

Remediation of Baltic anoxia with pure oxygen gas:

Lessons learned from hypolimnetic oxygenation in the
USA and design response to scale of the Baltic

David Austin

Professional Engineer

Senior Ecologist

Jacobs Engineering Group



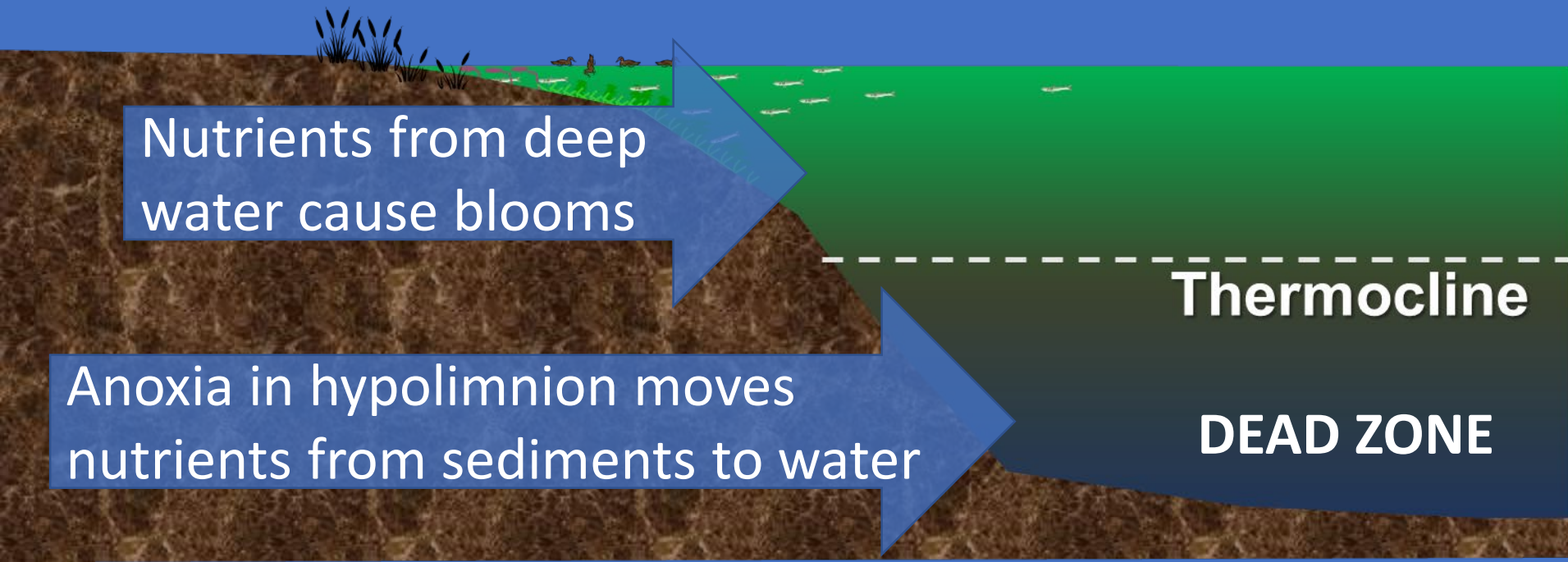
Outline

- Reservoir oxygenation in USA
- Application to Baltic scale

Problem: Anoxia in drinking water reservoirs is similar to Baltic

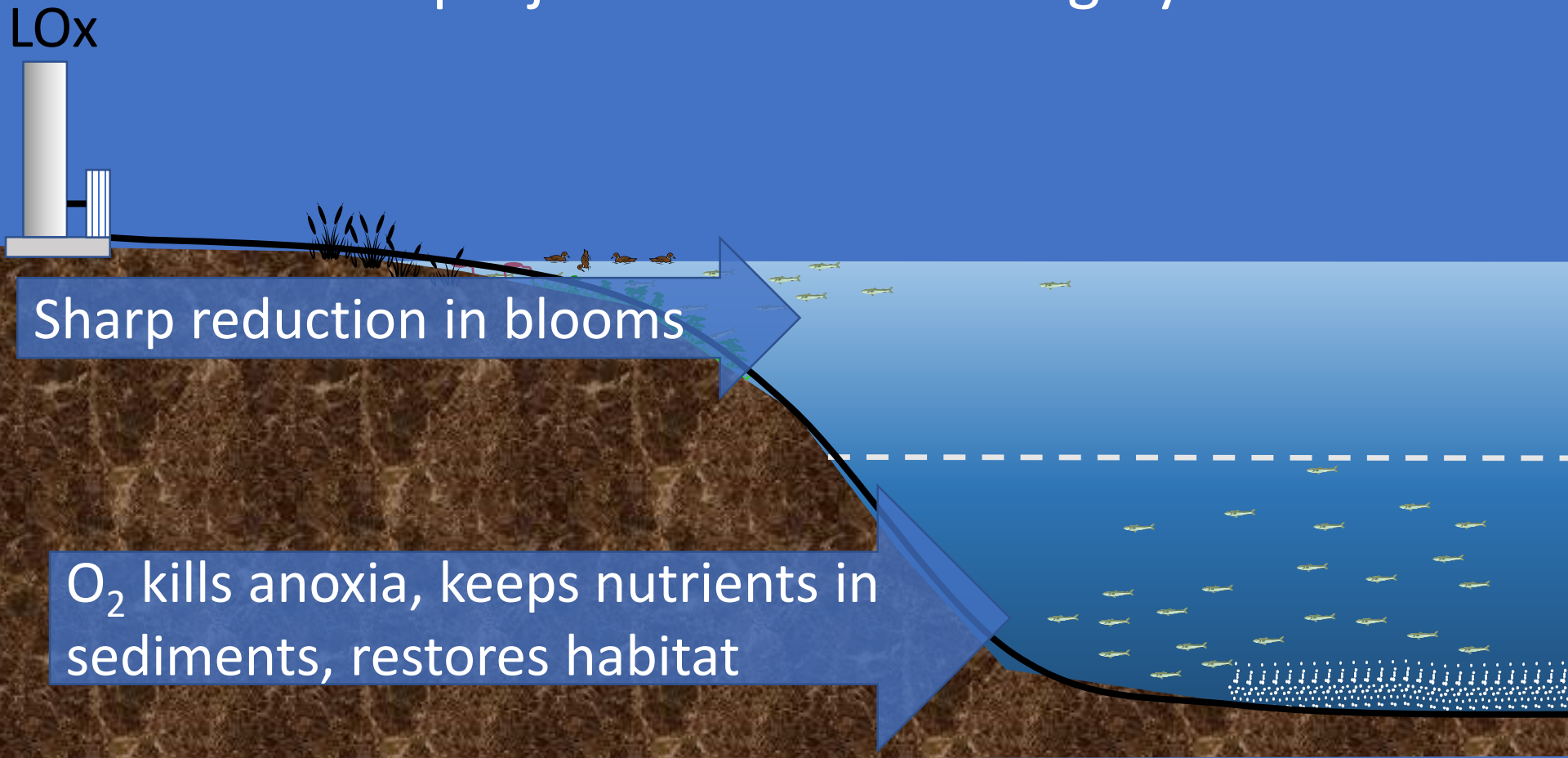
Epilimnion: warm, high DO from atmosphere & photosynthesis

Hypolimnion: cool/cold, stagnant, DO depleted by sediments



Fixing the problem

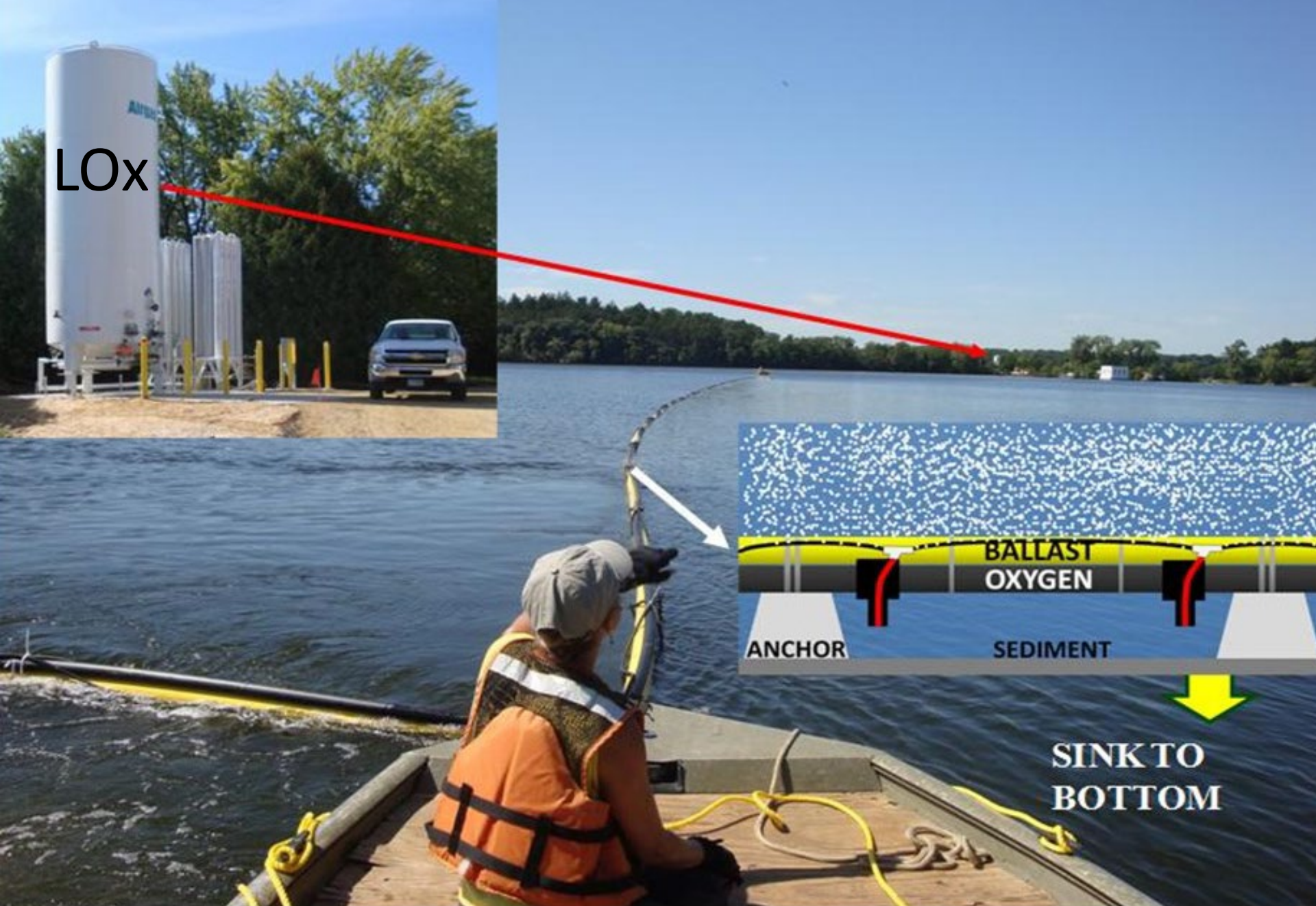
- Inject O_2 into hypolimnion (deepest part)
- 45 projects in USA – All highly successful



Why pure oxygen and not air?

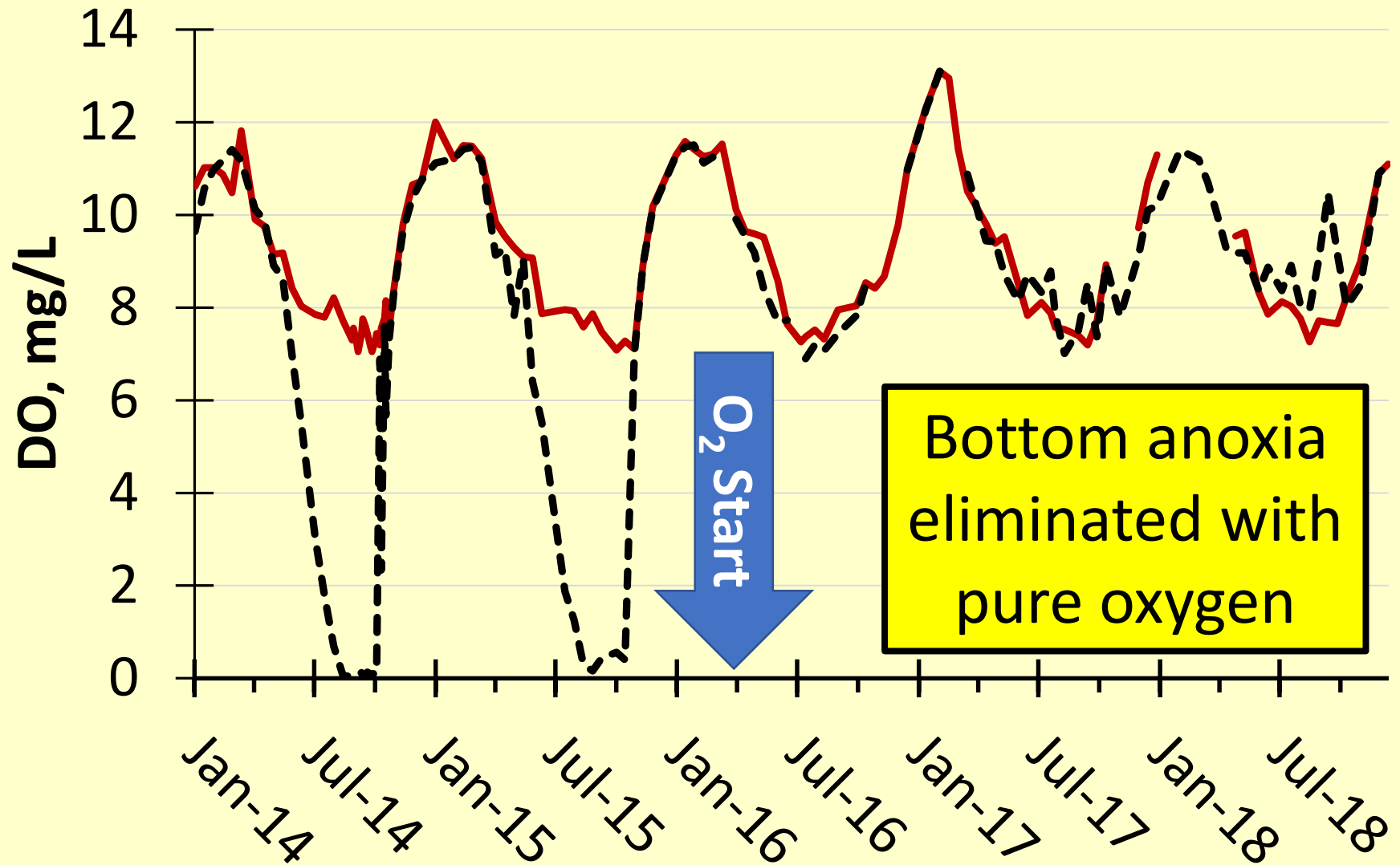
- Five times better oxygen transfer than air
- O_2 bubbles shrink as they rise → low induced currents
- Low currents critical to eliminating hypoxia
- Deep air injection no chance of success in the Baltic

Hypolimnetic oxygenation – deep oxygen injection

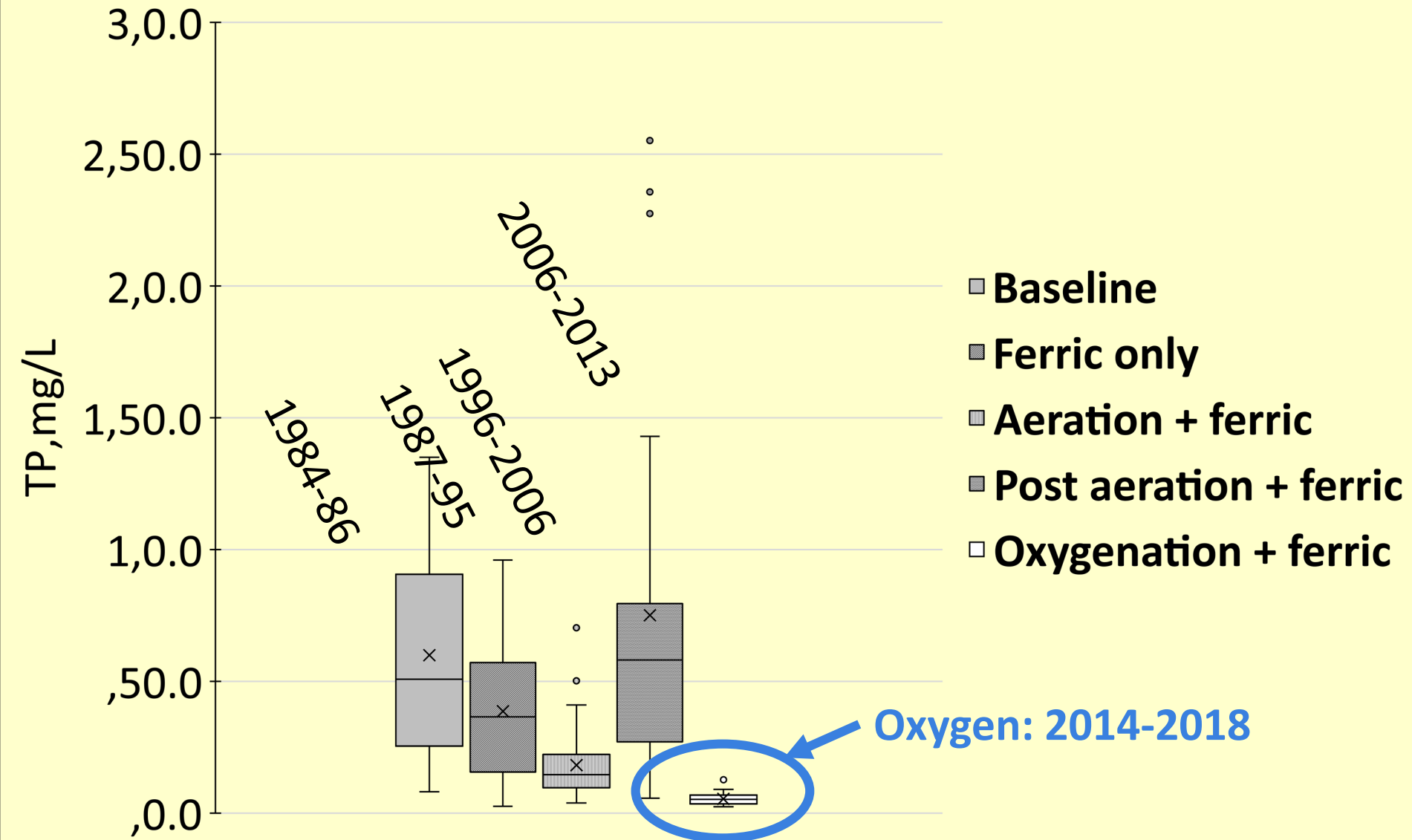


Deep oxygen injection: Aurora Reservoir, Colorado

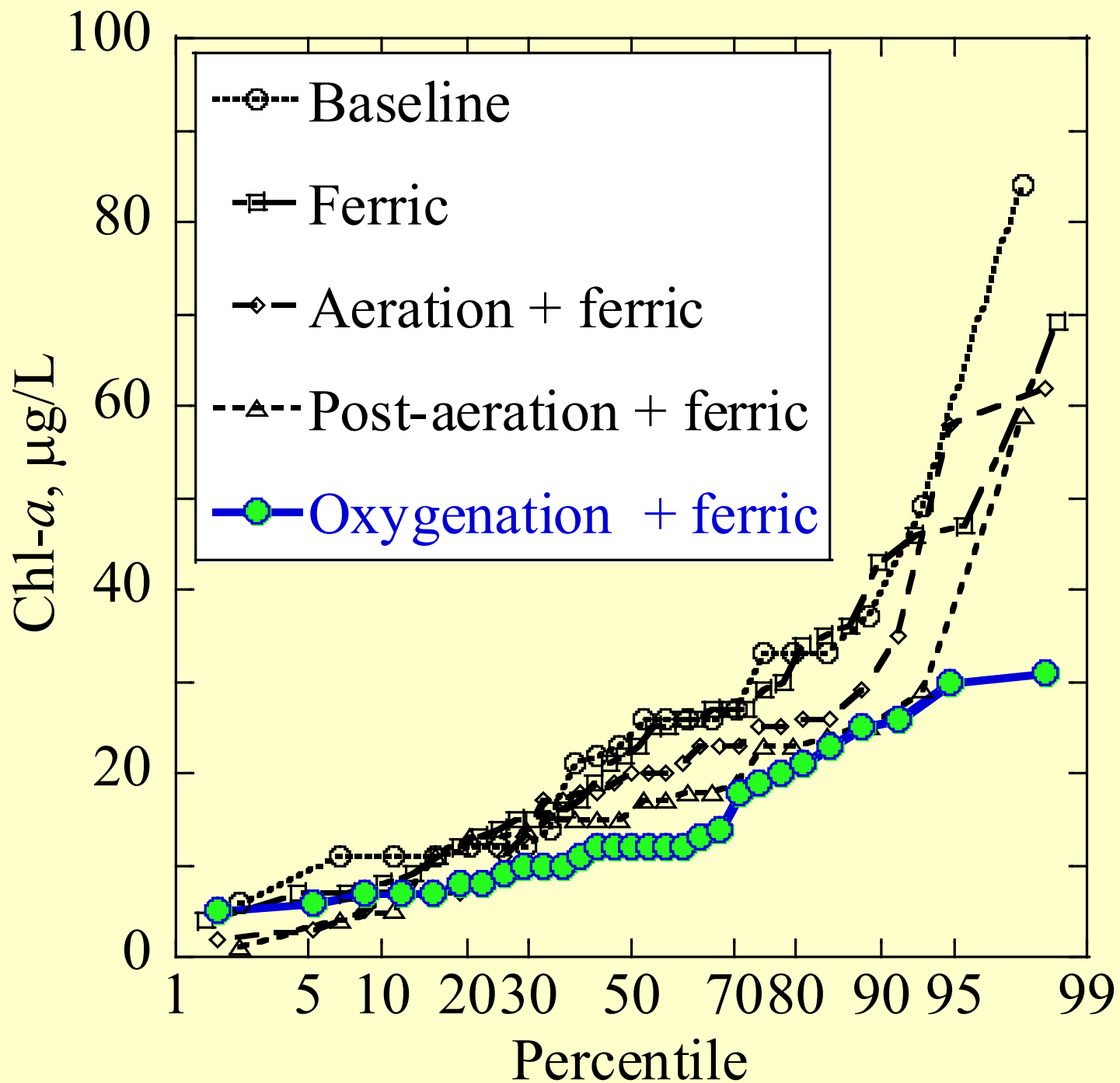
— DO Surface (1 m) -- DO Bottom (24 m)



Pleasant Lake, Minnesota: Hypolimnion Total Phosphorus



Pleasant Lake,
chlorophyll-*a*
(algae)

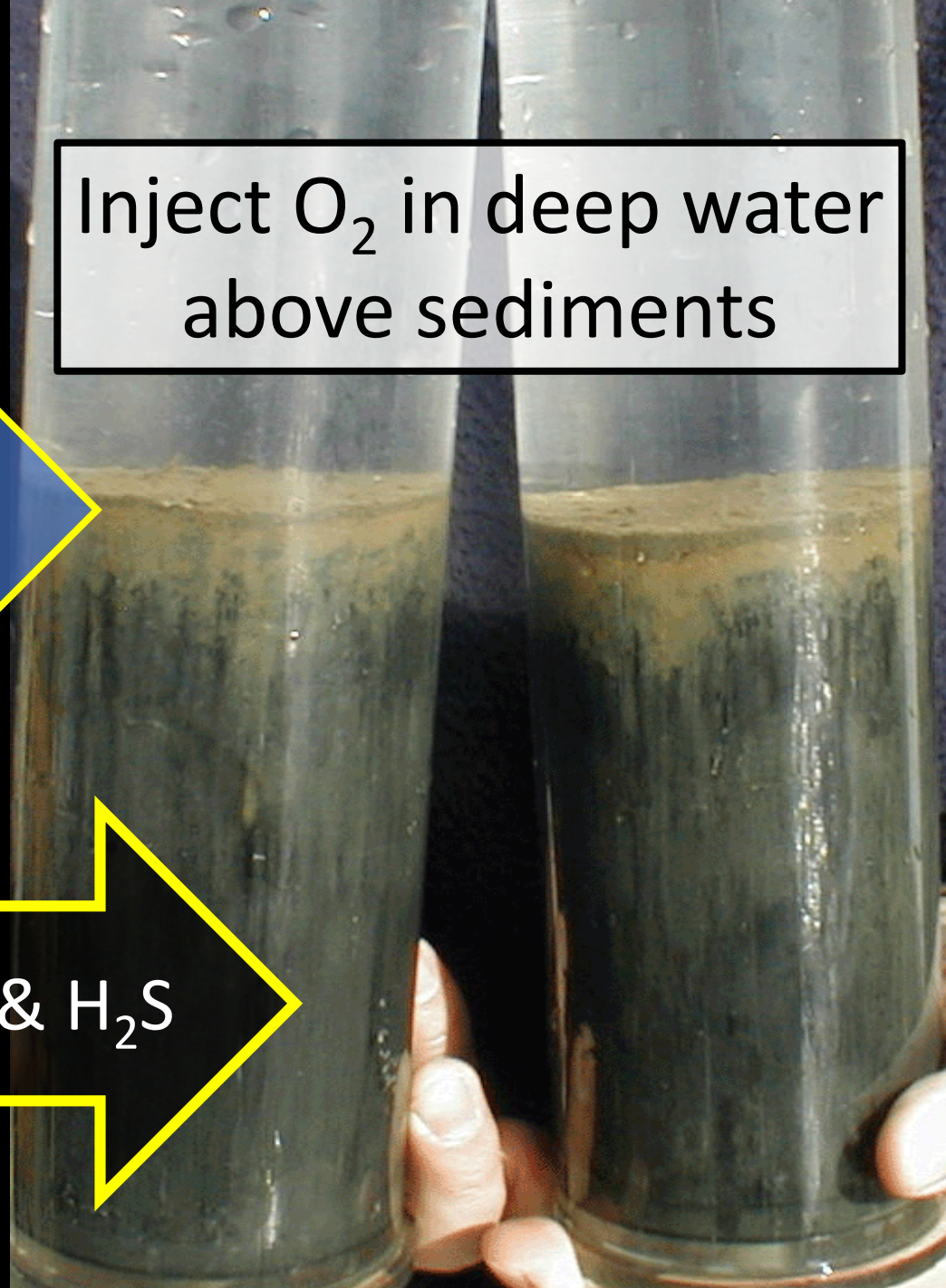


Mechanism

Inject O_2 in deep water
above sediments

To create ferric iron cap

To entomb phosphorus & H_2S

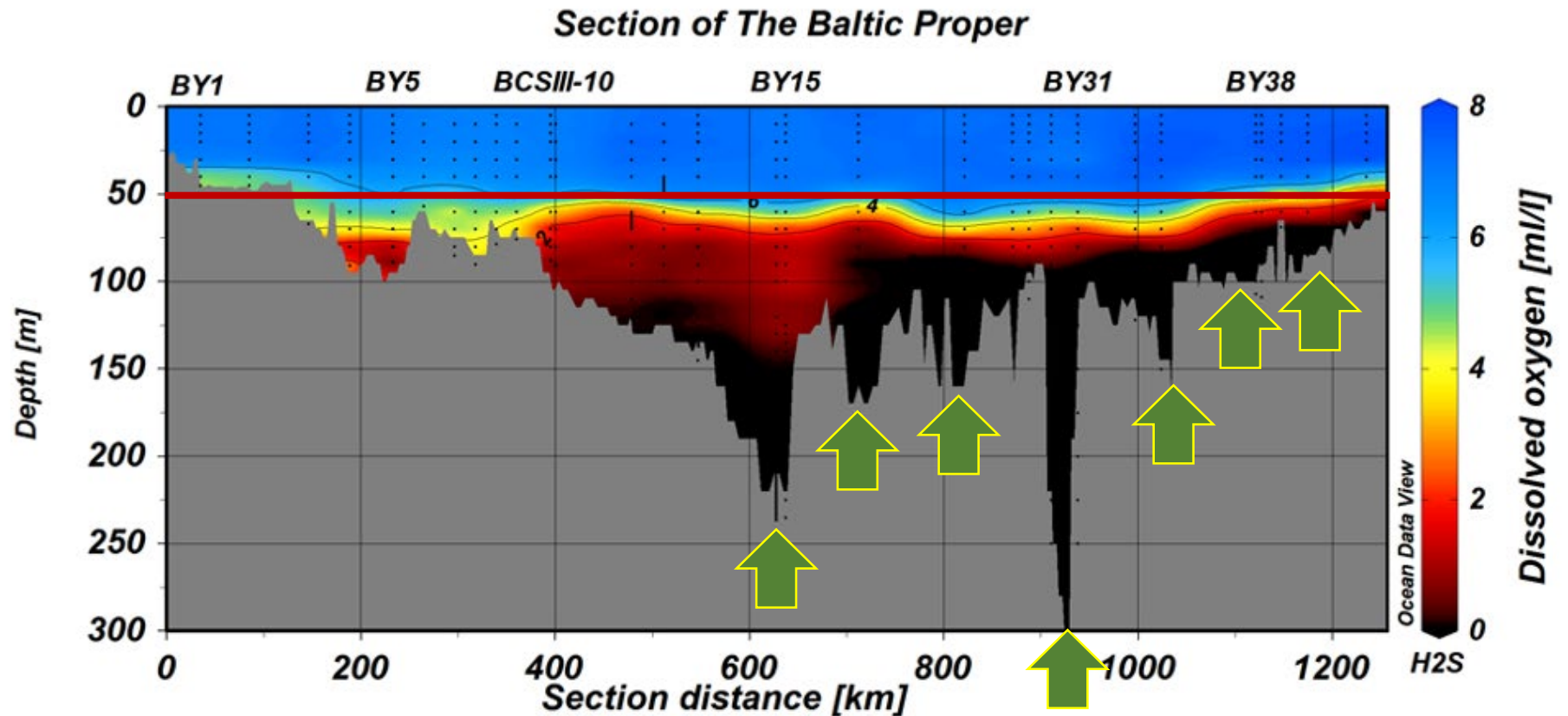


Reservoirs vs. The Baltic Sea

- **Reservoirs:** seasonal thermal stratification (epilimnion, hypolimnion)
- Baltic: seasonal stratification plus permanent saline stratification
- **Reservoirs:** hypolimnetic deep O₂ injection in the spring-fall
- Baltic: continuous deep O₂ injection in halocline (deepest sub-basins)
- **Reservoirs:** Mature O₂ injection technology at 1-10% Baltic design scale

Scaling up to the Baltic Sea

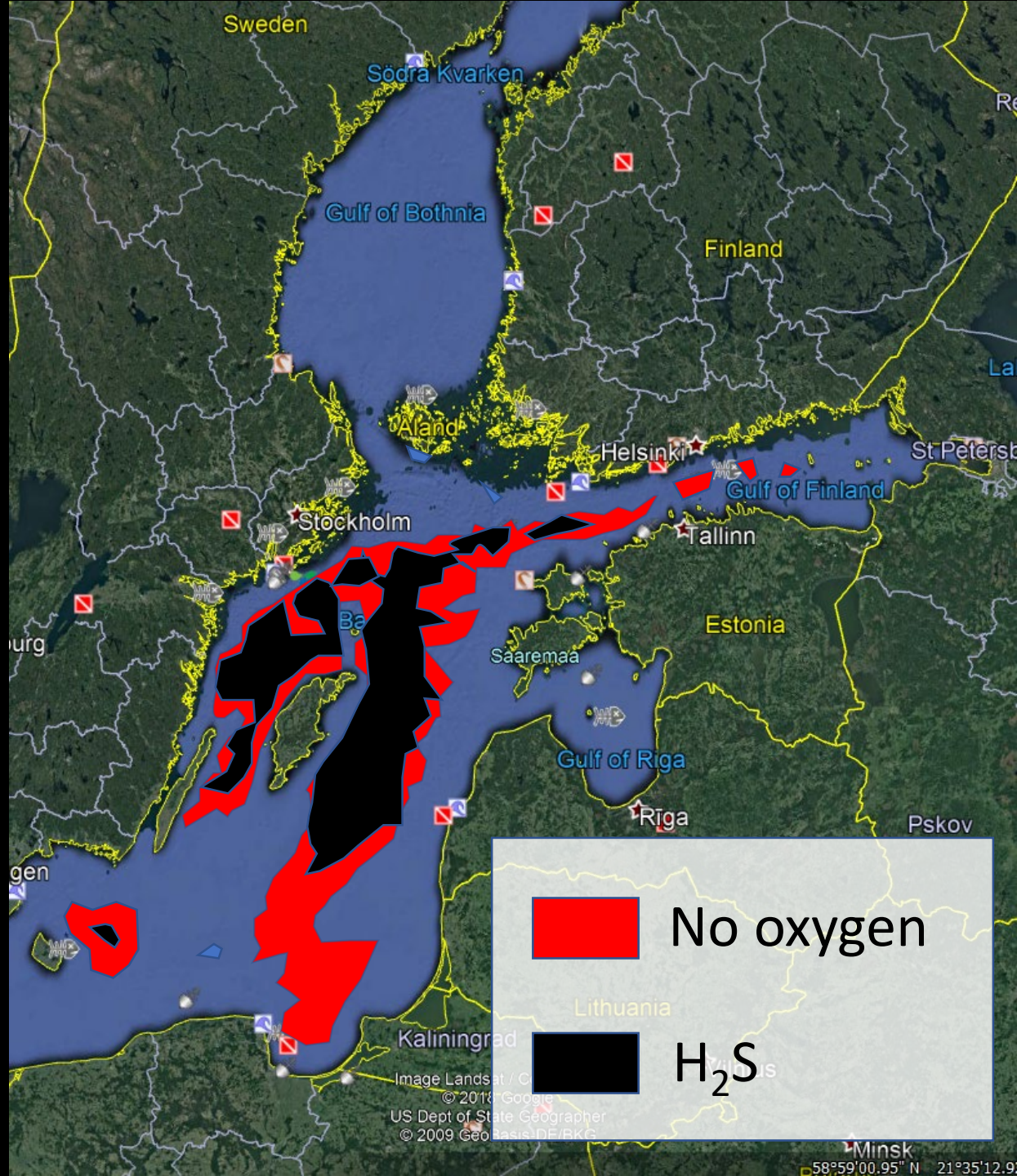
Standard engineering methods meet pressure requirements



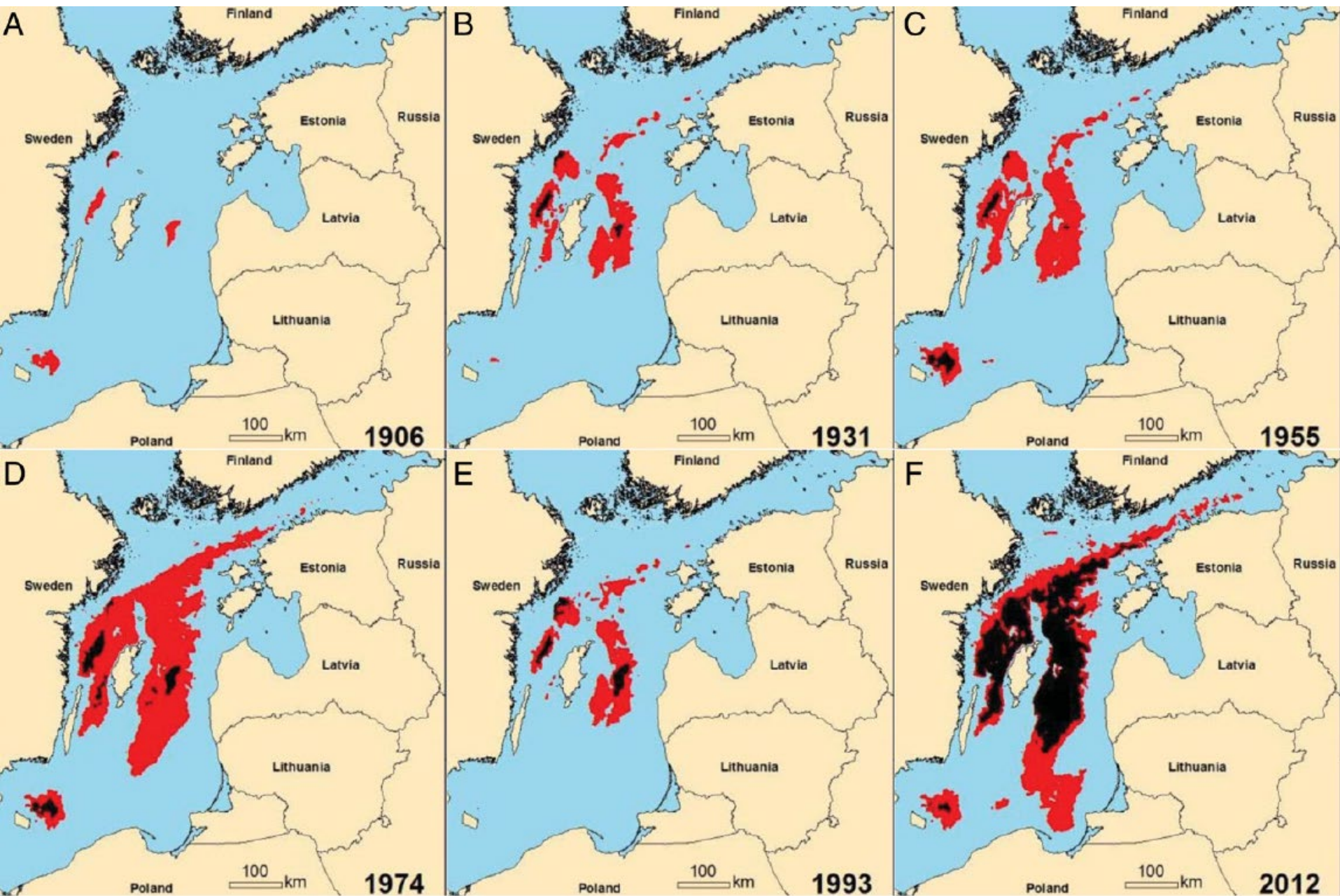
Inject pure oxygen gas in deeps

Baltic Anoxia

- Kill H_2S first
- Restore deep O_2



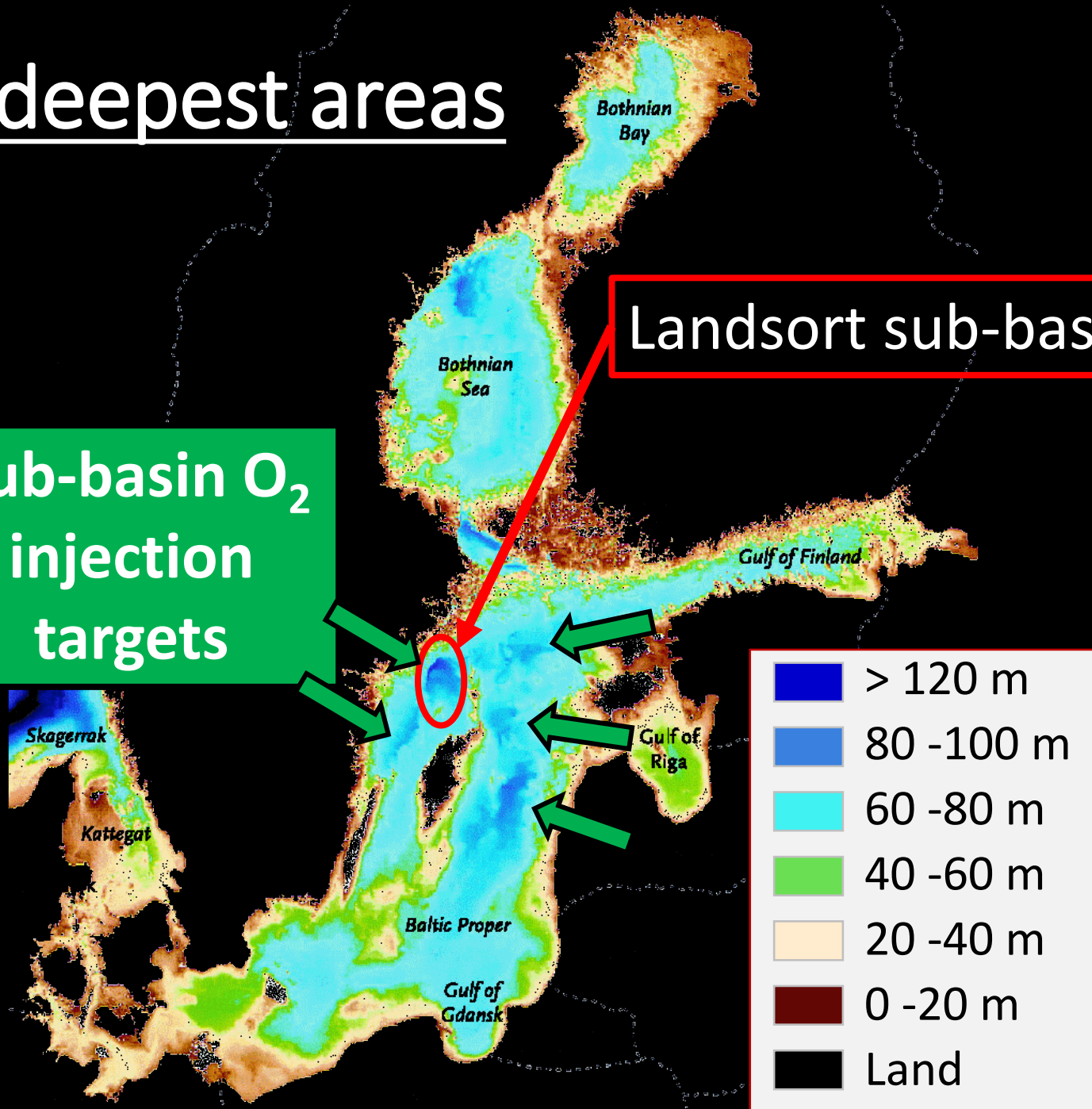
Historic anoxic progression from deeps



Target deepest areas

Sub-basin O₂
injection
targets

Landsort sub-basin



Scale

Ruler

Line Path Polygon Circle 3D path 3D polygon

Measure the distance or area of a geometric shape on the ground

Perimeter: 179.63 Kilometers

Area: 2,165,150,633.98 Square Meters

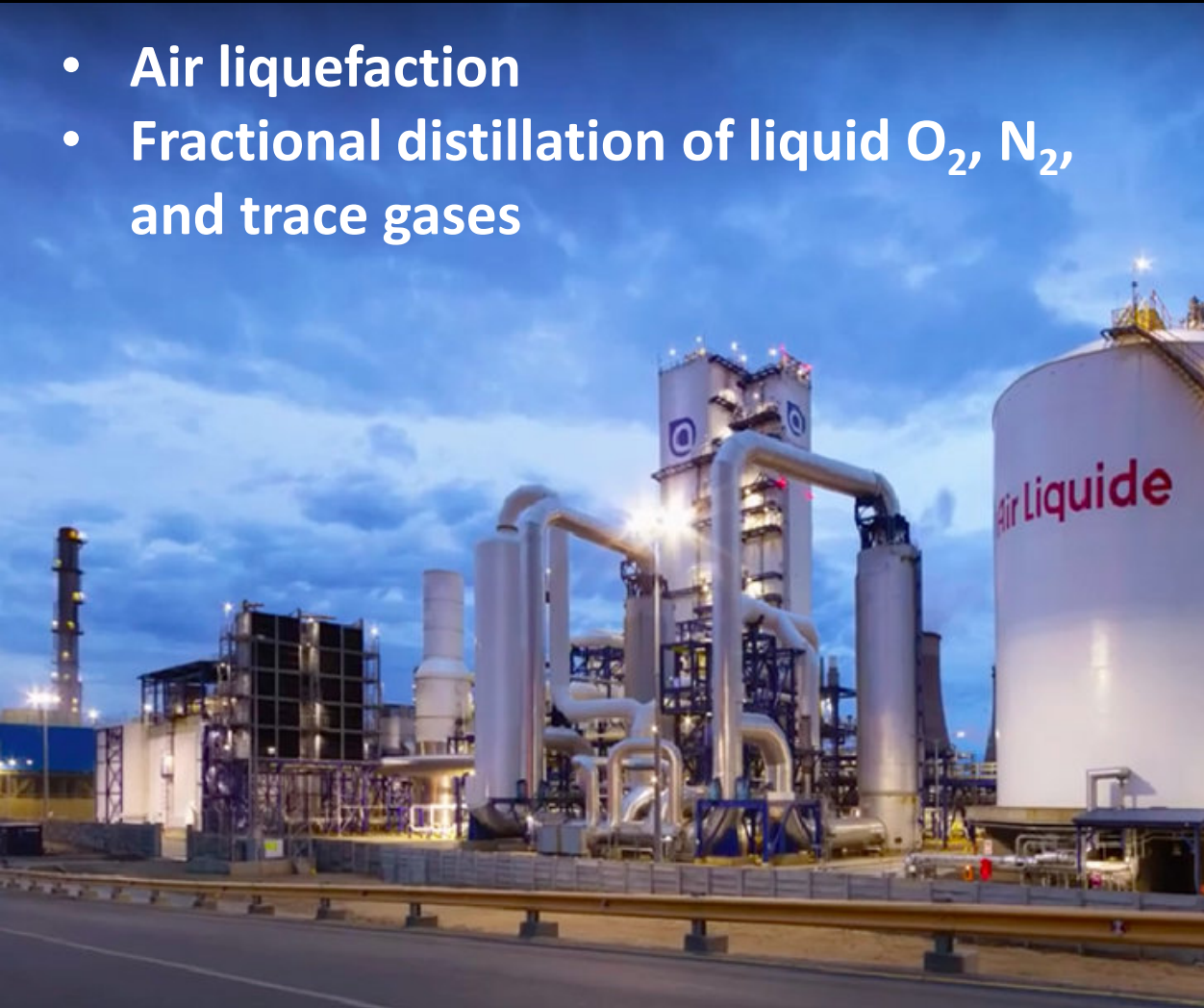
☒ Mouse Navigation Save Clear

Baltic Sea

- Landsort deep depression
- ~5,000 tons O₂/d

What does 5,000 tons O₂/d production look like?

- Air liquefaction
- Fractional distillation of liquid O₂, N₂, and trace gases



Over
5,000
tons¹

of oxygen
per day

Air Liquide DBOO (€200M) for Sasol, SA

¹ Equivalent to 5,800 tons per day at sea level.

Two months supply of O_2 at 5,000 tons/d



Cryogenic fluid carrier similar to LNG carrier
LOX carrier a bespoke design, however, not LNG conversion

Swedish expertise



Cryogenic expertise in Sweden:

- Swedegas
- Trelleborg
- Others

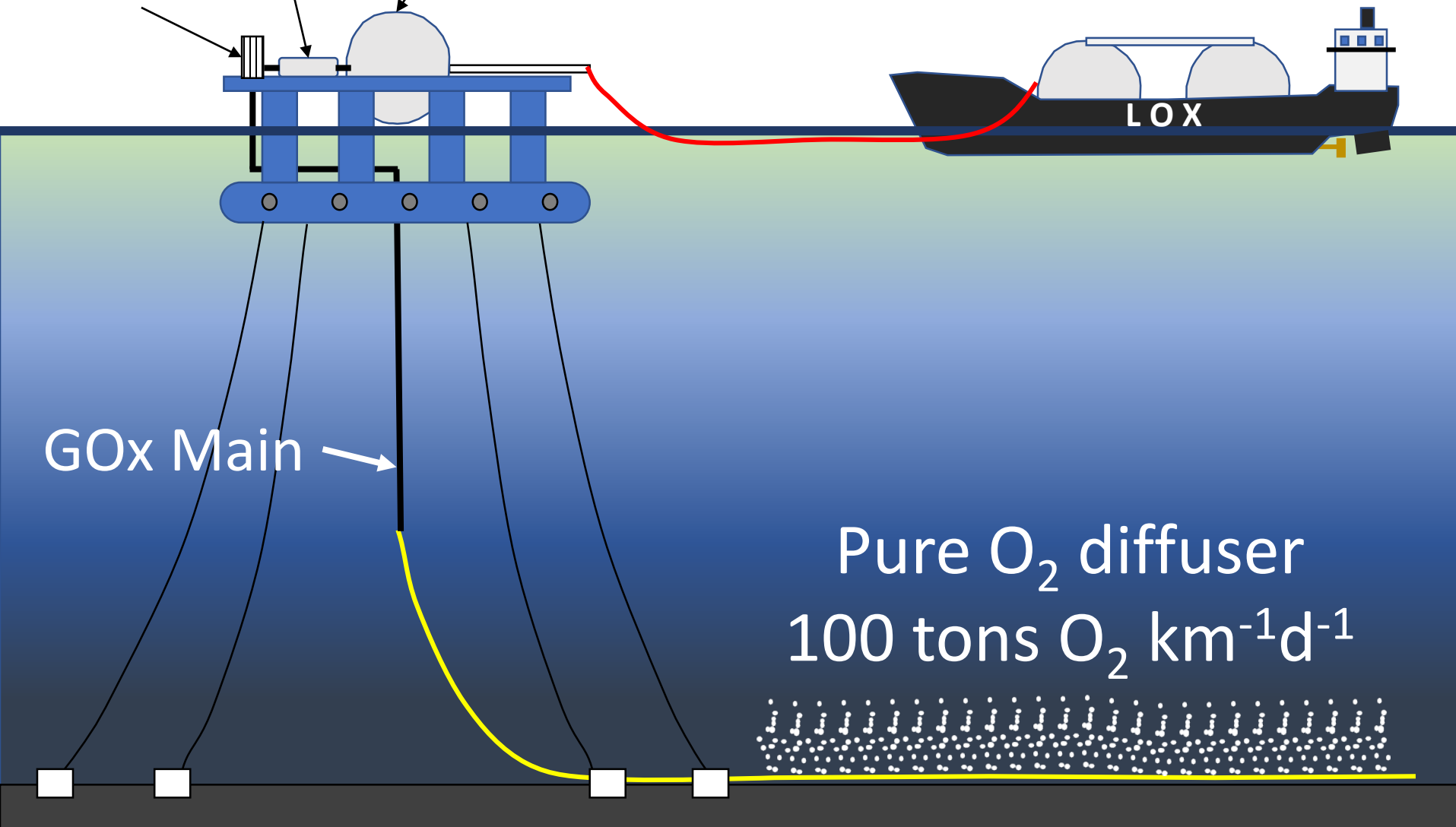
Pictures: Trelleborg

HP supply LOx

LP storage LOx

Vaporizer

LOx replenishment



GOx Main

Pure O₂ diffuser
100 tons O₂ km⁻¹d⁻¹

Infrastructure and opportunity

- Capital infrastructure of Baltic O₂
 - **Production** (land-based air liquefaction and separation)
 - **Distribution** (marine logistics)
 - **Dosing** (marine platform or land)
- Economic opportunity:

Integrate LOx production with grid batteries

Why Grid Batteries?

Renewable Energy Curtailment

- Curtailment: energy available **but** unused
 - ✓ Grid capacity limits
 - ✓ **Lack of storage** to match demand & production variability
- Impact: ~€1B German curtailment payouts in 2020





Curtailed



LOx



Liquid
nitrogen
grid
battery

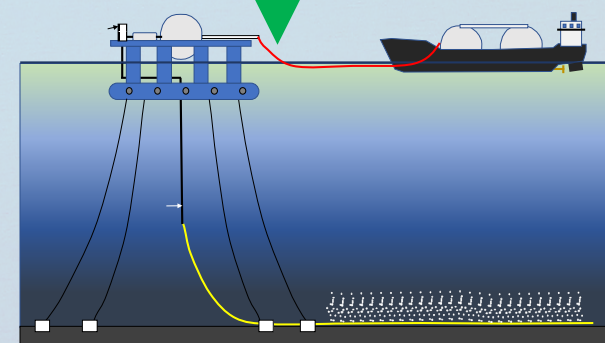


Up to 45%
energy
return on
LOx
production

Turbine
generator



GAS ← LIQUID





Curtailed

Electrolysis

→ O₂ →

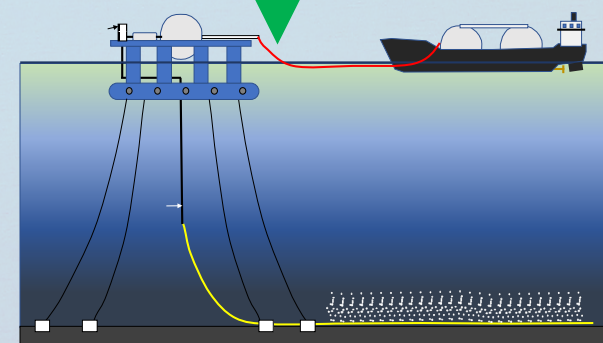


LOx



H₂

**HYDROGEN
ECONOMY
ENERGY
RECOVERY**



Note:

- **Cryogenic grid batteries design-ready**
- **H₂ production currently small scale**

Conclusions

- **Technical outcome of deep oxygen injection is certain:**
 - ❑ Eliminate anoxia in Baltic deeps
 - ❑ Strongly suppress internal nutrient loading
 - ❑ Reduce magnitude, frequency, and duration of blooms
- **Scale unprecedented, but feasible and practical:**
 - ❑ Entails large program integrating mature industrial sectors, scientific community, and ecology of Baltic
 - ❑ Integration with renewable energy sector may be critical to economic viability

Some philosophy



Making is knowing and
knowing is making

- Francis Bacon, 1561-1626



Those who are supposed to
know but do not act simply
do not yet know

- Wang Yangming, 1472-1529

Thank you.
Questions?

