Restoration is (already) happening

(left) Natural 2 meter tall beaver dam; (right) beaver dam analogue (BDA)

(left) Natural stream-spanning log jam; (right) engineered log jam (ELJ)

(left) Dolo-timber revetment structure deployed by crane; (right) detail of dolo-timber assembly Foundation module

Construction details for foundation of dolotimber water passage module.

(left) Boise River Park; (right) Hartland River Dam removal and river restoration project

Methods for transporting, integrating and assembling modules

(left): 7.2 metric ton dolos on flatbed trailer; (right) 4000 mm VLH in parts on trailer
Restoration Hydro: a vision for nature-based distributed hydro

- Turbine-generator Module
- Foundation Module and Passage Module: dolo-timber
- Foundation Module for turbine generator
- Water, Sediment, Fish, and Recreation Passage Module: natural rock arch passage
Restoration Hydro...

... applies in both greenfield as well as brownfield applications.

**Greenfield (new infrastructure; undammed reaches)**

River Restoration and/or Recreation projects with integrated low head power production.

**Brownfield (existing infrastructure)**

Dam removal (retrofit with nature-based drop structure); retrofit of old turbines with fish-safe turbines.
Conventional turbine design landscape: any room for innovation?

Most new hydro potential at <10 m head. Increasingly, fish passage + civil works cost is important.

High speed, small turbines, long draft tube, cavitation requires submergence, kills fish.

Fish exclusion adds cost, complexity, and head loss. Long draft tubes and submergence add civil works cost.
Raising the “speed limit” for 100% safe fish passage

Conventional: (thin blades, fish die)

Fish friendly: (thick blades, fish live)

Fish strike data and images from ALDEN Lab.
*Slanted blunt blade data preliminary and indicative only.
Modern design, for modern design constraints
fish safe, high efficiency, low civil works cost

Medium speed, low blade count
High efficiency, short draft tube
Fish safe, simple operation

\[ \sigma = \frac{2N \sqrt{\pi \dot{V}}}{(2gH)^{3/4}} \]
Fish safe, world-class performance

$\eta_{\text{hyd}}$ 0.91
$\eta_{\text{gross}}$ 0.89

Good part-load efficiency curve
Well-distributed suction pressures
Overspeed ratio ~ 2:1
Draft tube area ratio 2:1
Vertical Saxo RHT → economical at 6 m-10 m head

- Very compact powerhouse, while meeting stability requirements even on soil foundations.
- Simple concrete forms; limited draft tube and low tailworks construction effort.
- Turbine above tailwater, simplifies operation and maintenance.
- Vertical orientation increases turbine safety factors and reduces operation and maintenance cost.
- Plant can utilize either direct-drive or geared generators, depending on customer needs.
  - Overspeed ratio < 2:1 allows inexpensive generator construction.
- At fish-sensitive locations, Saxo RHT provides exceptional value to customer.
Pit RHT → economical for 3 m to 10 m head

- Efficient flow path
- Simple concrete forms; limited draft tube and low tailworks construction effort.
- Draft tube can be in-line (very low head), or at end of elbow, allowing turbine to operate above tailwater
- Easy access to gearbox and generator reduces cost, simplifies operation and maintenance compared to bulb turbine
- Plant can utilize either direct-drive or geared generators, depending on customer needs.
  - Overspeed ratio < 2:1 allows inexpensive generator construction.
- At fish-sensitive locations, RHT provides exceptional value to customer by eliminating fish exclusion requirements
Open-Flume RHT → Simple operations at 3 m-7 m for retrofits or new build

Self cleaning horizontal screen with integrated head control gate

Simple TG units: on/off flow control, 1 moving part

Completely dewater the module with built in upstream vertical slide gate and draft outlet gate
Validation: hydraulic scale model test

- Performance tests by Rennasonic, Inc. June 2019
- 80 kW, $\varnothing$ 0.55 m, $H_{\text{net}}$ 10 m
- $\eta_{\text{hydraulic}} \sim 90.5\%$ (met expectation)
- Experimental uncertainty $< 0.5\%$
- Exceeded expectation at some off-design conditions
Fish friendly + cavitation resistant = cost savings

$/kW low head (7m) side by side comparison

Common costs include intake, trash rack, spillway, interconnection, switchgear, engineering, permitting.

Some exclusion measures can be 3-10x more expensive than the values shown here.
What’s next?

Product development 2019-2020:

<table>
<thead>
<tr>
<th>RHT Model</th>
<th>Runner Dia (m)</th>
<th>Rated Pwr (kW)</th>
<th>Max Flow (cms)</th>
<th>Release</th>
<th>Planned Installs</th>
</tr>
</thead>
<tbody>
<tr>
<td>D55</td>
<td>0.55</td>
<td>80 @ 10m</td>
<td>.93</td>
<td>FY2019</td>
<td>Purpose: Small-scale pilot projects. Q4 2019: first field installation</td>
</tr>
<tr>
<td>D190</td>
<td>1.9</td>
<td>1,025 @ 10m</td>
<td>15.6</td>
<td>FY2020</td>
<td>First Commercial Release unit Q2 2020: first field installation</td>
</tr>
</tbody>
</table>

Natel Energy is actively marketing the Restoration Hydro Turbine for deployment in projects starting in 2020.

The first deployment of a utility-scale RHT will be in Oregon, at the Monroe Drop Hydro Project near Madras.
First large-scale RHT installation: Madras, OR

300 kW, 4.5 m head, Ø1.9 m.
3 m elevation over tailwater!
Originally developed in 2015 to demo linear turbine.
Retrofit complete ~Q2 2020.
Thank you!
Monroe Hydro Project (Redmond, OR)

- Apr 2012: Negotiated Power Sales Agreement with PacifiCorp
- Apr 2013: Execute interconnection agreement with PacifiCorp
- Aug 2014: FERC issued Conduit Exemption Order for Monroe Drop
- Dec 2014: December 2014 Apple purchased Monroe Hydro & groundbreaking
- May 2015: Monroe Hydro commissioned with SLH100
- Nov 2018: RHT concept development begins
- Jan 2019: SLH100 removed from Monroe powerhouse
- June 2020: Commissioned RHT D190 at Monroe
- June-Aug 2019: RHT scale model, fish passage testing
Monroe Hydro: Lessons Learned

Design & Engineering
- CFD
- Guidevanes
- Materials & corrosion
- Experienced Contractors
- Bull nose
- Trashrack

Permitting & Agencies
- Start early
- Ask questions
- Know costs

Plant Operations
- Excessive canal weeds
- Frequent grid rejections