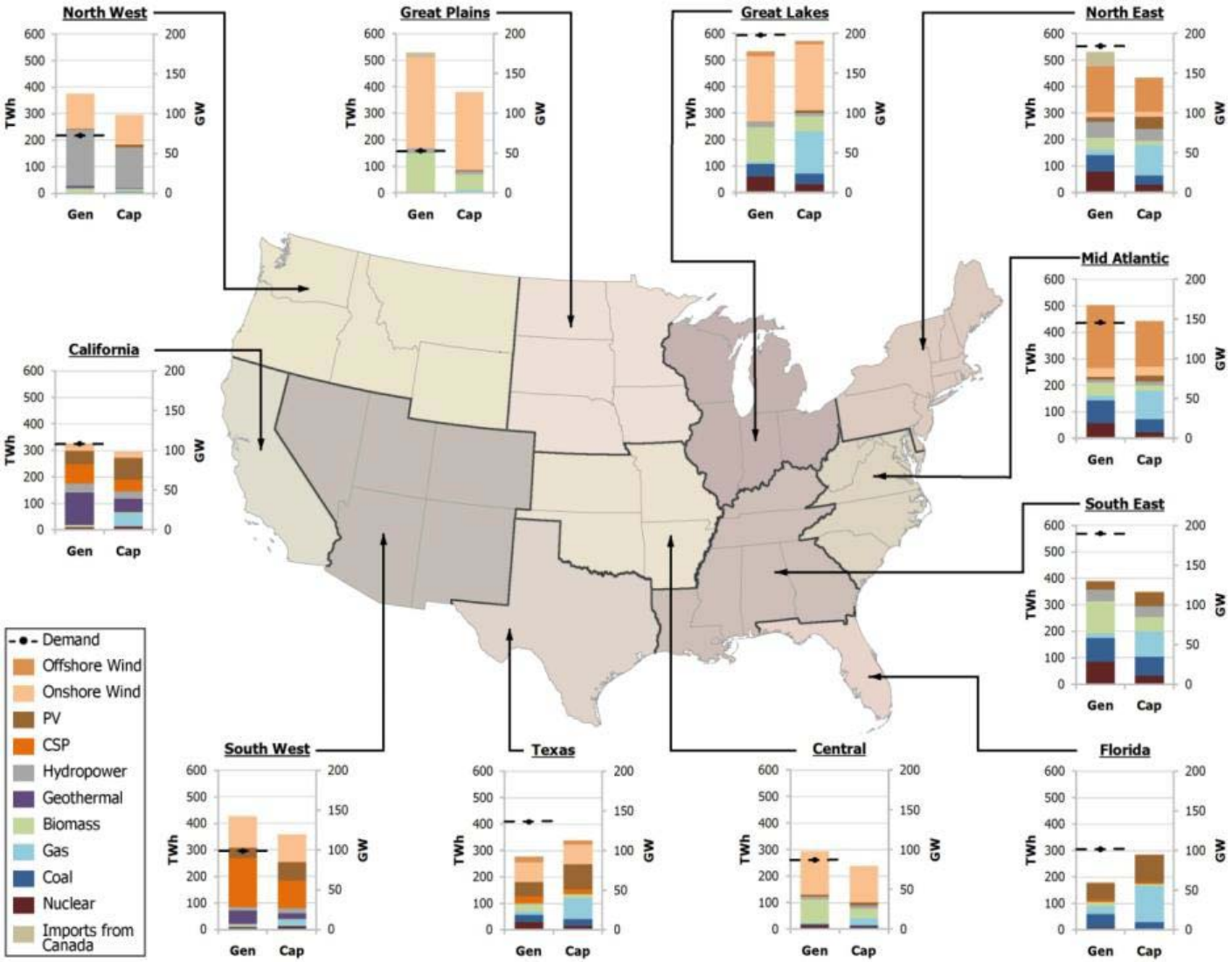
- **Legal, market, and institutional barriers—Increasing power system flexibility needed to integrate variable RE (e.g., through larger balancing areas, new market rules) may require significant ecosystem-wide changes**
- **Coordination—Due to the involvement of multiple agencies and jurisdictions, developing and implementing a shared vision could be challenging**
- **Public support—The public may not understand or support actions necessary to integrate renewables**
- **Customizing solutions—There is no one-size-fits-all solution to integrating variable renewables; countries need to determine the most appropriate combination of approaches**

High-Penetration Renewables



New study to be presented and discussed in WREF Thursday panel session

All regions of the country could contribute substantial renewable electricity supply in 2050



Innovation, Integration, & Adoption

Reducing Investment Risk

- Enable basic and applied clean energy technology innovation
- Accelerate technology market introduction and adoption
- Integrate technology at scale
- Encourage collaboration in unique research and testing “partnering” facilities
- Provide analysis and expertise to inform decisions

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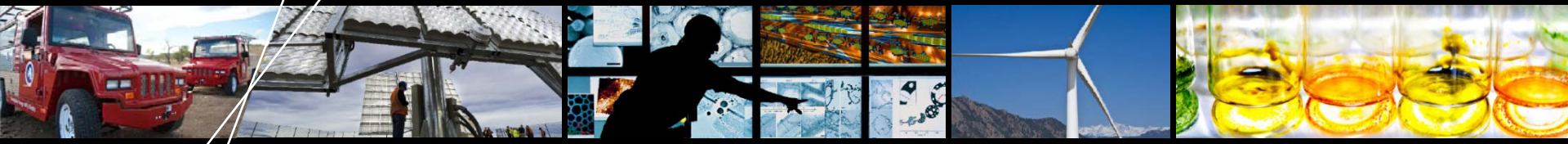
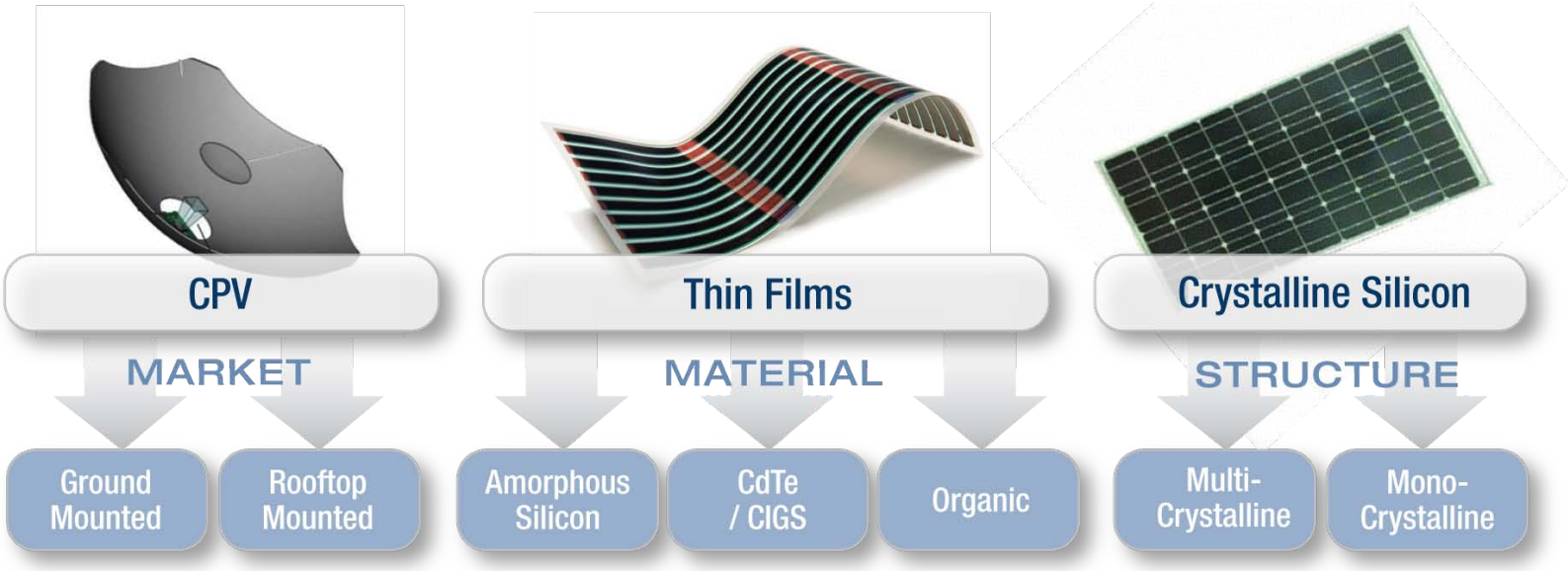


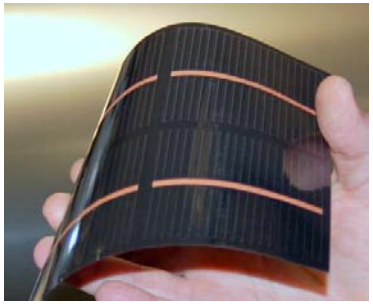
Status of the Technologies

Multiple Promising PV Technologies



20x-100x

500x

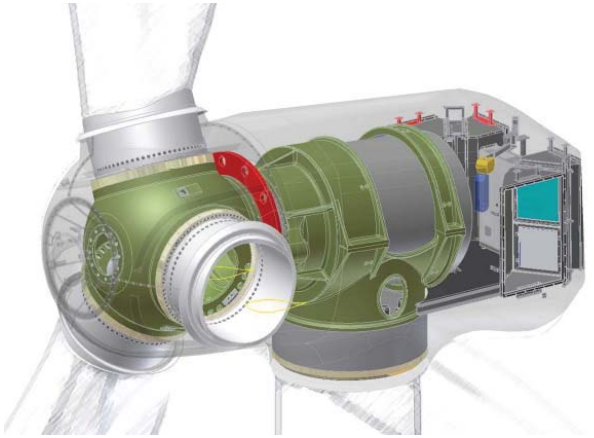


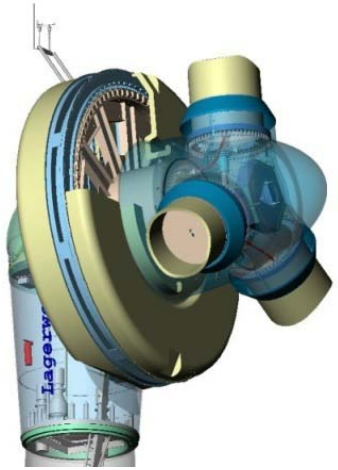
Cu(In,Ga)Se_2 ~ 1-2 um

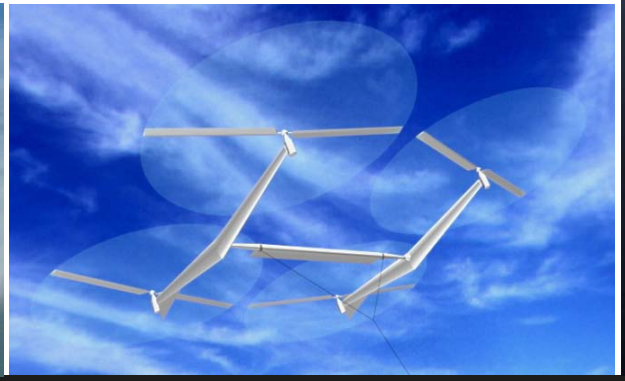
c-Si ~ 180 um

Wind Technology Innovation

- Modular large components – blades, drivetrains, and tall towers
- Advanced drivetrain power conversion systems – superconducting direct drive generators
- Flexible, ultra-large rotors and systems
- Active controls for structural load reduction, improved wind plant performance, and grid-friendly operation
- Floating offshore wind turbines
- Airborne wind power systems



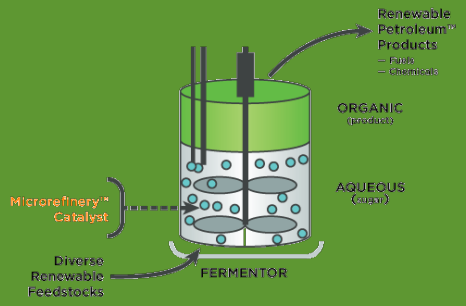




Biofuels Innovation

New conversion technologies are being developed, offering the possibility of revolutionary, high volume methods for producing biofuel hydrocarbon fuels for our trucks, trains, ships, and aircraft . . .

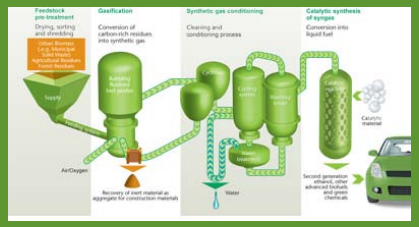
Biological Conversion



LS9

AMYRIS

Chemical Catalytic Conversion



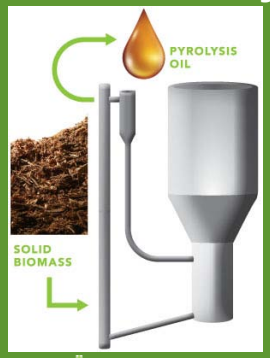
VIRENT
IT'S ABOUT TIME

RENTECH®

ClearFuels®
TECHNOLOGY, INC.

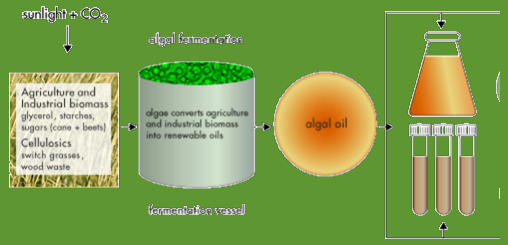
Enerkem

Pyrolysis/Bio-Oil Pathways



Envergent
TECHNOLOGIES
A Honeywell Company

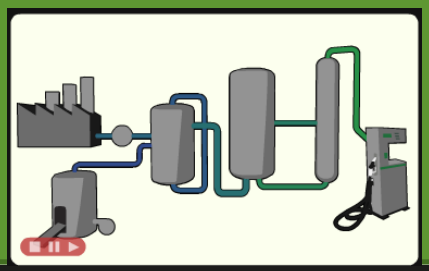
Heterotrophic Algae Conversion



solazyme®

MARTEK
life enriched™

Hybrid Conversion Technologies



LanzaTech

coskata

Transportation Innovation

Portfolio of technologies leading to 54.5 mpg

Degree of electrification (power electronics & energy storage)

Start/stop

Regenerative braking

Low rolling resistance tires

Electric infrastructure

Electric powered steering

Light weighting

8 speed transmissions

Turbocharging, direct fuel injection, advanced combustion

Variable cylinder mgmt

Improved aerodynamics

Diesel powered & or Alternative Fuels, H2

Buildings Innovation

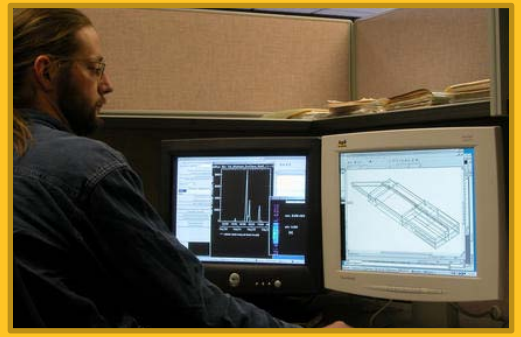
High Performance Buildings

BIPV Products & PV-T Array

Compressorless Cooling

Electrochromic Windows

Polymer Solar Water Heaters



Computerized optimization & simulation Tools

Efficiency/Integration Innovation

Buildings

- **Whole building systems integration**
- Computerized building energy optimization tools
- Advanced HVAC (Heating Ventilating and air conditioning)
- Cost effective ultra energy efficient retrofits

Grid Integration

Interconnection Standards

- IEEE Standards Development
- Standards Testing and Validation

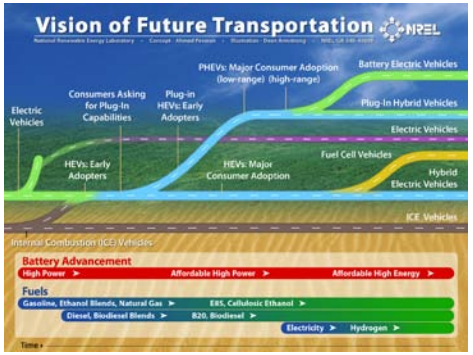
Smart-Grid Data Hub

RE Grid Integration

- Power Electronics for Interconnection monitoring and control
- Grid-to-vehicle interface

Advanced Vehicles

- Fuels utilization
- Component technologies
- Electric vehicle-to-grid interface



To achieve a clean energy vision, we must…

- Invest in innovation
- Invent the future we desire
- Improve access to capital
- Partner on a global scale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May 2011