# Blockchain-Enabled Campus Wine Supply Chain

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## Abstract

The growth of blockchain technology, a decentralized database of immutable information stored in "blocks," has recently fostered much interest due to its potential usage and integration from a business standpoint. Blockchain application yields greater transparency and traceability of products, an asset for wine sales by ensuring quality and authenticity. This paper examines the potential application of blockchain to commercial wine produced by the Wine and Viticulture Department at California Polytechnic State University-San Luis Obispo (Cal Poly). This study examines existing and future supply chains along with various blockchain formats and accessibility levels. We suggest a permissioned public blockchain be implemented for Cal Poly's commercial wine program.

## Keywords
Supply chain, blockchain, traceability, transparency, California wine

## 1. Introduction
The need for wine supply chain traceability presents itself in the face of issues like counterfeiting, adulteration, and the use of harmful additives. In 2016, the projected worth of fraudulent fine wine amounted to $3 billion (Schmitt 2016). Various traceability systems - such as barcode, radio frequency identification (RFID), quick response (Q.R.) code, electronic product code (EPC) – present ways to store traceability information in centralized databases, but face concerns with authenticity, as information can be reproduced or forged at any time (Biswas, Muthukkumarasamy and Tan 2017). Blockchain (B.C.) technology provides a promising solution for increased traceability and security, holding data in a decentralized, immutable database.

California accounts for nearly 90% of the wine produced in the United States, and if treated as its own country, would be the fourth leading wine producer globally (Bayar 2020). With the importance of wine production in local and national economies, the Cal Poly Wine and Viticulture Department, located in Central California, was established over 30 years ago, becoming one of the largest Wine and Viticulture programs in the United States (Lecot 2020). The Cal Poly Wine Club provides a retail outlet for the department, which is expanding with the development of the Justin and J. Lohr Center for Wine and Viticulture projected for completion in Fall 2021.

Cal Poly Wine currently follows a 3-tier distribution system with the total wine volume sold fairly evenly through three general outlets: on-campus, local businesses, and online through calpolywine.com. This program may benefit from the application of blockchain technology to ensure transparency and traceability among each supply chain entity.

## 2. Literature Review
### 2.1. Wine Supply Chain
The global volume of wine sold is projected to reach 2.7 billion 9-liter cases, with a value of $207 billion in 2022. In 2017, the United States was the most valuable wine market ($34.8 billion), followed by France ($16.7 billion), then China ($16.5 billion). The magnitude of these markets is largely based on population size. China's wine market value is expected to pass France as the second most valuable global wine market, with an estimated worth over $19 billion for 2020. Despite having markets with less overall worth, other European countries present more established wine industries, with Portugal, Italy, and France having the highest global per capita consumption (35 liters per person per year) (Elfman 2019).

Within this global dynamic, California produces the vast majority of American wine and is the fourth largest wine producer in the world. In 2019, California produced 276 million cases of wine, retailing $43.6 billion. (Wine Institute 2020)

Due to the variation in wine supply chains, it is difficult to create a universal, working model for an effective traceability system. Different global companies have various levels of complexity, technical capabilities, and unique supply chain characteristics. However, most wine supply chains include these key components:

- Grape Grower – produces, harvest, and delivers wine grapes
- Wine Producer – receives wine grapes and manufactures into wine
- Bulk Distributor / Transit Cellar – receives bulk wine for storage, dispatch, processing, sampling, and analysis (the primary distinction between the two is bulk distributors hold a commercial role with invoicing, whereas transit cellars only have a role of transit without commercial/invoicing aims)
- Filler / Packer – receives, stores, processes, samples, analyzes, fills, packages, and dispatches finished wine products
- Finished Goods Distributor – receives, stores, dispatches, and manages the inventory of finished wine products (also re-packages, re-labels, and quarantines as needed)
- Retailer – receives products form finished goods distributors and dispatched items to retail stores

(Armstrong et al. 2005)

Globally, the regulations for wine also vary considerably. For instance, South African, Australian, and European Union (E.U.) definitions for "wine" specifically refer to the use of fresh grapes as the only raw material for wine, whereas the United States allows a broader definition, including other fruits and vegetables as acceptable ingredients for wine (Meloni et al. 2019). The United States tends to have more relaxed legislation for wine, but certain regions within the U.S., namely California, have stricter regulations.

A widespread component of wine and agriculture regulation are geographical indications (G.I.s), which are "labels backed by government regulations that certify the geographical origin of a product" (Meloni et al. 2019). Originating in Europe, G.I.s are now globally dominant for wine, serving as potential indicators for quality, and authenticity in addition to product origin. However, there is no global standard for G.I.s qualifications, bringing two primary regulatory approaches. Associated mainly with the E.U., are G.I.s that establish quality in conjunction to the product origin. The other approach, used in the United States, establishes G.I.s only as certification of geographic origin under the trademark system. In place of a G.I.s system that provides quality assurance, United States wine also has a separate system of wine appellations of origin that includes recognized American Viticulture Areas (AVAs). AVAs are specific G.I.s for wine, closer to European standards. (Meloni et al. 2019)

## 2.2. Blockchain

To begin talking about blockchain and blockchain applications, first, we must understand what exactly a blockchain is. To put it simply, a blockchain is a special kind of database that has four key characteristics that distinguish it from your typical database. First, it is decentralized, meaning that all parties that participate get a copy of this database, and no singular organization or entity can own or edit this database. Second, it is tamper-resistant. This ties in with the decentralization of the blockchain, since an edit to the blockchain can only be made through a consensus agreement. This consensus mechanism varies between different blockchains, but for open blockchains such as Ethereum and Bitcoin, the consensus is 51% of users reaching an agreement to make a change. The next characteristic of the blockchain is that it maintains a sequential list of growing and verifiable transactions (these are the "blocks" that get approved to be added to the chain). The transactions typically pass through a cryptographic hash function in order to be verified, being a major reason why a blockchain is so technical. Finally, the last characteristic of a blockchain is that no party is required to operate it. It is an entirely cloud-based platform, so no single party is needed to maintain and verify this database (Awwad et al. 2018, Unnu et al. 2019).

There are three main types of blockchains. The first kind is an open blockchain, also known as a permissionless public blockchain. This means that anyone is allowed access to the blockchain (hence the name permissionless public) and may submit "blocks" for approval. This was the first kind of blockchain that was made readily available to the public and is the most famous kind. Online currency such as Bitcoin and Ethereum are public blockchains.

The next type of blockchain that exists is a private blockchain, also known as a permissioned-private blockchain. This is a type of blockchain that many large companies use to keep track of important data that they need for their own records. Like it says in the name, this blockchain is private and requires permission to have access. A private blockchain is somewhat of a modification to the classic blockchain. Since this blockchain is private and run by a singular company, it is more centralized and managed than a public blockchain. This also takes away some of the immutability of the data, since someone at the top of the company can request or require that data be approved for change. While these slight differences do exist, a private blockchain still maintains the characteristics of a typical blockchain.

The type of blockchain that we will be most interested in is the consortium blockchain, also known as a permissioned-public blockchain. A consortium blockchain is somewhat of a combination of public and private blockchains. It is typically spread out between multiple different companies and disciplines, but with every entity having access to different levels of information, as required by the companies. In our case, this would be the different entities in the wine supply chain (grape grower, wine bottler, etc.). The main benefit of a consortium blockchain is that information is better leveraged to improve workflows, accountability, and transparency. In any supply chain, this extra information that was not readily available before and can be made available within minutes or even seconds adds extreme value in the form of transparent accountability and efficient workflow.

### 2.3. Blockchain-enabled supply chain

Blockchain makes a good application for the supply chain because it requires "an increased need for trusted data to be shared across a growing number of parties" (Unnu et al. 2019). Switching from a current system that involves decentralized parties managing their own databases to a blockchain system allows for much easier operation and traceability for product owners that, in the end, can have great benefits for consumers of these products. As we went into detail above, there are several different parties involved in the winemaking and distribution process, so this will allow all these different parties to more easily access information and make supply chain decisions.

Blockchain is beneficial in this application because of its distributed nature. Since supply chain information is stored "in silos across supply chain parties,". Blockchain provides a secure way for this data to be accessed by all these parties. The technology is said to be most useful in this case because it can provide transparency and traceability. Depending on the organization and product, different types of blockchain may be implemented to meet these needs.

The requirements to implement blockchain in a supply chain depend on whether you are looking to promote traceability or transparency (Biswas et al. 2017). The first requirement is a form of product identification, as some form of RFID chip that can uniquely identify a product through the chain. The next requirement is a way of validating the data going into the chain. The final requirement is the standardization of data, so there is alignment upstream and downstream in the chain.

## 3. Cal Poly Wine Supply Chain

### 3.1. Background

Cal Poly Wine follows a 3-tier distribution system (in which wine goes from producer to distributor, to account, and then consumer). Approximately one-third of sales are on campus, one-third goes to local businesses, and the last third is sold online through calpolywine.com.

Since the new on-campus winery and viticulture facilities are not complete, the production currently takes place off-campus at a local winery and produces about 1800-2000 cases annually. One case includes 12 bottles. For distribution, a fulfillment center located in Paso Robles, California, is used, which uses a commercial online service delivery platform. However, calpolywine.com operates different e-commerce software. This disconnect between platforms requires manual entry of information between the two to communicate order data.

Blockchain technology may provide better traceability and transparency in Cal Poly Wine, disclosing product data to supply chain segments and consumers. This disclosure of data will verify product integrity and may improve connectivity among different entities in the supply chain. Furthermore, it will provide clear records of information, valuable for research, and improvement in the viticulture department.

### 3.2. Current Supply Chain

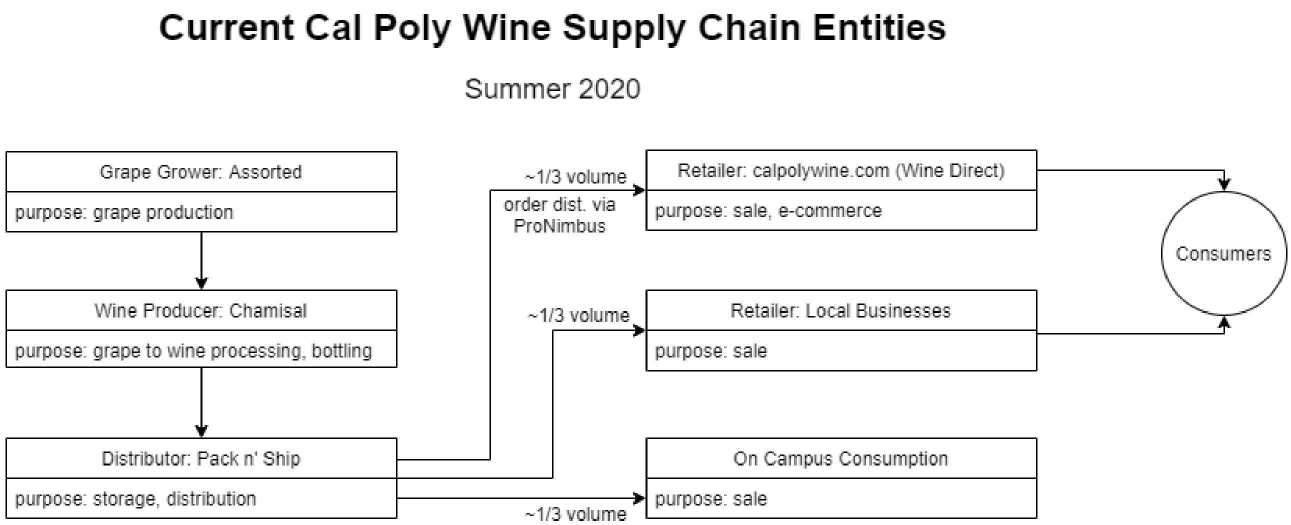


Figure 1. Current Cal Poly Wine Supply Chain Entities

The application of blockchain technology to the current Cal Poly Wine supply chain would face additional challenges because of their inconsistent sourcing of grapes. Presently, wine grapes are sourced from various growers around the central coast because Cal Poly does not have its own working vineyard. Wine processing also takes place off-campus at a local winery. Due to the irregular sourcing of grapes, wine varieties are inconsistent, depending on the grapes purchased. As Figure 1 illustrates, the current supply chain entities can be summarized, but the inconsistencies presented create issues with defining notes and recorded data for blockchain implementation.

Rather than study the application of blockchain to the current supply chain, this paper will instead focus on blockchain implementation to the projected supply chain model based on Cal Poly Wine's new on-campus viticulture infrastructure, estimated to be complete in Fall 2021.

### 3.3. Future Supply Chain

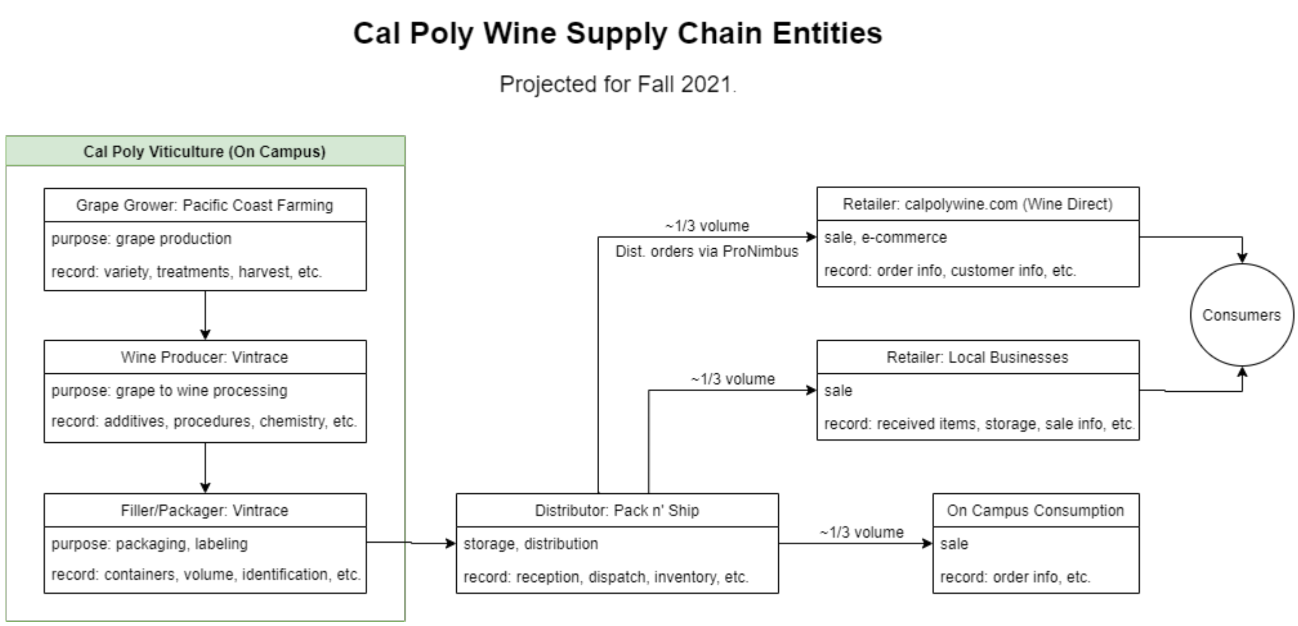


Figure 2. Projected Cal Poly Wine Supply Chain Entities

Production of Cal Poly commercial wine will begin with the growing of grapes on a 12-acre trestle vineyard on the Cal Poly campus. The grapes will be cared for by an external vineyard management company. This company tracks data about the grapes, such as cluster counts, harvest times, irrigation, treatments, etc.

After harvest, the grapes will be processed into wine (Pinot Noir and Chardonnay) at on-campus facilities. All data regarding age, variety, chemistry, added ingredients, fermentation, etc. will be recorded in a cloud-based wine software that assists the management of wine operations. The complete volume of wine produced will be packaged into 750 mL glass bottles, with 12 of these bottles making 1 case. These bottles have either a screw cap or cork for sealing. At this time, the bottles will also be labeled; the labels include the vintage, variety, appellation, and alcohol content.

In Figure 2, each box includes the generic wine supply chain entity name, associated company, purpose, and potential data to be recorded in a block for the blockchain database. The graphic also shows the proposed flow of data creating a traceable path for all wine produced.

# 4. Application - BC-enabled CP SC

## 4.1. Structure

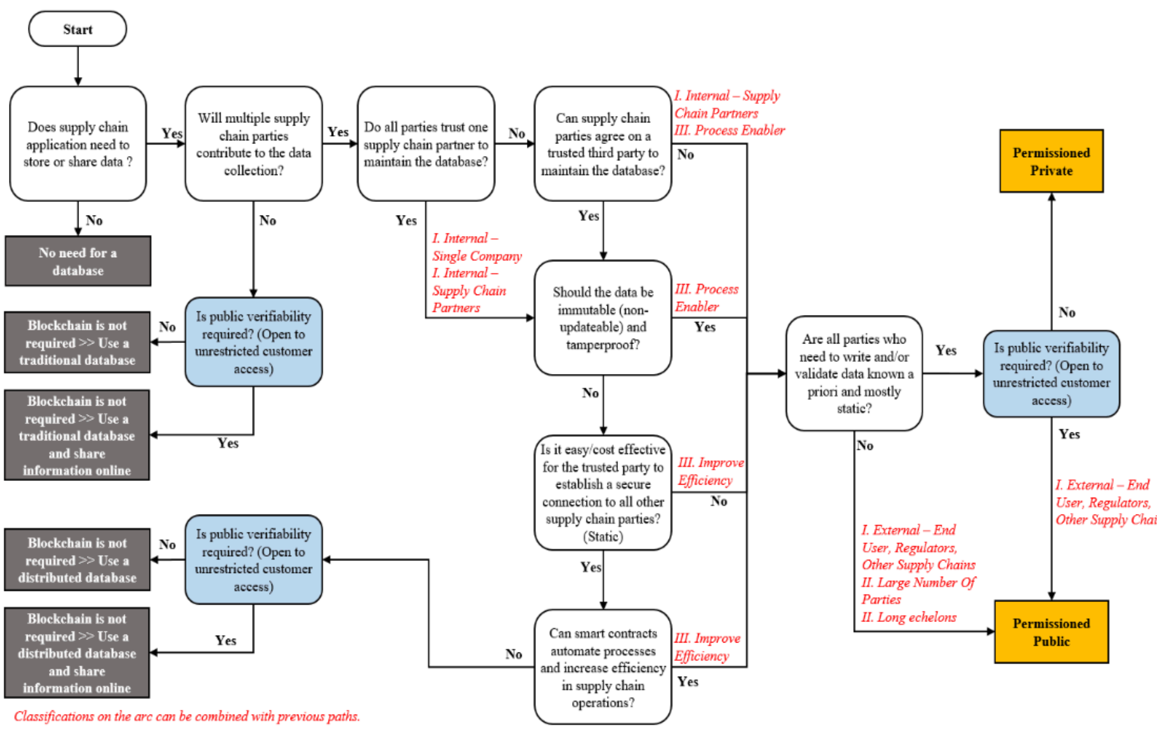


Figure 3: Decision-Making Map for Supply chain decisions (Unnu et al. 2019)

A permissioned public blockchain would be the best decision for the supply chain in our case. Permissioned Private blockchains are more appropriate for applications where entities do not often change (Unnu et al. 2019). In our case, since Cal Poly wine is in the process of changing their growers and producers, the entities are not fully static, so permissioned public is more appropriate. Cal Poly Wine's suppliers and distribution centers are also evolving, so having more flexibility would be appropriate. Also, allowing consumers to visualize where the wine was processed and grown would be valuable for them.

As mentioned earlier, in the wine industry, there are issues with counterfeiting. A permissioned private, or consortium, blockchain solution will provide consumers with the visibility to ensure they are purchasing the product they are sold and allow all the different participants with database access to post their information.

### 4.2. Cost/Implementation

| | Basic | Standard |
|---|---|---|
| | Environment for dev test | Run production workloads |
| Compute | 1 vCore | 2 vCores |
| Consortium Governance | ✔ | ✔ |
| Transaction Node price (per hour) | $0.0996/hour | $0.318/hour |
| Validator Node price (per hour) | $0.0996/hour | $0.318/hour |
| Blockchain Storage price GB per month | $0.05/month | $0.05/month |
| Blockchain data manager | $0.0001/transaction<br>Included transactions — 50/day | $0.0001/transaction<br>Included transactions — 50/day |

Figure 4: Cost of Blockchain Services in Azure
Picture and pricing information: https://azure.microsoft.com/en-us/pricing/details/blockchain-service/

For implementation, in this case, we investigated using the Microsoft Azure platform. From a cost perspective, two tables from the paper "Using Blockchain Services to Set Up A Business-Class Consortium Network," the cost was estimated for both AWS and Azure's blockchain solutions. Azure had a lower cost solution at $221.00 in a 700-hour test period, whereas AWS costs $473.20 (Mooers and Reimers 2020). As students, AWS and Azure were the most available platforms to us, so we looked into these to estimate the cost. Other options include a homegrown blockchain solution or working with a contracting service, but those were outside of our available budget. Since Azure supports our needs with their Quorum technology that alters the existing Ethereum technology to meet the privacy requirements of an enterprise, this supports our needs for Cal Poly wine. We estimated the monthly cost using Azure in a production environment as follows:

For Cal Poly's application on blockchain, we would have three members (Growers, Producer, and Distributor), would likely not need more than 10 G.B. of storage, so the cost calculation is as follows:
Node Cost: 3 members * 1 node/member * .318/node/hour * 700 hours/month = $667.80
Storage Cost: 3 members * 1 node/member * 10 GB/node * .05/GB/node/month = $1.5
Total monthly cost using Azure: $669.30

Note: If extending the blockchain to entities outside of Cal Poly, "Blockchain-based Wine Supply Chain Traceability System" recommends including the entities: grape growers, wine producer, bulk distributor, transit cellar, filler/packer, finished goods distributor, wholesaler, and retailer. In this model, the wine producer, bulk distributor, filler/packer, finished goods distributor, and wholesaler make up the consensus group. Modified to Cal Poly Wine's supply chain, this blockchain would include the entities mentioned, excluding the bulk distributor, transit cellar, and wholesaler, which are not separate entities in the supply chain. (Biswas et al. 2017)

## 5. Conclusion

Developing a consortium blockchain system on the Azure platform would cost roughly $669.30 a month but will provide the consumers of Cal Poly wine accurate, verified, and thorough information of where their wine is produced and distributed from. It will also benefit Cal Poly as they work to manage their blockchain as they will now have easier access and control over their supply chain database, will have more accessible means of record-keeping, and a simpler time connecting with the different entities. For the next steps, we recommend that Cal Poly Wine look into integrating one of the permissioned public blockchains discussed in this paper. This will allow Cal Poly Wine to improve their experience with managing and analyzing their Supply Chain data, as well as provide their consumers with a more reliable and extensive report on the wine they purchase.

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