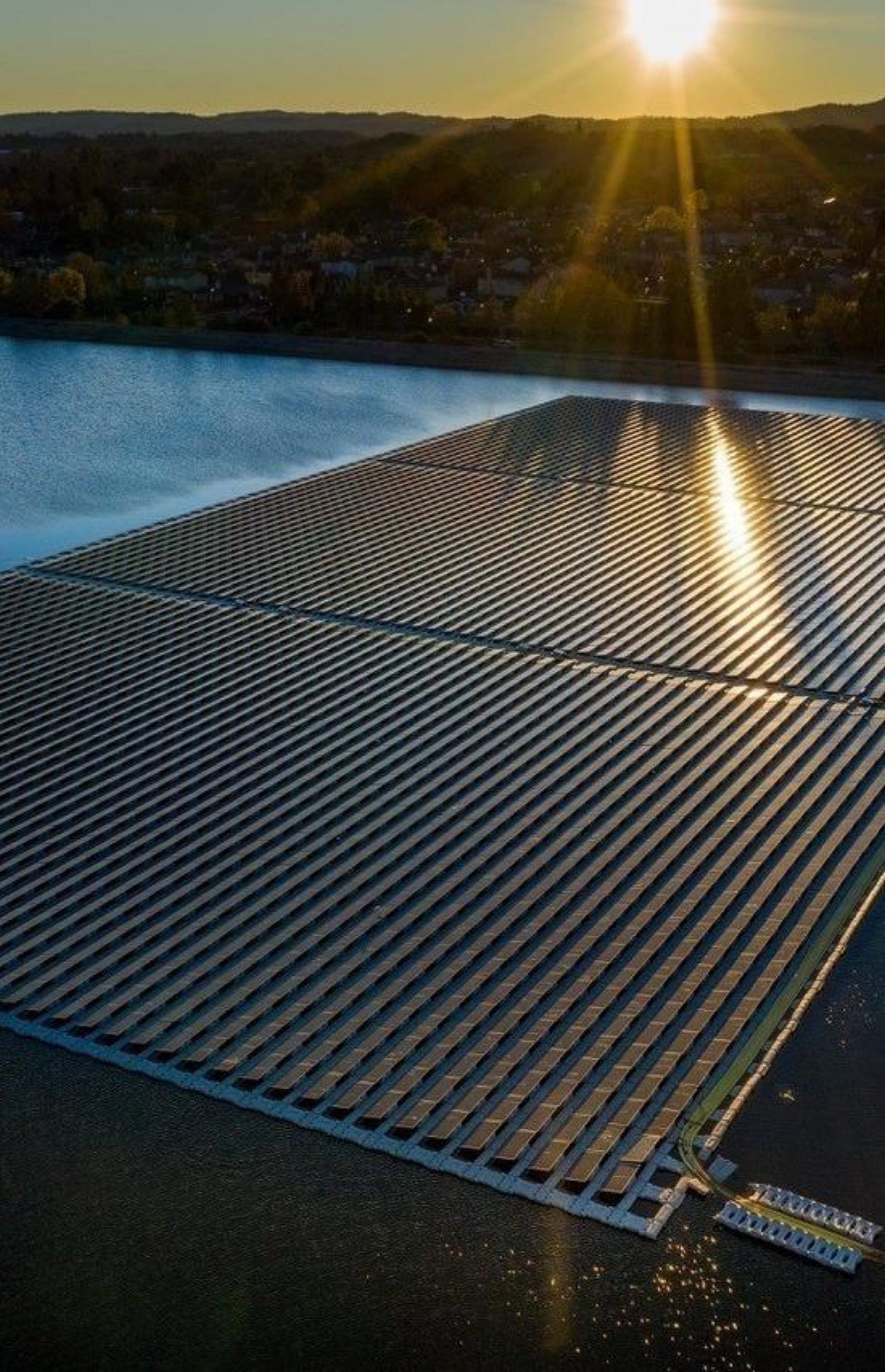

EXPLORING THE POTENTIAL FOR FLOATING PHOTOVOLTAIC SOLAR ON MAN-MADE RESERVOIRS IN THE UNITED STATES

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CAPSTONE PRESENTATION

M.S. IN ENERGY POLICY & CLIMATE

JOHNS HOPKINS UNIVERSITY

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RESEARCH QUESTION

What factors contribute to successful floating photovoltaic solar project development on man-made reservoirs in the US?

FPV BACKGROUND

- Rapidly emerging technology where PV solar systems are sited directly on water bodies using floats or pontoons and regular PV panels
- First project was in US in 2008 at CA Vineyard wastewater treatment – now over 20 operating projects in US
    - Largest US project online March 2021 – 4.78 MW Healdsburg Solar Project, California
- China & Japan are industry leaders – growth in Latin America, Southeast Asia, and Northern Europe
    - 3 GW operating globally in 2020
- NREL study found over 24,000 suitable man-made reservoirs in US for project sites

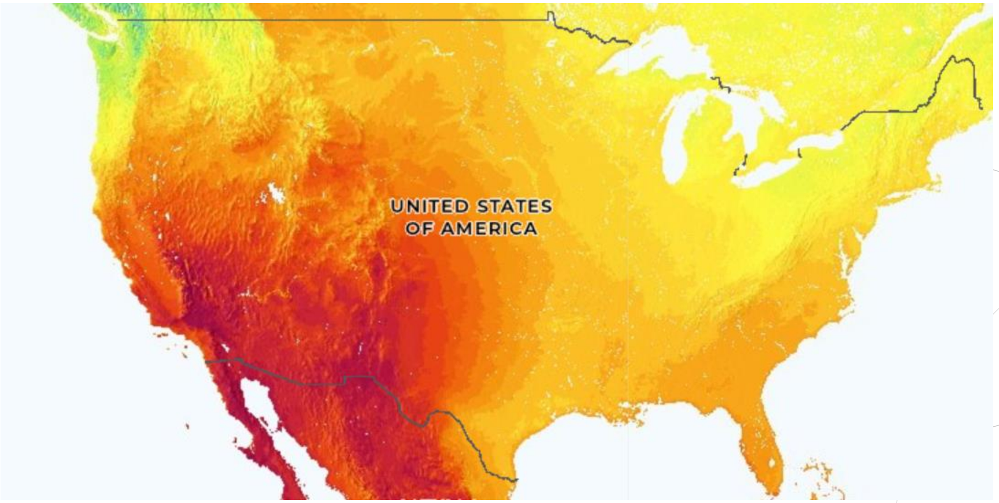
METHODS

- Extensive document analyses
  - World Bank FPV & Land-Based PV Development Handbooks
  - NREL, NRDC, EPA, SEIA, DNV, IFC, NRDC publications & data
  - Peer-reviewed academic journals
  - News articles
- Table comparison of key factors impacting both FPV & land-based solar project development
  - In-depth analysis of each factor to understand differences, similarities, and to make case for increased development of FPV in US.

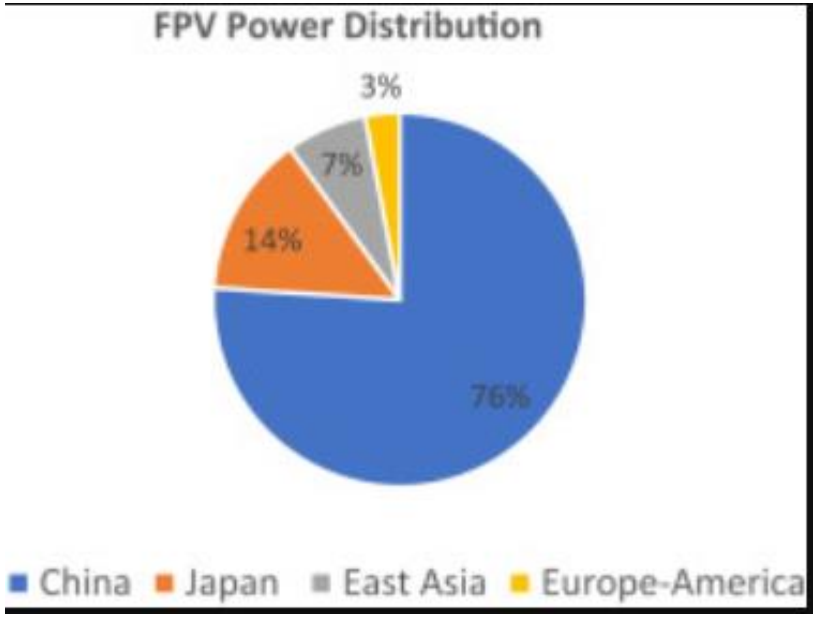
RESULTS: SITE ASSESSMENT

Key Factors:

- Transmission Line Proximity & Substation
- Location
- Water/Land Surface Use
- Underwater Terrain & Soil Conditions



- FPV spares land that can be used for agriculture, development, tourism, natural areas left for carbon-capture
  - Utilizing existing, typically untouched sites with existing infrastructure already in place
  - FPV can spare avg. of 2.7x area of land-based PV installed on capacity basis
  - Reduces need for tree clearing, land grading
- Excludes any man-made reservoirs used for fishing, navigation, recreation or are located >50 mi. from transmission line
- Potential FPV projects would cover no more than 27% of water surface



Key Factors:
- Risk Assessment
- Market Assessment
- Federal Regulations
- State Regulations & Permitting
- Local Regulations & Permitting

RESULTS: FEASIBILITY STUDIES

- FPV risk analyses can be modeled off land-based PV
- US FPV market capacity = 1,260 GWp
  - 1-5 MW projects - water utilities, industrial, commercial customers
  - Tracking vs. stationary panels
- US land-based PV – 97.7 GWdc total installed capacity 2020 (43% of all new capacity added in 2020)
  - Expect additional 324 GW by 2030
- Investment Tax Credit (ITC)
- Renewable Portfolio Standards/Clean Energy Standards
- Biden Administration Climate Plan & Paris Agreement

RESULTS: ENVIRONMENTAL & SOCIAL ASSESSMENTS

Key Factors:

- Environmental Impact
- Shading Impact
- Water Use
- Social Impact
- Safety

- Environmental Impact Statements
- Environmental Benefits:
  - Reduces water evaporation from reservoirs
    - Beneficial in drought-prone areas
  - Improves water quality
  - Bird collision reduction
  - Reduces water movement to minimize erosion
  - Shading reduces eutrophication
    - Improve drinking water quality
- Environmental & Social Risks:
  - System manufacturing requires lots of energy
  - Safety risk of falling into water, public access

RESULTS: FINANCING & CONTRACTING

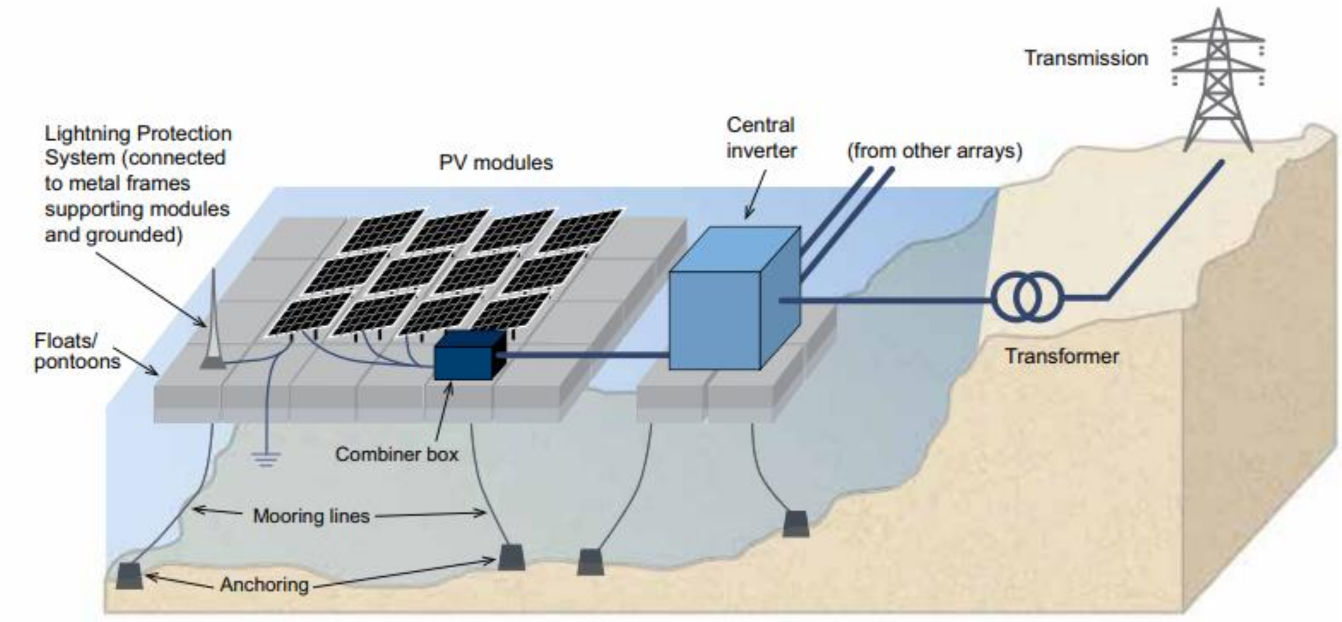
Key Factors:

- LCOE
- OpEx (O&M)
- CapEx (capital expenditure)
- Offtake Type
- Tax Incentives

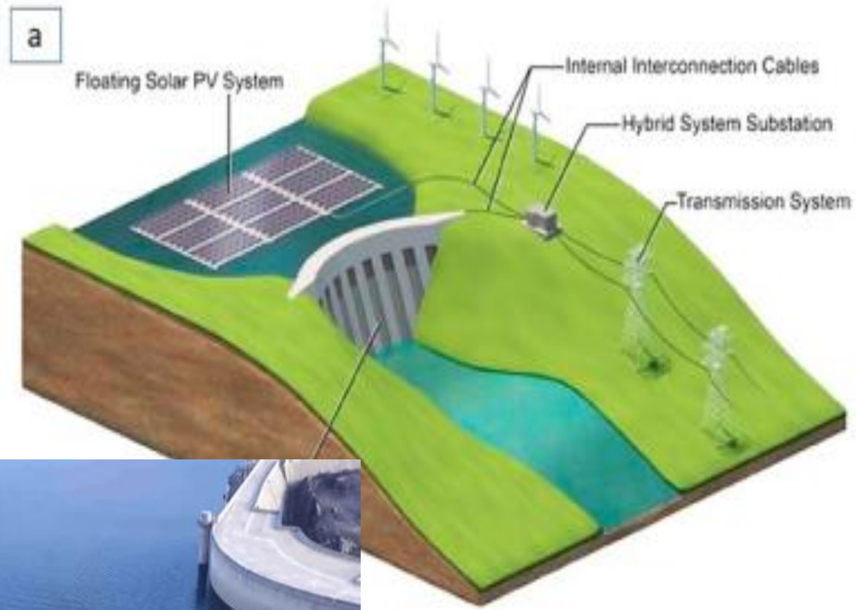
- Total cost of FPV sightly higher (10-15%) than ground-mounted, but nearing price equivalence
  - FPV higher CapEx
    - floats cost 25% of total CapEx
    - Offset by higher costs of land acquisition, permitting costs, soil leveling, civil works, etc. of land-based PV
  - FPV lower OpEx costs
    - Main costs = lease/rental fees for installation site, O&M costs, & insurance
  - Majority of projects have been contracted through power purchase agreements
  - Investment tax credit & MARCS as potential future incentive

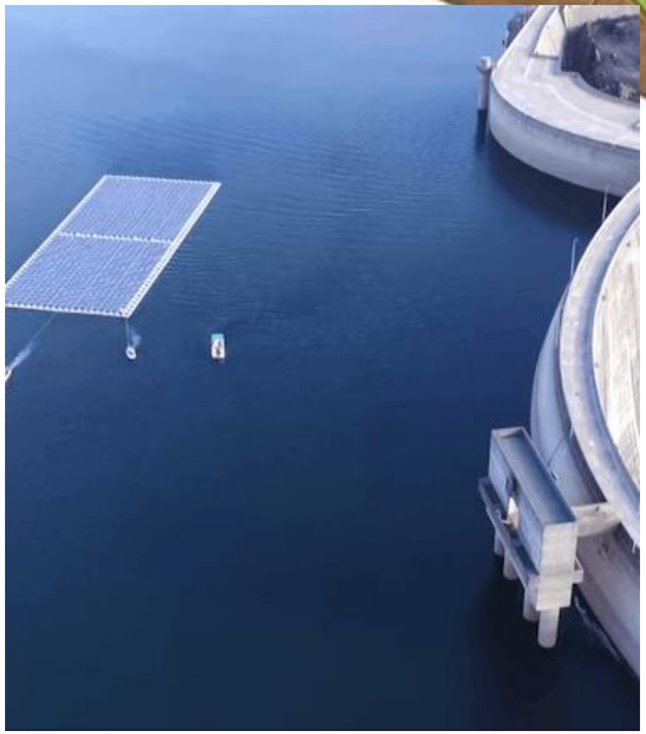
RESULTS: SYSTEM DESIGN

- PV modules are the same for FPV & land-based solar
  - Mounted on top of float or pontoons to convert incandescent solar irradiation into electricity
- Cooling Impact
  - Water has larger specific heat than ground – heats slower
  - Water can eject heat through evaporation
  - Operating temperature of FPV solar cells lower than land-based
    - increased efficiency by 5-10% in arid regions
    - Increased power production by 1.5% to 22%
- Weather resistant



Key Factors:
- Equipment
- Performance



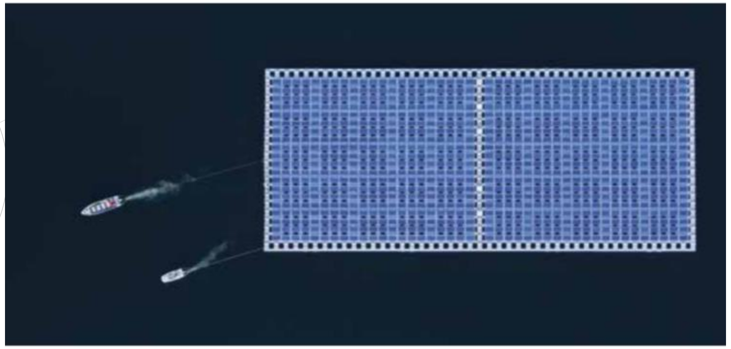


RESULTS: FPV & HYDROPOWER

- Reduction in evaporation rates can alleviate drought impacts
- Can utilize existing transmission infrastructure
- Sited closer to demand centers
- Covering 3-4% of hydropower reservoir with FPV could double installed capacity & strategically manage water resources
- Hybrid system smooths variability of solar output

RESULTS: PROCUREMENT & CONSTRUCTION

- Knowledgeable and experienced EPC contractor
- E, P & C management plans required
- Numerous stakeholders involved
- Components assembled on land
- Far less construction time & civil works than land-based
  - 1 week for FPV 3MW project vs. 8 weeks land-based



Key Factors:
- Suppliers & Procurement Management
- Construction Methods

RESULTS: OPERATION & MAINTENANCE

Key Factors:
- Technical Maintenance
- Cleaning & Site Upkeep

- FPV parts are more difficult to access & repair
  - Specific training required – less trained workers in field
- High humidity site can accelerate corrosion/oxidation of metal parts
- Lower risk of theft and vandalism
- Quick access to water & easy pathways between floats for cleaning
  - Bird dropping & dust removal

DISCUSSION & CONCLUSION

- Every state has floating solar potential
- Each project comes with own challenges and sets of characteristics, but are offset by significant benefits
- Analysis confirmed hypothesis that there is a high potential for increased FPV development on man-made reservoirs in the States, espeically on hydropower basins
- In-depth analysis of factors impacting project development can be utilized by stakeholders and developers

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