Clean Energy Technologies for Economic and Environmental Transitions

Air & Waste Management Association

EPA Region 8 Building

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National Renewable Energy Laboratory
**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:**

- Grid Integration
- Geothermal
- Energy Analysis
- Solar
- Buildings
- Wind
- Resource Measurement
- Batteries
- Fuel Cells
- Computational Science
- Biofuels
- Hydrogen

- 1800 employees, plus 400 postdoctoral researchers, interns, visiting professionals
- 327-acre campus in Golden, Colorado & 305-acre National Wind Technology Center 13 miles north
- 61 R&D 100 awards. More than 1000 scientific and technical materials published annually

[www.nrel.gov/about](http://www.nrel.gov/about)
JISEA
Joint Institute for Strategic Energy Analysis

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

Founding Members

[Logos of founding members: NREL, Colorado School of Mines, Colorado State University, MIT, Stanford University, University of Colorado Boulder]
Outline

• Energy Markets and Trends
• Clean Energy Technologies
  • Solar Photovoltaics
  • Wind Turbines
• Future Transitions and Discussion
Outline

• Energy Markets and Trends
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  • Solar Photovoltaics
  • Wind Turbines
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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

HYDROGEN & GAS

GEOTHERMAL

CONCENTRATING SOLAR

BATTERIES & STORAGE

EFFICIENCY & HEAT USE

Images from https://images.nrel.gov/
Global share of renewable energy

Estimated Renewable Energy Share of Global Electricity Production, End-2017

73.5% Non-renewable electricity
26.5% Renewable electricity

16.4% Hydropower
5.6% Wind power
2.2% Bio-power
1.9% Solar PV
0.4% Ocean, CSP and geothermal power

Global share of renewable energy

Estimated Renewable Share of Total Final Energy Consumption, 2016

79.5% Fossil fuels

- Nuclear energy: 2.2%
- Traditional biomass: 7.8%
- Wind/solar/biomass/geothermal/ocean power: 10.4%
- Modern renewables:
  - Hydropower: 3.7%
  - Biomass/solar/geothermal heat: 4.1%
  - Biofuels for transport: 0.9%

Global growth of renewable energy

Global Renewable Power Capacity, 2007-2017

Gigawatts

2,195 Gigawatts

Electricity Trending to Gas and Renewables

Power sector is undergoing profound transformation, shifting from coal to natural gas and renewable power generation.

Electricity Trending to Gas and Renewables

Solar Generation as a Percentage of Total Generation, 2014-2018, by U.S. State

Note: EIA monthly data for 2018 are not final. Additionally, smaller utilities report information to EIA on a yearly basis, and therefore, a certain amount of solar data has not yet been reported. “Net Generation” includes DPV generation. Net generation does not take into account imports and exports to and from each state and therefore the percentage of solar consumed in each state may vary from its percentage of net generation.


Cost of Renewable & Traditional Electricity Equalizing

Levelized Cost of Electricity ranges by technology. Values are in 2016$.

Variability due to: Technology; Location; Time (Present v. Future)

Wind similar cost as gas combined cycle
...and declining.

2018 ATB LCOE range by technology for 2016 based on R&D financial assumptions

Cost of Renewable Electricity at Auctions Driving Decrease

Cost of Renewable Electricity at Auctions Driving Decrease

Xcel Energy 2017 auction for Colorado: 430 bids (350 for renewable energy)

<table>
<thead>
<tr>
<th>Generation Technology</th>
<th># of Bids</th>
<th>Bid MW</th>
<th># of Projects</th>
<th>Project MW</th>
<th>Median Bid Price or Equivalent</th>
<th>Pricing Units</th>
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</thead>
<tbody>
<tr>
<td>Combustion Turbine/IC Engines</td>
<td>30</td>
<td>7,141</td>
<td>13</td>
<td>2,466</td>
<td>$4.80</td>
<td>$/kW-mo</td>
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<tr>
<td>Combustion Turbine with Battery Storage</td>
<td>7</td>
<td>804</td>
<td>3</td>
<td>476</td>
<td>$6.20</td>
<td>$/kW-mo</td>
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<tr>
<td>Gas-Fired Combined Cycles</td>
<td>2</td>
<td>451</td>
<td>2</td>
<td>451</td>
<td></td>
<td></td>
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<tr>
<td>Stand-alone Battery Storage</td>
<td>28</td>
<td>2,143</td>
<td>21</td>
<td>1,614</td>
<td>$11.30</td>
<td>$/kW-mo</td>
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<tr>
<td>Compressed Air Energy Storage</td>
<td>1</td>
<td>317</td>
<td>1</td>
<td>317</td>
<td></td>
<td></td>
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<tr>
<td>Wind</td>
<td>96</td>
<td>42,278</td>
<td>42</td>
<td>17,380</td>
<td>$18.10</td>
<td>$/MWh</td>
</tr>
<tr>
<td>Wind and Solar</td>
<td>5</td>
<td>2,612</td>
<td>4</td>
<td>2,162</td>
<td>$19.90</td>
<td>$/MWh</td>
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<tr>
<td><strong>Wind with Battery Storage</strong></td>
<td>11</td>
<td>5,700</td>
<td>8</td>
<td>5,097</td>
<td>$21.00</td>
<td>$/MWh</td>
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<tr>
<td>Solar (PV)</td>
<td>152</td>
<td>29,710</td>
<td>75</td>
<td>13,435</td>
<td>$29.50</td>
<td>$/MWh</td>
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<tr>
<td>Wind and Solar and Battery Storage</td>
<td>7</td>
<td>4,048</td>
<td>7</td>
<td>4,048</td>
<td>$30.60</td>
<td>$/MWh</td>
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<tr>
<td><strong>Solar (PV) with Battery Storage</strong></td>
<td>87</td>
<td>16,725</td>
<td>59</td>
<td>10,813</td>
<td>$36.00</td>
<td>$/MWh</td>
</tr>
<tr>
<td>IC Engine with Solar</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td></td>
<td>$/MWh</td>
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<tr>
<td>Waste Heat</td>
<td>2</td>
<td>21</td>
<td>1</td>
<td>11</td>
<td></td>
<td>$/MWh</td>
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<tr>
<td>Biomass</td>
<td>1</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td></td>
<td>$/MWh</td>
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<tr>
<td><strong>Total</strong></td>
<td>430</td>
<td>111,963</td>
<td>238</td>
<td>58,283</td>
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<td></td>
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</tbody>
</table>

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Solar energy is diverse

**BATTERIES & STORAGE**

**SOLAR PHOTOVOLTAICS (PV)**
- Residential: 1-10 kW scale
- Commercial: 1-20 MW
- Utility: 50-1000 MW

**CONCENTRATING SOLAR**

**PEROVSKITES (New!)**

Images from [https://images.nrel.gov/](https://images.nrel.gov/)
PV System Installation Prices

Colorado Solar Development

Colorado Rank – 12th
Installed: 1184 MW
Percentage of In-State Energy Production: 2.96%
Equivalent U.S. Homes Powered: 241,000
Manufacturers: 49. Installers: 231

Sources: NREL and SEIA,
Supply chain of PV panels

2017 Global PV Manufacturing: Top 373 Companies

From Woodhouse, et al. 2018 Shanghai New Energy Conference; Input data sources for map and pie chart: IHS and BNEF.
**Balance of trade varies across supply chain (2016 data)**

Economies that are net importers of end products may be major exporters of upstream processed materials and subcomponents of those same technologies.

<table>
<thead>
<tr>
<th>Region</th>
<th>Polysilicon</th>
<th>PV Cell</th>
<th>PV Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>$0</td>
<td>-$256</td>
<td>-$256</td>
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<tr>
<td>Canada</td>
<td>$1</td>
<td>-$76</td>
<td>$28</td>
</tr>
<tr>
<td>China</td>
<td>-$2187</td>
<td>$3809</td>
<td>$7177</td>
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<tr>
<td>Germany</td>
<td>$969</td>
<td>$319</td>
<td>-$678</td>
</tr>
<tr>
<td>India</td>
<td>-$40</td>
<td>-$456</td>
<td>-$376</td>
</tr>
<tr>
<td>Japan</td>
<td>-$962</td>
<td>-$2494</td>
<td>-$2900</td>
</tr>
<tr>
<td>Malaysia</td>
<td>$26</td>
<td>$712</td>
<td>$2727</td>
</tr>
<tr>
<td>Mexico</td>
<td>$0</td>
<td>$7</td>
<td>$838</td>
</tr>
<tr>
<td>South Korea</td>
<td>$1045</td>
<td>-$347</td>
<td>$1291</td>
</tr>
<tr>
<td>Taiwan</td>
<td>-$306</td>
<td>$3172</td>
<td>$302</td>
</tr>
<tr>
<td>UK</td>
<td>$7</td>
<td>-$537</td>
<td>-$498</td>
</tr>
<tr>
<td>US</td>
<td>$1577</td>
<td>-$8095</td>
<td>-$8037</td>
</tr>
</tbody>
</table>

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Wind Turbines - Onshore

Peetz Table Wind Energy Center
- Peetz, Colorado
- 575 MW

Cedar Creek Wind Farm
- Grover, Colorado
- 550 MW
Wind Turbines – Offshore

**Westermeerwind Wind Farm**
- Noordoostpolder, Netherlands
- 144 MW

**Horn Rev Wind Farm**
- West coast of Denmark
- 160 MW
Wind Market Growth Driven by Price Declines

U.S. 2019 1Q Cumulative – 97,223 MW

Source: DOE 2016: Revolution...now, the future arrives for five clean energy technologies; AWEA, https://www.awea.org.
U.S. & Colorado Wind Market (installed capacity, MW)

Colorado Rank – 8th for capacity
Installed: 3703 MW (2,248 turbines)
Percentage of In-State Energy Production: 17.3%
Equivalent U.S. Homes Powered: 944,100

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 Fired Plant: 53%; Nuclear: 92%;
Solar Photovoltaic: 27%
Wind Energy Potential Increasing to More Places

140m Hub Height
‘Near Future’ Turbine Technology

Wind Potential Capacity at 140m Hub Height
35% GCF
Future Technology

Area (sq km)
0
< 100
100 - 200
200 - 300
300 - 400
> 400
Land exclusions

Data sources: AWS Truepower, National Renewable Energy Laboratory

This map was produced by the National Renewable Energy Laboratory for the Department of Energy. September 2014
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Future: NREL electricity generation scenarios

NREL electricity scenario mid-case generation mix

Electrification Futures Study

All Figures from NREL’s Electrification Futures Study: www.nrel.gov/efs
Electrification Futures Study

All Figures from NREL’s Electrification Futures Study: www.nrel.gov/efs
Clean Power Technologies for Oil & Gas Industry Operations: 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
Renewables and Nuclear Hybrid Energy Solutions

Co-location of Wind/PV and Agriculture
Floating Solar PV (FPV)

- Analysis of cost, siting, and O&M tradeoffs
- GIS-based technical/market potential analysis for the U.S.
- Installing floating solar photovoltaics on the more than 24,000 man-made U.S. reservoirs could generate about 10 percent of the nation’s annual electricity production
- Reduces evaporation and algae growth

Top image from https://images.nrel.gov/
Circular Economy: Growing PV Waste Will Need Technology and Policy Solutions

Source: IEA/IRENA 2016
Conclusion and Discussion – Colorado

Trends and Potential Future Scenarios:

- Colorado moving toward cleaner and lower cost energy (renewables and gas) with potential for growth in manufacturing, extraction, deployment
- Increasing intersection of renewable energy with other sectors of local economy:
  - Oil & gas industry
  - Agriculture
  - Manufacturing
- Potentially increased electrification resulting in higher demand for power and higher-value use of hydrocarbon resources
Questions and Discussion

Thank you!

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www.nrel.gov
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