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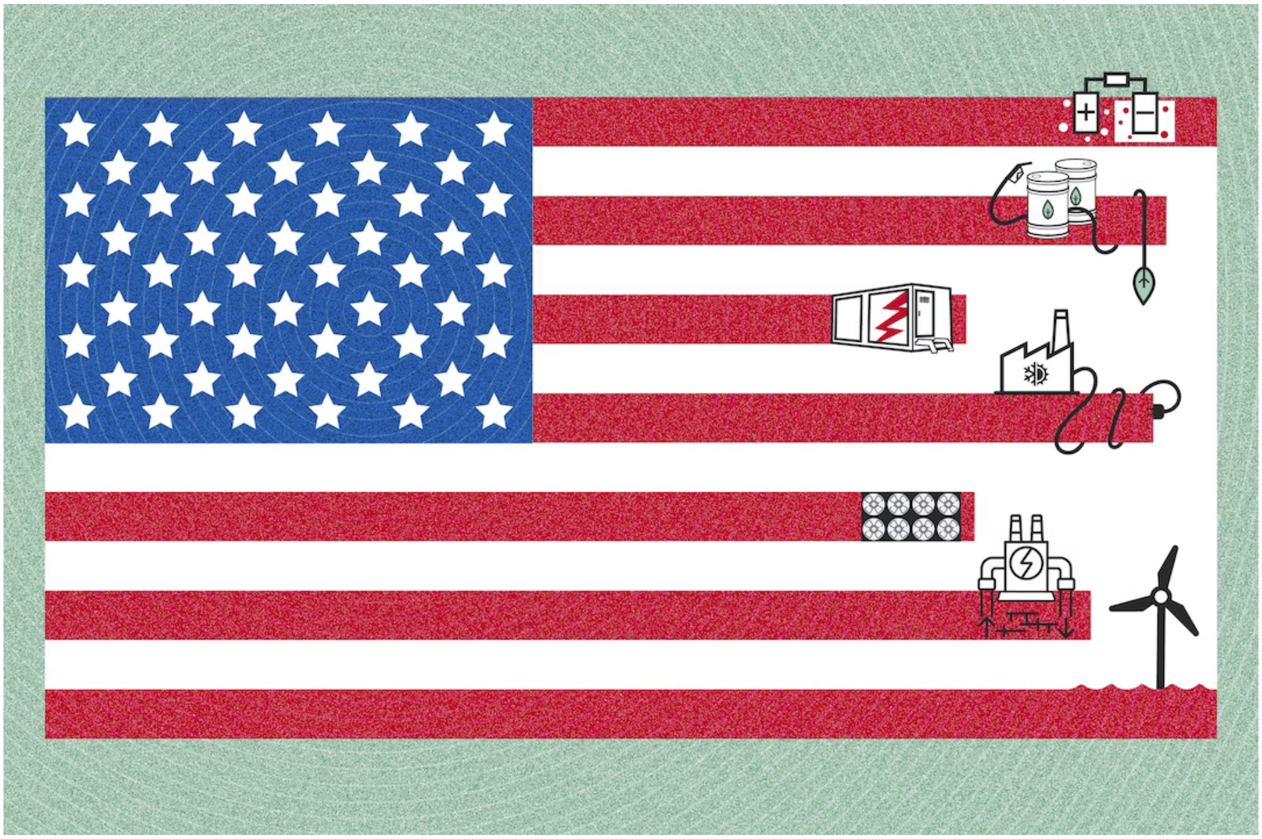
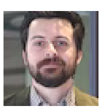
EXECUTIVE SUMMARY *Published June 23, 2023 • 15 minute read*

DOE's Energy Earthshots: Innovation Unlocks Big Cost and Emissions Savings





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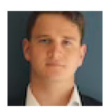

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Takeaways

- The Department of Energy's (DOE) Earthshots Initiative sets ambitious yet achievable targets aimed at coordinating and accelerating the innovation needed to bring down the cost of critical clean energy technologies.

- Achieving the first six Energy Earthshots simultaneously produces significant emission and cost savings over the next three decades: approximately 3,900 million metric tons of CO_2 and $850 billion in energy system costs are avoided.

- Energy Earthshots targeting technologies outside of electric power generation (Carbon Negative, Hydrogen, Industrial Heat) generate the largest emissions savings. In particular, direct air capture and electrolysis innovation are highly complementary since low-cost CO_2 and H_2 feedstocks create the opportunity for economic electric fuels.
- Earthshots focused on the electric sector (enhanced geothermal, long duration storage, etc.) show more modest impacts, as they compete with established renewables already being deployed, like solar and wind. However, the benefits of these firm technologies would likely grow under certain scenarios.
- Accomplishing the goals targeted by the Energy Earthshots Initiative will take Congressional support and thoughtful planning. Dedicated appropriations are needed for Earthshot research and development efforts, as well as to support coordination mechanisms for the Department of Energy and other entities.

The Energy Earthshots Initiative

In 2021, the US Department of Energy (DOE) launched its Energy Earthshots Initiative, a novel and innovative approach to catalyze decarbonization across some of the hardest to abate sectors of our economy. These 'Earthshots' are meant to tackle the toughest remaining scientific and technical barriers to deploying the technologies we need to rapidly reduce emissions. Modeled after the wildly successful 2011 SunShot Initiative, the current Earthshots set aggressive cost targets for seven critical areas: hydrogen, carbon removal, long duration energy storage, enhanced geothermal, floating offshore wind, low-carbon industrial heat, and clean fuels and products. [1] These goals are ambitious, well-thought-out, and inspiring. Achieving them would be an awesome accomplishment, setting the US up to be a global leader in the energy technologies that will define this century.

This report presents a first-of-its kind analysis of the potential impact the Energy Earthshots Initiative could ultimately have, modeling the total energy system cost and emissions reductions if the first six Shot targets are hit. To undertake this study, Third Way retained Evolved Energy Research to model each Shot's potential trajectory, as well as the potential impact if all the Shots are achieved simultaneously ("Combined Shot Scenario"). This report unpacks those findings, providing an overview of the modeling results and presenting policy recommendations for achieving them. The full analysis (APPENDIX A) and modeling methodology (APPENDIX B) are also provided to supplement these topline findings.

Energy Earthshot Targets

Energy Earthshot	Target
Hydrogen	Reduce clean hydrogen production cost to $1.0/kG by 2030
Long Duration Storage	Reduce storage costs by 90% (from a 2020 li-ion baseline) in systems that deliver 10+ hours of duration by 2030
Carbon Negative	Capture and store CO2 from the atmosphere for less than $100/t CO2e by 2030
Enhanced Geothermal	Reduce cost to $45/MWh by 2035
Floating Offshore Wind	Reduce cost to $45/MWh by 2035
Industrial Heat	Develop cost-competitive industrial heat technologies with at least 85% lower emissions by 2035

Source: "Energy Earthshots Initiative." Energy.gov, www.energy.gov/policy/energy-earthshots-initiative. Accessed 31 May 2023.

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While the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA) made strides towards lowering the anticipated costs for these technology areas, further research and development is needed to bring down the unsubsidized base cost of these technologies to meet all the Earthshot goals and maximize potential economic and climate success. [2]

Outlined by DOE's FY24 Budget Request, the Administration plans to utilize its "crosscutting activities" to drive the innovation breakthroughs needed to achieve the Earthshot goals. In practice, this means DOE will rely on synergistic collaboration across the Department, from the basic and applied science offices to ARPA-E and the National Labs. As DOE states, "The Energy Earthshots are an all-hands-on-deck call for innovation, collaboration, and acceleration." [3]

If the Administration accomplishes its goals, the results could be huge; **our model found that between now and 2050, Americans could save over $850 billion in energy costs and avoid over 3,900 million metric tons of CO2 emissions.** For reference, the energy provisions in the IRA – the largest investment in clean energy and climate change in US history [4] – is valued around $370 billion and is expected to reduce emissions by about 2,500 to 2,800 million metric tons by 2030. [5] Hitting these ambitious targets will require diligent planning and focused funding, but our findings are clear: achieving the Energy Earthshots would be truly historic.

Modeling Results

Combined Shot Scenario

Achieving all Energy Earthshots both: (a) accelerates deployment of clean energy technologies above and beyond the Baseline scenario; and (b) enables deployment that would not occur at today's cost and performance. For example, hydrogen production from electrolysis and floating offshore wind are both already incentivized today due to IRA tax credits and state policy goals. Still, their deployment increases both in the medium- and long-term with an Earthshot. CO2 capture from Direct Air Capture (DAC), enhanced geothermal, and long duration electric storage, which are not economical at today's costs, see substantial deployment with ambitious cost and performance improvements. A broad expansion of renewable electricity generation (12% and 18% higher than the Baseline by 2030 and 2050, respectively) occurs in the Combined Shot scenario to meet loads from hydrogen production, CO2 capture and heat production.

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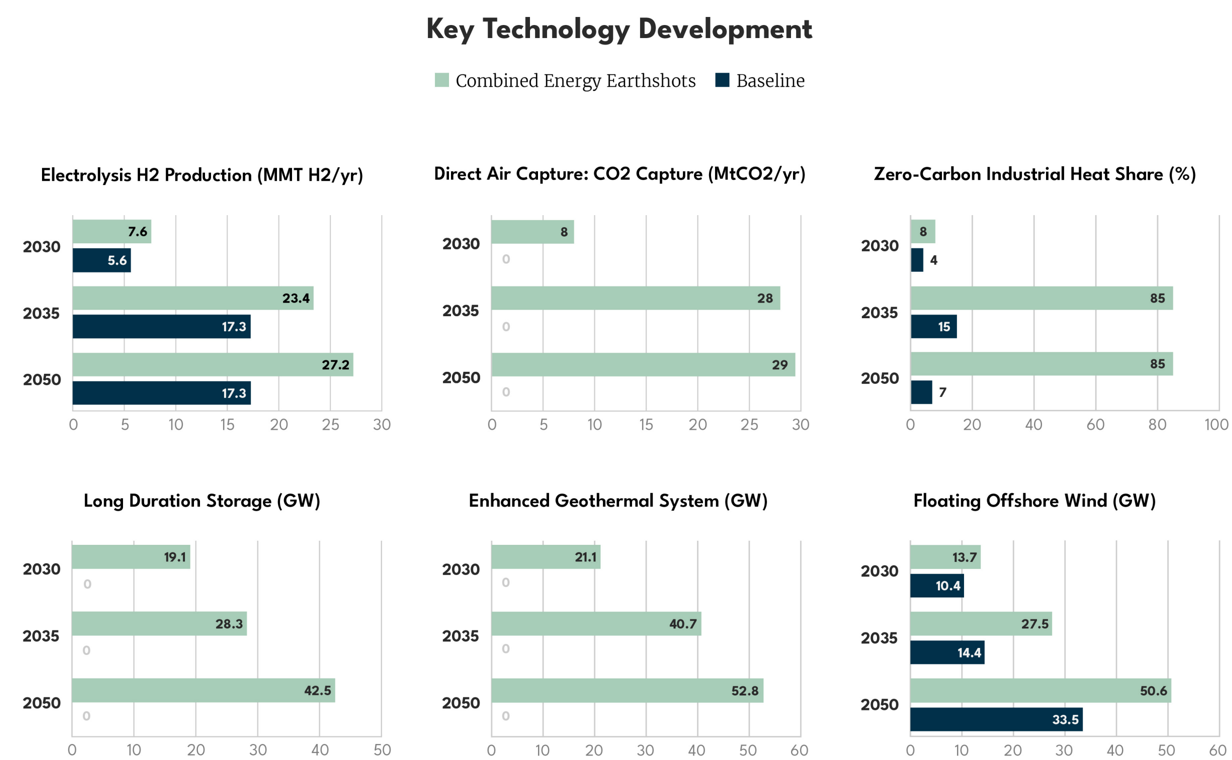

Source: Evolved Energy Research

We find nearly 3,900 million metric tons of CO2 and $850 billion of savings as a result of incremental clean technology deployment. These savings are the difference between a baseline emissions reduction scenario, which includes IRA subsidies and standard technological progress, and the 'Energy Earthshot Scenario' which reflects hitting DOE's targets. Emission savings primarily stem from:

- A replacement of coal- and natural gas-fired power generation with higher renewable uptake (Enhanced Geothermal Shot, Floating Offshore Wind Shot, Long Duration Storage Shot);

- A shift away from natural gas used in boilers towards electric heat technologies (Industrial Heat Shot); and

- Increased use of zero-carbon electric liquid fuels that serve as a "drop-in" replacement for refined petroleum products (Hydrogen Shot & Carbon Negative Shot).

The complementarity of the Hydrogen and Carbon Negative Shots drives down the production cost of synthetic electric fuels (e-fuels) since H2 and CO2 feedstocks make up nearly all the cost. If these Shots are hit, E-fuel's production cost decreases by more than half, relative to today's price. This has important implications for the competitiveness of e-fuels in sectors such as sustainable aviation fuels.

Individual Energy Earthshot Scenarios [6]

Hydrogen Shot: Achieving $1/kG hydrogen production costs by 2030 increases electrolyzer deployment by 50% relative to the Baseline scenario. Lower capital costs and improved efficiency allows for economic hydrogen production across the US, whereas Baseline production is highly concentrated in the onshore wind-heavy Great Plains region. Additional green hydrogen is used for e-fuel production, industrial heat and electric power generation.

Carbon Negative Shot: When the cost of CO2 capture is reduced to $100/tCO2e,capture from DAC, which is absent in the Baseline scenario, reaches 10 million tons CO2/yr in 2030 and expands to 40 million tons by 2050. Although the Shot focuses on storing CO2 (CCS), we find economic value for utilizing the captured CO2 to produce liquid e-fuels (CCU), which avoids fossil fuels and provides emission savings. DAC is co-located in regions with low-cost H2 production, notably Texas and the Rockies.

Industrial Heat Shot: Decarbonizing industrial heat production primarily comes from supplying steam from thermal energy storage, H2 boilers and heat pumps (). These technologies are all significant consumers of clean electricity and meeting new loads requires further scaling up renewables (180 GW of incremental renewables by 2035).

Long Duration Storage Shot: Deployment in the electricity sector is dependent on realizing the Shot's cost targets as there is zero deployment under the Baseline scenario. Innovation results in approximately 58 GW (2,000 GWh) of deployment by 2050, which avoids investment in short-duration battery storage and gas-fired resources. As a result, renewable curtailment decreases slightly but emission benefits are muted since the avoided resources are infrequently dispatched for energy. We note that LDS deployment in this analysis is generally lower than other analyses that consider similar renewable penetrations using electric sector-only models. This is because our model utilizes the Regional Investment and Operations (RIO) capacity expansion tool, which allows other sectors to compete for renewable overgeneration. Thus, much of the additional low-cost power is directed to hydrogen and low-carbon heat production.

Enhanced Geothermal Shot: Enhanced geothermal system (EGS) deployment reaches approximately 50 GW by 2050 when its costs are reduced to $45/MWh (). Investment is concentrated across the western US where the highest quality resources are located, and this translates into cost savings by avoiding lower-quality resources such solar, onshore wind and storage resource deployment.

Floating Offshore Wind Shot: A $45/MWh cost target for floating offshore wind (FOSW)(results in an additional 19 GW of deployment, which primarily displaces low-quality (marginal) solar resources in California, Hawaii, Great Lakes and the Northeast. Ambitious statewide clean energy (CES) & renewable portfolio standards (RPS) incentivize the deployment of FOWS and EGS to help meet clean electricity targets. The impacts from the Enhanced Geothermal and Floating Offshore Wind Shots are primarily cost savings, because the avoided resources from their deployment are other renewables.

Finally, on May 24, 2023, DOE announced a seventh Energy Earthshot: the Clean Fuels and Products Shot, focused on decarbonizing the fuel and chemical industries. This shot aims to advance "cost-effective technologies with a minimum of 85% lower GHG emissions by 2035." We did not model the impacts of achieving the Clean Fuels and Product Shot as we believe that the primary technologies that would be incentivized by this Shot overlap with those in the Hydrogen and Carbon Negative Shots. Thus, we believe the core impacts of this Shot are already captured in our Combined Shot scenario as low-cost H2 and CO2 result in the significant deployment of zer0-carbon fuels.

Summary of Impacts

Energy Earthshots	Cumulative Emission Savings 2021 - 2050 (Mt CO2)	Cumulative Cost Savings 2021 - 2050 ($B)
Hydrogen Shot	663	502
Carbon Negative Shot	995	49
Industrial Heat Shot	2,369	n/a*
Long Duration Storage Shot	50	4
Enhanced Geothermal Shot	524	46
Floating Offshore Wind Shot	150	94
Combined	**3,943**	**853**

*Costs are not reported since technologies are assumed to be economic.
Source: Evolved Energy Research.

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Discussion

Policy Recommendations

The DOE Energy Earthshots Initiative could be a game-changer. Achieving the Earthshots would help us reach our net-zero targets while saving Americans money and spurring new domestic industries and jobs around the technologies of the future. But realizing these goals will require sustained federal investments in researching, developing, demonstrating, and deploying these new technologies, as well a concerted effort by DOE to plan and coordinate across its many relevant offices.

Provide Increased, Sustained Funding

To reap the rewards modeled by this study, the US needs to prioritize funding for the Energy Earthshots Initiative over the next decade. Congress should provide increased funding for DOE's applied R&D offices working on individual shots (e.g. the Geothermal Technologies Office's efforts around the Enhanced Geothermal Shot), as well as for crosscutting initiatives that tie into the Earthshots (the Hydrogen and Carbon Dioxide Removal crosscuts, for example). However, Congress should be careful to boost funding for these efforts without reducing funding for its other innovation programs: robbing Peter to pay Paul would forfeit America's competitive advantage in other, more mature industries like electric vehicles and onshore wind. In the near term, specific focus should be given to traditionally underfunded technologies like enhanced geothermal and floating offshore wind so that we don't fall behind in developing these transformative but nascent technologies.

Develop Detailed Roadmaps

DOE's Crosscuts and Energy Earthshots team should develop detailed roadmaps that outline the strategies, policies, and funding mechanisms they have at their disposal to help achieve the Earthshot targets. DOE's Office of Technology Transitions' new reports – Pathways to Commercial Liftoff – are the gold standard. However, while two of the technologies these reports have focused on (Long Duration Energy Storage and Clean Hydrogen) have associated Earthshots, more can be done to build out a coordinated deployment strategy. Potential areas for collaboration, how the Earthshots are (or can) spur private investment and technological adoption, and how DOE plans to integrate Earthshot targets across the Department are all topics for further study.

Support the Full Innovation Lifecycle

Lastly, while the Earthshots can exist as a focusing mechanism for the Administration's energy related research and development activities, it will be important to continue supporting the entire innovation lifecycle. Later stage activities, such as demonstration and deployment programs, will ensure that lab innovations are routinely brought to market to prove their commercial viability. This will be critical for some of the emerging technologies highlighted in this study such as enhanced geothermal systems and direct air capture facilities.

Additional Considerations

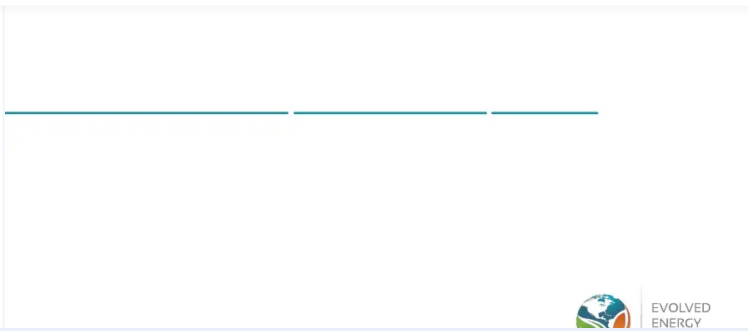
This study modeled how achieving each Shot would help reduce the costs and emissions associated with that technology's traditional impact area (e.g., EGS used for electricity generation) within a current policy scenario (i.e., existing CES/RPS regulatory environments). Ancillary uses of these technologies, like geothermal energy being used for industrial heating are not taken into account but could contribute to larger cost and emissions savings. Also, additional policies the federal government could pursue in the future, such as a 100% clean electricity standard, would increase deployment rates for electric-sector technologies substantially, and incentivize further cost reductions. Furthermore, if the growth of traditional renewables such as solar and onshore wind becomes limited by land use issues or electric transmission constraints, Earthshot technologies would see increased economic competitiveness, leading to further deployment and cost savings.

As studied, the potential impacts of achieving the Earthshot targets are impressive. But certain conditions not modeled in this analysis could exponentially increase their impact, incentivizing further deployment and pushing energy system costs and emissions down even further.

Conclusion

The Department of Energy's Earthshot Initiative is meant to be ambitious. It is intended to inspire, focus, and mobilize an integrated approach to energy innovation and deployment. Hitting these targets will take a concerted effort on the part of DOE, as well as sufficient funding from Congress over a multi-year period to invest in the RDD&D needed to reach the targets. But these investments are worth it: achieving the shots will reduce energy costs, which means lower costs for American households, in addition to slashing emissions. The slide deck below provides a full breakdown of the model's results, outlining the benefits and takeaways of our individual and combined Energy Earthshots Initiative scenarios.

APPENDIX A: Full Analysis



APPENDIX B: Modeling and Implementation

Modeling Methodology

Third Way retained Evolved Energy Research (EER) to evaluate the emissions and cost impacts from realizing the DOE's Energy Earthshot cost targets. To undertake this analysis, we simulated technology deployment for the US energy system through 2050 using the Regional Investment and Operations (RIO) capacity expansion tool. Although the Earthshots are generally technology-agnostic, we used a technology or subset of technologies to characterize each Earthshot (e.g., electrolyzers for the Hydrogen Shot). For technologies affected by the Earthshot Initiative, we developed innovation trajectories relative to today's cost and performance in order to hit the cost targets on an unsubsidized basis by 2030 or 2035.

We quantified the impact of Earthshot achievement using the following methodology. First, we developed a Baseline scenario reflecting existing policy, including: (a) state-level renewable portfolio standards (RPS) and offshore wind (OSW) procurement goals; (b) provisions from the IRA that provide tax credits for clean electricity, hydrogen and carbon capture and removal; (c) baseline technology cost and performance progress for technologies outside of the Energy Earthshot Initiative (e.g., continued solar PV and onshore wind improvements); and (d) no innovation for Energy Earthshot-related technologies (e.g., today's cost and performance levels through 2050).

Next, we simulated Energy Earthshot scenarios where technology cost and performance improve relative to today's level to realize the cost targets, including a scenario where all six targets are realized simultaneously, as well as each Earthshot achieved independently. These scenarios project economic deployment enabled by innovation under existing policy. Finally, we measure the difference in energy system-related costs and emissions for the Baseline and Energy Earthshot scenarios to estimate incremental impacts.

Implementation

The RIO model used for this analysis is a capacity expansion tool that produces a least-cost supply-side for the U.S. energy system under a set of scenario-specific inputs. Optimal investments across the electric, fuels and carbon management sectors are determined simultaneously, while hourly electricity operations are simulated. Many of the areas targeted by the Energy Earthshots Initiative cross sectors (e.g., H2 produced from electrolysis is a load for the electric sector and a supply source for industrial and transportation fuels), and our modeling approach considers all technology options within the same least-cost optimization. This allows us to evaluate all Energy Earthshots simultaneously and addresses potential limitations from sector-specific models.

We represent the US energy system across 27 geographic regions in line with the U.S. Energy Information Administration's (EIA) National Energy Modeling System (NEMS). Each region characterizes important differences that affect technology deployment, including: (a) renewable resource potential and quality; (b) biomass and geologic sequestration potential; and (c) electric transmission constraints.

As discussed above, we use a single technology or subset of technologies to characterize each Energy Earthshot despite targets generally being technology-agnostic. The technologies used for this analysis are summarized below. Apart from the Industrial Heat Shot, we developed cost and performance trajectories for each technology that achieve the stated DOE cost targets. A comparison of today's cost and performance to the levels needed to reach the 2030/2035 targets on an unsubsidized basis in 2021 dollars are also outlined in the table below. For example, one pathway to achieve the Carbon Negative Shot is to reduce DAC's capital cost by approximately 40% and improve its efficiency by more than 50% by 2030 to reduce its levelized cost of capture to $100/tCO2. Alternatively, we modeled achievement of the Industrial Heat Shot by requiring that at least 85% of industrial heat production comes from representative low-carbon technologies (e.g., hydrogen boiler). We modeled each of the Earthshot trajectories independently (six scenarios), as well as a Combined Shot scenario where all targets are realized.

Energy Earthshot Implementation

Technology Cost and Performance Targets

Energy Earthshot	Technologies	Target Year	Parameter	Today	2030/2035
Hydrogen Shot	Electrolyzer	2030	Capital cost ($/kW-e)	1,400	150
			Efficiency (%)	64%	74%
Long Duration Storage Shot	Electric storage with a 10-hr minimum duration	2030	Installed cost ($/kWh)	440	44
Carbon Negative Shot	Direct air capture	2030	Capital cost ($/ton)	743	460
			Efficiency (MMBtu/ton)	5.9	3.8
Enhanced Geothermal Shot	Enhanced geothermal system	2035	Capital cost ($/kW-e)	19,742	4,000
			Fixed O&M ($/kW-yr)	275	125
Floating Offshore Wind Shot	Floating offshore wind	2035	Capital cost: resource + grid connection ($/kW-e)	5,412	2,380
			Fixed O&M ($/kW-yr)	91	62
			Capacity factor (%)	49%	51%
Industrial Heat Shot	Thermal energy storage, electric boiler, hydrogen boiler, heat pump	2035	Minimum share of heat production from low-carbon technologies	n/a	85%

Source: Evolved Energy Research.

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Under our modeling framework, achieving an Earthshot cost target may reduce energy system emissions, costs, or both. In some instances, realizing a cost target may not reduce emissions, but could lower costs (e.g., economic enhanced geothermal systems displace utility-scale solar and battery storage). Cost savings can accrue in two ways; for example, if 10 GW of floating offshore wind is deployed in the Baseline scenario at $60/MWh and a total of 15 GW is deployed in an Earthshot scenario at $45/MWh then: (1) cost savings of $15/MWh ($60 minus $45) are applied to the initial 10 GW; and (2) the incremental 5 GW deployed avoids other investments at lower cost.

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ENDNOTES

1. This report exclusively focuses on the first six Earthshots DOE announced. On March 24, 2023, DOE announced a seventh shot, the *Clean Fuels and Products Shot* that aims to decarbonize the fuels and chemicals industry. However, as the modeling for this report had already been completed, that Shot is not included in the "combined scenario" presented in this report. However, as the seventh Shot is primarily focused on end-use products, we believe the ultimate emissions impacts are covered by the increased production of e-fuels that achieving the Hydrogen and Carbon Negative Shots bring about.

2. The cost targets established in DOE's Energy Earthshots Initiative are set on unsubsidized basis. Our modeling approach reflects this. For example, our bottom-up, indicative electrolytic hydrogen production cost excludes IRA hydrogen and renewable electricity subsidies. However, IRA tax credits for supply-side energy technologies are reflected in the modeling to determine economic deployment over time.

3. "Energy Earthshots Initiative." Energy.gov, www.energy.gov/policy/energy-earthshots-initiative. Accessed 31 May 2023.

4. Hill, Alice. "What the Historic U.S. Climate Bill Gets Right and Gets Wrong." Council on Foreign Relations, 17 Aug. 2022, www.cfr.org/in-brief/us-climate-bill-inflation-reduction-act-gets-right-wrong-emissions.; Larsen, John, et al. "A Turning Point for US Climate Progress: Assessing the Climate and Clean Energy Provisions in the Inflation Reduction Act." Rhodium Group, 12 Aug. 2022, rhg.com/research/climate-clean-energy-inflation-reduction-act/. Accessed 31 May 2023.

5. Mahajan, Megan, et al. Modeling the Inflation Reduction Act Using the Energy Policy Simulator. Energy Innovation Policy & Technology LLC, Aug. 2022.

6. To characterize Earthshots that do not target specific technologies (e.g., The Enhanced Geothermal Shot specifically applies to enhanced geothermal systems), select technologies were evaluated to characterize the Shot. To capture the benefits of the Hydrogen Shot, we used electrolyzers, and for the Carbon Negative Shot, we used direct air capture systems.