U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Pumped Storage Hydro Valuation Program

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Pumped Storage Hydro (PSH) Valuation Team

Valuation Guidance & Techno-Economic Studies and Tool for Pumped Storage Hydropower

Argonne National Laboratory (Argonne)

Idaho National Laboratory (INL)

National Renewable Energy Laboratory (NREL)

Oak Ridge National Laboratory (ORNL)

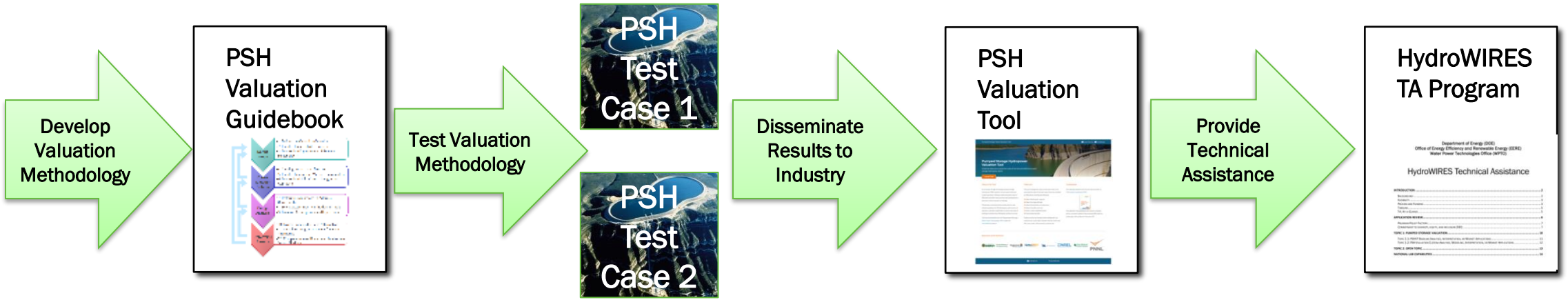
Pacific Northwest National Laboratory (PNNL)

Program Goals and Objectives

Objective: Advance the state of the art in the assessment of value of PSH plants and their role and contributions to the power system

Specific goals:

1. Develop and test a comprehensive and transparent valuation guidance that will allow for consistent valuation assessments and comparisons of PSH projects
2. Transfer and disseminate the PSH valuation guidance to the hydropower industry, PSH developers, and other stakeholders
3. Provide technical assistance (TA) to the hydropower industry ($4 million TA program)



Techno-Economic Studies

A variety of analyses were carried out to assess the costs and benefits of various PSH services and contributions to the grid

- Bulk power capacity and energy value over PSH lifetime
- Value of PSH ancillary services (regulation service, contingency reserves, etc.)
- Power system stability services (inertial response, governor response, transient and small signal stability, voltage support)
- PSH impacts on reducing system cycling and ramping costs
- Other indirect (system-wide or portfolio) effects of PSH operations (e.g., PSH impacts on decreasing overall power system production costs, benefits for integration of variable energy resources, and impacts on power system emissions)
- PSH transmission benefits (transmission congestion relief, transmission investments deferral)
- PSH non-energy services (water management services, socioeconomic benefits, and environmental impacts)

The Project Team Collaborated with Two Industry Partners

Absaroka Energy

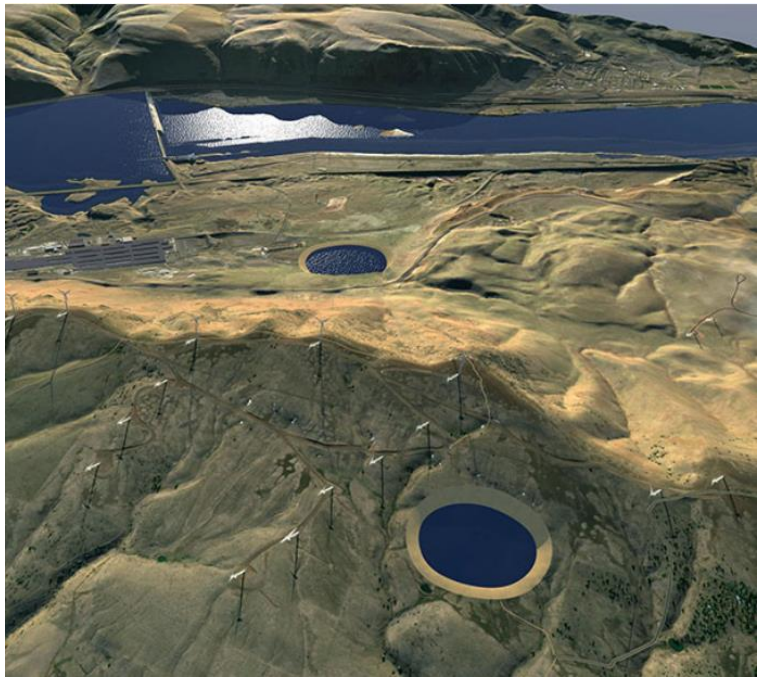
Banner Mountain PSH

- 400 MW, quaternary technology
- Closed loop
- Site near Casper, WY

CIP & Rye Development*

Goldendale Energy Storage Project

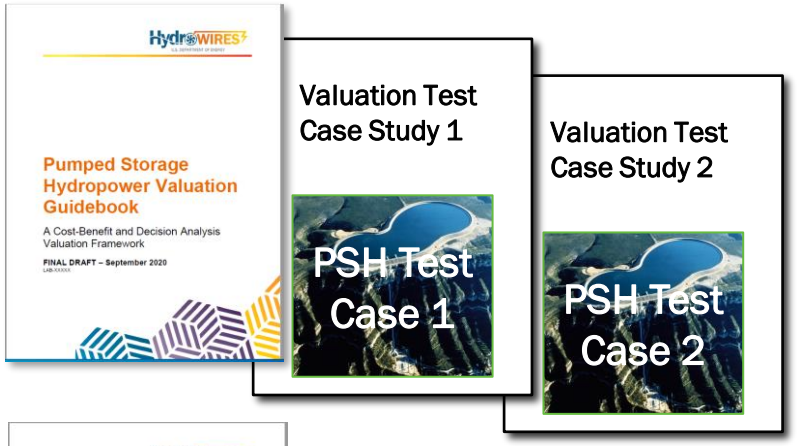
- 1,200 MW, adjustable speed technology
- Closed loop
- Site just north of OR/WA border



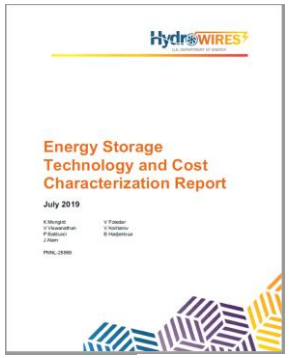
*CIP = Copenhagen Infrastructure Partners

Key Products of the PSH Valuation Project

- PSH Valuation Guidebook (published)
- Two technical reports illustrating test case studies for actual PSH projects (complete)



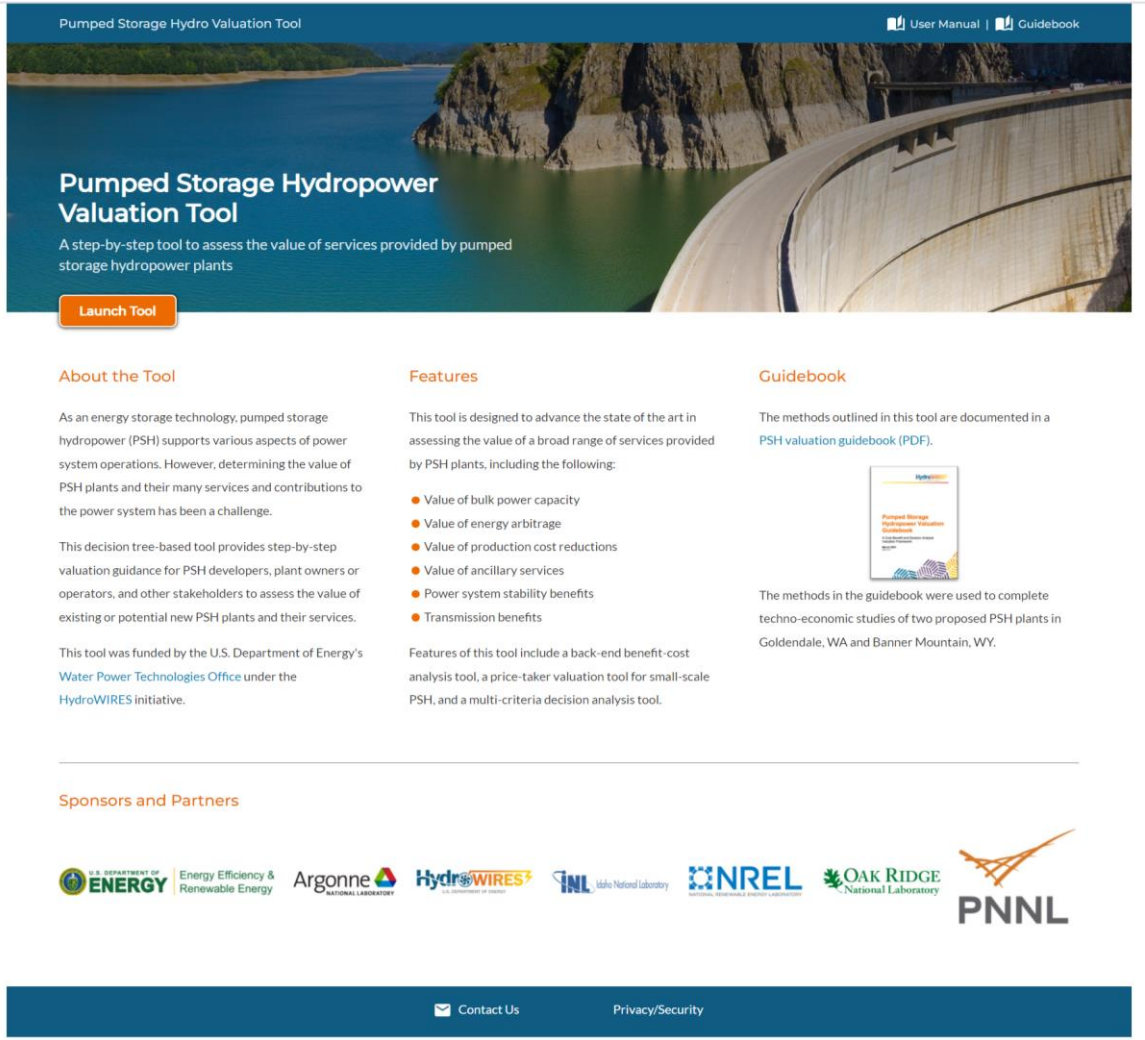
- Energy storage cost and performance study (published)



- PSH valuation tool to help the users navigate the PSH valuation process (https://pshvt.egs.anl.gov/)

PSH Valuation Tool

- PSH valuation tool provides step-by-step valuation guidance for PSH developers, plant owners or operators, and other stakeholders
- PSH tool advances the state of the art in evaluating a broad set of use cases from three perspectives: owner/operator, system, and society
- PSH tool has several advanced features:
  - Embedded price-taker model
  - Multi-criteria decision analysis (MCDA) tool
  - Embedded financial worksheets and benefit-cost analysis (BCA) model
  - Embedded price-influencer model



PSH Valuation Tool Home Page

Price-taker Model

- **PNNL adapted its Battery Storage Evaluation Tool (BSET) to PSH**
- **Embed BSET within the tool**
- **Tool provides:**
  - Optimization across single or multiple services customized by users
  - Optimization without perfect foreknowledge of prices; operations based on historical prices or price predictions
  - Power and energy limit specifications
  - Model can be used to determine optimal power capacity and energy ratings

Category	Use Case
Bulk Energy	Energy Arbitrage
	Capacity
Ancillary Services	Frequency Regulation
	Spin / Non-Spin
Transmission	Upgrade Deferral
	Congestion Relief
Distribution	Upgrade Deferral
	Volt-VAR
Customer Energy Management	Power Reliability
	TOU Charge Management
	Demand Charge Management

Price-taker Model Use Cases

MCDA Tool

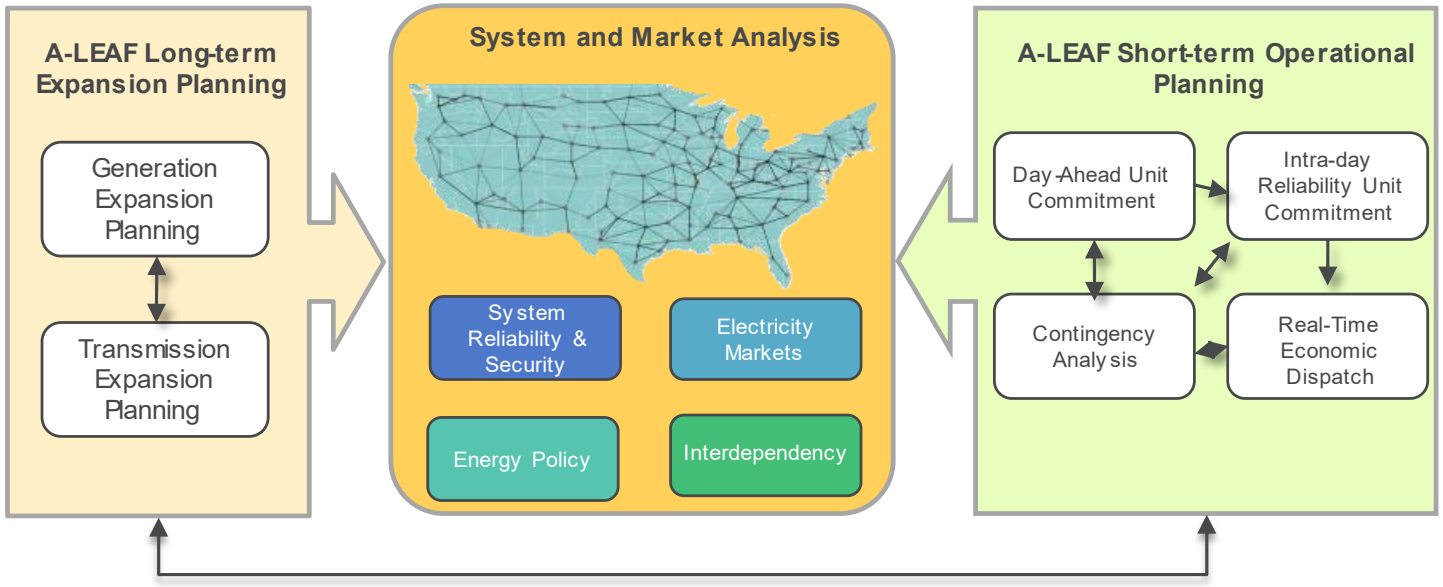
- Choosing among different alternatives with multiple attributes
- Many PSH impacts are not easily monetized and must be expressed in physical units or qualitatively
- How to compare different alternatives that are described by both monetized and non-monetized impacts?
- A decision-support system can help decision-makers choose among different alternatives defined by multiple attributes

					Entered Optimization Goal and Bounds of Measurement Scale Computed Performance Index Scores								
					Alternative 1			Alternative 2			Alternative 3		
		Lower Bound	Upper Bound	Goal									
Metric 1	NPV	-40.0	60.0	Maximize	45	85		30	70		40	80	
Metric 2	VER Curtailments	0.0	50.0	Minimize	30	40		40	20		45	10	
Metric 3	Interruption Cost	0.0	30.0	Minimize	15	50		22	27		19	37	
Metric 4	Environmental Score	0.0	5.0	Maximize	4	80		2	40		3	60	
						Average							
					Value	Weight	Weighted Scores	Value	Weight	Weighted Scores	Value	Weight	Weighted Scores
	NPV				85	0.222	18.88	70	0.222	15.55	80	0.222	17.77
	VER Curtailments				40	0.188	7.50	20	0.188	3.75	10	0.188	1.88
	Interruption Cost				50	0.289	14.47	27	0.289	7.72	37	0.289	10.61
	Environmental Score				80	0.301	24.08	40	0.301	12.04	60	0.301	18.06
	Performance Index						**64.93**			**39.06**			**48.31**

PSHVT MCDA Tool

Argonne Low-carbon Electricity Analysis Framework (A-LEAF)

- Integrated national-scale power system simulation framework developed at the Argonne National Laboratory, used to analyze various issues related to the evolution of the nation's power system.
- Suite of least-cost generation & transmission expansion, unit commitment, and economic dispatch models
- Determine system optimal generation portfolio and hourly or sub-hourly unit dispatch under a range of user-defined input assumptions for technology characteristics and system/market requirements



Embedded A-LEAF Tool

How A-LEAF Works in the PSH Valuation Tool

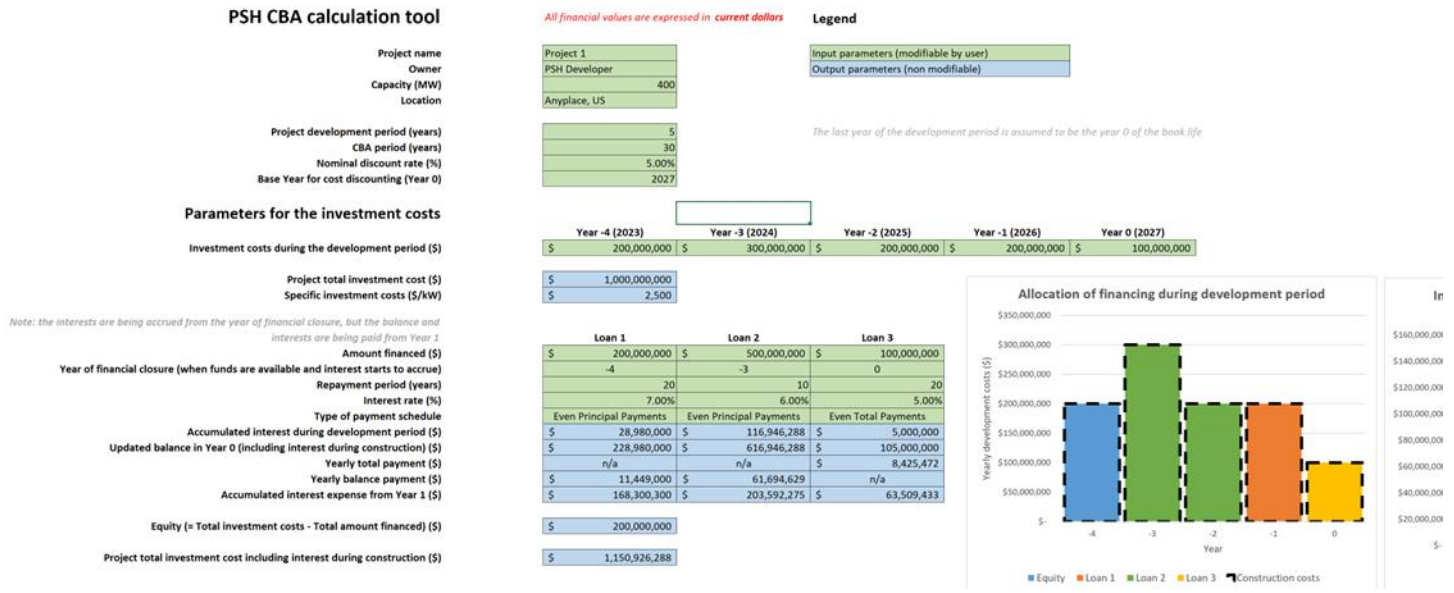
- **A-LEAF is embedded as an option**
  - Users can choose the current approach for estimating PSH values using multiple external tools or select the A-LEAF option
- **Data**
  - Users can use the default national scale dataset provided in A-LEAF
  - The tool supports users as they define input data for their own analysis
- **Alternative Scenarios**
  - Natural gas prices and technology costs
  - Environmental policies and tax credits
  - 134 balancing areas around US
- **Use Cases**
  - A-LEAF is customized to support several use cases in the PSH valuation tool

Category	Service
Bulk Energy Services	Electricity price arbitrage
	Bulk power capacity
Ancillary Services	Frequency regulation
	Contingency reserve
	Flexibility reserve
	Black start service
Reliability and Resilience	Reduced power outages
Power System Indirect Benefits	Reduced electricity generation cost
	Reduced ramping of thermal units
	Reduced curtailments of variable generation
Transmission Infrastructure Benefits	Transmission upgrade deferral
	Transmission congestion relief
Energy Security Benefits	Fuel savings and diversification
	Major blackouts avoided

A-LEAF Use Cases

BCA Calculator, Financial Worksheets, and Reporting

- BCA calculator runs the user through a series of data requests
- Model enables the user to define alternative scenarios, evaluate many use cases, and consider alternative debt structures, alternative depreciation methods, tax implications, salvage value, all capital and operations and maintenance costs, and refurbishment costs



PSH CBA calculation tool

All financial values are expressed in current dollars

Legend

Input parameters (modifiable by user)
Output parameters (non modifiable)

Project name	Project 1
Owner	PSH Developer
Capacity (MW)	400
Location	Anyplace, US
Project development period (years)	5
CBA period (years)	30
Nominal discount rate (%)	5.00%
Base Year for cost discounting (Year 0)	2027

The last year of the development period is assumed to be the year 0 of the book life

Parameters for the investment costs

	Year -4 (2023)	Year -3 (2024)	Year -2 (2025)	Year -1 (2026)	Year 0 (2027)
Investment costs during the development period ($)	$ 200,000,000	$ 300,000,000	$ 200,000,000	$ 200,000,000	$ 100,000,000

Project total investment cost ($)	$ 1,000,000,000
Specific investment costs ($/kW)	$ 2,500

Note: the interests are being accrued from the year of financial closure, but the balance and interests are being paid from Year 1

	Loan 1	Loan 2	Loan 3
Amount financed ($)	$ 200,000,000	$ 500,000,000	$ 100,000,000
Year of financial closure (when funds are available and interest starts to accrue)	-4	-3	0
Repayment period (years)	20	10	20
Interest rate (%)	7.00%	6.00%	5.00%
Type of payment schedule	Even Principal Payments	Even Principal Payments	Even Total Payments
Accumulated interest during development period ($)	$ 28,980,000	$ 116,946,288	$ 5,000,000
Updated balance in Year 0 (including interest during construction) ($)	$ 228,980,000	$ 616,946,288	$ 105,000,000
Yearly total payment ($)	n/a	n/a	$ 8,425,472
Yearly balance payment ($)	$ 11,449,000	$ 61,694,629	n/a
Accumulated interest expense from Year 1 ($)	$ 168,300,300	$ 203,592,275	$ 63,509,433

Equity (= Total investment costs - Total amount financed) ($)	$ 200,000,000
Project total investment cost including interest during construction ($)	$ 1,150,926,288

PSHVT BCA Calculator

- BCA calculator defines a benefit-cost ratio, discounted payback period, and an internal rate of return for each case
- The tool produces a report providing a technology overview, stakeholder engagement plan, use case and metrics, and results of the BCA and MCDA

Thank you! Questions?

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