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Special Edition : Study trip

EDITORIAL

In early March, the 17th graduating class of the Advanced Master of Energy Systems Optimization (OSE) traveled to California for a study trip. The voyage was part of a partnership between the CMA (Applied Mathematics Center) and BECI (Berkeley Energy & Climate Institute). During their eight-day stay, the students visited a number of installations, mostly centered on this year's major theme: converting waste into energy.

In this monthly issue, we invite you to discover the places we had the opportunity to visit.

Firstly, we would like to thank all those without whom this trip would not have been possible. Our thanks to the partners and industrialists who welcomed us and took the time to present their activities, show us round their facilities, and exchange with us. Thanks also to Berkeley University, Stanford University, All Power Labs, Altamont Landfill & Resource Recovery Facility, EDF Inc., EDF Renewable Energy, Puente Hills Landfill Gas-to-Energy Facility, Primus Power, the San Francisco Public Utilities Commission, Scavenger Company, SMUD, and Total, who all helped to make this trip such a learning experience. We would also like to thank Philippe Perez, scientific attaché at the French Consulate General in San Fransicso

Special thanks to Ankinée Kirakozian, Doctor of economics and post-doctoral researcher at the CMA, Gilles Guerassimoff, head of the MS OSE, and the entire CMA team for organizing this study trip.

We hope you enjoy sharing our impressions of the Californian energy world. Happy reading!

The students at Berkely University, California

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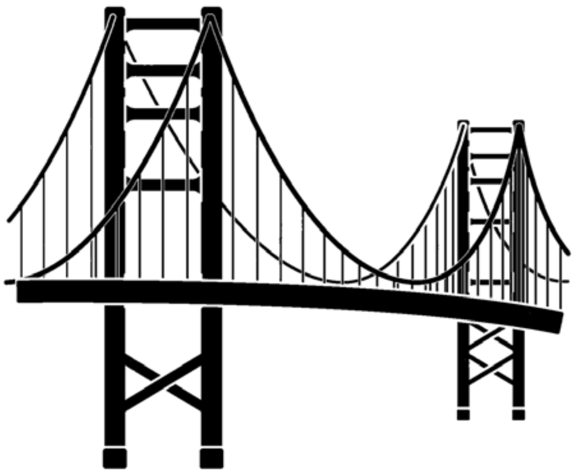


CALIFORNIA
LOS ANGELES
CALIFORNIA

Energy in California

The Californian energy transition was officially launched in 2006 when former governor Arnold Schwarzenegger signed the California Global Warming Solutions Act. The current governor, Jerry Brown, who was elected in 2011, is pursuing renewable energy efforts and aims to achieve the following three main objectives by 2030.

1. 1. Renewable share increase from 30% to 50% in the electric mix

Increasing the share of renewable energy in the Californian electric power mix serves two important objectives. First, the mix relies on fewer imports and second, it enables a 40% decrease in GHG emissions by 2030 (compared to 1990 levels). Under Schwarzenegger's governance, a target of 20% renewable electricity was set for 2010. This objective has been achieved. Mr. Brown is pursuing an ambitious policy for renewable energy deployment. By 2030, 50% of the electric power mix should come from renewable sources (cf. Figure 1).

Figure 1 : Share of renewable energy in the electric power mix in California
© G. California Energy Commission, 2016

Currently, the electric power mix relies on natural gas (which is the cleanest way to produce electricity from fossil fuel), while the remainder is composed of renewable (25%), nuclear (9%) and hydropower (6%) sources. Consequently, electricity in California has a relatively low carbon level. However, California imports more than one third of its electrical consumption, which means that the electric mix of neighboring countries must be taken into account as well. As a result, the mix becomes richer in carbon because of the use of coal-fired plants (6%).
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Although California is the second biggest CO2 producer in the USA, just after the Texas, if we look at the above figure, which presents levels per person, California has a very low emission level, and is one of the least-emitting states in terms of CO_2 (cf. Figure 2). One of the major drawbacks of this policy is that today electricity prices in California are among the highest in the USA (7th most expensive). Massive introduction of renewable electricity in the grid creates new challenges, such as grid flexibility enhancement. Thus, numerous startups, initiatives and new behaviors have emerged. Tesla has made electricity storage mainstream with its Powerwall, and other companies like Primus Power (cf. following article) have developed Redox Flow batteries for residential, industrial and many other applications.

Simultaneously, many microgrid projects have been developed to show the potential of renewable energy integration and illustrate the reliability of this type of grid. Examples include the SMUD microgrid and the Stanford tri-generation plant completed in 2015, which are the subject of an article in this Inf'OSE. Finally, Californians behave differently from other Americans in their enthusiastic adoption of renewable systems, self-consumption and low-energy consumption patterns.

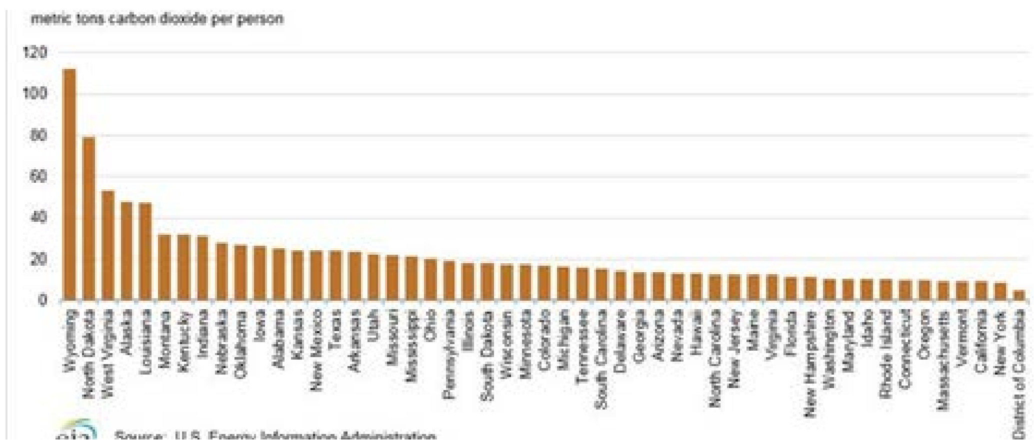

Figure 2 : Carbon dioxide emissions due to electricity in 2014 in USA © EIA, 2014

2. Reducing the use of oil in mobility by 50%

With its plan for a 50% reduction in the share of oil in mobility by 2025 (compared to 2014 levels), California expects an oil consumption reduction of 2,623 million liters (California Energy Commission, 2014). To achieve this, the state has implemented numerous incentives to promote alternative transport. The transport sector represents 39% of energy consumption in California, and its transformation will have a significant impact on GHG emissions: it is estimated that a GHG reduction of between 3.4 and 5.3 million metric tons of CO_2 equivalent could be possible by 2025.

California is leading a major turnaround in the transport sector. With almost 10,000 fast-charging electric stations installed throughout the state, around fifty hydrogen stations, and one hundred CNG stations, California has already begun its infrastructure conversion. Thanks to federal and governmental subsidies (which can be up to $10,000), Californians have access to electric vehicles, and the plan is to subsidize around 1.5 million clean vehicles by 2025. The success of this policy is so huge that clean car sales have already exceeded expectations (cf. Figure 3).

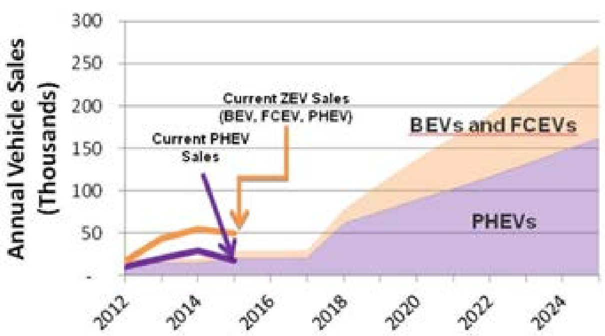

Figure 3: Sales of electric cars (BEV), fuel cell cars (FCEV) and hybrids (PHEV) in California © gov California Energy Commission, 2016

Many captive fleets such as buses, waste trucks, etc. are switching from oil to electric or natural gas. This is the case for the companies Waste Management (WM) and Scavenger (both visited during our trip) which use natural gas produced with waste to run their trucks. In California, no fewer than 2,725 trucks are powered by CNV. Today, Scavenger is not totally profitable without subsidies, but WM has overcome the hurdle, and is making gains on its fuel bills and truck maintenance.

3. Double energy efficiency in the building sector

Annually, California's energy consumption totals 191 MTep of which 18% is dedicated to residential uses. When added to commercial uses, this consumption is at the origin of 26% of the state's GHG emissions. The objective is to double the energy efficiency of buildings by 2030. In 2013, 70 TWh were saved thanks to design efforts in building (Energy Commission, 2015). Thanks to new regulations and standards, California has limited the sector's electricity consumption to 1% and natural gas consumption to 0%. Standards are driving the construction sector to produce net zero energy buildings, that is to say buildings that provide all the energy they need (thanks to local renewable sources). These new standards should come into effect by 2020 for the residential sector and 2030 for the commercial sector. In order to reach this objective, industrials that produce domestic appliances are required to reduce the electrical consumption of their products. The new rules should enable energy savings of 49% for TV and 2.2TWh for battery chargers.

4. To sum up

By aiming at these three objectives, California is following the common strategy of saving as much energy as possible by improving the overall design of various commodities. As a result, significant energy consumers, such as transportation, are transferred from a high-carbon to low-carbon source, i.e. electricity that relies on renewable sources. Such a strategy enables fast reduction of carbon dioxide emissions and is generally the outcome of many prospective models.

Baptiste CALMETTE

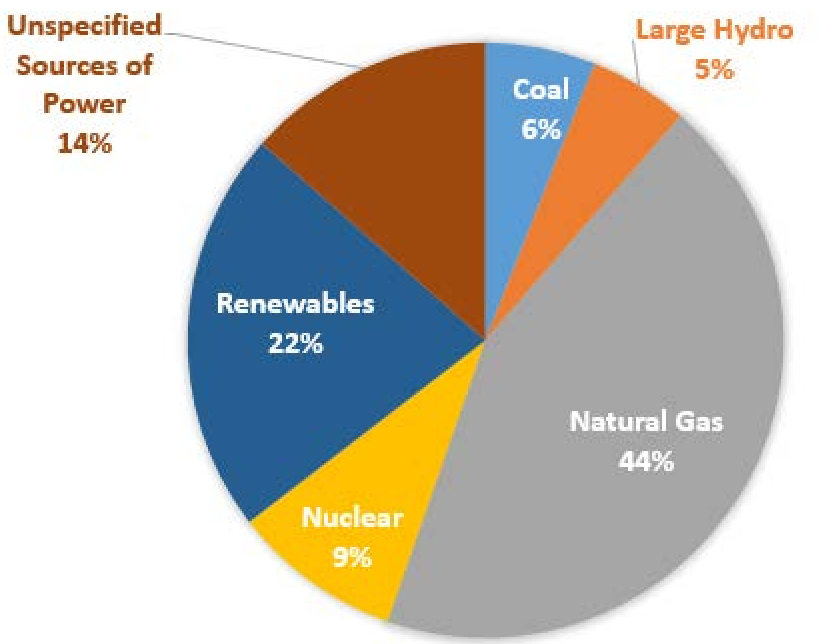

Figure 4 : consumption mix in California
© EIA, 2016

Sources :

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Berkeley Energy and Climate Institute

For the first visit of our study trip, the OSE Master's team was warmly welcomed by Professor Scott Moura and his students at the Berkeley campus. The morning was punctuated by four presentations. To start with, Scott Moura presented his activities and gave a general description of Berkeley University. Then two groups defended their projects in connection with the Start-up Elum, which had given the same subject to the French and American students. Finally, the French students spoke on the topic of the waste-to-energy schemes.

1. Elum: A Franco-American exchange

The aim of this project is to minimize the aging of lithium-ion batteries with heterogeneous characteristics. This is possible by optimizing the current delivered by the different batteries.
The Advaneced Master OSE students presented two approaches to answer the problem: linear and nonlinear.

Students making presentations

In the first case, a piecewise linearization of the objective function, coded in Python, was performed in order to solve the problem with a Gurobi solver. In the second case, a Pyomo modeler and IPOPT nonlinear solver were used to produce a resolution without approximation. In addition to these two resolution techniques, a dynamic thermal model was incorporated to refine our results. With both approaches the results were substantially the same. Following the presentation, we were asked many questions. We were challenged on both highly technical details, such as certain parameter values, and on much more theoretical considerations, such as our choice of reference model and economic considerations. The battery aging model choice was made in accordance with the Elum engineers' proposal. Nevertheless, the students took a critical look at the hypotheses and limits of the model. As to the economic issue, it was pointed out that this factor was not taken into account in the objective of the problem. The goal was to quantify the aging associated with the use of each battery in the park in order to propose economic criteria at a later stage.

The Berkeley students took a step back from the problem and, with their expertise in the field of batteries, presented a state of the art of approaches that could solve the problem. Their study validated the need to take temperature into account. They intend to propose a linear and nonlinear resolution of the problem in the future.
This meeting allowed us to discuss our modeling experience with the American students, and also to constructively criticize each other's work.
This peer-review event was one of the key events of the trip and one that the students will remember.

2. OSE advanced master class project presentation

The second lecture delivered by the OSE master students was dedicated to presenting their work on waste-to-energy schemes. During a twenty-minute speech, the various dimensions of the subject were approached.

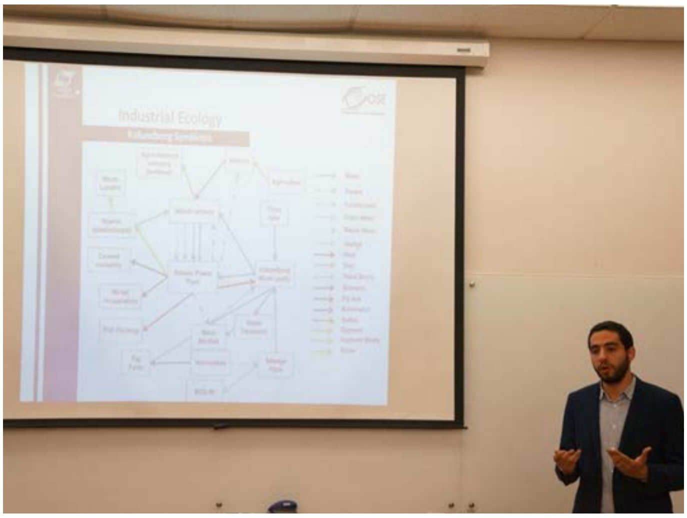
The various technologies of the waste-to-energy schemes were then evoked. The students began by discussing the direct methods used to recover energy from waste. Thus, the methanization process was presented and illustrated by the example of the wastewater treatment plant MAERA in the south of France, a site that produces electricity and heat and covers up to 60 % of its energy needs.

Waste pyrogazeification and incineration were also evoked as direct methods to extract energy from waste. This first part of the speech ended with a focus on the French case and a study of the Brest metropolis project, which produces electricity and heat for the entire city. The possibility of indirectly recovering energy from waste was also highlighted during the conference. The students focused in particular on the study of nuclear waste and showed that 96% of this waste could be recoverable as MOX fuel.

The second part of the conference focused on the role of waste-to-energy schemes to support the development of industrial ecology. The students began by introducing this concept as a set of operations inspired by natural ecosystems that aims to reduce the impact of industrial and human activities on the environment. The industrial symbiosis of Kalundborg in Denmark was given as an example. Kalundborg is an eco-industrial park set up in 2010 and clustering companies from the public and private sectors that collaborate to use each other's by-products and share resources. For a 75-million dollar initial investment, this project generates an annual profit of 15 million dollars.

At the end of their presentation, the students did not fail to underline the limits of certain waste-to-energy processes in relation with their environmental, climatic and sanitary impacts. They also pointed out several paradoxical objectives between reducing waste and increasing the number of waste-to-energy units, and the need to pay attention to the pernicious effects ensuing from this confusion of speech.

The conference ended with an exchange between Pr. Scott MOURA and the master's students on the favorable context required to foster the development of this industry. The discussion highlighted in particular the role of state policies in implementing a favorable framework to boost waste-to-energy technologies.



This morning session was an opportunity for the OSE master students to exchange with another team of students from one of the most famous universities in the world and to discuss issues related to the new energy context. All of the participants at the session would like to particularly thank Pr. Scott MOURA for organizing this conference.

Quentin SOUVESTRE

OSE Students in front of the Berkeley Building of engineering

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Altamont Landfill and Waste Management Facility

During our visit to the Altamont landfill facility operated by Waste Management ®, we greeted by Lawrence G. Lacera and William F. Louis, two gas operation managers who presented the facility's main activities, and Sara Fockler, an environmental protection specialist who was our guide throughout the tour. We would like to thank them for providing us with this opportunity.
Altamont Landfill and Resource Facility is a regional facility providing landfill, recycling and waste management services for households and industries in the County of Alameda, east of San Francisco Bay.
Established in 1980, the facility covers more than 2000 acres (approximately half a hectare) including 1000 acres of protected lands. The old fill area (Fill Area 1) covers 237 acres will soon be replaced by a scheduled 200-acre fill area (Fill Area 2) currently under construction. The daily waste treatment capacity is approximately 11,150 tons per day.

Before beginning the tour, Lawrence G. Lacera explained the gas production process: Under anaerobic conditions, waste burial produces a gas consisting of 50% methane (CH_4), 45% carbon dioxide (CO_2) and 5% nitrogen dioxide (N_2) and some other small components. After drilling a multitude of wells with a depth of 200 feet (about 60 meters) and a diameter of 3 feet (90 cm) each, the contained gas mixture is vacuum-extracted vertically through perforated PVC tubes that are each 6 inches long (about 15 cm). Therefore, gas extraction must be controlled in order to limit air intrusion leading to dioxygen and nitrogen dilution of methane. In fact, the critical threshold corresponds to 0.4% O_2 and 40% CH_4 levels.
The speakers clarified that monitoring the gas deposit as well as performing well tuning by adjusting equipment helps ensure good gas quality and limit methane surface migration to guarantee operators' safety on site. As part of their duties, operators carry out visual inspections of wells, verify the absence of a gas smell on the surface, and then proceed to measure the gas composition before establishing the necessary settings.

Gas Power Plant

A pipe network conveys the recovered gas to two gas plants: the first power plant
comprises 2 gas turbines producing 3.1 MW of electricity each. The second one is a gas to liquefied natural gas (LNG) plant, operated as a joint venture by the Linde ® group, that supplies a collection of vehicles and commercial fleets with CNG (Compressed Natural Gas) comprising more than 98% methane.

The engineers in front of the LNG production unit

CNG replacement of diesel fuel saves 30,000 tCO_2 of emissions annually. In fact, CNG, compared to diesel, generates 20% less CO_2 emissions and significantly reduces NOx and particulate emission levels by up to 75%.
Each plant is equipped with a flare that burns unprocessed gas, either produced in excess or induced by turbine maintenance, at a temperature of 600°F (about 315°C) and a flow rate of 600 cubic feet / min (approximately 17 cubic meters / min). It also aims to eliminate pollutants such as NOx and CO_2.

3.1 MW Turbine

Last year, the exported gas volume reached 3.1 million gallons (about 11,700 cubic meters), bearing in mind that the State of California subsidizes biogas sales through a carbon tax premium of $3 per gallon. However, the second landfill currently being constructed requires substantial investment. For instance, the cost of one well is estimated at US$ 15,000, given that a project requires at least 20 wells spread all over every 1.5 acres.

The facility faces several future challenges, such as ensuring the project's viability, dealing with changing air pollution regulations, and organic matter sorting. We would like to warmly thank our hosts for organizing this visit.

Adnane BAIZ

Lawrence G. Lacera and OSE' students

Stanford Energy System Innovations

SUSTAINABLE STANFORD

Stanford University is an American University of Excellence, ranked 2nd Best Global University (Shanghai 2016 Rankings). Stanford is located in the heart of Silicon Valley to the south of San Francisco. The university hosts more than 15,000 students and has 5 departments of research and teaching: Graduate School of Business, Law School, School of Engineering, University School of Education and University School of Medicine.

Joseph Stagner, Executive Director of Sustainable Energy Management, welcomed us and introduced us to Stanford Energy System Innovations (SESI).

Stanford Energy System Innovations (SESI) is a new university sustainability program designed to meet the energy needs of the Stanford campus through 2050. SESI represents a significant transformation of the university, from fossil-fuel-based cogeneration with a capacity of 50 MW, which had been used since 1987, accounted for 85% of university GHG emissions and used 25% of its fresh water supply, to the more efficient, electric-powered heat recovery system in use since 2015. The principle of this innovative system is to recover waste heat from the district cooling system and use it to heat water for district heating.

In the longer term, Stanford's heat recovery is predicted to capture 57% of this unwanted heat for re-use to supply 47% of campus heating needs. The CHC with heat recovery system will reduce Stanford's GHG emissions by 90% and save 18% more water.

In addition to the Central Energy Facility, the project involved the installation of 22 miles of piping across campus and updates to the mechanical systems of more than 150 buildings to accommodate the new hot water distribution system. The power plant consists of 3 large water tanks to store thermal energy. These tanks have a capacity of 5 million gallons (18.9 thousand m3) for cold water and 2.3 million gallons (8.7 thousand m3) for hot water. The power plant also includes an electricity substation for powering the plant and a heat recovery system that supplies Stanford with heat and cooling. The tanks have been optimally insulated because the loss of thermal energy is only 2% per day.

We also visited the control center of the heat recovery system. This dispatching hub controls the incoming heat and cold water from the university and manages the conversion system. The Central Energy Plant Optimize Model (CEPOM) was also developed by Stanford researchers and students. CEPOM designs, operates, and verifies the performance of the energy system. The tool is capable of designing a heat distribution plan hour by hour and choosing the best equipment for the CEF, taking into account weather conditions every 15 minutes and the electricity price hourly. The many benefits of this optimization program include:

- A 7.3 MW (-17%) reduction in Stanford's electricity demand peak
- Smoother energy demand
- Annual savings of $ 500,000 (-10%)
- Operation in autopilot mode for better energy efficiency

Although developed independently by Stanford from 2009 to 2011, SESI may be the first large-scale example in the world that employs the technology roadmap for building heating and cooling recommended by the International Energy Agency. This new system, along with Stanford's solar power procurement, reduces campus emissions by 68% compared to peak levels (2012). In its first year of operation it saved 18% of campus drinking water.

Control room

We would like to warmly thank Joseph Stagner for his warm welcome and interesting visit.

Geoffrey ORLANDO

The students in front of the CHC with heat recovery system

Primus Power

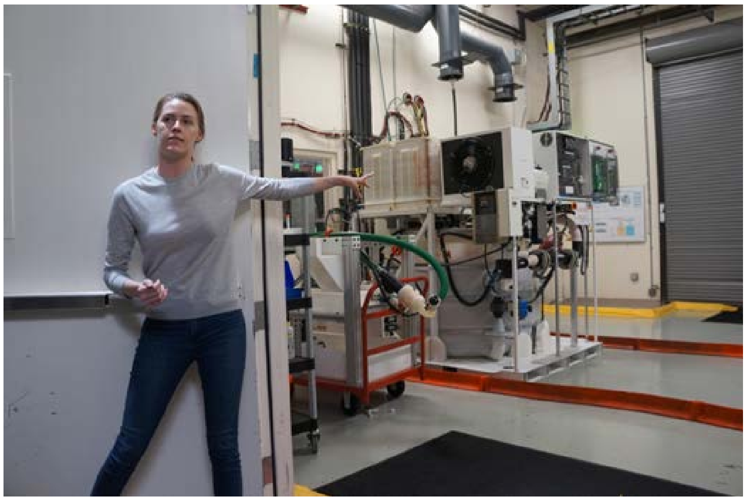
Energy storage solutions are critical to meet power grid challenges. We were received on Tuesday, March 7 at Primus Power in Hayward, California, by Vice President of Operations Mark Collins and Mechanical Engineer Emily Davenport.

They presented us the context in which the company was created, its positioning and the products developed. Founded in 2009, the company has developed, with support from the US Department of Energy, a zinc bromine flow battery, called the EnergyPod, intended for grid-scale energy storage applications. This battery has many advantages including a relatively low cost thanks to its readily available constituent materials. Also, it is designed to last twenty years and offers supply system capability from 25 kW to 25 MW with a five-hour discharge. The EnergyPod is suitable for a great variety of applications; today it is mainly installed on industrial and commercial sites in order to reduce premiums charged by utilities (Samruk in Kazakhstan, Microsoft data center in Washington) and on military microgrids to ensure reliability and energy supply autonomy (Miramar in Southern California). The EnergyPod is composed of a thermal management system, a battery management system, a pump, an electrolyte tank, and stacks of electrodes. Its maintenance is subject to a service agreement with the customer.

Mr. Collins explained to us that Primus Power has R&D and commercial partnerships with several leading companies producing electrical components, chemicals and power, such as Raytheon, Siemens and ICL. Additionally, the company is supported by international energy investors such as Anglo American, Chrysalix, DBL, IZBF, Kazyna Capital, KPCB and Rusnano.

According to a Goldman Sachs study, stationary energy storage is expected to grow to more than 30 GigaWatts, and $ 30 trillion over the next eight years. Flow batteries will be ideal for the stationary energy storage market, since electric grid applications need long-lasting, low-cost solutions.

For comparison, traditional power batteries are best suited to small-scale, short (less than an hour), shallow applications, while energy batteries (flow batteries) are best suited to large-scale, long (4 to 6 hours), deep discharge applications. A flow battery's capacity does not decrease over time, as opposed to a traditional battery. Several aspects make Primus Power batteries superior to traditional flow batteries: for instance the absence of membrane makes them cheaper and extends their life. Moreover, because they are composed of titanium electrodes rather than graphite electrodes, they are more competitive, robust and efficient.



Emily Davenport takes us to the laboratory

To conclude the discussion, Mr. Collins told us that the future improvements of Primus Power would include reducing the battery's cost even more. The company is currently producing its 2nd generation battery, the EnergyPod 2, which is less expensive, more reliable and robust.

Thanks to Mark Collins and Emily Davenport for welcoming us to Primus Power and for presenting us with this solution for the future.

Primus Power's EnergyPod

Dimitra IGNATIADIS

EDF Innovation Lab

Stéphanie Jumel, Energy Services Program Director, warmly welcomed us late in the day on Tuesday 8th March to present to us EDF projects in the United States and more precisely in San Francisco Bay. Ms. Jumel explained to us that EDF is present in the United States through its subsidiary EDF Renewable Energy, the biggest wind farmer in the US. The French energy company operates four solar power plants in the region, for a total installed capacity of 160MWp, including Catalina, the 8th biggest solar power plant in the world, which has an installed capacity of 140MWp.

EDF Renewable Energy is a leading company in the wind industry, having developed more than 7800MW of wind projects. Each year, the group ranks among the top ten wind project investors and owners in North America EDF Inc. comes under the direction of EDF R&D. Opened in 2014, the Los Altos site's research activities focus on technological and regulatory watch of the energy sector in the United States. More specifically, it targets clean techniques, such as energy efficiency, flexibility, storage, smart grids, and heat recovery. Thanks to its location in Silicon Valley, the 12 engineers at the Los Altos site can work with startups to integrate their solutions. This special situation enables them to identify the emergence of new services and new technologies. The detection, analysis and transfer of technology make it possible to strengthen the competitiveness of the EDF Group's business units. To facilitate these interactions, partnerships have been established with the Electric Power Research Institute (EPRI) and the universities of San Diego and Berkeley.

By observing the American electricity market, which is a precursor in terms of regulations, researchers at the Innovation Lab also identify opportunities and threats to the EDF group. For example, S. Jumel cited the appearance of Community Choice Aggregations (CCA) in several states, which aggregate demand for electricity from consumers locally and assign the supply of electricity to a non-profit institution, so as to secure access to energy.

Thibaud ROY
Geoffrey ORLANDO

Sacramento Municipal Utility District (SMUD)

On the morning of Wednesday 8th March, we went to the SMUD headquarters, where we were warmly greeted by Mr. Dagoberto Calamateo. The visit started with a presentation of SMUD and a demonstration of one of their microgrids by Mr. Mark Rawson, manager of the Distributed Energy Strategy and Innovation department.

The US energy landscape is made up of two main types of electricity utility. First, "investor-owned utilities", which are the largest utilities in the country. Stakeholders invest into these and receive a regular return through dividend payments. The other type is "publicly owned utilities", like SMUD, which are owned by the community and governed locally by an elected board of directors representing the different regions of the territory covered. As a result, SMUD does not aim to make a profit and its model is instead driven by the objectives imposed by the board.

We were told that investor-owned utilities are regulated by the California Energy Commission, while SMUD is regulated only by its own board, so that it is more autonomous in terms of decisions. The R&D program is made up of approximately 25 people - engineers, economists, analysts and scientists - and the research areas include renewable energies, energy efficiency, climate change, electricity transmission, energy storage, microgrids, etc. This program is quite unique for a small utility like SMUD.

Mr. Rawson then focused on the microgrid demonstration project, co-funded by the State of California, to demonstrate the feasibility of this type of project at the commercial and industrial facility level. SMUD is interested in understanding how on-site cogeneration could be used to provide high reliability to customers beyond standard levels.

For a long time, distributed generation was seen as a threat by utilities because an industrial customer who installs his or her own means of generation will require less energy from the utility. Moreover, utilities are concerned by this self-generation because they cannot visualize or control it. The idea was to create an interface to protect the relationship between the customer and the utility, ensuring reliability, power quality and safety requirements. In the future, on-site generation could become an asset that could be dispatched by the utility to ensure the reliability of the grid.

The composition of the microgrid is detailed in the table below:

Quantity	Technology	[Unit]
3	Natural gas engine	100 [kW]
1	Smart switch	1200 [A]
1	PV	10 [kW]
1	Absorption chiller	123 [ton]
3	Centrifugal chiller	500 / 600 / 200 [ton]
4	Natural gas fired boilers	-
1	Chilled water storage tank	760.000 [gallons]

Figure 1 : Microgrid demonstration technologies

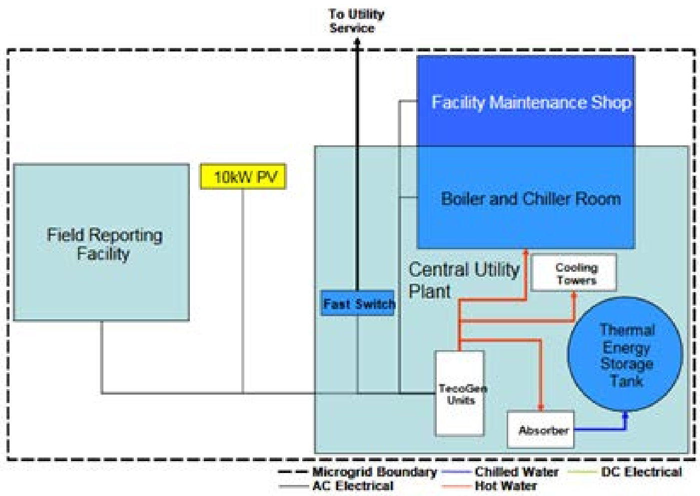


Figure 2 : Microgrid overview
source : SMUD Energy R&D Program

A "smart switch" is a high-speed switch that monitors the waveform of the voltage and the current on the grid side in order to isolate the microgrid - island mode - when certain set values are exceeded. During this period, the smart switch continues to monitor the grid until the microgrid can be reconnected.

Waste heat from the three gas engines - TecoGen - is used in the winter to preheat the water going into the boilers, which reduces gas consumption and saves energy. In the summer, the aim is to use this heat to run the absorbing chiller and thus generate chilled water to offset some of the chilled water normally generated by the electrical chillers. This is yet to be demonstrated.

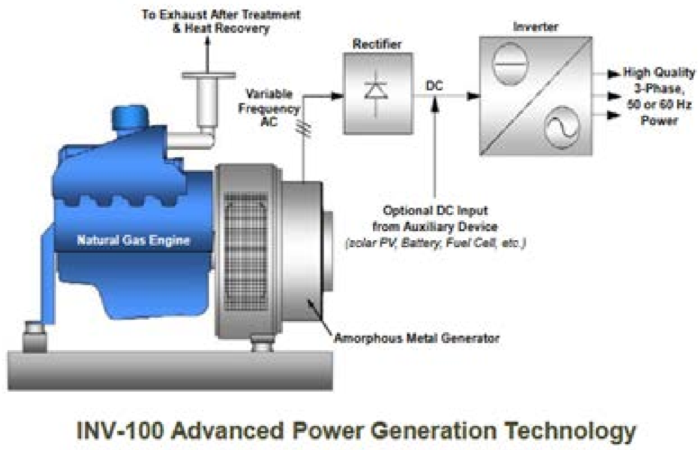


Figure 3 : TecoGEN
source : SMUD Energy R&D Program

The TecoGen rectifies a high-frequency voltage wave to DC, which is then released into a power inverter to generate a 60 Hz wave. Thus, these engines can be operated at variable speeds to efficiently consume fuel and generate fewer emissions. The TecoGen has an almost instantaneous response to variations in demand and can also regulate the voltage levels while the microgrid is in island mode.

Moreover, each TecoGen is fully independent: each generator checks the frequency of 60 Hz and adapts the delivered power. In other words, machines are controlled autonomously and do not depend on a centralized control system.

The microgrid also has a chilled water storage tank allowing the chillers to be operated at night, which is more efficient, since the system should not be subject to high air temperatures. As a result, electricity demand ranges from 1.5 MW to 60 kW at peak electricity consumption in the middle of the afternoon due to air conditioning. In addition, operating at night avoids high electricity prices in the middle of the day when the utility grid is more stressed.

The energy savings of this system are estimated at $ 50,000 / year and are mainly based on two principles:

• Delaying the purchase of electricity from the grid to off-peak hours.
• Reducing gas consumption in boilers.

Nevertheless, the payback of the system is quite long, due to the investments involved, i.e. three gas engines and the smart switch. This project was driven to create a program for customers who need high reliability.

At the end of this detailed presentation, we visited the facilities, accompanied by Mr. Rawson and Mr. Calamateo.

Heat Recovery system

Our thanks again to Mr. Mark Rawson and Mr. Dagoberto Calamateo for giving us their time.

Alejandro YOUSEF DA SILVA

M. Rawson in front of TecoGEN

All Power Labs

If you walk down Murray Street in the industrial district of West Berkeley, California, you cannot miss a strange waste ground with a "Back to the Future" movie-set décor. This is the All Power Labs company. Surrounded by robots, containers and colorful sculptures, Tom Price appeared with his Californian tan, dressed in a gold bomber jacket. This former environmental manager of the Burning Man Festival is now Director of Strategy at All Power Labs and was our guide on this amazing visit.

The central courtyard of the All Power Labs site in Berkeley, California

All Power Labs is a small, 44-person start-up present in three countries (USA, Philippines and South Africa) that develops small-scale, cheap, carbon-negative energy-generation technologies. Operating in the highly competitive San Francisco Bay area, this company stands out for its ability to draw inspiration from the region's historic open source and collaborative culture in order to integrate it into an energy project.

The story started seven years ago. At that time, 1010 Murray Street was a huge studio for artists abounding with creations for the Burning Man Festival. When the municipality of Berkeley cut off electricity from the studio in order to expel its residents, the small team decided to retaliate by producing its own electricity. A first attempt with solar panels coupled to generators failed due to the intermittence of the solar resource and the excessive price of the generators. Determined to find a solution, Jim Mason, the current CEO and founder of All Power Labs, decided to adapt a century-old technology discovered in a Swedish energy engineering manual: gasification from biomass.

Gasification's golden age dates from before the advent of oil, when it was used to produce artificial gas (syngas) from coal. The discovery of oil at the end of the 19th century and its ensuing massive exploitation led to the obsolescence of gasification. However, the enterprising team at All Power Labs is reviving this process by adapting it to the current problems of our society. Jim Mason's system works with biomass, enabling it to produce negative carbon energy and use a renewable resource in remote, often agricultural, areas. The general but disseminated presence of biomass means that this type of system can only be profitable on small installations.

Brainstorming and gigantic amounts of coffee were the daily routine in the studio to finish the first pilot system, before engineers came to complete the team. The first gasification system coupled with a generator producing electricity was modeled on Solidworks. The system ranges from 15 to 18 kW depending on the model and accepts a wide variety of inputs (walnut and coconut shells, agricultural residues, wood chips). Although the type of input conditions the performance of the system, on average it requires 1.2 kg / kWh of resources.

Engineers work on the biomass gasification system

Between two rusty containers and under a simple sheet protecting it from the sun, we discovered the “beast”, which follows a relatively simple process. The biomass is continuously mixed and introduced into the reactor heated to above 250°C to produce synthetic gas. This gas contains mostly dihydrogen, carbon monoxide and methane, and the combustion produces carbonaceous residues that can be upgraded and used as fertilizer.

The syngas then passes through a series of filters to precipitate the impurities and prevent them from settling in the gas engine. These filters can be coupled with heat exchangers for cogeneration and more optimal use of the system. The gas engine is the final device in the system and generates electricity less than 10 minutes after the introduction of the first inputs into the reactor.

The system is characterized by low costs i.e. $ 1.5/W for CAPEX and only $ 0.02 / kWh (not including maintenance costs) due to low biomass prices, simple temperature control, pressure, and the gas engine. Its size also makes it suitable for transportation in a maritime container. When we entered the main building with its prohibition-period café decoration, Tom explained to us that a number of improvements are in the pipeline for this dynamic team. One example is the addition of a fluidized bed that will allow the integration of a greater variety of inputs, such as coffee. Another plan is to install a cleaning system for the tubes and motor to avoid soot deposits and increase the lifespan of equipment. Digitizing the system would also be a great idea for a more efficient and handy man-machine interface.

The price (between $28,000 and $36,000) depends on option choices with an estimated life of 5 years. The ingenious system created by All Power Labs caters to a wide range of clients including NGOs, remote communities, the US government and universities. Today the price is still high (3 to 4 times more expensive than a generator) but the team’s determination and creativeness is bound to meet this daunting challenge. We are grateful to Tom for the time he devoted to us to present the project and take us round a very unusual site.

Tom Price tells us how powerful the system is

Léa TATRY

TOTAL Amyris

On Wednesday 8th March, we visited the premises of TOTAL New Energies located in Emeryville. We were welcomed by Sébastien Rifflart, the bioreactor and separation program manager.

Before visiting the laboratories, Mr. Rifflart explained to us TOTAL's positioning in the new biofuel market. As part of its investments in innovative processes to produce a sustainable energy source, the global energy leader has partnered with Amyris, a Californian company specialized in biotechnology since 2010. Established in 2003, Amyris is today at the forefront of technology to develop micro-organisms (strains and bacteria) capable of rapidly synthesizing molecules, targeting in particular the health field, cosmetics manufacturers and the industrial world (fuels, lubricants, solvents, etc.).

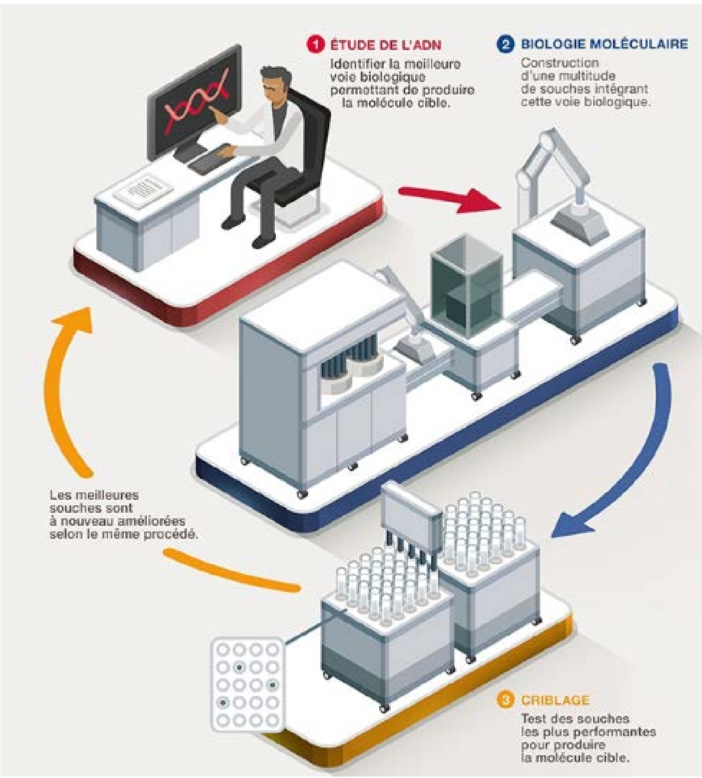


Figure 1 : Microorganism selection & optimisation by biology synthesis

SAlthough it now accounts for 14% of global energy consumption, the use of biomass for power generation and biofuels is expected to quadruple by 2035 according to IEA scenarios (IEA, 2012). Indeed, biomass is of great interest because of its availability, varied applications and contribution to the reduction of CO_2 emissions. Already with a strong presence in solar energy through its affiliate SUNPOWER, TOTAL's commitment to renewable energy, in particular biofuels, is the object of its partnership with Amyris. This collaboration also serves airlines in their drive to reduce CO_2 emissions generated by their fleets.

Sébastien Rifflart explains the farnesinesynthesis process

Located a few blocks away from the TOTAL premises, the Bio-Process Platform (BPP) synthesizes farnesane, a biofuel obtained by hydrogenating farnesene, Amyris's flagship molecule. The latter comes from fermenting cane sugar and can now be produced in large quantities thanks to Amyris's expertise in the genetic manipulation of microorganisms. Farnesane has many advantages over fatty acid methyl esters (FAMEs), which are widely used in the biodiesel market. It is particularly resistant to low temperatures and can be used in higher proportions in conventional fuel mixes. Jet fuel containing farnesane also has a slightly higher LHV (Lower Heating Value) than kerosene. S. Rifflart told us that several test flights from San Francisco-Paris and Paris-Toulouse operated by Air France use a jet fuel containing farnesane. Despite its advantages, the process of converting biomass has some disadvantages. Today, it is only possible to obtain 30g of farnesene from 100g of cane sugar. The overall process for obtaining farnesane has a yield of about 23%. In addition to low yields, the introduction of farnesane into jet fuel can only be achieved at a maximum of 10%. This maximum limit is due to restrictions on the freezing point of fuel. Since the farnesan molecule is very long, higher proportions would not comply with current standards. Finally, the selling price of biofuels remains high in relation to the market price, the target being to remain within the maximum 50% difference acceptable to airlines.

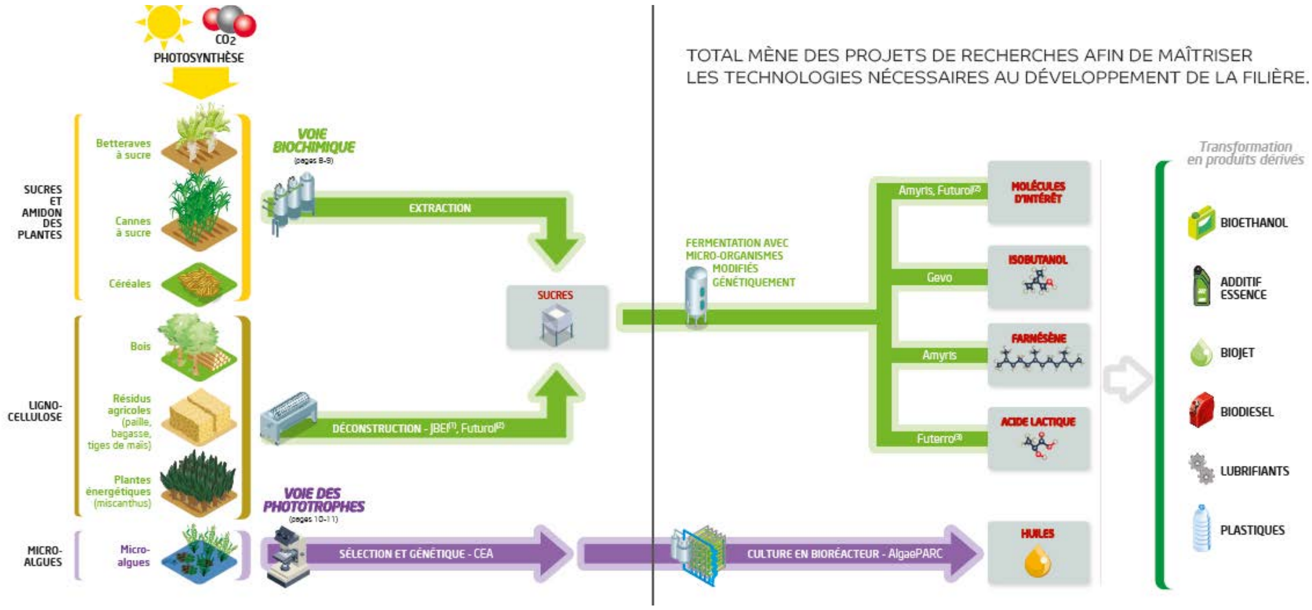


Figure 2 : Biomass valorization chain
TOTAL, 2014, Paris: Energies Nouvelles.

TOTAL's partnership with Amyris is not its only bioenergy initiative. The group is also developing research activities with the start-up Novogy, an MIT spin-off specializing in oilseed strains devised to produce specific lipids and lubricants. In addition, partnerships are working on an alternative to cane sugar used in the synthesis of farnesene. As Mr. Rifflart pointed out, today two companies are working on this challenge using cellulosic sugars. They are Futurol, a European company taking the enzymatic route, and Renmatix, an American company specialized in employing supercritical steam to extract sugar from cellulose. On a larger scale, note the group's bio-refinery project in the Mède plant, which aims to produce 500,000 tons of biofuel per year from vegetable and waste oils, with a launch planned at the end of 2017.

TOTAL New energy laboratory

We would like to thank the TOTAL group for giving us this opportunity to visit the BPP and particularly Sébastien Rifflart for his warm welcome and informative tour.

Gildas SIGGINI

AIE, 2012. World Energy Outlook 2012, Paris: IEA PUBLICATION.

San Francisco Public Utilities Commission (SFPUC)

The Advanced Master's OSE students were greeted by Jonathan Smith, an employee at the SFPUC for eight years, who introduced the students to the agency's activities and then accompanied them on a visit to the wastewater

Jonathan Smith on SFPUC site

The agency

The SFPUC is a public agency responsible for ensuring the water supply to the 6.5 million inhabitants of San Francisco Bay and for wastewater treatment. It also supplies some municipal services (e.g. airport, police) with renewable electricity (hydraulic and photovoltaic). San Francisco is one of the only cities on the West Coast (and the only one in California) to have a combined sewer system, which deals with domestic wastewater and rainwater. The network is 150 years old, and consists of more than 1,000 miles (1,600 km) of pipelines.

Improvement program

J. Smith explained that to deal with the deterioration of the sewer system and new standards, the SFPUC is planning a major project, called the Source System Improvement Program (SSIP), to renovate its infrastructures. This $ 6.5-million program will be completed over 20 years and should be capable of withstanding an earthquake of magnitude 6.

At the same time, a study is underway to construct a large treatment unit taking into account future needs and improving treatment for the southern districts.

Wastewater treatment process

Mr. Smith then showed us the sewage treatment facilities. On an ordinary day, 83 million gallons of wastewater are discharged into the sewers. Three treatment plants exist: the Ocean Side Treatment Plant (built in 1993), which treats 20% of the wastewater, the Southeast Treatment Plant (dating from 1951) which manages the remaining 80%, and a third in the north, used during peak periods and stormy episodes. The wastewater is first screened to separate non-organic waste (toilet paper, plastic bags, etc.) and then passed through a grit removal filter.

The waste recovered during these two stages is sent to landfill (8 trucks per day). A primary clarification is then made by sedimentation, where the solids are separated from the liquids. Originally, liquids were discharged directly into the Bay, but in 1972 the Federal Clean Water Act introduced more stringent standards, and several complementary treatment stages were added.

The next stage is "aeration" (oxygen being added at this stage), a biological process, where microorganisms feed on the pollutants and clean the water. A second clarification then takes place, during which the last solids are removed. A final disinfection (using chlorine and sodium bisulfite) enables the effluent to be discharged into the San Francisco Bay or the Ocean.

The solids resulting from these various steps are thickened with polymers and then used for anaerobic digestion. The heat required for the process is recovered for use in the treatment plants' boilers, and to generate electricity, as is the gas produced. Gas production covers 30% of the needs of treatment units. Residual biosolids (200 ton per day) are used as fertilizer.

The SFPUC plans to use recycled water to irrigate gardens.

The SFPUC also includes teams of chemists and biologists who test the discharged water and study its impact on aquatic life. Beach monitoring is also carried out to prohibit swimming when problems arise.

Some issues

Stormy episodes, which are sometimes violent and sudden, can lead to a surpassing of the sewer system's capacities. The water flows into the pipes by gravity. To avoid reflux, SFPUC has set up 200 million-gallon capacity boxes, which store rainwater to be dumped directly into the ocean in critical situations.

Cooking oils poured into the sewer system can also cause serious problems (stoppers, etc.). A collection program has been set up to transform the recovered oils into biofuels.

Thanks again to Jonathan Smith for this interesting visit, which took the Masters students into the underworld of the city!

Apolline FAURE

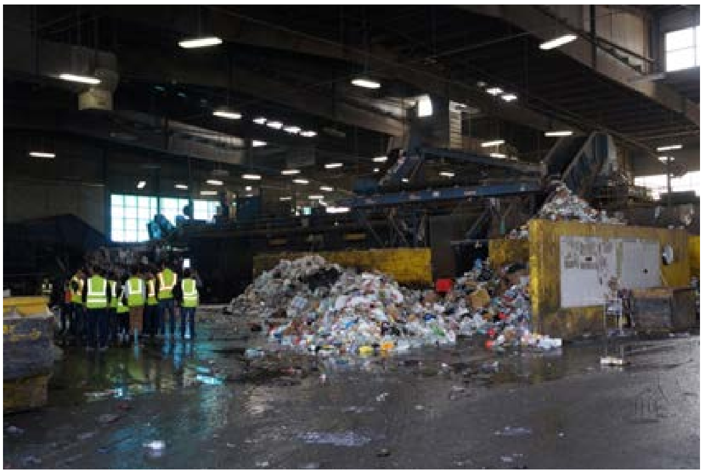
SCAVENGER

On Thursday morning, we were welcomed by Chris Axton, Sustainable Program Specialist at Scavenger, a company that collects waste and runs a methanization plant.

Scavenger SMARTFERM is a biogas plant located south of San Francisco, set up by three companies: Blue Line Transfer Inc. (a collection and recycling plant), South San Francisco Scavenger Co., Inc. (waste management) and Zero Waste Energy, LLC.

Built in 2015, this methanization plant processes more than 11,000 tons of waste per year to produce CNG and 5,000t of high-quality compost. The facility produces more than 100,000 gallons (equivalent to about 380,000 L) of CNG diesel per year, which supplies 10 of collection vehicles and a portion of the plant's needs.

The first part of the visit consisted in exploring the waste reception platform. The waste is sorted to separate recyclable waste, such as plastic bottles, which is sent to the recycling plant, from household waste, which is particularly interesting for the methanization process. A first sorting is carried out upstream, with collection vehicles comprising two compartments in order to reduce the number of rounds (recyclable waste and paper).



C. Axton explained that some of this non-recyclable waste is sorted so that it can be sent to the methanization unit (about 25% of the daily household waste). Sorting involves removing any material that may degrade the efficiency of the digestion process.

The methanization unit is composed of:
- 8 anaerobic dry thermophilic digesters
- a purifier to clean ammonia

In the first stage, the organic waste is stored before being sent to the digesters. These are fed every 21 days to ensure biogas production throughout the year. The blend is composed of 30% green waste and 70% pre-sorted household waste.

Following the digestion and production of biogas, a purification step is necessary to obtain a concentration of 91% methane in the gas. At the same time, the digestate obtained is stored and heated for a first treatment in order to collect the ammonium sulfide and eliminate any remaining pathogens.

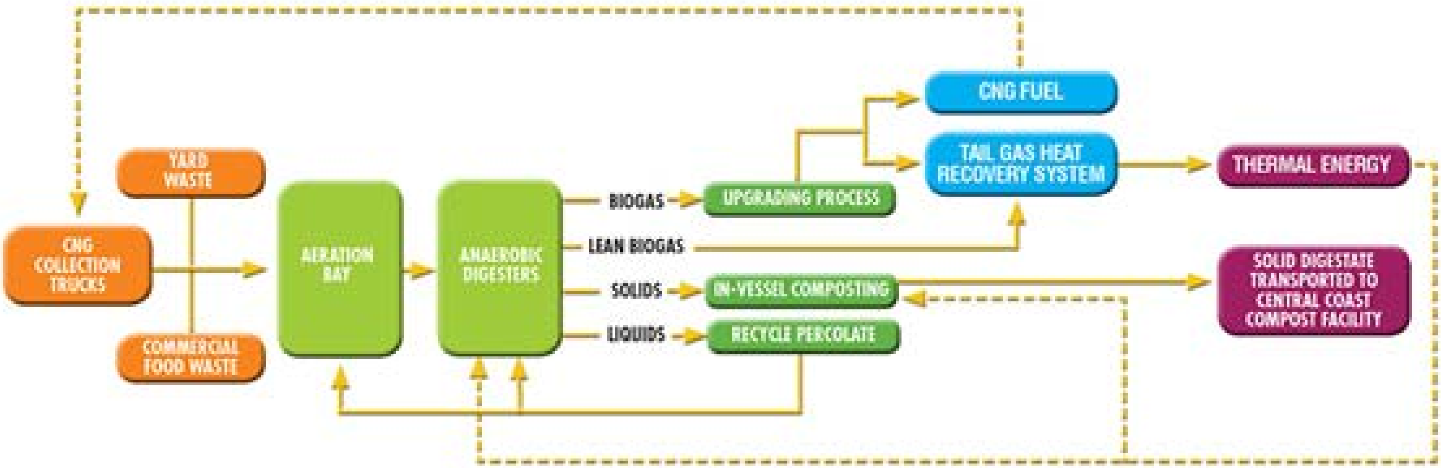
Biogas purification unit

Mr. Axton also told us that anaerobic digestion can produce fuel for collection vehicles and high-quality fertilizer, and reduce waste volume by 30%. The firm made this choice to reduce its greenhouse gas emissions. In addition, CNG vehicles offer advantages in terms of durability and maintenance compared to conventional vehicles.

We would like to thank Chris Axton and SCAVENGER for this interesting visit.

Yanis HIRIDJEE

CNG vehicle



Plant operation

Source : http://zerowasteenergy.com/what-we-do/our-projects/south-san-francisco-scavengers-blueline/

Chris AXTON explaining the process

CATALINA solar power plant EDF Renewable Energy

Solar in the State of California

The United States of America has a very high solar irradiation potential in the south-west of the country. In some areas of California, in particular, irradiation rates are above 2000 kWh / m2, representing significant exploitable energy. Thus, California hosts 7 of the 15 largest solar PV plants in the world. Dating from the end of 2014, California is the first state in the United States to have more than 5% of its electricity generated by solar power plants, with 6 801.7 MWp of total installed capacity and 8 336 GWh of generated energy.

OSE master's students had the opportunity to visit the CATALINA solar power plant, thanks to Mr. Noel Hidalgo, the site supervisor. We would like to thank him for the time he gave us and his readiness to answer our questions.

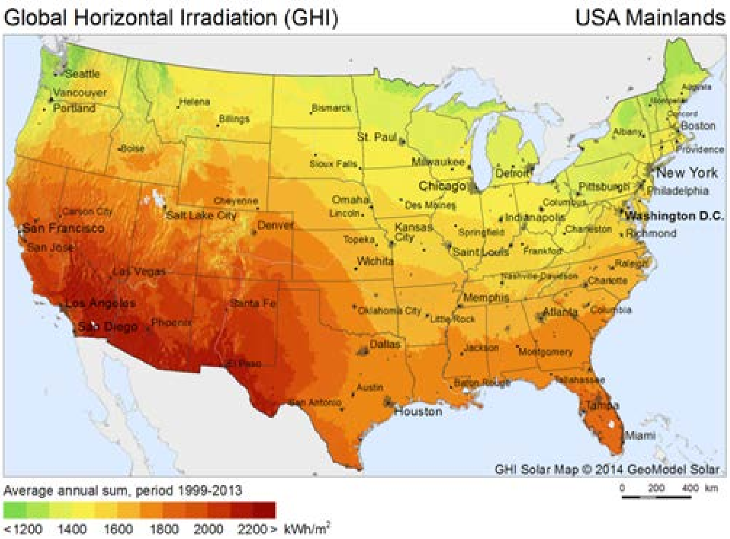


Figure 1 : Global horizontal annual solar irradiation Source : SolarGIS (https://solargis.info/)

Presentation of the Catalina project

In May 2012, EDF Renewable Energy, the US subsidiary of EDF, began the construction of a new photovoltaic solar power plant with a surface area of 445 hectares, called Catalina, in the Mojaves desert. This project created direct and indirect economic activities, as well as more than 500 jobs at the construction site. The Catalina solar power plant became operational in two phases: the first phase started in December 2012 with 60 MWp and the second phase in August 2013 with an additional 83 MWp. In total, the plant has a power capacity of 143.2 MWp from more than 1.1 million photovoltaic solar panels. The electricity produced by the park is equivalent to the annual consumption of about 35,000 houses. The supply is provided by the US company San Diego Gas & Electric, on a 25-year repurchase contract. At the environmental level, the Catalina project avoids the emission of 250,000 tons of CO_2 each year.

In 2014, EDF Renewable Energy sold 50% of the capital of the Catalina power plant to the insurance and American investment fund company, TIAA CREF. However, EDF Renewable Energy Services continues to be responsible for operation and maintenance works.

Figure 2 : Photovoltaic panels at Catalina solar power plant

Photovoltaic modules

The photovoltaic panel modules at the Catalina power plant are based on so-called thin-film technology. This is the second generation of cells, in which the semiconductor is deposited by vaporization directly onto a support material (glass or other). The advantage of this technology is that it is less expensive, the cell manufacturing is less polluting, and it can operate at low lighting levels. On the other hand, its efficiency is lower, between 9% and 11% (12% and 20% for monocrystalline and polycrystalline technologies), and its performance decreases more significantly over time. The Catalina PV modules are of two types:

- CIGS-type modules (with absorbers made from alloys of copper, indium, gallium or selenium) by Solar Frontier, representing 82 MWp of the plant's power;
- CdTe-type modules (used on the basis of cadmium tellurium) by First Solar, and representing 61 MWp of the plant's power (690,000 modules).

The photovoltaic panels at the plant are stationary and do not have automatic trackers, allowing the panels to remain perpendicular to the solar radiation during the day. Note that the plant does not have an electricity storage system, which means that all of the electrical energy produced is injected directly into the grid.

Figure 3 : Characteristics of the First Solar PV CdTe panel

To exploit California's significant solar potential, EDF Renewable Energy has begun construction of a new power plant called Catalina Solar 2, operational since July 2015.

To conclude, we would like to thank EDF Renewable Energy and the entire team, and in particular Mr. Noel Hidalgo, for giving us the opportunity to take a close look at the photovoltaic panels of a major solar power plant.

Figure 4 : Characteristics of the Solar Frontier PV CdTe panel

OSE Master's students in front of the solar panels at the Catalina power plant (OSE Mastere's photo)

Amine EL MOUSSAOUI

La centrale Pacific Wind

We were welcomed for this visit by Mr. Dale Whinery and Rich JIGARJIAN in charge of operations at the Pacific Wind Farm. We would like to thank them for their availability during this visit, which allowed us to take a concrete and detailed look at the operation of a wind power plant.

View of a wind turbine at Pacific Wind Park

The Pacific Wind farm is located in the Antelope Valley (Kern County) north of Los Angeles. The plant, which was commissioned in 2012, consists of 70 turbines with a rated output of 2.05 MW and provides electricity to 40,069 households. The installation of these turbines has prevented the annual emission of nearly 321,000 tons of CO_2, which corresponds to the use of more than 63,000 vehicles. A Power Purchase Agreement was signed with the US energy company San Diego Gas & Electric (SDGE) in 2012 for a 20-year operating period. As in France, an incentive scheme exists in the United States to encourage the penetration of renewable energy into the California electricity mix: the PTC (Renewable Electricity Generation Tax Credit) makes it easier to install this type of project thanks to a credit for each MWh produced from renewable energy sources.
These measures should enable the State of California to meet its energy transition targets by increasing the percentage of electricity from renewable sources to 33% by 2020.

OSE students at the foot of a wind turbine

All wind turbines at the Pacific Wind power plant were produced by the German manufacturer Senvion (formerly RE Power System): each turbine measures 78.5 meters high with a rotor diameter of 92.5 meters. Wind direction and intensity are measured using an anemometer at the top of each wind turbine. If the wind direction is constant for at least 10 minutes, the turbines begin to produce electricity from a wind speed of 4 m/s. The nominal power of the turbines, corresponding to the maximum power delivered by the generators, is reached for a wind speed equal to 12.5 m / s. The direction of the wind is measured manually at each wind turbine in order to adapt the pitch angle. The orientation of this pitch angle is used to increase efficiency: it takes 10 minutes for the wind turbine to adjust this pitch angle.

During windstorms, when the wind speed is greater than 24 m/s, wind turbines can be stopped after a few seconds by a manual pitch angle change. The farm mainly receives a northwest wind resulting from a temperature gradient between the desert and the sea: a meteorological tower located within the park centralizes the data and detects possible faults.

Control center inside the wind turbine

Significant disparities concerning the amount of electricity produced have been observed in previous years: in 2015, the average capacity factor for all of the wind turbines on the farm was about 30%, yet it only reached 20% in 2016. The turbines are placed at four different altitudes on the foothills of the Antelope valley and are subject to severe turbulence due to their proximity, resulting in a phenomenon commonly known as the "wake effect", whereby some wind turbines produce electricity while others remain at a standstill. Installing the turbines at distances of at least three times the rotor (270 meters) has allowed the operator to limit this disruptive effect. Unlike the Catalina solar power plant, the wind farm is not subject to a limit of power injection into the grid. However, the electricity produced by the turbines is increased at a voltage of 40 kV before being injected into the CAISO (Californian Independent System Operator) network, which is the operator that distributes electricity in the County of Kern.

Pacific Wind

The investment cost of each wind turbine is approximately 2 million euro, bringing the cost of each MWh installed to 1 million euro. Turbine maintenance operations are carried out twice a year by a team from EDF EN, comrising six technicians and two supervisors. On week days, an on-site team continuously controls the farm, while the dispatching center takes over during the night and on weekends. Investors are responsible for the maintenance and repair costs of the turbines.

In spite of the satisfactory performance of the Pacific Wind field, for its next project EDF EN is looking towards developing a farm of PV solar panels equipped with its own sub-station to inject into the grid.

OSE students in front of a wind turbine

Our special thanks to Dale Whinery, all of the team who showed us round the Pacific Wind plant, and Rich Jigarjian, VP of Generation at EDF renewable Energy. This visit was an opportunity for us to observe the inside of a wind turbine and have a very concrete overview of its operation. Like the Catalina solar farm, this visit demonstrated California's ambition to become a leader in the energy transition.

Jean BERTIN

Puente Hills Landfill Gas-to-Energy Facility

We were welcomed by Marie-Christine Wiltord who was our guide throughout the tour, by Don Volmer, the plant's operations engineer, who presented the different activities carried out in Puente Hills with a particular focus on the Gas-to-Energy plant, and by Luis Llerena, supervising engineering technician, who gave us an overview of the landfill. We would like to warmly thank them for their time and their readiness to answer our questions.

Sanitation Districts of Los Angeles County

The activity of this public agency is to treat solid waste and wastewater in 24 districts located in Los Angeles County. This area accommodates 5.6 million people and covers 543,631 acres (2,200 square kilometers). One of the facilities they operate is Puente Hills landfill, located east of Los Angeles, with an associated power plant. The entire site covers 1,290 acres (i.e. 5.22 km^2).
Although the landfill was opened in 1970, Phase I of the power plant was not put into operation until 1987. Phase II, built in 2006, corresponds to the expansion of the plant following an increase in the volume of biogas produced.

The landfill

Characteristics

This landfill covers more than 500 acres (i.e. 2.55 square kilometers), making it the largest in the USA. It was closed to the dumping of new waste in October 2013, following pressure from local opponents. However, the plant will continue to operate as long as biogas can be produced from the waste currently buried on site (estimated at 12 to 15 years).

Overview of the landfill
http://www.puentehillslandfillpark.org/gallery/

Tour of the site

Methane production

The process involved is methanization, which is the fermentation of buried waste in an anaerobic atmosphere (i.e. absence of oxygen) which contributes to the degradation of organic matter and releases a gas composed mainly of methane and carbon dioxide, produced continuously.

Biogas is collected via 1,400 mostly vertical recovery wells and from trenches. In recent years, the flow of collected biogas has been close to 8,000 scfm (i.e. 3.78 m^3 / s). A control device is placed on the surface to check the level of the different emissions and to ensure compliance with Californian legislation, the most stringent in the United States of America. Thus, methane emissions should not exceed an average of 25 ppm, and 500 ppm for exceptional peaks. Gas quality and temperature are also monitored as they are important for the anaerobic digestion process: for instance, a temperature above 130°F (54°C) may indicate oxygen infiltration (as the composting process is exothermic).

The Gas-to-Energy facility

Electricity generation process

This plant is based on a Rankine steam cycle with a capacity of 50 MW. It is fuelled by the gas collected from on-site buried waste. Mr. Volmer told us that the plant was originally made up of gas turbines, and then steam boilers, and steam turbines, until finally internal combustion engines were added. Today, only one steam turbine is still in operation at the plant.

Visit of the power plant

Gas turbines and engines have been phased out as biogas production is decreasing due to the closure of the landfill in 2013. The multi-stage centrifugal turbine has several levels of exhaust in order to maximize efficiency and recover steam at the different available pressure levels. Mechanical energy is recovered from steam expansion in this 50 MW turbine and then converted into electrical energy thanks to an alternator. Before entering the turbine, the water is preheated using a shell and tube heat exchanger. There are four cooling towers at the outlet.

Twenty-six flares have also been installed for safety reasons. Indeed, since gas cannot be stored, it must be consumed all the time, even when there is no consumption or when the power station is not in operation (due to maintenance operations, incident, etc.).

Control station

At the time of the plant's construction, only 8 flares were installed; the others were added gradually, increasing in size to correspond to the quantity of biogas produced on site. The plant operates continuously. Until the closure of the landfill in 2013, it produced 50 MW all year round. The production of biogas and therefore electricity is currently decreasing and was on average 40 MW in 2015.

<u>*Operation*</u>

The control station at the plant is permanently monitored by two operators. The data relating to the plant, in particular the pumping station, the cooling towers and the water supply of the boiler, are analyzed and controlled in real time.

<u>*Maintenance*</u>

Maintenance of the steam turbine is carried out every 10 years. An inspection is conducted every 18 months to anticipate the most common problems, namely cracking of the turbine blades. The plant also stores a lot of redundant equipment to ensure continuity of production in case of incidents

Value of the power produced

We were told that the initial contract for the sale of the electricity produced set a price of $ 0.08 / kWh for 15 years, and a new contract at $ 0.03 / kWh has been concluded for the future. Only the landfill part of Puente Hills receives incentives from the state, but not the Gas-to-Energy plant specifically.

The plant uses all of the discharge gas produced and so reduces the electricity expenses of Puente Hills.
Production of CNG (compressed natural gas) has been attempted but was discarded because it was not economically viable.

We would lije thanks Marie-Christine Wiltord, Don Vomer and Luis Llerena who welcomed us on the site

Cécilia REILHAN

Student inside the power plant

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Altamont Landfill and Waste Management Facility
Sara Fockler
Lawrence G. Lacera
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Stanford Energy System Innovations
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All Power Labs
Tom Price

TOTAL Amyris
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San Francisco Public Utilities Commission (SFPUC)
Jonathan Smith

SCAVENGER
Chris Axton

EDF Renewable Energy
Rich Jigarjian

PV Plant CATALINA
Noel Hidalgo

Wind farm Pacific Wind
Dale Whinery

Puente Hills Landfill Gas-to-Energy Facility
Marie-Christine Wiltord
Luis Llerena
Don Volmer

SUSTAINABLE STANFORD

SANITATION DISTRICTS OF LOS ANGELES COUNTY

TOTAL

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EDF renewable energy

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San Francisco Water Power Sewer

EDF

ALL Power Labs

SOUTH SAN FRANCISCO SCAVENGER COMPANY, INC.

SMUD

PRIMUS POWER

Master OSE students class of 2016 at Alcatraz's Jail

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OPTIMISATION DES SYSTÈMES ÉNERGÉTIQUES