# open**solar**

## problem & opportunity statement

### THE GLOBAL CONTEXT

By 2050, the world needs to achieve a net-zero carbon emission state. The transition to renewable energy is accelerating, but is still not on pace to meet this global target. Solar power is a consolidated viable option for household and utility power in many parts of the world, both where there is a functioning electric company and where one is absent. Solar power is now affordable and increasingly accepted as a viable alternative to legacy energy systems. It's also a solid generator of jobs

There are many options for financing solar energy, particularly in the USA. However, the underlying contractual frameworks to finance renewable energy are not fit for the purpose of a radical mobilization of capital to achieve global goals. Most long-term power purchase agreements (PPA), lease-to-own models and the procedures to capture the associated investment tax benefits and green attribute credits are cumbersome and require economies of scale to be affordable.

Furthermore, the industry lacks a common platform and standard to seamlessly integrate a full array of investors–overseas, institutional, public and private– with beneficiaries using accessible debt and equity securities. To the energy finance world "there is more money available than there are projects." In part, this is due to the cumbersome legal pipeline that developers must navigate from project inception to capitalization.

We believe that by applying a combination of IoT & blockchain technology, we can significantly advance contractual automation in energy project finance. By embedding this in the backend of adaptive peer-to-peer open platforms and intuitive user interfaces, we can significantly remove the financial frictions preventing a full decarbonization of the energy sector.

### THE LOCAL PUERTO RICO CONTEXT

One and a half years after hurricane Maria hit the island, schools are still exposed to a centralized and high-carbon energy system vulnerable to climate impacts. At the same time, most schools are becoming grass roots community centers facilitating discussions of concerned parents on how to increase climate & social resilience in the whole community.

The Puerto Rican (PR) government and the department of education are working to appoint schools as emergency shelters –nodes with robust energy and communication systems– for the community to reach out in the event of unavoidable climate shocks. Financing is a key gap.

The American Red Cross has allocated a grant to the PR department of education that will cover solar systems for 100 schools. We believe an advanced finance system and model could provide secure and novel financing for the solar conversion of the other 700 public schools on the island, delivering a substantial cost-savings in the education budget. In the process, by introducing a new open source platform to structure peer-to-peer solar finance and payments, we could accelerate the flow of funds to Puerto Rican solar projects, and spur a new economic model for the island.

Furthermore, by replacing the now outdated power payment agreement (PPA) model for residential and commercial solar with an adaptive and data-driven pay-to-own model, solar assets could be owned and managed by the local communities. Our vision is to show how communities, when armed with smart devices, open data, and market pricing signals, can use energy resources far more efficiently than under the current, centralized paradigm. Financing and empowering community based microgrids is part of what's becoming known as "energy democracy."

Yale openlab. mit media lab digital currency initiative

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proof of concept solar+iot+blockchain deployment in Pasto School, Aibonito, Puerto Rico.

# why blockchain?

## GENERAL TECHNOLOGY STATEMENT

To build a more resilient, decentralized energy grid requires more decentralized finance and energy management systems, one which, on the one hand, assigns ownership and control over data to the individuals and entities from which it emanates and on the other, allows them to securely share it in a peer- to-peer manner. Hence the value of a blockchain ledger, which provides a common software protocol to a distributed network of computers, allowing them to collectively update and track changes to a data set – manifest as transactions or transfer of power and money -- without relying on a centralized record-keeper. We believe a blockchain is needed to provide trusted contractual automation in a peer-to-peer finance community.

The data generated in this decentralized, Internet-of- Things-driven system is not only useful for people within the beneficiary community. Rich, provable data is also valuable to outside participants, most importantly investors. When coupled with smart contracts and smart devices that respond to digital money signals, blockchain-based models portend decentralized asset registration, smart collateral contracts and direct investment opportunities that could unlock financing for any community's solar array or microgrid, regardless of the state of its local legal infrastructure or jurisdictional conflicts. An investor in Munich could contribute to a pool of loans that provides affordable funding to a microgrid in Vieques, Puerto Rico, and know that the rights to the power generated are being managed equitably. If repayments aren't fulfilled, consumer connections could be limited or disconnected and surplus production supplied to a reservoir of storage and other paying users, all within a system in which neither the borrower or the lender can manipulate the result. It points to a decentralized system of property rights, one that bypasses official property registries and inefficient legal proceedings to protect the rights of all parties to a financial contract.

Blockchain development efforts essentially focus on lowering the upfront capitalization burden of developing and expanding solar arrays and microgrids. This includes the use of energy-pegged tokens as a claim on verified solar energy, akin to the analog Renewable Energy Certificate, but with greater trading capability. To de-risk the investors' position, we focus on the application of blockchain-based collateralized grid assets, with smart contracts and smart meters used to automatically control rights and access to power based on whether digital-currency-based loan repayments are up to date. Associating these solutions with crowdfunding models, we believe we can build tools to unlock international flows of capital to communities looking to develop these decentralized energy systems.

## CONCRETE APPLICATIONS

***Dis intermediation and contractual automation for:***

- **Low cost solar financing:** high trust and peer-to-peer transactions using security instruments (equity and bonds)
- **Digitized Power Purchase Agreements:** IoT-driven payment from offtakers to investors with associated ownership changes and tariffs anchored to local values using independent oracles.
- **Breach response:** contract execution of hardware overrides, and guarantor (blended capital) flows.
- **Environmental and social impact certification:** Attestation of events, packed into data rich non fungible tokens that replace the analog version of the Renewable Energy Certificate.

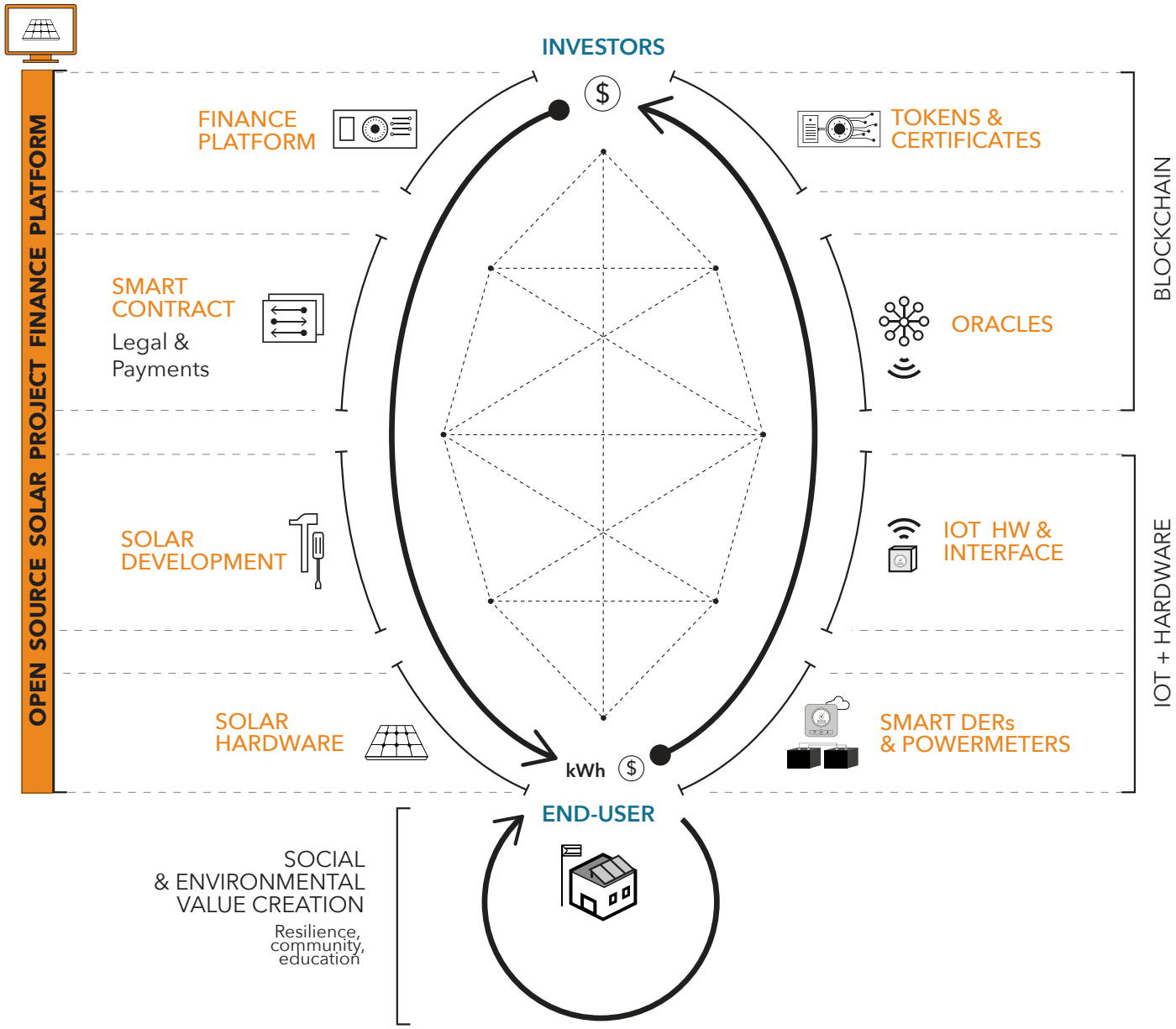
# opensolar

**PROJECT STATEMENT**

The OpenSolar Project and platform aims to use blockchain and IoT-based smart contracts for disintermediation and contractual automation in financial processes to drive community-owned solar projects.

We seek to develop open source core technology to streamline the flow of crowd-based funds (eg. muni bonds and equity) to finance the deployment of solar assets, and allow the end-users to own these resources in a short time frame through regular utility-like payments driven by energy generation and consumption IoT data.

The payment platform is built on the Stellar blockchain, and our pilot projects are done in public schools in Puerto Rico.



INSPIRATION STATUS & REPORT

# puerto rico's public schools and emergency shelters

Our team has successfully deployed two proof-of concept solar systems in our partner school and community in Aibonito, Puerto Rico. Our first proof-of-concept system was a minimum size of (200W) to stress test connectivity and evaluate bottlenecks. These assets were only sized to power data sensors that were directly connected to the Ethereum test-network and triggered dummy payments through an architecture of smart solar contracts already in place (using Solidity language). Our second proof-of-concept system is a 1000W system to further stress test connectivity and evaluate frictions of local solar contractors during the deployment phase. The system covers the Admin building's critical loads and provides resilience in case of energy blackouts. The IoT data from the system is being onboarded into the newer fintech platform built on Stellar (replacing the Ethereum instance).

Our roadmap seeks to successfully deploy a full pilot project to install a 5kW system in the school by mid 2019. This pilot would use a first full simulation of a municipal smart solar bond. With a successful pilot, we will present a project finance document for a real-world muni bond pilot with the PR government and a subsequent proposal to use the mechanism for the reconversion of 700 public schools.

Martin Wainstein (Yale & MIT) –the manager of this project– has held successful meetings with the greater school community in Aibonito, Puerto Rico and, more importantly, with top representatives of the PR department of education and the innovation and technology office. Specifically, Martin has held recurring meetings with Glorimar Ripoll, the chief innovation officer for the PR government, and with accountants at the Department of Education. Both departments endorse this project, validate its value proposition and show continuing enthusiasm to collaborate.

## Roadmap to finance solar for 700 of Puerto Rico's public schools

**POC1:**

**200W**
**Admin building**

**POC2:**

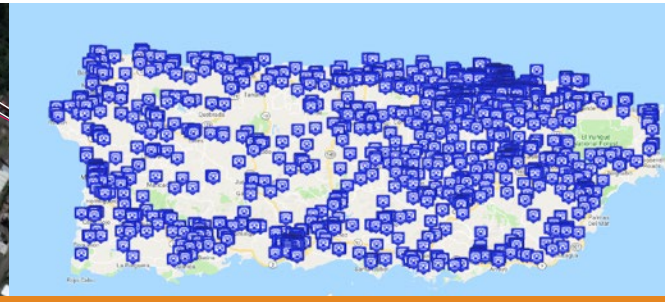
**1kW**
**Admin building**

**PILOT 1**

**3-5 kW**
**Middle-School Back-up**

**PILOT 2**

**20kW**
**SU Pastos Whole Campus**



**PROJECT:**

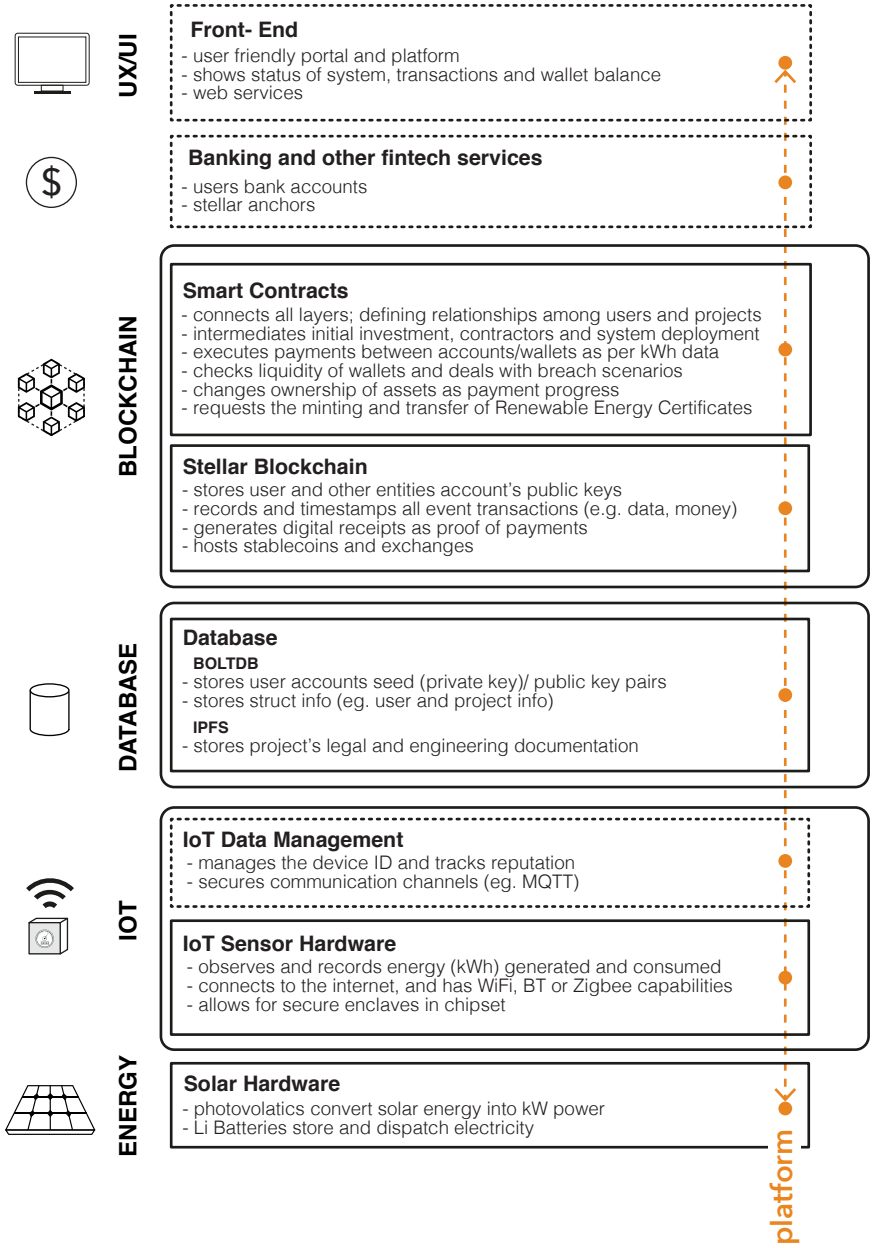
**Financing 700 of Puerto Rico's 800 public schools**

2018 | 2019 +


## COMMUNITY CONSULTATION

Our team holds recurring meeting with the parent-teacher organisation of the Aibonito school to discuss community ownership of solar microgrids and alternative peer-to-peer financial mechanisms.

# full stack integration for smart solar contracts




## OPEN SOLAR VALUE CREATION LOGIC

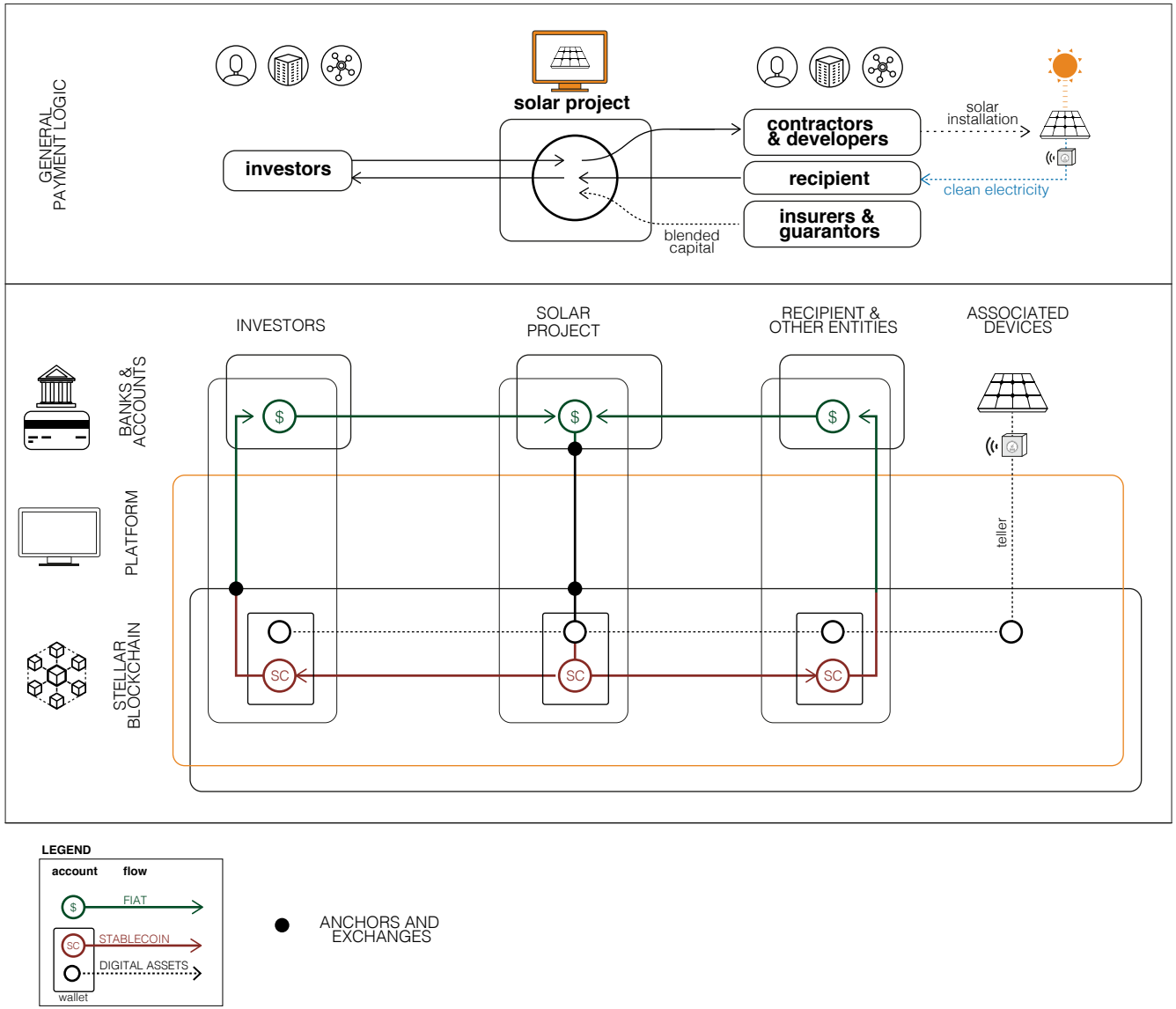
Investors can finance solar photovoltaic systems around the world using a seamless cross-border payment network. Several project finance features are used to de-risk investments and certify the social and environmental value. End-users (or 'recipients') can receive the solar systems with no downpayment, pay for the energy per kWh just like they do with the current utility, but once they pay off the cost of the system plus a low interest (i.e. a return to investors), they will fully and legally own the system (zero energy cost thereafter).

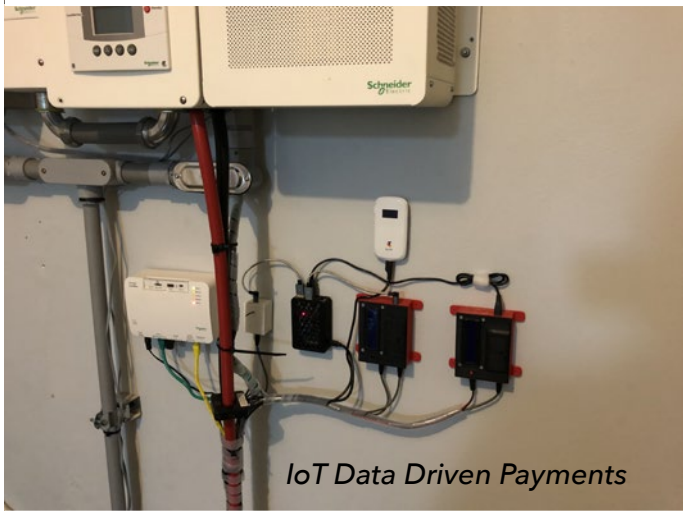
The first financial investment model considered here is that of the issuance of a municipality bond as the debt instrument. Other models include equity crowd funding and normal crowdfunding. With the municipal bond, the issuer (eg. end-user) issues a bond through a platform (eg. neighborly), and the investors buy enough bonds (at different values) to cover the principal (i.e. capex) of the solar system. The smart solar contract will organise bidding processes with contractors (i.e. solar developers), pay out contractors and inform when the system is 'live'.

Different layers of IoT energy monitoring devices attest to the energy generated by the solar system and the energy consumed by the end-user. This energy data (eventually using an oracle as an intermediary) activates payment transactions per kWh at a specific tariff rate (e.g. also using an oracle to determine the normal tariff) and at specific intervals (eg. monthly). Energy payment transactions occur between the recipient/end-user's wallet/account and a main escrow smart contract that accrues the funds and issues payment on interests (i.e. coupons) to investors. Once the accrued funds can cover the original principle, the contracts pay off investors and the bonds matures.

Other relevant contract layers include risk mitigation processes to deal with payment breaches (i.e. end-user doesn't pay for energy), and the issuance/minting of Renewable Energy and Carbon Certificates based on the kWh energy reported by the IoT devices.

# payment architecture using stellar



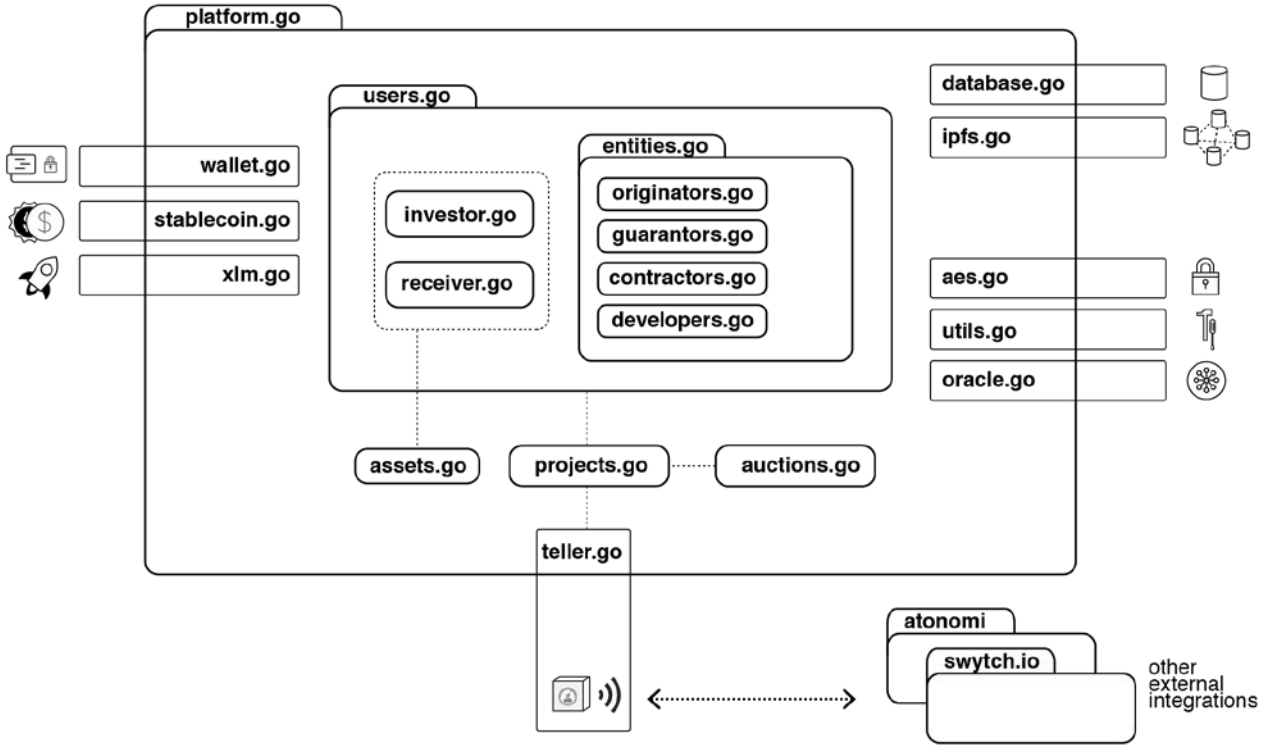

The diagram explains the general payment logic between investors, recipients and other project entities. The payment architecture is built on the Stellar blockchain which enables fiat and stablecoin interactions, and digital 'assets' that act as proof of payment or debt and can be fungible. The integration of the IoT devices (eg. the powermeter) is what drives payments once the project is fully deployed.

# hardware & repository development status

IOT POWERMETER HARDWARE

**Milestone achieved:** Open source IoT powermeter developed (beta version). This system uses a non-invasive sensor to measure current in an AC cable and broadcasts its information through both WiFi and Zigbee. A raspberry Pi receives the information and acts as a light client communicating with the smart contracts associated with the projects and solar assets

Future efforts: An IoT Xanbus data listener (Not-started). Priority: low




BACKEND REPOSITORY

See status of GitHub repository with 300 commits.
https://github.com/YaleOpenLab/openx

**Mature development in:** Platform, entities, contracts, IPFS integration, assets tokenization, IoT integration, stable coin integration, database setup (Private/public), API to front end through RPCs

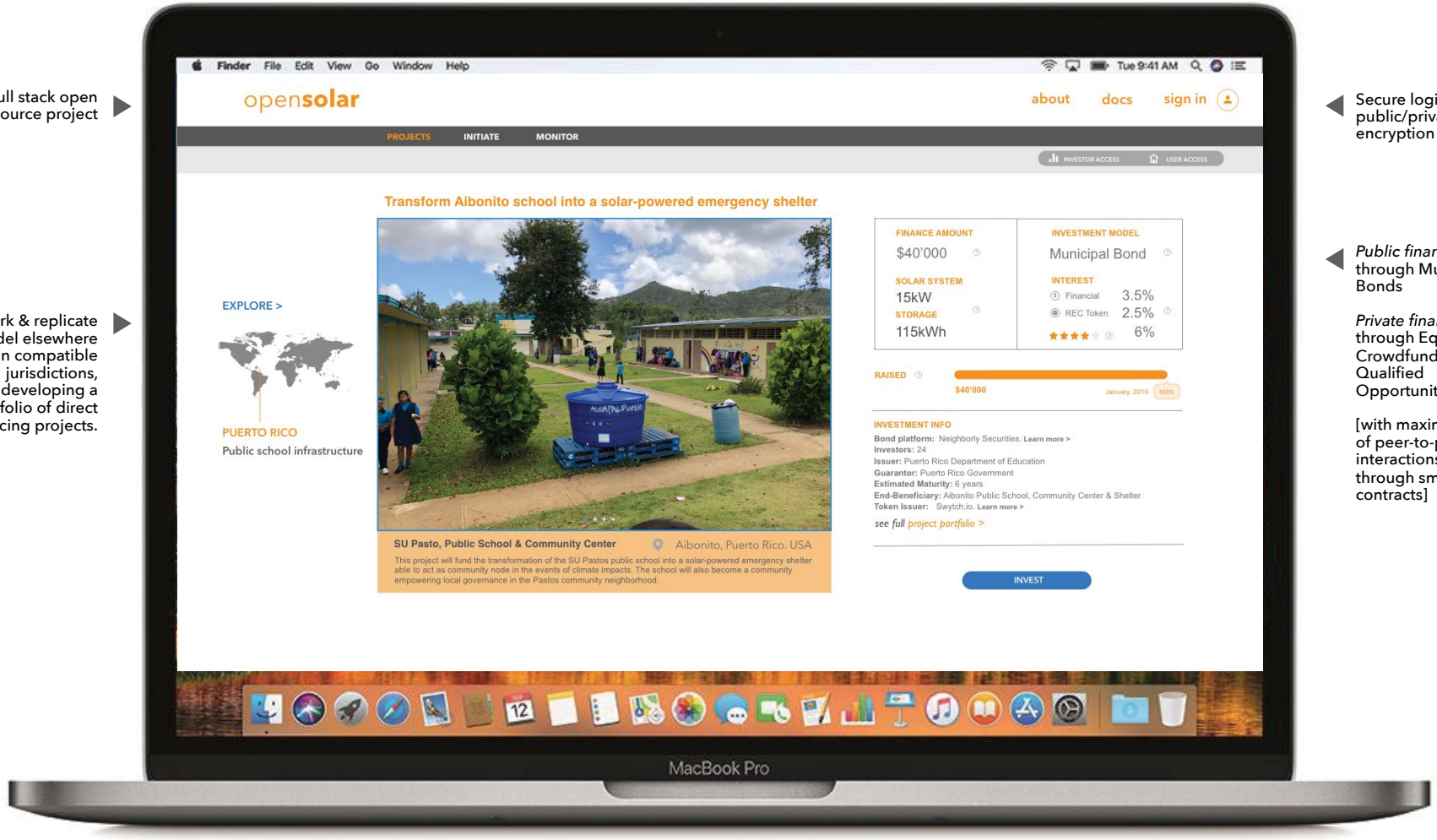
Near term focus: full stack prototype via front-end integration.

Oracle stage: general architecture. Not developed

# front end / opensolar PLATFORM

Full stack open source project

Fork & replicate model elsewhere in compatible jurisdictions, developing a portfolio of direct financing projects.




Secure login with public/private key encryption

*Public financing* through Municipal Bonds

*Private financing* through Equity Crowdfunding and Qualified Opportunity Funds

[with maximization of peer-to-peer interactions through smart contracts]

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OpenSolar Platform

# Drive the Solar Economy

DECENTRALIZED FINANCE FOR ENERGY PROJECTS

## Invest

Build a low risk & low carbon securitized portfolio with certified impact metrics.

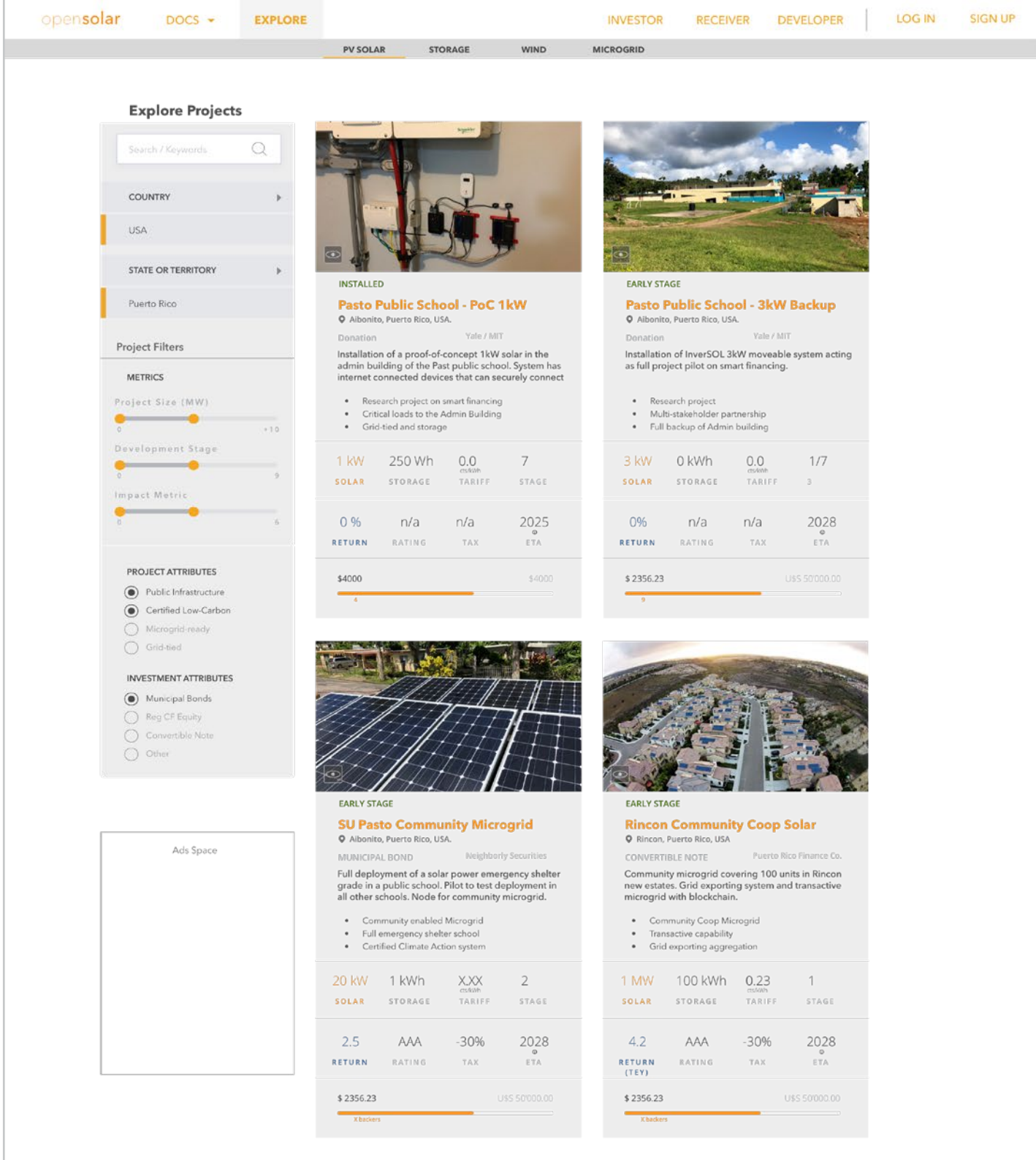
## Develop

Originate a project by mobilizing your community and coordinate contractors.

## Receive

Host a solar project in your land or roof, pay to own it using your normal tariff.

# explore page UX/UI design



Thanks to teacher engagement, students in the Aibonito school are exposed to semesterly events around climate awareness and renewable energy learning, using the very solar systems installed in the pilot school.