GridTokenX

Blockchain-Based Peer-to-Peer Solar Energy Trading Platform

White Paper v2.0

Development of Peer-to-Peer Solar Energy Trading Simulation System using Solana Smart Contract (Anchor Framework Permissioned Environments)

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Abstract

This white paper presents GridTokenX, a conceptual design for a decentralized Peer-to-Peer (P2P) solar energy trading simulation platform operating on a private Solana network. The platform enables prosumers to tokenize surplus solar energy production into GRID tokens (1 kWh = 1 GRID) and trade directly with consumers through an automated order book mechanism.

Our implementation leverages the Anchor framework to deploy five interconnected smart contracts: Registry (user/meter management), Oracle (data validation), Energy Token (SPL-compliant minting), Trading (order book settlement), and Governance (configuration). Performance benchmarks demonstrate 21,378 tpmC (356 TPS) with 11ms average latency and a "Trust Premium" of 5.67x compared to centralized databases.

The objectives of this research are: (1) to study and present the architecture of a P2P energy trading simulation using Solana in a Permissioned (PoA) environment; (2) to develop a Proof-of-Concept capable of simulating GRID Token exchange with an AMI Simulator; and (3) to evaluate the performance in terms of Throughput and Latency.

Keywords: Blockchain, Solana, P2P Energy Trading, Smart Contracts, Tokenization, TPC-C

1 Executive Summary

1.1 Problem Statement

The traditional energy market faces fundamental challenges limiting distributed renewable energy adoption:

- **Centralized Intermediaries**: Energy flows through utilities with high fees and limited transparency
- **Lack of Direct Trading**: Prosumers cannot sell directly to neighbors
- **Settlement Inefficiencies**: Monthly billing cycles and delayed payments
- **Trust and Verification**: Reliance on utility meters with limited audit capabilities

1.2 Proposed Solution

GridTokenX addresses these challenges through a blockchain-based P2P energy trading simulation platform designed for private/permissioned Solana networks:

- **Tokenization**: 1 kWh = 1 GRID token (SPL-compliant, 9 decimals)
- **Direct P2P Trading**: Order book matching without intermediaries
- **Real-time Settlement**: Atomic trade execution with instant finality
- **Verified Green Energy**: On-chain ERC certificates

1.3 Technical Innovation

Table 1: Platform Comparison

Criterion	**Solana (Private)**	**Ethereum**	**Polygon**
Transaction Speed	11ms	12-15s	2s
Cost per TX	$0.00025	$1-50	$0.01
TPS Capacity	356+ (tested)	15-30	7,000
Finality	Deterministic	6 blocks	256 blocks

2 Business Model

2.1 Revenue Streams

The platform generates revenue through three primary channels:

1. **Transaction Fees (60% of revenue)**
   - Trade fee: 0.25% (split between buyer/seller)
   - Settlement fee: 0.1% (seller)
2. **Certificate Fees (25% of revenue)**
   - ERC Issuance: 5 GRID per certificate
   - ERC Validation: 2 GRID per approval
3. **Premium Services (15% of revenue)**
   - API Access: 100 GRID/month
   - Premium Analytics: 50 GRID/month

2.2 Compute Economics (Private Network)

Since GridTokenX operates on a private/permissioned Solana network, compute costs differ significantly from public mainnet:

Table 2: Compute Unit Cost Breakdown

Instruction	**Est. CU**	**Public Cost**	**Private Cost**
`create_sell_order`	50,000	$0.025	$0.001
`create_buy_order`	45,000	$0.023	$0.001
`match_orders`	80,000	$0.040	$0.002
`submit_reading`	30,000	$0.015	$0.0005
`mint_tokens`	60,000	$0.030	$0.001

Private Network Advantage: No validator fees results in 95%+ cost reduction vs public Solana.

3 System Architecture

3.1 Four-Layer Model

The platform architecture consists of four distinct layers:

1. **Presentation Layer**: Web/Mobile clients, user interface
2. **Application Layer**: API Gateway, WebSocket server, event processors
3. **Data Layer**: PostgreSQL (off-chain), Redis (cache), Solana RPC
4. **Blockchain Layer**: Anchor programs, SPL Token, System Program

3.2 Smart Contract Programs

Five interconnected Anchor programs form the blockchain layer:

Table 3: Program Architecture

Program	**Purpose**	**Key Functions**
Registry	User/Meter Management	`register_user`, `register_meter`
Oracle	Data Validation	`update_price`, `submit_reading`
Energy Token	Token Operations	`mint_from_production`, `burn`
Trading	Marketplace	`create_sell_order`, `match_orders`
Governance	Configuration	`issue_erc`, `validate_erc`

3.3 Program Relationships

Programs interact through Cross-Program Invocation (CPI):

- Registry $\rightarrow$ Energy Token: Mint tokens from settled production
- Trading $\rightarrow$ SPL Token: Escrow and settlement transfers
- Oracle $\rightarrow$ Registry: Submit verified meter readings

4 Token Economics

4.1 GRID Token Specification

- **Standard**: SPL Token (Solana Program Library)
- **Decimals**: 9 (divisible to nano-tokens)
- **Backing**: 1 GRID = 1 kWh verified energy production
- **Supply**: Elastic (minted on production, burned on consumption)

4.2 Token Conservation Invariant

The system enforces strict conservation of energy. Tokens can only be minted when physically generated energy is mathematically settled:

$$\Delta Supply_{GRID} = \max(0, (E_{produced} - E_{consumed}) - E_{settled}) \tag{1}$$

This prevents double-spending by tracking the $E_{settled}$ accumulator per meter.

4.3 VWAP Pricing Mechanism

The clearing price is calculated using Volume-Weighted Average Price:

$$P_{base} = \frac{P_{bid} + P_{ask}}{2} \tag{2}$$

$$P_{clearing} = P_{base} + \left(P_{base} \times \min\left(\frac{V_{trade}}{V_{total}}, 1.0\right) \times 0.10\right) \tag{3}$$

5 Performance Evaluation

5.1 Benchmark Methodology

We adapt the TPC-C benchmark for energy trading workloads:

Table 4: TPC-C to Energy Trading Mapping

TPC-C Transaction	Mix	GridTokenX Function
New Order	45%	`create_sell_order` / `create_buy_order`
Payment	43%	`transfer_tokens`
Order Status	4%	`get_order_status`
Delivery	4%	`match_orders`
Stock Level	4%	`get_balance`

5.2 Results

Table 5: Performance Benchmark Results (Local Validator)

Metric	Observed Value
tpmC (Transactions/min)	21,101
TPS Equivalent	352
Total Transactions	23,848
Successful Transactions	23,817
Average Latency	11.30 ms
p50 Latency	11.00 ms
p95 Latency	18.00 ms
p99 Latency	20.00 ms
Transaction Success Rate	99.9%
MVCC Conflict Rate	1.3%

5.3 Trust Premium

$$Trust\ Premium = \frac{Latency_{Blockchain}}{Latency_{Baseline}} = \frac{11.34ms}{2.00ms} \approx 5.67x \tag{4}$$

This overhead is negligible for energy trading where traditional settlement takes days.

6 Security Analysis

6.1 Threat Model

- **Meter Spoofing**: Mitigated by Ed25519 signature validation
- **Double Spending**: Prevented by atomic settlement and PDA ownership
- **Front Running**: Reduced by 11ms finality window
- **Oracle Manipulation**: Anomaly detection at 10x threshold

6.2 Access Control

Program Derived Addresses (PDAs) enforce ownership:

```
seeds = [b"order", authority.key(), market.active_orders.to_le_bytes()]
```

Only the original authority can modify or cancel their orders.

7 Comparative Analysis

Table 6: Platform Comparison

Platform	**Avg Latency**	**Finality**	**Notes**
GridTokenX	11ms	<1s	Solana PoA
Power Ledger	3-5s	10s	Custom chain
Energy Web	5s	5s	PoA chain
WePower	15s	15s	Ethereum

8 Future Roadmap

8.1 Development Phases

1. **Phase 1 (Q1 2025)**: Pilot launch with 100 prosumers
2. **Phase 2 (Q2-Q4 2025)**: Scale to 10,000 users
3. **Phase 3 (2026)**: Southeast Asia expansion
4. **Phase 4 (2027+)**: Cross-chain integration, AI optimization

8.2 Performance Targets

Table 7: Performance Roadmap

Metric	**v1.0**	**v2.0**	**v3.0**	**v4.0**
TPS	50	200	1,000	10,000+
Latency (p99)	20ms	15ms	10ms	5ms
Users	10K	100K	1M	10M

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