Project 16.1: Optimization of Hydrogen Production Schedule and Strategy of Power Trading.

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Project Outline

Project Objectives

- The goal of the project consisted of optimizing the hydrogen production schedule to reduce costs and increase profits of the hydrogen station and analyzing the benefits of conversion of the Cal State LA fleet from gasoline powered to hydrogen fuel cell powered.

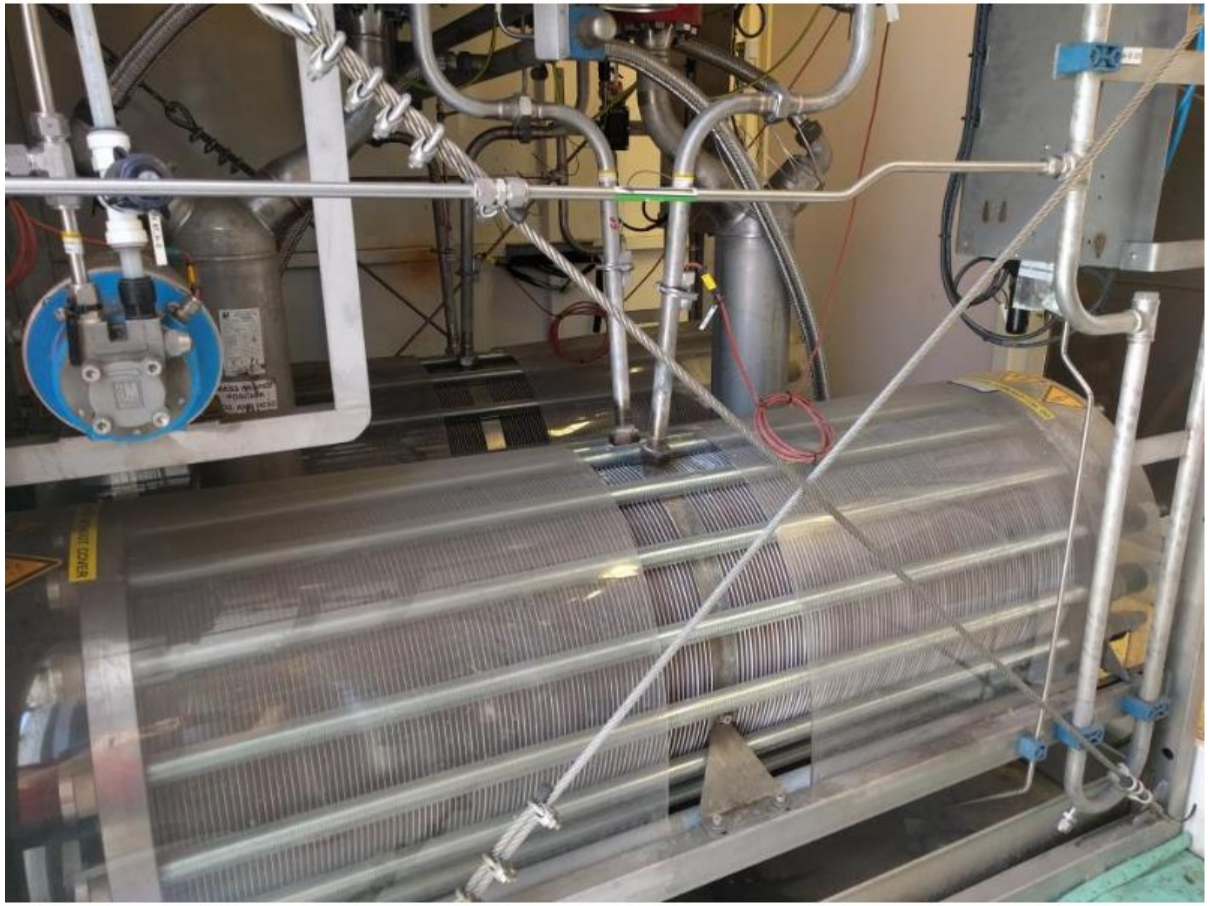
PROJECT BACKGROUND

- Hydrogen fuel is an alternate fuel produced by an electrolysis process which uses electrical current to separate diatomic molecules of hydrogen and oxygen from water.
- Currently the electricity provided by LADWP that is used by the electrolyzer is 33 percent renewable, by 2036 LADWP will provide 80% renewable energy and by 2045 100%.
- Electrolysis process will result in zero greenhouse emissions by 2045. The exhaust from the hydrogen powered cars currently produces zero emissions when using hydrogen.
- Hydrogen is a solution to help climate change concerns and improve the environment. It will also help reach California’s goal to have vehicles that produce zero emissions.
- Hydrogen fuel costs range from about $12.85 to more than $16 per kilogram but the most common price is $13.99 per kilogram.

CSULA HYDROGEN STATION

- On May 7, 2014, CSULA was the first university in the U.S that could produce and dispense hydrogen on site. The hydrogen station has the capacity to produce up to 60 kilograms per day.
- On November 12, 2014, the Cal State LA Hydrogen Research and fueling facility became the first in the world to sell hydrogen fuel by the kilogram directly to retail customers.
- Hydrogen station is conveniently located 6 miles away from downtown Los Angeles.

Electrolyzer Electricity Consumption



- Electrolyzer consumes 63kWh/kg.
- Electrolyzer works throughout the day at any given hour.
- Currently Electrolyzer operates when the electricity rates are high.

LADWP Energy Rates

Period	Time(s)
Base Period	8pm-10am
Low Peak Period	10am-1pm 5pm-8pm
High Peak Period	1pm-5pm

Period	High Season (June-September)	Low Season (October-May)
Base Period	$0.03522/kWh	$0.03895/kWh
Low Peak Period	$0.05595/kWh	$0.05688/kWh
High Peak Period	$0.06322/kWh	$0.05688/kWh

- Seasonal energy rates during different periods are provided by LADWP.

OPTIMIZATION GOALS

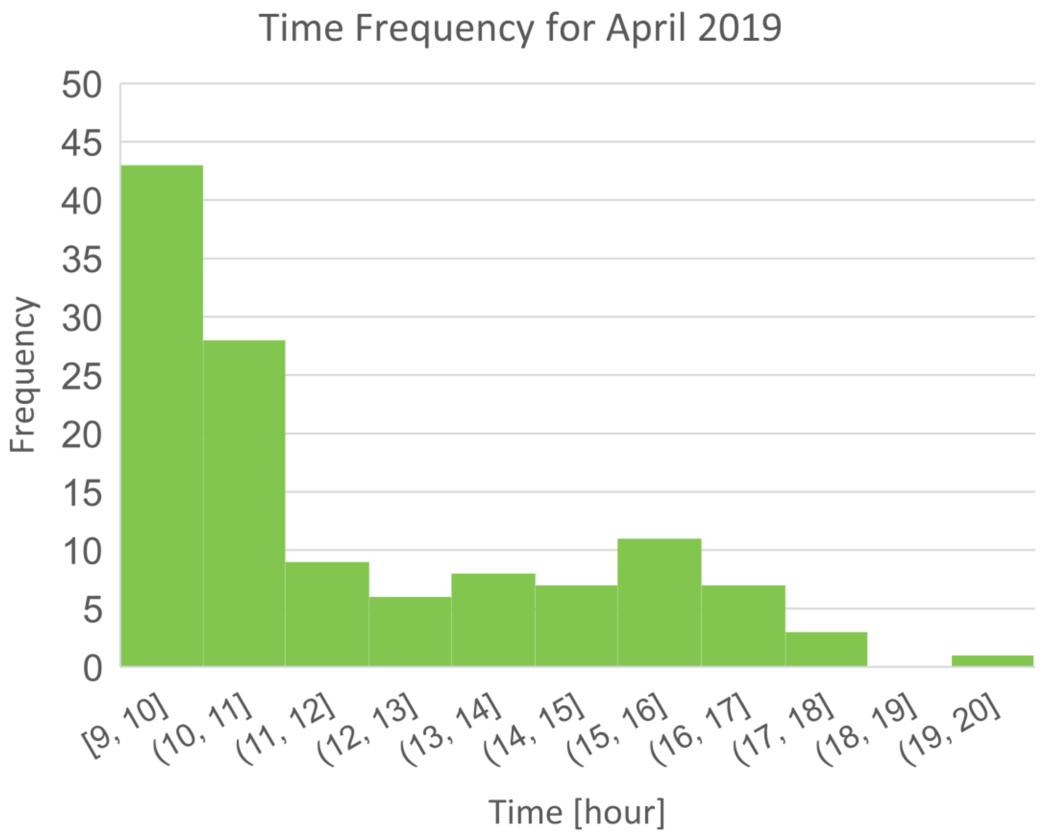
The objective functions of the optimization strategy are to

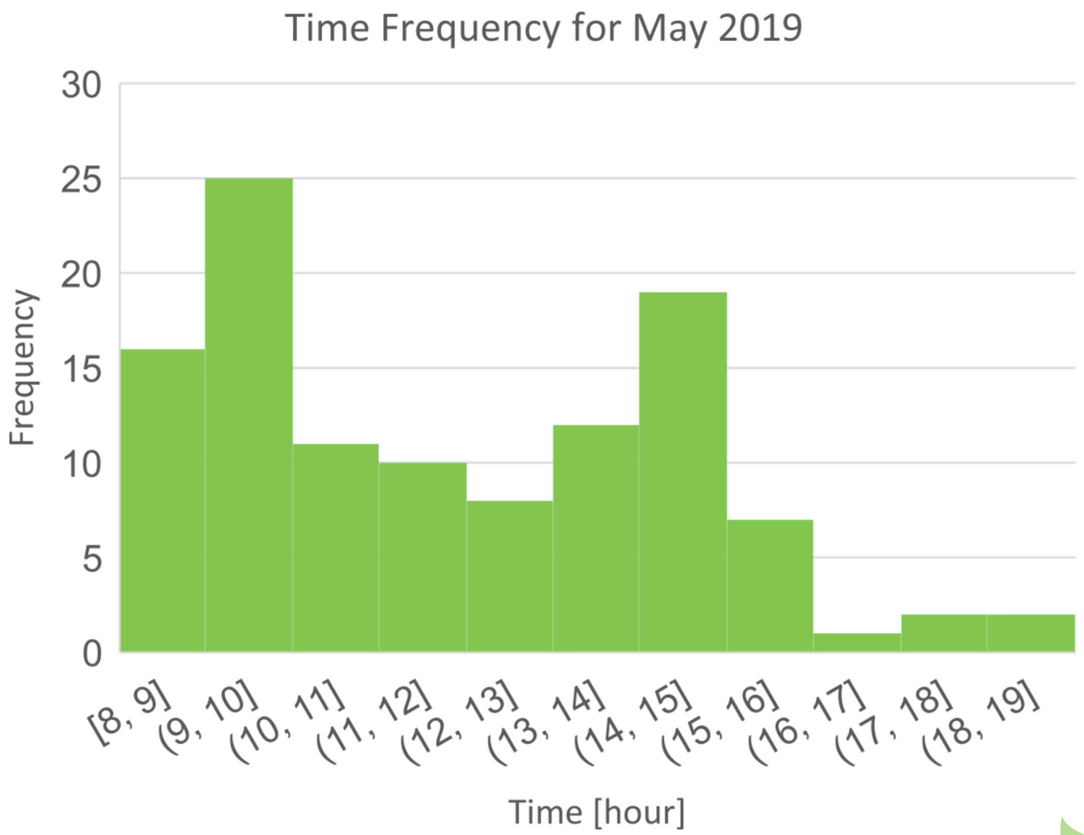
- Minimize electrolyzer electricity costs.
- Analyze implementing solar energy for the hydrogen station

The constraints for the optimization strategy are

- Electrolyzer production capacity (60 kgs per day)
- Size of the storage tanks (20kgs x 3)

Data Analysis





- These frequency plots represents a specific time when a sale occurred.
- This is one sample block of the extensive analysis that was done using excel data provided by station. Each sale had a corresponding time.
- There was never a specific pattern where the frequency was the same.

Data Analysis

Month	Avg Sale of Hydrogen per day [kg]	Minimum Sale of Hydrogen [kg]	Maximum Sale of Hydrogen [kg]
January	18.52	0.034	4.507
February	24.07	0.041	4.253
March	18.51	0.010	4.774
April	12.76	0.020	4.004
May	13.85	0.076	4.028
June	9.38	0.052	4.194
July	8.25	0.032	3.541
August	10.63	0.024	4.527
September	10.11	0.044	3.339
October	8.73	0.003	3.955
November	12.85	0.021	4.352
December	24.08	0.013	4.490

- For most months, the average was less than 15 kilograms.
- Highest sale was 4.774kg in March.

Baseline

Baseline represents the actual frequency and amount of hydrogen fuel sales at the station located at CSULA.

Algorithm Parameters

Variable(s)	Data
Electrolyzer Hydrogen Production Rate	2.4 kg/hour
Electrolyzer current ON/OFF Time	Turns ON after a sale of 3 kgs (anytime of day) Turns OFF after tanks are full (total of 60 kgs)
Current Production Cost Per Kg	$ 8/kg
Current Production Sales Per Kg	$ 16/kg
Electrolyzer energy consumption	63kWh/kg

Baseline

	Filling	TankLevel (kg)
1	0	60.0000
2	1	56.8220
3	1	57.0220
4	1	57.2220
5	1	57.4220
6	1	54.8160
7	1	55.0160
8	1	55.2160
9	1	55.4160
10	1	55.6160
11	1	53.4540
12	1	53.6540
13	1	53.8540
14	1	54.0540
15	1	54.2540
16	1	54.4540
17	1	54.6540

- For scenario baseline, the electrolyzer works after sales of 3 kilograms of hydrogen are made. That is when tank level equals 57.
- The figure shows that when Filling equals one the electrolyzer is working.

Baseline

Scenario Baseline

Total Yearly Hydrogen Sales	**3,965.6 kilograms**
Total Yearly Hydrogen Production	3,963.4 kilograms
Total Yearly Electrolyzer Electricity Costs	13,480 dollars
Average Electricity Cost per Kilogram	3.39 dollars/kg

- Table represents the total yearly results of hydrogen sales, hydrogen production, electrolyzer electricity costs, and average electricity cost per kilogram calculate using MATLAB.

Scenario B & Scenario C

Scenario B: Optimization based on hydrogen demand profiles.

Scenario C: Optimization based on hydrogen demand profiles with different criterions than scenario B.

Data Analysis

- Daily sales were calculated in Excel for the months provided by station. Results showed that there were consecutive days that sales were less than 15 kilograms.

- Results on daily sale calculations were useful to conclude that electrolyzer could be turned on after a total sale of 15 kilograms. This was adapted for both Scenario B and C.

Operation Constraints

- Tank level can't fall below 15kg.
- An additional condition was implemented onto both scenario B and C.
- Electrolyzer will start production when tank level is lower than 20kg while ignoring other criterions.
- Guarantee that tank level won't fall below safety limit and insures the maximum amount of savings.

Scenario B

Period	Time(s)	Production Time
Base Period	8pm-10am	Electrolyzer will start producing Hydrogen only if tank level is lower than 45 kilograms.
Low Peak Period	10am-1pm 5pm-8pm	Electrolyzer will start producing Hydrogen only if tank level is lower than 45 kilograms.
High Peak Period	1pm-5pm	Electrolyzer is not producing Hydrogen. *Note: Electrolyzer will only turn on if tank level is below 20 kilograms.

Scenario C

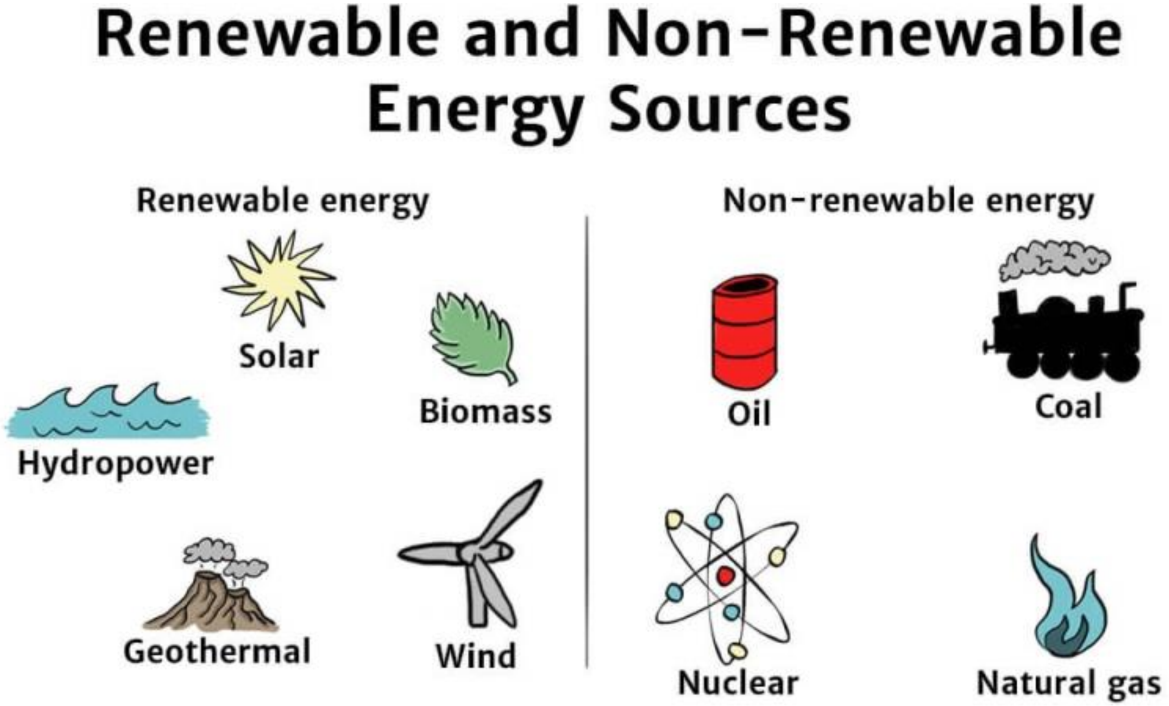
Period	Time(s)	Production Time
Base Period	8pm-10am	Electrolyzer will start producing Hydrogen only if tank level is lower than 45 kilograms.
Low Peak Period	10am-1pm 5pm-8pm	Electrolyzer is not producing Hydrogen. *Note: Electrolyzer will only turn on if tank level is below 20 kilograms.
High Peak Period	1pm-5pm	Electrolyzer is not producing Hydrogen. *Note: Electrolyzer will only turn on if tank level is below 20 kilograms.

Comparing Scenario Savings

	Scenario B	Scenario C
Total Yearly Savings ($)	2,613	2,972
Total yearly electrolyzer electricity cost ($)	10,867	10,508
Average Electricity cost per kg ($/kg)	2.69	2.58

Solar Energy Alternative for Hydrogen Station

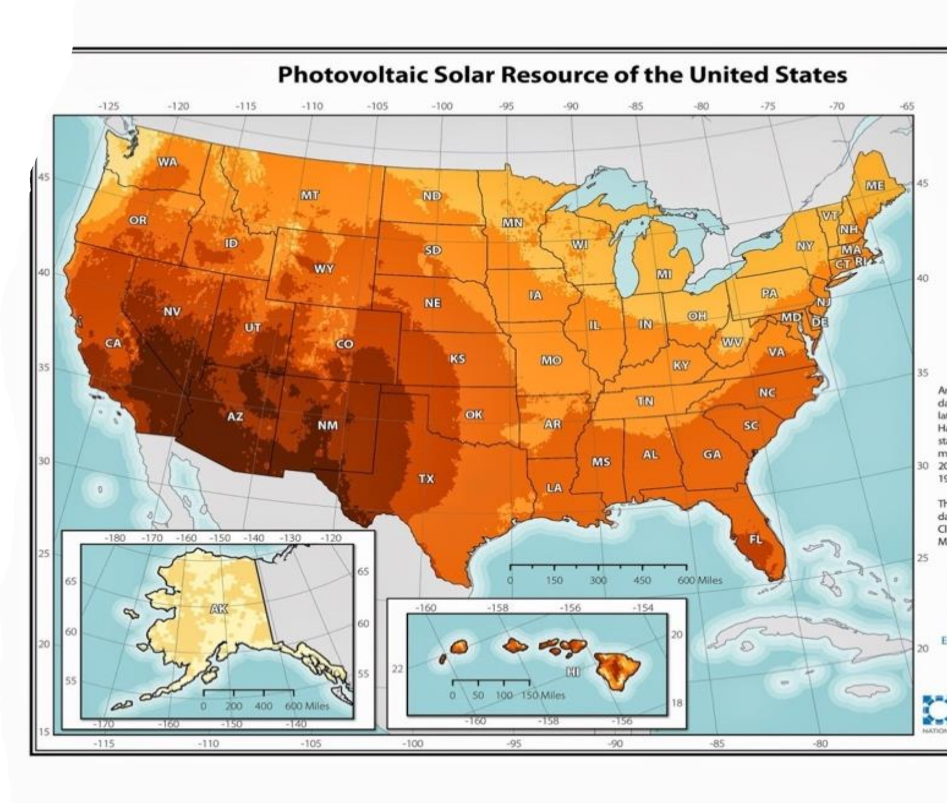
- When the station first opened one of the main goals was to produce hydrogen through 100% renewable energy, currently only 33% of the energy provided from LADWP is renewable.
- Solar Energy is dire for our current society due to global warming.
- Solar Energy does not create greenhouse gas emissions.



Solar Energy Alternative for Hydrogen Station

Solar Panel Geolocation Irradiance

- According to the National Renewable Energy Laboratory:
- Cal State Los Angeles is in the geolocation where solar panels can produce energy an average of 6 hour a day
- Los Angeles has 300 sunny days
- Peak Solar hours 9 AM and 4 PM



Solar Energy Alternative for Hydrogen Station

Alternative A: Represents a solar grid that will be producing 14.4kg of hydrogen per day, during the high solar peak hours of the day.

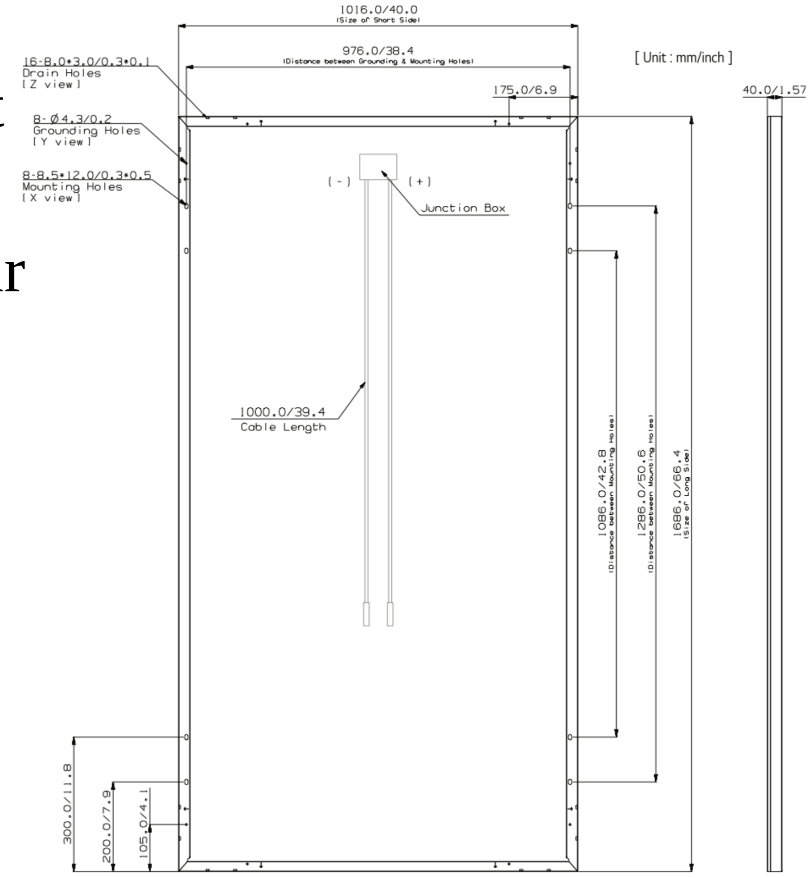
Alternative B: Daily Hydrogen Production of 11kg because after analyzing the hydrogen station's sales, mean of sales did not exceed 11 kg per day.

Alternative C: No Solar System.

Solar Energy Alternative for Hydrogen Station

After researching various solar panels, the module that is the most adequate is the LG NeON2

- This panel is 98% effective and comes with a 25-year warranty.
- Capability to produce 350W
- 1 Solar Panel Costs = $317.19



Sample Calculations: Alternative A.
Daily Hydrogen Production of 14.4 kg

Solar Power System Size in [W]	$\frac{14.4\ kg\ of\ Hydrogen\ *\ 63000\ Wh\ (per\ kg\ of\ h2)}{6\ hours\ of\ sunlight}$	151200
Solar to DC Efficiency	Average efficiency of inverters is 95%.	0.95
350 W Solar panel-DC Power [W]	$Solar\ to\ DC\ efficiency * 350W = 332.5\ W\ per\ panel$	332.5
Solar Panels required	$\frac{Solar\ panel\ system\ size}{332.5\ W\ per\ panel} = Modules\ Required$	455
Surface Area Required for Panels in²	$Panel\ Surface\ Area * Panels\ Required = Surface\ Area\ Required\ [in^2]$	1207781

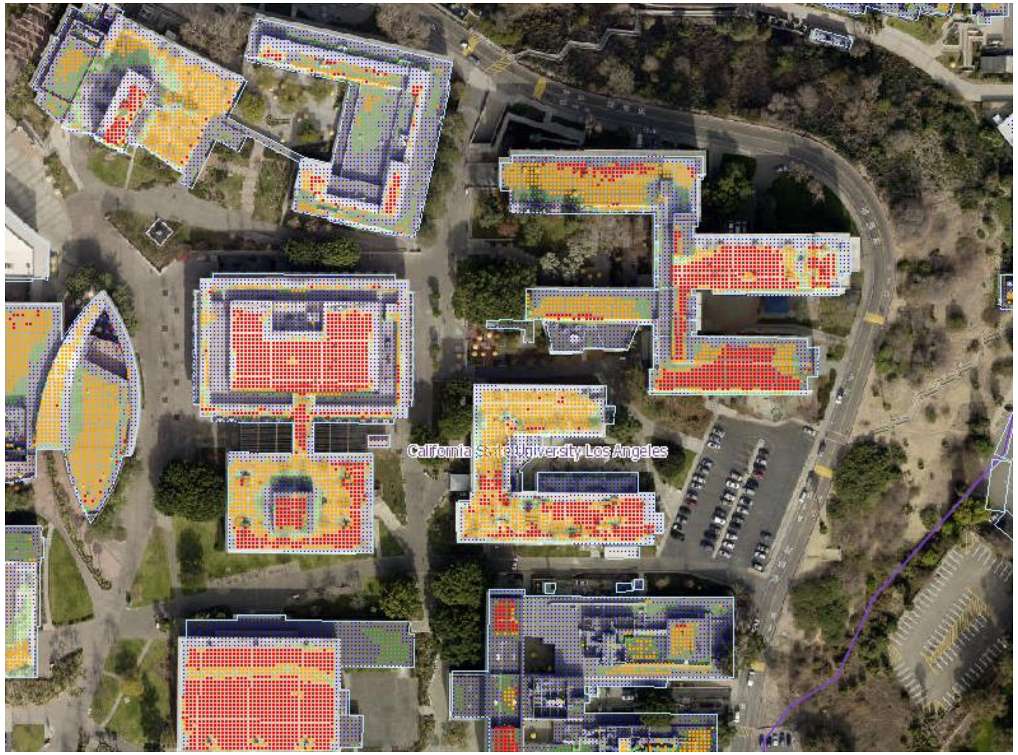
Panel Cost	1 Solar Panel Costs = $317.19 [3] $Solar\ Panels\ Required * \$317.19 = Panel\ Cost$	$ 144,237.98
Inverter Cost	$Required\ Power\ [W] = 60kW * 4 * \$4{,}550 = Inverter\ Cost$	$ 27,300.00
Permitting cost	$\$0.06W*$ Power Required [W]=Permitting Cost	$ 9,072.00
Install Labor	$\$0.29W*$ Power Required [W]=Installation Labor Cost	$ 43,848.00
Electrical and Structural Cost	$\$0.29W*$ Power Required [W]=Installation Labor Cost	$ 34,776.00
Sales Taxes 9%	Los Angeles has sales taxes of .095% * (Electrical and Structural Cost+ Panel Cost +Inverter Cost)	$ 19,599.83
Total Cost	Summation of all the lines.	$ 278,833.81
Rebate Incentive	*Rebate* (26%)* Total Cost	$ 72,496.79
Final Cost	Total Cost -Rebate	$ 206,337.02

Profits for Alternatives			
LADWP Electricity Cost during High Peak hours	Alternative A	Alternative B	Alternative C
25 Years with 2.4% electricity increase	$ 476,278.16	$ 476,278.16	$476,278.16
Profit/Savings			
Total Cost	$209,745.98	$ 278,833.81	
Rebate Incentive - 26%	$54,533.96	$ 72,496.79	
Final Cost	$155,212.03	$ 206,337.02	
Profit after 25 years	$ 321,066.14	$197,444.35	
Return in investment years	11	13.5	

Solar Energy Alternative for Hydrogen Station

Structural Capabilities

- CSULA has the capability of installing 349,575 Sq. Ft. of solar panels which is more than sufficient for hydrogen station
- King Hall alone has the surface area for 320 solar panels.



Solar Energy Alternative for Hydrogen Station

Alternative C: No Solar System

The final alternative is do nothing and leave the station as is. Since, there is an incentive of 26% rebate, installing solar panels will cost the station more after December 2022. Additionally, the cost of installation will also increase with the increase of solar demand. Finally, not producing hydrogen from renewable energies will cause deception with consumers that truly care about the environment.

Solar Energy Alternative for Hydrogen Station

Solar Results:

- After calculating the cost of installing the solar panels, it has been concluded that now it would be a good investment to install solar panels.

- The return in investment will be from 11-13.5 years for the solar panels' installation
- New hydrogen vehicle owners are offered 3 years of free hydrogen fuel, and they can choose any place to refuel. Offering 100% renewable energy is a sufficient incentive to increase sales.

Expanding Utilization of Hydrogen

Utilization Analysis: Converting Cal STATE LA transportation from fossil fuels to hydrogen fuel.

Objective

To provide a practical utilization roadmap for the Hydrogen production at the Cal State LA Hydrogen plant while reducing Cal State LA carbon footprint by:

Converting Cal State La Vehicle Fleet to Hydrogen Powered Fuel Cell vehicles

Vehicle Fleet system Analysis

- Cal State La has 184 vehicles that operate on-campus. 4 are Hydrogen fueled vehicles, 87 are 100% electric, and 93 are gasoline-electric, non-plug-in hybrid vehicles.
- From table , we can attain that 24,804 Gasoline (Gallons) and 2,382 Diesel (Gallons) were used during the ‘15/16 calendar year (highlighted in yellow)
- Green House Gas (GHG) emissions rate for gasoline and diesel displayed in figure and are highlighted in green.

Item	FY '90/91	FY '15/16	% Change from FY '90/91	Notes
Campus-wide Electricity Use (kWh), Including PV	35,605,386	42,193,417	19%	
PV Produced Electricity (kWh)	0	11,369		[1]
Utility Purchased Electricity (kWh)	35,605,386	42,182,048	18%	[1]
Natural Gas Use (Therms)	663,449	570,066	-14%	[1]
Gasoline (Gallons)	29,240	24,804	-15%	[1]
Diesel (Gallons)	100	2,382	2282%	[1]
GHG Emmission Rate for:				
Electricity (Lbs./kWh)	1.551	1.132	-27%	[2]
Natural Gas (Lbs./Therm)	11.665	11.665	0%	[3]
Gasoline (Lbs./Gallon)	19.643	19.643	0%	[3]
Diesel (Lbs./Gallon)	22.377	22.377	0%	[3]
Building GSF	2,375,431	3,066,840	29%	[1] [4]
GHG Emissions (Lbs./Year)	63,539,685	54,940,425	-14%	
GHG Emissions (Metric Tons/Year)	28,821	24,921	-14%	
Building Site Energy Use Index (kBTU/GSF)	80.6	66.6	-17%	[5]

Benefit of Credit System

- Hydrogen station receives 1 unit of credit for every 250kg of hydrogen sold.
- 1 unit of credit is worth $200.
- The total yearly hydrogen needed to convert CSULA vehicle fleet is 9881.19kgH2.
- 9881.19kgH2 will give a total of 39.52 credits per year.
- 39.52 credits are worth $6718.40.

Fossil fuels Vs Hydrogen

- Gasoline current retail price **$3.70/gallon**.
- Diesel current retail price **$3.90/gallon**.
- Hydrogen current retail price **$16/kgH2**.
- 24,804 gallons of gasoline used by vehicle fleet.
- 2,382 gallons of diesel used by vehicle fleet.

- 2025 projected Gasoline retail price **$4.81/gallon**.
- 2025 projected Diesel retail price **$4.86/gallon**.
- 2025 projected Hydrogen retail price **$10.66/KgH2**

Savings Analysis

Currently(2021)

Gasoline Cost	$91774.8
Hydrogen Cost	$149725.92
Savings = (Gasoline cost – Hydrogen cost)	No savings
Diesel Cost	$9289.8
Hydrogen Cost	$8373.12
Savings = (Diesel cost – Hydrogen cost)	$916.68 saved
Total Potential Savings including Benefit	No savings

2025

Gasoline Cost	$119307.24
Hydrogen Cost	$99754.89
Savings = (Gasoline cost – Hydrogen cost)	$19552.35 saved
Diesel cost	$11576.52
Hydrogen cost	$5578.59
Savings = (Diesel cost – Hydrogen cost)	$5997.93 saved
Total Potential savings including Benefits	$31868.94 saved

- By Converting the CSULA vehicle fleet to hydrogen powered vehicles currently will not produce any potential savings but by 2025 there is a potential saving of $31,868.94.

Green House Gas Emissions Reduced by converting vehicle fleet to hydrogen powered

GHG Emission Rate for Gasoline (lbs./Gallon)	19.643 lbs./Gallon
GHG Emission for current gasoline vehicle Fleet	$\mathbf{24804 \times 19.643 = 487224.97}$**lbs./Gallon**
GHG Emission Rate for Diesel (lbs./Gallon)	22.377lbs./Gallon
GHG Emission for current Diesel vehicle Fleet	**2382** $\mathbf{\times 22.377 =}$ **53302.01lbs./Gallon**
Total GHG Reduced	**487224.97 + 53302.01 = 540,526.98 lbs./Gallon**

- Important because it reduces Cal State LA carbon energy efficiency initiatives and can assist the campus to To continue making progress towards a carbon neutrality campus.

Conclusion

- Scenario C produced the greatest amount of savings.
- The best alternative for the station would be the alternative A, this is because the return in investment will be 11 years and it would have the highest profit at the 25th year with more than $ 321,066.14.
- Converting the CSULA vehicle fleet to hydrogen powered vehicles currently will not produce any potential savings but by 2025 there is a potential saving of $31868.94.
- Vehicle fleet will also reduce CSULA carbon footprint and reduce greenhouse emissions by 540,226.984(lbs./gallon) annually.

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