WELCOME !!!

Modelling Decarbonization Technologies

an OVERVIEW of the available features...

Thursday, 27 May 2021 13:30 Central European Time

Thermoflow´s Europe and MENA Team

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AGENDA – Thursday, 27 May 2021 13:30 Central European Time (Amsterdam, Paris, Berlin)**:**

(1) Welcome & Overview

(2) Demonstration of selected sample files:

- "Traditional" Renewable Technologies
- CO_2 Capture (new plant design with CCS & adding CCS to an existing plant)

(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

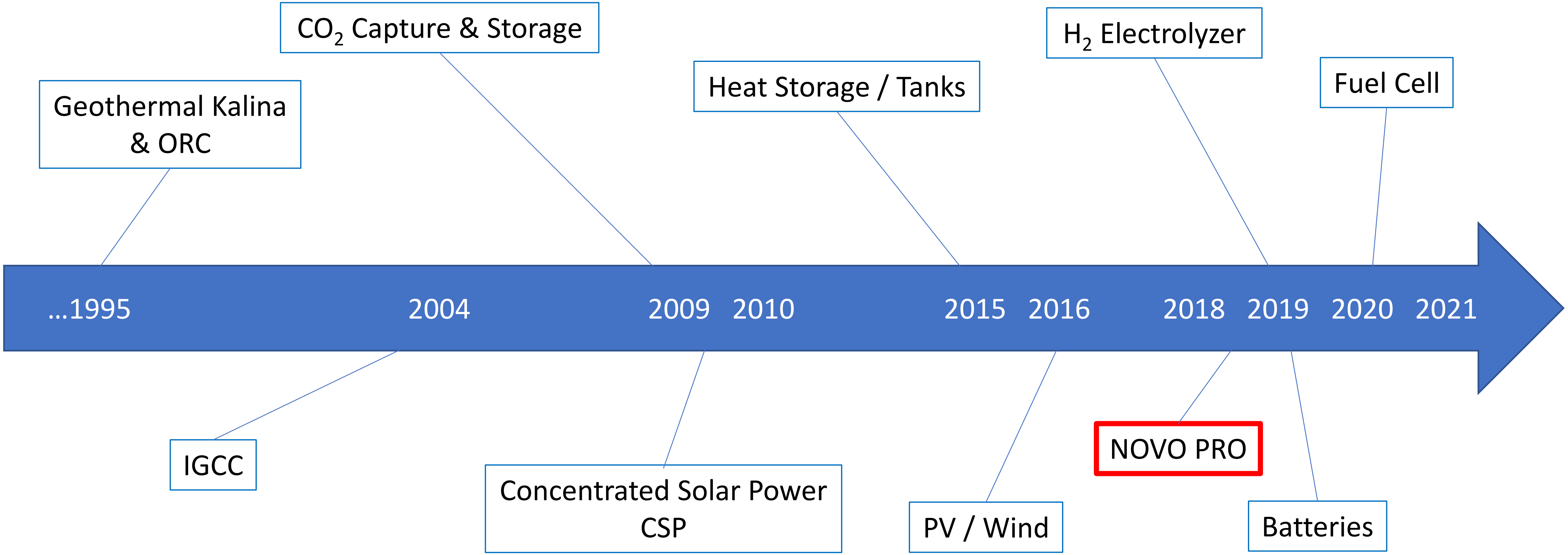
(4) Power-to-X features

- Hydrogen
- Storages

(5) Questions & Answers (approx. 15min)

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
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 PAGE 2 of 2
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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(5) Questions & Answers (approx. 15min)

"Traditional", "Old", "Thermal", … lower emissions & Renewable options

- High Efficiency Thermal plants
- Biomass / Waste to Energy
- Solar Thermal
- Geothermal
- Biogas + Recip. Engines
- sCO_2 cycles
- CO_2 capture

- Hybrid Plants

High Efficiency Thermal Plants → *less specific CO_2 kg/MWh*

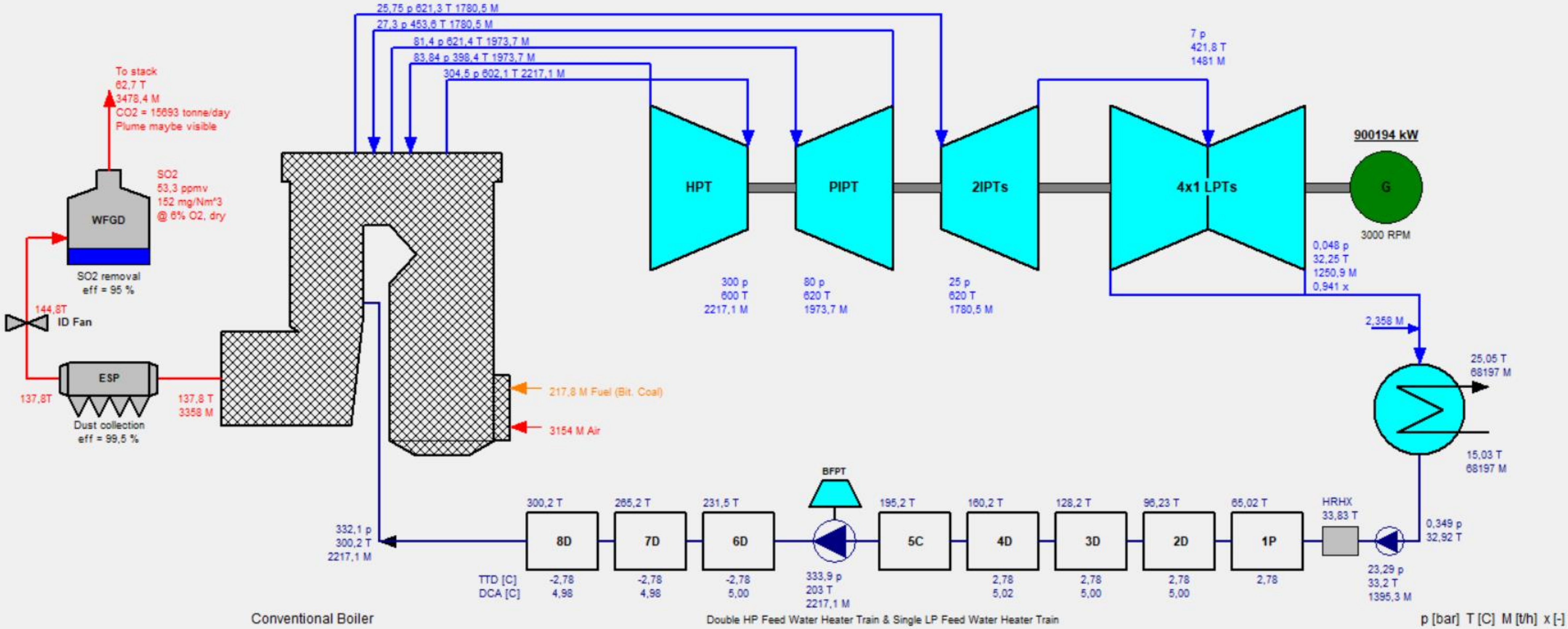
- Ultra Supercritical + Double Reheat Conventional Steam Plants (STPM &TFX)
- Advanced H-Class Gas Turbine Combined Cycles

2.1 1000 MW UltraSupercritical Double RH Coal Plant in STEAM PRO

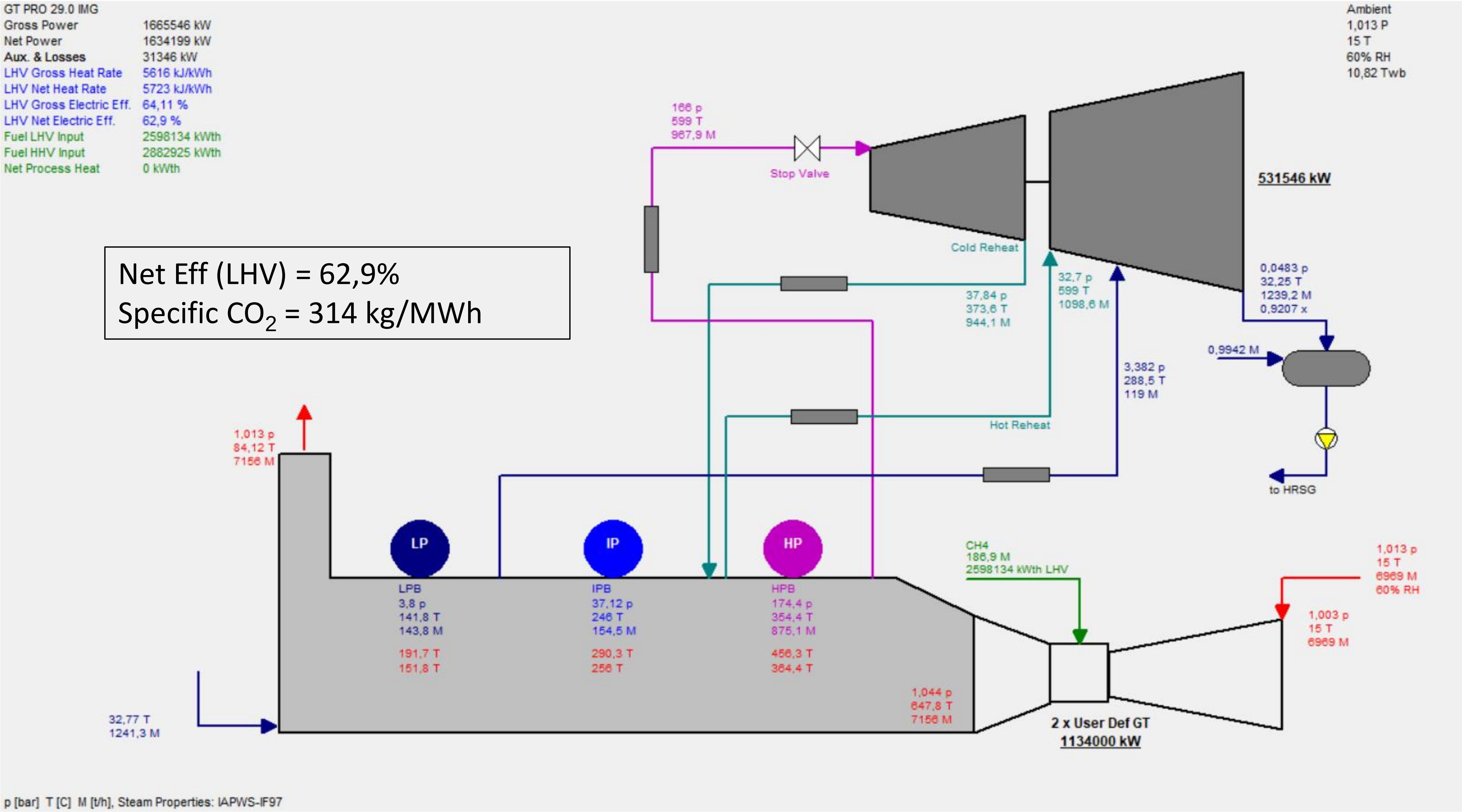
Plant gross power	900194	kW
Plant net power	865496	kW
Number of units	1	
Plant net HR (HHV)	8376	kJ/kWh
Plant net HR (LHV)	8099	kJ/kWh
Plant net eff (HHV)	42,98	%
Plant net eff (LHV)	44,45	%
Aux. & losses	34698	kW
Fuel heat input (HHV)	7249	GJ/h
Fuel heat input (LHV)	7010	GJ/h
Fuel flow	5227	t/day

Ambient
1,013 p
15 T
60% RH
10,82 T wet bulb

Net Eff (LHV) = 44,5%
Specific CO_2 = 725 kg/MWh



2.2 2x1 H-Class GT Combined Cycle Plant in GT PRO

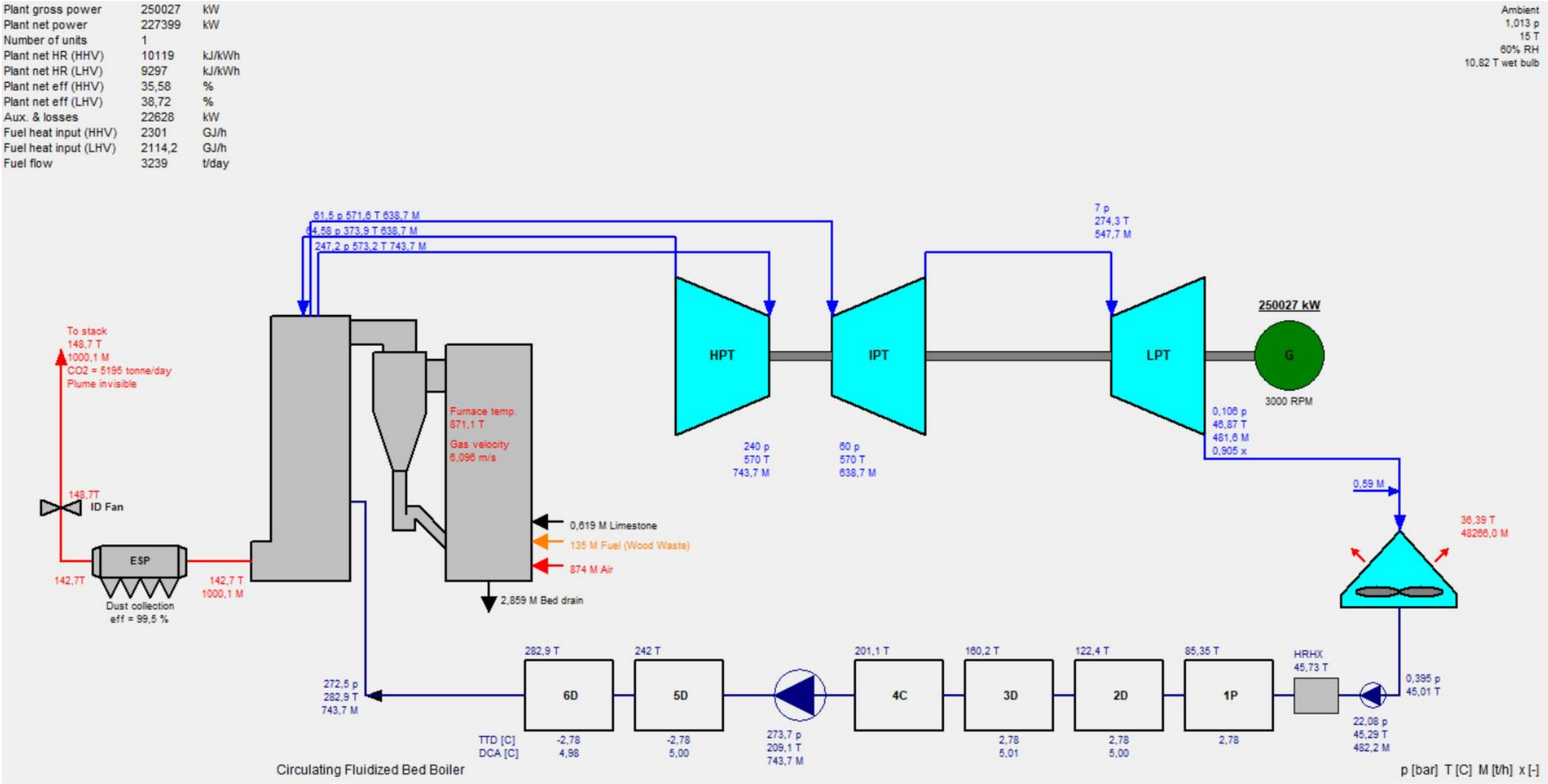


Net Eff (LHV) = 62,9%
Specific CO_2 = 314 kg/MWh

Biomass – Waste to Energy (TFX / STP-STM)

- Boiler Types
  - Grate Fired
  - Fluidized Bed
  - Adiabatic Combustion Chamber (TFX) for wet biomass
- Biomass / Waste Fuel library
- Cogeneration / DH&C available
- Automatic Steam Cycle configuration
- Automatic Boiler & Auxiliaries Design
- Several Cooling System types available

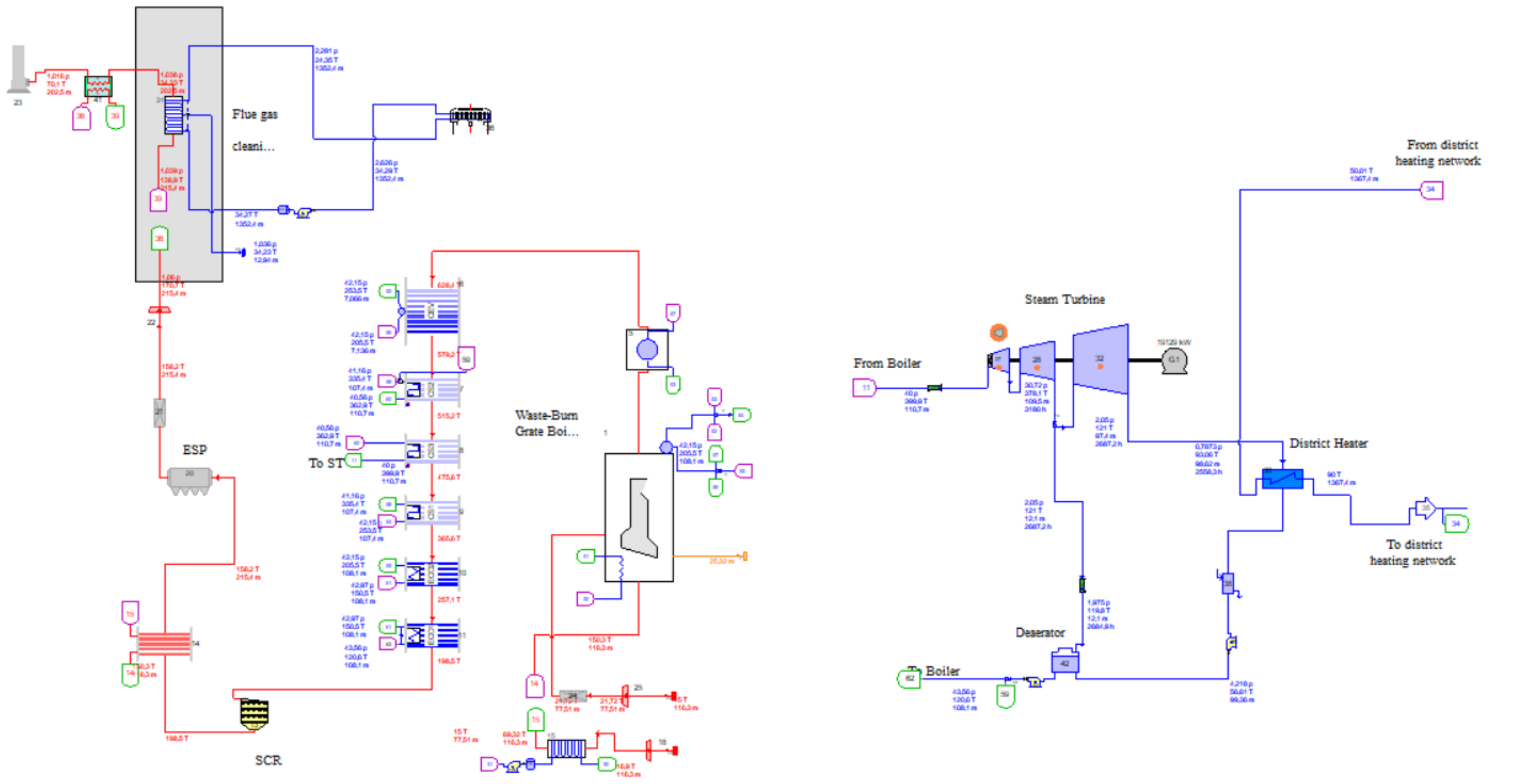
2.3 250 MW Supercritical CFB Biomass Plant in STEAM PRO



2.4 20 MW Waste to Energy + District Heating Plant in THERMOFLEX

TFX Sample *S3-22*

Gross power	19129 kW
Net power	16786 kW
Net process heat output	63581 kW
CHP efficiency	83,35 %

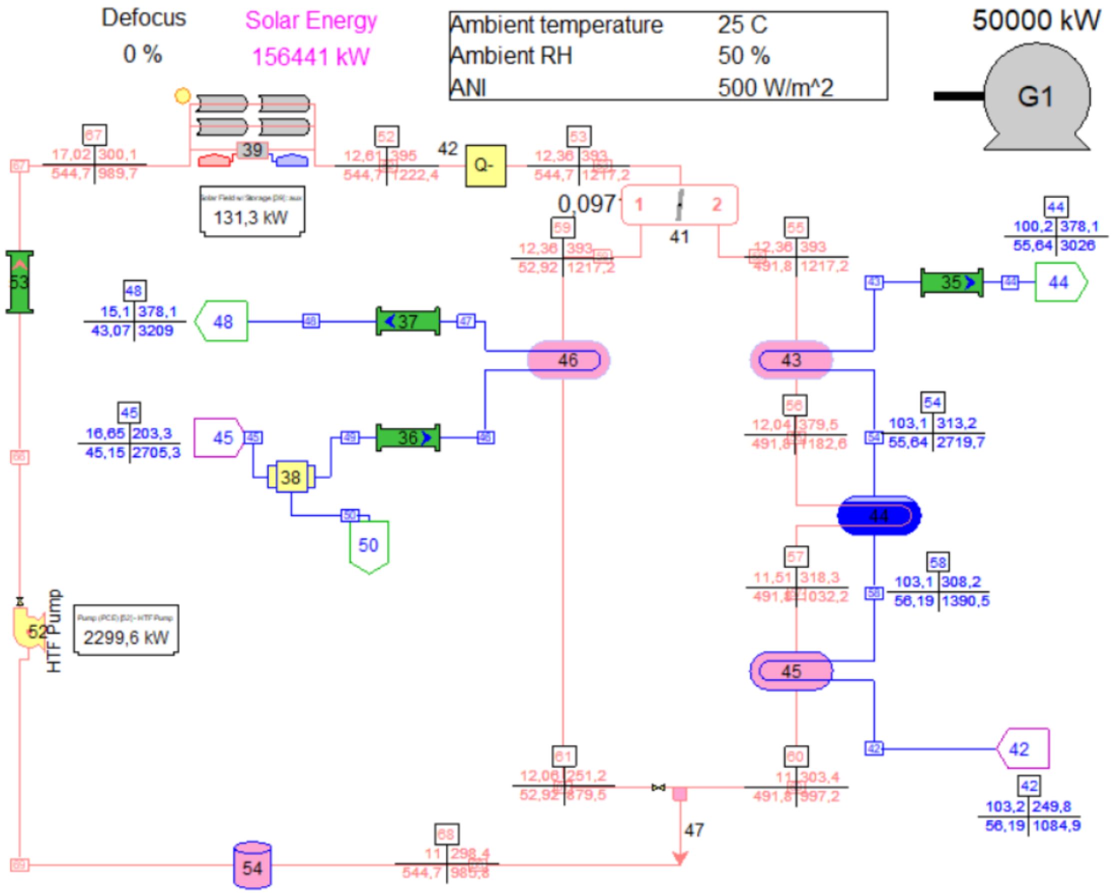


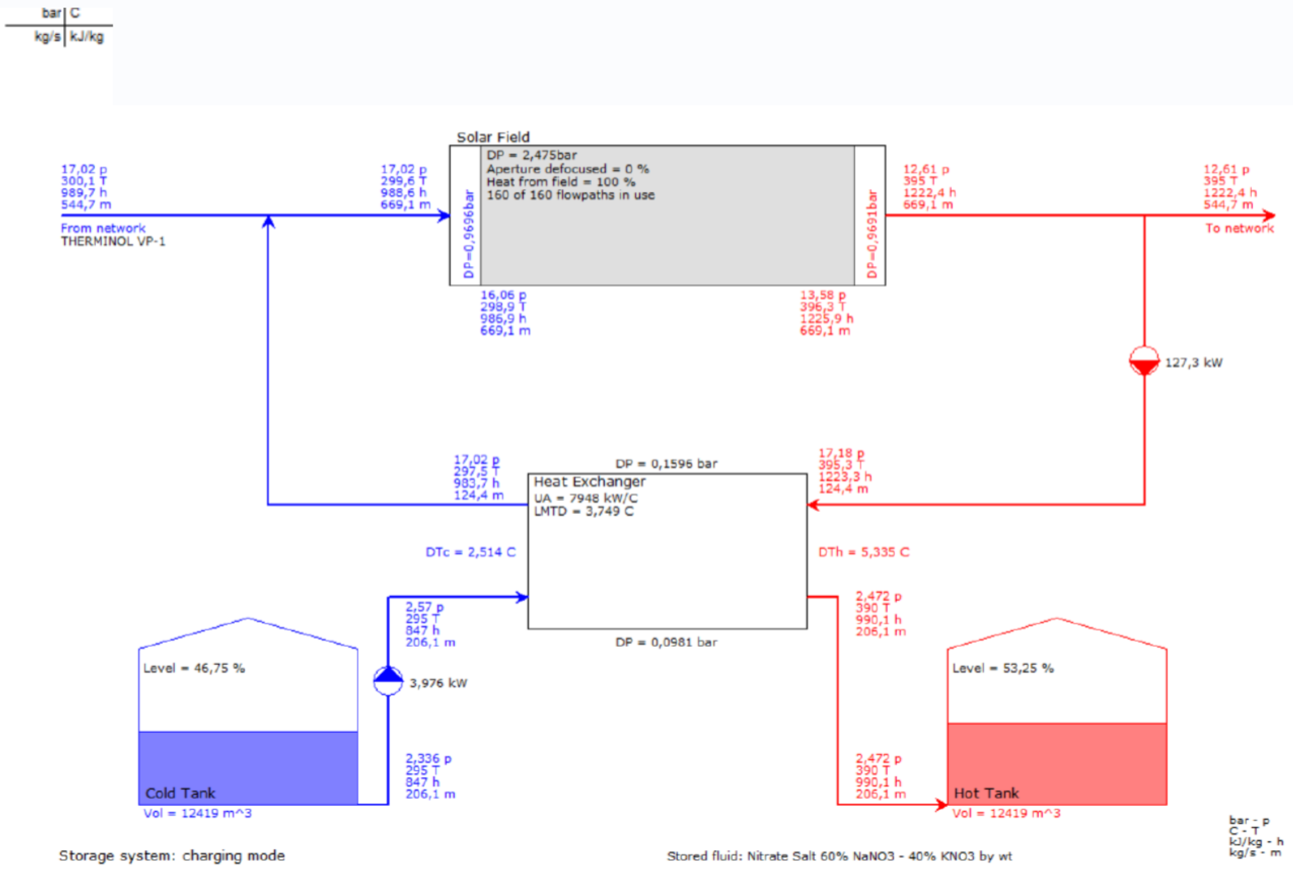
Solar Thermal (TFX)

- Types
  - Parabolic Trough
  - Central Tower + Heliostats
  - Linear Fresnel Collectors

- Options
  - HTF and Molten Salts database / User Defined
  - With or without molten salts thermal storage
  - Direct steam generation
  - 24 hours / Annual Yield calculation, ELINK

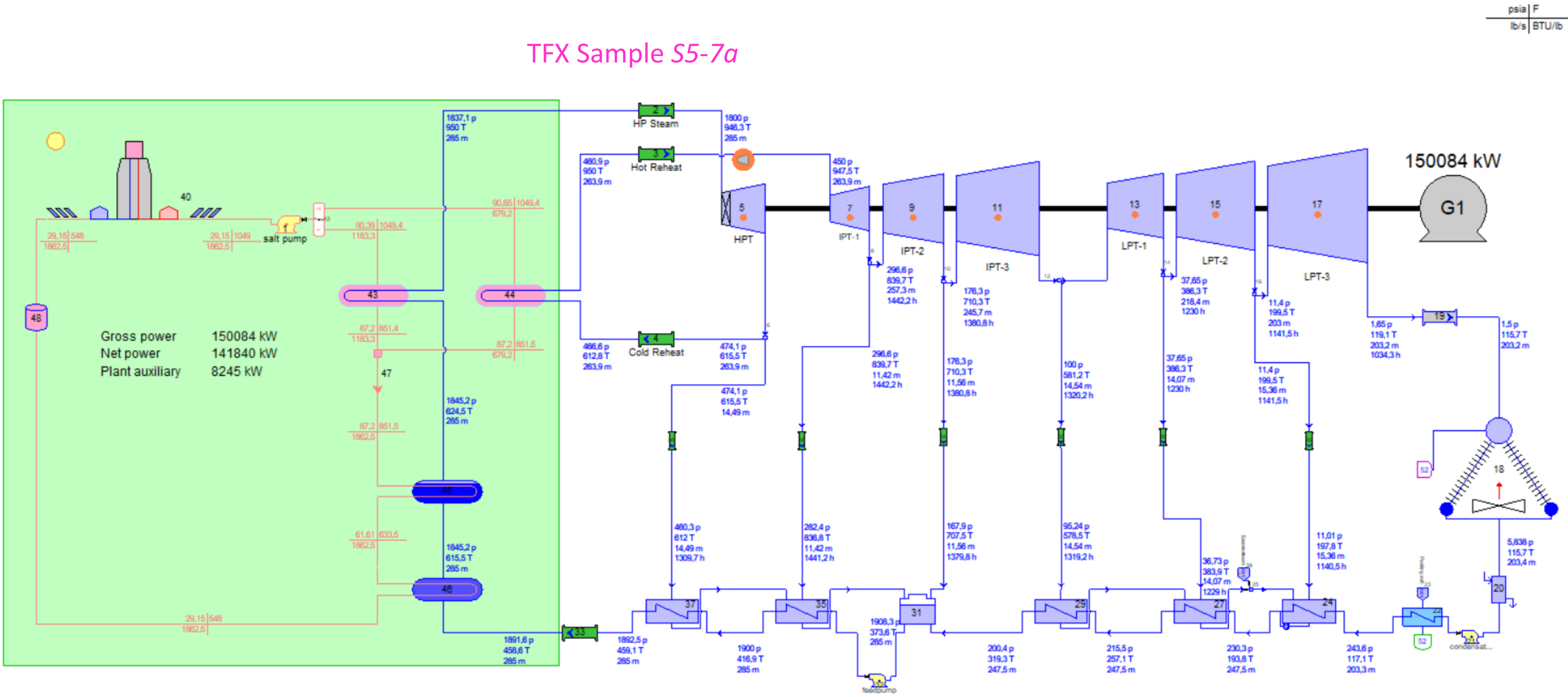
2.5 Solar Thermal Parabolic Trough + MS Storage(TFX)





2.6 Solar Tower + MS Storage(TFX)

TFX Sample *S5-7a*



Solar Thermal + Storage: Annual Yield calculation in ELINK

Sample (Elink4) Hourly Simulation-Entire Year.xlsm

Start Case	1	
End Case	10	
Current Cas	10	

Compute Cases | Press to Cancel

Case Number	Week of Year	Day of Year	Hour of Day	Daily Average Temperatur	Hourly Average Temperatur	Haze Factor
-	-	-	-	°C	°C	-
10	1	1	10	-1,9	2,5	0,14

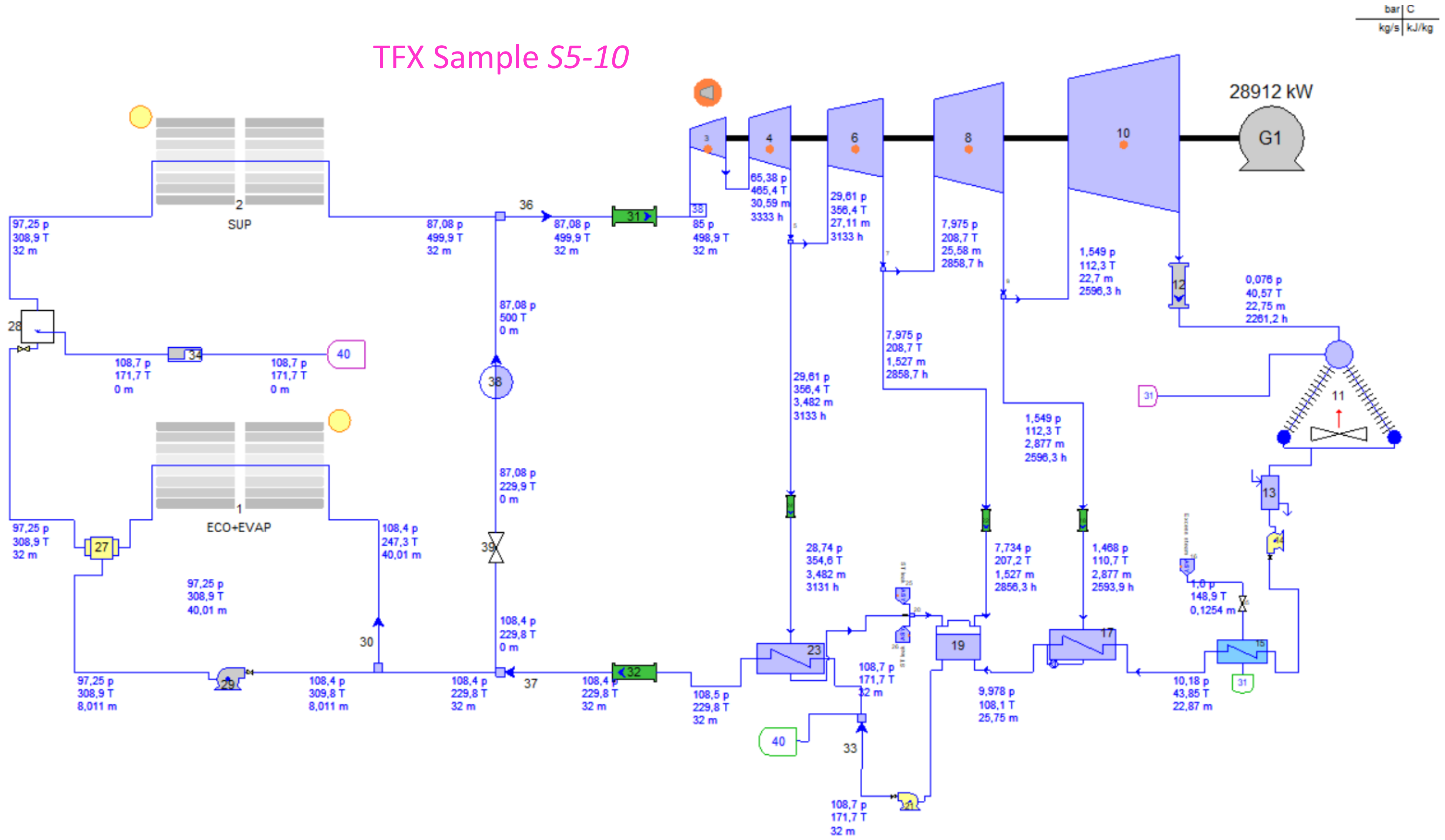
<- This row of data comes from the Input Data Stack based on the 'Current Case'. Don't edit this by hand.

INPUT DATA STACK / **OUTPUT DATA TABLE**

Case Number	Week of Year	Day of Year	Hour of Day	Daily Average Temperature	Hourly Average Temperature	Haze Factor	Aperture normal direct irradiance	Azimuth angle	Zenith angle	Altitude angle	Aperture tracking angle	Oil flow in field	Net heat absorbed by oil	Solar field efficiency	Steam Delivery Pressure	Steam Delivery Temperature	Steam Delivery Flow	Compute Date+Time
-	-	-	-	°C	°C	-	W/m^2	Degrees	Degrees	Degrees	Degrees	kg/s	kW	%	bar	C	kg/s	
1	1	1	1	-1,9	-6,7	0,14	316,611298	149,849396	66,360497	23,639502	48,9292679	112,622284	19983,2246	58,366562	121,96629	378,792755	11,76	8/19/16 17:48
2	1	1	2	-1,9	-6,2	0,14	0	70,0407639	150,69028	-60,690269	-27,819592	0	0	0	122,00001	325,914734	0,00	8/19/16 17:48
3	1	1	3	-1,9	-5,4	0,14	0	83,0701981	139,04192	-49,041912	-40,750237	0	0	0	122,00001	325,914734	0,00	8/19/16 17:48
4	1	1	4	-1,9	-4,4	0,14	0	92,5584106	127,08339	-37,083385	-52,889126	0	0	0	122,00001	325,914734	0,00	8/19/16 17:48
5	1	1	5	-1,9	-3,1	0,14	0	100,776154	115,19633	-25,196327	-64,40876	0	0	0	122,00001	325,914734	0,00	8/19/16 17:48
6	1	1	6	-1,9	-1,9	0,14	0	108,757729	103,62126	-13,621261	-75,645477	0	0	0	122,00001	325,914734	0,00	8/19/16 17:48
7	1	1	7	-1,9	-0,6	0,14	0	117,150589	92,59549	-2,5954826	-87,083626	0	0	0	122,00001	325,914734	0,00	8/19/16 17:48
8	1	1	8	-1,9	0,6	0,14	68,5349731	126,486618	82,416489	7,5835128	80,5975723	0	0	0	122,00001	325,914734	0,00	8/19/16 17:48
9	1	1	9	-1,9	1,7	0,14	281,897308	137,257782	73,489937	16,510071	66,4079666	96,1009674	17209,6523	56,348091	121,97488	379,754669	10,10	8/19/16 17:49
10	1	1	10	-1,9	2,5	0,14	316,611298	149,849396	66,360497	23,639502	48,9292679	112,622284	19983,2246	58,366562	121,96629	378,792755	11,76	8/19/16 17:49
11	1	1	11	-1,9	3,0	0,14	308	164,3	61,68	28,32	26,66	19252	57,91	122	379,1	11,32	108,30	4/30/14 17:19
12	1	1	12	-1,9	3,1	0,14	299,1	180	60,04	29,96	-8,689E-06	18521	57,42	122	379,3	10,88	103,90	4/30/14 17:19
13	1	1	13	-1,9	3,0	0,14	308	195,7	61,68	28,32	-26,66	19252	57,91	122	379,1	11,32	108,30	4/30/14 17:19
14	1	1	14	-1,9	2,5	0,14	316,6	210,2	66,36	23,64	-48,93	19983	58,36	122	378,8	11,76	112,70	4/30/14 17:19
15	1	1	15	-1,9	1,7	0,14	281,9	222,7	73,49	16,51	-66,41	17209	56,35	122	379,8	10,1	96,15	4/30/14 17:19
16	1	1	16	-1,9	0,6	0,14	68,53	233,5	82,42	7,584	-80,6	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:19
17	1	1	17	-1,9	-0,6	0,14	0	242,8	92,6	-2,595	87,08	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:19
18	1	1	18	-1,9	-1,9	0,14	0	251,2	103,6	-13,62	75,65	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
19	1	1	19	-1,9	-3,1	0,14	0	259,2	115,2	-25,2	64,41	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
20	1	1	20	-1,9	-4,4	0,14	0	267,4	127,1	-37,08	52,89	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
21	1	1	21	-1,9	-5,4	0,14	0	276,9	139	-49,04	40,75	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
22	1	1	22	-1,9	-6,2	0,14	0	290	150,7	-60,69	27,82	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
23	1	1	23	-1,9	-6,7	0,14	0	313	161	-70,98	14,14	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
24	1	1	24	-1,9	-6,9	0,14	0	2,732E-05	166	-76,04	-6,793E-06	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
25	1	2	1	-1,9	-6,7	0,14	0	46,8	160,9	-70,92	-14,15	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
26	1	2	2	-1,9	-6,2	0,14	0	69,91	150,6	-60,64	-27,84	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
27	1	2	3	-1,9	-5,4	0,14	0	82,96	139	-49	-40,78	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
28	1	2	4	-1,9	-4,4	0,14	0	92,47	127	-37,04	-52,93	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
29	1	2	5	-1,9	-3,2	0,14	0	100,7	115,2	-25,15	-64,46	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
30	1	2	6	-1,9	-1,9	0,14	0	108,7	103,6	-13,58	-75,7	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20
31	1	2	7	-1,9	-0,6	0,14	0	117,1	92,54	-2,544	-87,14	0	0	122	325,9	8,172E-08	0,00	4/30/14 17:20

ELINK Main | Help+Information | Input+Output Data

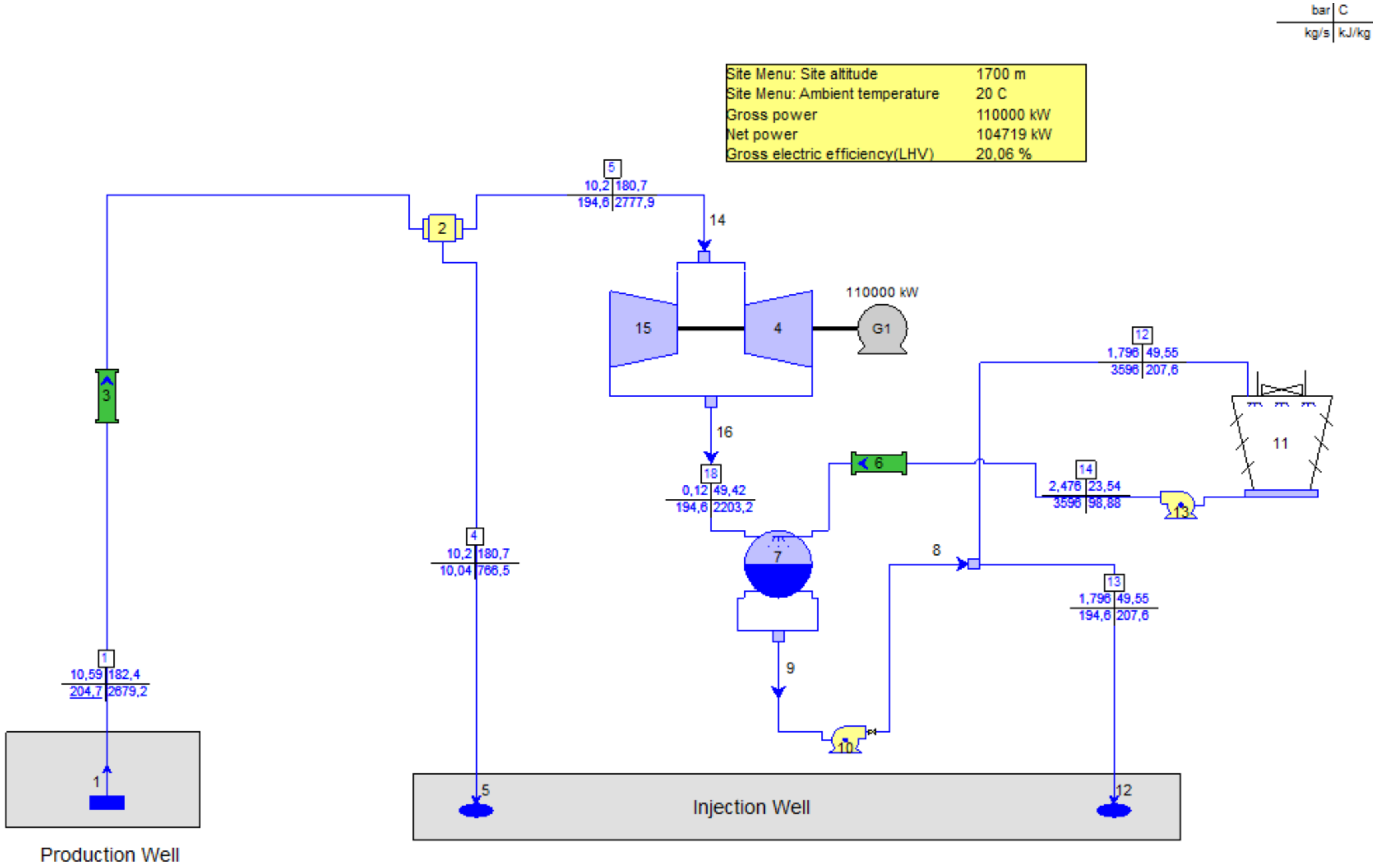
2.7 Solar Thermal Fresnel Direct Steam Generation with Biomass backup



Geothermal (TFX)

- Flash Steam
- Binary Cycles
  - Refrigerants REFPROP database / User Defined

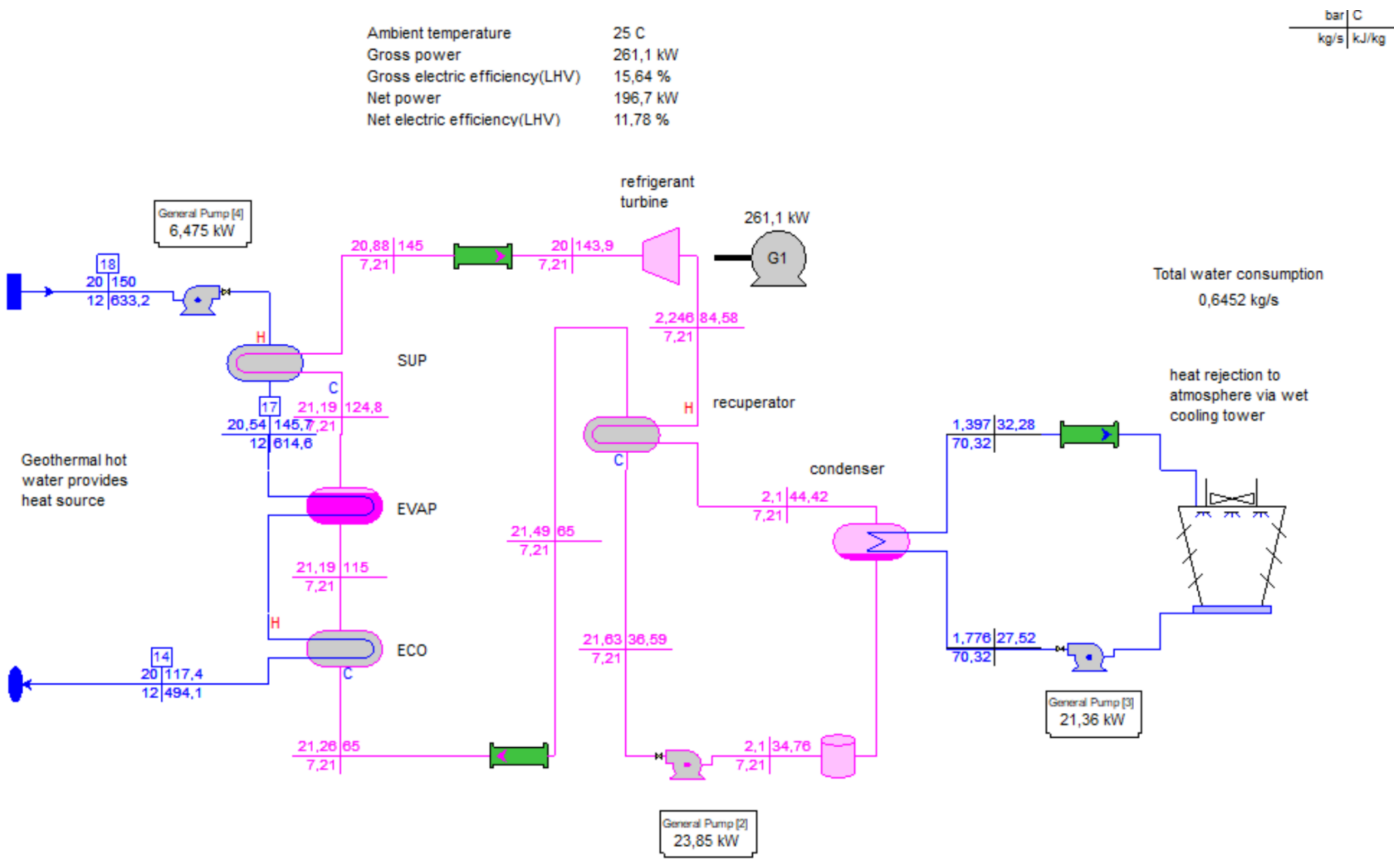
2.8 Geothermal Flash type (TFX)



2.9 Geothermal Binary ORC (TFX)

TFX Sample *S6-16b*

Ambient temperature	25 C
Gross power	261,1 kW
Gross electric efficiency(LHV)	15,64 %
Net power	196,7 kW
Net electric efficiency(LHV)	11,78 %

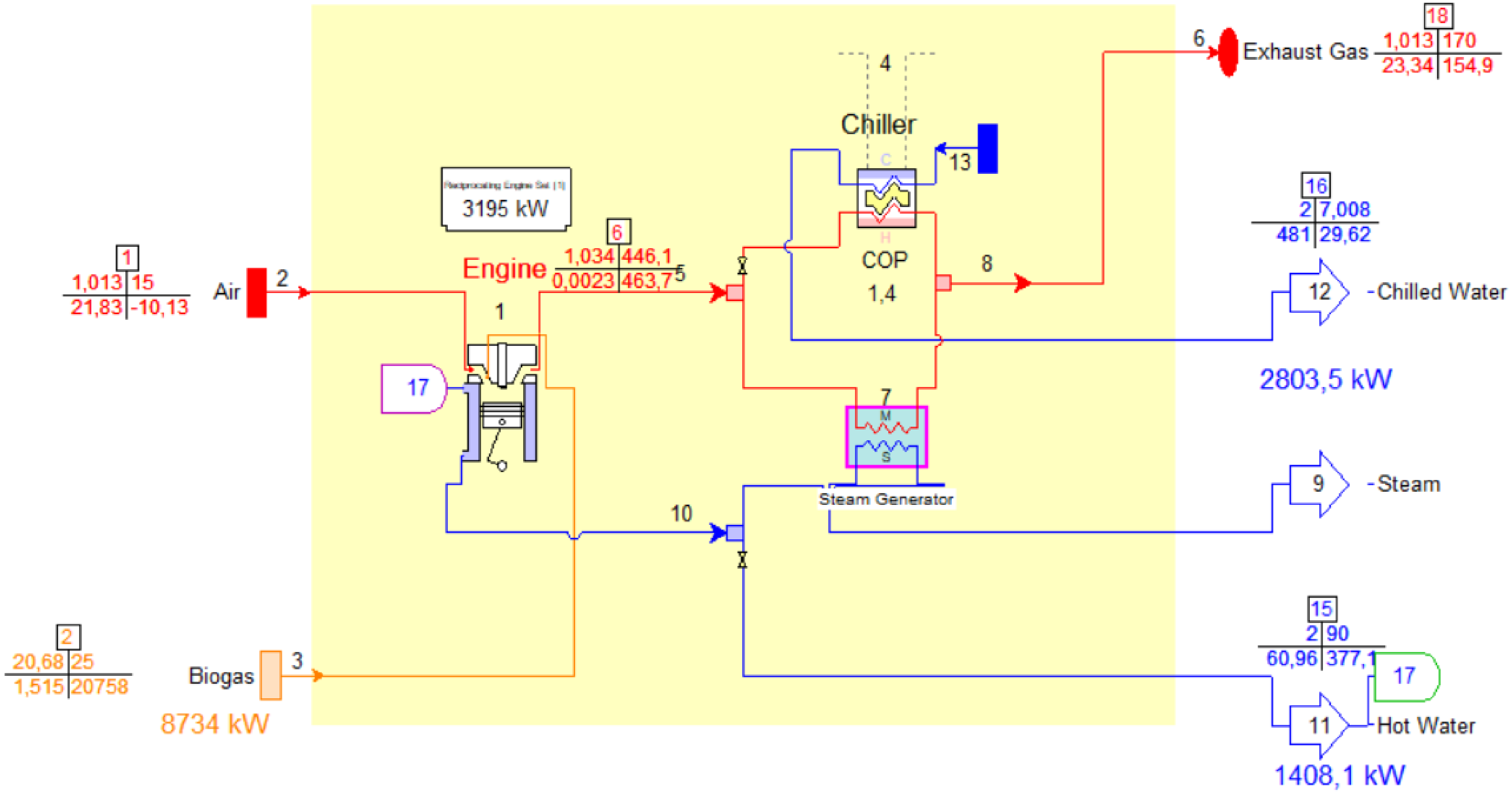


Biogas & Gas Engine (GTP-GTM / TFX)

- Recip Engine database in GTP / TFX
- Recip Engine User Defined in TFX
- Heat recovery options
- Trigeneration: hot water, steam, chilled water

2.10 Biogas & Gas Engine + Heat Recovery / Trigeneration in TFX

Net power	3163 kW
CHP Eff	84,4%



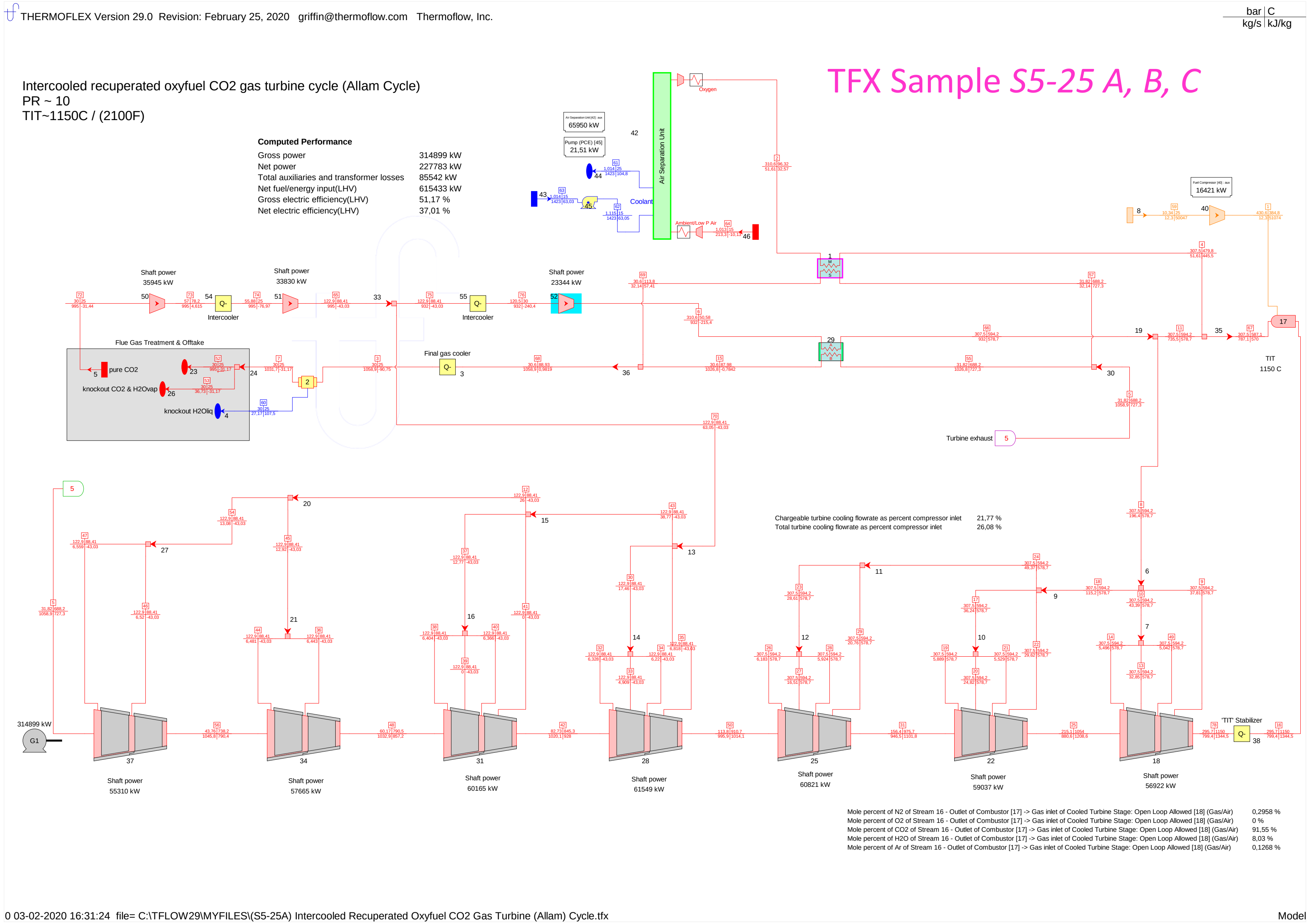
Supercritical CO_2 Cycles

- Supercritical CO_2 properties (REFPROP) in TFX
- ASU / Oxyfuel Combustion
- Steam Cooled Gas Turbine
- Cooled Turbine Stage Calculation

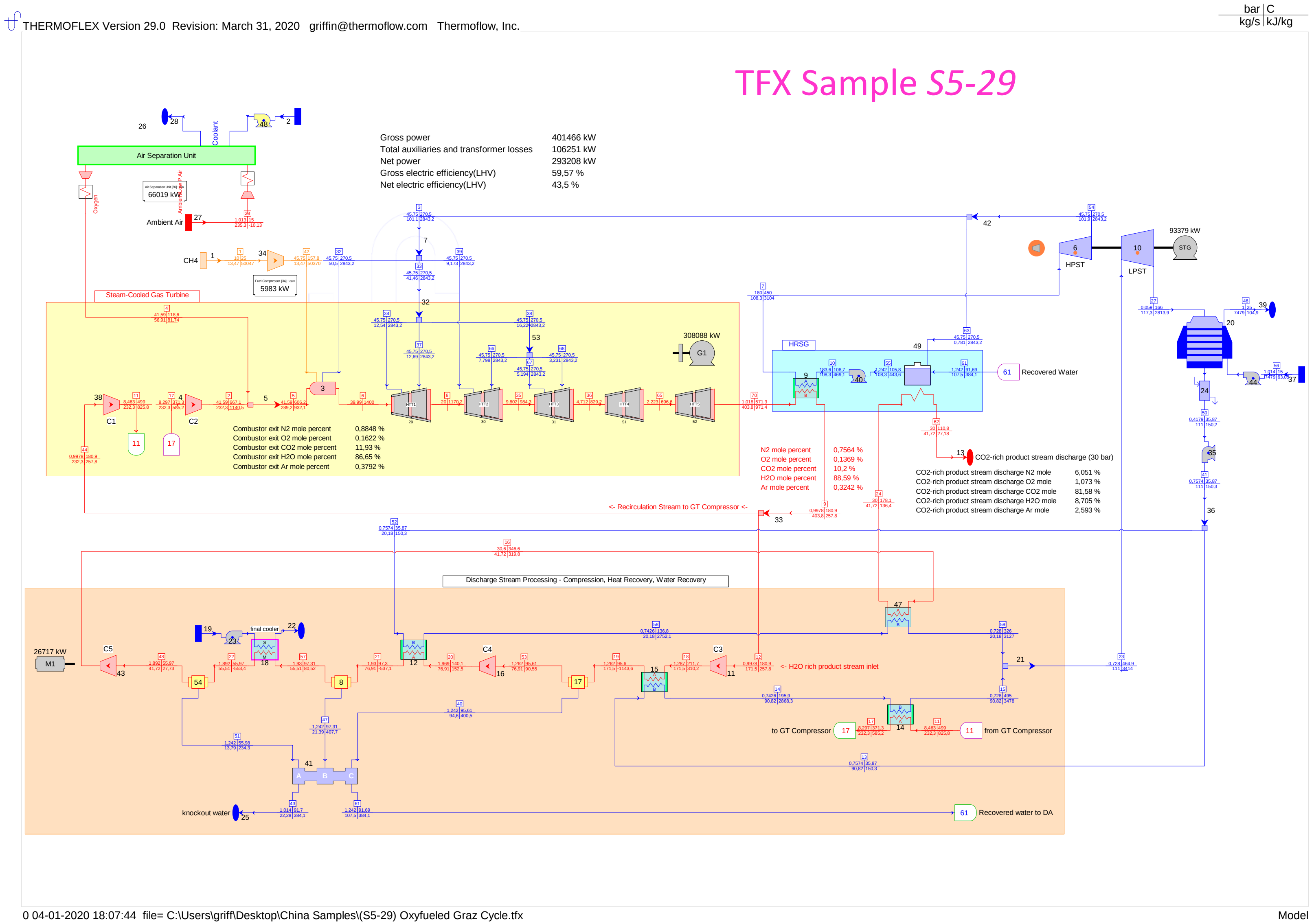
→ The Allam cycle is a novel **CO_2**, oxy-fuel power cycle that utilizes hydrocarbon fuels while inherently capturing approximately 100% of atmospheric emissions, including nearly all CO_2 emissions at a cost of electricity.

→ 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.

2.11 Intercooled Recuperated Oxyfuel CO_2 Gas Turbine (Allam) Cycle



2.12 (S5-29) Oxyfueled Graz Cycle



CO_2 Capture

- **Post combustion CO_2 capture →** *CO_2 is separated from the flue gases*
  - Chemical absorption using amine-base solvents (MEA)
  - Available in GTPM, STPM & TFX

- **Precombustion CO_2 capture →** *CO_2 is removed from the fuel before it's burned*
  - Physical Absorption (Selexol)
  - Available in GTPM for IGCC plants & TFX

- **Oxyfuel combustion →** CO_2 is removed from combustion products that are mostly CO_2 and water vapor
  - Air Separation Unit
  - Available in TFX

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(5) Questions & Answers (approx. 15min)

CO_2 Capture Options in THERMOFLOW software

- **Post combustion CO_2 capture** → *CO_2 is separated from the flue gases*
    - Chemical absorption using amine-base solvents (MEA)
    - Available in GTPM, STPM & TFX

- **Precombustion CO_2 capture** → *CO_2 is removed from the fuel before it's burned*
    - Physical Absorption (Selexol)
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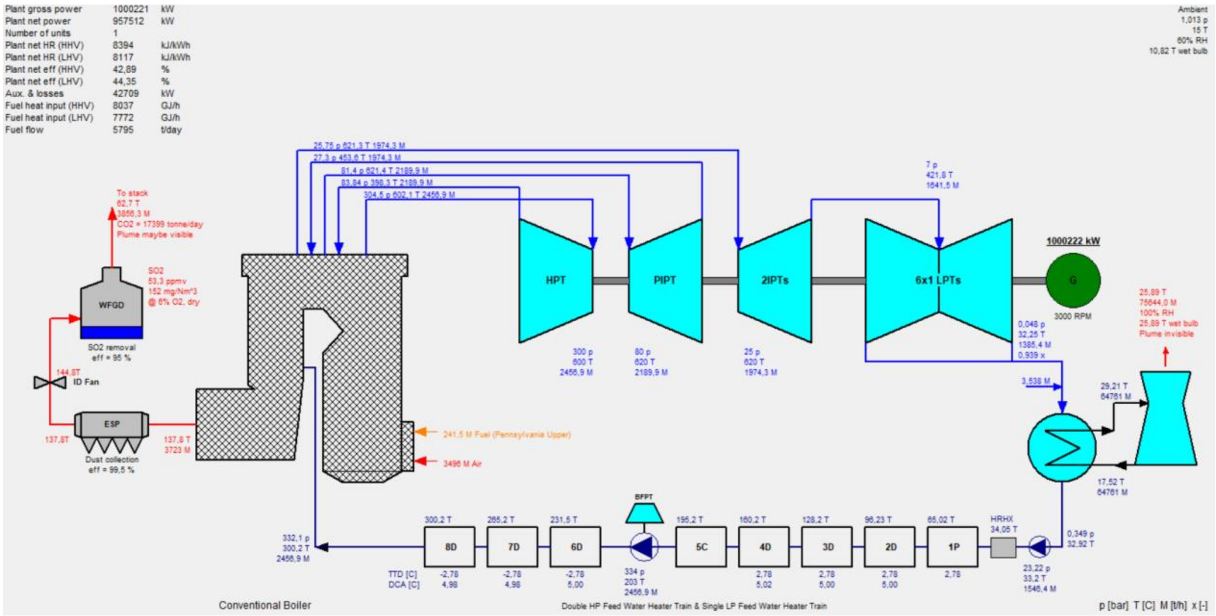
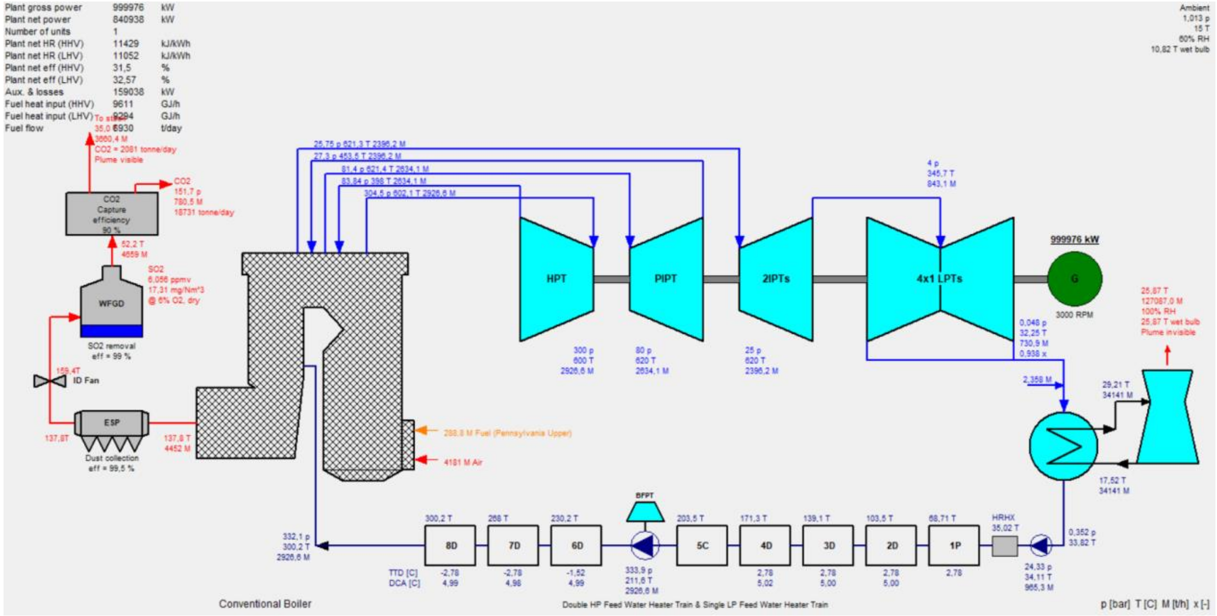
- **Oxyfuel combustion** → *CO_2 is removed from combustion products that are mostly CO_2 and water vapor*
    - Air Separation Unit
    - Available in TFX

Examples of CO_2 capture

- **Post combustion CO_2 capture in STP** → Differences vs a plant without CCS
- **Post combustion CO_2 capture added to an existing CCGT plant** → GTP-GTM-TFX
- **IGCC Precombustion CO_2 capture in GTP** → Coal Gasification + CCS

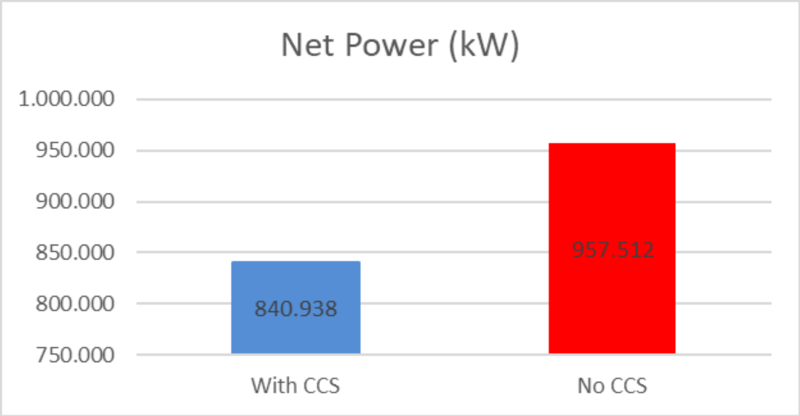
2.b.1 Post Combustion CO_2 capture in STEAM PRO

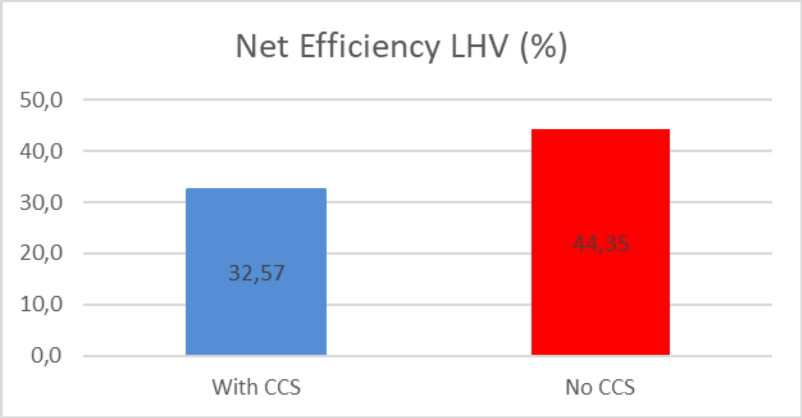


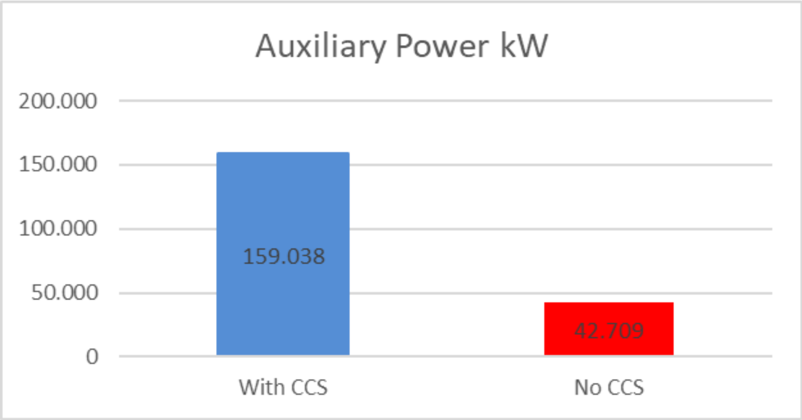


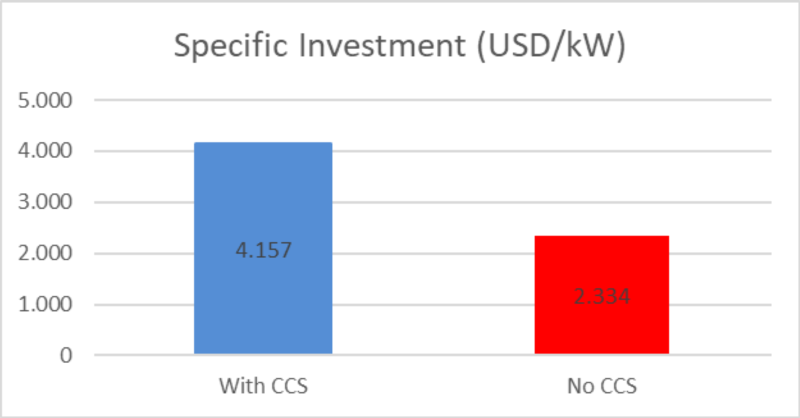
		no CCS	with CCS	
Gross Power	MW	1.000	1.000	
Net Power	MW	960	847	-11,8%
Net Efficiency - LHV	%	44,5	32,8	-11,7
Specific Investment	€/kW	1.872	3.372	80,1%
CO2 emitted	ton/year	5.872.022	702.417	
Specific CO2	kg/MWh	753	100	
CO2 captured	%		88%	

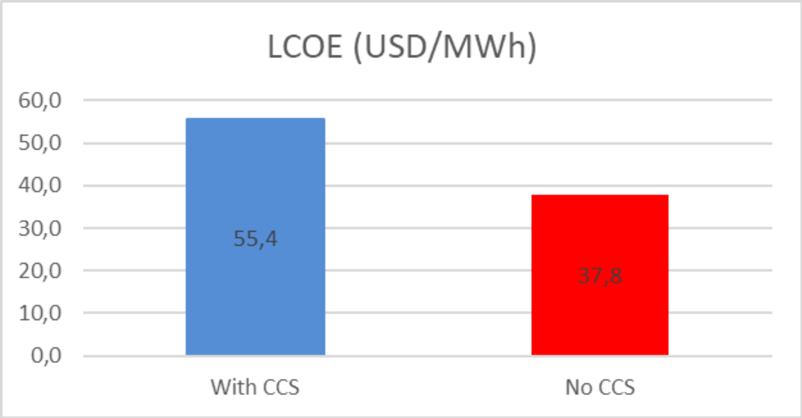
2.b.1 Post Combustion CO_2 capture in Steam Pro

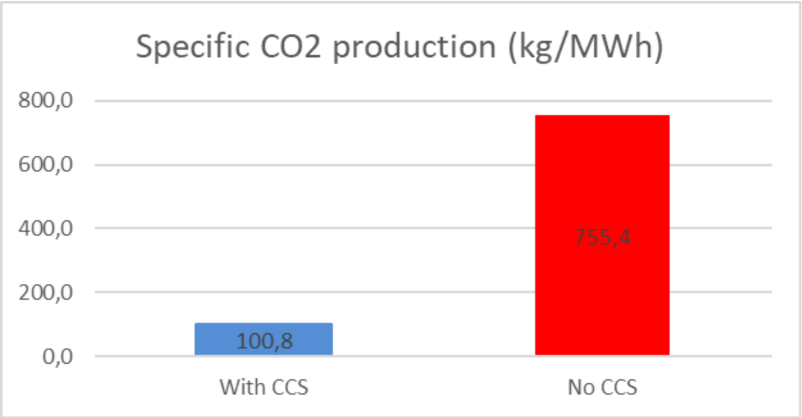






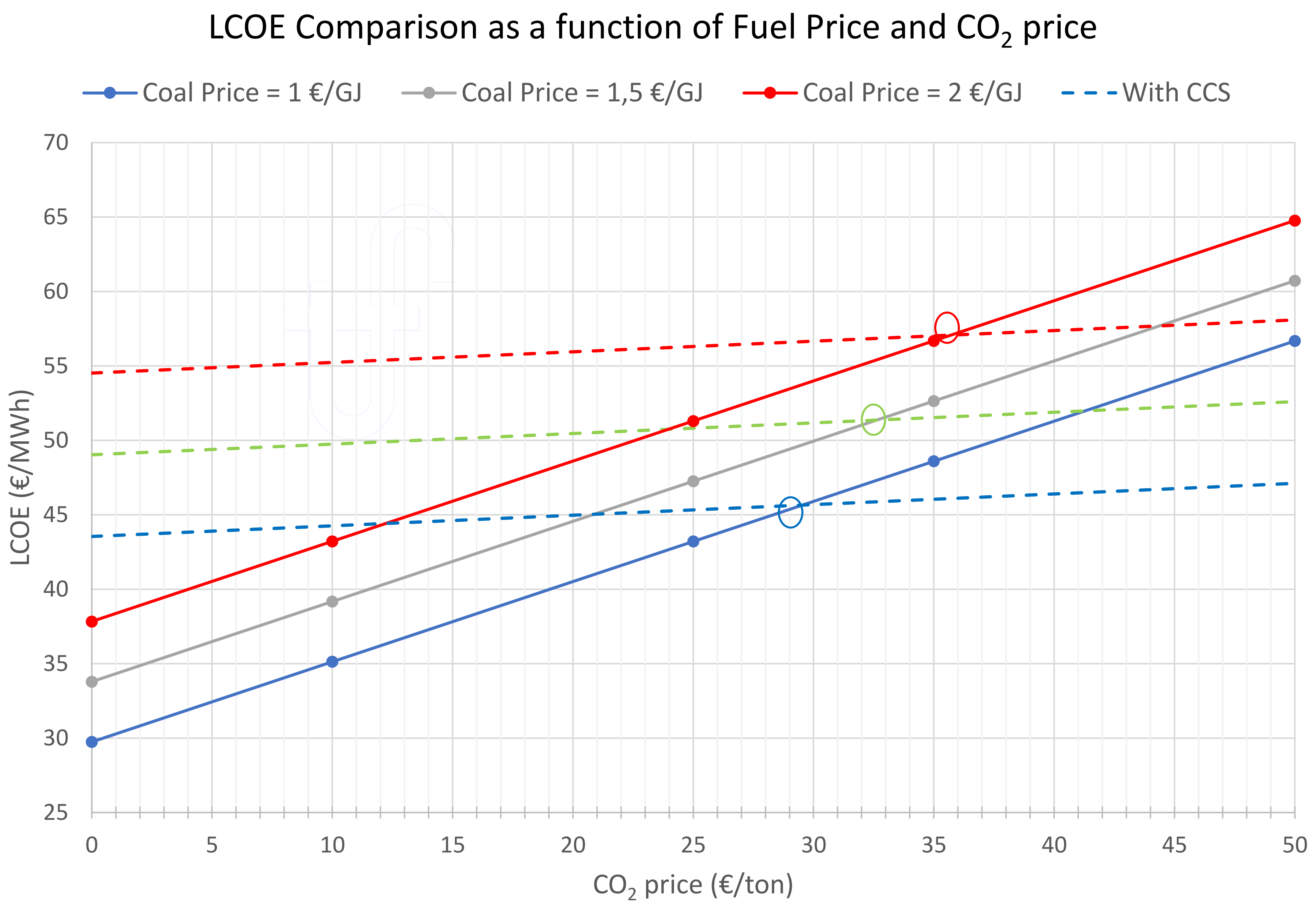






Thermoflow

2.b.1 Post Combustion CO_2 capture in STEAM PRO



2.b.2 Adding Post Combustion CO_2 capture to a CCGT Plant using GT PRO – GT MASTER - THERMOFLEX

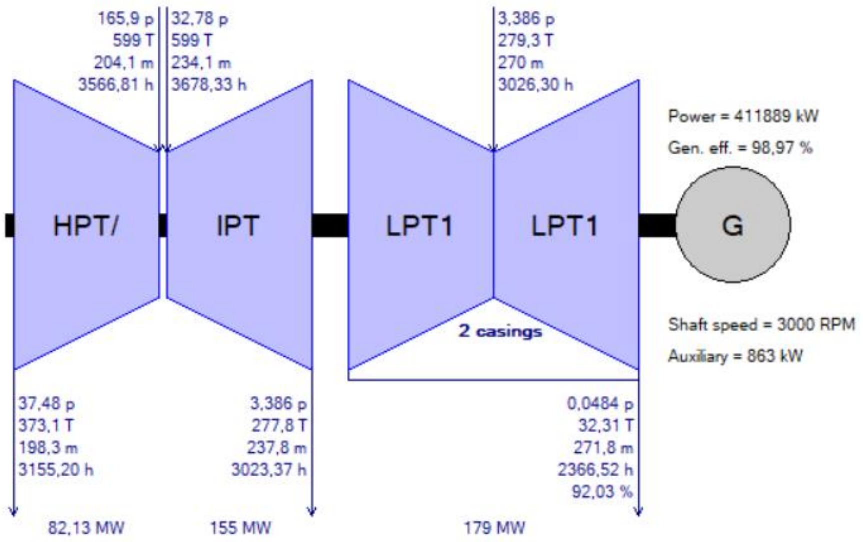
- Design the CCGT Plant in GT PRO, without CCS
- Convert the design to GT MASTER
- Import the GTM file into THERMOFLEX
- Add the CO_2 Capture in THERMOFLEX

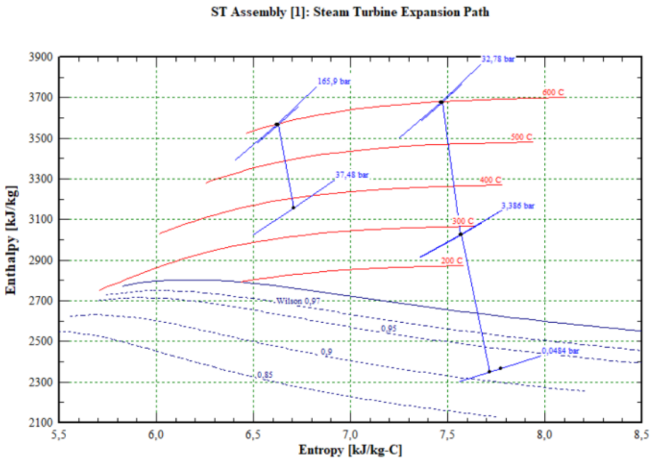
		no CCS	added CCS	*Dif*
Gross power	kW	1.292.359	1.200.587	*-7,1%*
Net power	kW	1.259.463	1.105.221	*-12,2%*
Total auxiliaries and transformer losses	kW	32.896	95.366	
Net electric efficiency(LHV)	%	61,45	53,91	*-7,5*
Net fuel/energy input(LHV)	kW	2.049.463	2.050.252	
Specific Cost	€/kW	618	1350	*118,4%*
LCOE	€/MWh	26,9	36,9	*10*
Assumptions				
Operating Hours (full load equivalent)		8100	8100	
Fuel LHV price	€/GJ	3,0	3,0	
CO2 price	€/ton	25	25	
Discount Rate	%	6	6	

Thermoflow

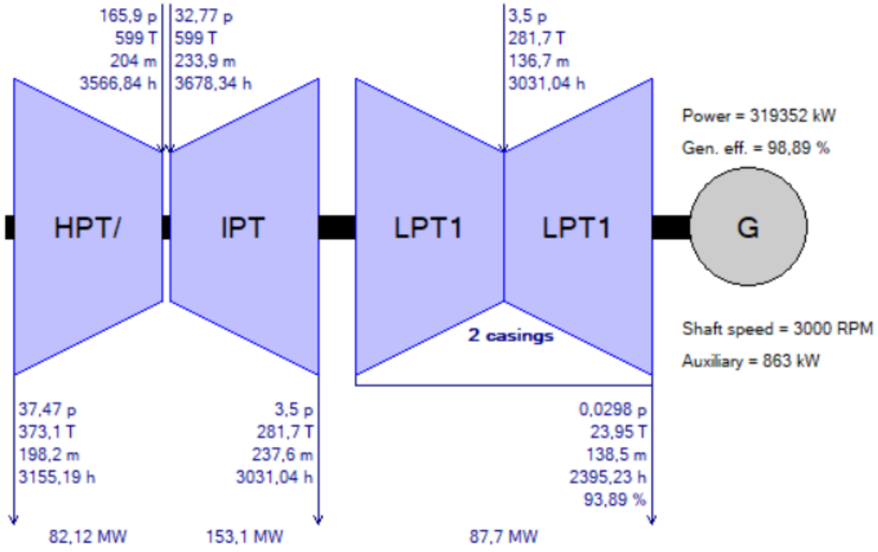
2.b.2 Adding Post Combustion CO_2 capture to a CCGT Plant using GT PRO – GT MASTER - THERMOFLEX

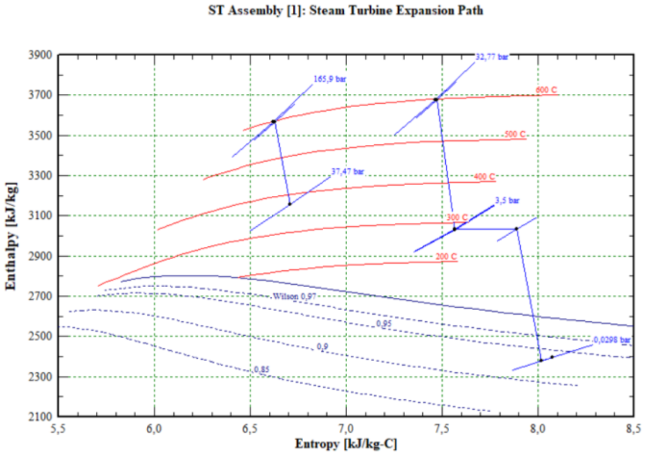
No CCS



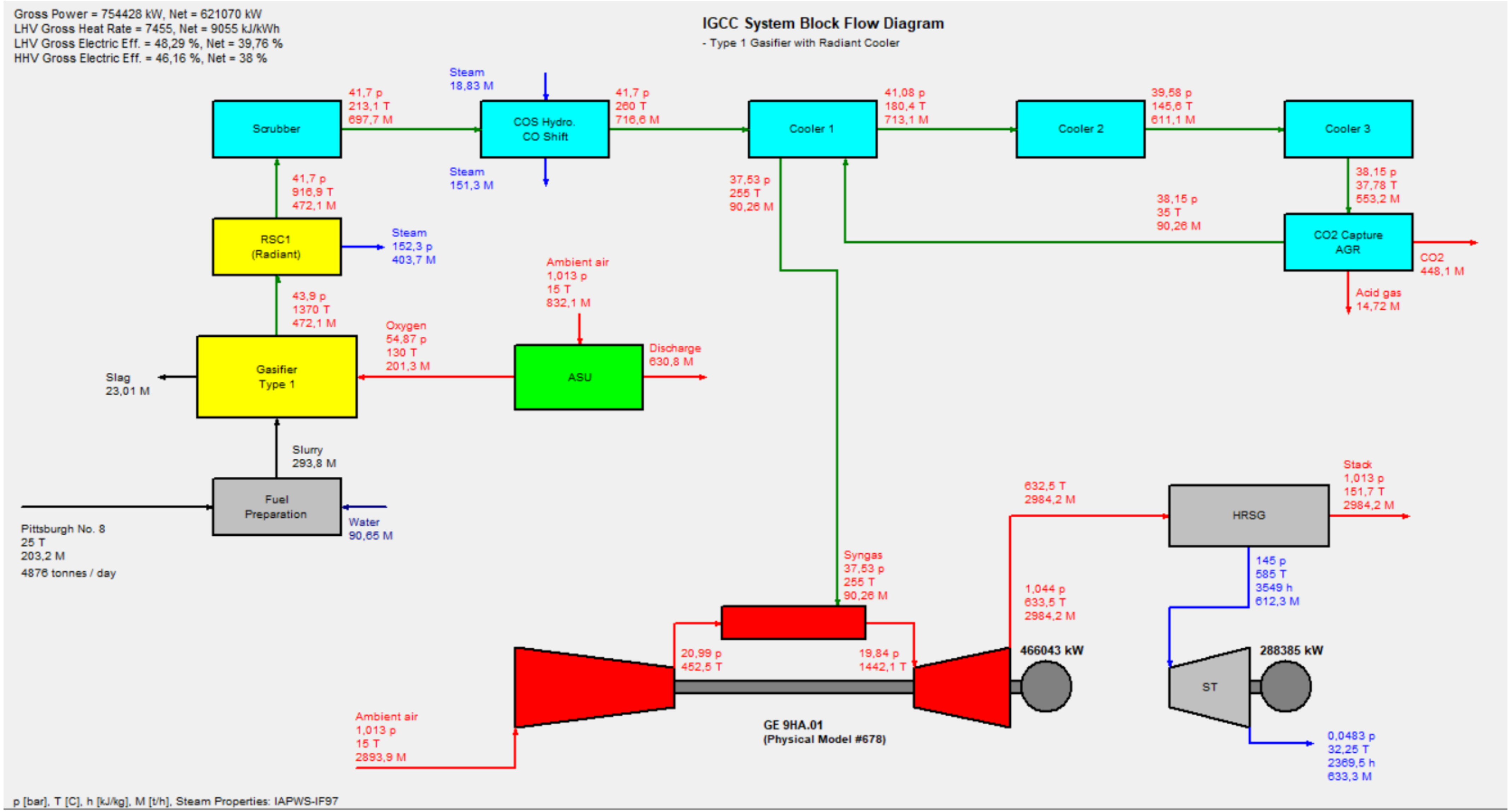


With CCS





2.b.3 IGCC with Precombustion CO_2 capture in GT PRO



Modelling Decarbonization Technologies

AGENDA – Thursday, 27. May 2021 13:30 Central European Time (Amsterdam, Paris, Berlin)**:**

(1) Welcome & Overview

(2) Demonstration of selected sample files:

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

(4) Power-to-X features

- Hydrogen
- Storages

(5) Questions & Answers (approx. 15min)

What is NOVO PRO and what role does it play in the Thermoflow package?

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

"Thermal World"

Coal, GT, Recips,
Biomass, WtE,…

"Renewable World"

PV, Wind, Hydro, …

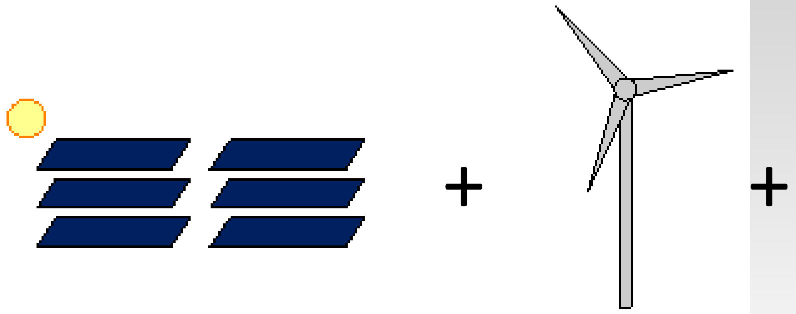
Hydrogen (H_2),
eFuels,
Storages,…

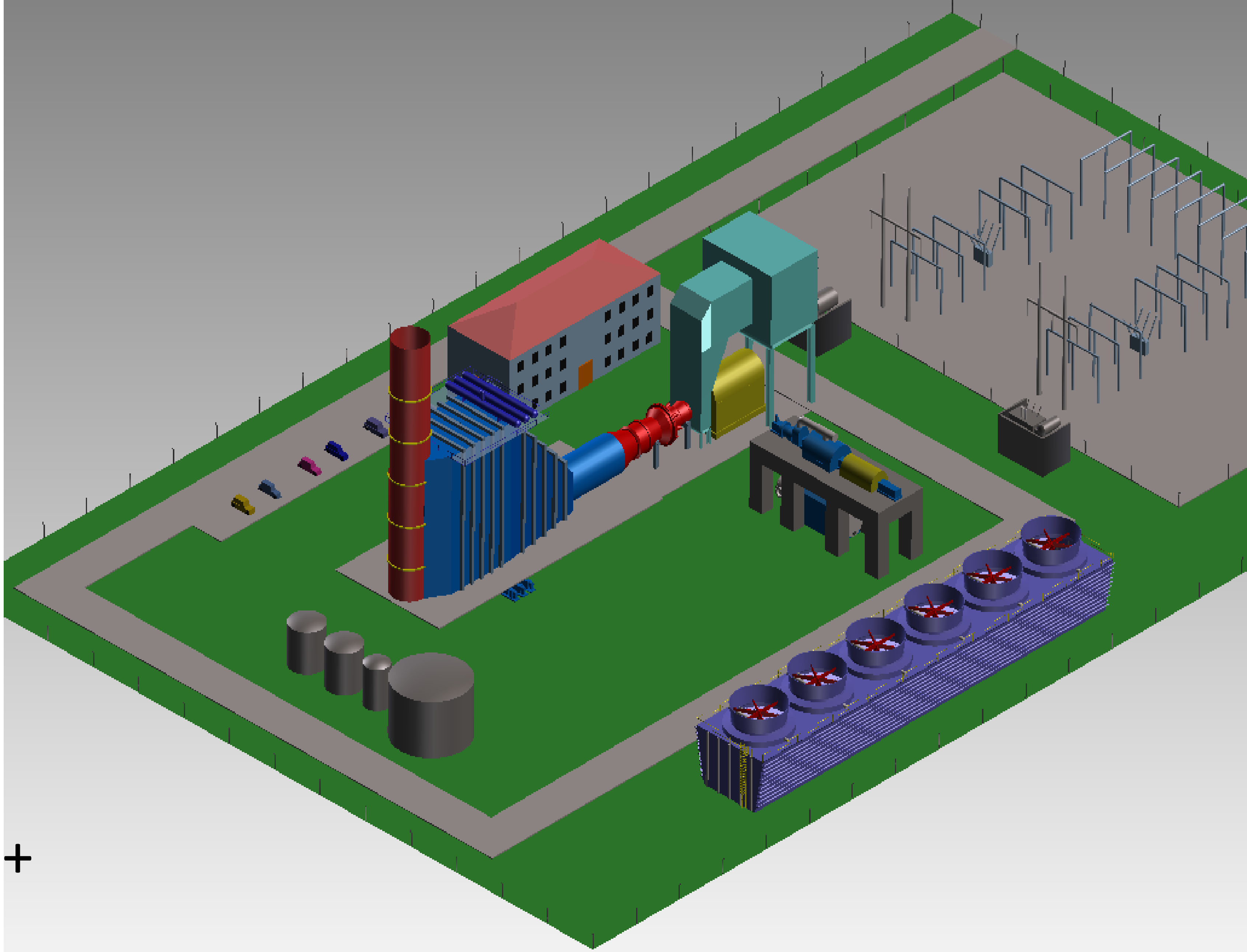
Hypothetical Hybrid Plant Arizona / USA

300MW PV + 300MW Wind

+ Gas Fired Thermal

(Backup) Plant





NOVO PRO Sample 1:

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

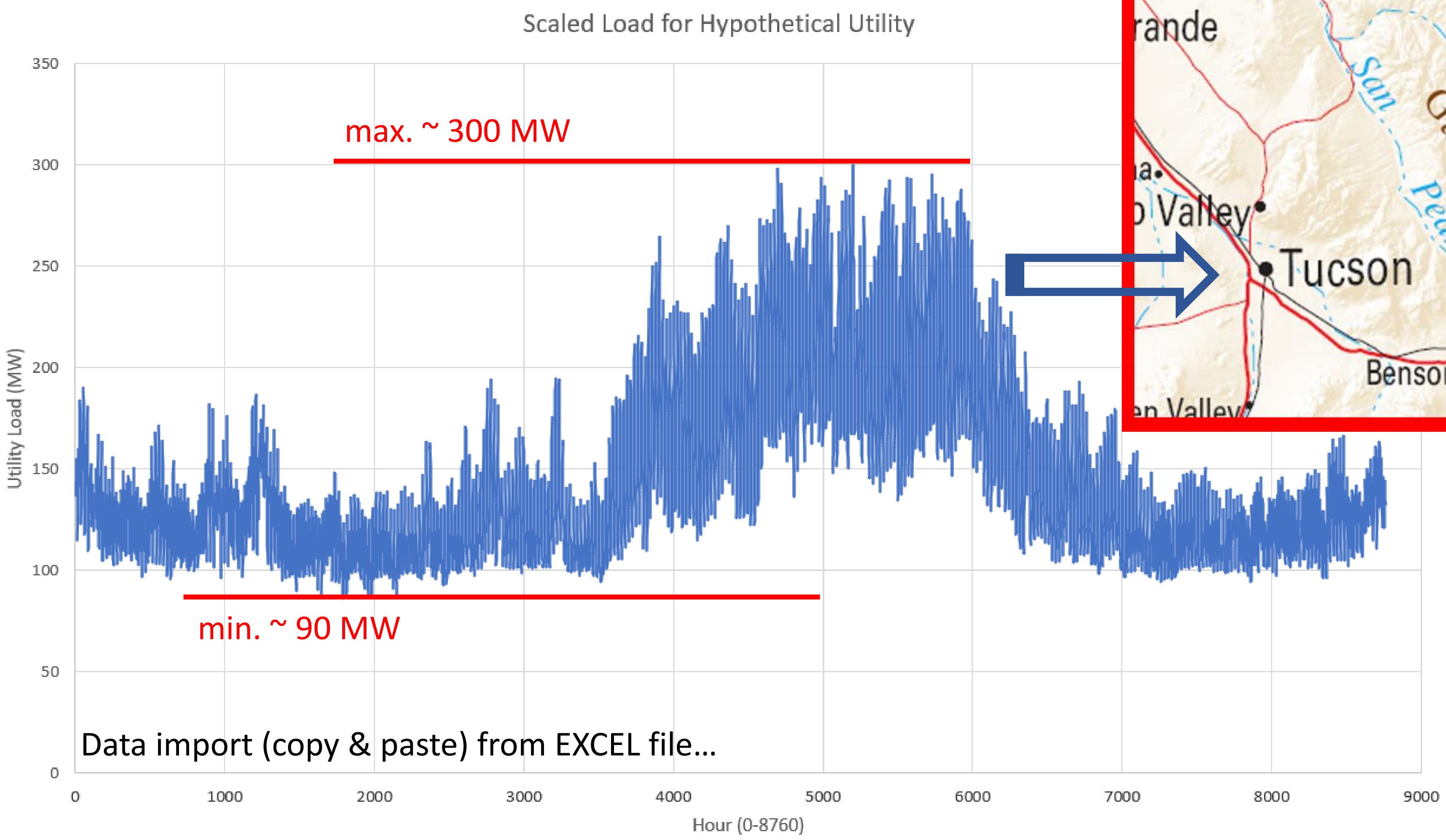
What can I expect from the NOVO PRO Introduction:

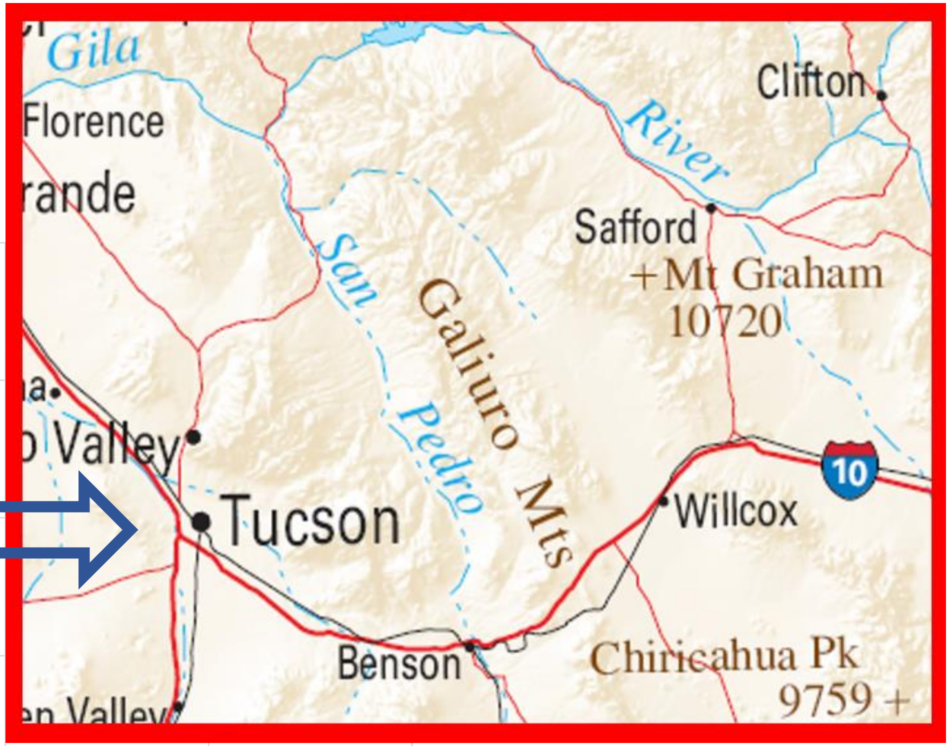
- Which inputs are needed to get started ?
- How to setup to site conditions, economical parameters and power demand ?
- How to setup renewable systems: PV Plant and Wind Farm ?
- How to setup a "customized" thermal Power Plant in GT PRO/GT MASTER/ THERMOFLEX and how to import it to NOVO PRO ?
- How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

Location:

Tucson area, Arizona, USA

Power Demand





Ambient Conditions, Wind Resource Data & Solar Irradiation

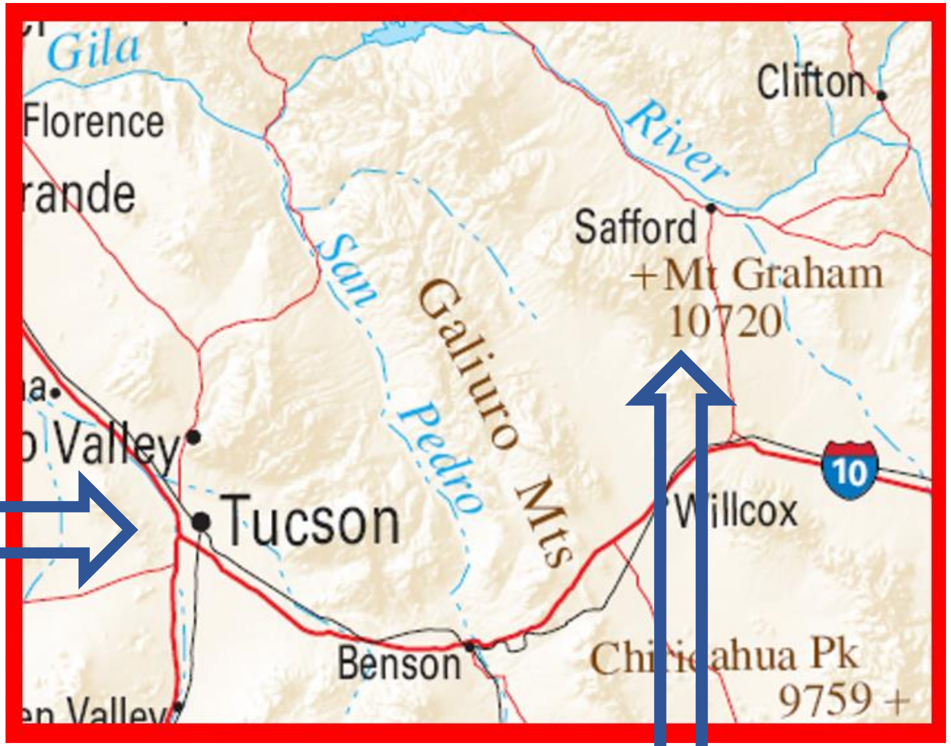
PV Solar Irradiation Data from: TMY = Typical Meteorological Year

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

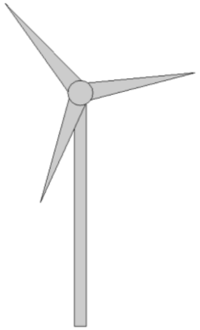
[Google Earth - PV]



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

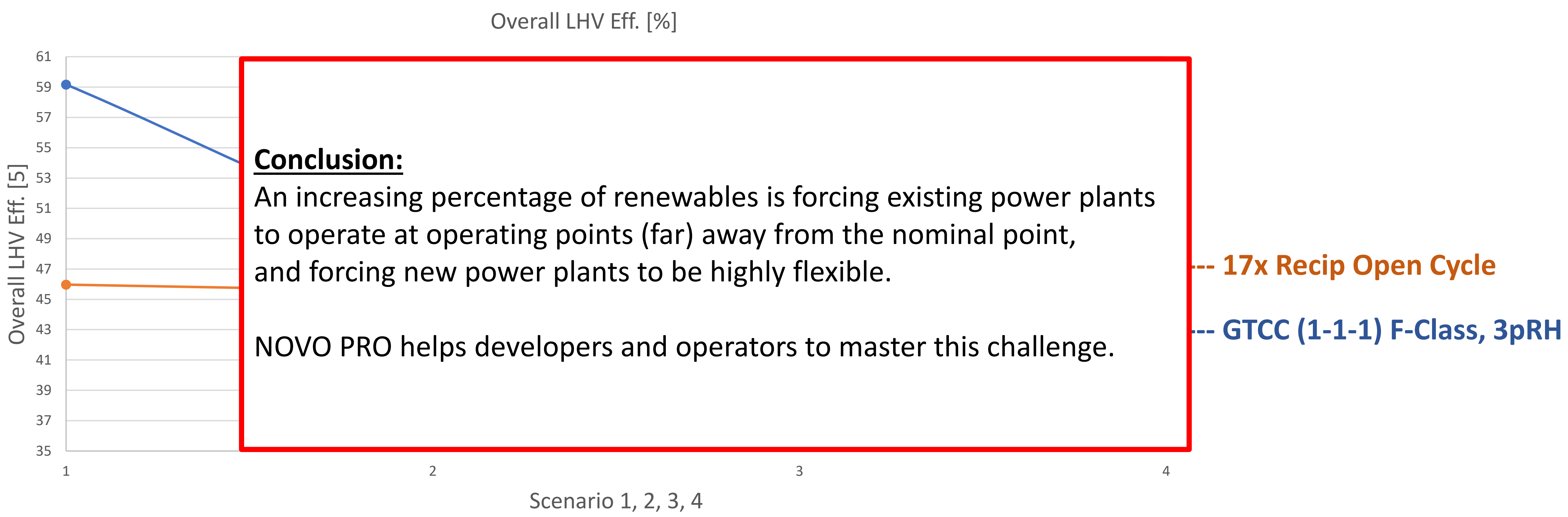
ID	Model	Fuel	Aspiration	Mode	RPM	Freq. Hz	Power kW	Texh C	Exh. flow t/h	Elec. Eff. %
446	MAN 20V35/44G	G	TA	C	750	50	10420	302	64,76	46,4
447	MAN 20V35/44G	G	TA	C	720	60	10027	302	62,32	46,4
448	MAN 18V51/60G	G	TA	C	500	50	18654	327	109,31	47,4
449	MAN 18V51/60G	G	TA	C	514	60	18654	327	109,31	47,4
451	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		Thermal + 300MW PV		Thermal + 300MW PV + 300MW Wind	
		GTCC	Recips	GTCC	Recips	GTCC	Recips	GTCC	Recips
Gross Power	**[MW]**	374	317.118						
Net Power	**[MW]**	364	307.644						
Net El. Eff.	**[%]**	59,17	45,97						
Capacity Factor	**[%]**			41,00	46,98	27,43	31,45	24,15	27,18
Overall LHV Eff.	**[%]**			49,03	45,53	45,44	45,1	44,26	44,94
Fuel Consumption	**[GJ]**			9.373.851	10.011.260	6.766.298	6.765.180	6.126.693	5.867.830
CO_2 production	**t/year**			513.841	550.086	370.904	371.724	335.843	322.418
Total Owner´s Costs	**[USD]**	300.000.000	220.000.000	300.000.000	220.000.000	656.000.000	576.000.000	1.107.000.000	1.027.000.000

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

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(4) Power-to-X features

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(5) Questions & Answers (approx. 15min)

50MW OCGT Plant Replacement by Hybrid Renewables with Storage

(NOVO PRO sw Simulation)

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 & Conclusion

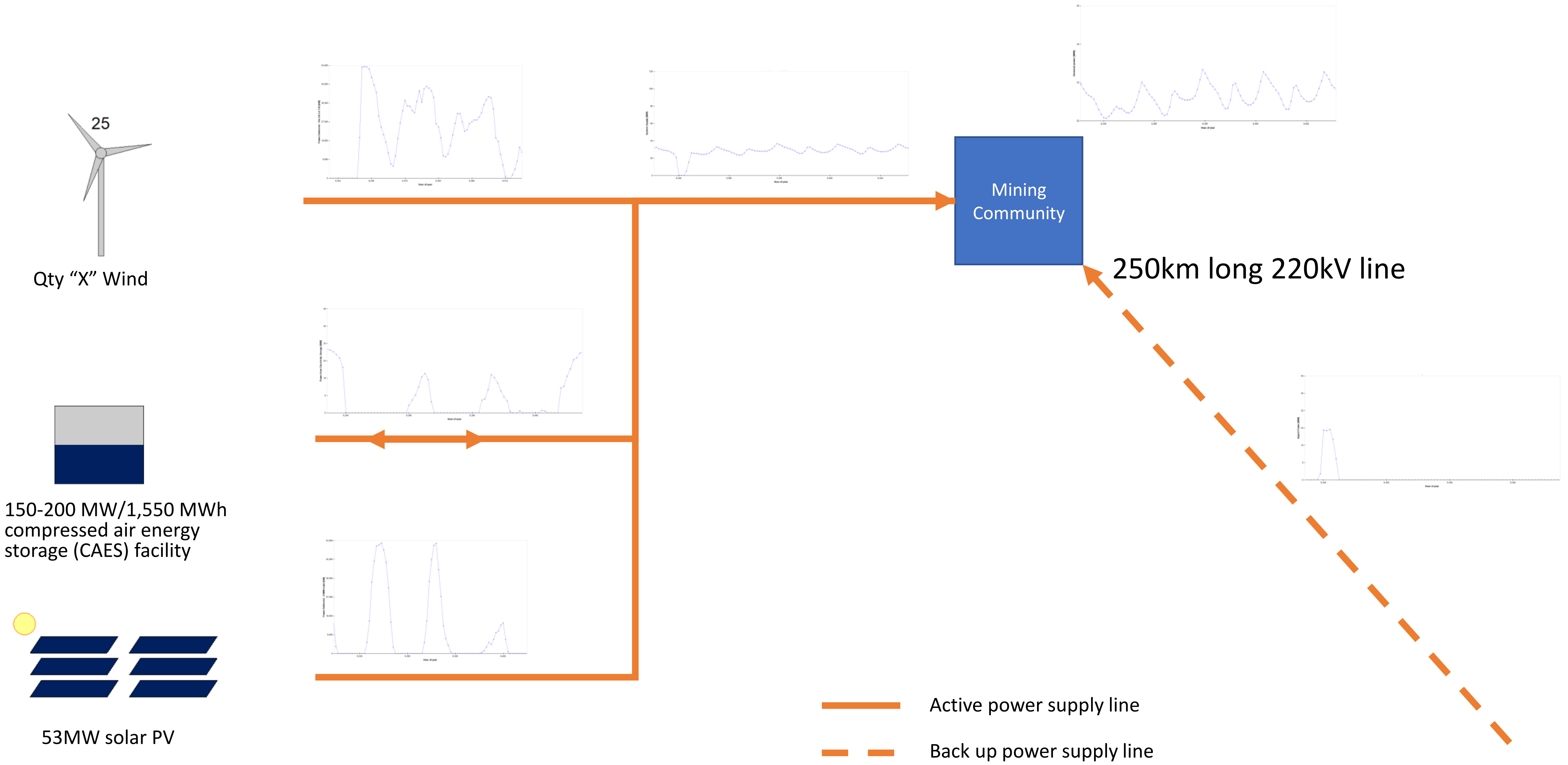
Option 1 is more expensive than Option 2 and consequently offers inferior financial performance. Both options have inferior performance relative to the existing OCGT in terms of expected import power requirement (up to 33MW for Options 1 & 2, practically zero MW for the OCGT plant). The advantage of Option 1 and Option 2 over the existing OCGT is the CO_2 emissions (zero for Options 1 & 2, up to 237000 t/yr for the OCGT). Retaining the OCGT plant may be justified in light of the fluctuating import power requirement and the absence of a scheme in Australia to monetise the avoided CO_2 emissions

Existing Configuration – normal operation

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

Option 1

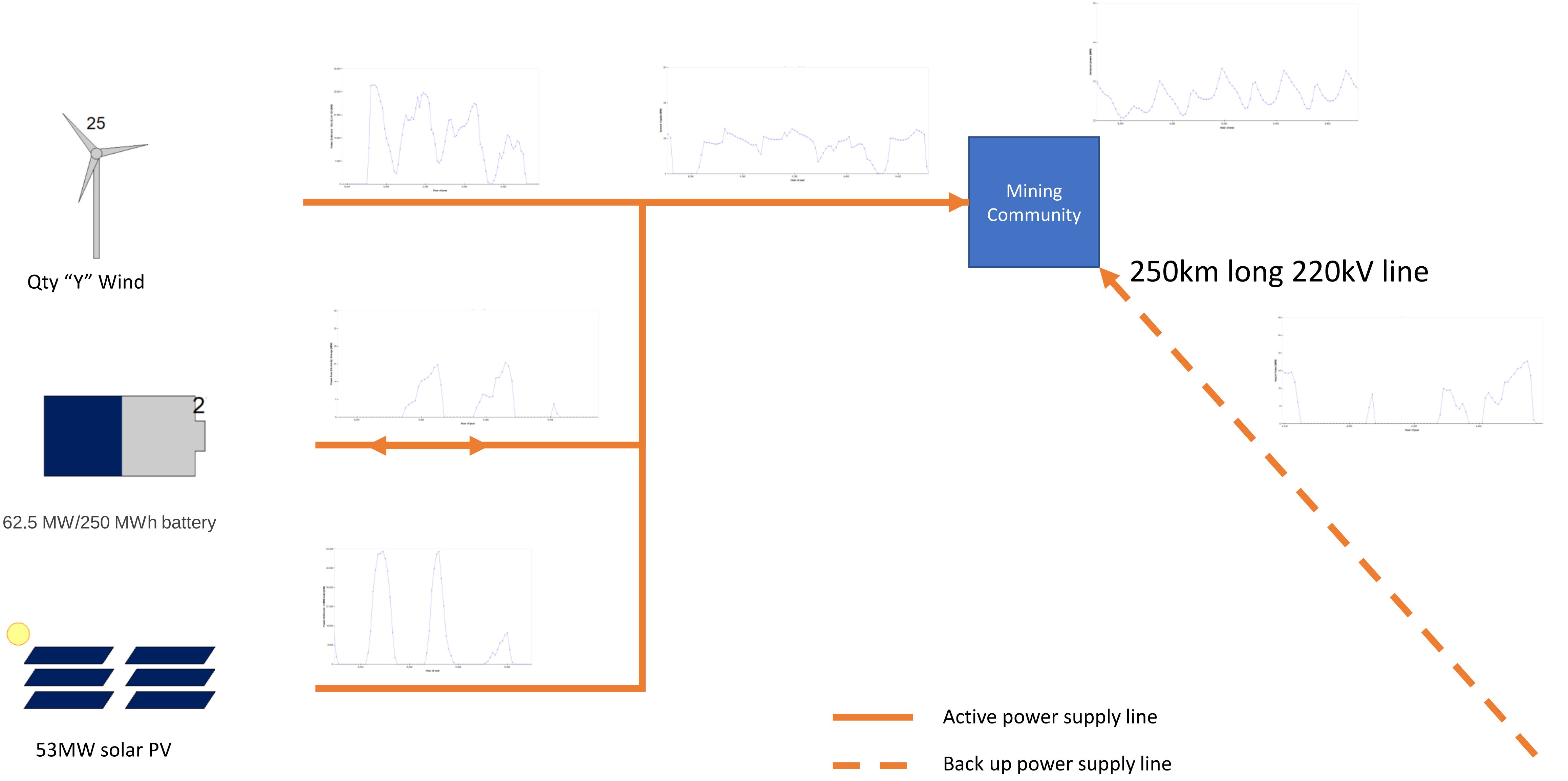
(snapshot of performance for Sept 20th -23rd)



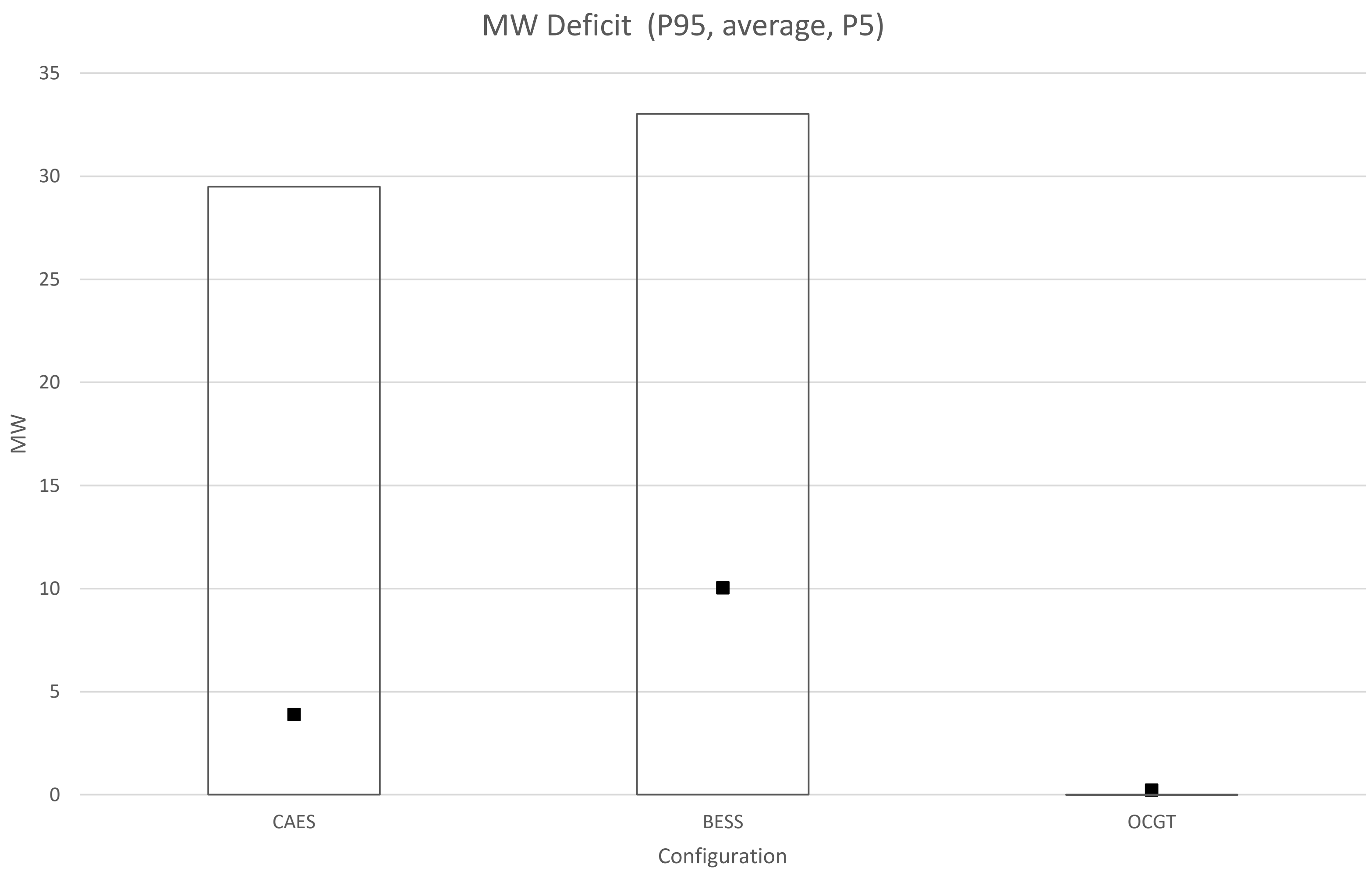
Thermoflow

Option 2

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



MW Deficit Box Plot



Conclude that even an optimised hybrid system still has associated with it a large deficit power spread

Appendix

-Satellite image of location

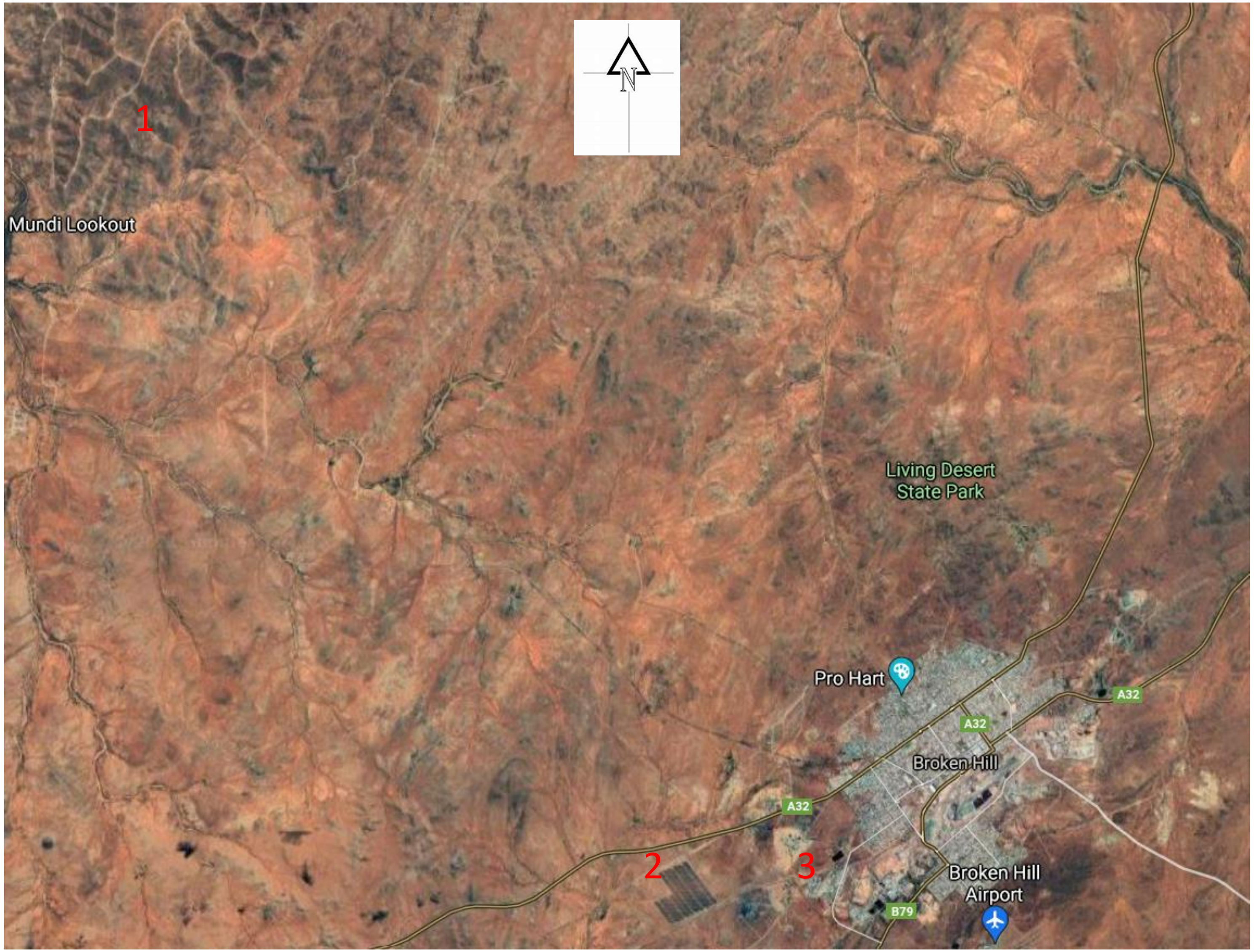
-Key data sources

-Wind turbine count optimisation for CAES system (using "CAES percent active" as the criterion)

-Wind turbine count optimisation for BESS system (using "BESS percent active" as the criterion)

-Option 3 (no storage) predicted performance

Satellite Image of Location



1- Silverton wind turbine farm
2- 53MW solar pv plant
3- 50MW OCGT plant

Key data sources

Energy storage systems: Capital costs, maintenance costs etc: https://www.energy.gov/sites/prod/files/2019/07/f65/Storage%20Cost%20and%20Performance%20Characterization%20Report_Final.pdf

Energy prices & demand data (NSW, Australia): https://aemo.com.au/Energy-systems/Electricity/National-Electricity-Market-NEM/Data-NEM/Data-Dashboard-NEM

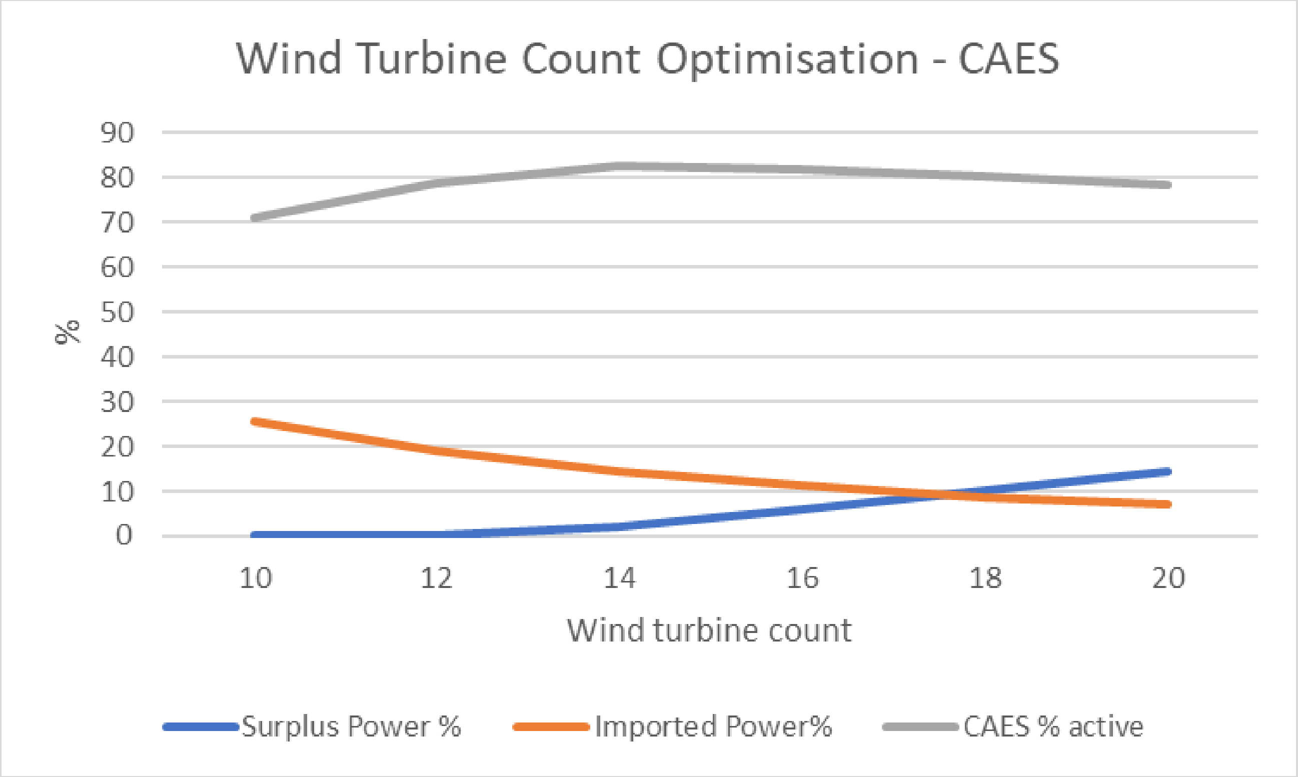
BOM website (Broken Hill meteorological data): http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=122&p_display_type=dailyDataFile&p_startYear=2020&p_c=-442734627&p_stn_num=047048

Wind turbine count optimisation for CAES system (using "CAES percent active" as the criterion)

Require to optimise the wind turbine count for the CAES capacity and charge/discharge performance since the CAES represents 80% of the estimated overall project cost (737.5 MM AUD). Put simply:

-too few wind turbines means that the CAES will never charge to capacity.

-an excess of wind turbines means that the CAES will charge to full capacity, but will seldom discharge.



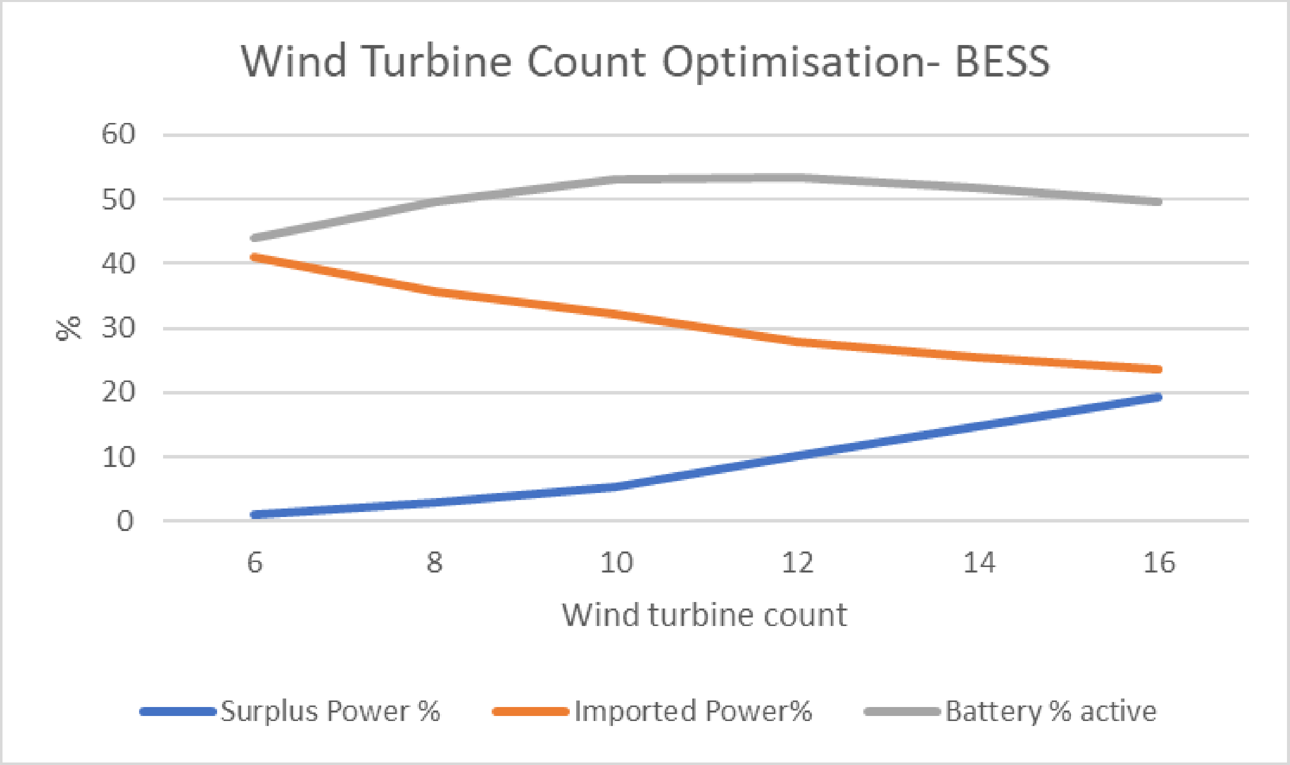
Conclude that 14 wind turbines is the optimum. Note that for wind turbine counts of 10 & 12, NOVO PRO issues advisory messages that "…the storage system may be oversized"

Wind turbine count optimisation for BESS system (using "BESS percent active" as the criterion)

Require to optimise the wind turbine count for the BESS capacity and charge/discharge performance since the BESS represents 50% of the estimated overall project cost (296.86 MM AUD). Put simply:

-too few wind turbines means that the BESS will never charge to capacity.

-an excess of wind turbines means that the BESS will charge to full capacity, but will seldom discharge.

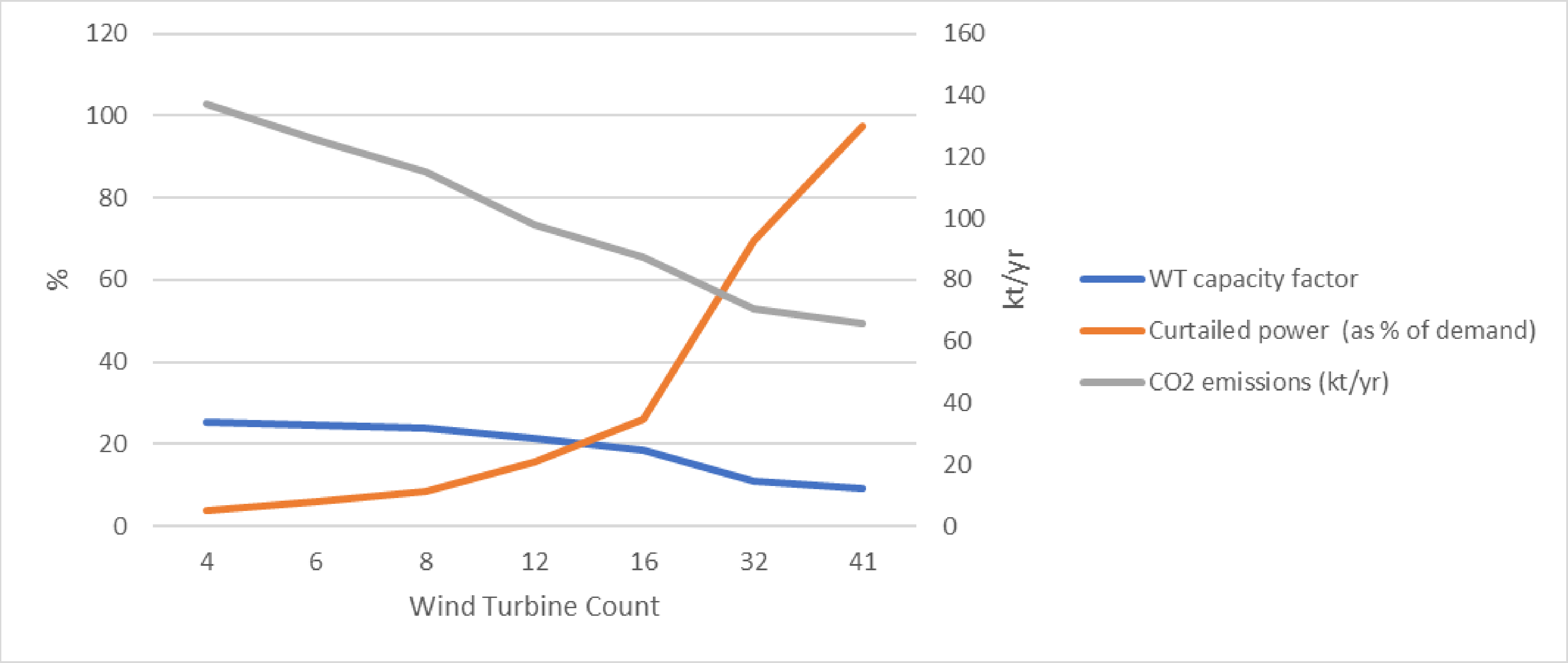


Conclude that 10-12 wind turbines is the optimum.

Option 3 – 53MW solar PV + Qty "n" Wind Turbines + Existing OCGT

This option is considered since no carbon trading scheme exists at the present time in Australia, hence demonstration of reduced CO_2 emissions at Broken Hill has potentially the same merit of zero CO_2 emissions.

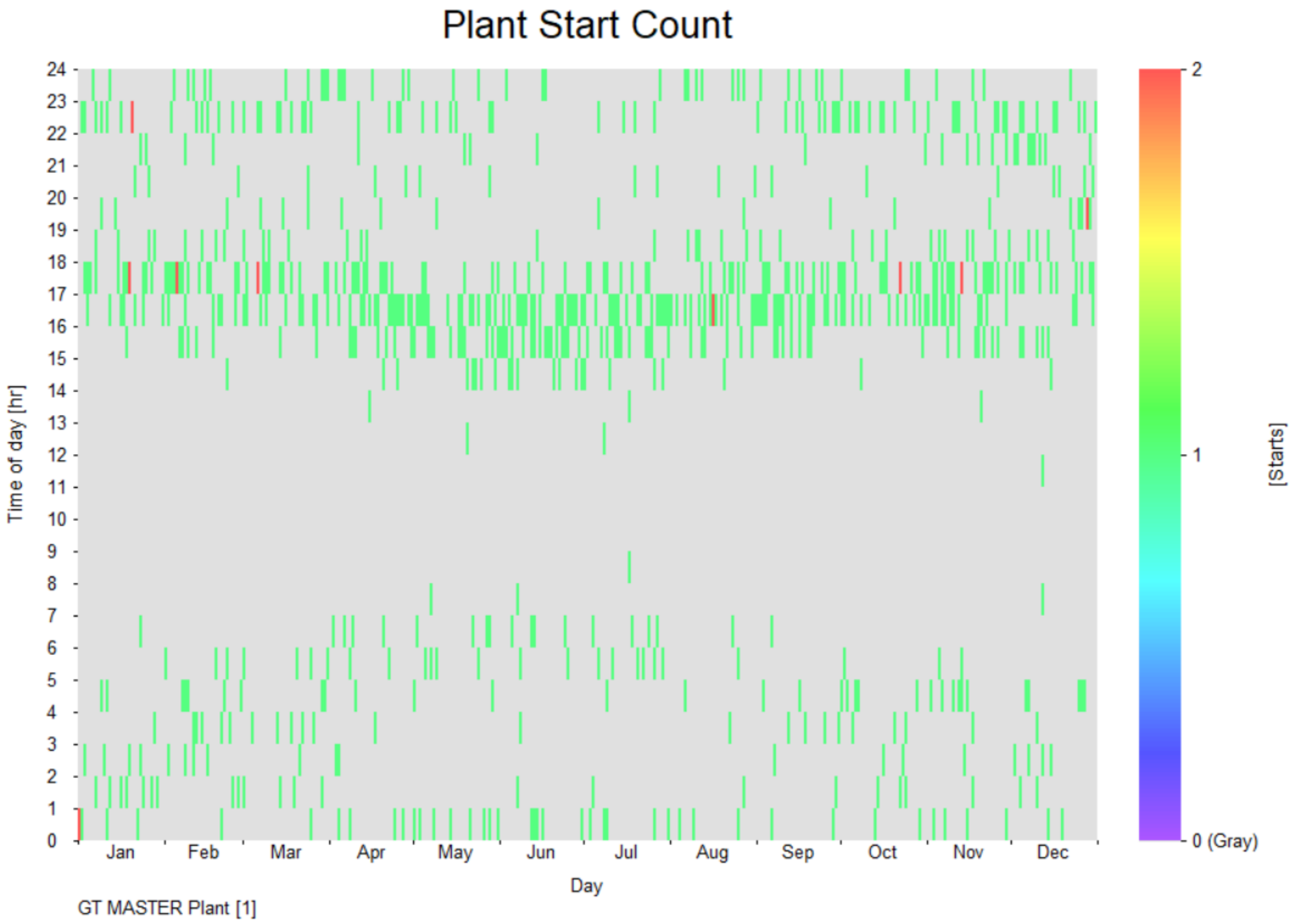
The method is similar to that used for the simulation of Options 1 & 2, except in this case wind turbine power curtailment is employed to limit the power that would otherwise need to be exported to the grid.



Conclude that around 16 wind turbines will provide a reasonable reduction of CO_2 emissions for the overall plant while ensuring that the wind turbine capacity factor remains at around 18%. There is no point having more than 41wind turbines in the plant since curtailed energy will be greater than the demand energy beyond this point.

Option 3 – Implications for Existing OCGT in terms of plant starts

NOVO PRO predicts a very dynamic demand for the OCGT plant in terms of the plant starts - further investigation would be required to determine the suitability of the existing thermal plant for the anticipated duty.



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(4) **Power-to-X features**

- Hydrogen
- Storages

(5) Questions & Answers (approx. 15min)

Hydrogen options in Thermoflow software

- Steam Methane Reforming available in THERMOFLEX
  - Sample
  - Option to add Carbon Capture

- Electrolyzer available in TFX / NVP
  - Predefined Electrolyzer models & User Defined
  - Deoxo Dryer to increase the purity of H_2
  - Storage and Compression
  - Desalination Plant coupled in TFX

- Use of Hydrogen: flexibility in THERMOFLEX

Examples Hydrogen

- Steam Methane Reformer in THERMOFLEX

- Stand Alone Electrolyzer in NVP
  - Annual yield or demand set in NVP
  - Levelized Cost of Hydrogen (LCOH) as a function of Electricity Price
  - Storage / Compression

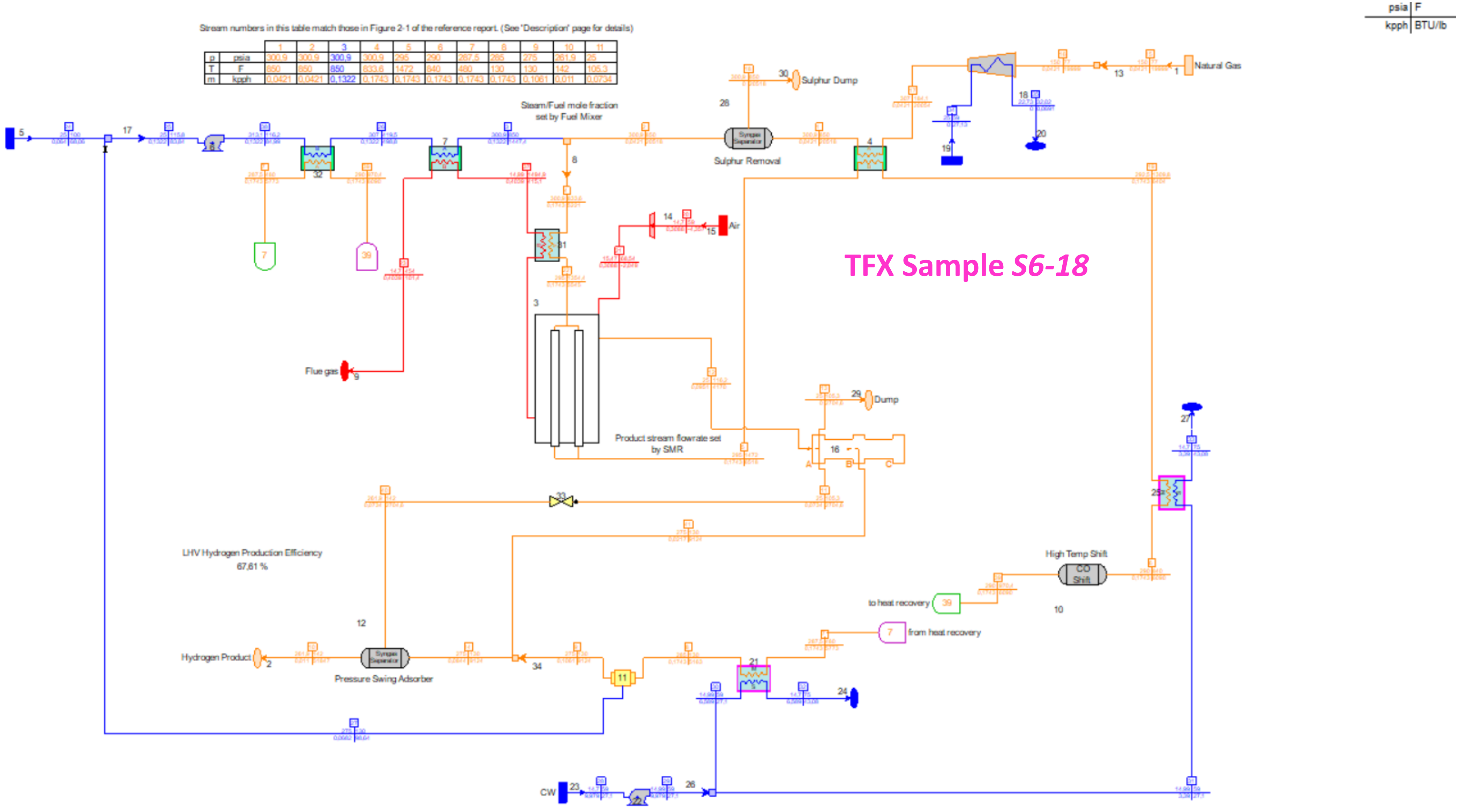
- PV + Electrolyzer in NVP
  - Same size → same capacity factor
  - Different size → Optimization based on Electricty and H_2 prices

- Power to X

4.1 Steam Methane Reforming in THERMOFLEX

Stream numbers in this table match those in Figure 2-1 of the reference report. (See 'Description' page for details)

		1	2	3	4	5	6	7	8	9	10	11
p	psia	300,9	300,9	300,9	300,9	295	290	287,5	285	275	261,9	25
T	F	850	850	850	833,6	1472	840	480	130	130	142	105,3
m	kpph	0,0421	0,0421	0,1322	0,1743	0,1743	0,1743	0,1743	0,1743	0,1061	0,011	0,0734

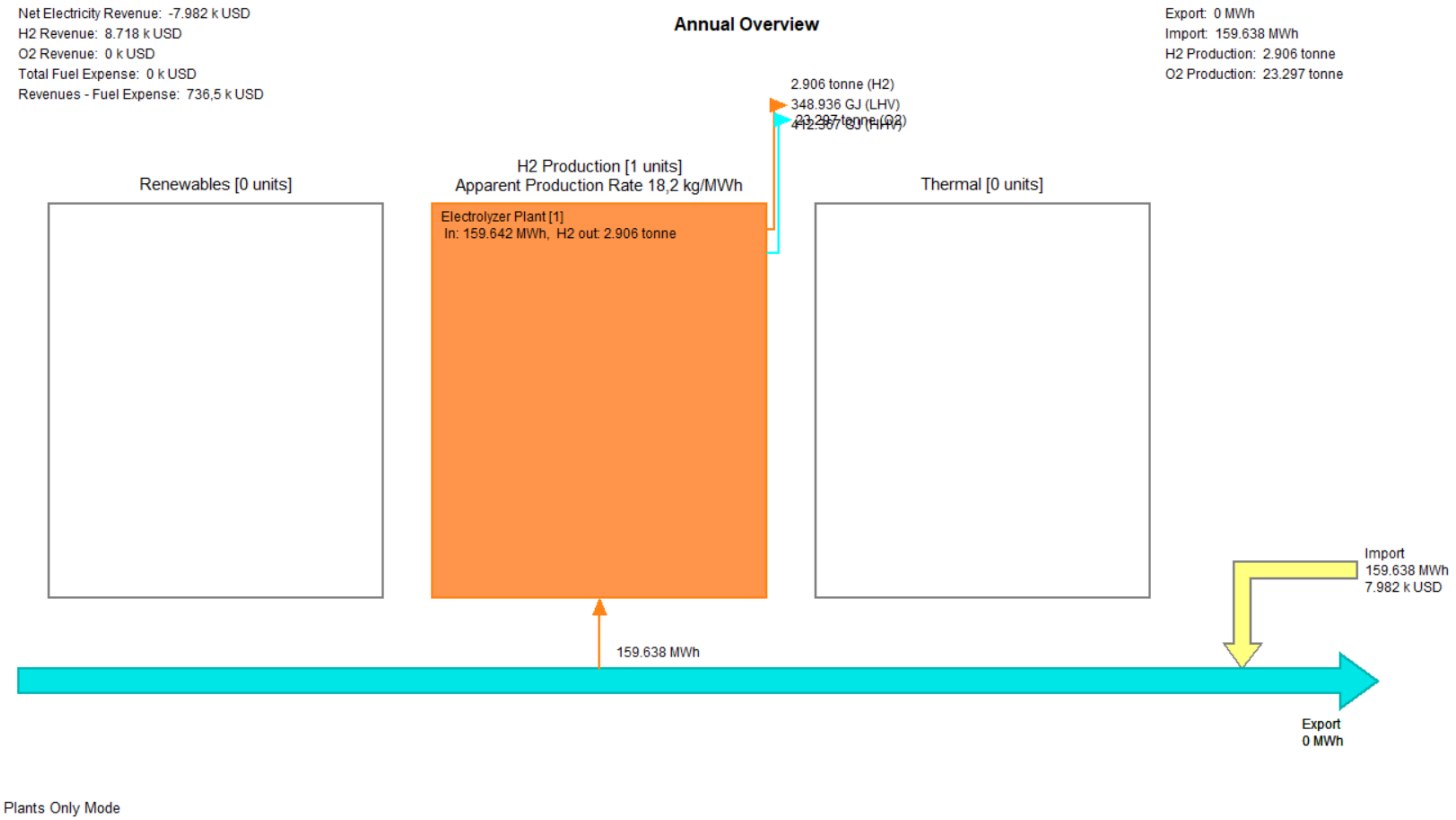


4.2 Hydrogen from Electrolysis in NOVO PRO (Standalone)

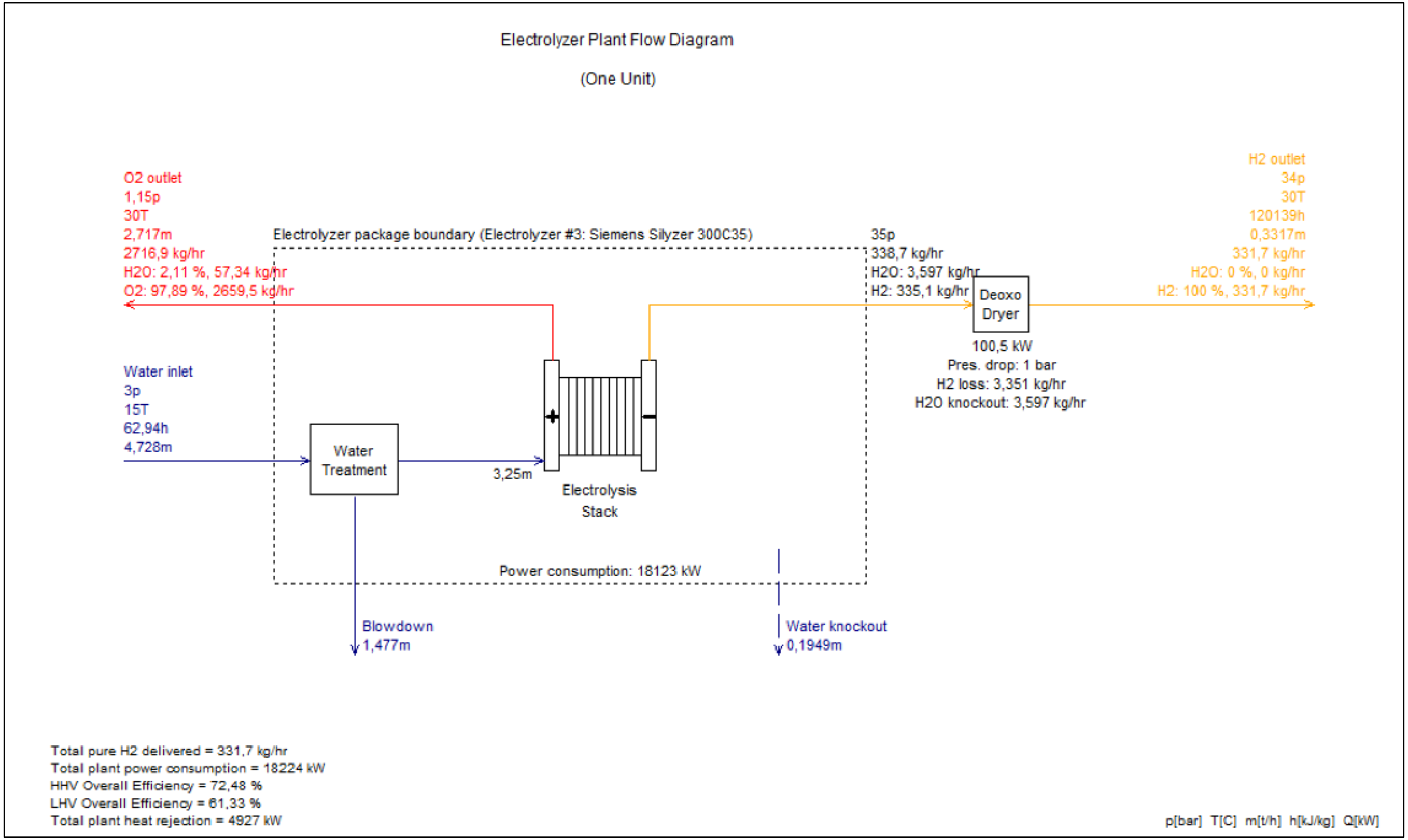
- Plants Only Mode
- Add Electrolyzer, select a predefined model or User Defined
- Include Deoxo-Dryer / Storage / Compression
- Schedule, set the hourly demand as a % of the rated production
- Economics: Electricity Price, Hydrogen Price, CAPEX, OPEX, Financial assumptions

→ Calculate the Levelized Cost of Hydrogen (LCOH) as a function of Electricity price

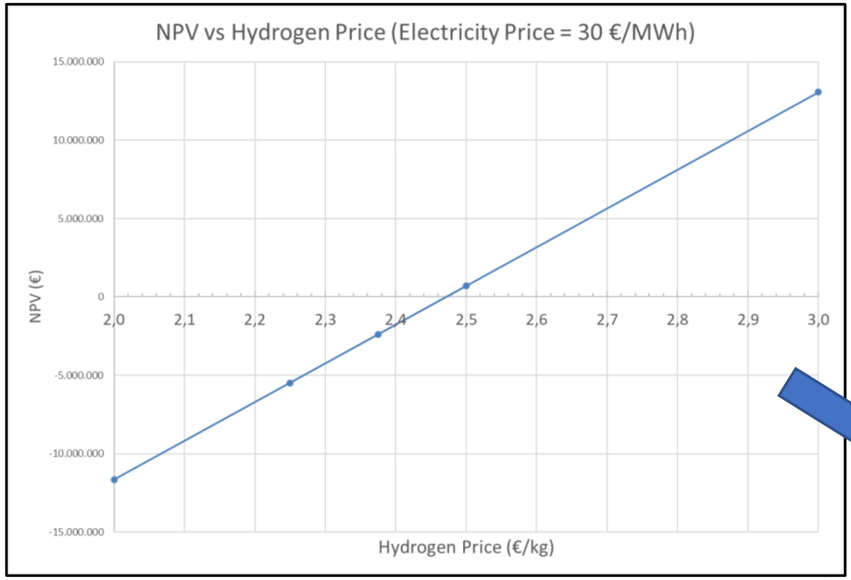
4.2 Hydrogen from Electrolysis in NOVO PRO (Standalone)

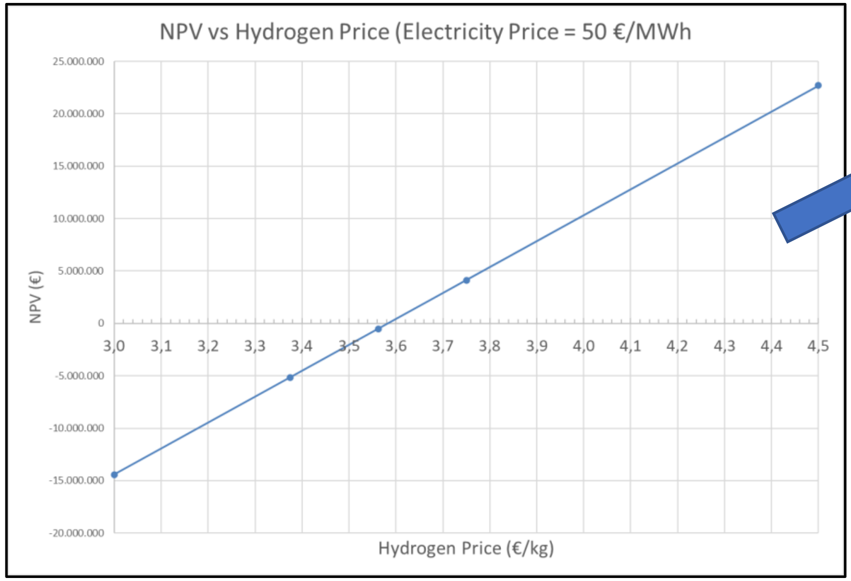


4.2 Hydrogen from Electrolysis in NOVO PRO (Standalone)



4.2 Hydrogen from Electrolysis in NOVO PRO (Standalone)





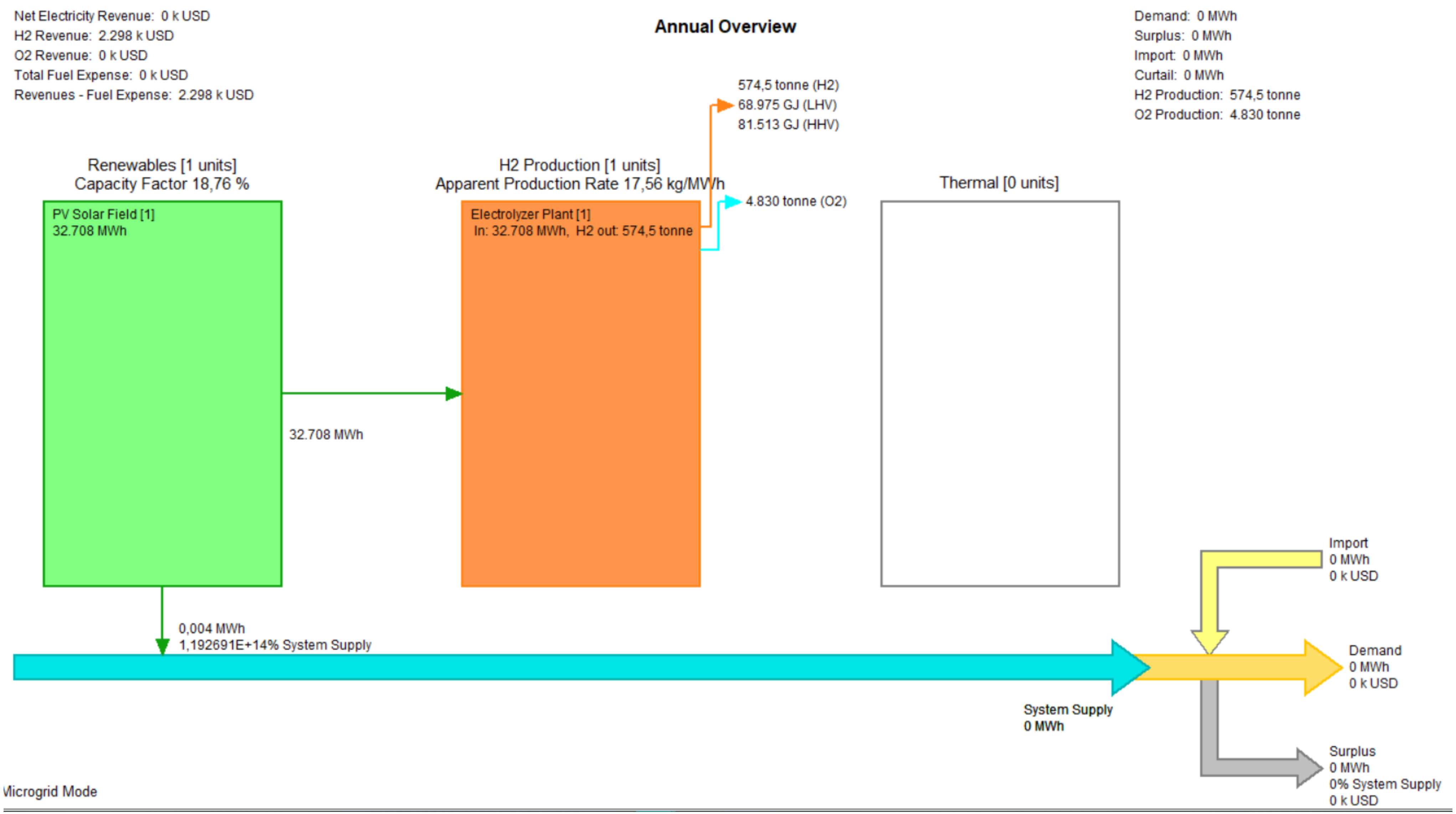
LCOH calculation (Electrolyzer 100 % Capacity Factor)

4.3 PV + Hydrogen from Electrolysis in NOVO PRO (Same Size)

- Microgrid Mode
- Demand Power = 0 → all the PV power to produce Hydrogen
- PV Field 20 MWp
- Electrolyzer 18,2 MW / 331,7 kg/h of H_2
- Economics: Electricity Price, Hydrogen Price, CAPEX (PV+Elect.), OPEX (PV+Elect.), Financial assumptions

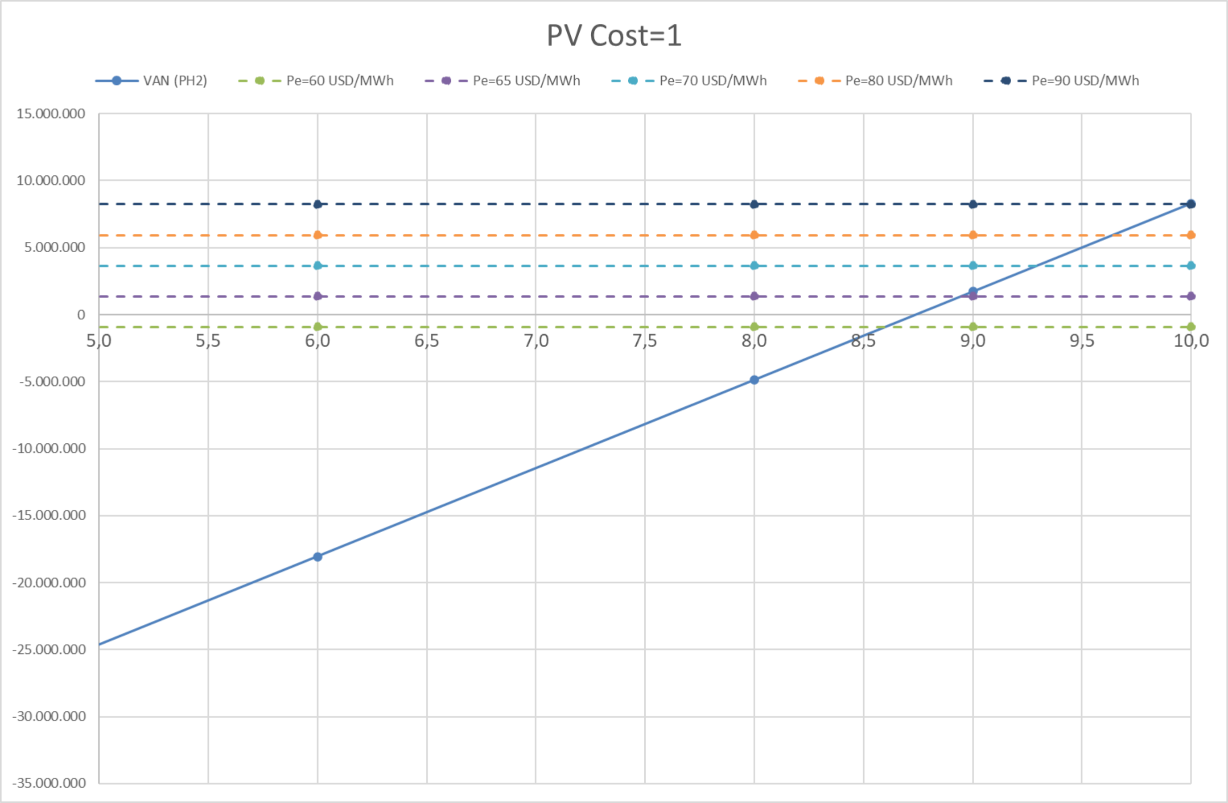
→ Calculate the Minimum Hydrogen Price which makes cost-effective to produce Hydrogen from PV instead of selling PV Electricity to the grid, as a function of Electricity Price

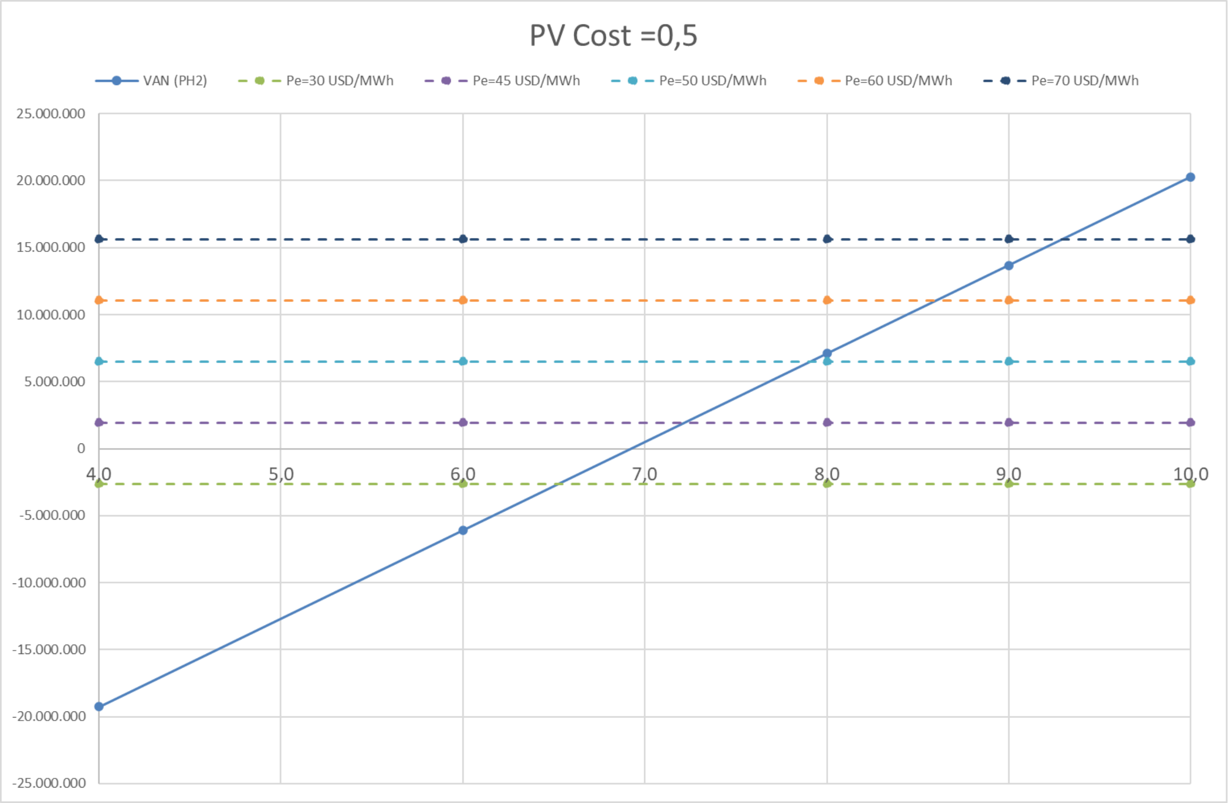
4.3 PV + Hydrogen from Electrolysis in NOVO PRO (Same Size)



4.3 PV + Hydrogen from Electrolysis in NOVO PRO (Same Size)

Minimum H_2 Price calculation as a function of Electricity Price (PV and Electrolyzer same size, 20% Capacity Factor)





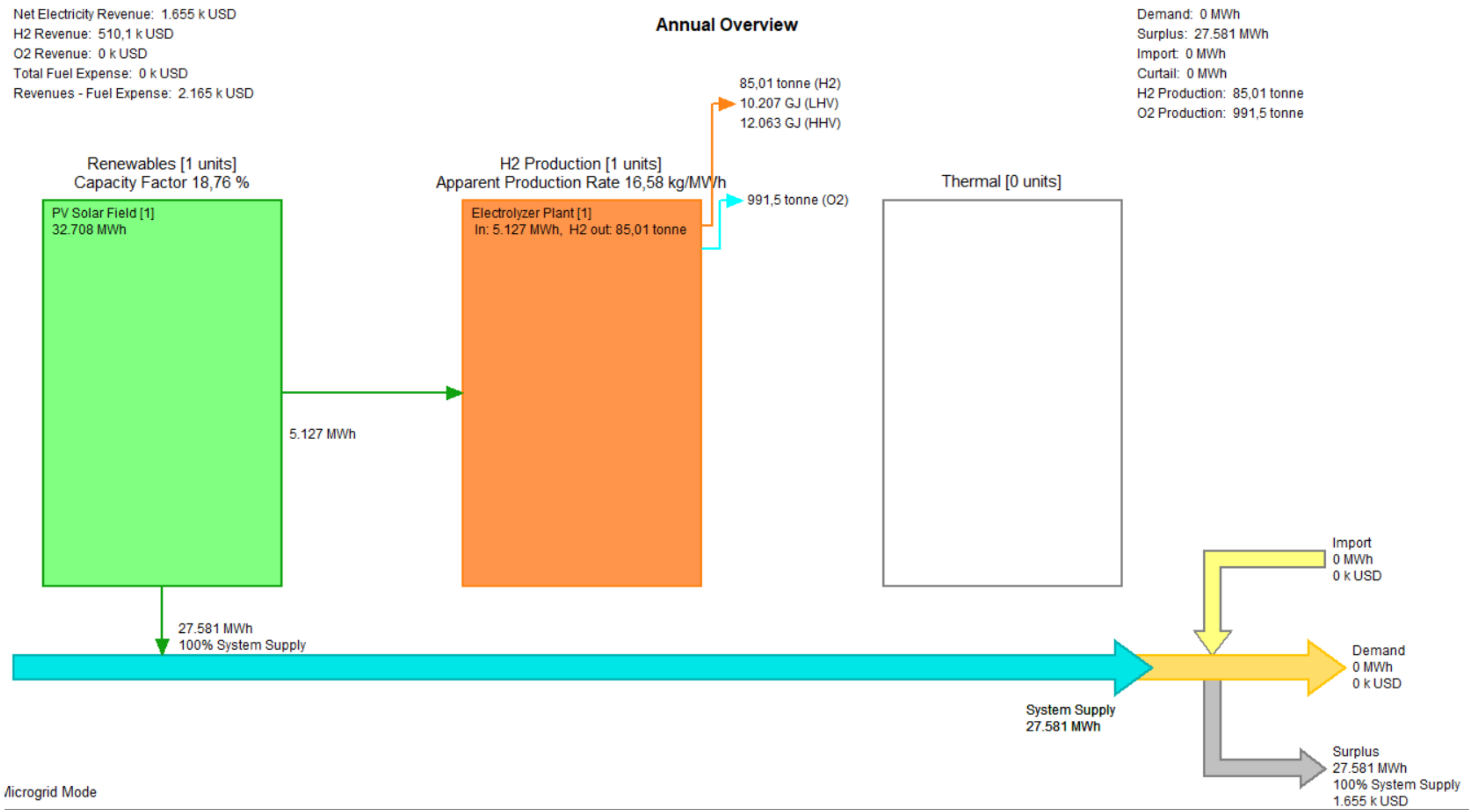
4.4 PV + Hydrogen from Electrolysis in NOVO PRO (Different Sizes)

- Microgrid Mode
- Demand Power = 0 → Exported Power = Surplus Power
- PV Field 20 MW DC
- Electrolyzer 1,2 MW / 20,5 kg/h of H_2
- Economics: Surplus Electricity Price, Hydrogen Price, CAPEX (PV+Elect.), OPEX (PV+Elect.), Financial assumptions

→ Calculate the Minimum Hydrogen Price which makes cost-effective to produce Hydrogen from PV instead of selling PV Electricity to the grid, as a function of Electricity Price

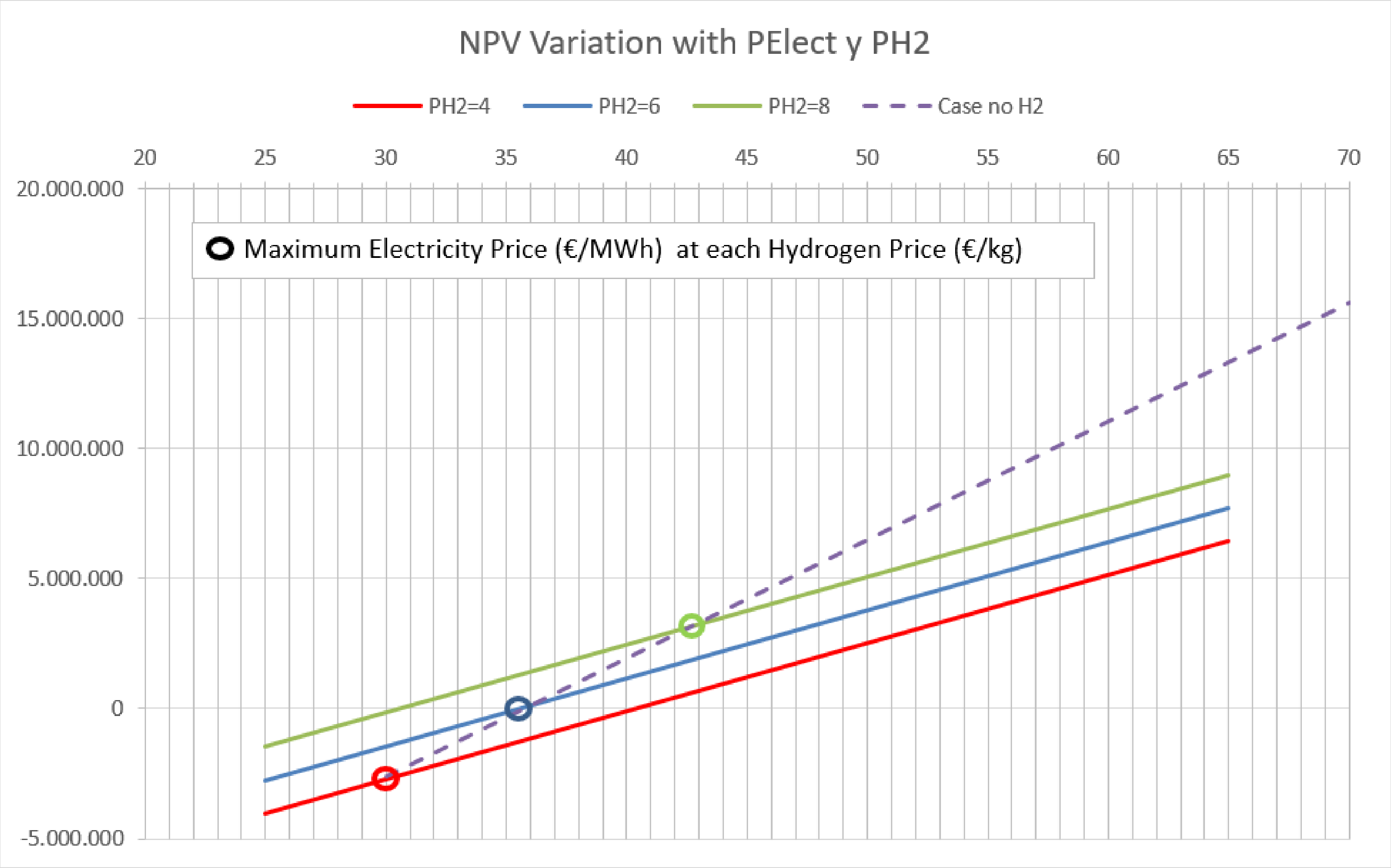
→ Optimize the relative size PV / Electrolyzer for a given demand of Hydrogen

4.4 PV + Hydrogen from Electrolysis in NOVO PRO (Different Sizes)

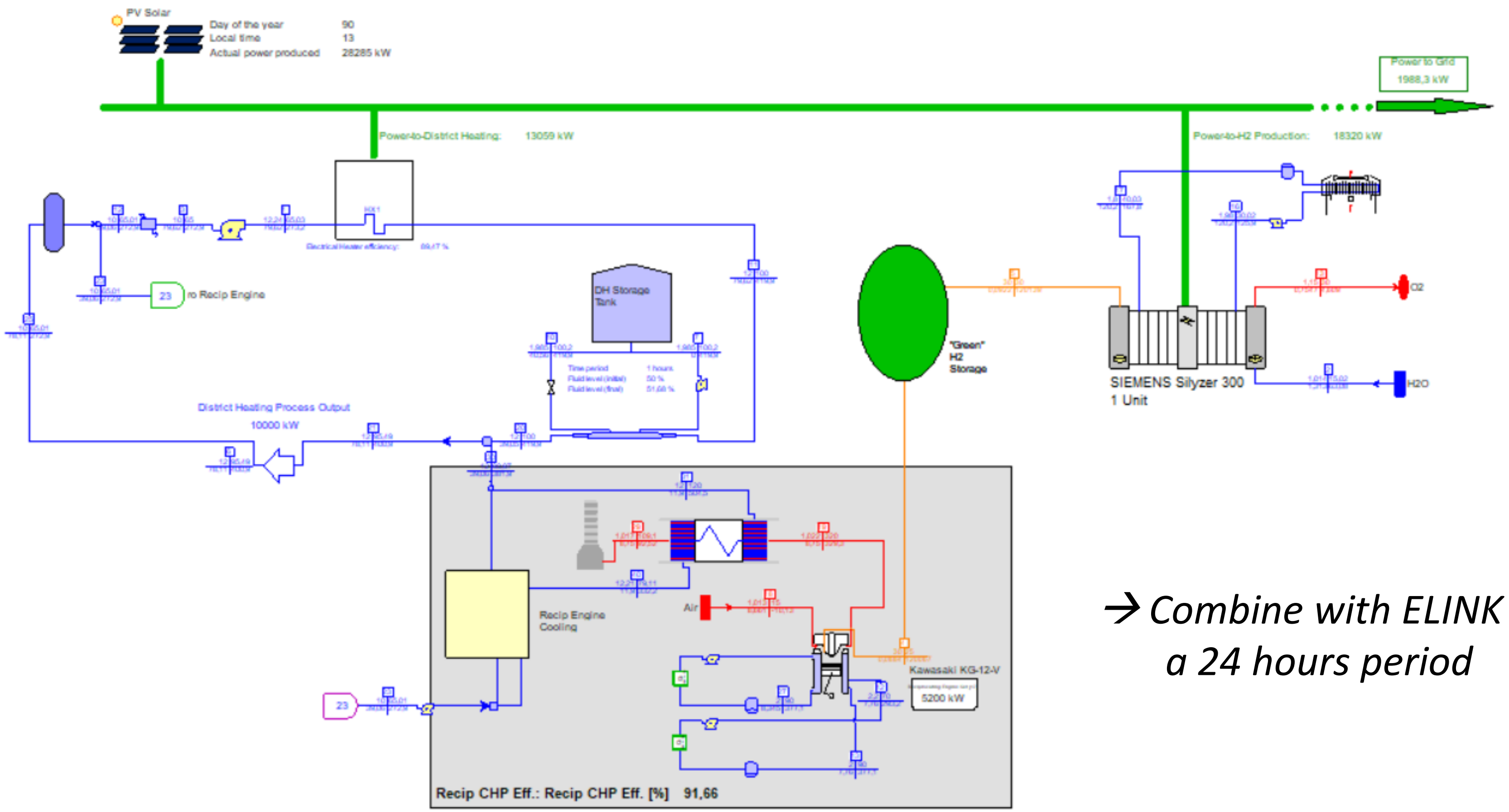


4.4 PV + Hydrogen from Electrolysis in NOVO PRO (Different Sizes)

Maximum Electricity Price at each Hydrogen Price (PV and Electrolyzer different size, Elect. @47% Capacity Factor)



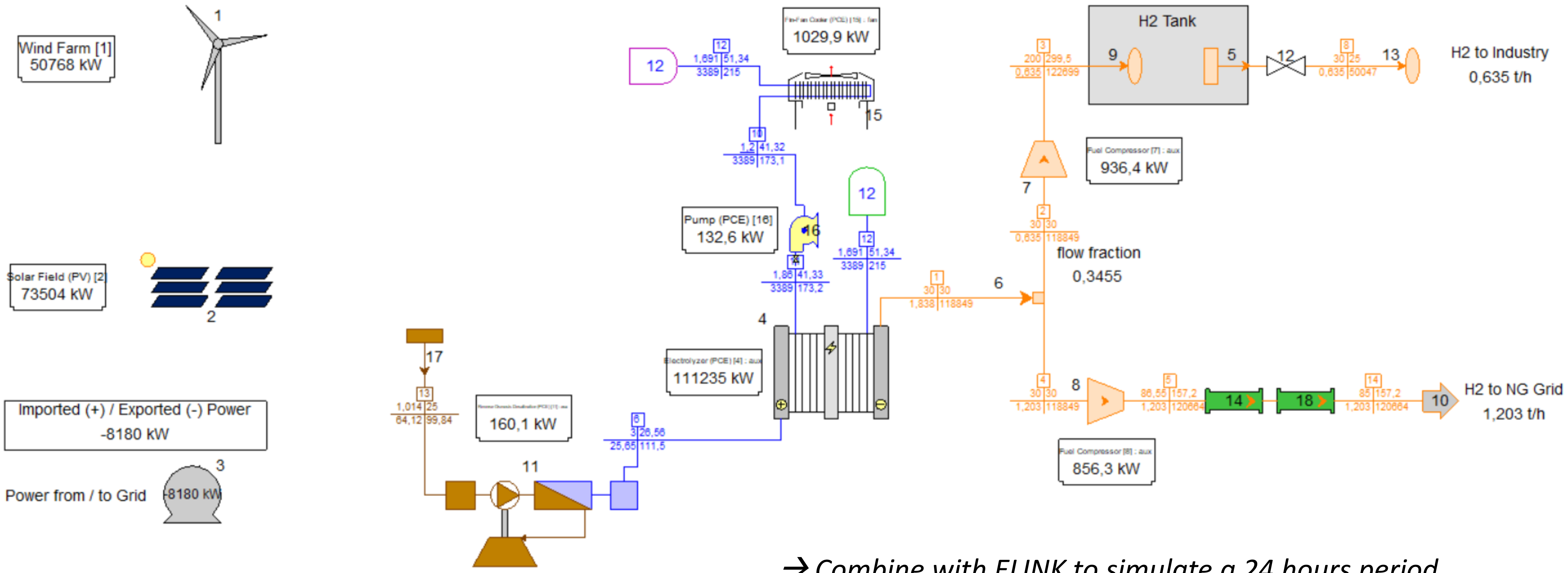
4.5 Power(PV)-to-H_2 and Heat(DH)+Storage_recip



→ Combine with ELINK to simulate a 24 hours period

INPUTS:
(1) Power to Grid via CONTROL LOOP input
(2) District Heating Output via PROCESS component.

4.6 PV + Wind, Electrolyzer + Desalination, H_2 to Industry or NG Grid



→ *Combine with ELINK to simulate a 24 hours period*

Modelling Decarbonization Technologies

AGENDA – Thursday, 27. May 2021 13:30 Central European Time (Amsterdam, Paris, Berlin)**:**

(1) Welcome & Overview

(2) Demonstration of selected sample files:

- "Traditional" Renewable Technologies
- CO_2 Capture (new plant design with CCS & adding CCS to an existing plant)

(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) **Power-to-X features**

- Hydrogen
- Storages

(5) Questions & Answers (approx. 15min)

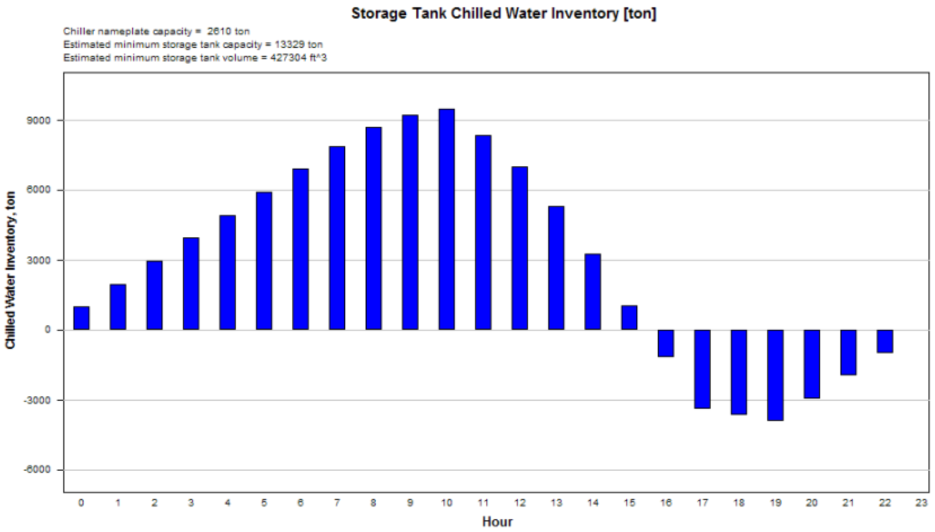
Storage Systems in Thermoflow software

- Batteries
- Hydrogen Storage
- Pumped Hydro
- Molten Salts Storage
- Chilled Water Storage (Stratified Tank)
- Liquid Air Energy Storage (LAES)
- Electric Thermal Energy Storage (ETES) – Hot Air
- Compressed Air Energy Storage (CAES)
- Coal Boiler replacement by Renewables+Electric Heater+Molten Salts
- …..

→ User Defined Storage

4.b.5 Chiller w/ Storage 24 Hours operation in GTM

CHILLED WATER STORAGE 24-HR MODEL SUMMARY		
Total electricity export	12.6	10^6 kWh
Total gas turbine fuel LHV import	78.53	GBTU
Total duct burner fuel LHV import	0	GBTU
Total heat export	0	GBTU
Plant average LHV heat rate (excl. starts)	6231	BTU/kWh
Number of cold starts in 24-hr period (user-defined)	0	
Number of hot starts in 24-hr period (user-defined)	0	
Plant average LHV heat rate (incl. starts)	6231	BTU/kWh
Electric chillers		
- Number of chillers in plant	4	
- Chiller nameplate capacity @ standard conditions (each)	652.5	ton (R)
- Chiller nameplate capacity @ standard conditions (plant total)	2610	ton (R)
- Total chiller power consumption in 24-hr period	32124	kWh
Storage tank		
- Estimated minimum storage tank capacity	13329	ton water
- Estimated minimum storage tank volume	427304	ft^3
- Total chilled water inventory gain in 24-hr period	0.0131	ton



HOURLY REPORT - I

Hour	Tamb	GT Load	Chiller			Coil			CW to	CW
		% or kW	CW	Load %	Capacity	CW	Air DT	Tair out	Storage	Inventory
	F		ton		ton (R)	ton	F	F	ton	ton
0	65	60	983.5	100	3114	0	0	65	983.5	983.5
1	64	60	984	100	3116	0	0	64	984	1967.5
2	64	60	984	100	3116	0	0	64	984	2951.5
3	63	60	984.4	100	3117	0	0	63	984.4	3936
4	63	60	984.4	100	3117	0	0	63	984.4	4920
5	62	60	984.6	100	3118	0	0	62	984.6	5905
6	62	60	984.6	100	3118	0	0	62	984.6	6889
7	65	70	982.9	100	3113	0	0	65	982.9	7872
8	70	80	1162	100	3134	352.1	5	65	809.9	8682
9	75	90	1064.2	100	3104	532.2	10	65	532	9214
10	80	100	1024.9	100	3075	802.8	15	65	222	9436
11	82	100	0	0	0	1129.4	17	65	-1129.4	8307
12	85	100	0	0	0	1333.8	20	65	-1333.8	6973
13	87	100	0	0	0	1681.9	22	65	-1681.9	5291
14	89	100	0	0	0	2044.5	24	65	-2044.5	3247
15	92	100	0	0	0	2209.6	27	65	-2209.6	1037.1
16	92	100	0	0	0	2209.6	27	65	-2209.6	-1172.5
17	90	100	0	0	0	2231.5	25	65	-2231.5	-3404
18	85	100	1015.3	100	3046	1259.7	20	65	-244.4	-3648
19	85	100	1015.3	100	3046	1259.7	20	65	-244.4	-3893
20	80	90	961.5	100	3045	0	0	80	961.5	-2931.2
21	75	80	970.5	100	3073	0	0	75	970.5	-1960.7
22	70	70	979.5	100	3102	0	0	70	979.5	-981.2
23	68	60	981.2	100	3107	0	0	68	981.2	0.0128

HOURLY REPORT - II

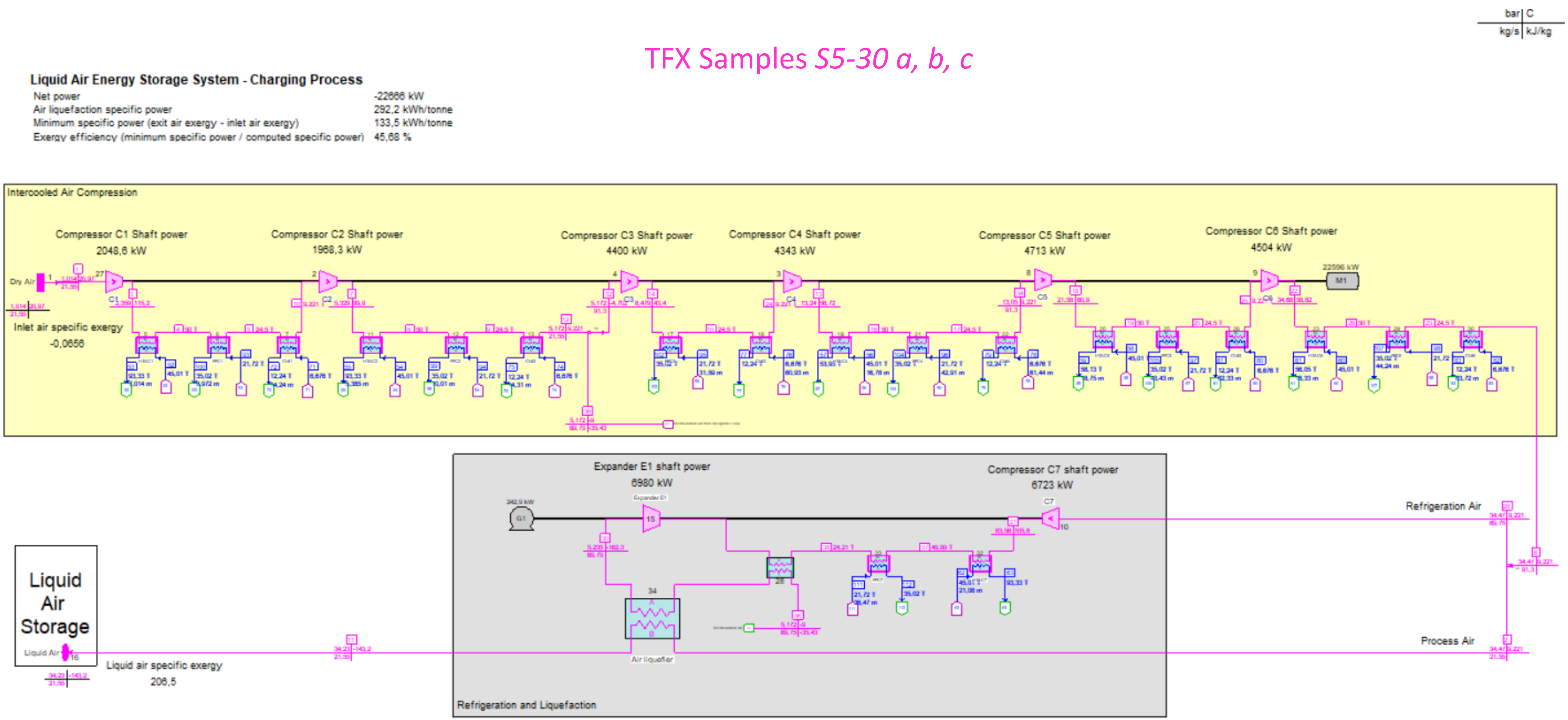
Hour	Plant Net		Gas Turbine	ST	Aux.	Elec.	Fuel
	Output	Heat Rate	Output	Output	Load	Chiller	Flow
	kW	BTU/kWh	kW	kW	kW	kW	kpph
0	420513	6510	252200	183703	15390	1852.2	127.2
1	421199	6509	252793	183799	15393	1847.2	127.4
2	421199	6509	252793	183799	15393	1847.2	127.4
3	421880	6508	253387	183887	15393	1842	127.6
4	421880	6508	253387	183887	15393	1842	127.6
5	422553	6508	253982	183966	15395	1836.8	127.8
6	422553	6508	253982	183966	15395	1836.8	127.8
7	471050	6362	293196	193594	15740	1857.1	139.3
8	519842	6248	333924	202253	16335	1933.3	151
9	567492	6154	374382	209753	16643	1954.4	162.3
10	613780	6073	414439	216269	16928	1967.1	173.2
11	615704	6054	414453	216175	14923	0	173.2
12	615464	6057	414448	215941	14925	0	173.2
13	615037	6061	414445	215517	14925	0	173.2
14	614557	6066	414441	215046	14930	0	173.2
15	614327	6068	414437	214821	14931	0	173.2
16	614327	6068	414437	214821	14931	0	173.2
17	614299	6068	414439	214791	14931	0	173.2
18	613188	6079	414448	215673	16932	1975.8	173.2
19	613188	6079	414448	215673	16932	1975.8	173.2
20	553272	6161	361130	208453	16311	1915	158.4
21	511276	6254	326076	201235	16035	1899.8	148.6
22	467096	6367	289741	193081	15727	1874.8	138.2
23	418401	6513	250429	183359	15386	1867.3	126.7

4.b.6 Liquid Air Energy Storage Systems (LAES), Charging mode

TFX Samples *S5-30 a, b, c*

Liquid Air Energy Storage System - Charging Process

Net power	-22666 kW
Air liquefaction specific power	292,2 kWh/tonne
Minimum specific power (exit air exergy - inlet air exergy)	133,5 kWh/tonne
Exergy efficiency (minimum specific power / computed specific power)	45,68 %



4.b.6 Liquid Air Energy Storage Systems (LAES), Discharging mode

psia	F
lb/s	BTU/lb

Liquefied Air Energy Recovery with Combined Cycle

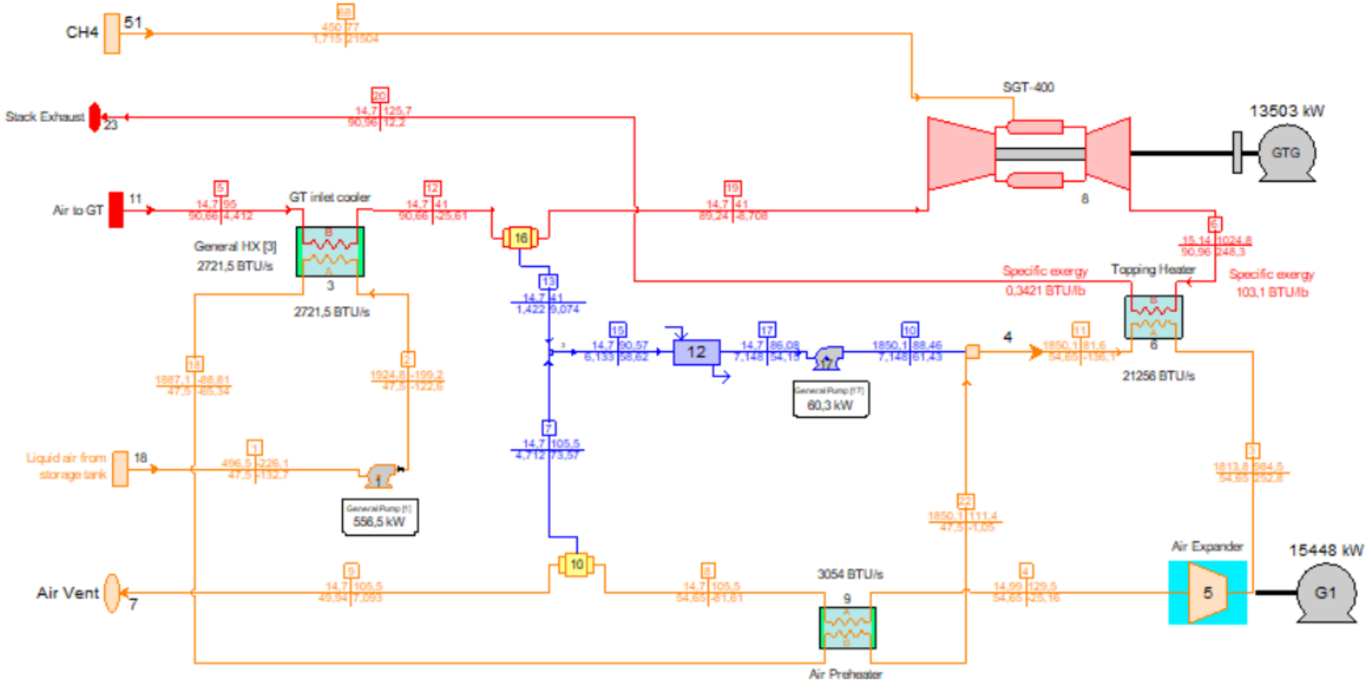
Overall Plant Summary

Gross power	28951 kW
Plant auxiliary	642,6 kW
Net power	28308 kW
Net gaseous fuel LHV input (FuelLHV)	132877 kBTU/hr
Liquid air exergy input (ELA)	11416 BTU/s
Total exergy input (TEI, =ELA+FuelLHV)	48326 BTU/s
Exergy efficiency (Net power / TEI)	55,52 %

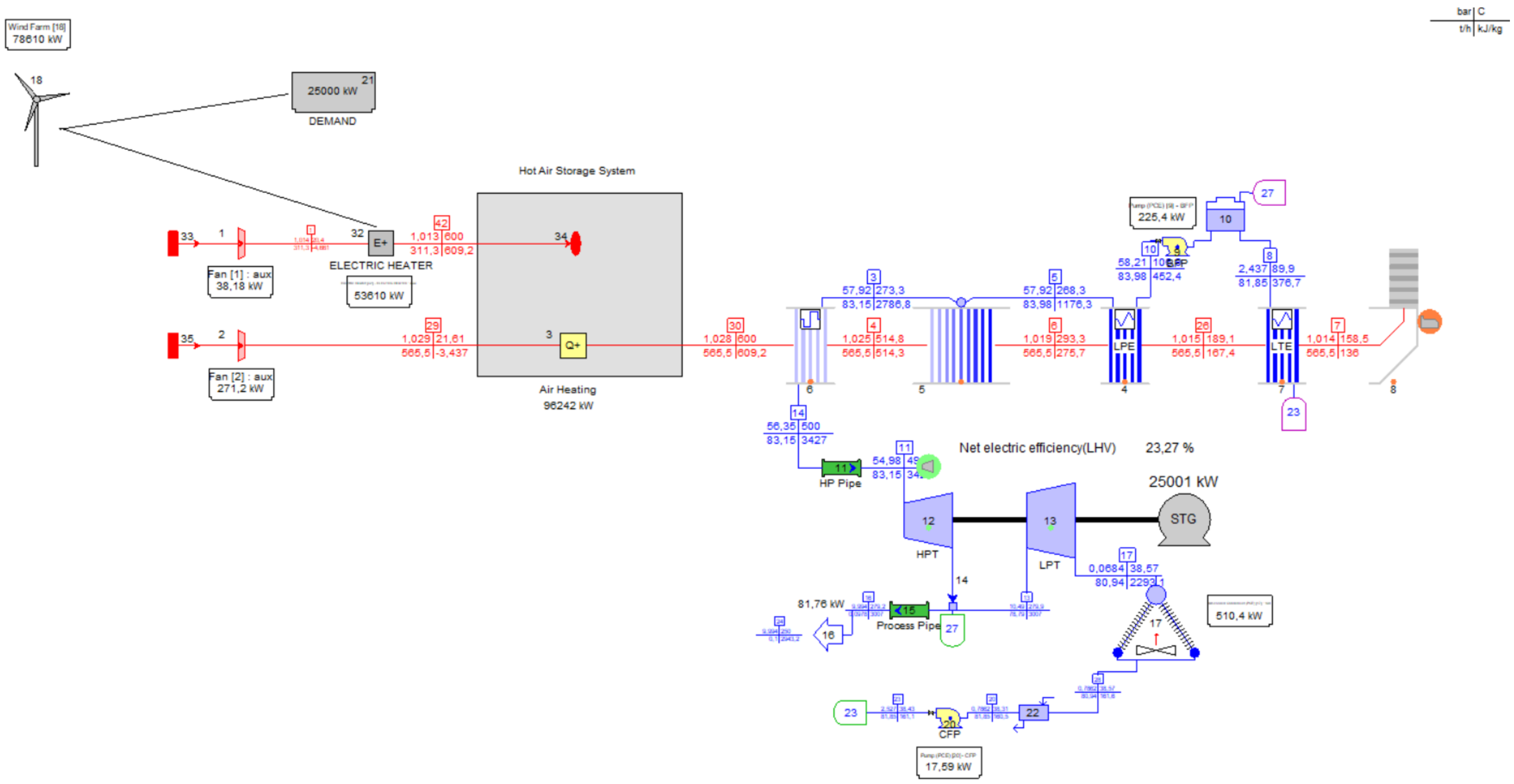
Energy Recovery Cycle (Bottoming Cycle) Summary

Gross power generation	15448 kW
Avoided electric chiller power for GT inlet air cooling (+)	820,3 kW
Bottoming cycle auxiliary load	616,8 kW
Equivalent net power recovery (ENPR)	15651 kW
Liquid air exergy input (ELA)	11416 BTU/s
Exergy from GT exhaust (EGTX)	9349 BTU/s
Total exergy input (TEI, =ELA+EGTX)	20764 BTU/s
Exergy efficiency (ENPR/TEI)	71,45 %

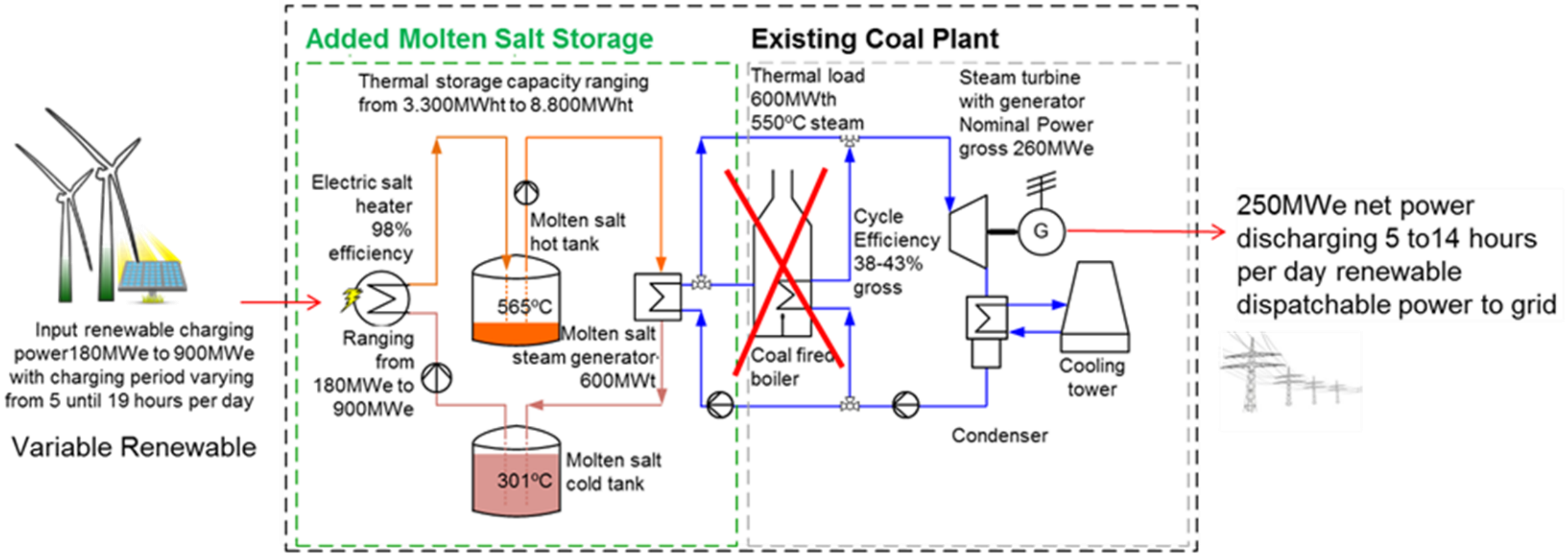
(Refer to sheet "Exergy Flow Diagram" for more info)



4.b.7 Electric Thermal Energy Storage (ETES) – Hot Air

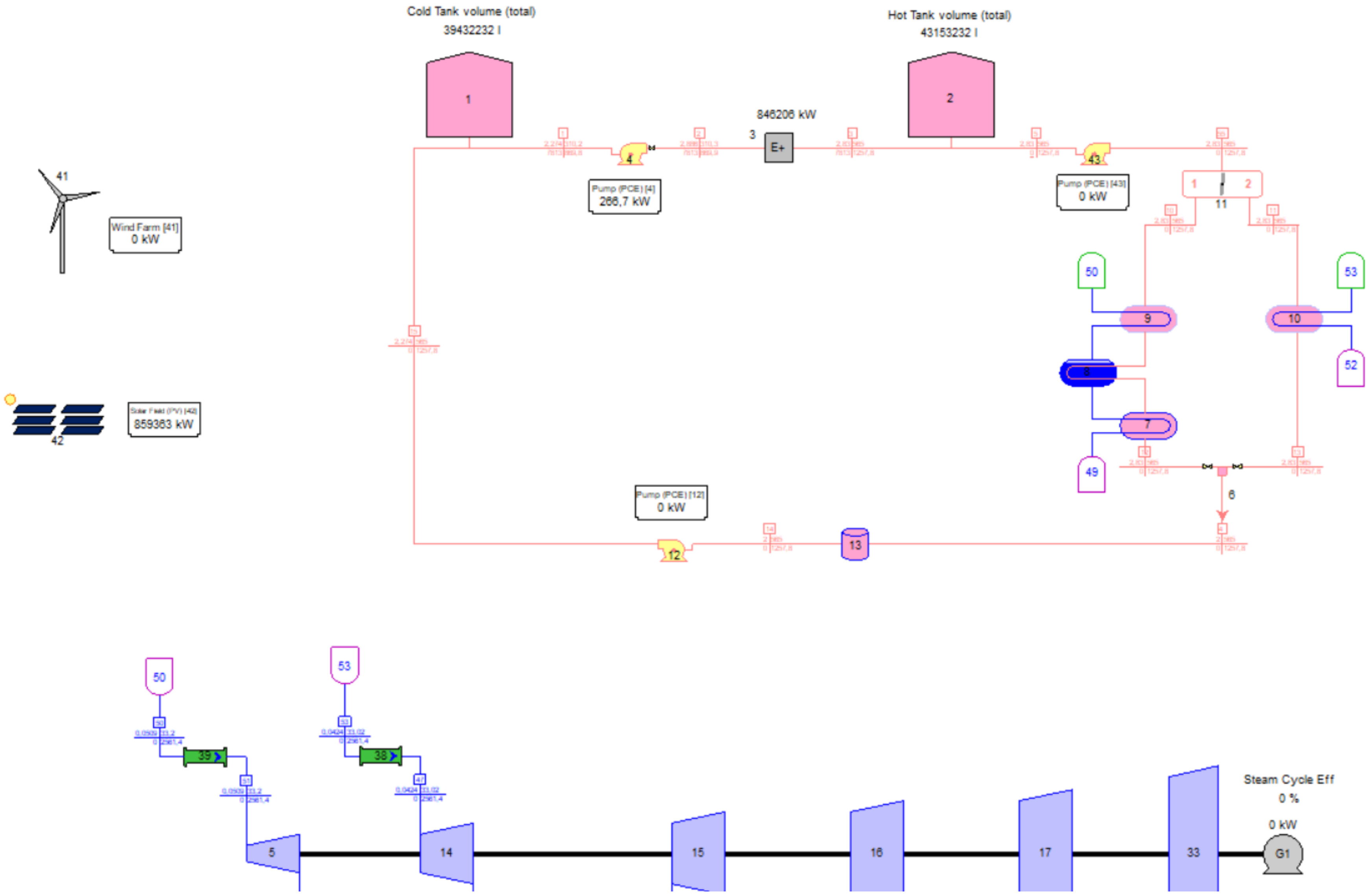


4.b.8 Coal Boiler replaced by Renewables, Electric Heater & MS Storage

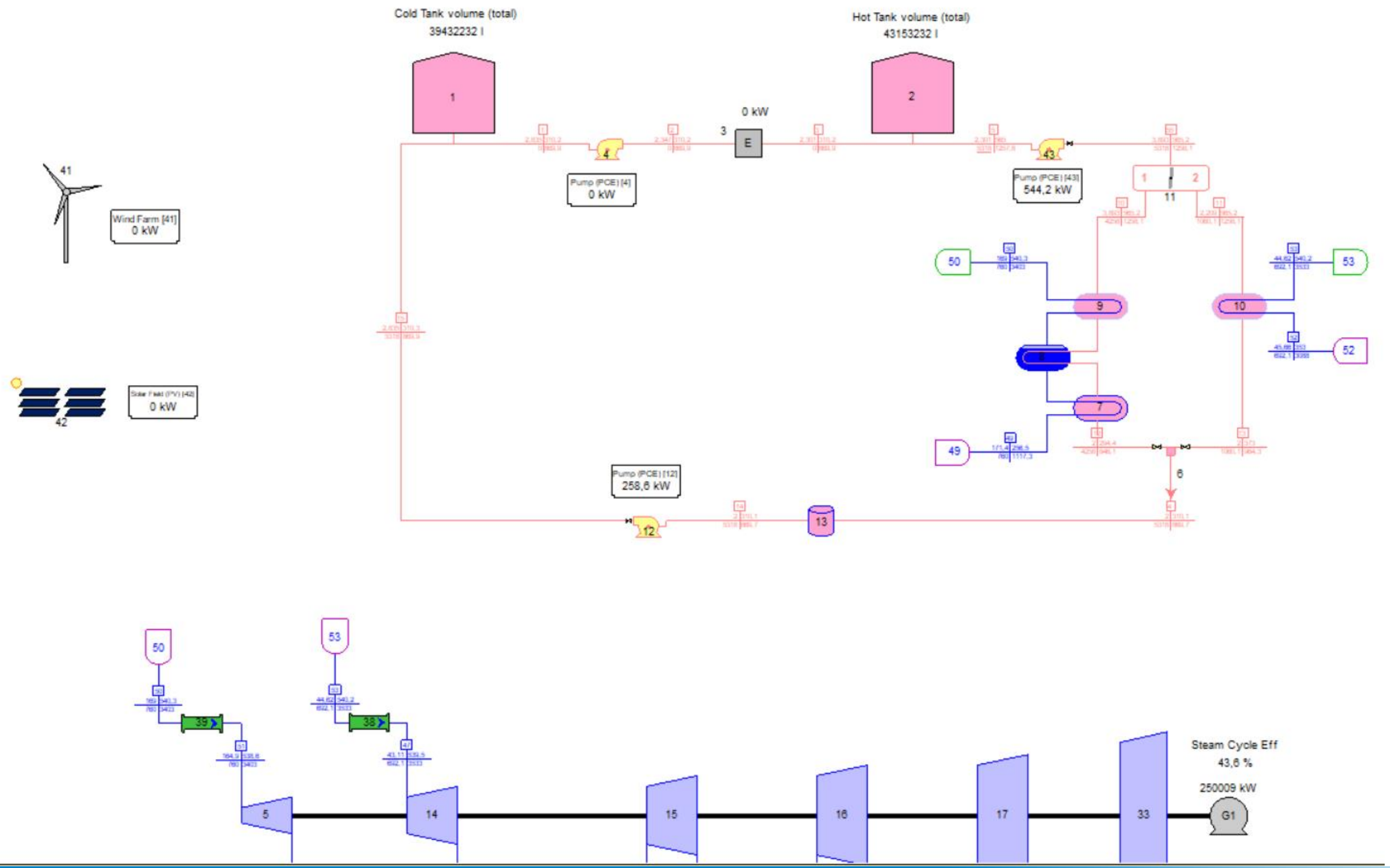


Sensitivity Variant	Unit	V1-O1	V1-O2	V1-03	V1-O10	V1-O11	V1-O12
Discharging Duration	[hours]	5,00	5,00	5,00	8,00	12,00	14,00
Thermal storage capacity	[GWht]	3,33	3,33	3,33	5,15	7,57	8,79
Charging Duration	[hours]	5,00	10,00	19,00	11,00	11,00	10,00
Charging el. salt heater capacity	[MWe]	680	340	179	478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

4.b.8 Coal Boiler replaced by Renewables, Electric Heater & MS Storage, Charging mode

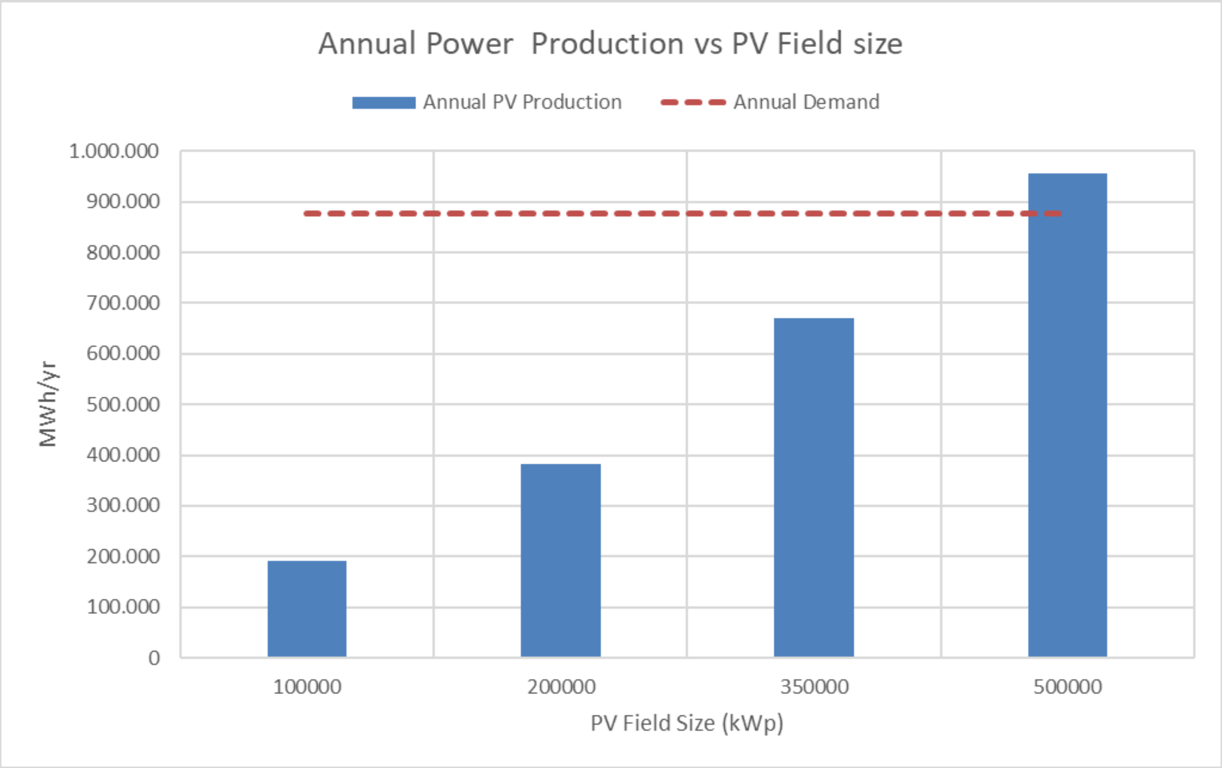


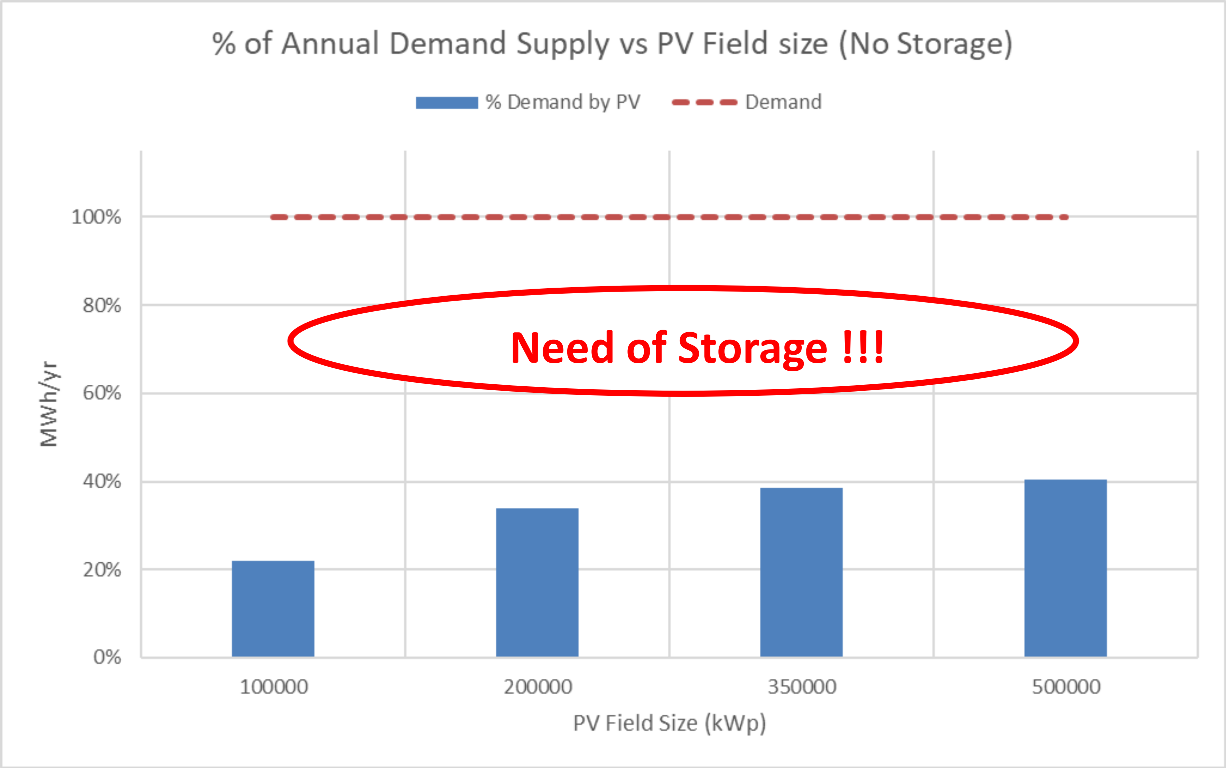
4.b.8 Coal Boiler replaced by Renewables, Electric Heater & MS Storage, Discharging mode



4.b.9 PV + User Defined Storage in NOVO PRO

- Location in Chile, 23,8 % DC Capacity Factor (no tracking)
- 100 MW demand, flat
- PV Field, sizing





Thermoflow

4.b.9 PV + User Defined Storage in NOVO PRO

- User Defined Storage Inputs

Name: User-Defined Storage [1]

Units

Power: ○ kW ◉ MW ○ GW

Energy: ○ kWh ◉ MWh ○ GWh

Sizing

Total capacity	1500	MWh
Max allowed state of charge	100	%
Min allowed state of charge	0	%
Implied usable capacity	1500	MWh
Max charging rate (to storage)	375	MW
Max discharging rate (from storage)	110	MW
Charging efficiency	90	%
Discharging efficiency	90	%

Other

☑ Requires step up transformer

Transformer efficiency: 99,5 %

OD Main Inputs | PEACE Inp

Name: User-Defined Storage [1]

Total Owner's Installed Cost

User-defined total owner's installed cost (energy portion)	250	€/kWh
User-defined total owner's installed cost (power portion)	250	€/kW

Annual Land Cost

Site area: 5 hectare

◉ Crude estimate ○ User-defined

Annual land cost for first year (escalates with inflation): 250 €/ha

First Year O&M Costs

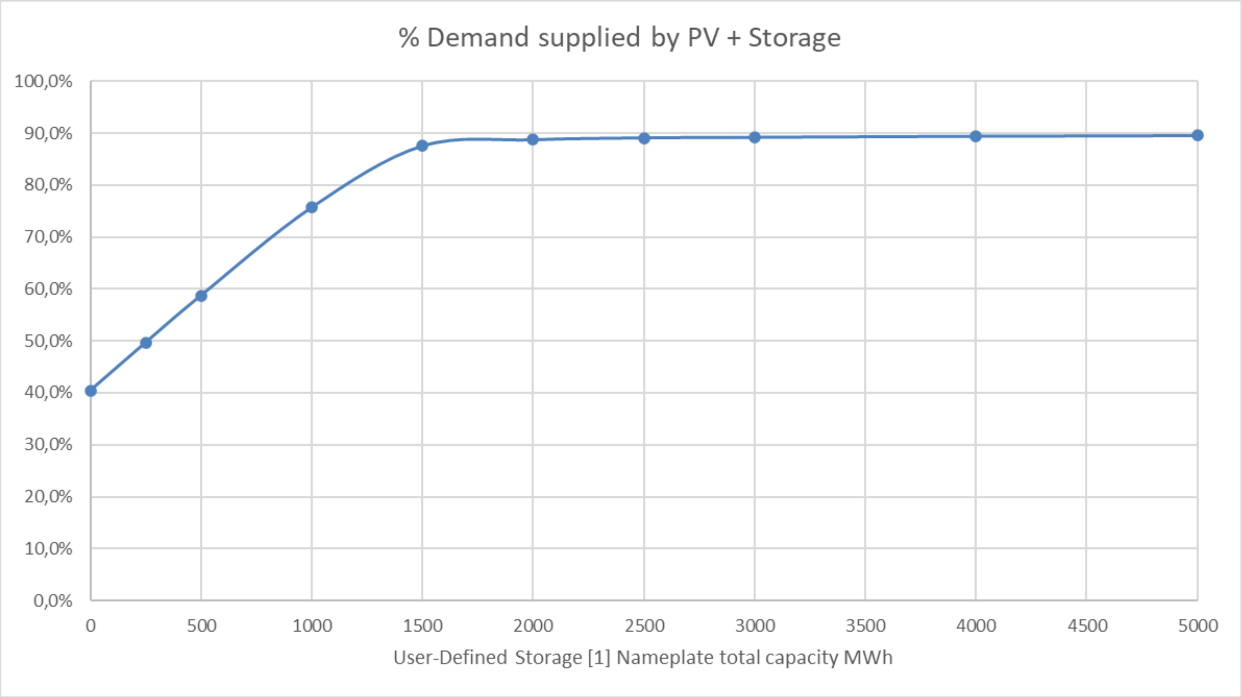
Fixed O&M costs, per net kW capacity per year	8,5	€/kW
Variable O&M costs, per kWh transferred	2,55E-4	€/kWh

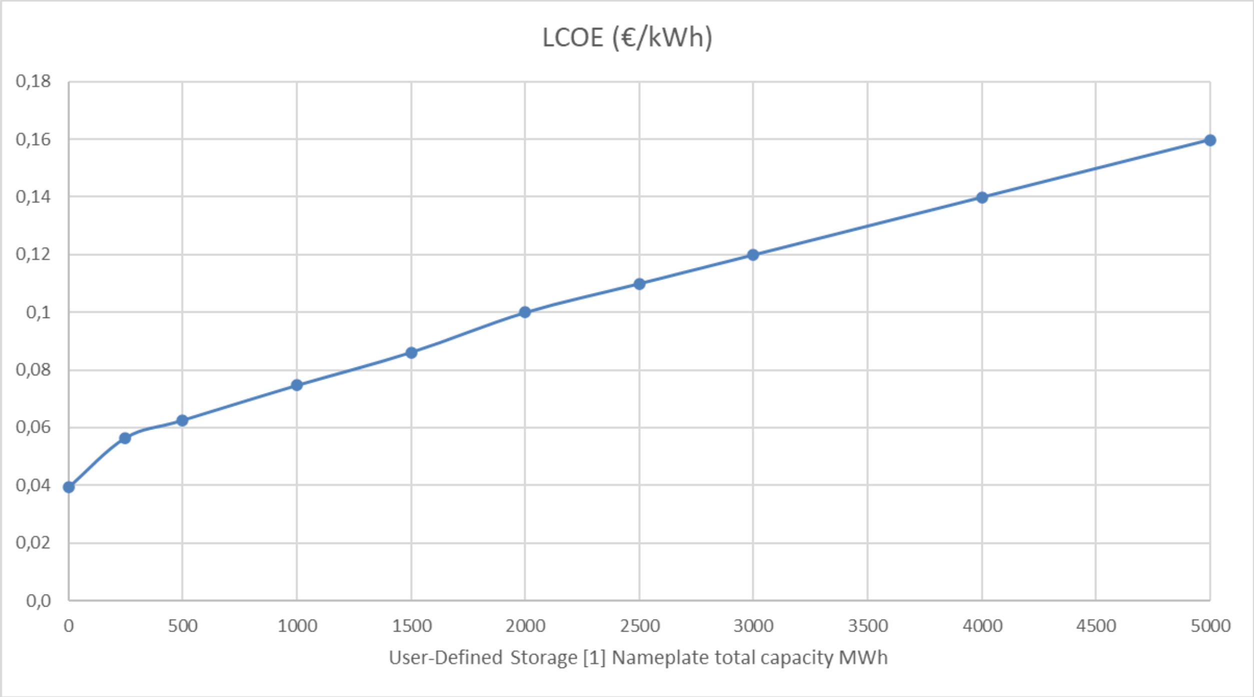
NOVO PRO Outputs

Thermal plant unit running hours	0	hr
Fuel Consumption (LHV)	0	GJ
CO2 emission	0	tonne
Annual Extrema		
Maximum Surplus during an hour of the year	368	MW
Maximum Import during an hour of the year	100	MW
System Supply vs. Demand		
Percentage of year with Surplus power export	35,51	%
Percentage of year with Import power	64,49	%
Percentage of year where System Supply matches Demand	0	%
Hours per per year with Surplus power export	3111	hr
Hours per year with Import power	5649	hr
Hours per year where System Supply matches Demand	0	hr

4.b.9 PV + User Defined Storage in NOVO PRO

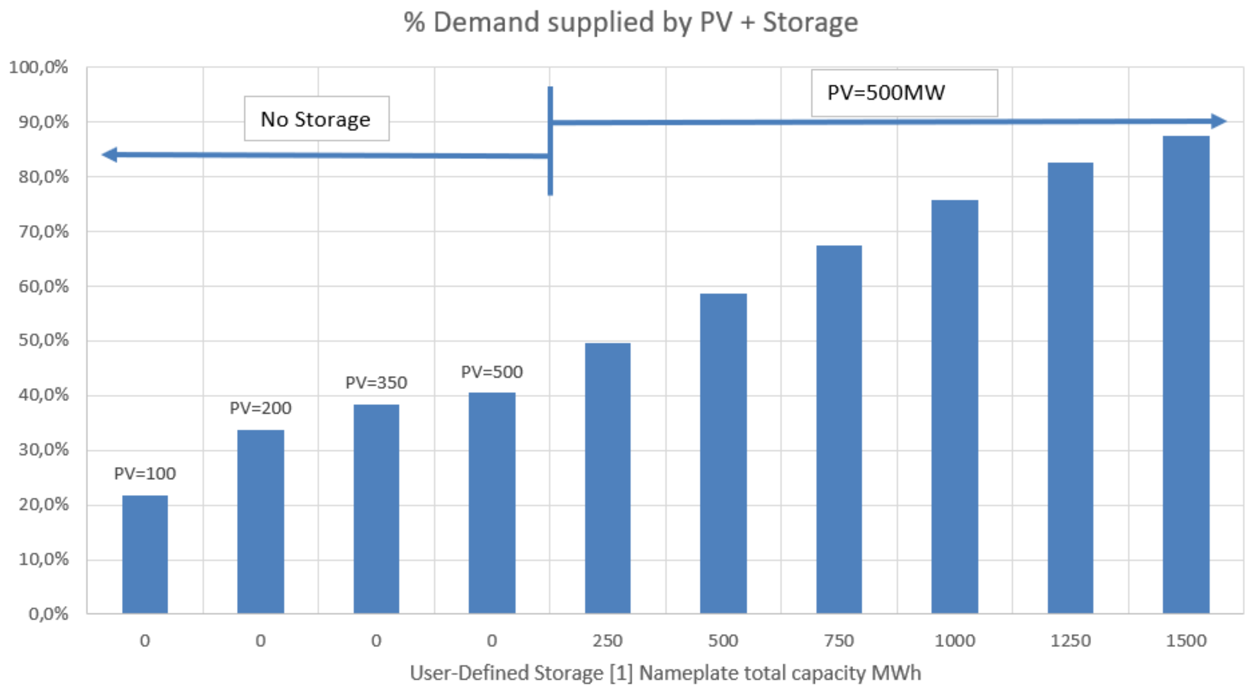
- Increasing the Storage size

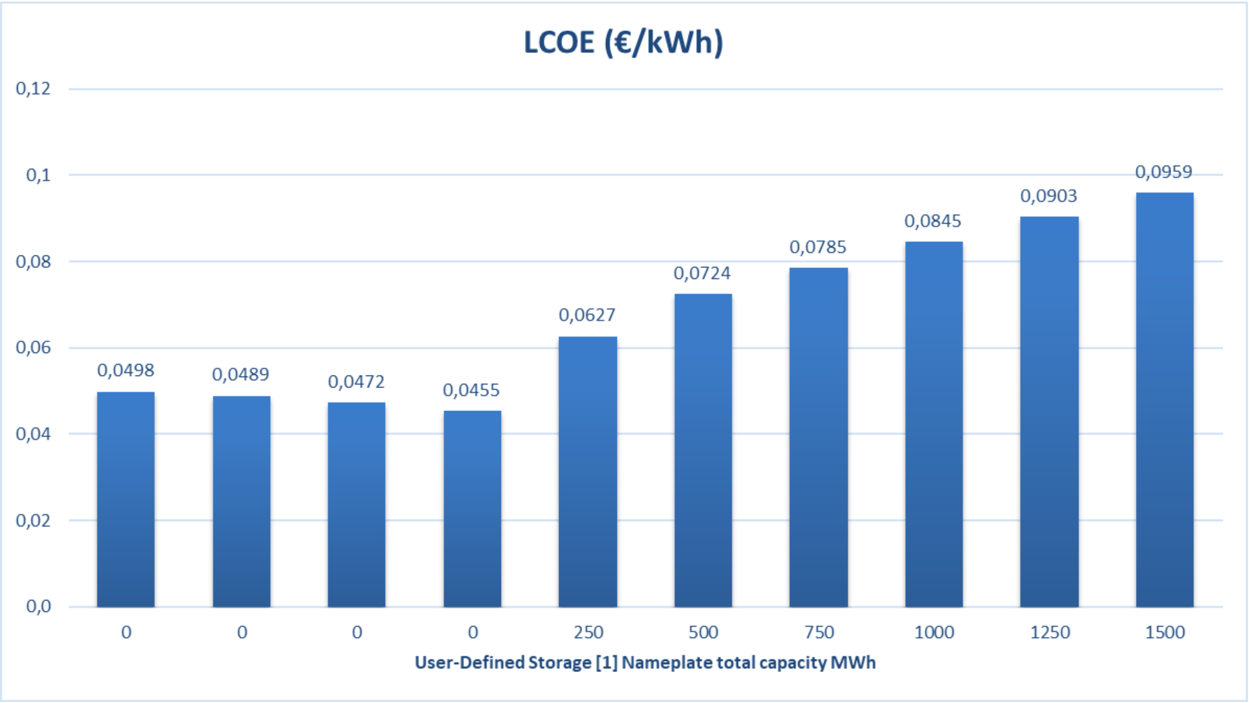




4.b.9 PV + User Defined Storage in NOVO PRO

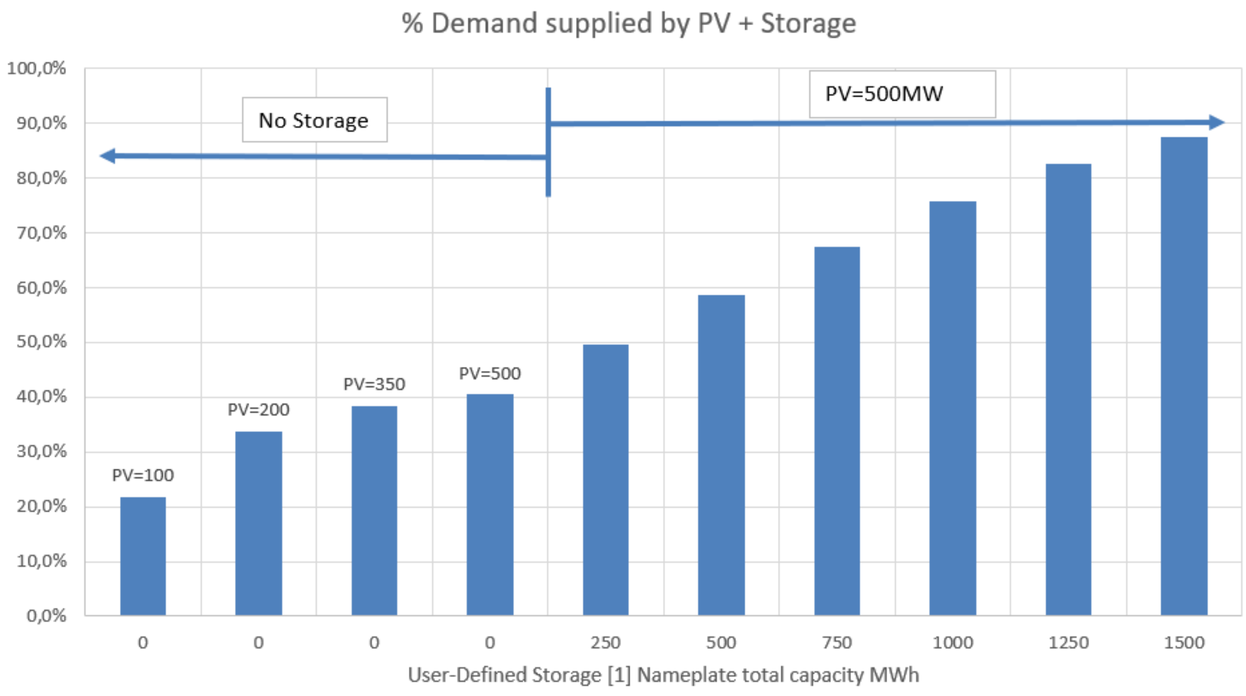
- Comparison, Current Prices

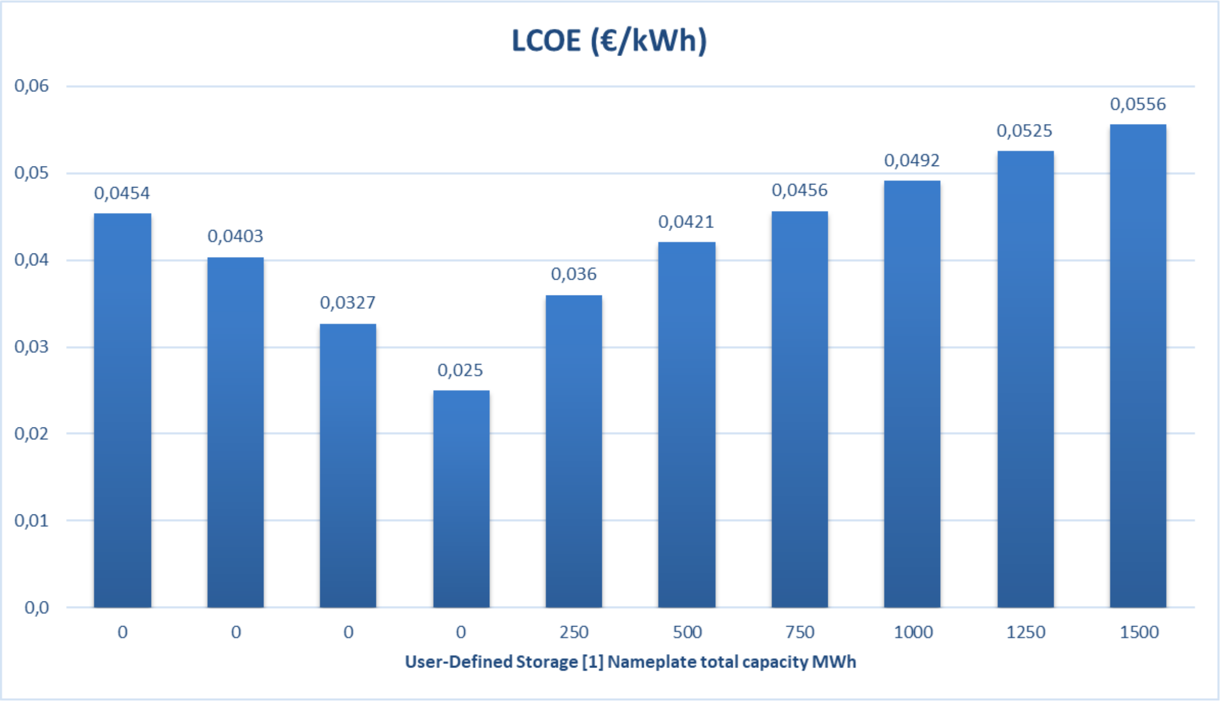




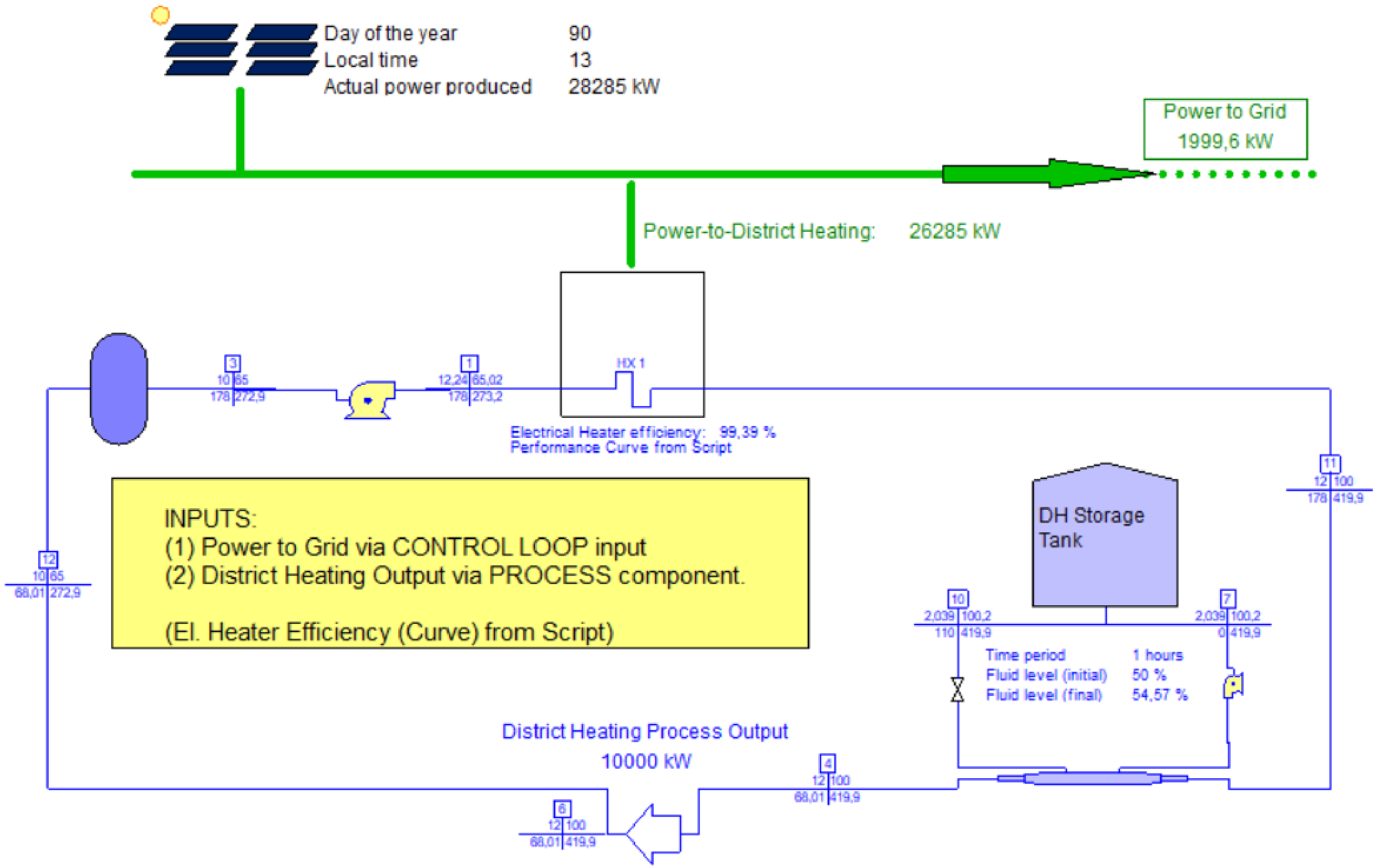
4.b.9 PV + User Defined Storage in NOVO PRO

- Comparison, Future Prices = Half of Current Prices





4.b.10 Power(PV)-to-Heat(DH)+Storage_final in TFX



Mnohokrát děkuji!

Grazie molto!

Mange tak!

¡Muchas gracias!

Vielen Dank !

Merci beaucoup!

Wielkie dzięki!

Thank you !!!

Paljon kiitoksia!

Çok teşekkürler!

Questions? Email us: info@thermoflow.com

Tack så mycket!

Muito obrigado!

Erg bedankt!

Πολλά ευχαριστώ!

Mange takk!