Turbine Design for Eel Passage

IFM Fish Impingement & Entrainment Conference, 11 July 2023

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Natel Energy - turbine design for fish passage

OUR MISSION

Support healthy rivers, promote biodiversity, and decarbonize the grid.

Since 2019, Natel has focused on studying the factors that affect fish survival in turbine passage, and incorporating those learnings into turbine designs.

OUR PRIORITIES

Maximize survival for all fish species, sizes, and life stages that enter turbines.

Accommodate conventional hydro constraints: form factor, power production, manufacturability.

Set a new standard for fish survival through turbine design that promotes biodiversity and fishery management goals.

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Migrating eels are hard to protect from conventional turbines

Compared to other fish species, relatively large eels are able to enter turbine intakes.

Downstream migration occurs at maximum size, and eels may need to pass multiple hydropower facilities to reach the ocean.

Eels tend to follow currents and bulk flows, which pass through generating turbines.

Implementing effective exclusion is difficult on major migration corridors (eg. St. Lawrence River, Canada/USA; River Rhine).

Can turbines be made safe for fish?

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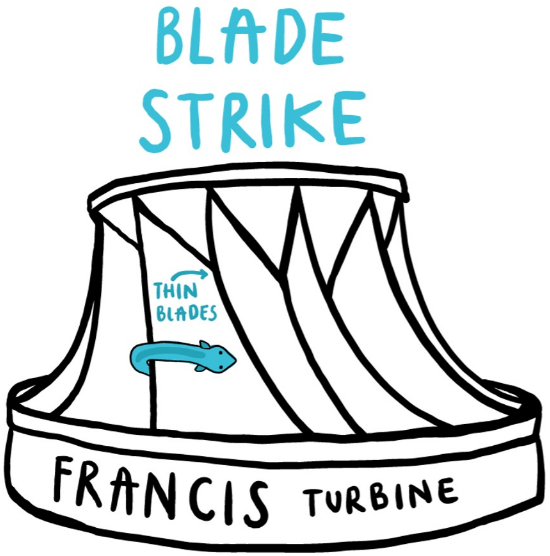
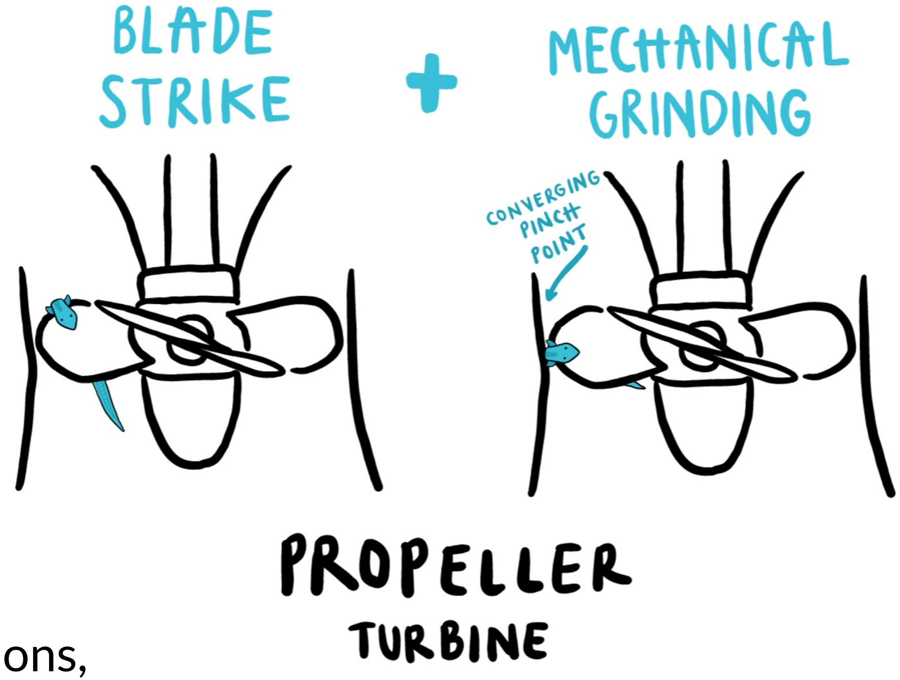
Injury mechanisms for eels

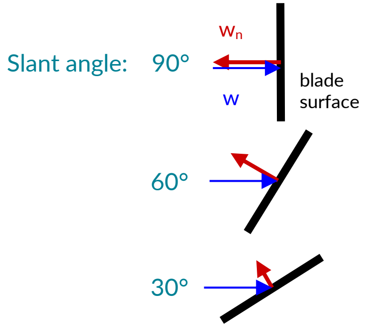




Blade strike: spinal fracture, contusions, lacerations,internal organ damage

Mechanical grinding: severing, laceration

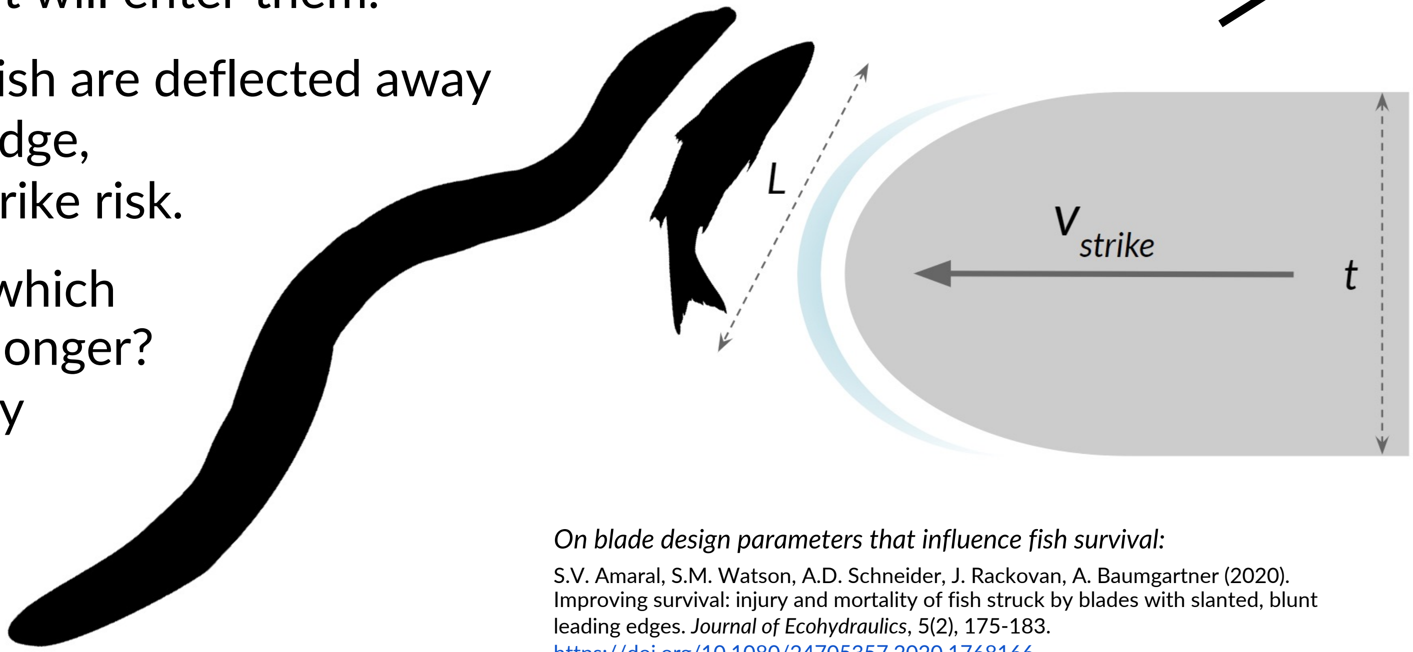
Fish-inclusive runner design



If turbines function as a downstream passage route for fish, they should be safe for all fish that will enter them.

At low *L/t* ratios, fish are deflected away from the leading edge, reducing severe strike risk.

What about eels, which may be 3-5 times longer? What are the injury mechanisms?



On blade design parameters that influence fish survival:

S.V. Amaral, S.M. Watson, A.D. Schneider, J. Rackovan, A. Baumgartner (2020). Improving survival: injury and mortality of fish struck by blades with slanted, blunt leading edges. *Journal of Ecohydraulics*, 5(2), 175-183. https://doi.org/10.1080/24705357.2020.1768166

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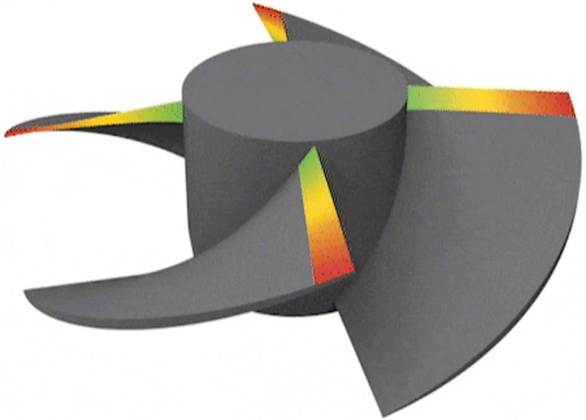
Improving strike survival by design

Thick, slanted blade
Restoration Hydro Turbine (RHT)



Thin, straight blade
Conventional turbine

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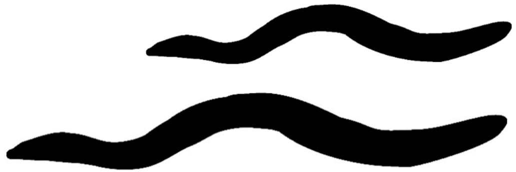
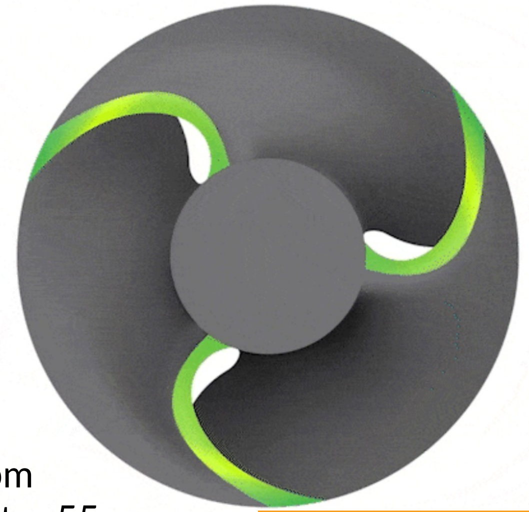
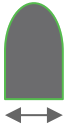
Direct observation of eel passage through RHT



Group 1: 34–51 cm

Group 2: 46–66 cm

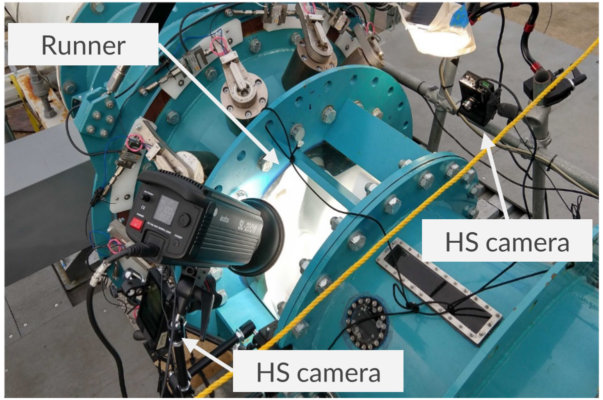




Blade thickness: 5.5 cm

667 rpm
Diameter 55 cm

Tip speed: 19.2 m/s



RESULTS:

Immediate survival:	**100%**
48-hour survival:	**100%**
Immediate injury rate (<5 min gill hemorrhaging):	
Group 1	6%
Group 2	18%

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High-speed video observations

All eels contacted at least one blade.

No entrapment or grinding.

Gill hemorrhaging (< 5 min) was correlated with either:

- direct contact of the gill region with the leading edge of the blade, or
- a “whiplash” style strike to the mid-body, with the gill region contacting the blade pressure surface.

S.M. Watson, A.D. Schneider, L. Santen, K.A. Deters, R. Mueller, B. Pflugrath, J. Stephenson, Z.D. Deng (2022). Safe passage of American Eels through a novel hydropower turbine. *Transactions of the American Fisheries Society*, 151(6), 711-724. https://doi.org/10.1002/tafs.10385

Eel survival varies

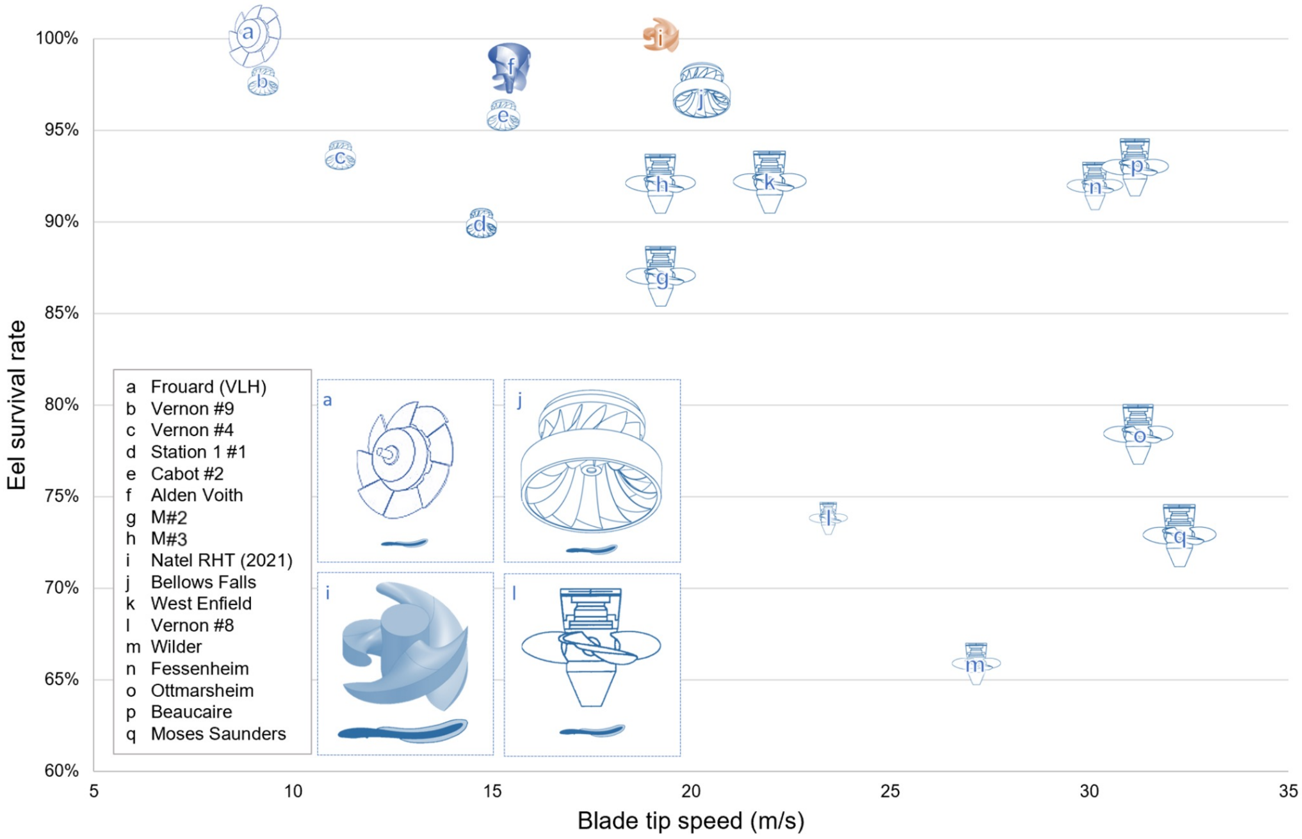
For a given speed condition, size scale and design features influence injury and mortality risk

Sources:

Cook T. C., Hecker G. E., Amaral S.V., Stacy P. S., Lin F., Taft E. P. (2003). – Final report – Pilot scale tests Alden/Concepts NREC Turbine. Report DE-AC07-99ID13733 for U.S. Department of Energy.

Heisey, PG, Mathur, D, Phipps, JL, et al. Passage survival of European and American eels at Francis and propeller turbines. *J Fish Biol*. 2019; 95: 1172– 1183.

Lagarrigue, T., Frey, A. (2010). – Test for evaluating the injuries suffered by downstream-migrating eels in their transiting through the new spherical discharge ring VLH turbogenerator unit installed on the Moselle River in Frouard. E.CO.G.E.A. report for MJ2 Technologies.



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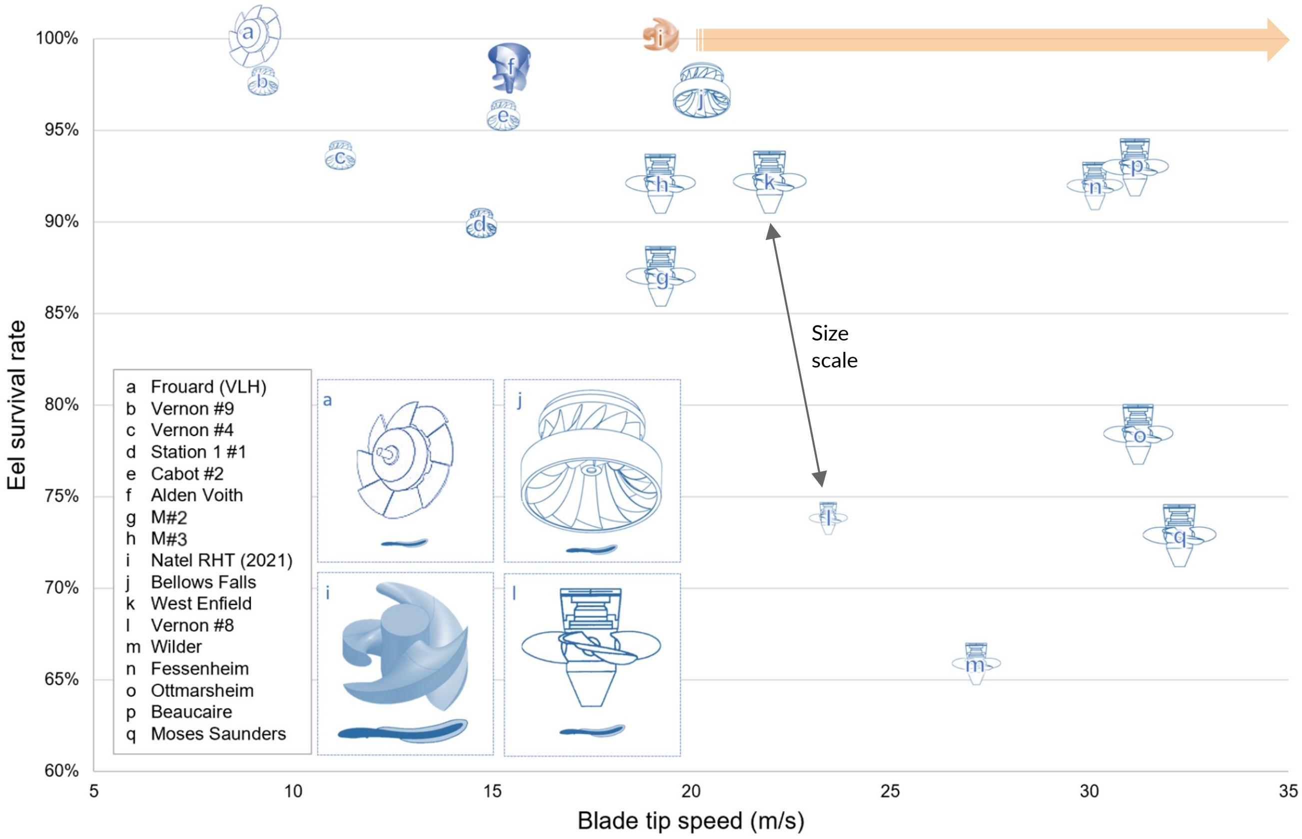

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What's next?

Innovative turbine design for eel passage has enabled 100% survival of eels up to:

- 19.2 m/s tip speeds (for example, 122 rpm for a 3m dia turbine)
- 66 cm eel length, at extreme proportional size
- *L/t* = 12

Continue to expand and define these boundaries to encompass as much of the hydropower fleet as possible.

Remaining questions:

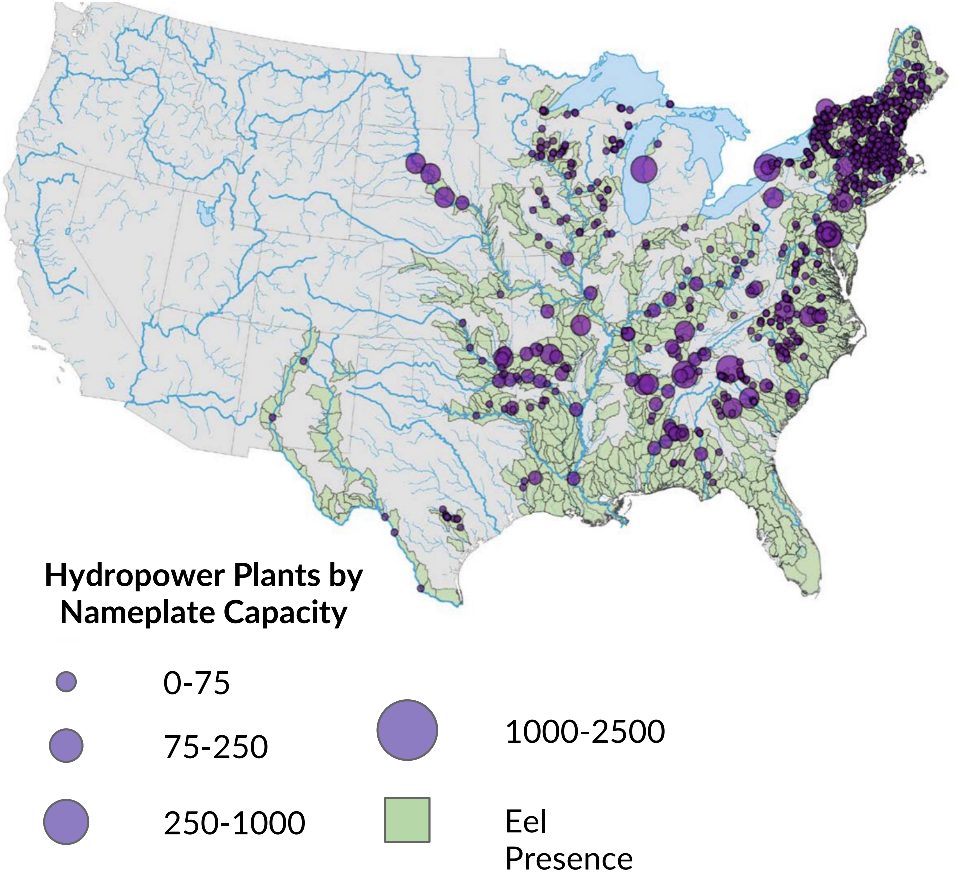
- *How do larger eels pass through larger turbines designed for eel passage?*
- *How do we deterministically design turbines for safe eel passage?*

Implementation & concluding thoughts

In the United States and Europe, the aging hydropower fleet is currently undergoing equipment upgrades and turbine replacements.

Direct runner replacement with innovative eel-safe designs could increase turbine passage survival to 98-100% at sites that currently kill 5-35% of eels.

Implications for migratory success should be studied…expedite passage, compare migratory behavior to baselines, implement best available technology.



H. I. Jager B. Elrod, N. Samu, R. A. McManamay, and B. T. Smith (2013). ESA Protection for the American Eel: Implications for U.S. Hydropower. ORNL/TM-2013/361. https://info.ornl.gov/sites/publications/Files/Pub45569.pdf

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Thank you!

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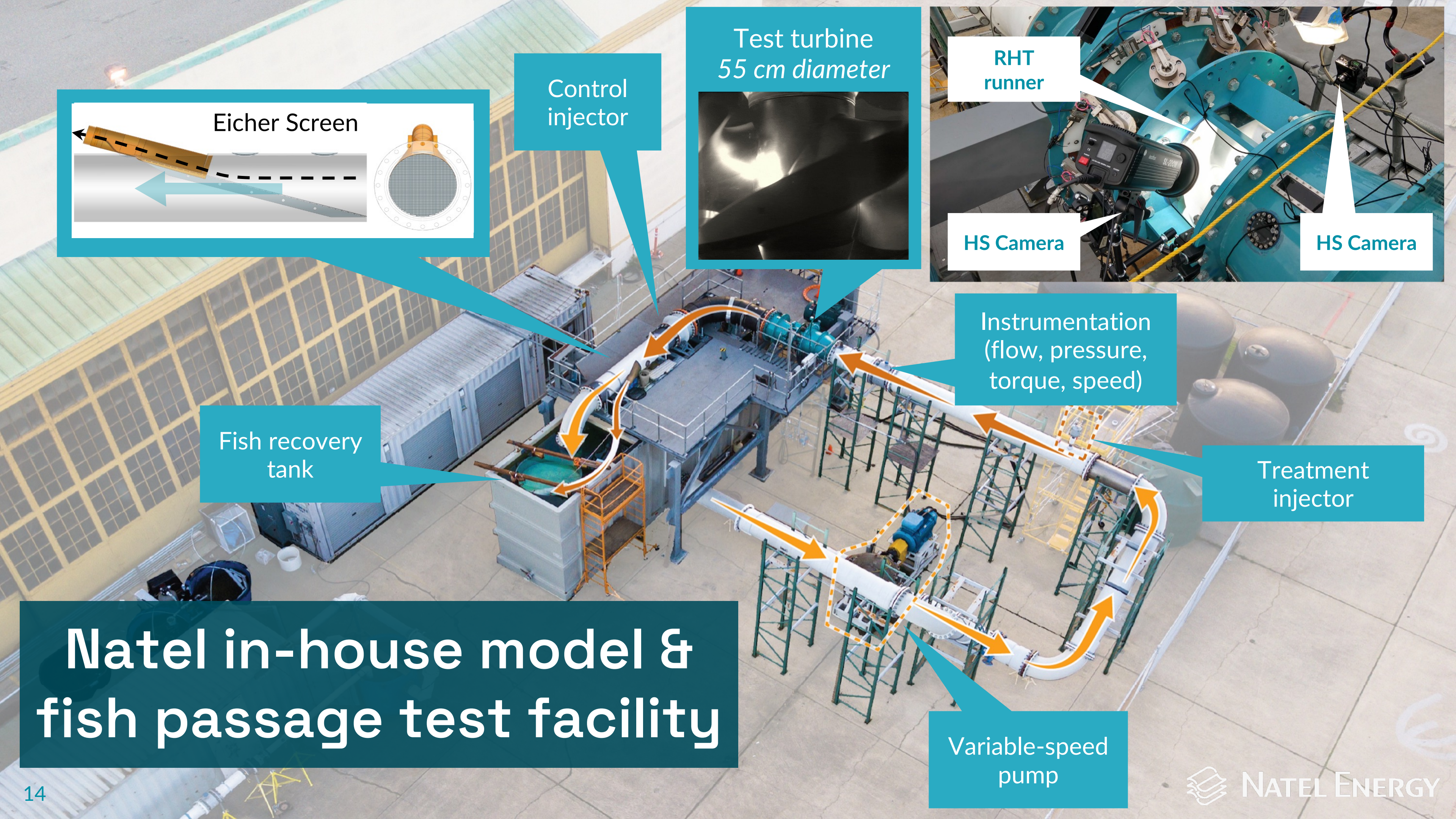
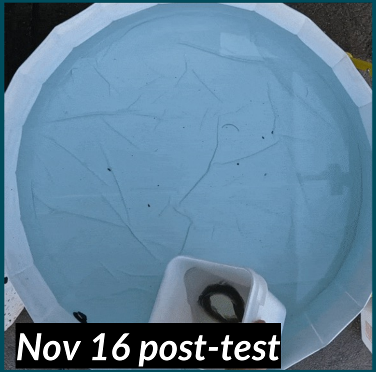
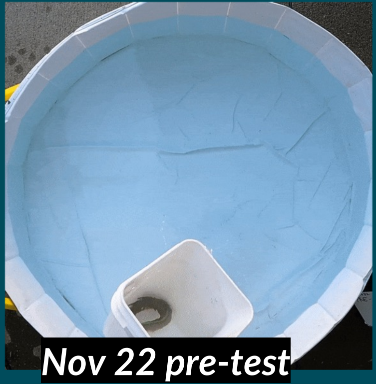
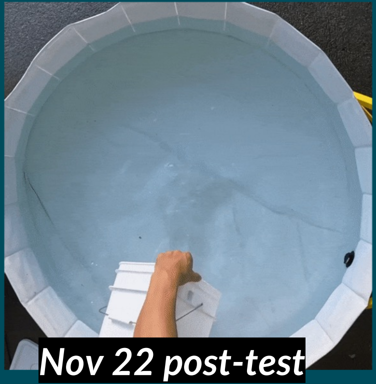
Natel in-house model & fish passage test facility



Sublethal effects, repeat passages







100% survival after 7-day hold for eels passed **twice** through the RHT.

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