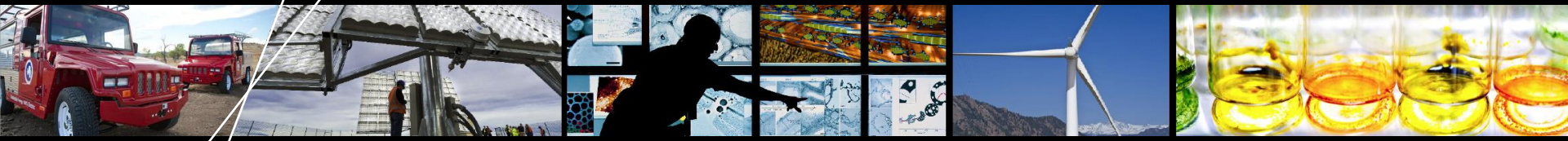
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Innovation: Enabling a Sustainable Energy Future



Dr. Dan E. Arvizu

Laboratory Director

SunShot Summit

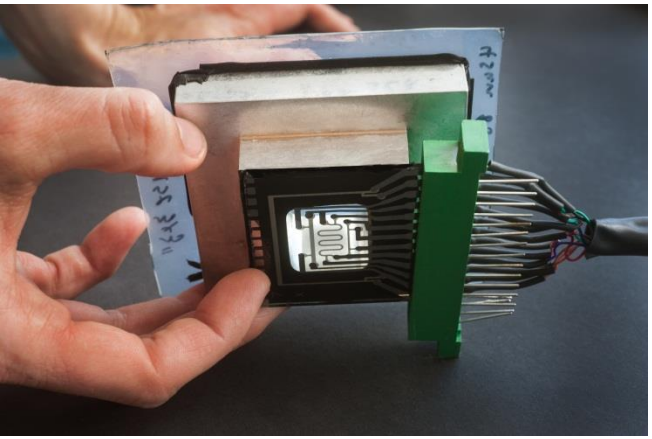
May 21, 2014

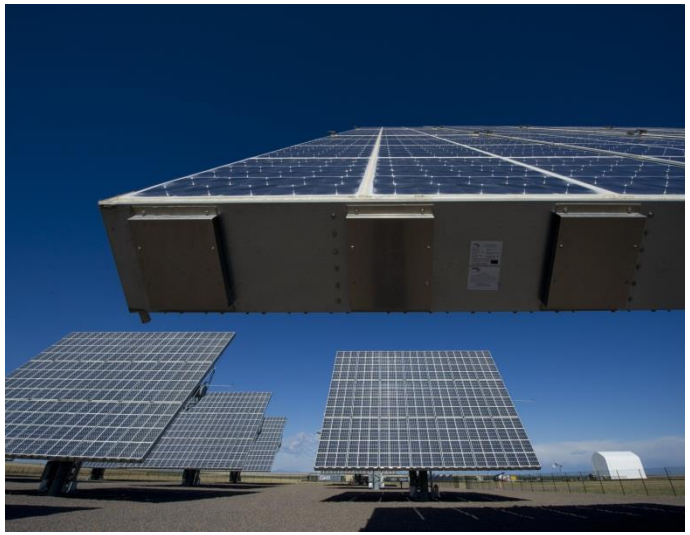
SunShot
U.S. Department of Energy

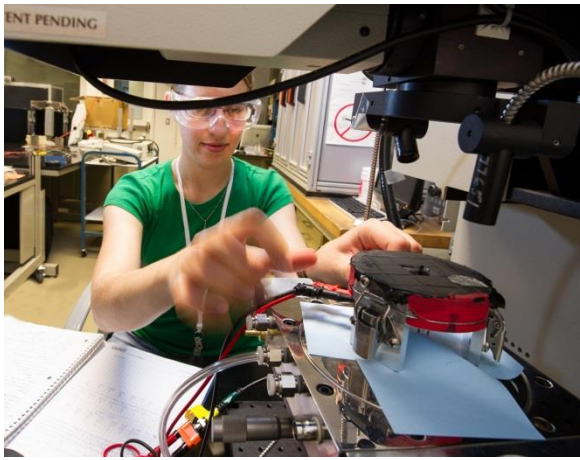
NREL Supports SunShot

SunShot
U.S. Department of Energy

Our scientists are pursuing critical activities that will help to accomplish the goal of the U.S. Department of Energy's SunShot Initiative—to make large-scale solar energy systems cost-competitive with other energy sources by 2020.







Energy Market Dynamics

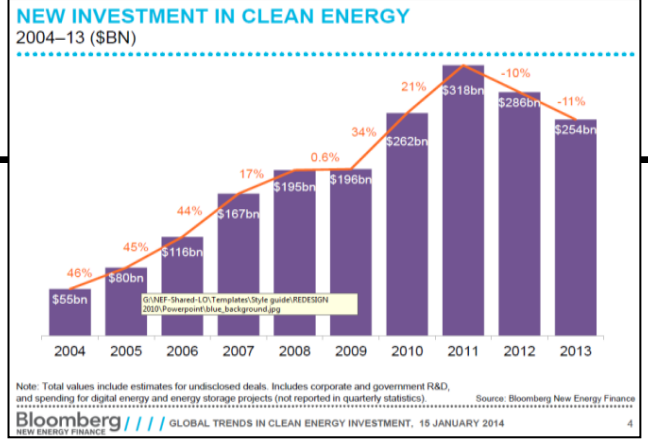
Global renewable industry growing, still faces challenges

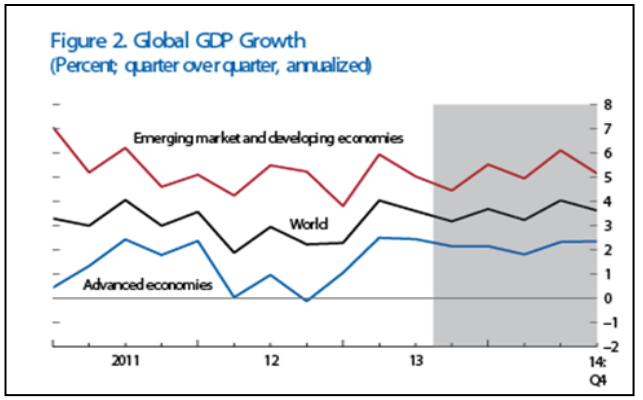
Public policy evolving

Effects of Great Recession still evident

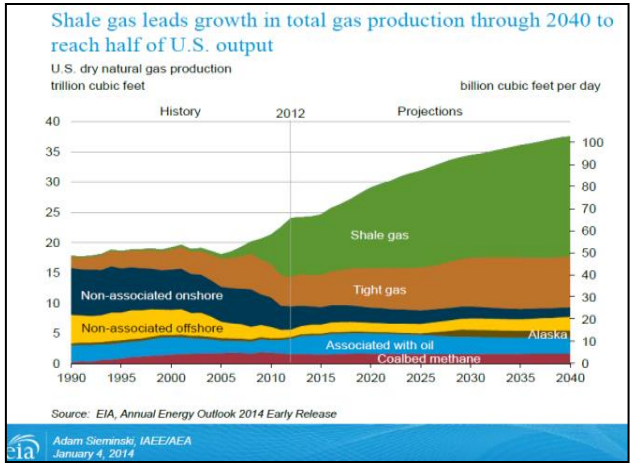
Shale gas a growing focus in U.S. and elsewhere

Infrastructure investments will be made, must focus on flexibility





http://www.imf.org/external/pubs/ft/weo/2014/update/01/index.htm



Rev 5/14/14

A Profound Transformation is Required

Today's Unsustainable Energy System

Future Sustainable Energy System

TRANSFORMATION

- Limited fuel diversity
- Subject to price volatility
- Inefficient and rigid
- Significant carbon emissions
- Delivery systems vulnerable
- Aging infrastructure

- Diverse supply options
- Affordable, stable and reliable
- Efficient and flexible
- Carbon neutral
- Secure and resilient
- Engine for innovation

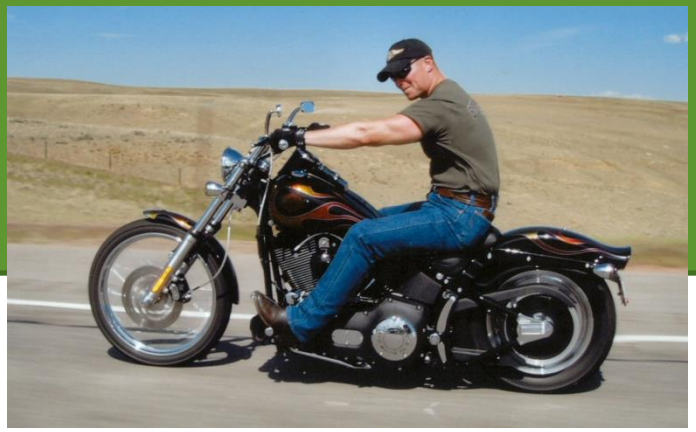
1/13/2014

Change is Hard

"Facts are important but not sufficient to change human behavior."

—Dr. Arthur Caplan, Bioethicist

2014 National Science Board Award Winner for Public Service



Smoking causes cancer.

Riding without a helmet is dangerous.

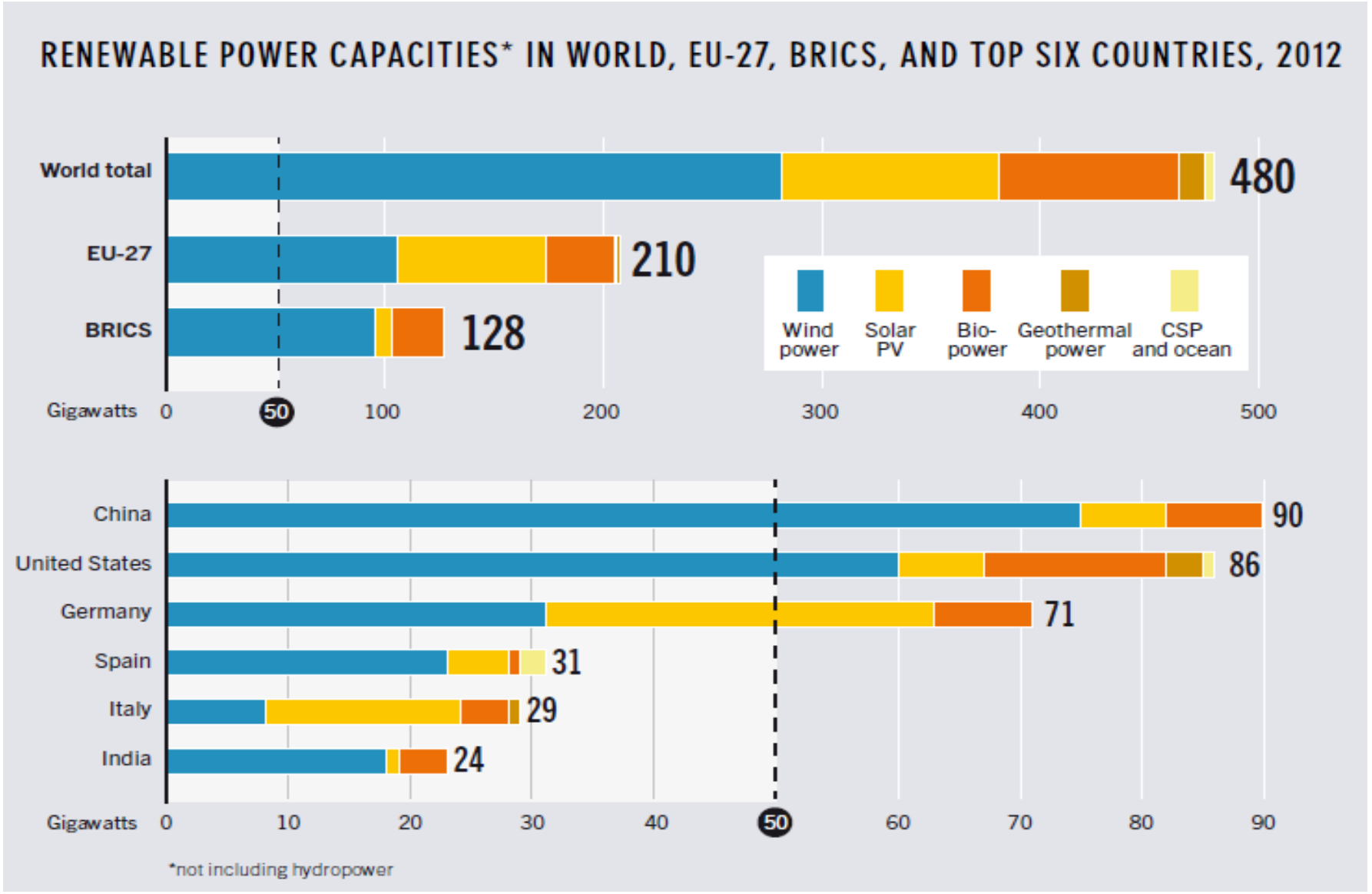
Vaccinations prevent disease and death.

Transition to a Sustainable Energy Economy

What will compel a transition? *Addressing the three myths….*

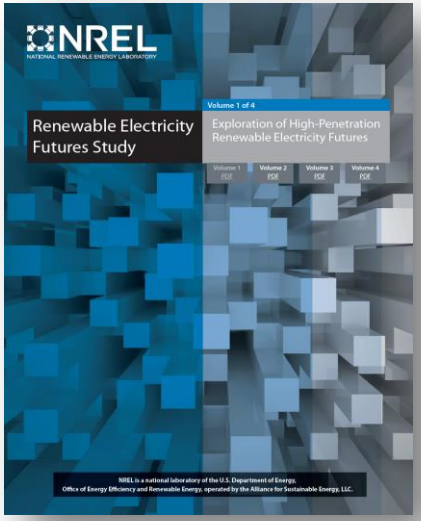
- **You don't have to go without.** ***No sacrifice required.***
- **You can still have choice.** ***Choices are enhanced.***
- **Pace matters; there are consequences for not acting now.** ***Security, cost and competitiveness, and environmental quality.***

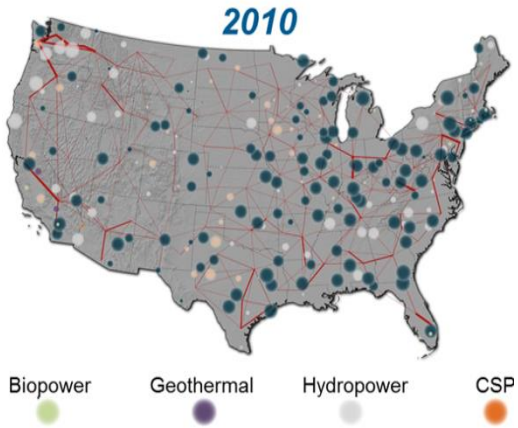
Worldwide Renewable Capacity

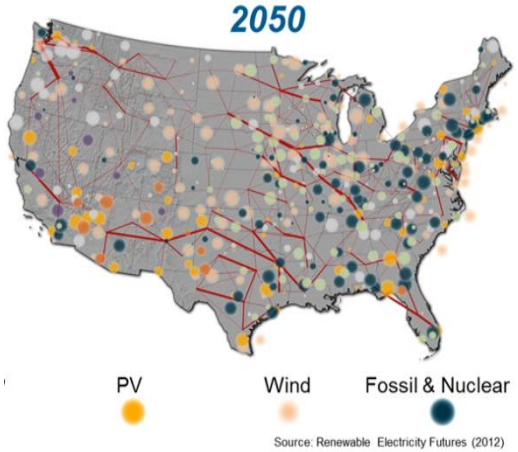


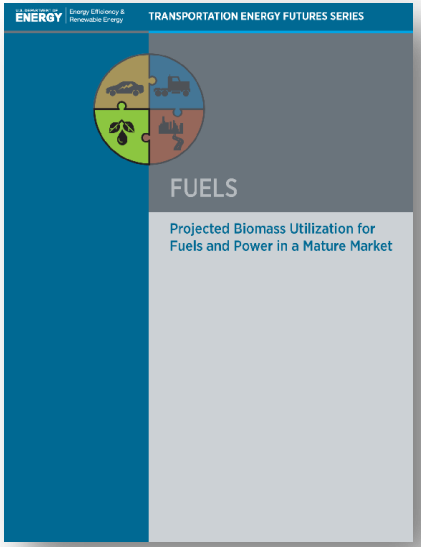
Source REN21 *Renewables 2013 Status Report*

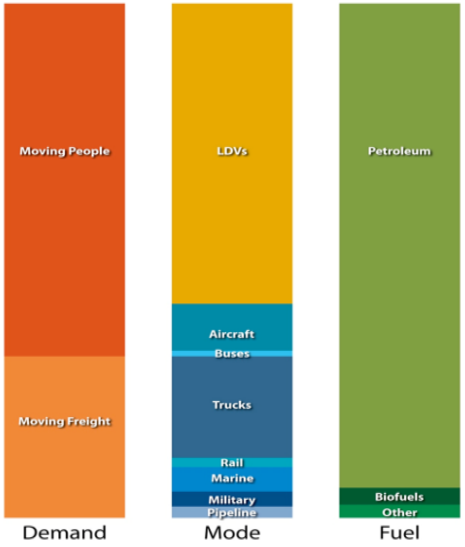
Comprehensive Studies Validate Opportunity for U.S. Renewables

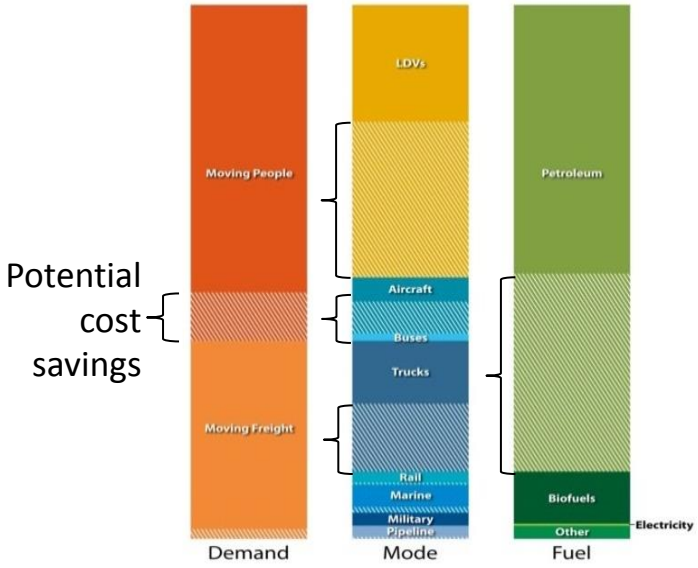




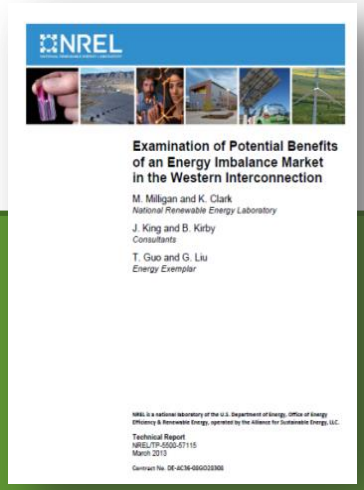


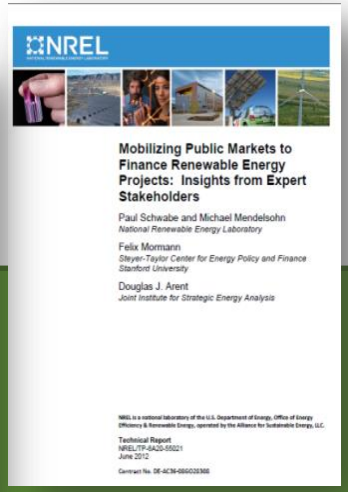


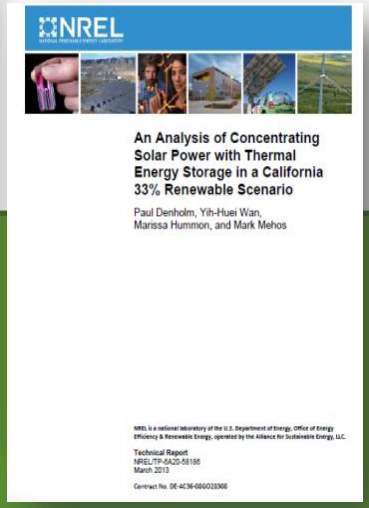


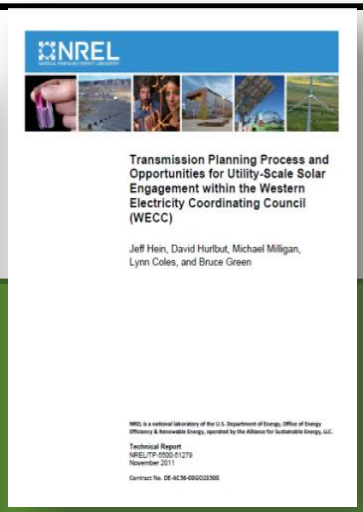


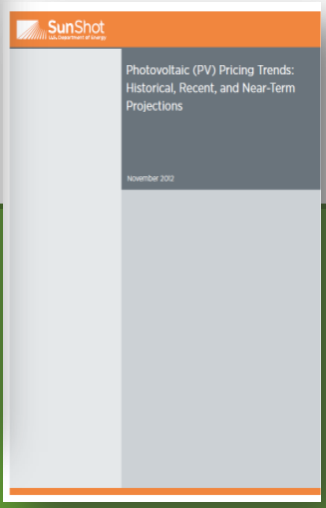
Looking Toward Implementation

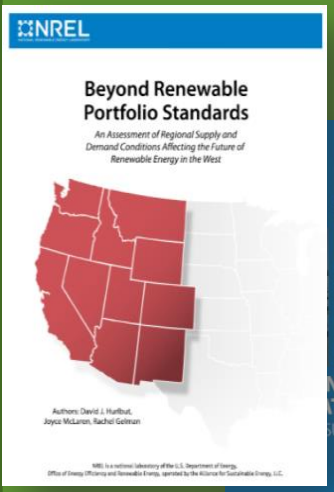


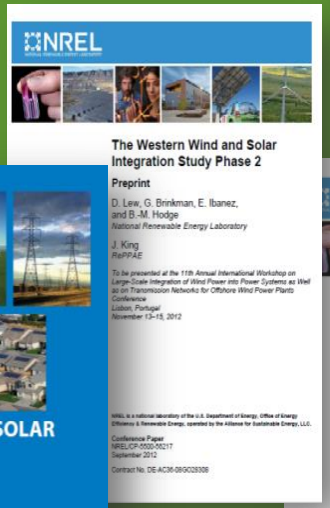


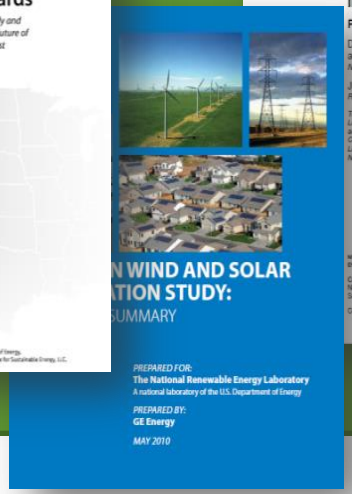












- Benefits of distributed generation
- Economics of technical pathways
- Implications of high penetration renewables
- Value of regional cooperation

Technology Innovation

Sustainable
TRANSPORTATION

Renewable
ELECTRICITY GENERATION

Energy Saving
HOMES, BUILDINGS, & MANUFACTURING

Solar Electricity: *State of the Technology*

Photovoltaics (PV)

- Market: Residential; Commercial, Utility
- Geographically diverse
- kWs to MWs to GWs
- U.S. Capacity: 12.1 GW
- U.S. Forecast: 40+ GWs in pipeline
- Costs: <$2 to $6/W: *LCOE 7 to 16¢/kWr
- Technologies: Conversion; thin-films, crystalline silicon. Storage; battery

Solar Thermal Electric (CSP)

- Market: Commercial; Utility
- Geographically confined to “sun bowls”
- MWs to GWs
- U.S Capacity: 1186 MW at year end 2013, 672 MW installed in 2013, 640 MW under construction in 2014
- U.S. Forecast: 3.5 GWs in pipeline
- Costs: $4 to $8/W[†]: *LCOE 12 to 16¢/kWr
- Technologies: Conversion; parabolic troughs, central receivers, linear Fresnel, dish. Storage; thermal, up to 15 hours.

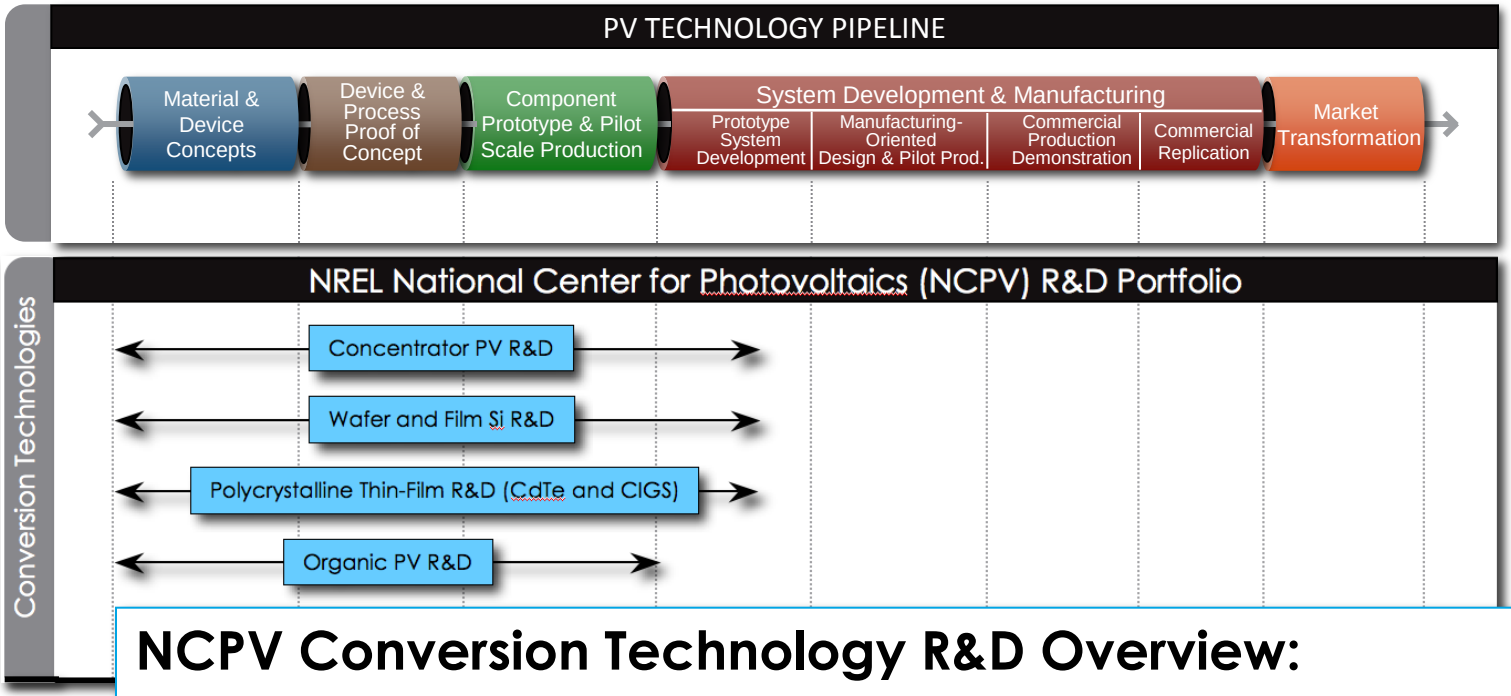
*With federal incentives, e.g., the FTC.

[†]Dependent on storage capacity

Updated: May 2014

Source: GTM/SEIA : U.S. Solar Market Insight 2011 - 2013 Year-in-Review

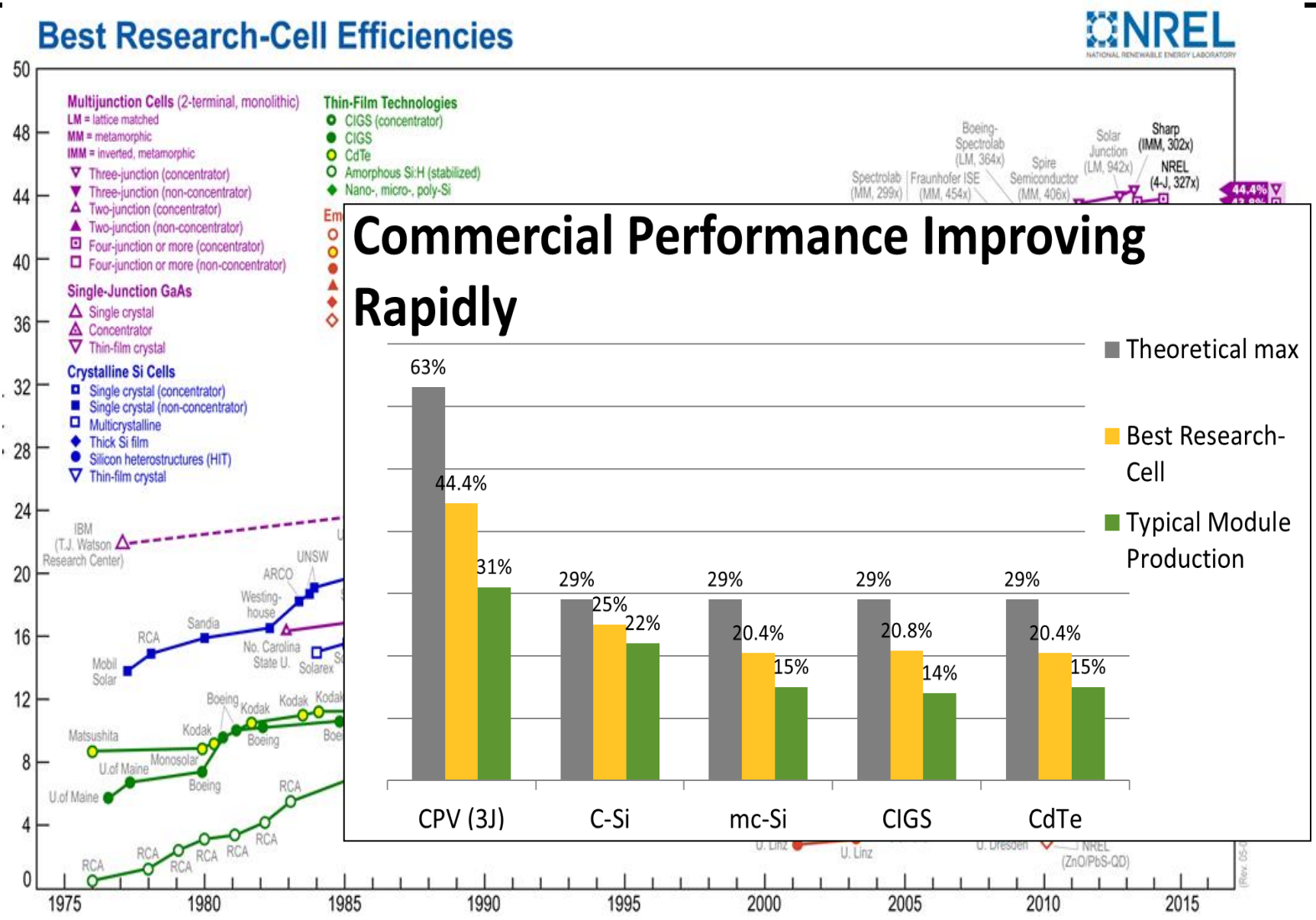
NCPV Conversion Technology R&D Portfolio



NCPV Conversion Technology R&D Overview:

- III-V Multijunction — Highest potential η, > 50%
- Wafer Si — Most common technology, ~25% 1-J η today
- Thin Si — Potential for low cost and > 20% η
- CdTe — Lowest cost in HVM today, potential for > 20% η
- CIGS — Can be flexible, potential for > 20% η
- Organic PV (OPV) — Flexible, potentially very low cost

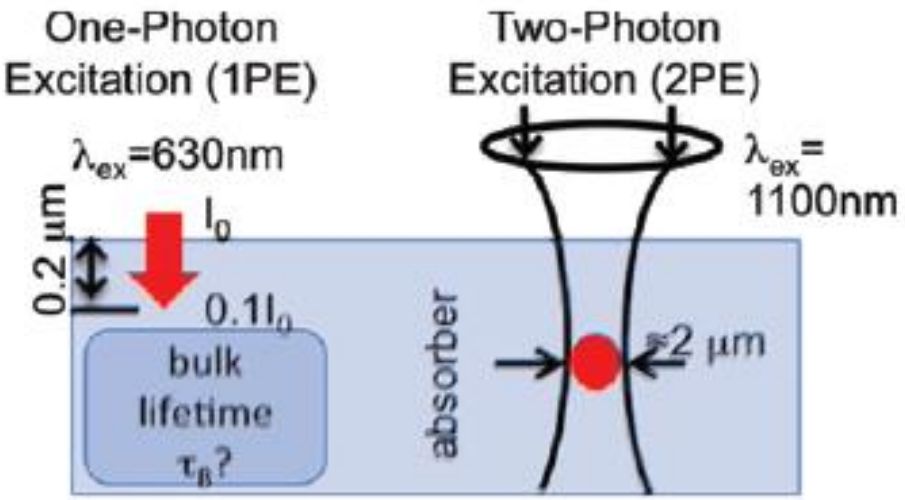
PV Research—Significant Innovation Space



Commercial Performance Improving Rapidly

Technique Reveals Critical Physics in Deep Regions of Solar Cells

NREL's improved time-resolved photoluminescence method measures minority-carrier lifetime deep within photovoltaic samples to help develop more efficient solar cells.



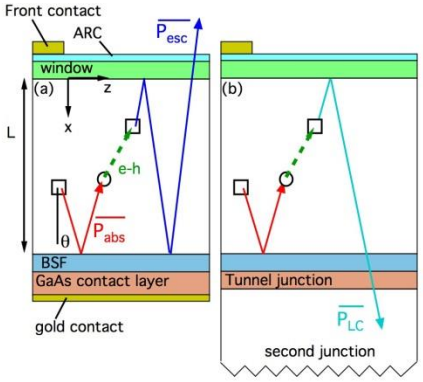
Using two-photon excitation (right side), light is absorbed in the laser-beam focus region, which can be either at the sample surface or in the bulk.

Recent NREL Solar Cell Records

III-V multijunctions:

31.1% one-sun record for two junctions

34.1% (467 suns) concentrator two junction record

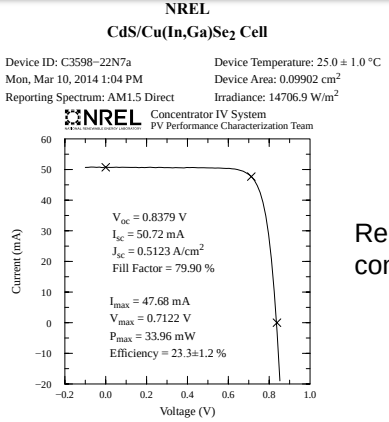


NREL model of internal cell optics guides development of world record cells

CIGS:

23.3% (15 suns) CIGS concentrator record

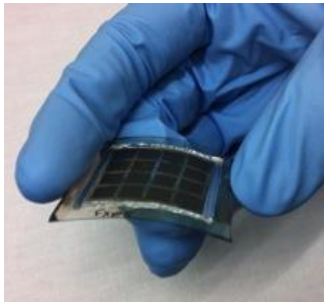
20.65% (near the 20.9% record)



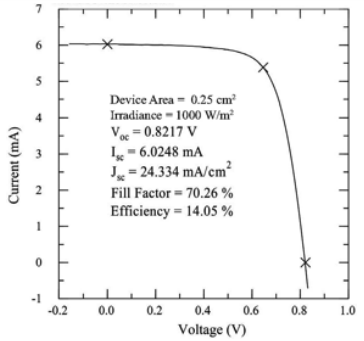
Record CIGS concentrator cell

CdTe:

14.05% record for flexible CdTe cell



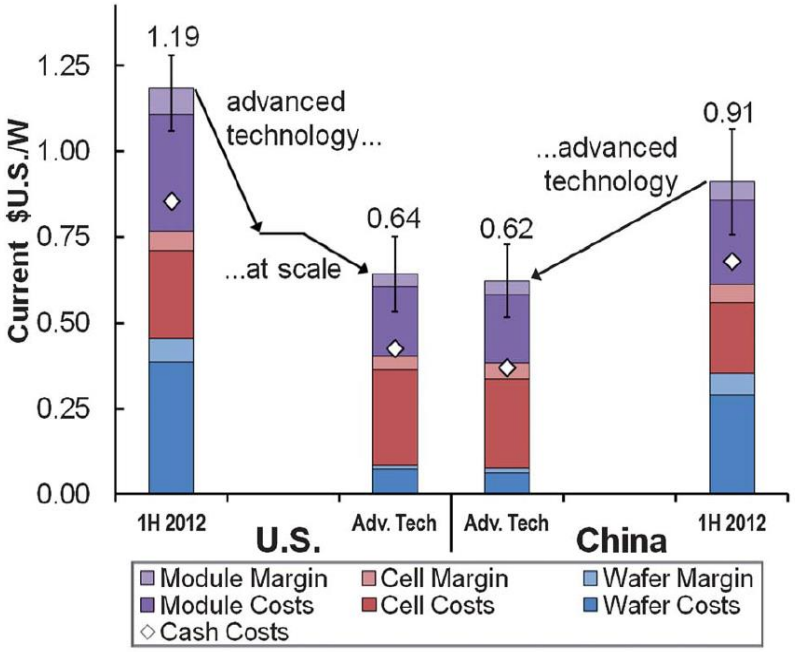
Record flexible CdTe cell



Solar Manufacturing and Systems Cost Analysis

- **Benchmark the cost of solar techs, evaluate the range of technical pathways being pursued, and reallocate R&D resources as necessary**
- **Evaluate technical improvements opportunities through detailed cost modeling**
- **Enhance understanding of the economic competitiveness of solar technologies and manufacturing locations.**

U.S. Competitiveness



System Installation Costs Analysis and Roadmapping

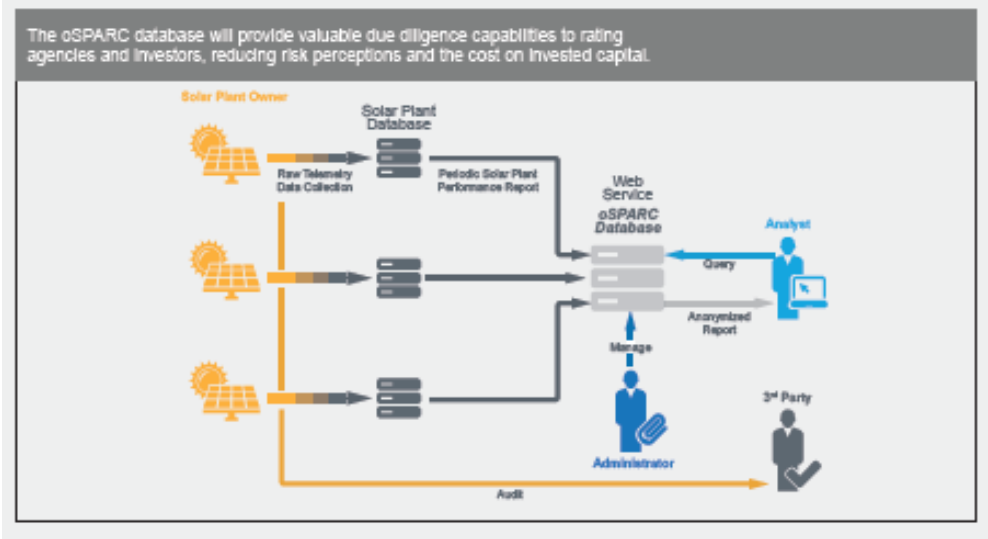
Modeled (Bottoms-Up) PV System Prices by Sector (2009-2012).

Advanced Financing to Achieve SunShot Goals

The Advanced Financing to Achieve Sunshot project seeks to expand the availability and lower the cost of capital to deploy solar in the United States.

FY13-15: NREL has assembled two working groups to perform its tasks under the DOE award.

- **The Solar Access to Public Capital (SAPC) group facilitates solar securitization and opens the capital markets to the solar asset class.**
- **The Banking on Solar group increases the availability of loan products in the residential and commercial solar areas.**



Next Steps:

- **Standardize contract terms and documents Build endorsement among developers.**
- **Engage broader investment community.**
- **Expand mock securitization to commercial portfolio.**
- **Standardize loan document and develop education materials.**

NREL Mission Focus

Energy Efficiency	Renewable Energy	Systems Integration	Market Focus
Residential Buildings	Solar	Grid Infrastructure	Private Industry
Commercial Buildings	Wind and Water	Distributed Energy Interconnection	Federal Agencies
Personal and Commercial Vehicles	Biomass	Battery and Thermal Storage	State/Local Govt.
	Hydrogen	Transportation	International
	Geothermal		

The New Frontiers: Integration and Scale

- Integration of high-penetration renewables requires enhanced system-wide flexibility
  - Variable supply and variable load
  - Increased distributed resources
  - Enhanced energy imbalance market cooperation
  - Changing roles of consumers, utilities, investors, power providers, vendors, and regulators
- Regional considerations continue to drive progress
- Production scale and supply chain crucial to lower manufacturing costs
- Investment in technology R&D imperative
  - Better monitoring and measurements
  - Advanced analytics processing and control
  - Demand-shifting and load profile shaping techniques
  - Two way power flow control electronics

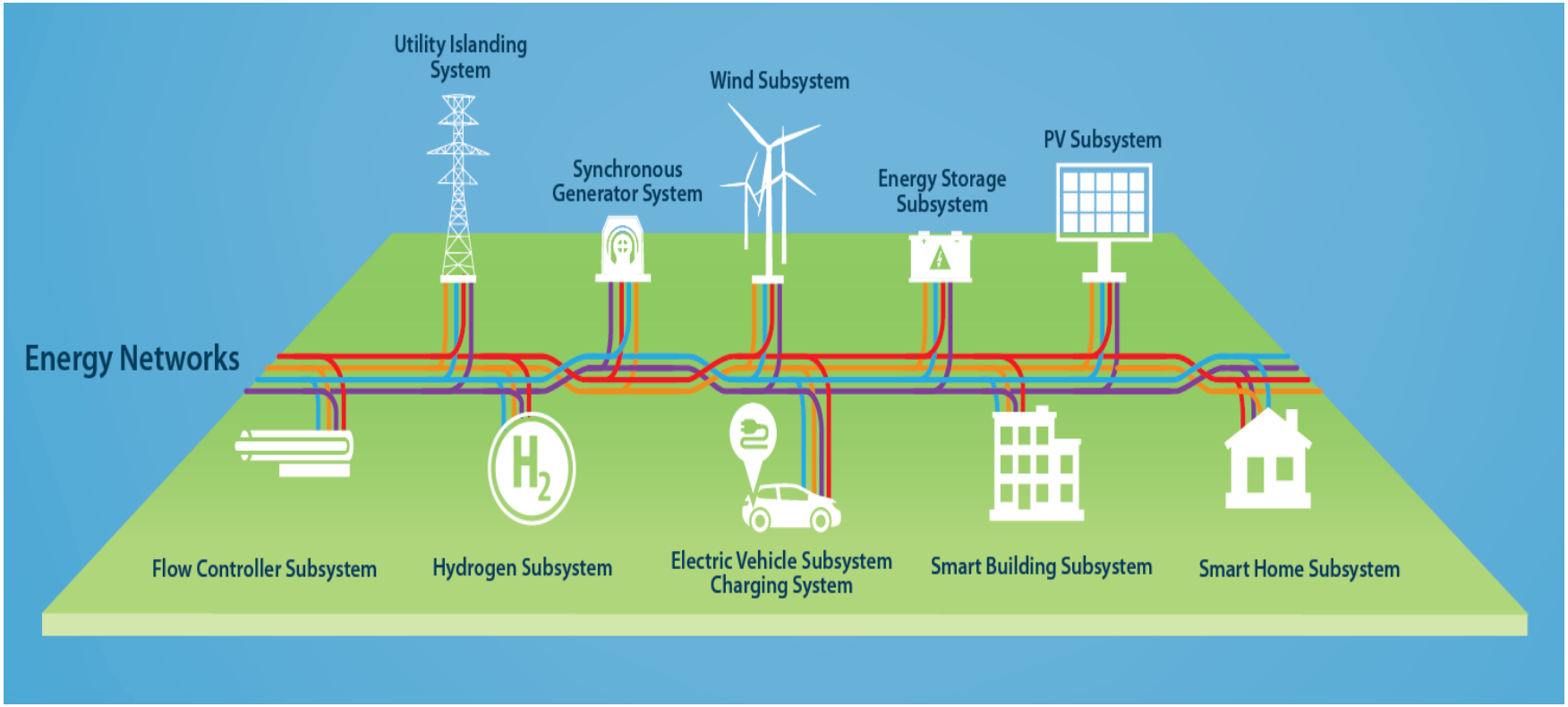
Innovation, Integration and Adoption

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

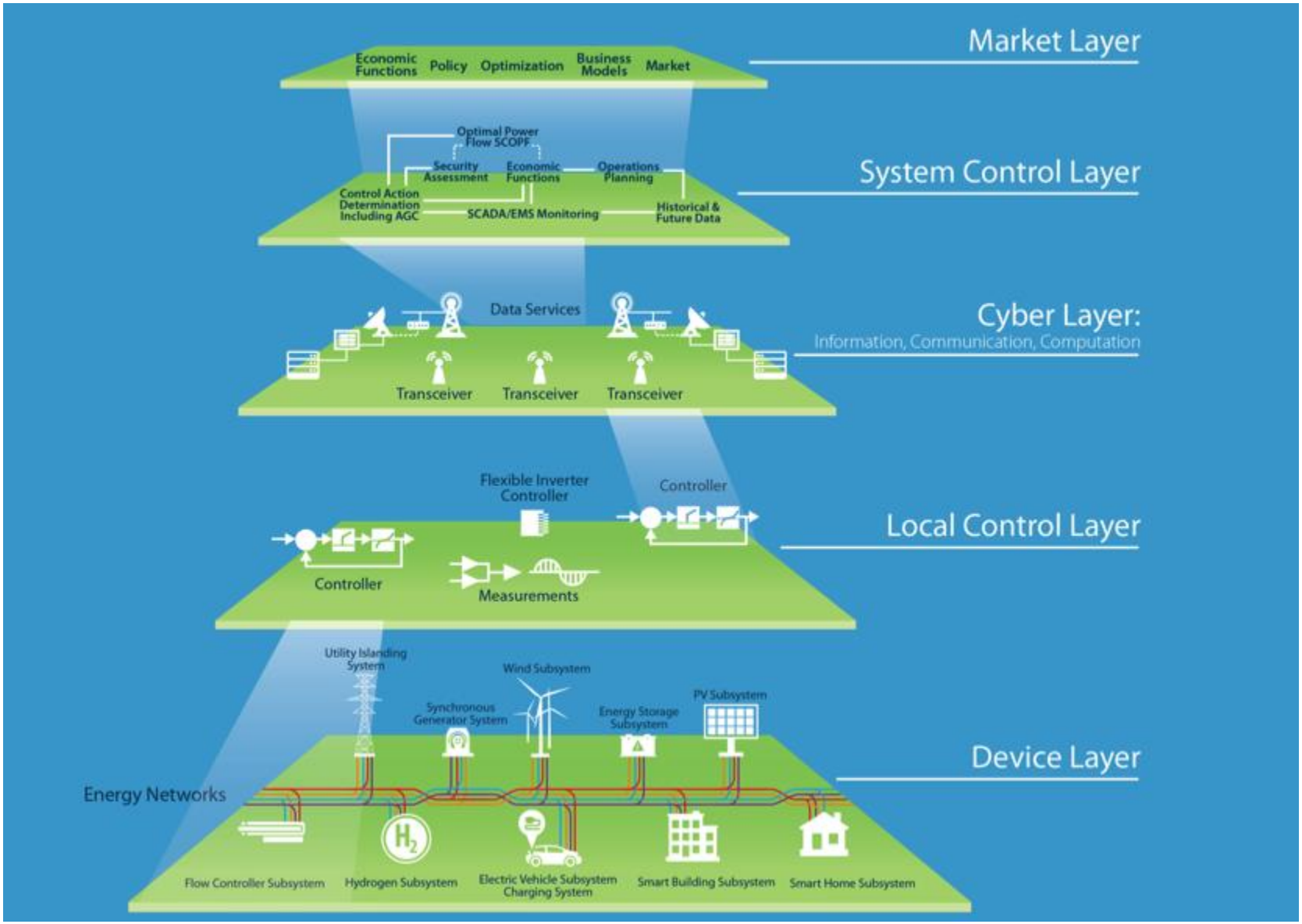
Mobilizing Capital

Integrate Technologies Into System

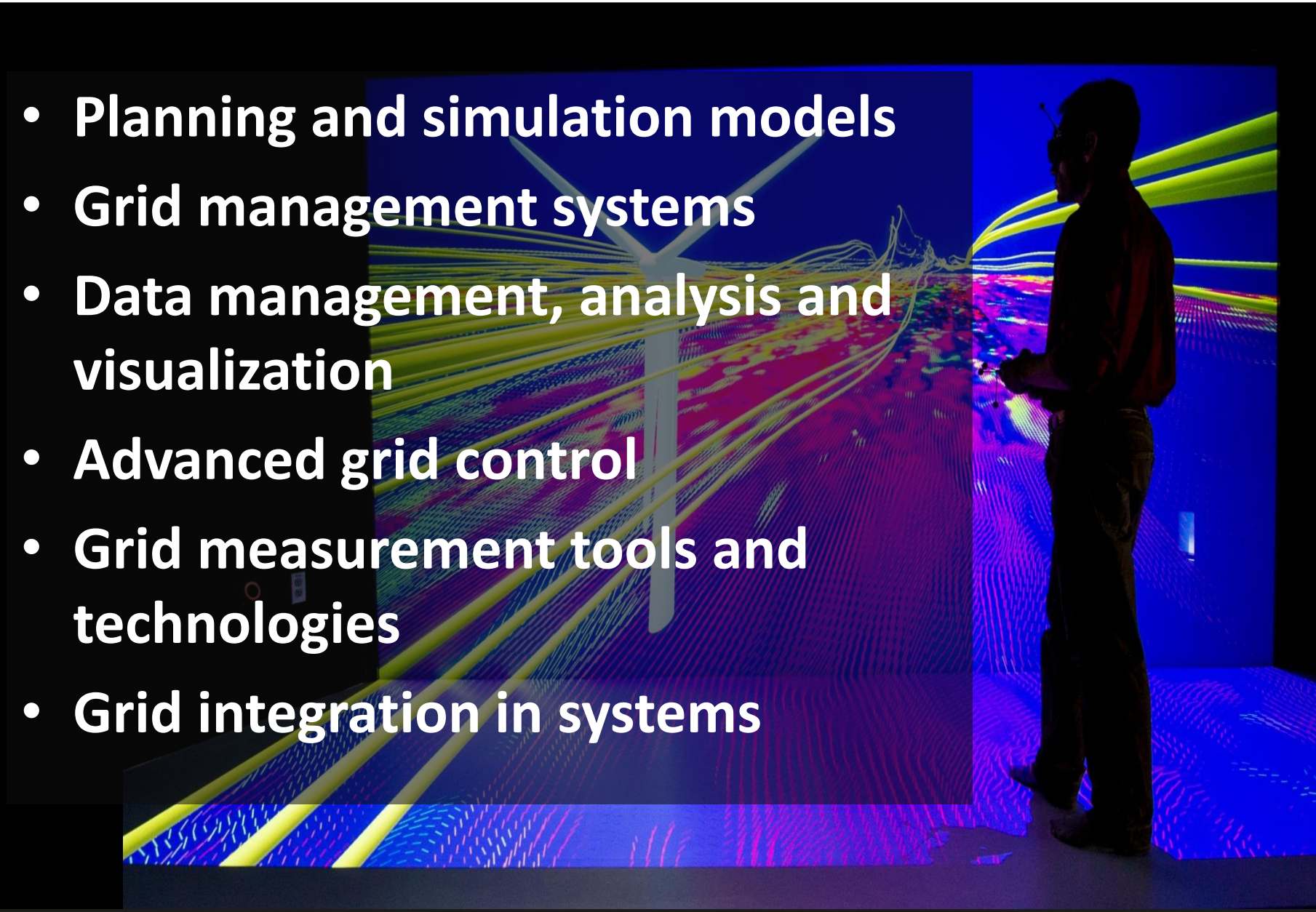


Characterize and predict how components and devices will interact with the others in the system

Integrate Across Functional Layers



Systems Integration R&D Agenda



- Planning and simulation models
- Grid management systems
- Data management, analysis and visualization
- Advanced grid control
- Grid measurement tools and technologies
- Grid integration in systems

Engaging Industry

Energy Systems Integration

HOUZE®

THE POWER OF ZERO

ASETEK

DATA CENTER LIQUID COOLING

- HPC Cooling
- Thermal and optical performance
- Electric vehicles
- Green Hydrogen
- Military apps
- Control algorithms
- Residential scale up
- Storage systems

ADVANCED ENERGY®

TOYOTA

ABENGOA

Innovative technology solutions for sustainability

CSIRO

SOLECTRIA RENEWABLES

SPI SOLAR POWER INC

wyle

EPRI ELECTRIC POWER RESEARCH INSTITUTE

NREL + Advanced Energy

Energy Systems Integration

TECHNOLOGY ADDRESSED

Solar inverter controls validation for high penetration utility and commercial photovoltaics (PV).

R&D STRATEGY

Demonstrate 500 kW PV inverter performance by connecting the inverter to NREL's megawatt scale grid simulators, PV simulators, load banks and real-time electric distribution feeder models.

IMPACT

Increase PV saturation without negatively impacting the distribution grid through modifying the behaviors of inverters.

ADVANCED ENERGY®

NREL + Toyota

Energy Systems Integration

TECHNOLOGY ADDRESSED

Electrical distribution system impacts

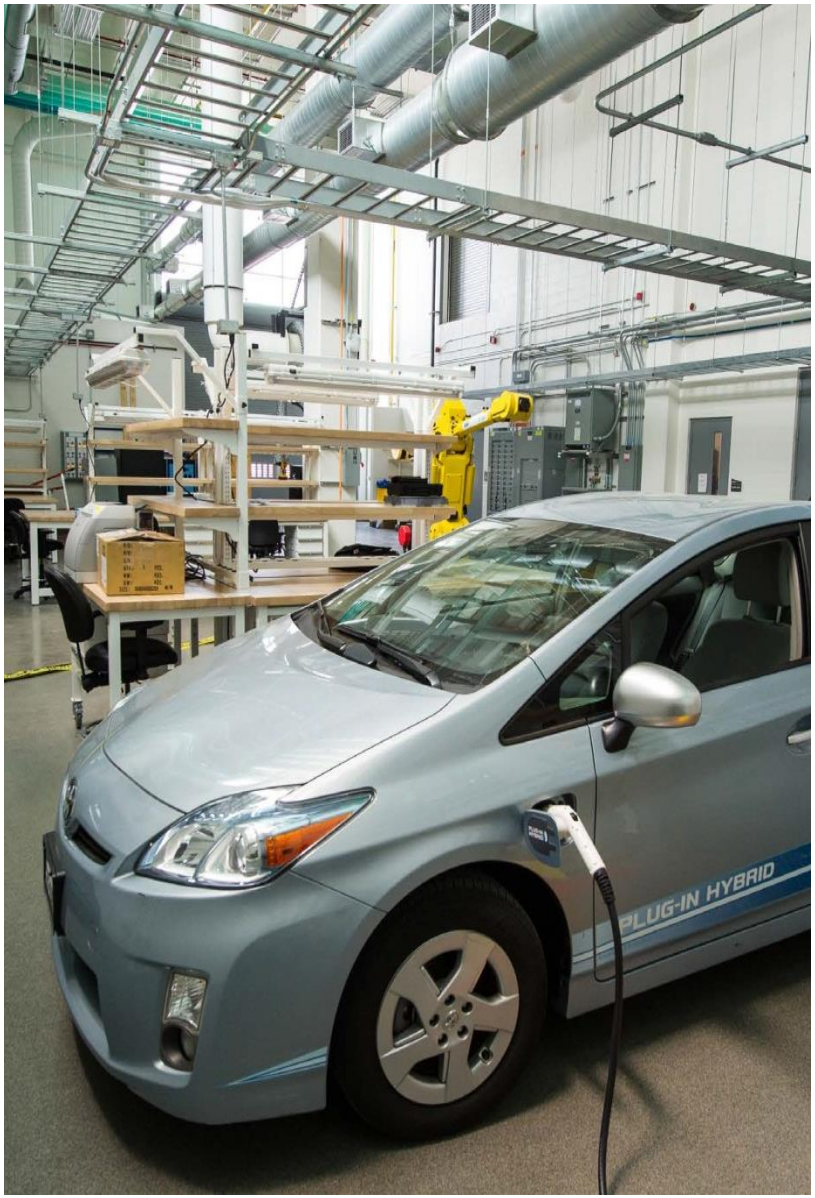
R&D STRATEGY

Collect data and conduct simulations to guide future experiments and projects that aid in the deployment of plug-in electric vehicles (PHEVs).

IMPACT

Correlation of individual vehicle power quality attributes to a system of PHEVs on a distribution network.

TOYOTA



NREL + Abengoa

Energy Systems Integration

TECHNOLOGY ADDRESSED

Molten Salt Heat Transfer Fluid

R&D STRATEGY

Provide reliable thermophysical property data over a temperature range for 2 different mixtures of salts. The two salts listed below are to be tested, along with some commonly accepted and previously tested characteristics.

IMPACT

Integrated thermal storage technologies with concentrated solar.

ABENGOA

Innovative technology solutions for sustainability

NREL + CSIRO

Energy Systems Integration

TECHNOLOGY ADDRESSED

Advance microgrid technology for remote outback applications. 'Plug and play' discovery of components in a microgrid and optimization of energy use when incorporating distributed generation from solar.

R&D STRATEGY

Prototype testing of the microgrid controller to test the hardware's ability to manage the output power of a diesel generator in the presence of a load bank and solar simulator.

IMPACT

By simplifying the process of implementing, expanding and operating solar hybrid systems, this technology will assist system developers, owners and operators and help maximize the contribution of solar energy in these systems.

NREL + Solectria

Energy Systems Integration

TECHNOLOGY ADDRESSED

Advanced Inverter SmartGrid features

R&D STRATEGY

Loop the SGI-500 utility-scale photovoltaic inverter to ESIF's hardware-in-the-loop capability and test its controls and functionality at full power in a real-world simulated environment.

IMPACT

Increase the speed of response to grid emergencies and improve grid power reliability and quality.

SOLECTRIA RENEWABLES

Innovation through Integration

….individual clean energy technologies are now coming together under the integrated approach of energy systems integration…

Solar's Time has Arrived…

"If you sit on the porch with the big dogs, and occasionally bark like a big dog, the world will view you as a big dog."

- Professor Richard Tapia


NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Visit us online at www.nrel.gov