Research for the Transformation of the Global Energy System

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In this lecture I would like to show the NREL's approach, what is happening on a global scale and where the trend is going.

About NREL

In 2017 NREL celebrates 40 years of clean energy research. NREL has a lot of industry partnerships which helps to overcome the "valley of death". Our laboratories are very active to develop and de-risk technologies to help the industry to push out innovations into the market place.

NREL's Portfolio

- renewable power: solar, wind, water, geothermal
- sustainable transportation: bioenergy, vehicle technologies, hydrogen
- energy efficiency: buildings, advanced manufacturing, government energy management
- energy systems integration: high-performance computing, data and visualizations

Climate goals and renewables

What do we need to do to keep global warming below 2 °C? A real impact on climate change requires decarbonization of global energy systems. The need is great because energy consumption is predicted to grow 56 % by 2040. Renewables are providing energy and cutting emissions, but there are challenges. Energy needs are spread across many end-use sectors. In the U.S., more than half of CO_2 emissions come from industrial and transportation sectors. There are a lot of gaps that research has to fill.

Energy use in the U.S.

The U.S. economy is growing while energy use is shrinking. Gross domestic product (GDP) grew 12 % since 2007, while total energy use fell 3,6 %. So, the energy productivity of the U.S. economy – the ratio of U.S. GDP to energy consumed – grew 16 %. (Source: 2017 Sustainable Energy in America Factbook, Bloomberg New Energy Finance and the Business Council for Sustainable Energy, February 2017) Renewables represent growing share of U.S. generation. Far from "alternative," renewable energy is the new normal in the United States. Global solar and wind generation show sharp increase.

Costs for renewable technologies are falling.

This incredible increase was driven by falling costs, especially dramatic cost reductions for solar. Advanced energy technologies are providing real-world solutions. They drive a domestic energy economy and are increasingly cost-competitive. Energy manufacturing and installations provide major opportunities for American workers.

Creating global economic opportunity
What's driving the momentum?

- Government commitments on national, state and community levels. Nearly 50 countries vow to use 100 % renewables by 2050.
- Private sector commitments: There are 62 large U.S. companies which pledged that they are going 100 % renewables.
- Investments
- Advancements in technology
- According to IRENA, decarbonizing global energy systems requires $29 trillion of investment – only about 0,4 % of GDP (2050)

NREL's Research Activities

Continuing R&D is essential to transform the global energy system. These are some of the key fields we think it´s important to make a change:

1. Solar Technologies

For solar technologies, a major goal is scale up to make a significant impact – 10 terawatts by 2030, or ~50 % of world electricity generation. The cost of solar energy has fallen 96 % and now stands at less than a dollar a watt for solar module, pre-installation. But this is still not good enough, so we need more research.

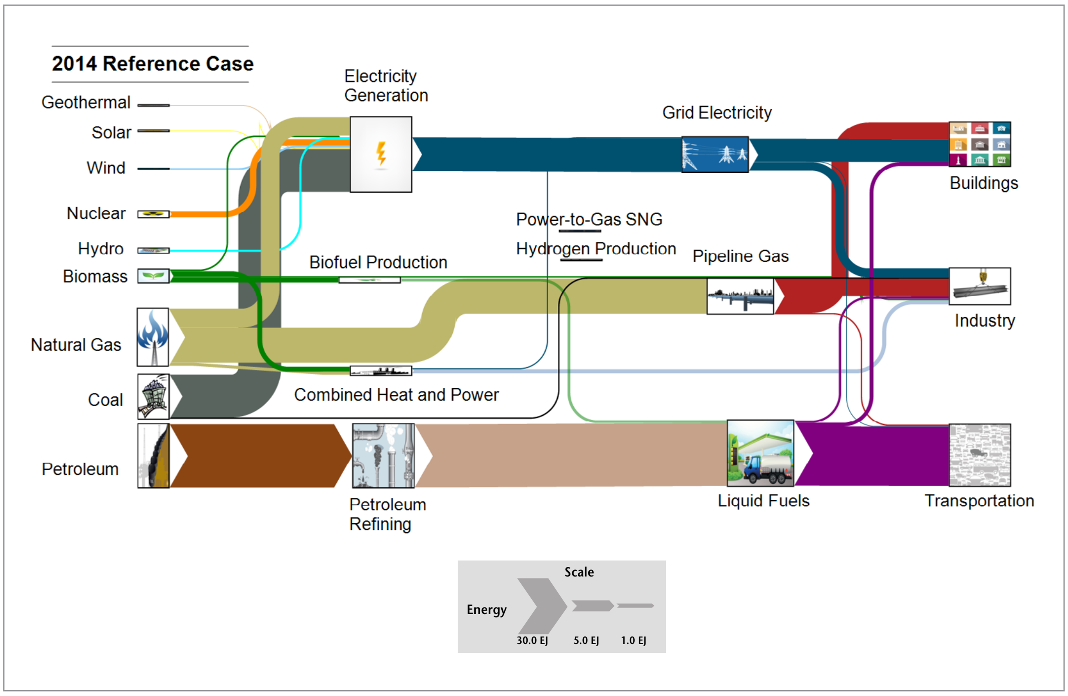
Market Impact

- costs: from less than $1 to $6/W
- levelized cost of energy at 7-16 cents/kWh
- Solar provides nearly 1% of U.S. power generation.
- U.S. installed capacity at 45 GW
- Solar power employs nearly 374,000 U.S. workers.
- U.S. forecast (through 2040) is for nearly 40 GW of photovoltaic (PV) capacity in pipeline.

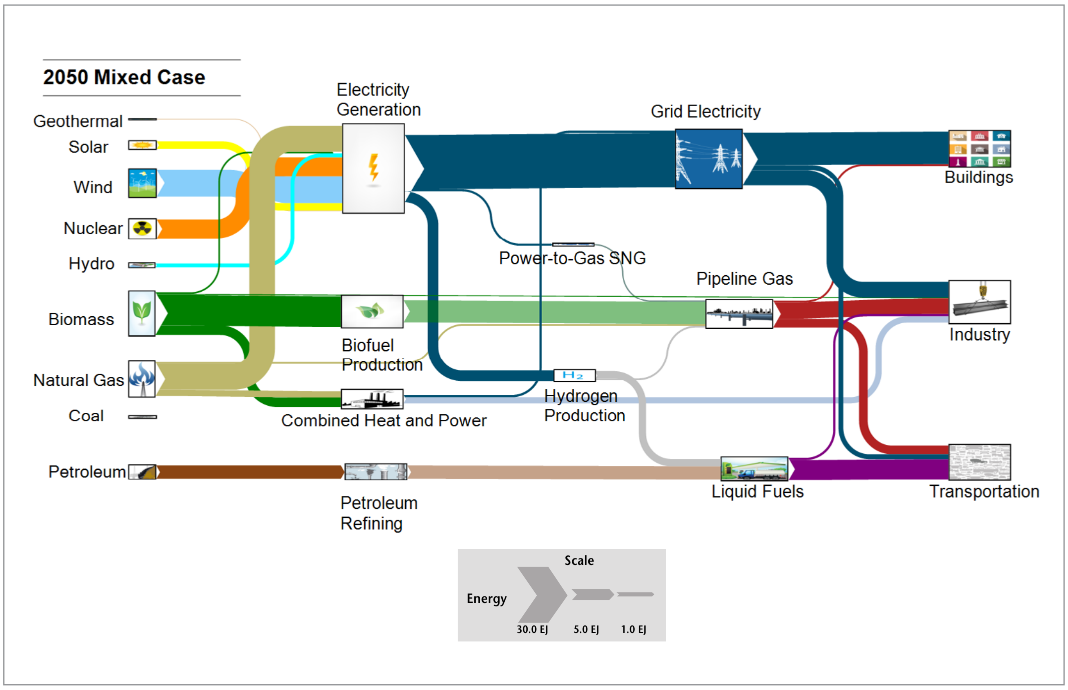
Key Research Areas

- Providing rapid growth: perovskite technology has provided new materials with an efficiency of more than 20 %.
- Boosting efficiency of modules high-efficiency thin films improve carrier lifetime of commercial products.

Decarbonization of global energy systems



Current Energy System (2014 Reference)
Source: DDPP (Deep Decarbonization Pathways Project), Dr. Jim Williams, U.S. DDPP Director, NREL, 2016



Deeply Decarbonized Energy System (2050)
Source: DDPP (Deep Decarbonization Pathways Project), Dr. Jim Williams, U.S. DDPP Director, NREL, 2016

- Increasing cell efficiency: research in silicon tandem cells improves the best cell efficiencies by 10 %-30 %.
- Improving applications for high-efficiency technologies: 1- and 2-junction III-V cells lower growth cost.

NREL's research activities for PV:

- *materials*
  - six-junction solar device: possible >50 % efficiency
  - multijunction, III-V cells: efficiency >30 %
  - Perovskites show steep climb in efficiency: 22.1% efficiency for most recent lab device and there is a potential for higher efficiencies and lower production costs, but we still have to work on stability.

Perovskite technology can completely change the way of manufacturing solar cells and help to actually manufacture the PV capacities needed. Hybrid Perovskite Solar Cells (HPSCs) could be manufactured more than 50 times faster than current silicon cells. Similar to newspaper production, HPSC manufacturing can use a roll-to-roll web printing method. Benefits of HPSCs are low-capex and high-volume manufacturing for PV.
  - dual-junction III-V solar cell: world record 32.6% efficiency
- *next generation of manufacturing*
  - roll-to-roll consortium
  - perovskite inks
  - thin-film manufacturing – cadmium telluride
- *integration of renewables onto the grid*

2. Wind Energy

The U.S. wind industry is striving toward supplying 2% of the nation's electrical demand in 2030 – or four times the current installed wind capacity. Innovations have driven down the cost of wind energy as much as 90% between 2009 and 2016, enabling industry success.

Market Impact
- Installed capital cost between $1,300 and $1,900/kW
- Costs: 4-7 cents/kWh
- U.S. ranks second in world for installed capacity at 82 GW.
- Wind provides about 6.2% of U.S. electricity.
- Wind power employs more than 101,000 U.S. workers.
- More than 500 wind-related manufacturing facilities in the U. S.

Key Research Areas
- optimizing wind plants – individual wind turbine controls for improved performance
- eliminating transportation constraints – process for on-site production of turbine blades
- integrating with the grid – insights on higher wind generation in power grid through high-performance computing
- improving operations and reliability – modeling wake effects from wind turbines and their impact
- increasing offshore and distributed wind technologies – focus on new concepts, materials, and components
- accelerating market impacts – lightweight carbon fiber materials for turbine blades

3. Bioenergy

Bioenergy has a major push to scale up the technology to 60 billion gallons biofuel by 2030. NREL contributed to first-of-a-kind commercialization of cellulosic ethanol technologies in the United States.

Market Impact
- integrated and scaled up bioconversion technology
- modeled cost-competitive production of cellulosic ethanol

Key Research Areas
- Using refinery infrastructure that already exists – feasibility of co-processing pyrolysis oil (drop-in hydrocarbons) with Ensyn Corporation.
- Producing natural bioplastics, acids, and alkanes – pathway found in nature (lignin valorization) uses "waste" lignin.
- Developing new chemicals and materials – includes renewable carbon fiber, sustainable ammonia production, ethylene via sunlight, bioconversion of methane to lactate.

4. NREL's Vehicles Research

R&D breakthroughs provide efficient, high-performance, and market-ready transportation solutions for consumers and industry.

Market Impact
- per capita consumer fuel economy savings of $600/year
- potential annual supply of more than 30 billion gallons of fuel from domestic biomass feedstocks
- electric vehicle battery cost 70% less than 2008
- fuel efficiency standards with potential for $170 billion cost savings for commercial truck operators
- fuel cell electric vehicle range of more than 300 miles

Key Research Areas for Sustainable Transportation Technologies
- co-optimizing fuels and engines – R&D to maximize performance, efficiency, and compatibility with existing infrastructure
- increasing sustainable mobility – connected and autonomous transportation innovations for intelligent, efficient, integrated network
- reducing expense of battery development
- improving efficiency of heavy-duty vehicles – commercial truck fuel, engine, thermal management, and powertrain innovation
- demonstrating electrification of vehicles – energy storage for plug-in electric and fuel cell electric vehicles; power electronics; and infrastructure R&D to boost performance and market viability

5. Energy Systems Integration

We have to integrate the technology we already have but also to identify the gaps in the energy system. The aim is to fortify energy infrastructure at a pace and scale that matters.

Research Focus Areas

- renewable electricity to grid integration
- vehicle-to-grid integration
- renewable fuels to grid integration
- battery and thermal energy storage
- microgrids
- large-scale numerical simulation
- cybersecurity and resilience
- smart home and building systems
- energy-water nexus
- high-performance computing, analytics, and visualization

Advanced Energy System Design

This tool creates a computer model of energy systems. So researchers are coming up with a blue print which they can give to cities to help them to lay out their energy demand.

- High-Performance Computing (HPC) models enable interactive evaluation of potential power system design choices-wide variety of technology, infrastructure, operation, economic and policy possibilities.
- Additional integration opportunities: heating/cooling, hydrogen, natural gas, liquid transportation fuels, water and wastewater systems, and communications networks.
- Optimized energy system designs with higher reliability, security and resilience, affordability, and use of advanced technologies.

Making progress on a global scale requires …

- continued investment in innovation,
- integration of renewables and efficiency,
- partnering across political and socio-economic barriers.