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NATIONAL RENEWABLE ENERGY LABORATORY

A Renewable Energy Future: Innovation and Beyond

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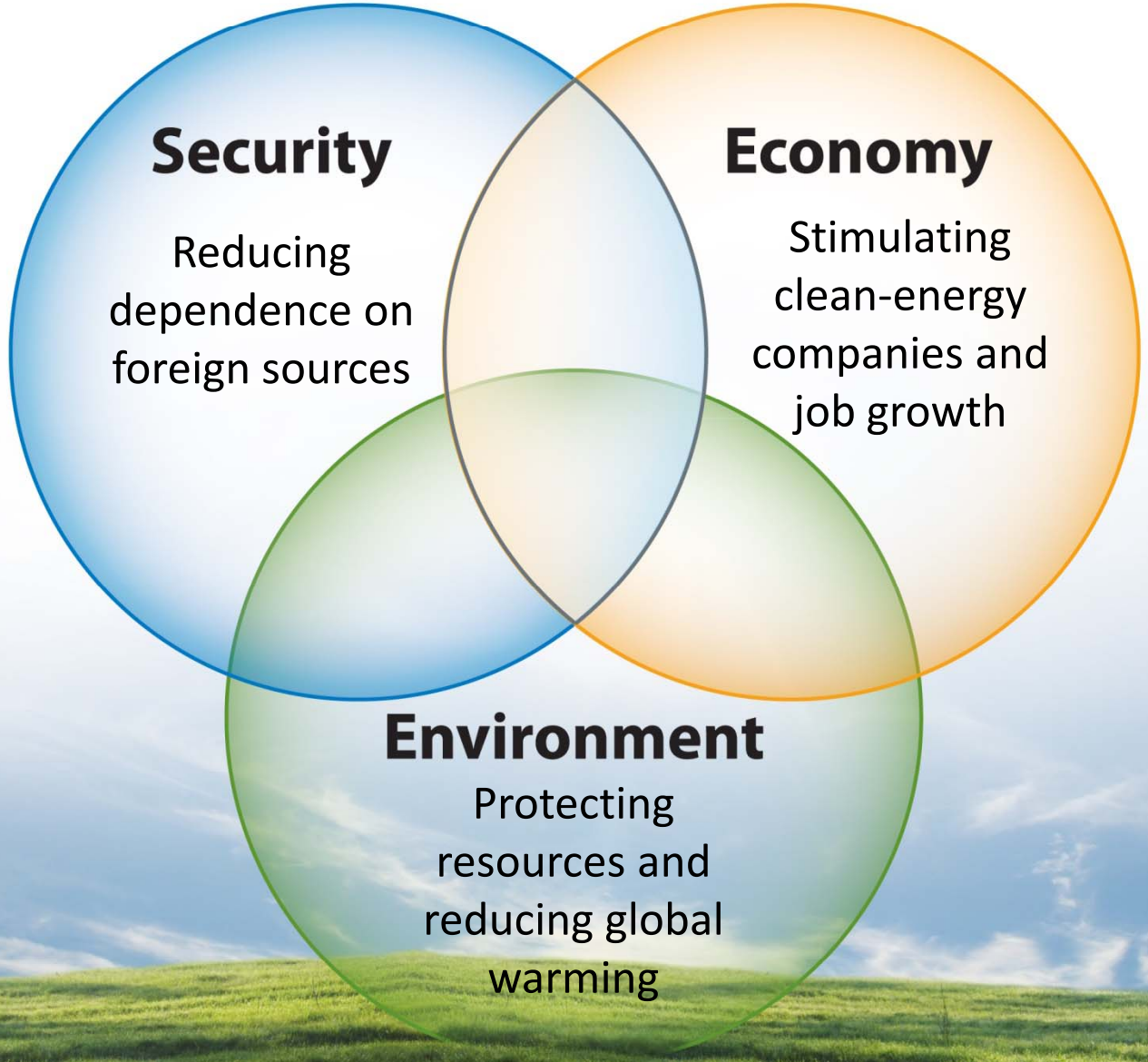
SUNSHOT GRAND CHALLENGE
Summit and Technology Forum

SunShot
U.S. Department of Energy

Energy Sector

TRANSFORMATION IS REQUIRED

National Energy Imperatives



A Profound Transformation is Required

Today's Energy System

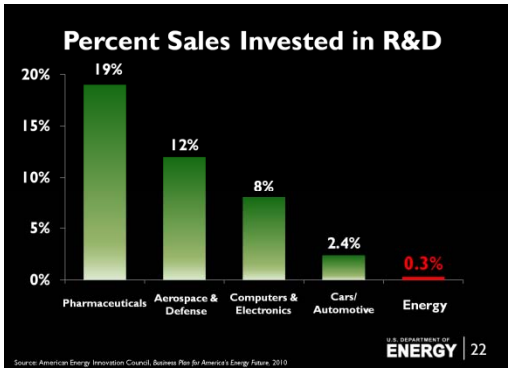
- Dependent on non-domestic sources
- Subject to price volatility
- Increasingly vulnerable energy delivery systems
- 2/3 of source energy is wasted
- Significant carbon emissions
- Role of electricity increasing

TRANSFORMATION

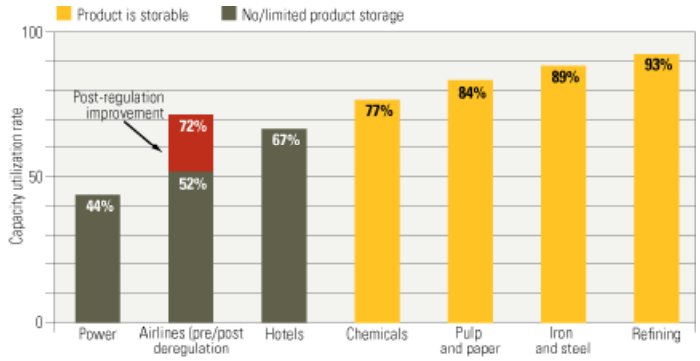
Sustainable Energy System

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

Energy Sector Challenges



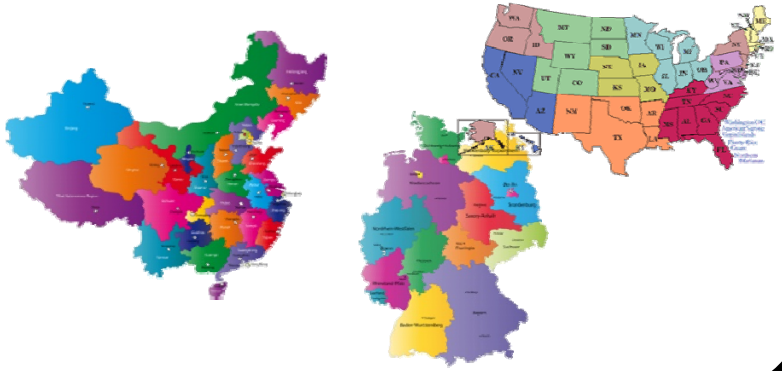
R&D Investment Drives Innovation



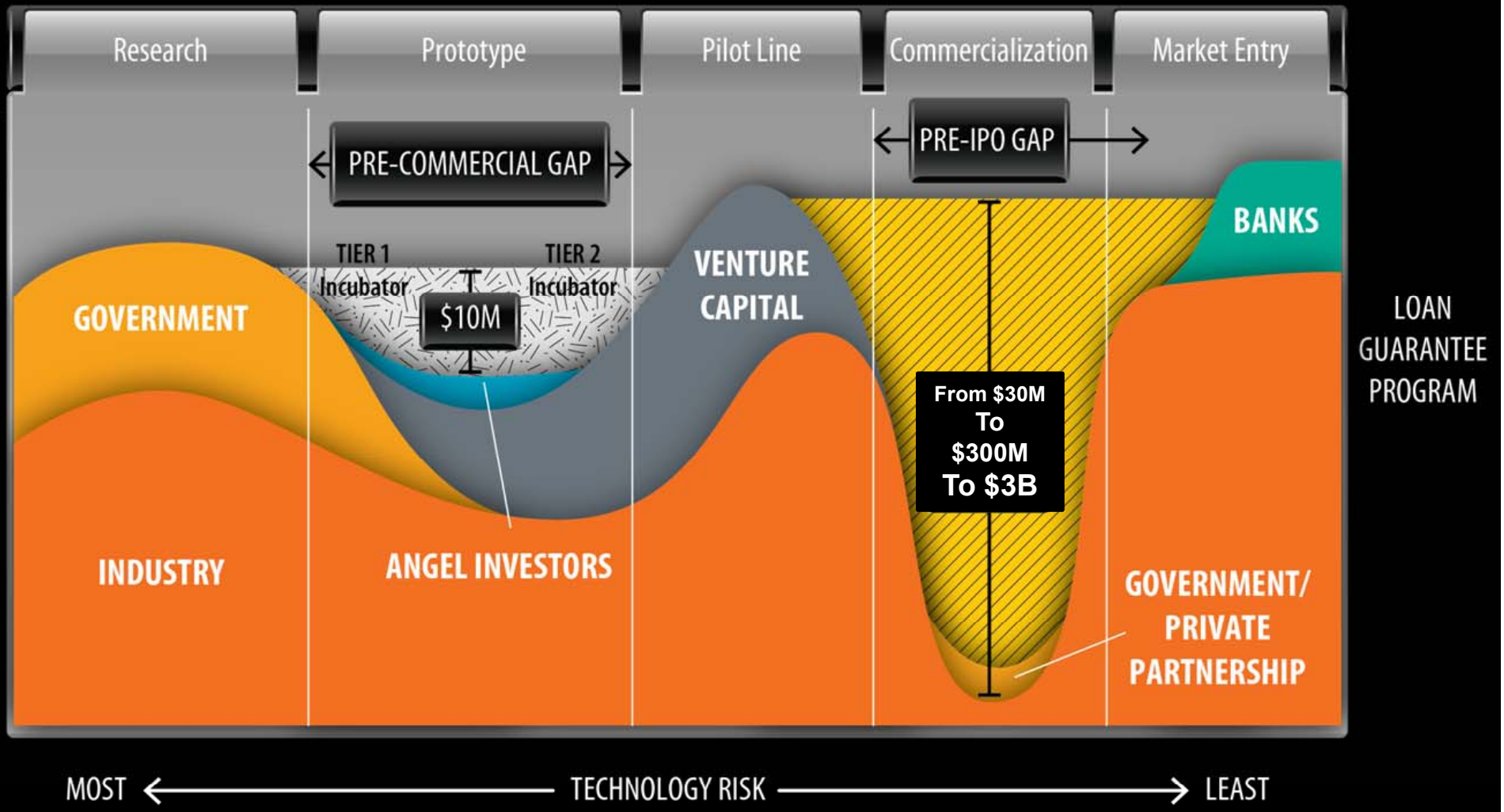
Asset Utilization

Capital Intensive with Long Life Cycles

National Strategies Driving Energy Market



Investment Pipeline



Innovation, Integration, & Adoption

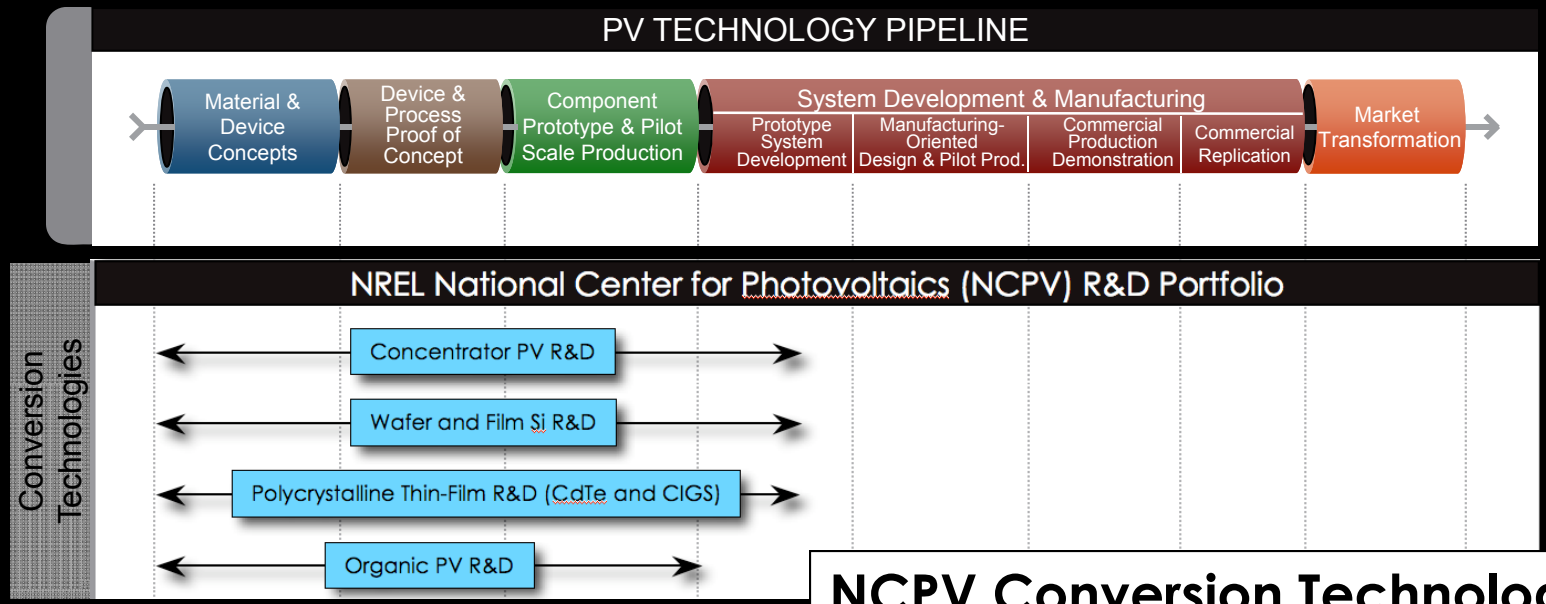
Reducing Investment Risk

- 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

How do we get there?

IT WILL TAKE INNOVATION

NCPV Conversion Technology R&D

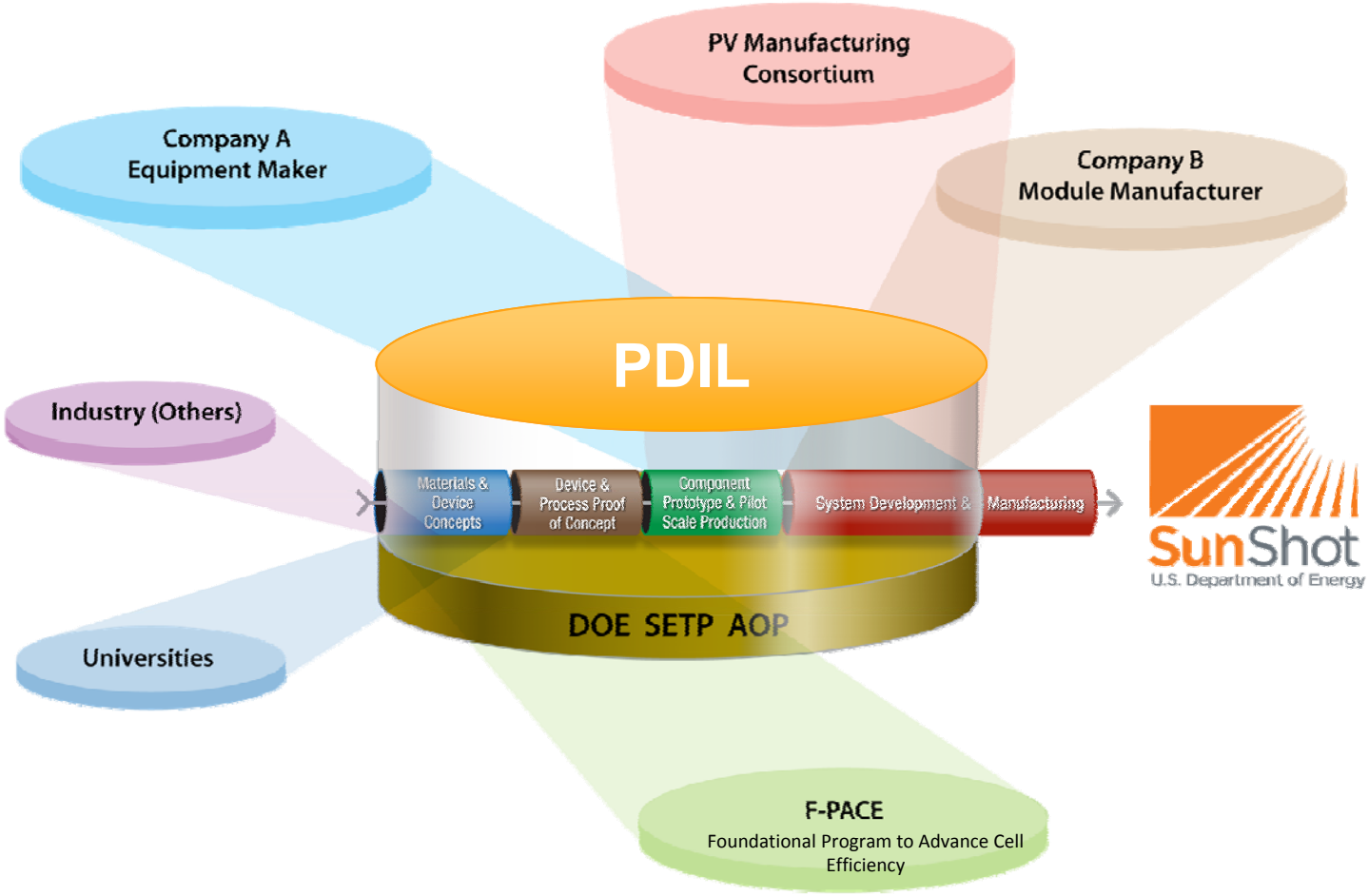


NCPV Conversion Technology R&D:

- CIGS
- CdTe
- Next Gen Si
- III-V
- Organic PV (OPV)

Conversion Technologies

Strategically Focused Portfolio



SunShot Targets:

CIGS/CZTS

	Cell Efficiency	Commercial Module Efficiency	Cost	Reliability
Current Status	20.3%	11-13%	<$1.50/Watt (estimate)	0.5-5% annual degradation in pilot arrays
2015 Targets	23%	13-16%	<$0.70/Watt	<1% annual degradation

CdTe

	Cell Efficiency	Module Efficiency	Cost	Module Reliability
Current Status	17.3%	11-12%	0.75-0.80/W	0.6-1.2 %/year
2015 Targets	19-20%	14.0%	0.60/W	0.5-1.0 %/year

Wafer-Si

	Cell Efficiency	Module Efficiency	Cost
Current Status	25%	14-20%	$1.0/W
2015 Targets	27%	16-23%	$0.6/W

SunShot Targets:

Film-Si

	Cell Efficiency	Module Efficiency	Cost	Comment
Current Status	12.7%	7-11%	$0.70-1.50/W	a-Si/nc-Si tandem or triple junction
2015 Targets	15%	12%	$0.6/W	likely early commercialization of film c-Si

III-V

	Multijunction Cell Efficiency	Module Efficiency	Cost
Current Status	41.6%-lab 40%-commercial	28%	>30¢/kWh
2015 Targets	48%-lab 44%-commercial	30%-36%	<7¢/kWh

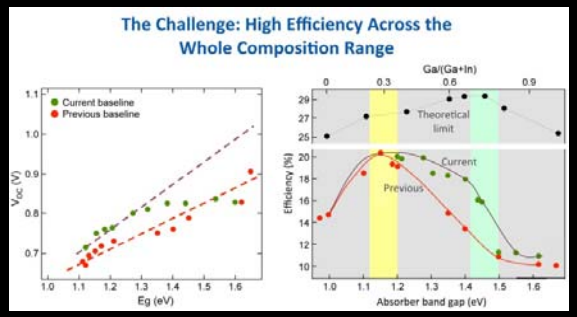
OPV

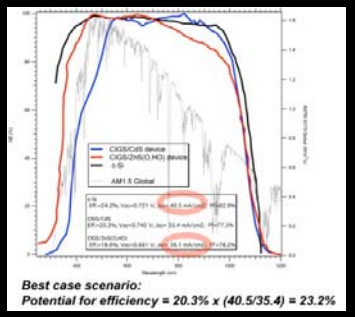
	Cell Efficiency	Module Efficiency	Cost	Reliability
Current Status	10.6%	5.2%	?	Stability beyond 10,000 hours
2015 Targets	>13.5%	10% 100 cm^2	<1$/W	>30,000 hours

Needs/Challenges

CIGS/CZTS

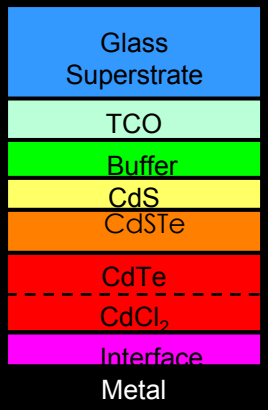
- Higher photovoltage
- Higher photocurrent
- Rapid growth rate
- Minimize electrical defects in PV quality



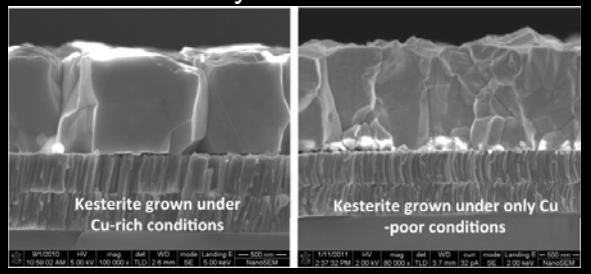


CdTe

- Minority carrier lifetime
- Grain boundary structure and charge transport
- Correlation between TRPL lifetime and device performance
- Synthesize an effective set of samples

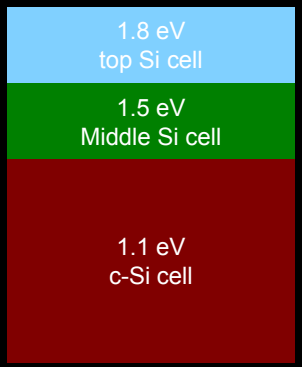


Efficiency = 9.2%



Wafer-Si

- Multijunction device modeling
- Engineered (tailored material) for middle and top cell
- High quality middle Si cell around 1.5 eV
- High performance and understand the tunneling junction
- Surface and bulk passivation of c-Si
- Improved light management for component cell



Needs/Challenges

Film-Si

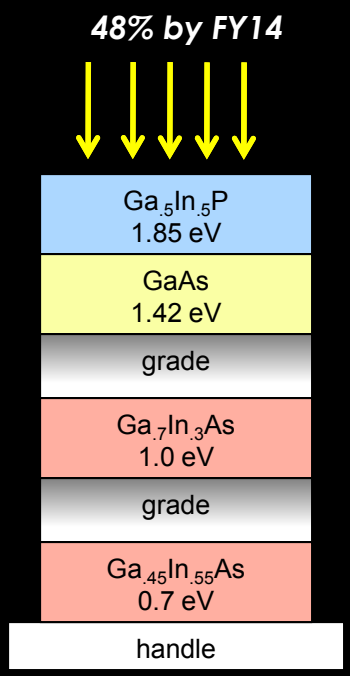
- Improved thin-film silicon cells at high growth rate
- Develop low-cost oriented crystal seeds for film c-Si
- Improve epitaxy quality and rates at low T
- Develop light-trapping for thin c-Si

III-V

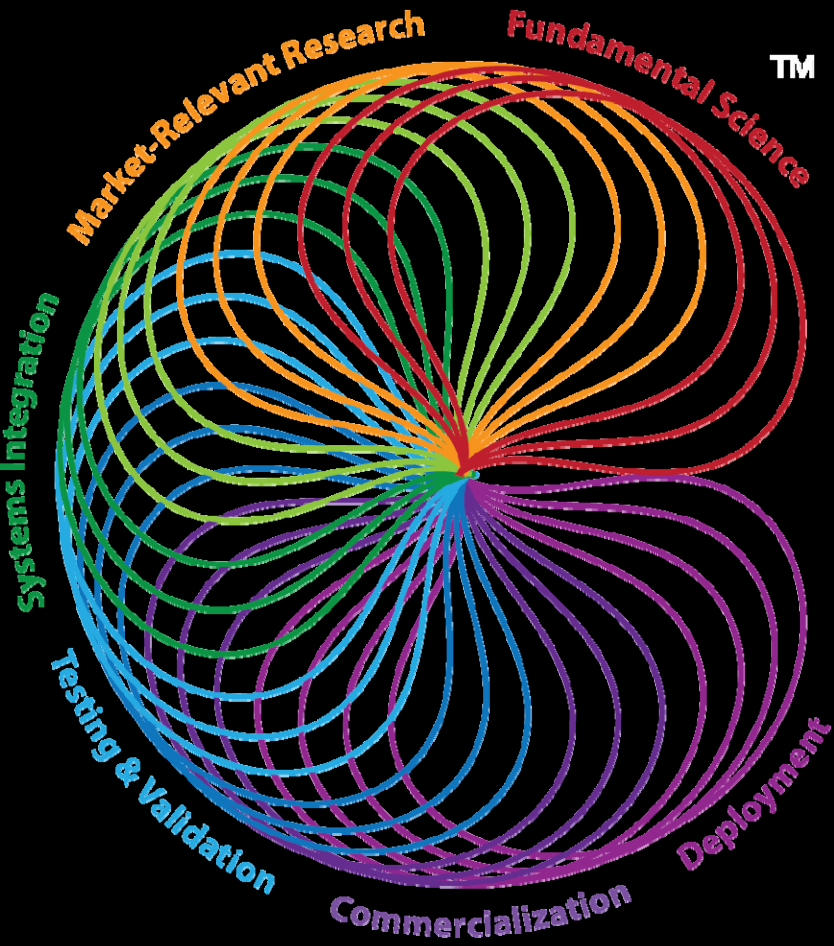
- Next-generation cells to increase power/lower LCOE
- Deeper reliability heritage for cells and systems
- Design cells for operation in real-time systems

OPV

- Lower band gap absorbers with appropriate HOMO/LUMO
- Stability >30,000 hours (intrinsic and extrinsic)
- Scalability of lab scale efficiencies to >100 cm^2 modules
- International coordination and standardization



innovation



Spectrum of Innovation

From Science through Deployment

- Comprehensive approach to innovation
- Collaboration with private industry
- Connects science to the marketplace
- Delivers market-relevant technologies and competitive clean-energy products

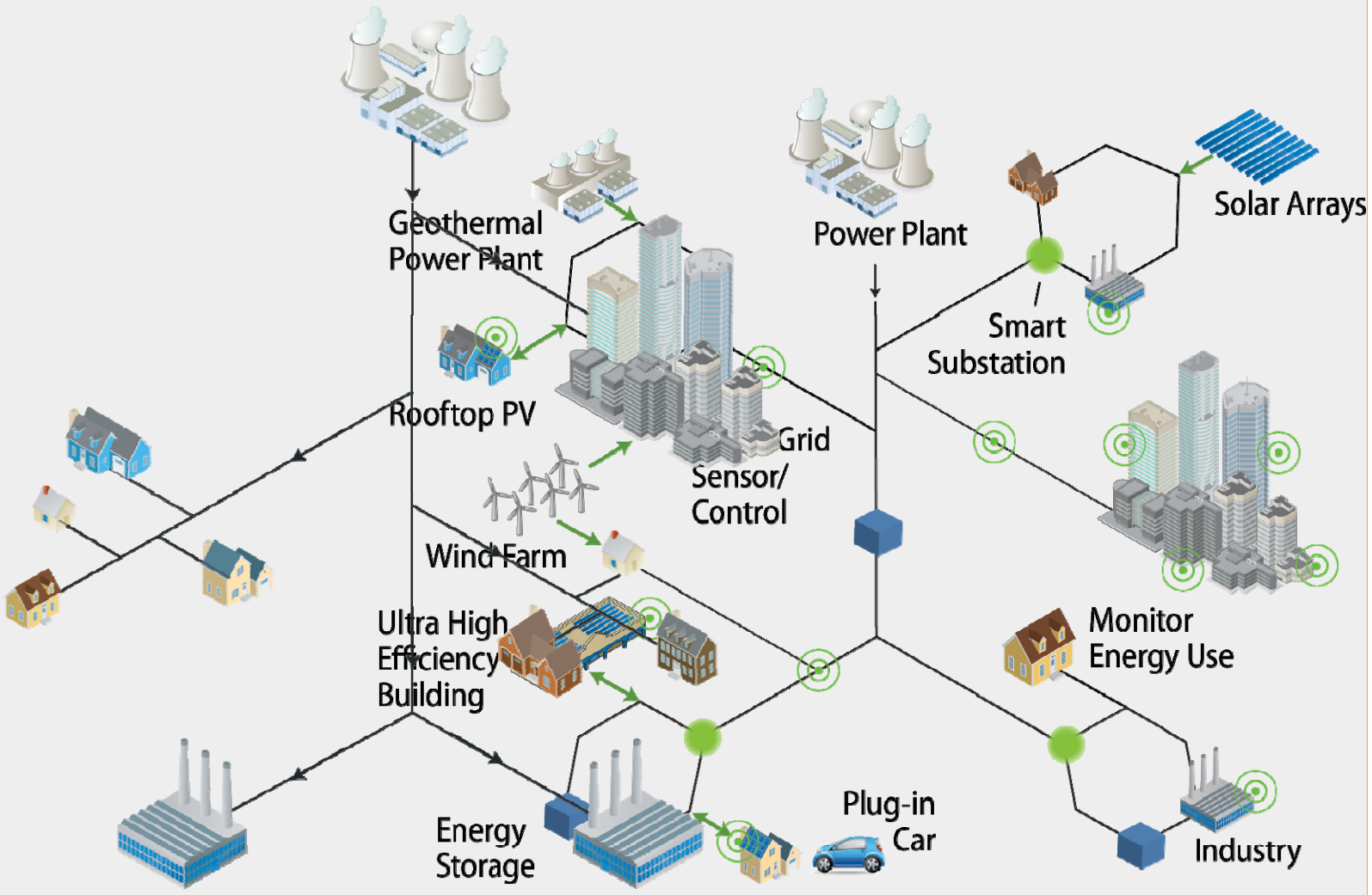
innovation Impact

Transformation

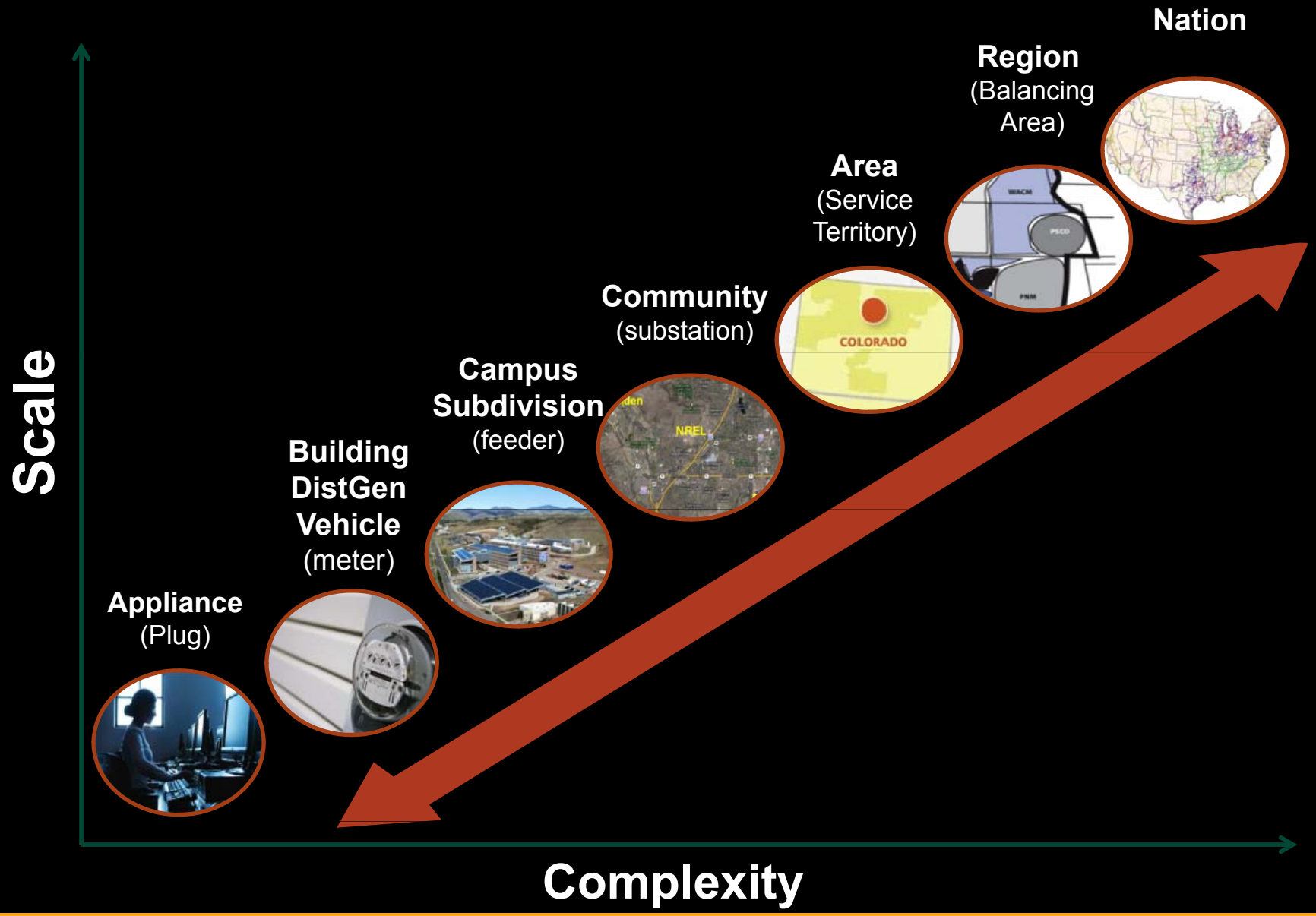
INTEGRATION IS KEY

Transforming Our Electricity Infrastructure

Current Energy Systems **Future Energy Systems**



Requires Integration Across All Scales



Energy Systems Integration

Key Challenges

- Increase overall energy system efficiency
- Integrating new technologies in existing infrastructure
- Engagement of consumers in energy use – increases complexity but also increases system flexibility

Gaps in the ability to address these questions

- Difficult to test large-scale deployments of new technologies
- Difficult to obtain information on actual performance
- Energy systems cuts across a variety of pathways so it requires an interdisciplinary approach

Opportunities for science-based approach

- Linking hardware and control testing to system simulation environment
- Using actual operations data to develop evidence based solutions – mining massive new data sets
- Complex systems analysis and control – scalable synergistic operations of large interconnected systems

NREL Energy Systems Integration Facility

Solving the challenges of large-scale integration of clean energy technologies onto the energy systems infrastructure

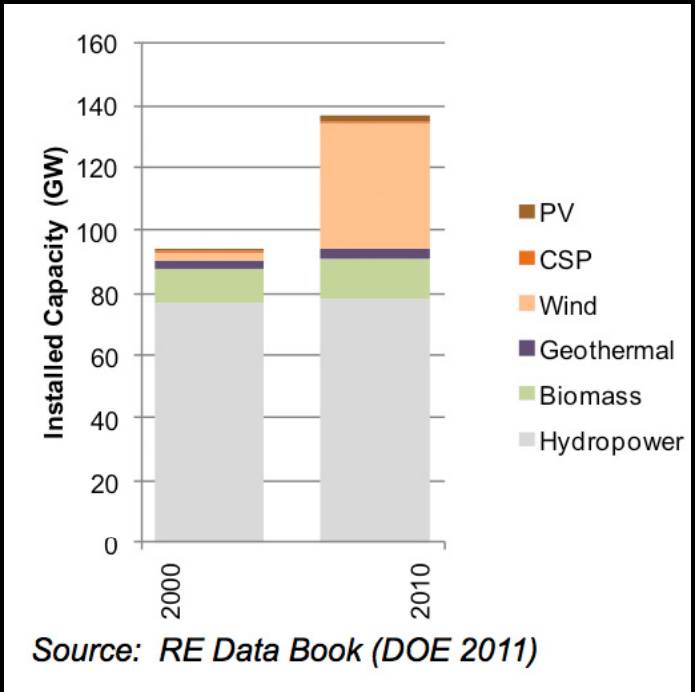
ESIF – A Unique Technology User Facility

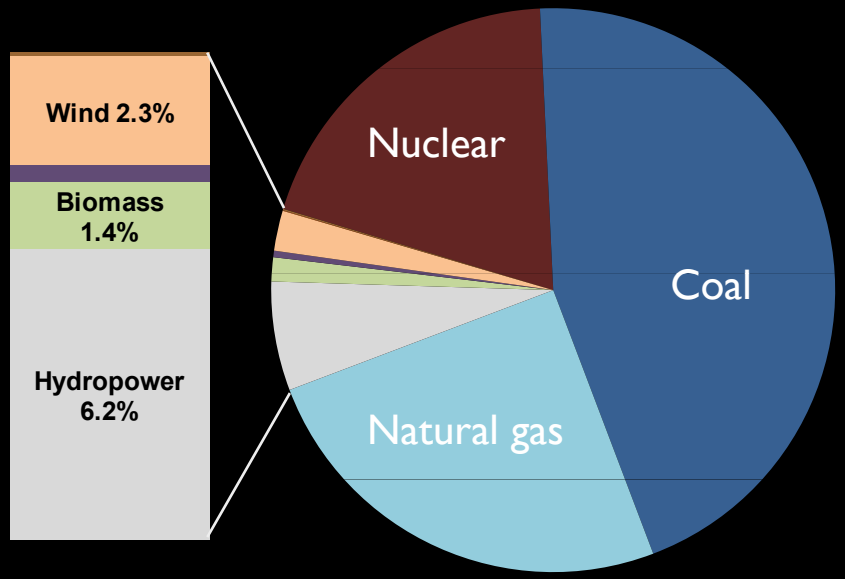
- A unique national asset for energy systems integration R&D, testing, and analysis
- Designed for conducting research and development of renewable energy technologies in a systems context at deployment scale

80% Renewable Electricity

TRANSFORMED BY 2050

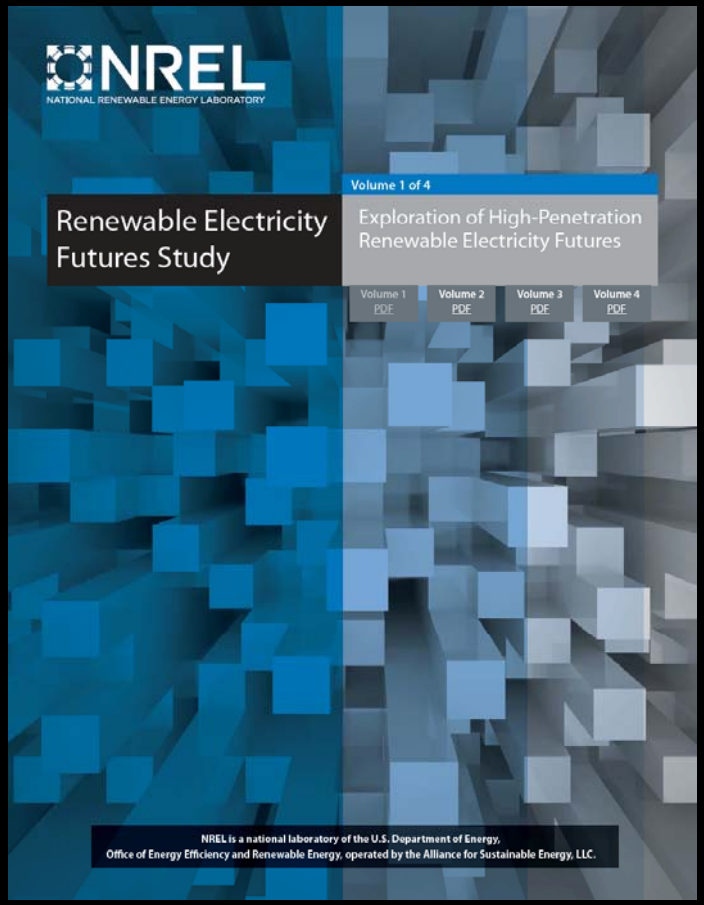
Renewable Electricity Futures Motivation





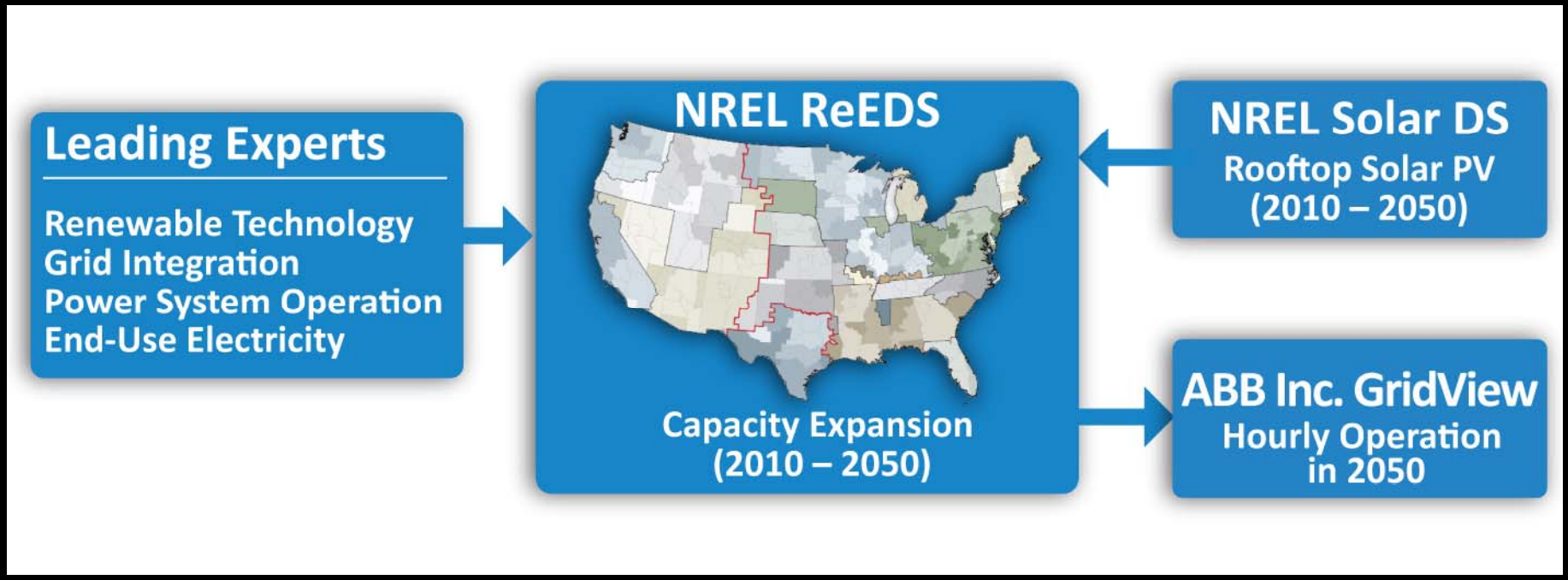
- **RE is a low carbon, low air pollutant, low fuel use, low water use, domestic, sustainable electricity source.**
- **To what extent can renewable energy technologies commercially available today meet the U.S. electricity demand over the next several decades?**

Renewable Electricity Futures Study



U.S. DOE-sponsored collaboration with over 110 contributors from about 35 organizations including national laboratories, industry, universities, and NGOs

State of the Art Electric System Models



- Unprecedented geographic and time resolution for the contiguous United States
- Over two dozen scenarios of RE generation focused on 2050

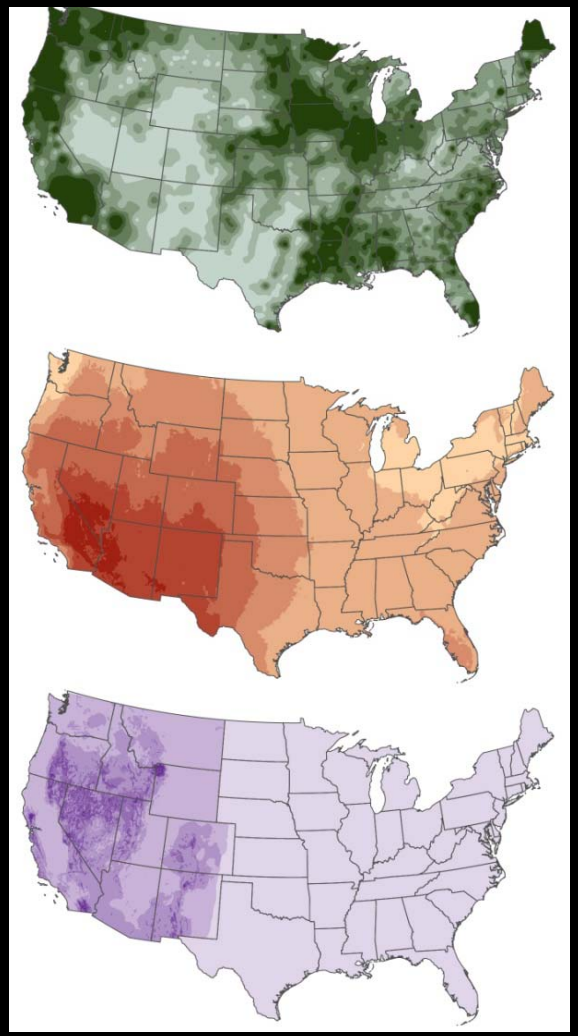
Abundant Renewable Energy Resources

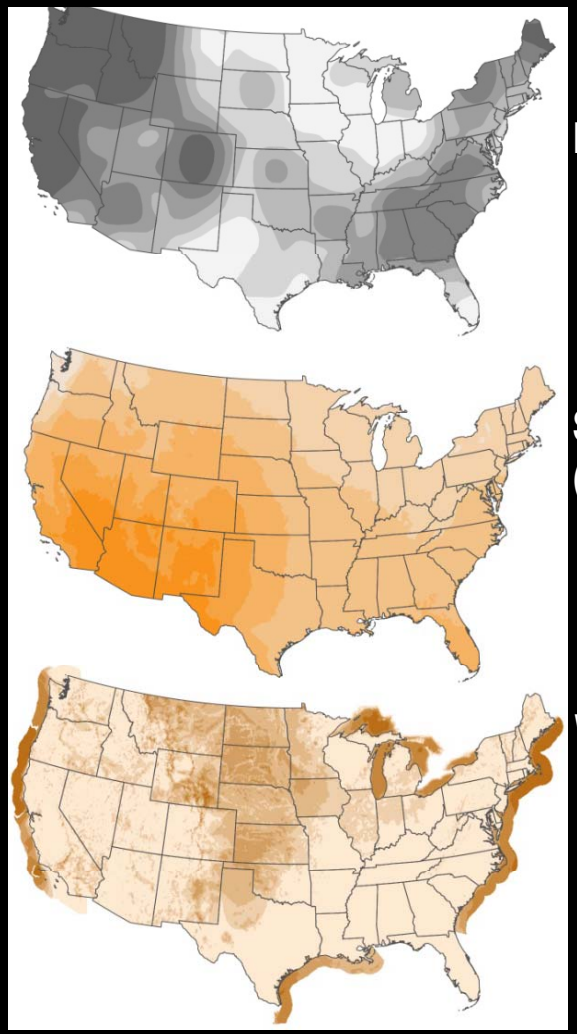
Biopower ~100 GW
- Stand-alone
- Cofired with coal

Solar CSP ~37,000 GW
- Trough
- Tower

With thermal storage

Geothermal ~36 GW
- Hydrothermal





Hydropower ~200 GW
- Run-of-river

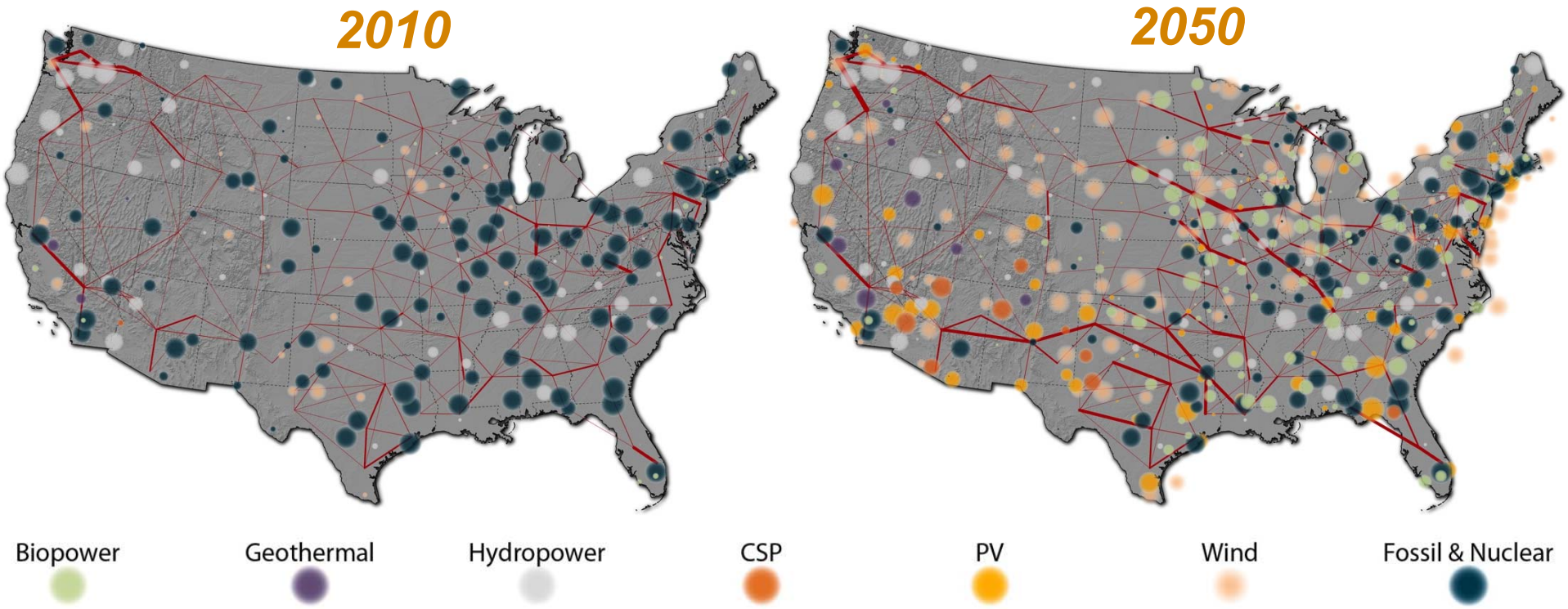
Solar PV ~80,000 GW (rooftop PV ~700 GW)
- Residential
- Commercial
- Utility-scale

Wind ~10,000 GW
- Onshore
- Offshore fixed-bottom

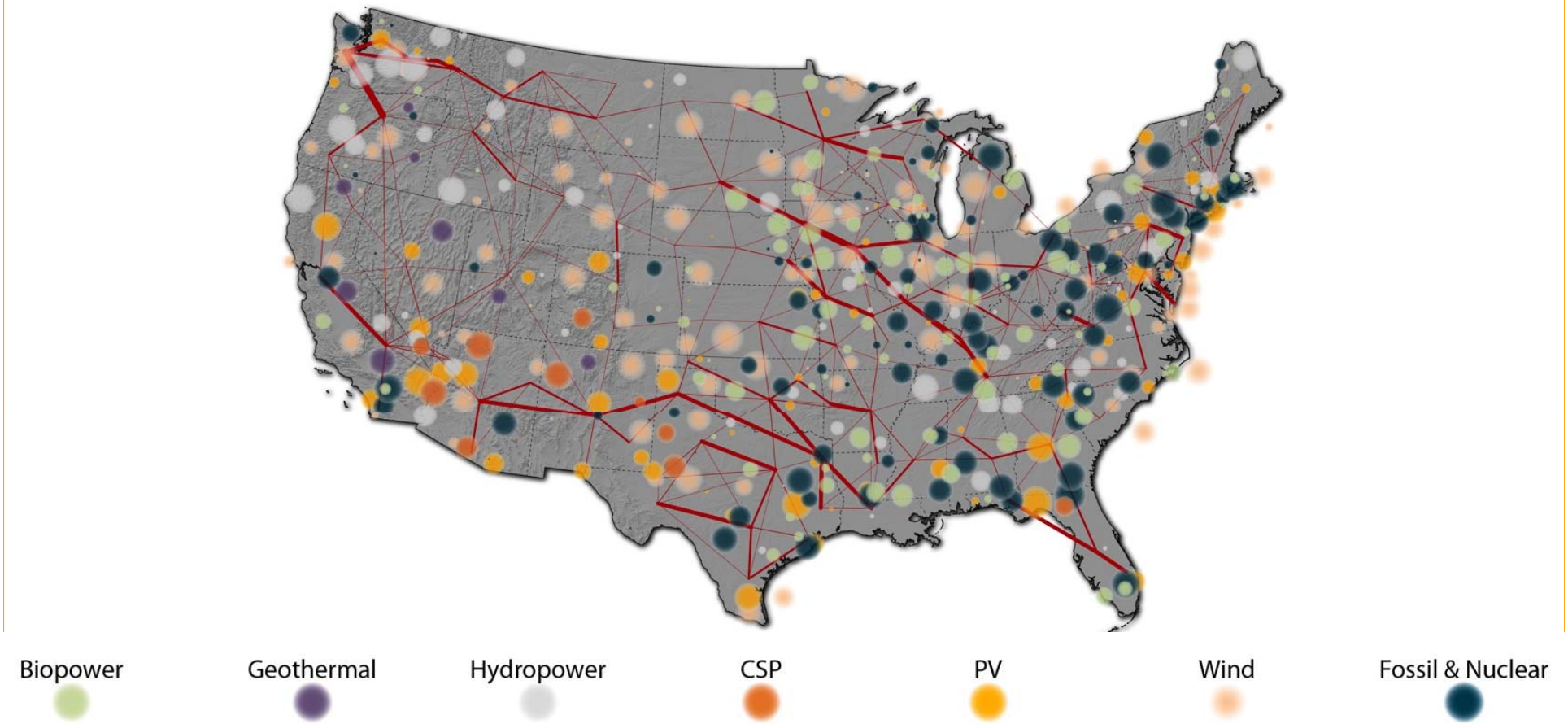
Darker Colors = Higher Resource

Geographic location, technical resource potential, and output characteristics are unique to each RE generation technology.

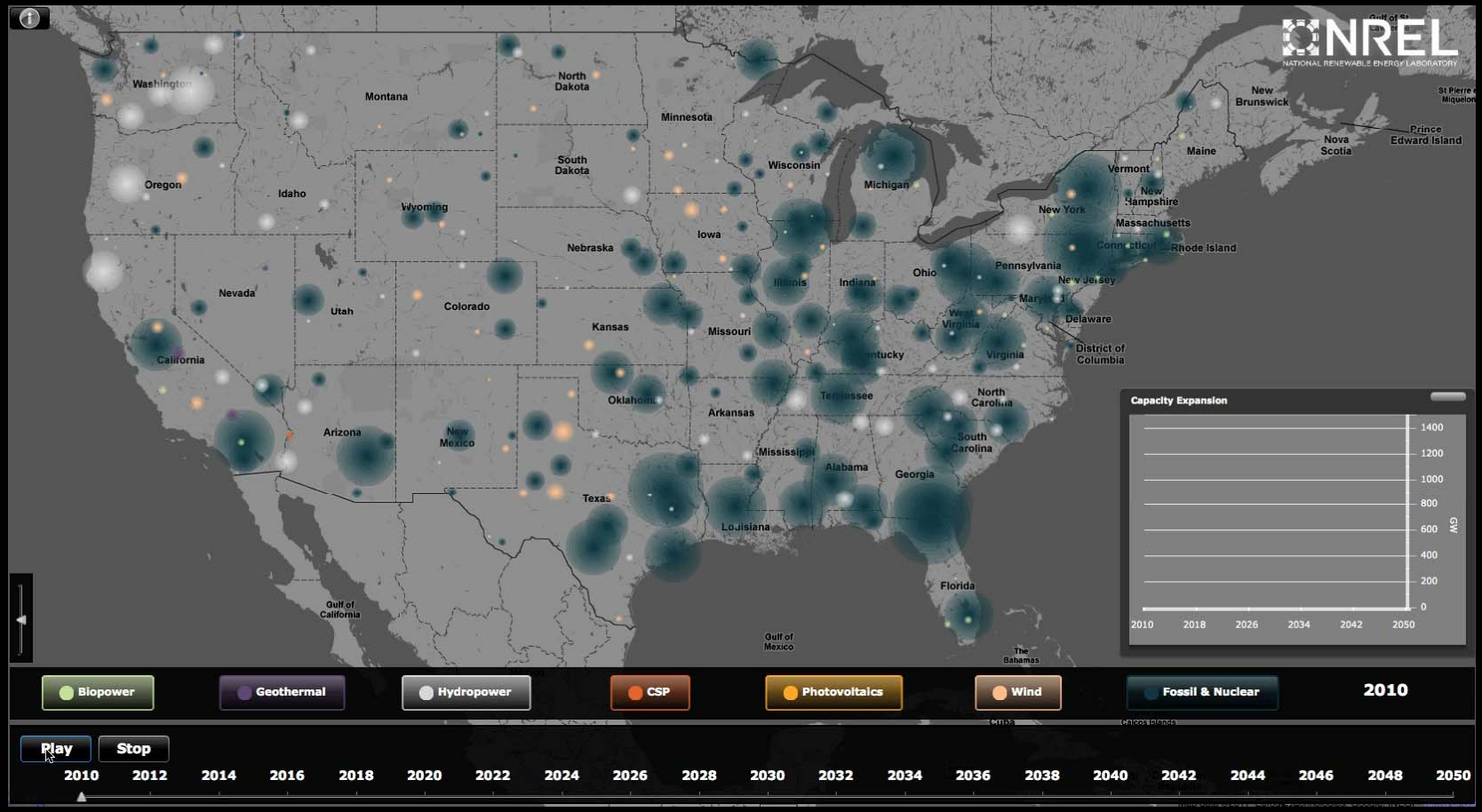
A Transformation of the U.S. Electricity System



RE generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the country



A future U.S. electricity system that is largely powered by renewable sources is possible, and further work is warranted to investigate this clean generation pathway.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Alabama
Georgia
Texas
Louisiana
Florida
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Gulf of Mexico
The Bahamas
New Brunswick
Maine
Vermont
New Hampshire
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Rhode Island
Nova Scotia
Prince Edward Island
Delaware
District of Columbia
Virginia
North Carolina
South Carolina
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Geothermal
Hydropower
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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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