Annual Technology Baseline: ATB-calc Open Source Tools

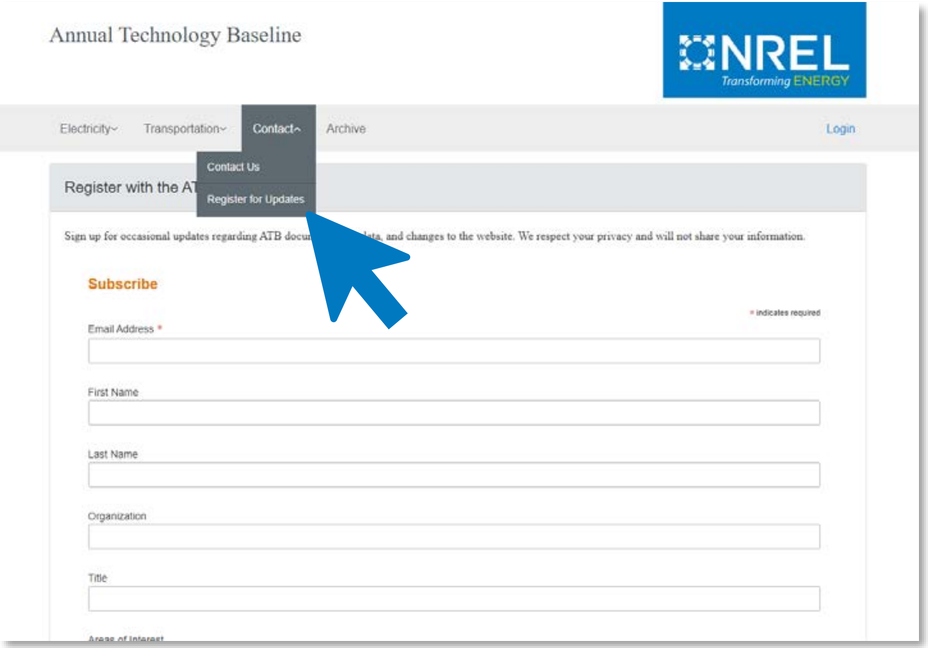
Brian Mirletz, Michael Bannister, Laura Vimmerstedt, Dana Stright, Matthew Heine

September 26, 2023

ATB Day

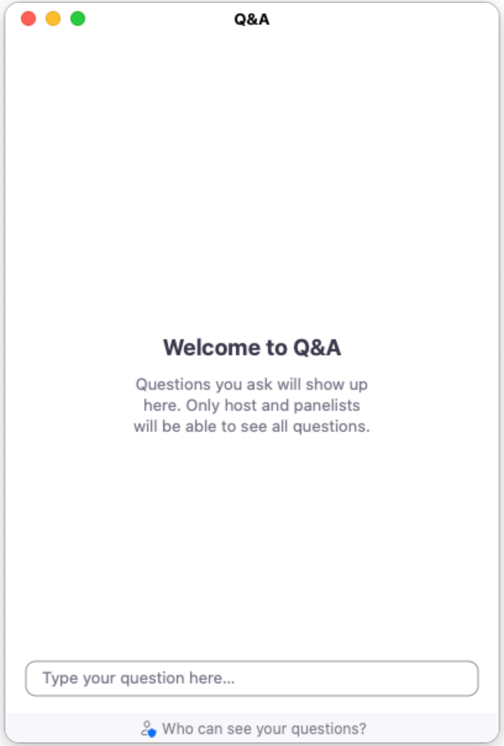
- **June 28th was ATB Day** meaning the 2023 Electricity Annual Technology Baseline data is now available
  - Includes distributed wind and pumped storage hydropower supply curve data for the first time
  - Access the 2023 Electricity ATB at https://atb.nrel.gov/electricity/2023/data

- Register for ATB email updates at https://atb.nrel.gov/register



Housekeeping

- **This webinar is being recorded**
- **Attendee microphones and cameras are disabled for the webinar**
- **Have a question or comment?**
  - Please submit questions using the “Q&A” panel
  - We will answer as many questions as possible at the end of the webinar
- **Zoom controls are located at the bottom of your screen**
  - If they aren’t appearing, move your cursor to the bottom edge



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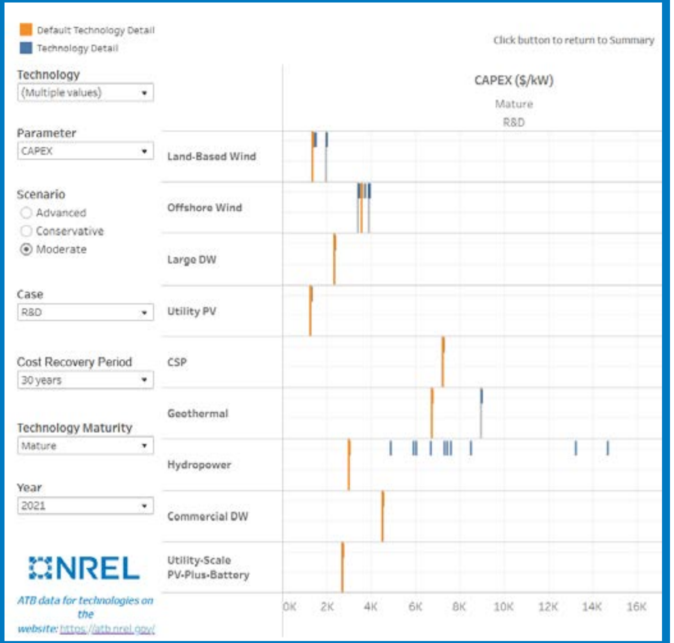
Agenda

- Introduction and Overview
  - Why the ATB?
  - ATB Overview
- ATB-calc
  - First Time Setup
  - Calculating LCOE and Modifying Data
  - Introduction to SAM and PySAM
  - Tax Credit Adjustment Demo
- Questions and Comments

Why the ATB?



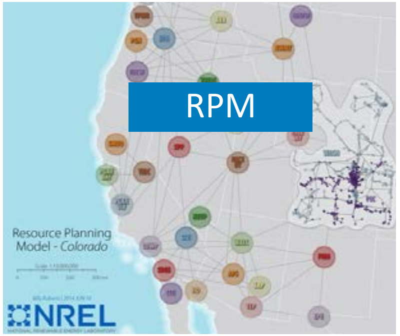
Annual Technology Baseline

About Technologies Data Contact

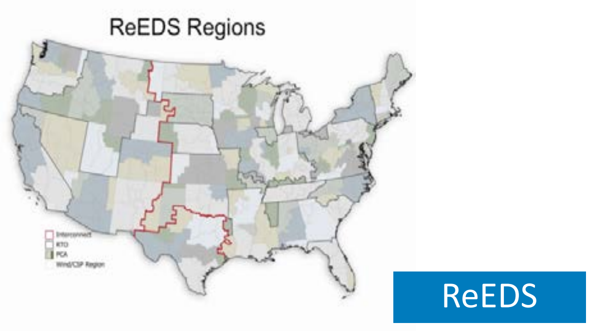
- Ever-changing technologies result in *conflicting reports of technology progress* based on inconsistent—and often opaque—assumptions.
- A *single data set is needed* to credibly and transparently assess the evolving state of energy technologies in the United States.
- The ATB enables *understanding of technology cost and performance across energy sectors* and thus informs electric sector analysis nationwide.

ATB Project Overview

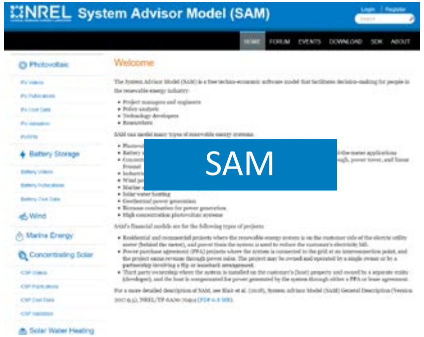
The ATB anchors key DOE and national lab analyses.



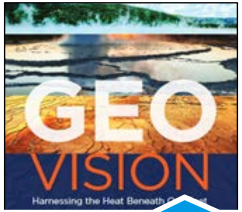
Resource Planning Model



Regional Energy Deployment System



System Advisor Model



Geothermal Vision

Hydropower Vision

Evaluating Impacts of the Inflation Reduction Act and Bipartisan Infrastructure Law on the U.S. Power System

LA100

Standard Scenarios

Storage Futures

Important Scenario Analyses Used ATB Projections

Now in its ninth year, the ATB is frequently used by planners, academics, analysts, and others.

Federal Agencies
Bureau of Land Management, U.S. Department of Energy and labs, U.S. Environmental Protection Agency

Grid Operators
North American Electric Reliability Corporation, Midcontinent Independent System Operator, Pennsylvania-New Jersey-Maryland Interconnection, New York Independent System Operator

Utilities
Hawaii Electric Company, Dominion Energy, Xcel Energy

Consultants
Rhodium Group, Navigant, M.J. Bradley & Associates, Analysis Group

Nonprofits
Resources for the Future, Environmental Defense Fund, Union of Concerned Scientists

Academia
Stanford University, University of Maryland, University of Texas, Duke University, University of Colorado, Colorado School of Mines

State Officials
Hawaii, Michigan, California

International
Chilean Ministry of Energy, Global Carbon Capture and Storage Institute, Institute, Canadian Institute for Integrated Energy Systems

Media
Utility Dive

These are examples of users—*not* a comprehensive list.

The ATB data are inputs for the Standard Scenarios.

Annual Technology Baseline

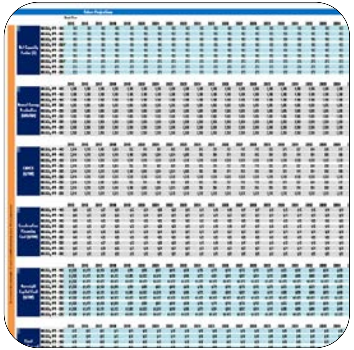
Cost and performance assumptions for renewable and conventional technologies

↓

Standard Scenarios

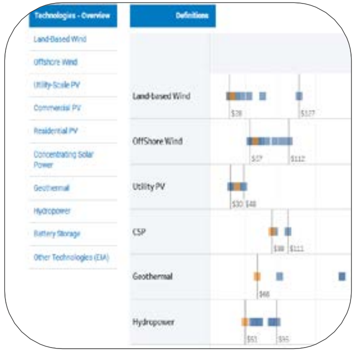
Ensemble of future scenarios for the U.S. electric power sector

The ATB includes a suite of products.



Spreadsheet

- Calculations
- Cost and performance projections, 2021–2050
- Capacity factor
- Operation and maintenance (O&M) costs
- Capital expenditures (CAPEX)
- Financing assumptions
- Levelized cost of energy (LCOE)



Web App

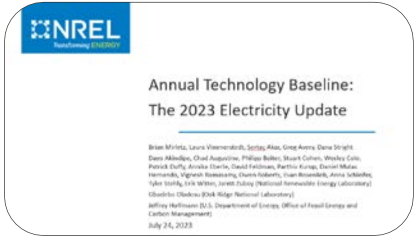
- atb.nrel.gov
- User guidance
- Additional analyses
- Methodologies
- Interactive charts
- Historical trends and comparison to other projections (e.g., EIA)

Interactive Charts

Tableau Workbook

Formatted Data

- Summary of selected data (no calculations)
- Interactive charts
- Visual exploration
- Cost and performance projections, 2021–2050
  - Capacity factor
  - O&M costs
  - CAPEX
  - Financing assumptions
  - LCOE
- Structured format



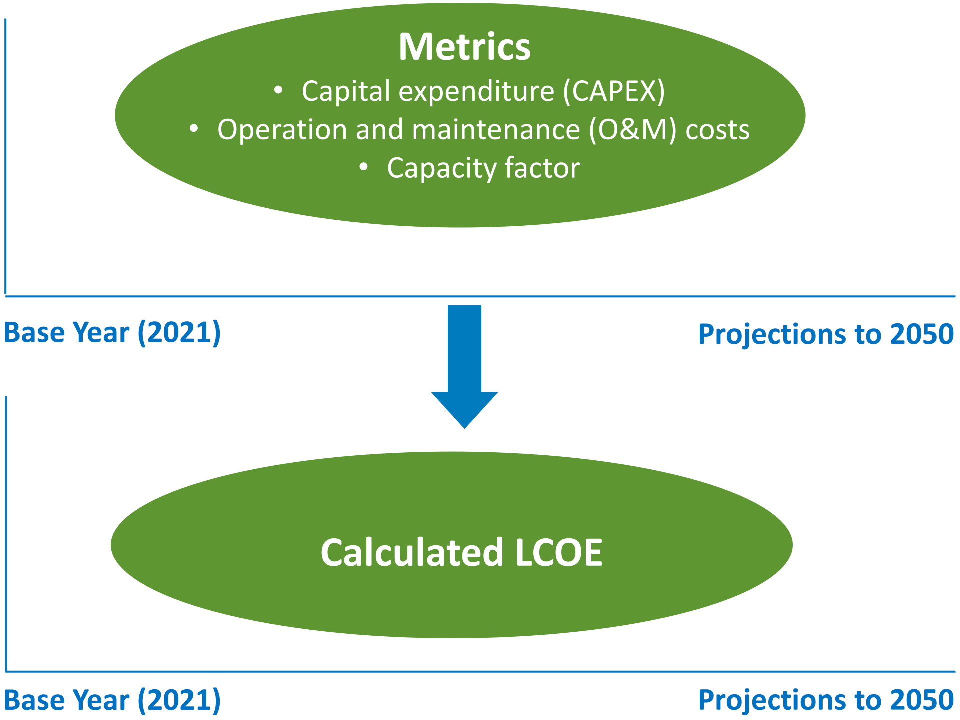
PowerPoint

- Webinar presentation
- Summary presentation

Open Data / Code

- Data published in Open Energy Data Initiative
- Programmatic access through AWS-S3
- Jupyter notebook
- ATB-calc GitHub Repository

The ATB provides cost and performance data.



Cost and performance data are:

- Provided for each:
  - Year
  - Metric
  - Resource
  - Technology
  - Technology cost scenario
- Used to calculate LCOE.

LCOE is provided as a summary metric, but it is *not* used as an input to NREL models such as ReEDS, RPM, or SAM. Its limitations are described in the documentation. The user can select or specify financial assumptions for calculating LCOE.

Technologies Covered

Renewable Energy Technologies

New in 2023

Wind
- Land-based
- Offshore
- Distributed

Solar
- Utility photovoltaics (PV)
- Commercial and industrial PV
- Residential PV
- Utility PV-plus-battery
- Concentrating solar power (CSP)

Hydropower
- Non-powered dams (NPD)
- New stream-reach development (NSD)
- Pumped storage hydropower

Geothermal (Flash and Binary)
- Hydrothermal
- Near-field enhanced geothermal systems (EGS)
- Deep EGS

Storage
- Utility-scale
- Commercial-scale
- Residential

Fossil Energy Technologies

Natural Gas
- Natural gas combined cycle (NGCC)
- NGCC-carbon capture and storage (95%, 97% CCS)
- Combustion turbine (CT)
- **NEW: Natural Gas Fuel Cell (no CCS, 98% CCS)**
- **NEW: Retrofits (90%, 95% CCS)**

Coal
- Integrated gasification combined-cycle (IGCC)
- Pulverized coal
- Pulverized coal w/ 95%, 99% CCS
- **NEW: IGCC w/ 99% CCS**
- **NEW: Retrofits (90%, 95% CCS)**

Other Technologies

(Energy Information Administration, Annual Energy Outlook 2023)

Nuclear
- Pressurized water reactor (AP1000)
- Small modular reactor (SMR)

Biopower
- Dedicated (woody biomass)

Methodology Overview: Three Steps

1. Define resource bins for each technology

Group range of resources for contiguous United States into bins with common resource quality and characteristics, or develop representative plants.

2. Develop cost and performance data

Develop base year and projected values for Conservative, Moderate, and Advanced technology cost scenarios for CAPEX, capacity factor, and operation and maintenance (O&M).

3. Calculate LCOE

Use selected financial assumptions to calculate LCOE from CAPEX, capacity factor, and O&M.

Step 1: Define Technologies/Resource Bin Categories

Bins changed in 2023

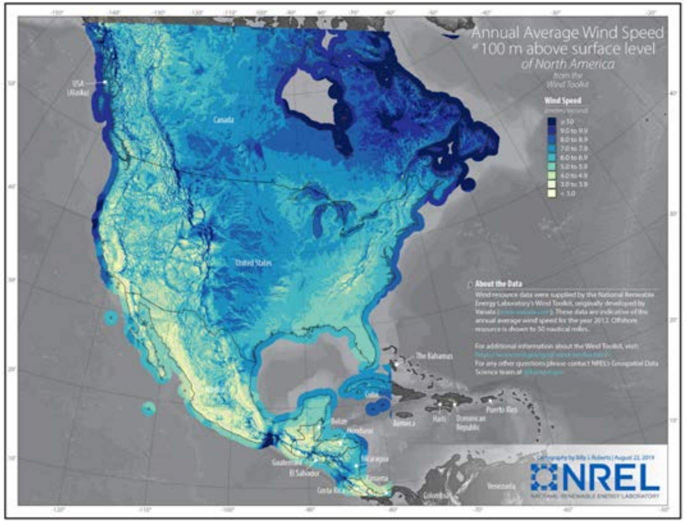
Technology	Bins	Distinguishing Characteristics
Land-based wind	10	Annual average wind speed
Offshore wind	14	Annual average wind speed
Distributed wind	40	Turbine size, annual average wind speed
Utility-scale, commercial, residential PV, and utility-scale PV-plus-battery	10	Horizontal solar irradiance resource level
CSP	3	Direct normal solar irradiance
Geothermal	6[a]	Hydrothermal, EGS, binary or flash systems, reservoir temperature
Hydropower	12[a]	Non-powered dams, new stream-reach development, head, and design capacity
Pumped storage hydropower	15[a]	CAPEX
Utility-scale, commercial, residential battery storage	5	Storage duration
Natural gas	9	Turbine technology, level of CCS
Coal	5	Pulverized coal, IGCC, level of CCS
Nuclear	2	Pressurized Water Reactor (AP1000) or SMR
Biopower	1	Dedicated
Natural gas and coal retrofits	6	Turbine technology, level of CCS

[a] Representative bins for the ATB only: the NREL Regional Energy Deployment System (ReEDS) implements a full site-specific supply curve.

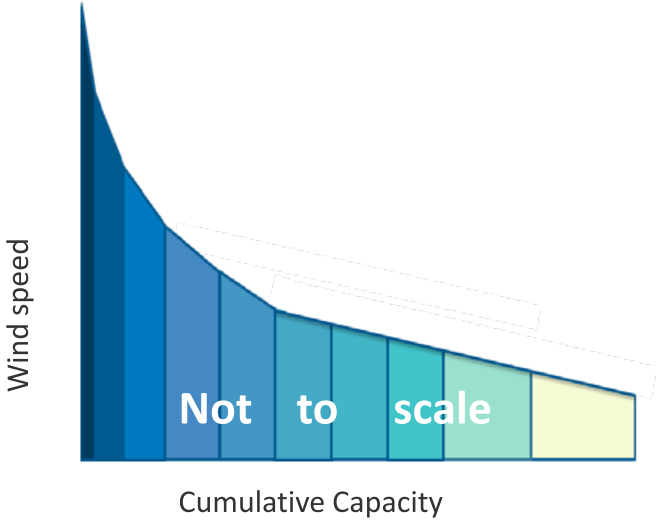
ATB Bins Technologies and Resources Based on Various Characteristics

Example: Wind ATB bins based on annual average wind speed

Annual average wind speed → ATB wind classes



https://www.nrel.gov/gis/assets/images/wtk-100-north-america-50-nm-01.jpg



Step 2: Develop Cost and Performance Data

Base Year (2021): Informed by market reports, market data, and bottom-up modeling

Projections: Generally, rely on bottom-up modeling and published studies; qualitatively harmonized to three scenarios of future technology innovation:

Conservative
Technology Innovation

- Today's technology with little innovation
- Continued industrial learning
- Decreased public and private R&D

Moderate
Technology Innovation

- Widespread adoption of today's cutting edge
- Expected level of innovation
- Current levels of public and private R&D

Advanced
Technology Innovation

- Market success of currently unproven innovation
- New technology architectures
- Increased public and private R&D

Sources of Base Year (2021)

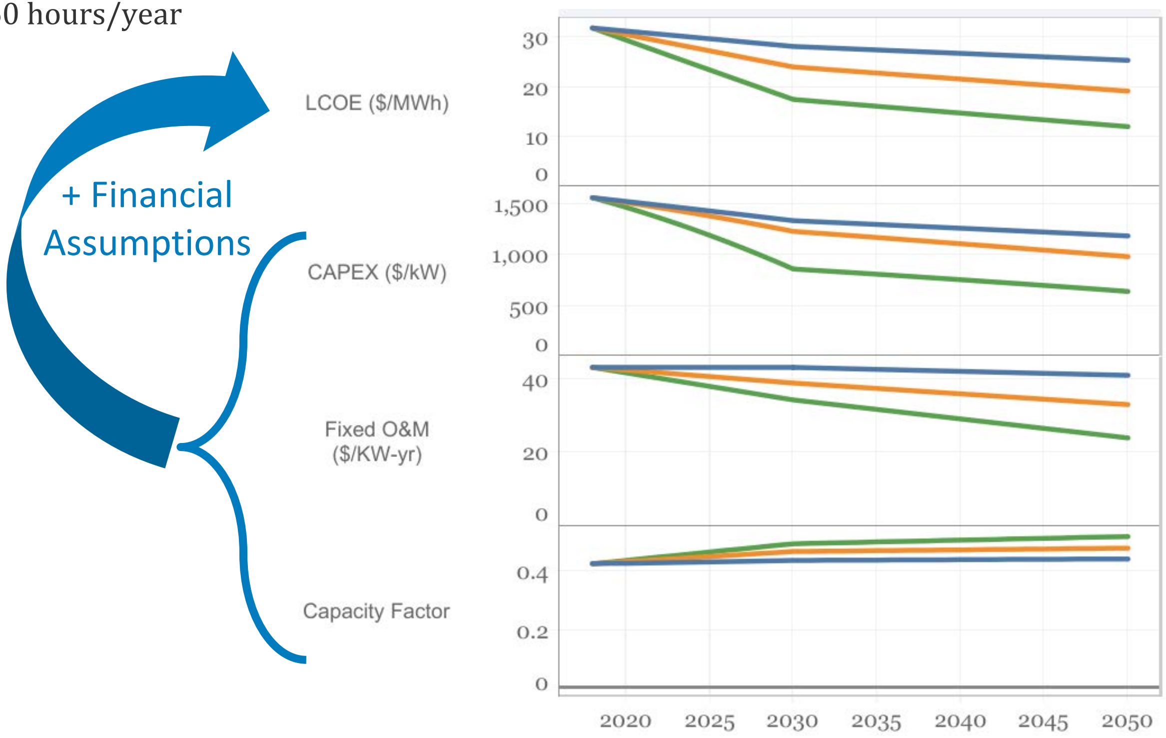
Technology	Source
Land-based wind power plants	Capital expenditures (CAPEX) associated with the four representative technologies are estimated using bottom-up engineering models for hypothetical wind plants installed in 2021 (Wiser and Bolinger, 2022). The all-in OPEX (O&M) cost for each representative technology is informed by recent literature (Liu and Garcia da Fonseca, 2021) and (Wiser et al., 2019).
Offshore wind power plants	Base year estimates are derived from a combination of bottom-up techno-economic cost modeling (Beiter et al., 2016) and experiential learning effects with economies of size and scale from higher turbine and plant ratings (Beiter et al., 2020), (Shields et al., 2022).
Distributed wind power plants	Base year costs and performance estimates are data obtained from NREL's 2020 Cost of Wind Energy study (Stehly and Duffy 2022).
Utility, residential, and commercial PV plants	CAPEX and O&M for 2021 are based on bottom-up cost modeling and market data from Ramasamy et al. (2021).
Concentrating solar power plants	Assumptions are based on recent assessment of the industry in 2022 and bottom-up CSP cost analysis for heliostat components (Kurup et al. 2022).
Geothermal plants	Bottom-up cost modeling uses Geothermal Electricity Technology Evaluation Model (GETEM) and inputs from the GeoVision BAU scenario (DOE 2019; Augustine et al. 2019).
Hydropower plants	NPD data are based on bottom-up 2020 cost analysis (Oladosu et al. 2021). NSD data from previous years based on Hydropower Vision study (DOE, 2016); bottom-up cost modeling is from O'Connor et al. (2015).
Utility-scale PV-plus-battery	CAPEX assumptions for utility-scale PV-plus-battery are based on new bottom-up cost modeling and market data from Ramasamy et al. (2022)
Utility, residential, and commercial battery storage	Costs for utility-scale battery energy storage systems (BESS) are based on a bottom-up cost model using the data and methodology for utility-scale BESS in Ramasamy et al. (2021).
Pumped storage hydropower	Resource characterizations and capital costs are from Rosenlieb et al. (2022) with updates described at https://www.nrel.gov/gis/psh-supply-curves.html, which describes a national closed-loop PSH resource assessment. O&M costs are from Mongird et al. (2020).
Natural gas and coal	Estimates of performance and costs for currently available fossil-fueled electricity generating technologies are representative of current commercial offerings and/or projects that began commercial service within the past ten years (Schmitt et al., 2022), (Buchheit et al., 2023), (Schmitt and Homsy, 2023).
Nuclear and biopower plants	Values from Annual Energy Outlook (EIA 2023) are reported.

Step 3: Calculate Levelized Cost of Energy (LCOE[a])

$$\text{Levelized Cost of Energy} = \frac{\text{Fixed Charge Rate} \times \text{Capital Expenditures} + \text{Fixed Operations and Maintenance Cost}}{\text{Capacity Factor} \times 8760\ \text{hours/year}}$$
$$+ \text{Variable Operations and Maintenance Cost}$$
$$+ \text{Fuel Cost} - \text{Production Tax Credit}$$

LCOE is a summary metric with important limitations. See documentation at atb.nrel.gov.

Capacity factor refers to utilization for geothermal, hydropower, coal, gas, nuclear, and biopower.



[a]LCOE is for generation technologies only. Levelized cost of storage is not reported.

Step 3: More Details on Fixed Charge Rate

Fixed Charge Rate = Capital Recovery Factor X Project Finance Factor

Capital Recovery Factor = Weighted Average Cost of Capital X

$$\frac{1}{\left(1-\frac{1}{(1+WACC)^{Cost\ Recovery\ Period}}\right)}$$

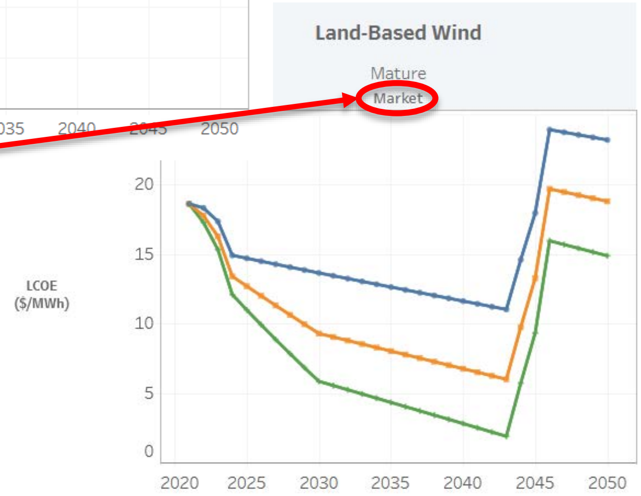
Project Finance Factor =

$$\frac{(1-Tax\ Rate\times Present\ Value\ of\ Depreciation)\times\left(1-\frac{Investment\ Tax\ Credit}{2}\right)-Investment\ Tax\ Credit}{(1-Tax\ Rate)}$$

https://atb.nrel.gov/electricity/2023/equations_&_variables

ATB Financial Cases

- Two financial cases:
  - R&D: This sensitivity case allows technology-specific changes to debt interest rates, return on equity rates, and debt fraction to reflect effects of R&D on technological risk perception, but it holds background rates constant and excludes effects of tax reform and tax credits.
  - Markets + Policies: This sensitivity case retains the technology-specific changes to debt interest and return on equity rates from the R&D Only Case and adds in the effects of the tax credits in the Inflation Reduction Act of 2022.



2023 ATB Financial Case Details

- Base year = 2021. Dollar year = 2021. Historical data include data reported in 2021.

- Added Inflation Reduction Act tax credits to Markets + Policies case, with phase out starting in 2038 based on 2022 Standard Scenarios mid-case

  - Assumes labor requirements are met but no bonus credits (30% ITC, $27.50/MWh PTC deflated to 2021$)
  - ATB year is commercial online date. Four year safe harbor plus phase out schedule means credits are first reduced for most technologies in 2044.

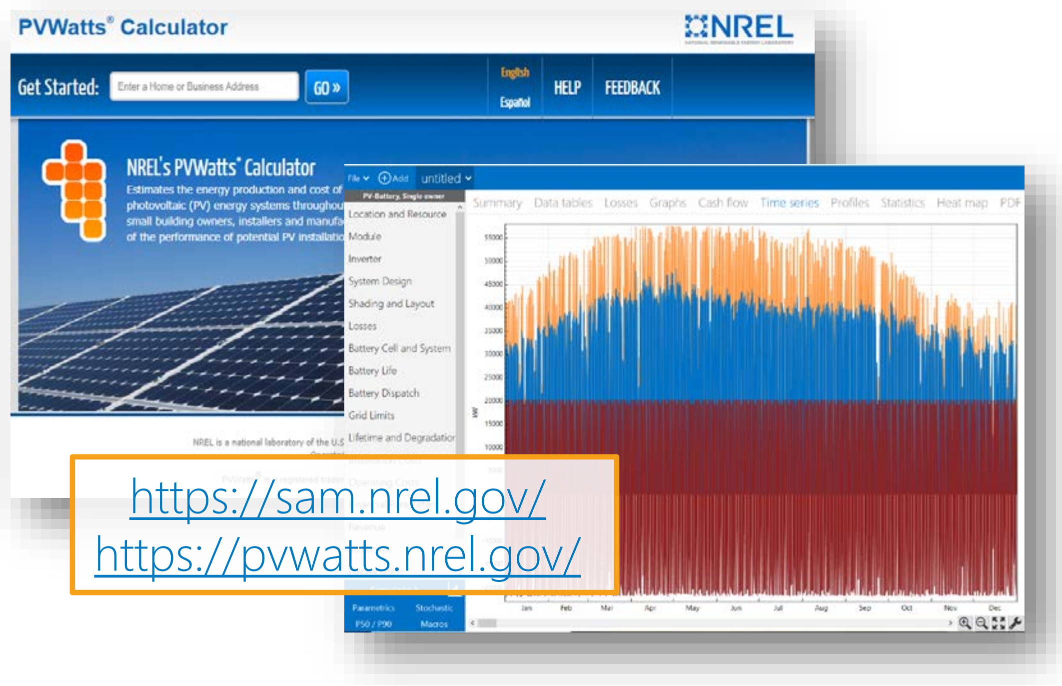
- Using System Advisor Model (SAM) to calculate debt fractions, including annual calculations for markets case

Live Demo

- Code available from https://github.com/NREL/ATB-calc/
- Data available at https://data.openei.org/submissions/5865 (or https://atb.nrel.gov/electricity/2023/data)
- Live demo assumes Python, a package manger, and a virtual environment are already installed
- More ways to interact with ATB data available at: https://github.com/openEDI/open-data-access-tools

System Advisor Model (SAM) & PVWatts

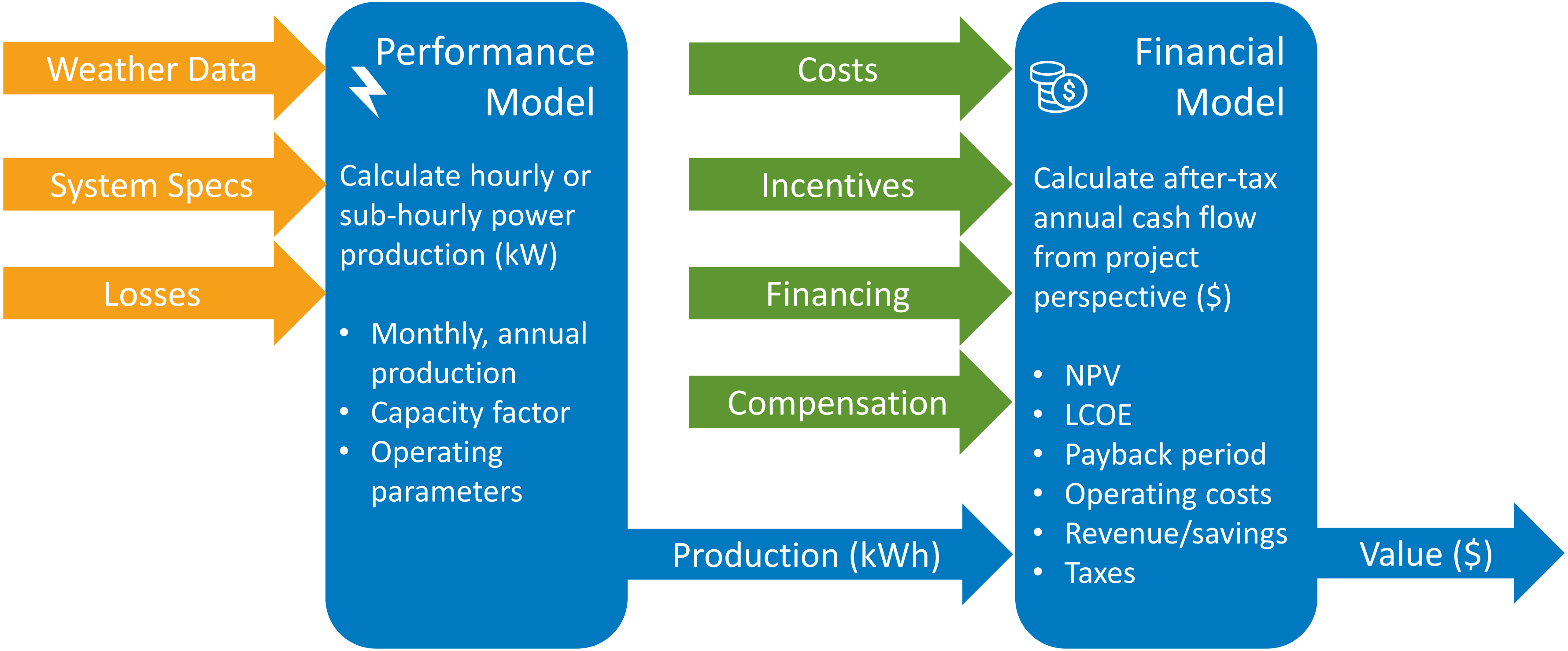
Free software that enable detailed performance and financial analysis for renewable energy systems



https://sam.nrel.gov/
https://pvwatts.nrel.gov/

- ✓ Desktop application
- ✓ PVWatts web tool & API
- ✓ Software development kit
- ✓ PySAM Python package
- ✓ Open source code
- ✓ Extensive documentation
- ✓ User support

Model Structure



Technologies

- Photovoltaic
- Energy storage
  - Electric battery
  - Electric thermal storage
- Concentrating solar power
- Industrial process heat
- Marine energy
- Wind power
- Fuel cell
- Geothermal power
- Solar water heating
- Biomass combustion
- Generic system

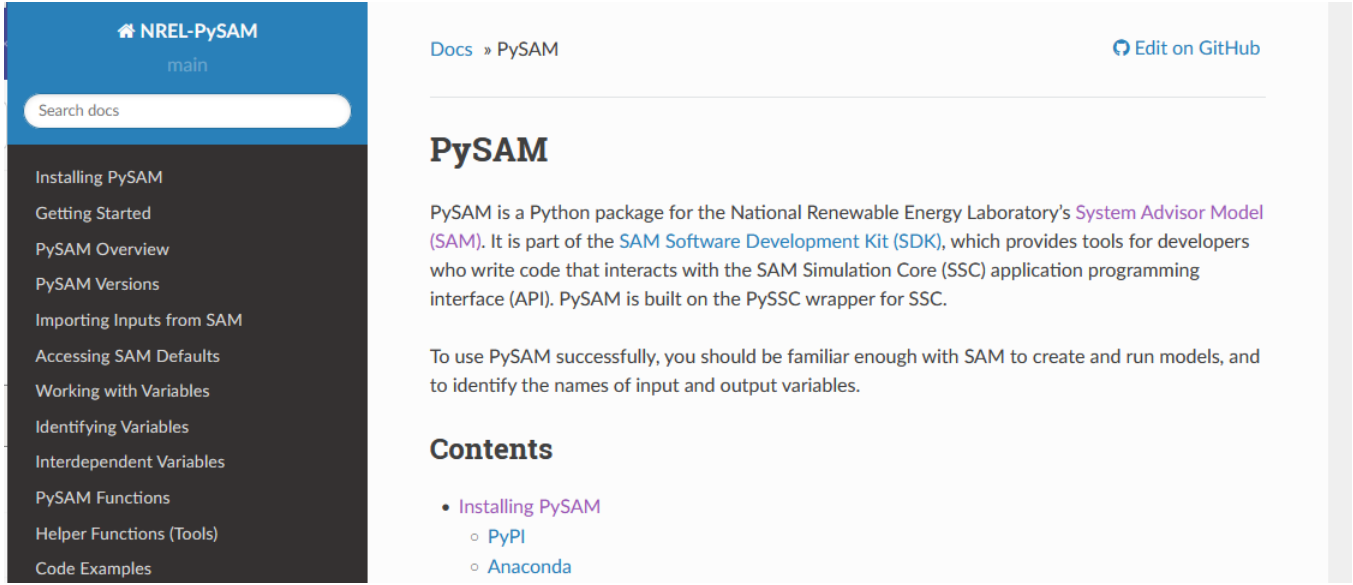
Financial Models

- Power purchase agreements
  - Single owner
  - Partnership flips
  - Sale leaseback
- Residential
- Commercial
- Third party ownership
- Merchant plant
- Community solar
- Simple LCOE calculator

What is PySAM?

Python package that enables you to run the underlying modules that make up a simulation in SAM

- Package name nrel-pysam
- Unit modules called compute_modules in the SSC code



NREL-PySAM
main
Search docs

Installing PySAM
Getting Started
PySAM Overview
PySAM Versions
Importing Inputs from SAM
Accessing SAM Defaults
Working with Variables
Identifying Variables
Interdependent Variables
PySAM Functions
Helper Functions (Tools)
Code Examples

Docs » PySAM
Edit on GitHub

PySAM

PySAM is a Python package for the National Renewable Energy Laboratory's System Advisor Model (SAM). It is part of the SAM Software Development Kit (SDK), which provides tools for developers who write code that interacts with the SAM Simulation Core (SSC) application programming interface (API). PySAM is built on the PySSC wrapper for SSC.

To use PySAM successfully, you should be familiar enough with SAM to create and run models, and to identify the names of input and output variables.

Contents

- Installing PySAM
  - PyPI
  - Anaconda

What is PySAM?

Python package that enables you to run the underlying modules that make up a simulation in SAM

- Unit modules called compute_modules in the SSC code

A single simulation is a process chaining together multiple unit modules

- Order
- Information needs to be passed from one to the next

Generic System-Battery – Commercial Owner

Generic system model with battery storage. Renewable energy system displaces commercial building electric load.

Configuration name for defaults: *"GenericBatteryCommercial"*

GenericSystem, Battery, Grid, Utilityrate5, Cashloan

https://nrel-pysam.readthedocs.io/en/main/

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- Information needs to be passed from one to the next
- Assembled behind the scenes in SAM user interface

PySAM, and SAM's other software development kits, expose these unit modules so that they can be customized and embedded in software applications

https://nrel-pysam.readthedocs.io/en/main/

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PySAM does NOT contain all the features in the SAM GUI

https://nrel-pysam.readthedocs.io/en/main/

SAM Help Resources

Help System

- Press F1 key or click **Help** in SAM software
- Web version at https://sam.nrel.gov/help

SAM Forum

- https://sam.nrel.gov/forum
- Use search box to find information
- Register on website to post questions

Email

- sam.support@nrel.gov

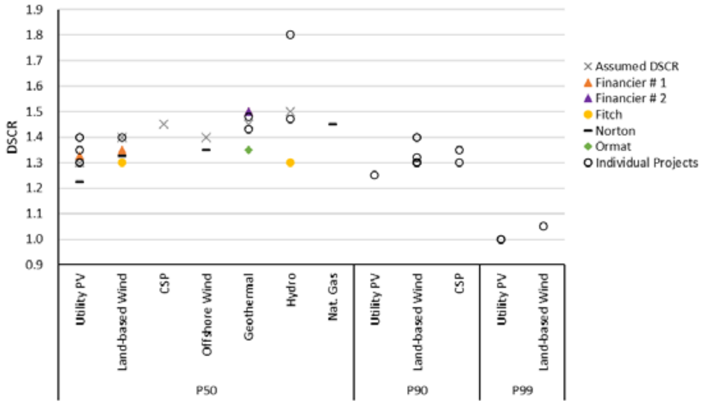
Financial Cases and Method

https://atb.nrel.gov/electricity/2023/financial_cases_&_methods

Define Financial Scenario, Collect Data, Run Models

- Collected data for renewable energy project financing owned by independent power producers with long-term power purchase agreements, as well as natural gas financial arrangements with quasi-merchant power contracts. (Represents the largest share of new projects in the United States, particularly for renewable energy.)
- Built cash flow model, with ATB and financing inputs, to determine project leverage over time. Methods, analysis, and data fully described by David Feldman, Mark Bolinger, and Paul Schwabe. *Current and Future Costs of Renewable Energy Project Finance Across Technologies*. (Golden, CO: NREL, 2020). NREL/TP-6A20-76881. https://www.nrel.gov/docs/fy20osti/76881.pdf.
    - Interest rate and cost of equity assumptions updated for this ATB (see previous slide). More recent DSCR industry data was assessed and found to be generally consistent with previous assumptions.
- Developed values for two financial cases (R&D and Market + Policies) to reflect current assessments. "R&D" financial case assumes no tax credits and no change in interest rate.
- Financing costs for each technology are developed for (1) construction period and (2) operating period to account for different levels of risk.

DSCR data at different probability of exceedance levels, by technology



Inflation Reduction Act Bonus Credits

- PTC and ITC can increase for domestic content or for projects located in an energy community
- Additional credits for projects located in low-income communities or on tribal land.
- More information: https://www.whitehouse.gov/cleanenergy/clean-energy-tax-provisions/

References

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Thank you.

atb.nrel.gov

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NREL/PR-7A40-87622

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Strategic Priorities and Impact Analysis and Office of Renewable Power. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

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