Outline

• About NREL and JISEA
• Energy Technology Markets and Trends
  • Example: Wind Turbines
• Hydrogen and Industrial Systems
• Renewable Energy for Oil & Gas
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17 U.S. Department of Energy National Laboratories

“Government owned, contractor operated”
Mission: NREL advances the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems.

Example Technology Areas:

- 2,300 employees, plus 460 postdoctoral researchers, interns, visiting professionals, and subcontractors
- 327-acre main campus in Golden & 305-acre Flatirons Campus with National Wind Technology Center 13 miles north
- 61 R&D 100 awards. More than 1,000 scientific and technical materials published annually
This is a 10-year $100 million partnership that is intended to fill gaps in traditional energy approaches. Our scientists and engineers are collaborating to conceive and create solutions for today’s energy challenges.

Shell Gamechanger Powered by NREL is our five-year multi-million-dollar partnership program with Shell. We have branded the program GCxN, and it focuses on battery longevity and advanced smart grid controls.

NREL and Eaton are working together in the ESIF on grid intelligence, distributed energy resource management, advanced energy storage systems, virtual modeling and analysis, high-performance computing, and other research.

Our Innovation Incubator (IN²) is expanding this scalable model to other partners and technologies and growing to a multiyear, $30 million program.
JISEA
Joint Institute for Strategic Energy Analysis

Connecting technologies, economic sectors, and continents to catalyze the transition to the 21st century energy economy.

Founding Partners:
JISEA
Joint Institute for Strategic Energy Analysis

Connecting technologies, economic sectors, and continents to catalyze the transition to the 21st century energy economy.

Brings together consortiums of diverse partners
JISEA Research Portfolio

- Clean energy for Industry & Agriculture
- Energy System Integration and Transformation
- Advanced Manufacturing Analysis
- International Collaboration and Capacity Building

Learn more on our website and in the 2020 Annual Report.

@JISEA1  www.jisea.org
Learn more at our JISEA Virtual Meeting

Thursday 9 April 2020: Register at link on our LinkedIn, Twitter, or at https://www.jisea.org.

AGENDA:
Welcome and Introduction to JISEA (9:00 – 9:05 MDT) – Jill Engel-Cox

Power Systems (9:05 – 10:30 MDT)
• Innovative Utility Offerings at the Distribution Edge
  – Travis Lowder and Jeffrey Logan
• Options for Resilient and Flexible Power Systems in South America
  – Jeffrey Logan and Josh Prado
• Power and Natural Gas Systems Interface
  – Bri-Mathias Hodge

Industry & Agriculture (10:30 – 12:00 MDT)
• Renewable Energy in Mining
  – Tisi Igogo and Travis Lowder
• LED Lighting: A Global Enterprise
  – Samantha Reese
• Spanning the Nexus: Integrated Energy Research on Agriculture & Water Challenges
  – Jordan Macknick and James McCall
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Clean energy is diverse

- **WIND**
  - Onshore
  - Offshore

- **SOLAR PV**
  - Distributed & Micro Grids
  - Utility Grid Connected

- **HYDROPOWER**
  - Large & Small
  - Wave & Tidal

- **BIOMASS & WASTE**

- **GEOTHERMAL**

- **CONCENTRATING SOLAR**

- **HYDROGEN & GAS**

- **BATTERIES & STORAGE**

- **EFFICIENCY & HEAT USE**

Images from [https://images.nrel.gov/](https://images.nrel.gov/)
Global share of renewable electricity

Estimated Renewable Energy Share of Global Electricity Production, End-2018

73.8% Non-renewable electricity

26.2% Renewable electricity

15.8% Hydropower

5.5% Wind power

2.4% Solar PV

2.2% Bio-power

0.4% Geothermal, CSP and ocean power

Note: Data should not be compared with previous version of this figure due to revisions in data and methodology.

# Global share of renewable energy

## Estimated Renewable Share of Total Final Energy Consumption, 2017

<table>
<thead>
<tr>
<th>Source</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear energy</td>
<td>2.2%</td>
</tr>
<tr>
<td>Traditional biomass</td>
<td>7.5%</td>
</tr>
<tr>
<td>Wind/solar/biomass/geothermal/ocean power</td>
<td>10.6%</td>
</tr>
<tr>
<td>Modern renewables</td>
<td></td>
</tr>
<tr>
<td>Hydropower</td>
<td>3.6%</td>
</tr>
<tr>
<td>Biomass/solar/geothermal heat</td>
<td>4.2%</td>
</tr>
<tr>
<td>Biofuels for transport</td>
<td>1.0%</td>
</tr>
</tbody>
</table>

**Fossil fuels** 79.7%

Note: Data should not be compared with previous years because of revisions due to improved or adjusted data or methodology. Totals may not add up due to rounding.

Source: Based on OECD/IEA and IEA SHC.

Global growth of renewable power

Annual Additions of Renewable Power Capacity, by Technology and Total, 2012-2018

Additions by technology (Gigawatts)

- Solar PV
- Wind power
- Hydropower
- Bio-power, geothermal, ocean power, CSP

181 Gigawatts added in 2018
Total additions (Gigawatts) 200

Note: Solar PV capacity data are provided in direct current (DC).

U.S. Energy Supply is Shifting

In 2019, renewable energy—not including hydropower—generates 11% of the total U.S. electricity (~7% wind, 2% solar, 1.5% biomass, 0.5% geothermal)

With hydropower, renewable electricity is ~18%

Natural gas power is ~38%
Variation by Location: Solar Generation as a % of Total Generation, 2014-2018, by U.S. State

Texas electricity transition favors wind and gas

Electricity Generated:

2019: 47% Natural Gas, 20% Coal, 20% Wind, 11% Nuclear, 2% Other

A decade of ERCOT fuel mixes

<table>
<thead>
<tr>
<th>Year</th>
<th>Natural Gas</th>
<th>Coal</th>
<th>Wind</th>
<th>Nuclear</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>44%</td>
<td>25%</td>
<td>19%</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>39%</td>
<td>32%</td>
<td>17%</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>44%</td>
<td>29%</td>
<td>15%</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>48%</td>
<td>28%</td>
<td>12%</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>41%</td>
<td>36%</td>
<td>11%</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>40%</td>
<td>37%</td>
<td>10%</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>44%</td>
<td>34%</td>
<td>9%</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>40%</td>
<td>39%</td>
<td>9%</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>38%</td>
<td>40%</td>
<td>8%</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>42%</td>
<td>37%</td>
<td>6%</td>
<td>14%</td>
<td></td>
</tr>
</tbody>
</table>

Electricity Capacity:

- 2020 Generating Capacity:
  - 14.5% Coal
  - 23.3% Wind
  - 52.8% Natural Gas

*Includes hydro, biomass-fired units and DC tie capacity
Costs for renewables are falling

Source: Lazard’s 2017 Levelized Cost of Energy Analysis, Version 11, 2 November 2017
NREL models scenarios of future electricity generation


Key:
- RE = Renewable Energy
- NG = Natural Gas
- VRE = Variable Renewable Energy
NREL models scenarios of future electricity generation

Example: Mid Case Scenario

City Example: LA100: The Los Angeles 100% Renewable Energy Study

LADWP
$6 billion annual budget
9,400 employees
4 million residents

Advisory Group
Diverse energy backgrounds
Quarterly meetings
Policy oriented

Integrated Electricity Modeling
Full range power system modeling
Integrated transmission and distribution analysis

Environmental Analysis
Air quality
Environmental Impact

Economic Analysis
Job creation
Job migration
Economic development
South America: Adaptation of hydropower to changing hydrological phases and increased renewables

- Countries that traditionally rely heavily on large (dammed) hydropower face increasing risk and reliability concerns during El Niño and La Niña hydrological phases
- Rainfall and snowmelt patterns are changing making hydropower resources more unpredictable, variable
- Aging infrastructure susceptible to a variety of hazards
- Adaptation:
  - Expand emphasis of system design on flexibility and resiliency at different time scales
  - Increase coordination among dam operators and other end users (e.g. agricultural sector) to better serve water needs
  - Increase use of medium and long-range forecasting to enable better watershed planning and dispatch
  - Diversification of energy sources, including other renewable energy and natural gas

Electric-Natural Gas Interface Study

Electricity & Gas networks are interconnected energy infrastructures whose operation and reliability depend on one another. As the percent of gas and variable renewable power plants increase, the connection between these networks becomes increasingly important.

**Goal of project** is to:

- Co-simulate power and natural gas network operations.
- Define an interconnected power and natural gas test system
- Determine value of coordination of day-ahead operations

**Funded through JISEA sponsorship by:**
- American Electric Power
- Environmental Defense Fund
- Hewlett Foundation
- Kinder Morgan
- American Gas Association
- Midcontinent Independent System Operator

Source: JISEA project in progress.
Electrification Futures Study

All Figures from NREL’s Electrification Futures Study: [www.nrel.gov/efs](http://www.nrel.gov/efs)
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Wind Turbines – Onshore and Offshore

Peetz Table Wind Energy Center
• Peetz, Colorado
• 430 MW, 300 turbines
• Opened 2001, expanded 2007
• Capacity Factor 34.5%

Block Island Wind Farm
• New Shoreham, Rhode Island
• 30 MW, 5 turbines
• 100 m hub height, 150 m diameter
• Opened 2016
• Capacity Factor 48% (projected)
Wind market growth driven by price declines

Unsubsidized Wind LCOE

U.S. Wind Market (installed capacity, MW)

Wind capacity installed in Oklahoma, Iowa, and Kansas supplied >30% of all in-state electricity generation in 2018. 14 states were greater than 10%.

Wind Machines – Scale, capacity factor Increasing, Manufacturing costs declining

Onshore: 2-3 MW
50 m blade length

Avg. Wind Turbine Capacity Factors (% of capacity) by Build Year
1998-2001: 24.5%
2004-2011: 32.1%
2014-2015: 42.6%

Compare: Natural Gas Plant: 56%;
Coal Faced Plant: 53%; Nuclear: 92%;
Solar Photovoltaic: 27%

Wind energy potential capacity at 80m hub height
2008 turbine technology
Wind energy potential capacity at 110m hub height

Current turbine technology
Wind energy potential capacity at 140m hub height
‘Future’ turbine technology
Wind plant modeling

Blade-resolved simulations of whole wind plants
- Developing predictive capability to better understand complex fluid flow in wind plants with complex terrain, focus on turbine-turbine impacts, and address wind plant energy losses
- Growing fleet requires advanced sensors and simulation for improved reliability and energy security
- Inaccurate forecasts cost the industry $300M+/yr
- Simulations of single blade-resolved turbine exceed current ESIF HPC capabilities

POTENTIAL IMPACT
- Improve wind plant efficiency 4% to generate $1 billion in annual savings.
Adaptation of wind turbines for bigger storms

Current wind turbines face up-wind and use feathering or full shut down in high winds

Hypothetical 50-megawatt offshore down-wind facing wind turbine for 25-meter deep waters in Gulf of Mexico

Technology vision studies
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Enabling hydrogen to be a common means of transporting, storing, and transforming energy at the scale necessary for a clean and vibrant economy. Collaborating with key government and industry partners who will accelerate this technology development and adoption.

**Research Challenges**

- Improve the economics of hydrogen production to enable it to shift energy across time, sectors, and location—including providing electric grid support.
- Develop materials and advanced cell concepts for polymer electrolyte fuel cells and electrolyzers, focusing on the emerging markets of intermittent H2 production and heavy-duty transportation.
- Develop new infrastructure technologies to enable safe fueling for heavy-duty hydrogen trucks and reduce the cost and improve reliability of fueling FCEVs.
- Research hybrid bio-electrochemical processes and advanced cell concepts.
Hydrogen infrastructure testing and research facility

Fully integrated system capable of experiments on advanced components and subsystems and innovative component/system concepts

**Production**
- 250 kW PEM stack
- 120 kg/day
- 1 MW capable

**Dispensing**
- Commercial dispenser
- Research dispenser
- Recirculation loop (High-P to Low-P)

**Compression**
- High throughput compressor up to 1 kg/min (Low-P to High-P)

**Storage**
- 90 kg @ 900 bar
- 80 kg @ 415 bar
- 210 kg @ 200 bar

Images: NREL

Hydrogen Infrastructure Testing and Research Facility
Hydrogen @Scale

Source: https://www.energy.gov/eere/fuelcells/h2scale
Renewable hybrid energy solutions

Integration of renewable & carbon capture systems

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Building on our methane emissions work, started with a workshop

Workshop: Nexus of Oil & Gas and Renewables in the Energy Future, NREL, Sept 2017
Co-Sponsored with IEA Gas & Oil Technology Programme

Keynote: Colorado Governor John Hickenlooper

Purpose: Explore how the renewable energy industry and oil & gas industry can work together for a clean energy future

Key Topics:

1. Renewable energy for oil and gas operations
2. Efficient use of process heat and water
3. Gas and renewable energy for utilities
4. Industry investment in renewable energy

Followup workshops in Brussels and Houston
Example Onshore Power Solution: Electrification of the Wellpad and Platform via Microgrids

• Electrification of all equipment at wellpad connected via microgrid

• Power could consist of:
  – Field/Flare Gas fired generator
  – Solar PV/wind systems
  – Fuel cells
  – Energy Storage
    • Hydrogen
    • Batteries
  – Grid power (or offgrid)

• Benefits:
  – Resiliency during outages
  – Optimize for least cost
  – Reduce emissions

• Leverage work on
  – Remote bases & communities
  – Islands

Opportunities for Collaboration: Design of complete system, technology evaluation & selection, “utility in a cube” technology
Example Offshore Power Solution: Offshore Wind for Platform Power & Water Injection

- Electricity from wind turbine is used to power pumps, treatment, and injection
- Integrated with microgrid and energy storage
- Feasibility study by DNV-GL shows the system has higher operational costs but lower capital expenditure that over a 20-year life-cycle is competitive with alternatives
- Opportunity for conversion of decommissioned platforms

Example Thermal Solution: Enhanced Oil Recovery using Concentrating Solar Power (CSP)

Chevron/BrightSource Solar-to-Steam Demonstration
Location: Coalinga, CA
Facility Size: 100 acres
Steam Production: 29 MWt (megawatts thermal)
Electrical Output Equivalent: Approx. 13 MWe (megawatts electric)
Tower Height: 327 feet
Number of Heliostats / Mirrors: 3,822 heliostats; 7,644 mirrors
Years of Operation: 2011-2014

Miraah CSP system in Oman
Produce 6,000 tons of solar steam each day for thermal EOR
Energy production: 1021 MWt on 741 acres
Save 5.6 trillion Btus of natural gas each year
Reduce CO2 emissions by more than 300,000 tons each year

http://www.glasspoint.com/markets/projects/
http://www.brightsourceenergy.com/coalinga#.V-QUkjsSfPE
Example Thermal Solution: Geothermal-powered Desalination Technologies

NREL is working to develop desalination technologies with geothermal:
- Partnership with Colorado School of Mines
- Pilot plant development in the U.S. Southwest
- Development of a geothermal desalination decision support tool

Key research benefits include:
- Access to and development of data on cutting-edge RD&D in brackish water desalination technology
- Demonstration pilot
- Decision support tool to identify promising new locations

Membrane Distillation has advantages for renewable energy integration:
- Uses low-temp (< 90°C) thermal energy
- Suitable for high-salinity, poor-quality source water
- Compatible with sensible heat transfer
- Amenable to small-scale units
- Potentially low-cost membranes
Clean Power Technologies for Oil & Gas Industry Operations

**Value Proposition:** Demonstrate highly reliable, affordable, clean power for oil & gas operations.
- Reduce risk to operations
- Collaboratively identify ‘best practices’ to reduce cost
- Access to unique, world class capabilities
- Leverage research/testing dollars

**Program Results:**
Operational, financial, and environmental improvements within oil & gas operations

**Governance:**
Consortium of industry partners to leverage resources for benefit of those involved, supported/managed by JISEA

**Program Targets:**
- Support the identification, development, and adaptation of highly reliable, cost-effective clean energy solutions for oil and gas operations
- Perform techno-economic analysis and site-specific optimization of combinations of renewable and conventional generation, storage, and energy conservation
- With industry partners, demonstrate the most promising technologies for validation of performance in a variety of field environments, while analyzing optimization scenarios.
Phase 1:

**Identify potentially highly reliable, cost-effective clean energy** solutions for priority energy needs of oil and gas operations

**Analyze and model site- and technology-specific solutions** considering:
- Innovation
- Performance
- Costs/Savings
- Deployment Potential
- Project Value
- Technical Risk
- Business Viability

Phase 2:

**Objectively evaluate real-world performance** in a variety of field environments to determine return on investment and impact on environmental and social license.

**Prepare analysis results to inform decisions** on technologies with broad deployment potential
REopt Platform inputs and output

**Goals**
- Minimize Cost
- Net Zero
- Resiliency

**Drivers**
- Economics: Financial Parameters, Technology Costs, Incentives
- Utility Costs: Energy Charges, Demand Charges, Escalation Rate

**Economics**
- Financial Parameters
- Technology Costs
- Incentives

**Utility Costs**
- Energy Charges
- Demand Charges
- Escalation Rate

**Technology Options**
- Renewable Generation
  - Solar PV
  - Wind
  - Biomass, etc.
- Conventional Generation
  - Electric Grid
  - Fuel Supply
  - Conventional Generators
- Energy Storage
  - Batteries
  - Thermal storage
  - Water tanks
- Dispatchable Technologies
  - Heating and Cooling
  - Water Treatment

**Load Types**
- Thermal Loads
- Electric Loads
- Water Demand

**Optimized Minimum Cost Solution**
- Technologies Mix
- Technology Size
- Operations: Optimal Dispatch
- Project Economics: CapEx, OpEx, Net Present Value

Source: [https://reopt.nrel.gov](https://reopt.nrel.gov)
Analysis Overview

• Two case studies being done using publicly available data and assumptions:
  – Hypothetical refinery in Louisiana (and California)
  – Well site in Pennsylvania’s Marcellus Shale (on grid and off grid)

• Preliminary analysis evaluates the opportunity for solar photovoltaics, wind turbines, and/or a battery energy storage system (BESS)

• Additional analysis considering the opportunity for thermal energy technologies, such as solar steam, biogas, electrification of thermal processes, energy efficiency measures, and/or carbon capture and sequestration (CCS)

• Supported by a consortium of industry sponsors to obtain load and generation data and evaluate these clean energy technologies at actual oil and gas sites.

Current members:
  – Baker Hughes
  – Conoco Phillips
  – Extraction Oil and Gas
  – Kinder Morgan
  – INGAA Foundation

Consortium planning site analysis at:
  – Offgrid upstream Western U.S. site
  – Mid-stream pipeline/compressor station

Consortium still accepting sponsors
Many oil & gas regions have great wind AND solar resources
Conclusions and Discussion

- Trend toward cleaner and lower cost energy (renewables and gas) that is more distributed
- Potential for increased electrification resulting in higher demand for power
- Renewable energy can help power, industrial, and agricultural systems to reduce emissions, and operate more resiliently, but needs research and demonstration
- Need improved standards, models, policies, and technologies to enable systems to adapt
Thank you! Questions?

NREL/PR-6A50-76510