WELCOME !!!

Modelling Decarbonization Technologies

Thursday, 20 May 2021 14:00 Korea Time (Seoul, GMT+09:00)

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(1) Welcome & Overview
(2) Demonstration of selected sample files:

- Post-combustion CO_2 Capture
- Advanced Supercritical CO_2 cycles (Allam / Graz Cycles)
- Solar Thermal Plants (CSP) and Molten Salt storage
- Modeling Liquid Air Energy Storage
- Coal Boiler replaced by PV + Electric Heater & Molten Salt Storage

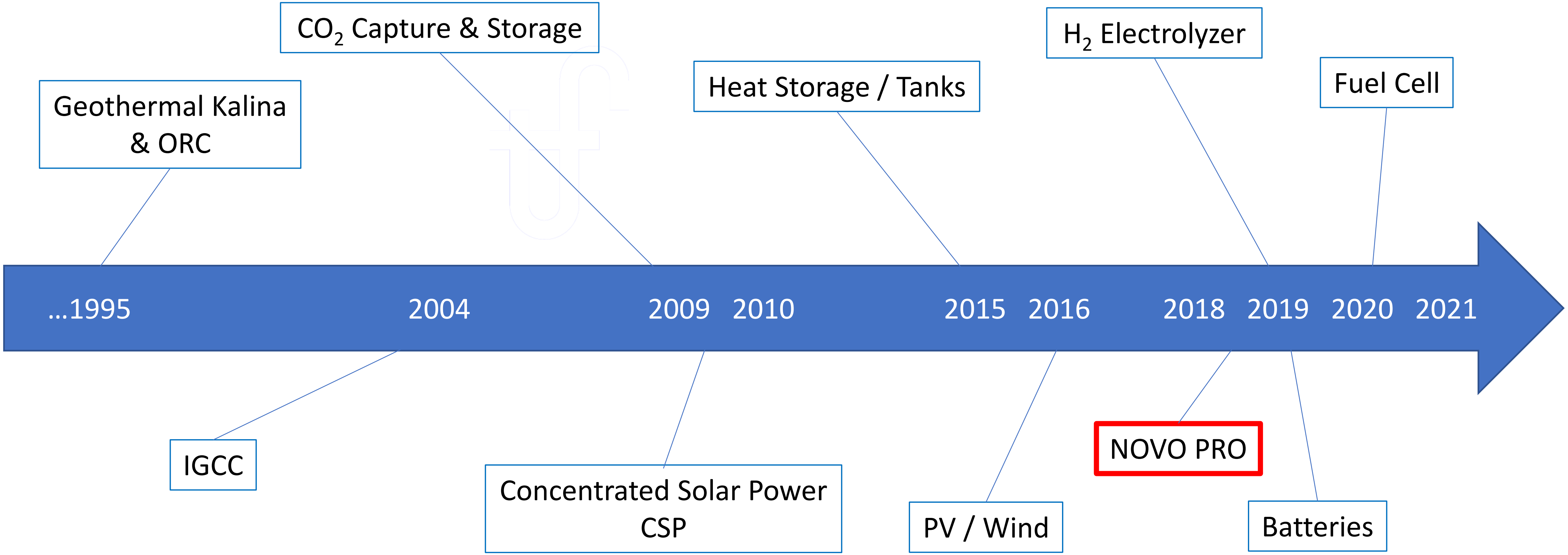
(3) NOVO PRO

- Introduction
- Sample 1: 300MW Hybrid Plant (PV + Wind + Thermal Plant), Grid Simulation
- Sample 2: 50MW Open-Cycle Gas Turbine Replacement Project in Australia

(4) Questions & Answers

Thermoflow´s Products contribute to the "Green Transition"

Highlights / Milestones…



Decarbonization Technology - OVERVIEW	GT PRO®/ GT MASTER®	STEAM PRO®/ STEAM MASTER®	THERMOFLEX® - PEACE®	NOVO PRO®
Conventional coal plants with flue gas CO_2 capture		Yes	Yes	FDM link
Biomass and WtE plants with or without flue gas CO_2 capture		Yes	Yes	FDM link
GT Combined Cycles with flue gas CO_2 capture	Yes		Yes	FDM link
IGCC plants with flue gas CO_2 capture	Yes		Yes	FDM link
IGCC (or NG) plants with pre-combustion carbon capture	Yes		Yes	FDM link
Combined Cycle or cogen flexibly integrated with SMR pre-combustion carbon capture			Yes	FDM link
Oxy-fuel coal fired plants		"Yes"	Yes	FDM link
Supercritical CO_2/Oxy-Fuel cycles incl. "Allam Cycle" and "Graz Cycle"			Yes	FDM link
Solar Thermal (CSP), and/or integrated solar thermal systems (e.g. ISSCC)			Yes	DU Ren + TFX
Liquid Air Energy Storage (LAES)			Yes	DU Storage
Wind Farms and Power-to-X, Electric Heater, Heat Pumps, Heat Storages			Yes	Yes
PV Plants and Power-to-X, storages, Electric Heater, Heat Pumps, Heat Storages			Yes	Yes
Hydrogen production			Yes	Yes
Hydrogen as fuel in any thermal plant	Yes	Yes	Yes	FDM link
Batteries, Pumped Hydro, User-Defined Storage, Heat Storages, Fuel Cell			Yes	Yes

Decarbonization Technology	Sample File in Library PAGE 1 of 2
Conventional coal plants with flue gas CO_2 capture	THERMOFLEX file: Coal Plant (STM) Linked to CCS (S6-14) Conventional coal plant with flue gas CO_2 capture.STP
Biomass and WtE plants with or without flue gas CO_2 capture	THERMOFLEX file: Waste to Energy (S2-15a) MSW plant with flue gas CO_2 capture.STP MSW plant without flue gas CO_2 capture.STP
GT Combined Cycles with flue gas CO_2 capture	Conventional NG cmbined cycle with flue gas CO_2 capture.GTP
IGCC plants with flue gas CO_2 capture	THERMOFLEX files: IGCC with post-combustion CCS (S5-16a), (S5-17a) IGCC plant with flue gas CO_2 capture.GTP
IGCC (or NG) plants with pre-combustion carbon capture	THERMOFLEX files: IGCC with pre-combustion CCS (S5-16b), (S5-17b) IGCC plant with pre-combustion carbon capture.GTP
Combined Cycle or cogen flexibly integrated with steam-methane reformer (SMR) pre-combustion carbon capture	THERMOFLEX file: Simple steam methane reformer (S6-18)
Oxy-fuel coal fired plants	THERMOFLEX files: Supercritical PC with post-comustion CCS (S5-11) Supercritical Oxy-fuel PC with post-combustion CCS THERMOFLEX files (S5-14a), (S5-14c) Pressurized CFB Oxy-fuel with CCS THERMOFLEX file (S5-21) Hybrid GT Oxy-fuel with CCS THERMOFLEX files (S5-13), (S5-12)
Supercritical CO_2/Oxy-Fuel cycles incl. "Allam Cycle" and "Graz Cycle"	THERMOFLEX files: Graz Cycle (Oxy-Fuel) (S5-29) Allam Cycle (Oxy-Fuel) (S5-25a), (S525b), (S5-25c)

Decarbonization Technology	Sample File in Library
Solar Thermal (CSP), and/or integrated solar thermal systems (e.g. ISSCC)	THERMOFLEX files: Solar Thermal (S5-07), (S5-07a), (S5-09), (S5-09b), (S5-10), (S5-10a) Integrated Solar GTCC (S5-08) Integrated Solar Gas Turbine Cycle (S5-08b)
Liquid Air Energy Stor	(S5-30a) ing (S5-30c)
Wind Farms and Pow Heat Pumps	(S5-23), (S3-22b),
PV Plants and Power-	-22), (S3-22b),
Hydrogen production from Wind and PV	THERMOFLEX file: Wind to Hydrogen (S5-24a)
Hydrogen production from Steam-Methane Reformer SMR	THERMOFLEX file: Steam Methane Reformer (S6-18)
Batteries, Pumped Hydro, User-Defined Storage, Heat Storages, Fuel Cell	THERMOFLEX file: Absorption Chiller + Stratified Storage Tank THERMOFLEX files (S3-24)

…and more samples: http://thermoflow.com/decarbonization.html

Sample Files – default folder: "C:\Program Files (x86)\Thermoflow 29\Samples"

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(2) Demonstration of selected sample files:

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(4) Questions & Answers

Post-combustion CCS in Combined Cycle (GTPM/TFX)

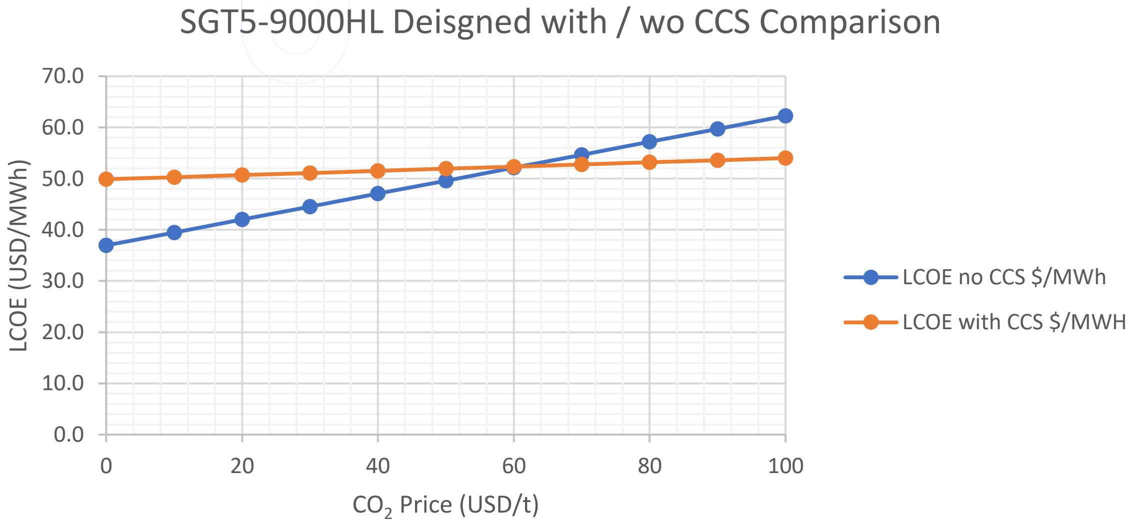
- Brief introduction of CCS system in GTP

  Flue Gas CO_2 Capture Process Flow Diagram

  Amine-based / Advanced

- Model **new** GTCC projects with CCS in GTP

  Rapid analysis of the Power Output, Heat consumption, CO_2 emissions, Economic parameters, etc



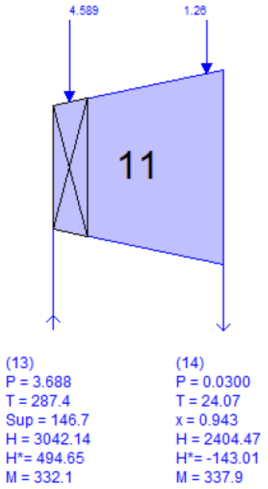
Assumptions:
GT fuel LHV price: 4.265 USD/GJ
Operation hours per year (full-load equivalent): 6570
Discount rate for NPV calculation: 6%

Post-combustion CCS in Combined Cycle (GTPM/TFX)

- Add CCS to **existing** power plants, with THERMOFLEX

  (GTP/GTM -> TFX) Mixed TD + OD mode

			New plant		Existing plant	
			1)no CCS	**2)with CCS @ design point (!)**	3)no CCS	**4)Add CCS**
Heat Balance	Plant gross output	MW	859.0	799.8	859.0	796.9
	Plant net output	MW	837.4	738.9	837.4	734.8
	Plant net elec. eff (LHV)	%	61.46%	54.23%	61.46%	53.92%
	Group LPTL - Group inlet massflow	t/h	653.7	335.1	653.7	332.1
	Group LPTL - Group inlet pressure	bar	3.4	3.7	3.4	1.76
	Group LPTL - Group inlet temperature	C	279.8	289.6	279.8	284.9
	CO2 Capture Steam Mass Flow	t/h	-	326.0	-	326.1
	CO2 Capture Steam Pressure	bar	-	3.45	-	3.45
	CO2 Capture Steam Temperature	C	-	287.5	-	287.1
	CO2 Capture Efficiency	%	-	85%	-	85%
	Stack CO2	t/h	270.6	40.6	270.6	40.6
Economics	Specific Investment	USD/kW	654	1531		
	Internal Rate of Return on Investment (ROI)	%	27.33	10.99		
	Internal Rate of Return on Equity (ROE)	%	68.29	21.45		
	Net Present Value	kUSD	1,460,411	695,747		
	Break-even Electricity Price @ Input Fuel Price	USD/kWh	0.037	0.050		
	Assumptions: 1) GT fuel LHV price: 4.265 USD/GJ 2) Operation hours per year (full-load equivalent): 6570 3) Discount rate for NPV calculation: 6%					



Controlled Extraction added to existing ST to maintain the required process steam pressure to feed the CC system.

Alternatively, LPT could be revised to reflect the new (lower) LPT flow after adding the carbon capture system.

Oxyfuel Combustion — Allam Cycle / Graz Cycle (THERMOFLEX)

The Allam cycle is a novel **CO_2**, oxy-fuel power cycle that utilizes hydrocarbon fuels while inherently capturing approximately 100% of atmospheric emissions, including nearly all CO_2 emissions at a cost of electricity .

Graz Cycle is also a **zero emission** power cycle of high efficiency, which uses well-established gas turbine technology. The combustion with almost pure oxygen and the recycling of the water leads to a working fluid consisting mostly of water and less of CO_2.

- ASU / Oxyfuel Combustion
- Supercritical CO_2 Brayton Cycle
- Use REFPROP (NIST) Property functions
- Steam Cooled Gas Turbine
- Cooled Turbine Stage Calculation

Solar Thermal Tower with Storage (THERMOFLEX & ELINK™)

- Solar thermal energy is the important alternative energy sources of fossil fuels. Solar Thermal Tower with Storage realizes the stable and adjustable power output.
- This sample uses a molten salt power tower together with direct thermal storage in a two-tank configuration.
- Calculate the entire year cases with ELINK. (Solar multiple 1.2 VS 1.5)

Solar Tower w/ Storage [40] (Thermodynamic Design)

Solar Tower w/ Storage [40] (Thermodynamic Design)

File Edit

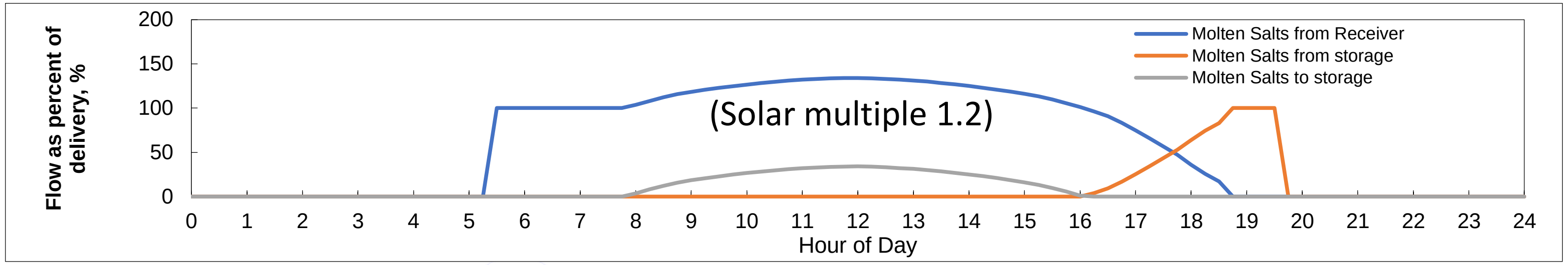
Solar Tower w/ Storage [40]
- Component Graphic
- Heat Balance
- Collector Description
- Storage System
- Specification
- Collector Plan
- Flow Diagram
- Irradiance Graph
- View/Edit Note

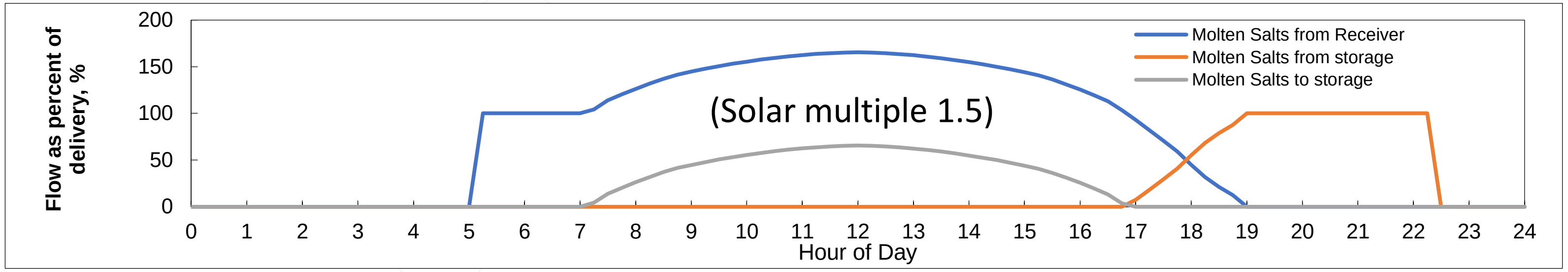
Estimated Collector, Field, and Direct Storage System Data	(Solar multiple 1.2)		(Solar multiple 1.5)	
Solar Tower w/ Storage [40]				
1. Field				
Number of tower fields	1		1	
Tower structure height	500.3	ft	559.3	ft
Tower inner diameter	51.61	ft	57.69	ft
Reflective area	10054150	ft^2	12564626	ft^2
Number of heliostats	14968		18706	
Heliostat field land area	55242584	ft^2	69036408	ft^2
Heliostat field land area	1268.2	acre	1584.9	acre
Total encompassed land area	55489204	ft^2	69344608	ft^2
Total encompassed land area	1273.9	acre	1591.9	acre

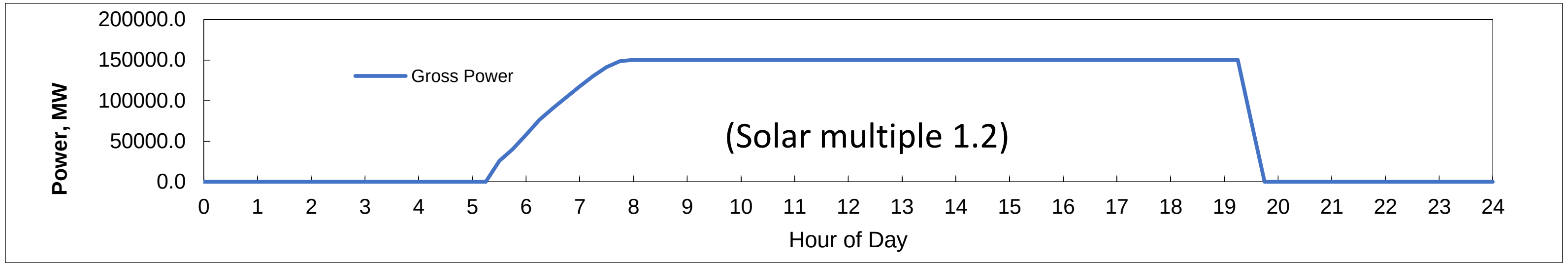
4. Contractor's Price 683,742,000 USD 807,341,700 USD

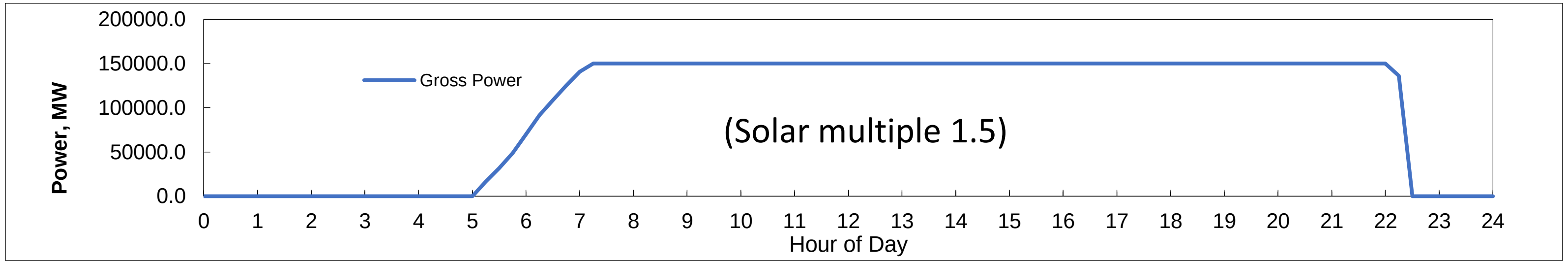
4. Contractor's Price	683,742,000	USD	807,341,700	USD
Owner's Soft & Miscellaneous Costs	129,500,000	USD	153,269,200	USD
5. Total - Owner's Cost - See Cautionary Note Below	813,242,000	USD	960,610,900	USD
6. Plant Net Electric Output	141.9	MW	141.8	MW

Solar Thermal Tower with Storage (THERMOFLEX & ELINK)









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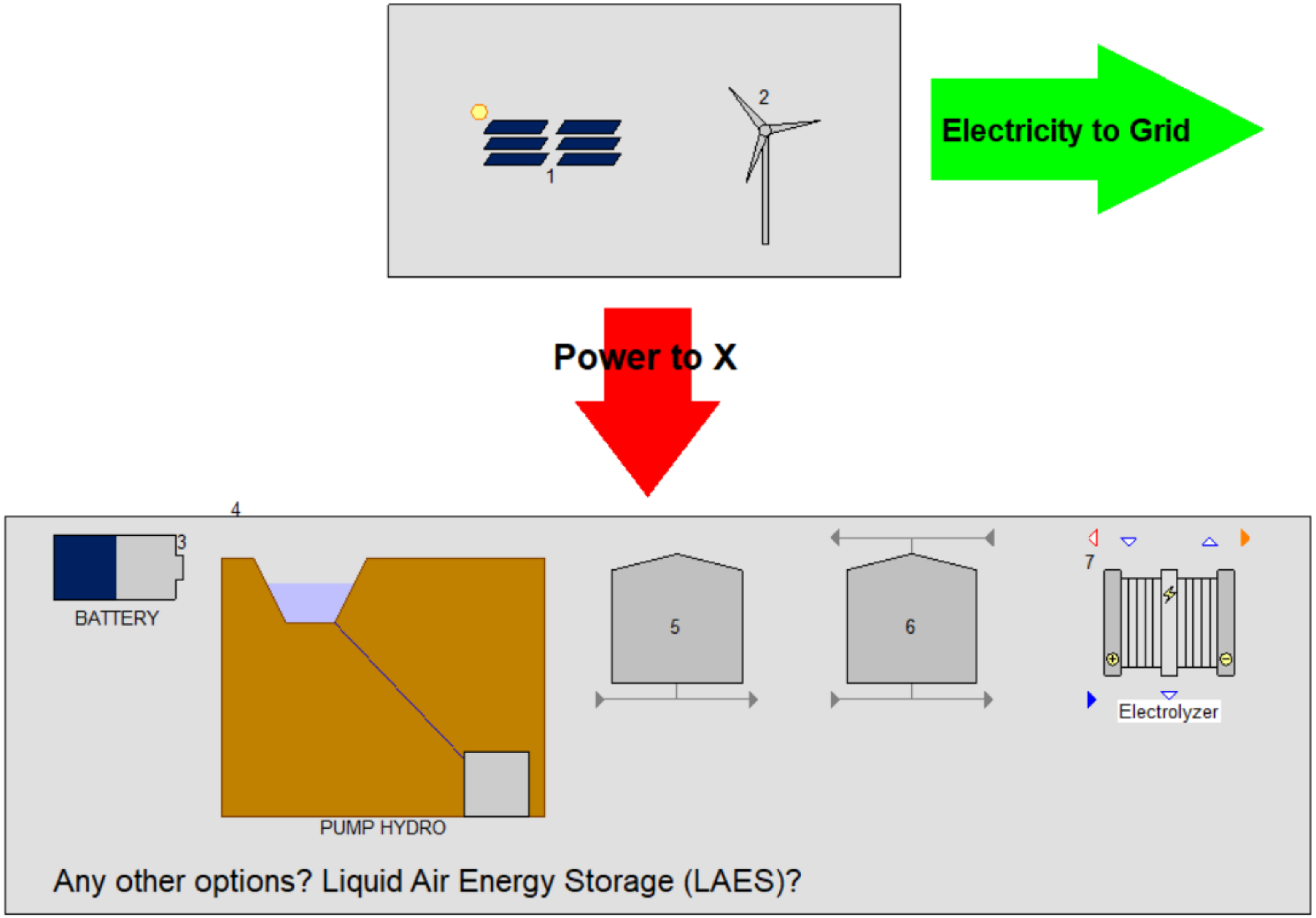
Modelling Liquid Air Energy Storage (LAES) in THERMOFLEX



Modelling Liquid Air Energy Storage (LAES) in THERMOFLEX

Energy Storage Mode (TFX Sample: S5-30a)

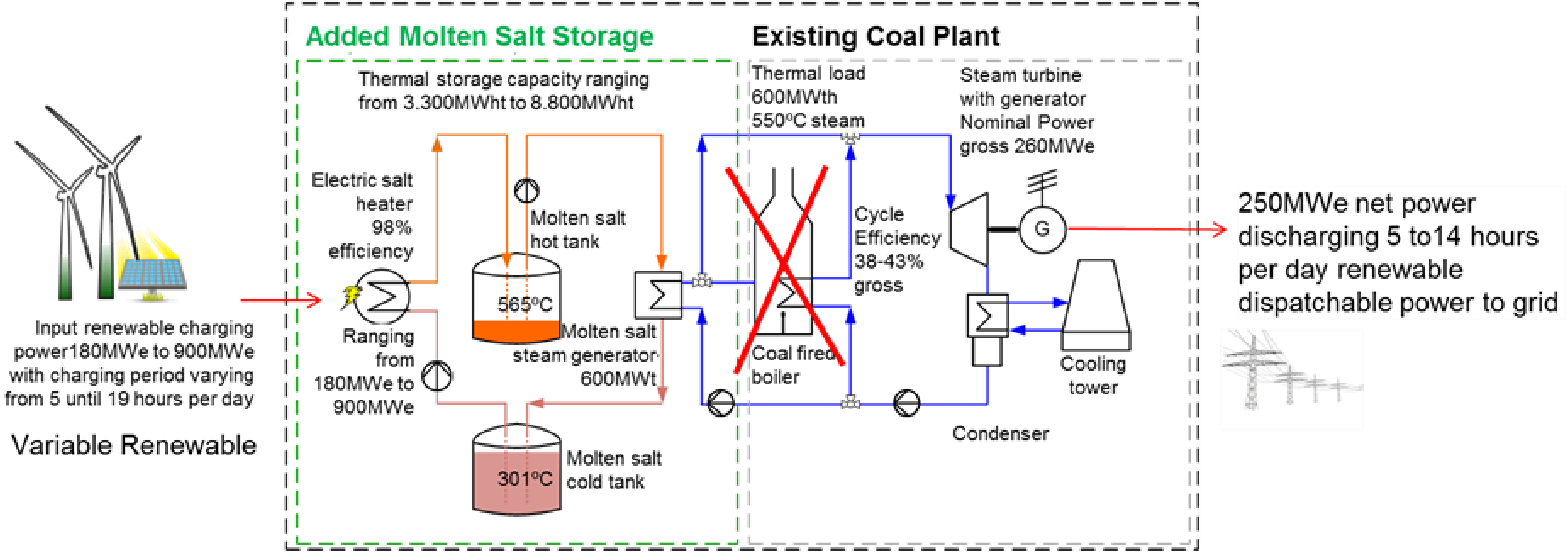
- Consumes pretreated ambient air (no moist and CO_2), produces cold, high pressure, liquefied air (-143 C, 34 bar)
- Specific electricity consumption: 292 kWh/tonne, efficiency: 45.7%.

Energy Recovery Mode

- TFX Sample: S5-30b: Precooling GT inlet air increases the GT output power; heated Air (to 529 C by GT Exhaust) expands to almost atmospheric pressure
- TFX Sample: S5-30c: the air is heated and expanded to atmospheric pressure to produce electricity. Primary liquefied air heating is to cool the return water from District Cooling.

Coal Boiler replaced by PV + Electric Heater + Molten Salt Storage

Analysis of a 250MWe Chilean Coal Plant



Sensitivity Variant	Unit	V1-O1	V1-O2	V1-03	V1-O10	V1-O11	V1-O12
Discharging Duration	[hours]	5,00	5,00	5,00	8,00	12,00	14,00
Thermal storage capacity	[GWht]	3,33	3,33	3,33	5,15	7,57	8,79
Charging Duration	[hours]	5,00	10,00	19,00	11,00	11,00	10,00
Charging el. salt heater capacity	[MWe]	680	340	179	478	703	897

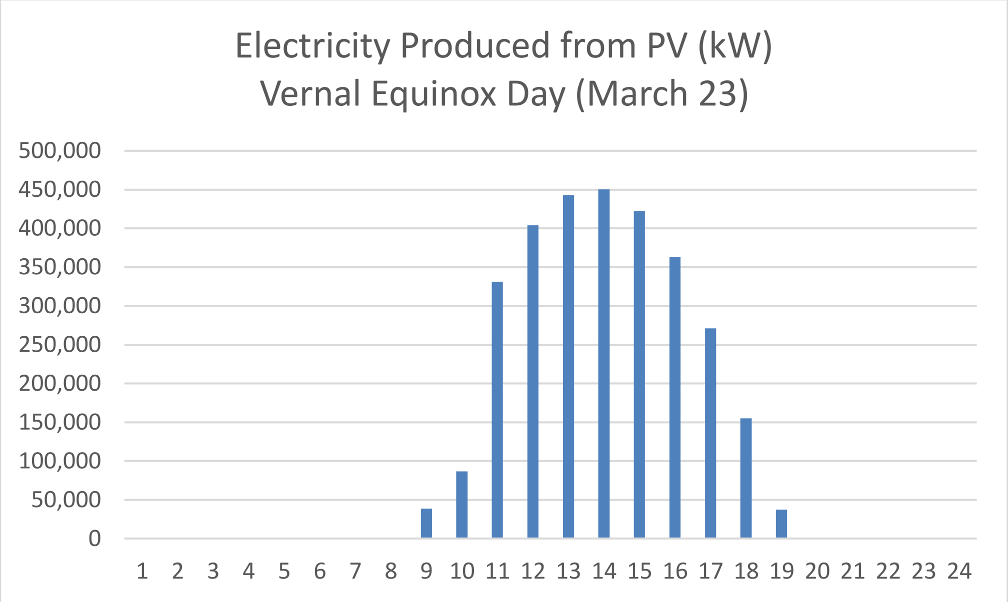
Coal Boiler replaced by PV + Electric Heater + Molten Salt Storage

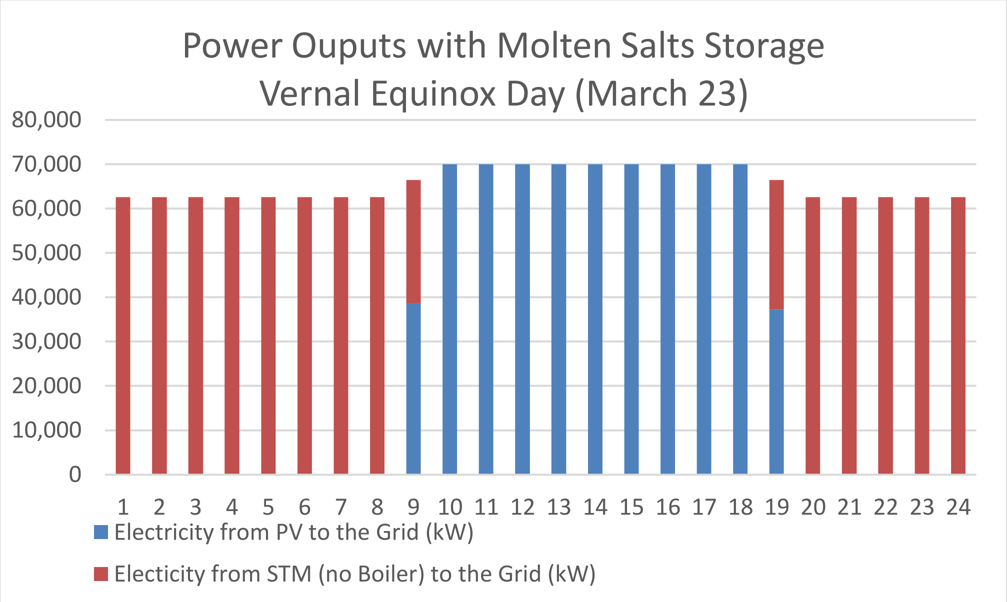
Remove the boiler in a Coal fired Power plant in STPM

➢ Design a 70 MW coal fire plants in STP; turn it to a STM model; Select Cycle w/o boiler (TFX link) at Plant Control Mode to remove the boiler

Design PV + Electric Heater + Molten Salts Storage system in TFX

➢ Electricity from PV is used to heat up the molten salts and store the energy; the heated molten salts is used to produce HP steam for the steam turbine to generate electricity whenever the PV electricity is insufficient.





2 NOVO PRO Samples:

(1) Introductory

- 300 MW Hybrid Plant in Arizona / USA

(2) Wind / PV System Sizing

- Open Cycle GT Replacement (50MW) in Australia

What is NOVO PRO?

Design, (grid) simulation and techno-economic optimization of Hybrid Systems

"Thermal World"

Coal, GT, Recips,
Biomass, WtE,…

"Renewable World"

PV, Wind, Hydro, …

Hydrogen (H_2),
eFuels,
Storages,…

NOVO PRO Sample 1:

Introductory (get started): Hybrid Plant in Arizona / USA

What can I expect from the NOVO PRO Introduction:

- Which inputs are needed to get started ?
- How to setup to site conditions, economical parameters and power demand ?
- How to setup renewable systems: PV Plant and Wind Farm ?
- How to setup a "customized" thermal Power Plant in GT PRO/GT MASTER/ THERMOFLEX and how to import it to NOVO PRO ?
- How to use the NOVO PRO Outputs to analyze and optimize the Hybrid Plant ?

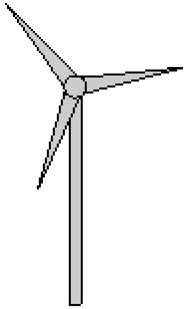
Hypothetical Hybrid Plant Arizona / USA

300MW PV + 300MW Wind

+ Gas Fired Thermal

(Backup) Plant

+



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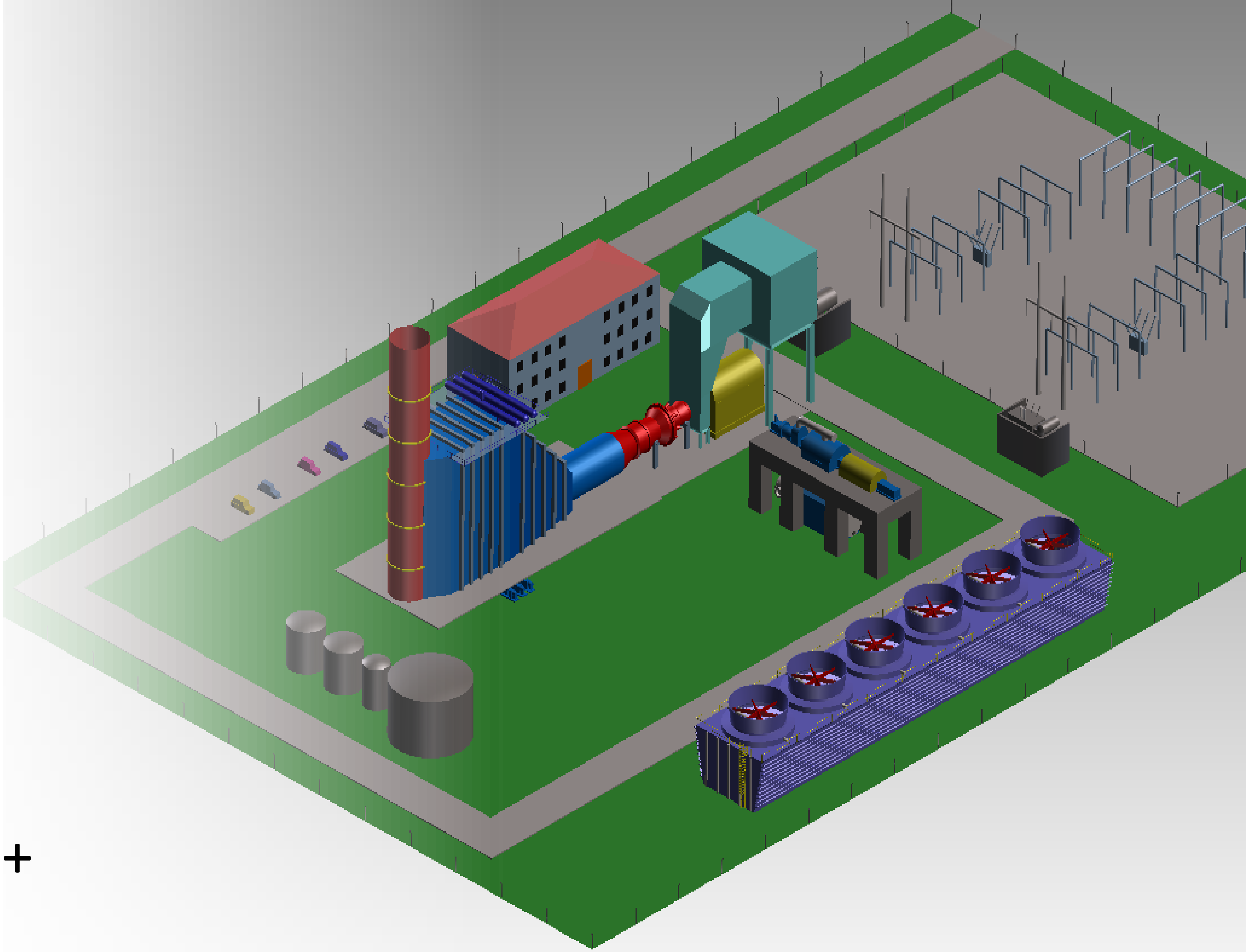
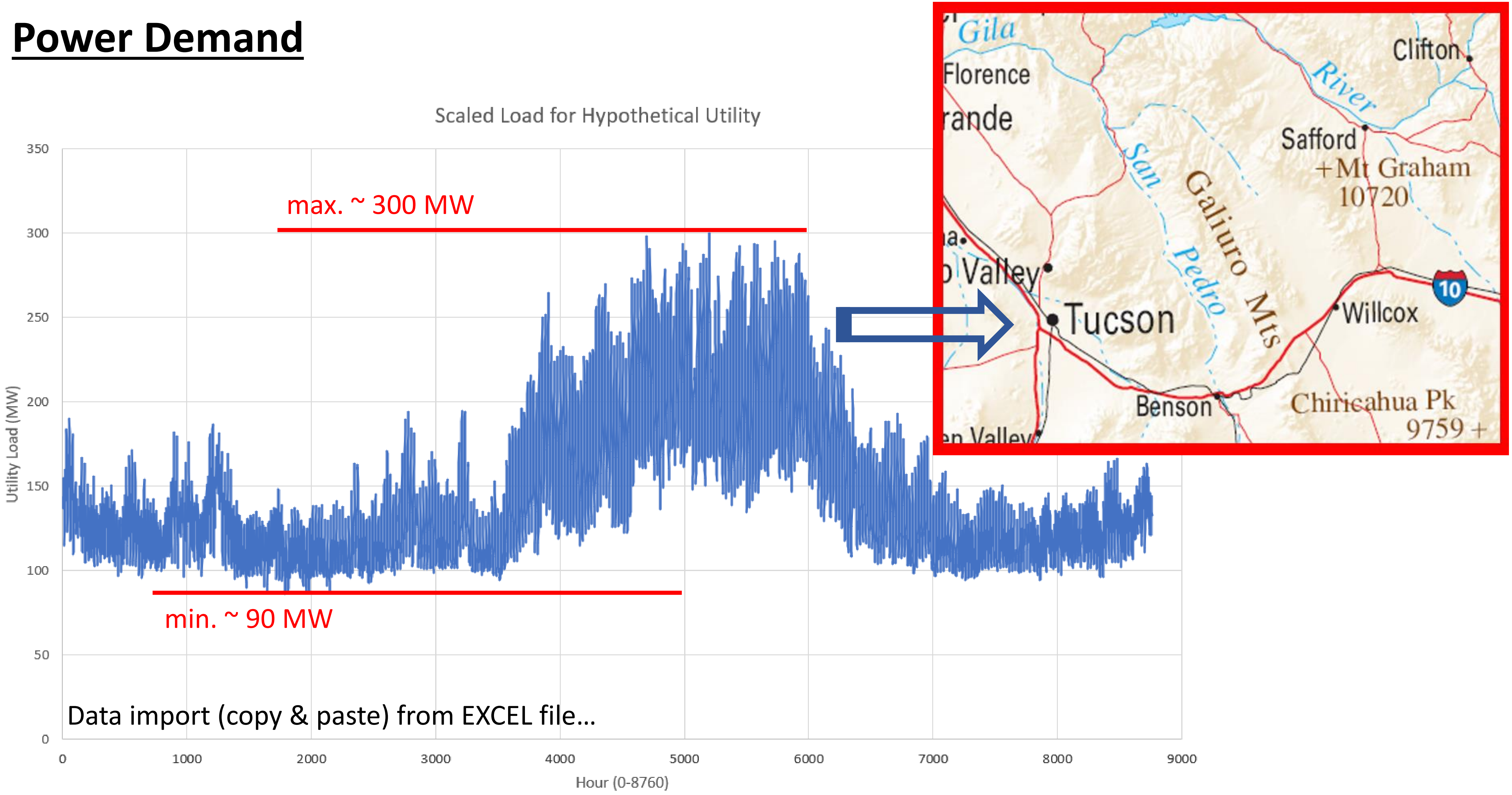


Location:

Tucson area, Arizona, USA

Power Demand



Data import (copy & paste) from EXCEL file…

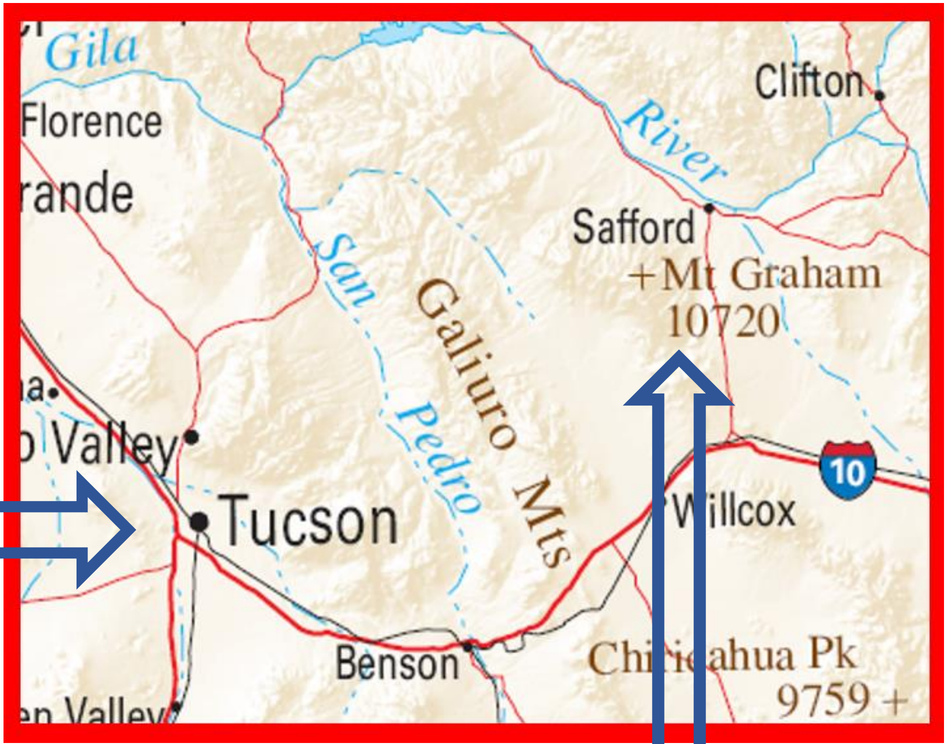
Ambient Conditions, Wind Resource Data & Solar Irradiation

PV Solar Irradiation Data from: TMY = Typical Meteorological Year

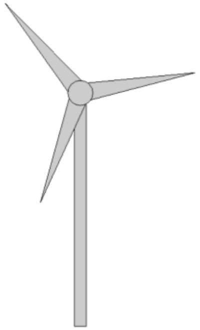
Typical Meteorological Year (TMY): is a set of meteorological data with hourly values in a year for a given location. The data are selected from hourly data in a longer time period (normally 10 years or more). For each month in the year the data have been selected from the year that was considered most "typical" for that month.

Available data in Thermoflow:
- US NREL TMY3 Data
- Environment Canada CWEC Data
- EnergyPlus US/DOE

Google Earth - PV



Wind Resource Data from: built-in ERA5 database



ERA5 / European Copernicus Project – www.Copernicus.eu : provides hourly estimates of a large number of atmospheric, land and oceanic climate data.

Google Earth - Wind

Economic Inputs

Demand Power Price:	60 USD / MWh
Surplus Power Price:	0 USD / MWh
Import Power Price:	no power import
Gas Fuel Price:	3 USD / GJ

Scenarios

(1) Large F-Class GTCC, 3pRH, 1-1-1 Config., Wet Cooling Tower
(2) Reciprocating Gas Engines (open cycle), approx. 10-20 units

(3) Scenario (1) + 300MW PV
(4) Scenario (2) + 300MW PV

(5) Scenario (1) + 300MW PV + 300MW Wind
(6) Scenario (2) + 300MW PV + 300MW Wind

New MAN Reciprocating Gas Engine Specifications

Courtesy of MAN Energy Solutions
Future in the making

35/44G Single staged/ two-staged	7,368 – 12,800 kW_{mech} η > 51,3 %* $_{mech}$ NG, biogas, H_2 < 20%, MN60-100
51/60G Single staged/ two-staged	18,900 – 20,700 kW_{mech} η > 51,8 %* $_{mech}$ NG, biogas, H_2 < 20%, MN60-100
51/60DF Single staged/ two-staged	6,300 – 18,900 kW_{mech} η > 51,8 %* $_{mech}$ NG, biogas, liquid biofuels, MGO/ MDO, HFO

*Reference according ISO 3046-1 & ISO 15550, 5% tol.

GT PRO / GT MASTER database:

ID	Manufacturer & Model
MAN Energy Solutions - Combustion Engines	
734	MAN 12V35/44G TS - 60Hz (**)
733	MAN 12V35/44G TS - 50Hz (**)
732	MAN 20V35/44G - 60Hz (**)
731	MAN 20V35/44G - 50Hz (**)
736	MAN 20V35/44G TS - 60Hz (**)
735	MAN 20V35/44G TS - 50Hz (**)
737	MAN 18V51/60G High Efficiency (**)
739	MAN 18V51/60G TS High Efficiency (**)

New MAN Reciprocating Gas Engine Specifications

NOVO PRO and THERMOFLEX database:

Engine Selection Filter

Smallest power 50 kW   Largest power 20000 kW

Sort: (•) Manufacturer   ( ) Smallest to largest power   ( ) Largest to smallest power

[x] Show 50 Hz engines   [x] Show 60 Hz engines

[x] Show gas engines   [ ] Show Diesel engines

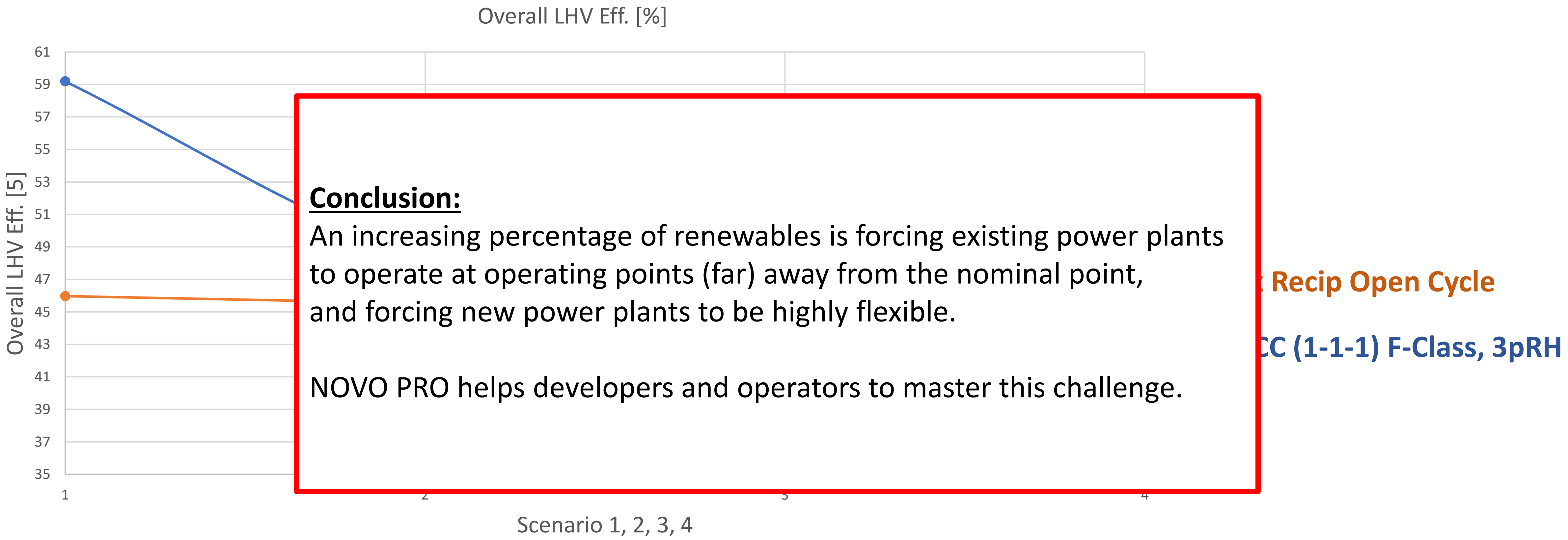
ID	Model	Fuel	Aspiration	Mode	RPM	Freq. Hz	Power kW	Texh C	Exh. flow t/h	Elec. Eff. %
446	MAN 20V35/44G	G	TA	C	750	50	10420	302	64,76	46,4
447	MAN 20V35/44G	G	TA	C	720	60	10027	302	62,32	46,4
448	MAN 18V51/60G	G	TA	C	500	50	18654	327	109,31	47,4
449	MAN 18V51/60G	G	TA	C	514	60	18654	327	109,31	47,4
451	MAN 12V35/44G TS	G	TA	C	750	50	7534	289	43,00	47,9
452	MAN 12V35/44G TS	G	TA	C	720	60	7228	289	41,30	47,9
453	MAN 20V35/44G TS	G	TA	C	750	50	12582	289	71,70	48,0
454	MAN 20V35/44G TS	G	TA	C	720	60	12071	289	68,80	48,0
457	MAN 18V51/60G TS	G	TA	C	500	50	18654	304	112,50	48,3
458	MAN 18V51/60G TS	G	TA	C	514	60	18654	304	112,50	48,3
461	MAN 6L51/60DF	G	TA	C	500	50	6180	334	37,90	46,3
462	MAN 6L51/60DF	G	TA	C	514	60	6180	334	37,90	46,3
465	MAN 6L51/60DF	G	TA	C	500	50	6180	364	37,60	45,3
466	MAN 6L51/60DF	G	TA	C	514	60	6180	364	37,60	45,3
469	MAN 6L51/60DF	G	TA	C	500	50	6769	324	47,10	44,6
470	MAN 6L51/60DF	G	TA	C	514	60	6769	324	47,10	44,6
473	MAN 12V51/60DF	G	TA	C	500	50	12411	334	75,80	47,2
474	MAN 12V51/60DF	G	TA	C	514	60	12411	334	75,80	47,2
477	MAN 12V51/60DF	G	TA	C	500	50	12411	364	75,30	45,8
478	MAN 12V51/60DF	G	TA	C	514	60	12411	364	75,30	45,8
481	MAN 12V51/60DF	G	TA	C	500	50	13593	315	94,30	45,0
482	MAN 12V51/60DF	G	TA	C	514	60	13593	315	94,30	45,0
485	MAN 18V51/60DF	G	TA	C	500	50	18654	334	113,70	47,3
486	MAN 18V51/60DF	G	TA	C	514	60	18654	334	113,70	47,3
489	MAN 18V51/60DF	G	TA	C	500	50	18654	364	112,90	45,9
490	MAN 18V51/60DF	G	TA	C	514	60	18654	364	112,90	45,9
497	MAN 18V51/60DFTS	G	TA	C	500	50	18654	315	116,50	48,8
498	MAN 18V51/60DFTS	G	TA	C	514	60	18654	315	116,50	48,8

Summary NOVO PRO Outputs

		Nominal		Thermal only (grid simulation)		Thermal + 300MW PV (grid simulation)		Thermal + 300MW PV + 300MW Wind (grid sim.)	
		GTCC	Recips	GTCC	Recips	GTCC	Recips	GTCC	Recips
Gross Power	**[kW]**	393.016	317.118						
Net Power	**[kW]**	382.588	307.644						
Net El. Eff.	**[%]**	59,19	45,97						
Capacity Factor	**[%]**			38,82	46,98	25,98	31,45	22,46	27,18
Overall LHV Eff.	**[%]**			48,33	45,53	44,89	45,1	43,04	44,94
Fuel Consumption	**[GJ]**			9.431.993	10.011.260	6.798.060	6.765.180	6.126.693	5.867.830
CO_2 production	**t/year**			517.028	550.086	372.645	371.724	335.843	322.418
Total Owner´s Costs	**[USD]**	305.120.000	220.119.000	305.120.000	220.119.000	661.200.000	576.199.000	1.112.953.000	1.027.951.000

Capacity Factor describes the relative power output for the power plant compared to a theoretical output where the plant operates at rated output for the same number of hours.

Summary NOVO PRO Outputs



Conclusion:
An increasing percentage of renewables is forcing existing power plants to operate at operating points (far) away from the nominal point, and forcing new power plants to be highly flexible.

NOVO PRO helps developers and operators to master this challenge.

1: Nominal / Design Point Performance
2: Thermal Power Plant only
3: Thermal Power Plant + 300MW PV
4: Thermal Power Plant + 300MW PV + 300MW Wind

Introduction

A remote mining location (NSW, Australia) with an existing grid connection is to have its existing 50MW OCGT back-up PP replaced by an installation combining Wind and Solar PV with storage.

Two configurations of renewables plant are considered, differing only in the energy storage technology:
- Option 1: 53MW Solar, qty "x" wind turbines (Silverton wind farm) + 150-200 MW/1,550 MWh CAES
- Option 2: 53MW Solar, qty "y" wind turbines (Silverton wind farm) + 62.5 MW/250 MWh BESS (Li Ion type)

The existing configuration is to be compared to the performance of Options 1 & 2 and suitable conclusions made.

Method

GT PRO is used to establish the 50MW OCGT fuel demand model for subsequent use in NOVO PRO.

Demand power, demand power price and site data are determined. NOVO PRO is used to model the existing case plus Options 1 & 2. Manipulations are carried out to determine the optimum wind turbine count for each Option.

NOVO PRO outputs are used to determine the economics of the options and existing case and conclusions are drawn.

Findings

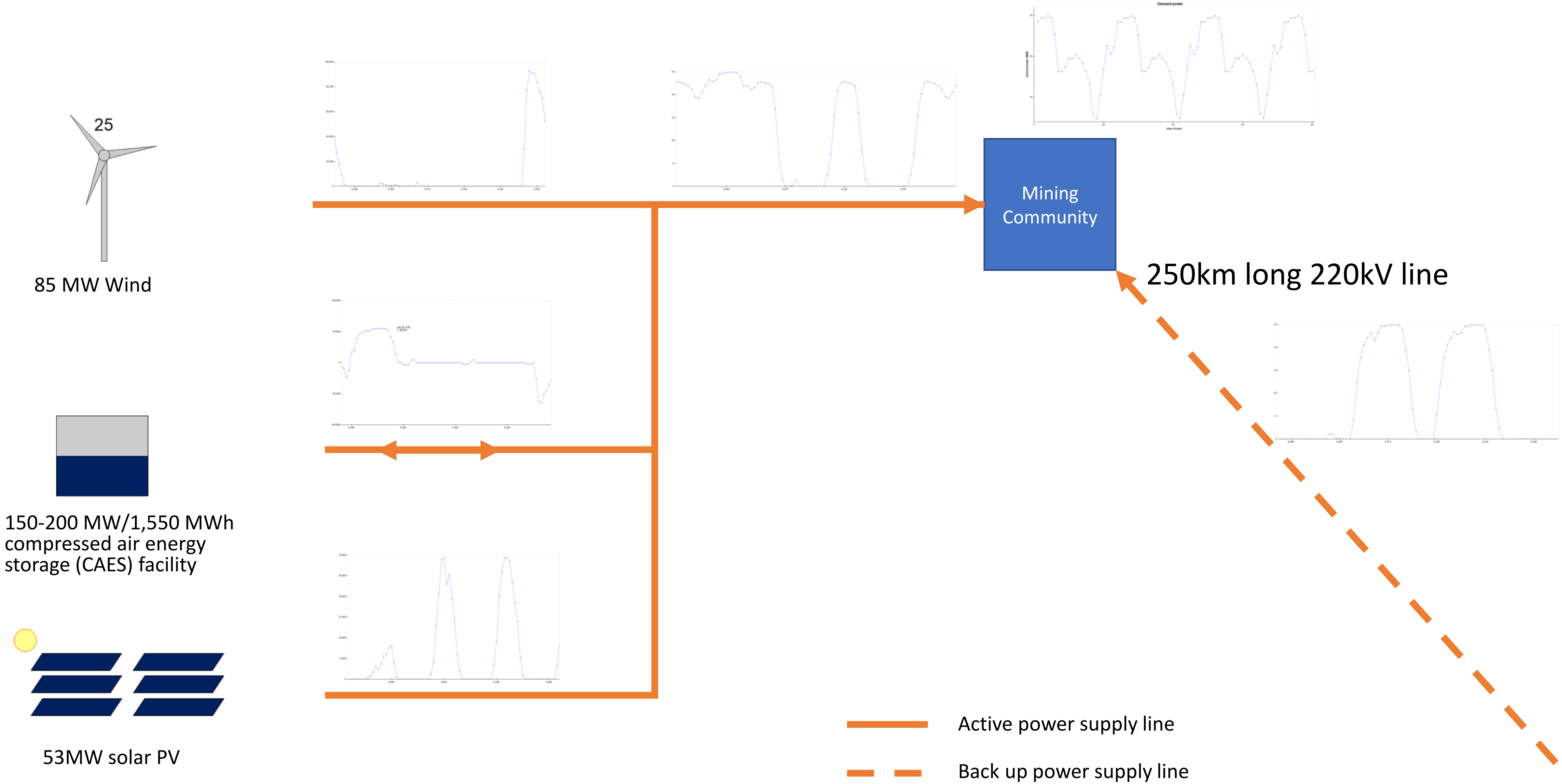
Option 1 is more expensive than Option 2 and consequently offers inferior financial performance. Both options have inferior performance relative to the existing OCGT in terms of expected import power requirement (up to 41MW for Options 1 & 2, approx. 7MW for the OCGT plant). The advantage of Option 1 and Option 2 over the existing OCGT is the CO_2 emissions (zero for Options 1 & 2, range from zero to 274000 t/yr for the OCGT). Retaining the OCGT plant may be a good idea in light of the fluctuating import power requirement.

Existing Configuration – normal operation

(snapshot of performance for Sept 20th -23rd)

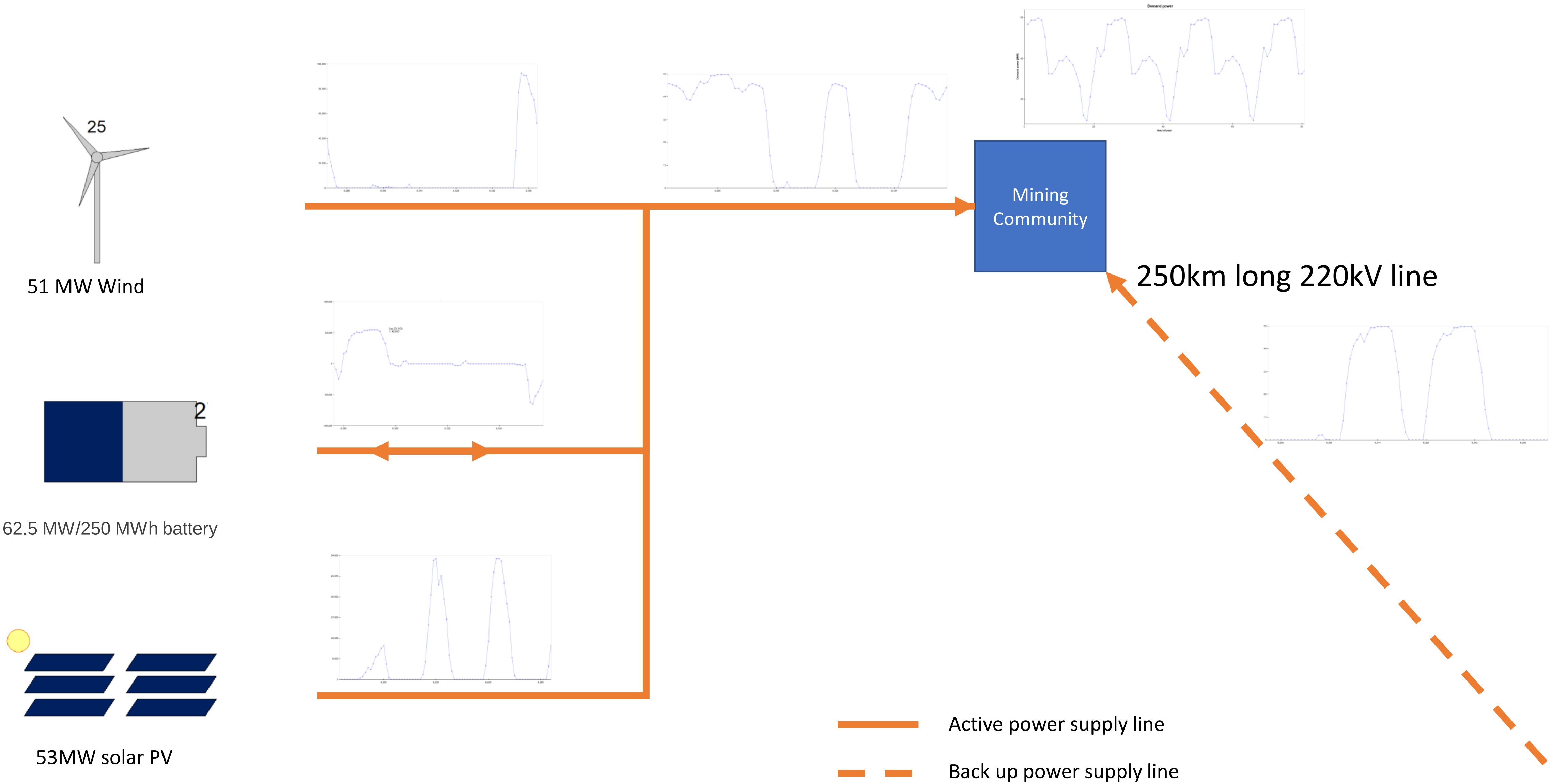
Option 1

(snapshot of performance for Sept 20th -23rd)

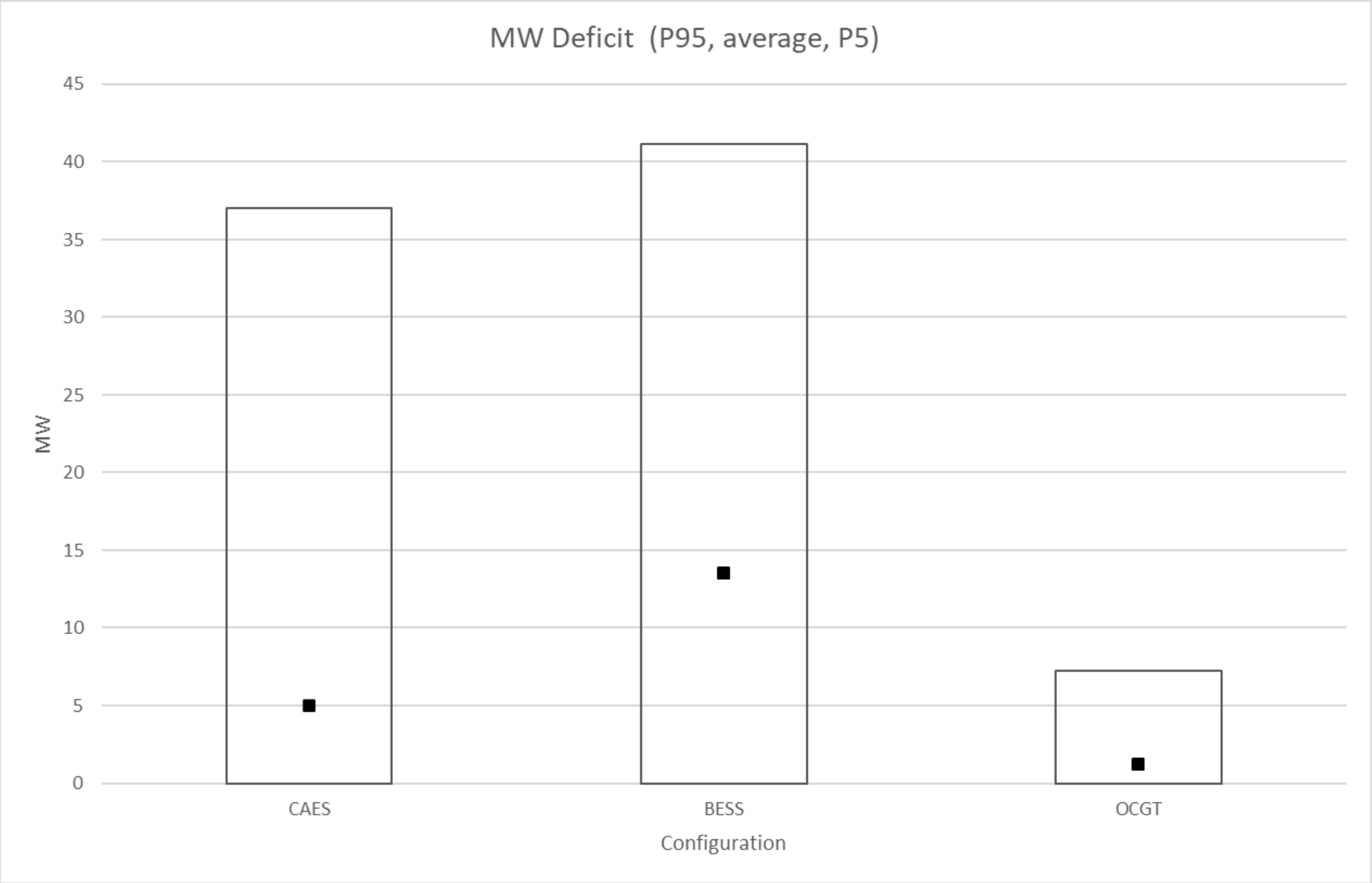


Option 2

(snapshot of performance for Sept 20th -23rd)



MW Deficit Box Plot



Thank you !!!

Questions? Email us: info@thermoflow.com