CHEMICAL ENGINEERING TRANSACTIONS

VOL. 94, 2022

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Yee Van Fan, Jiří J. Klemeš, Sandro Nižetić
Copyright © 2022, AIDIC Servizi S.r.l.
ISBN 978-88-95608-93-8; **ISSN** 2283-9216

DOI: 10.3303/CET2294215

Hydrogen-based Energy Storage Targeting for the Integrated Heat and Power System in Urban-Industrial Symbiosis

Wan Aina Syahirah Wan Abdullah[a], Imran Ismail[b,c], Peng Yen Liew[a,*], Kok Sin Woon[d], Wai Shin Ho[c], Jiří Jaromír Klemeš[e]

[a] Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, WP Kuala Lumpur, Malaysia
[b] BASF PETRONAS Chemicals Sdn. Bhd., Kuantan Integrated Chemical Site, Jalan Gebeng 2/1, Kawasan Perindustrian Gebeng, 26080 Kuantan, Pahang.
[c] School of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM, Johor Bahru, Johor, Malaysia
[d] School of Energy and Chemical Engineering, Xiamen University Malaysia, Jalan Sunsuria, Bandar Sunsuria, 43900 Sepang, Selangor, Malaysia
[e] Sustainable Process Integration Laboratory – SPIL, NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology - VUT Brno, Technická 2896/2, 616 69, Brno, Czech Republic
pyliew@utm.my

Greenhouse gaseous (GHG) emissions are significant global challenges, leading to climate change. The industrial sector is the most significant contributor to global energy consumption, burning fuel and emitting GHG. This study aims to extend the Total Site Heat Integration (TSHI) methodology for clean decentralised energy systems to power an eco-city with Urban-Industrial Symbiosis (UIS). The system is assumed to work on the UIS's thermal energy and power systems. A Pinch-based cascade analysis is extended to simulate the hydrogen energy storage to recover thermal and electricity in the energy system, which can determine the hydrogen storage capacity, known as Total Site - Hydrogen Storage Cascade (TS-H_2SC). The hydrogen energy storage system is configured to store excess electricity, and waste heat energy potential to be consumed later or sold off by the system. The methodology is demonstrated with an illustrative case study to integrate hydrogen storage for energy recovery in an Urban-Industrial Energy System. In the illustrative case study, the total electricity to be sold to the grid is found at 701 kWh, while the capacity of the Liquid Organic Hydrogen Carrier (LOHC) system is targeted at 2,616 kg of loaded LOHC. The application of a hydrogen storage system is compared with thermochemical energy storage and power storage systems. The research found that the LOHC system with condensing steam turbine rather than ORC has the most significant potential for energy saving in the UIES.

1. Introduction

United Nations stated the Sustainable Development Goals at UN General Assembly in September 2015. Goals no. 7, 11 and 13 in Affordable and Clean Energy, Sustainable Cities and Communities and Climate Action are addressed by this research. Goal 7 ensures affordable, reliable, sustainable, and modern energy access. By 2030, international cooperation enhances access to clean energy research and technology, including renewable energy, energy efficiency and cleaner fossil-fuel technology, and clean energy technology. Energy is the dominant contributor to climate change, accounting for around 60 % of global greenhouse gas emissions.

Decentralised energy systems were found highly effective in energy efficiency, including the Total Site Heat Integration Urban-Industrial Symbiosis (UIS), which powers up the Eco-City (Yong et al., 2021). This concept enhances energy efficiency by synergising the energy availability between industries and urban sectors, i.e. civil, residential, business or commercial and services complexes. The improvement of energy efficiency through heat integration in industries and the integration of renewable energy systems in urban facilities would significantly contribute to the development of the energy industry. This concept has been proven in certain cities

Paper Received: 11 May 2022; Revised: 07 June 2022; Accepted: 13 June 2022
Please cite this article as: Abdullah W.A.S.W., Ismail I., Liew P.Y., Woon K.S., Ho W.S., Klemeš J.J., 2022, Hydrogen-based Energy Storage Targeting for the Integrated Heat and Power System in Urban-Industrial Symbiosis, Chemical Engineering Transactions, 94, 1291-1296 DOI:10.3303/CET2294215

globally for their energy efficiency. Therefore, the Urban-Industry Energy System (UIES) can be the emerging energy system concept to reduce greenhouse gas emissions.

With the integration of renewable energy and urban energy requirement in the UIS, energy storage has become vital in handling the fluctuation of energy and process to balance the energy supply and demand (Butturi et al., 2019). Thermal energy storage (Mahon et al., 2022) and battery storage (Lin and Zamora, 2022) have been studied for implementation in the UIES. Liew et al. (2018) integrated the thermochemical energy storage for thermal energy recovery for Total Site industrial and urban energy systems. Mohammad Rozali et al. (2018) studied battery storage for harmonising the electricity supply and demand through a hybrid power system for industrial and residential energy systems using Power Pinch Analysis. Lee et al. (2020) studied thermal energy and battery storage for electricity and heat recovery for locally integrated energy sectors.

Hydrogen energy storage is believed to be capable of storing energy at a large scale for achieving a 100 % renewable energy system (Colbertaldo et al., 2019), in which the energy content of liquid and gaseous hydrogen has exceeded double energy storage intensity of the conventional fuel (Abe et al., 2019). Mah et al. (2021) integrated the Liquid Organic Hydrogen Carrier (LOHC) as energy storage for a standalone hybrid power energy system with a solar PV energy supply.

This work introduces the Total Site Hydrogen Storage Cascade (TS-H_2SC) to integrate hydrogen energy storage with Urban-Industrial Symbiosis based on the Total Site Heat and Power Integration methodologies, as shown in Figure 1. The figure illustrates that LOHC is integrated as the storage system for this methodology, which could later be adapted to other hydrogen storage systems. In addition, the methodology considers the energy recovery for the thermal and power energy systems using a hydrogen storage system.

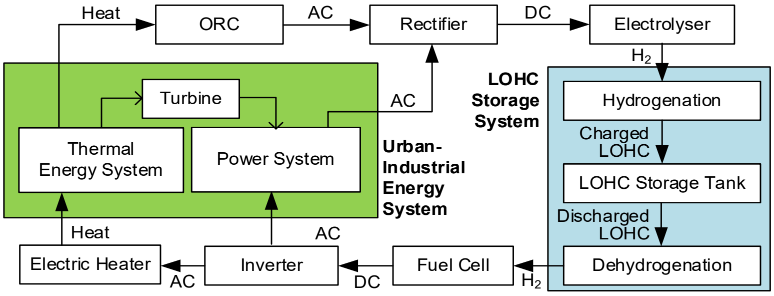

Figure 1: Integration of the hydrogen energy storage system in Urban-Industrial Energy System, after Eypasch et al. (2017)

2. Methodology

The following methodology is proposed for targeting the hydrogen storage system for the urban-industrial integrated heat and power system.

a. Collect the thermal energy stream and electricity consumption data for all the industrial and commercial buildings in the UIS system.
b. Perform thermal energy targeting for the individual processes at all time slices (TSLs) to determine minimum energy requirements using Problem Table Algorithm (PTA) and Multiple-Utility PTA (MU-PTA) analysis (Liew et al., 2018).
c. Perform thermal energy targeting for multiple plants with multiple utilities to determine minimal overall utility requirements using Total Site PTA (TS-PTA) (Liew et al., 2018).
d. Using the cogeneration estimation table, estimate the power generation potential through backpressure and condensing turbines (Lee et al., 2020).
e. Determine the net electricity generation based on electricity demand and renewable energy power generation for every hour.
f. Perform hydrogen energy storage targeting for determining the storage capacity using Total Site Hydrogen Storage Cascade (TS-H_2SC), as shown in Table 1. The steps are described as follows:
    - Determine the amount of power generation potential from the waste heat every hour, as follows:
        - Record the different types of waste heat available from the thermal energy system
        - Determine the amount of Alternative Current (AC) generated by the ORC system, while the efficiency of an electric heater would be used when there is heat demand from the process.
        - Determine the amount of Direct Current (DC) converted from the AC generated
        - Sum up the total amount of DC generated from the waste heat ($DC_{thermal.i}$) in the UIS energy system (Column 3, Table 1).

- Record the net electricity generation and convert it into the amount of DC ($DC_{power,i}$) (Column 4).
- Sum up the DC generated from the waste heat and electricity generation ($DC_{net,i}$) (Column 5).
- Convert DC generation potential into hydrogen production potential based on an electrolysis system and the LOHC hydrogenation process. Since the electrolysis system is producing vapour hydrogen and the storage system is working with LOHC, convert the amount of hydrogen produced by the electrolyser into the amount of LOHC, which is also known as hydrogen generation potential ($H2_{gen,i}$) at the time *i* (Column 6). When the $DC_{net,i}$ is a negative value, it represents that net energy demand happened in the UIS system, which the $H2_{gen,i}$ should be calculated based on the fuel cell efficiency and the LOHC dehydrogenation process to produce electricity from the LOHC in a negative value.
- Perform hydrogen storage cascade ($H2Casc_i$) to obtain the Pinch location and minimum hydrogen requirement and excess (Columns 7 and 8).
- Perform balanced hydrogen storage cascade ($BH2Casc_i$) to model the LOHC flow of the hydrogen storage system, in which the cascade is based on the mass of LOHC, as follows:
  - For start-up operation, cascade the LOHC production into the $BH2Casc_i$ from the earliest time (*i* = 0) using Eq(1), in which the $BH2Casc_{i=0}$ is assumed to be zero (Column 9), and the amount of LOHC in deficit ($BH2_{Def,i}$) to be zero (Column 11). Set up the $H2_{loss,i}$ for all *i* using Eq(2) (Column 10), which $\eta_{charging}$ and $\eta_{discharging}$ represent charging and discharging efficiencies.

$$BH2Casc_i = H2_{gen,i} + BH2Casc_{i-1} + H2_{loss,i} + BH2_{def,i} \tag{1}$$

$$H2_{loss,i} = \begin{cases} -\left(H2_{gen,i} + BH2_{Def,i}\right) * \left(1 - \eta_{charging}\right), & H2_{req,i} < 0 \\ \left(H2_{gen,i} + BH2_{Def,i}\right) * \left(1 - \eta_{dicharging}\right), & H2_{req,i} > 0 \end{cases} \tag{2}$$

  - For continuous operation, repeat the $BH2Casc_i$ from the earliest time (*i* = 0) using Eq(1), in which the $BH2Casc_{i=0}$ is assumed to $BH2Casc_{i=max}$ in the start-up operation cascade (Column 13). Set up the $H2_{loss,i}$ for all *i* using Eq(2).
  - Determine the amount of LOHC in deficit ($BH2_{def,i}$) or excess (when $BH2_{def,i} < 0$) (Column 12 and 16):
    - ❖ When the $BH2Casc_i$ show a negative value; this represents a point that the stored amount of LOHC is insufficient to satisfy the energy requirement from the system. Therefore, the $BH2_{def,i}$ is added to ensure there is no negative value in the cascade $BH2Casc_i$.
    - ❖ When all the $BH2Casc_i$ show positive values, and there isn't any zero value; this represents a feasible cascade, and there would be accumulation in the storage system. Therefore, deducting the $BH2_{def,i}$ from the earliest time with positive $H2_{gen,i}$ to ensure there is a time that the $BH2Casc_i$ shows a zero value.
- Convert the $BH2_{def,i}$ into the equivalent electricity deficit ($Elec_{req,i}$), which represents the amount of outsourced electricity requirement (positive value) and the amount of electricity to be sold off (negative value).

3. Case Study

The methodology is demonstrated with an illustrative case study modified from Lee et al. (2020), in which industrial processes, hotel, hospital and residential area are assumed to be part of the UIES. This case study uses the power consumption of 250 residential houses as the residential area. Four-time slices are assumed in this case study at 20:00-06:00 (TSL 1), 06:00-17:00 (TSL 2), 17:00-18:00 (TSL 3) and 18:00-20:00 (TSL 4). Besides a power distribution system, the thermal energy is supplied through the Middle-Pressure Steam (MPS – 220 °C), Low-Pressure Steam (LPS - 130 °C), Hot Water (HW – 70-80 °C) and Cooling Water (CW – 30-40°C). The minimum temperature difference between process-to-process streams and process-to-utility streams are assumed to be 20 °C and 10 °C.

The single process Heat Integration and TSHI targetings are performed according to the TSLs and recorded in Table 2. MPS has demand for all the TSLs. LPS has excess on TSLs 1, 3 and 4, while LPS has a requirement at TSL 2. Then, the cogeneration potential during the pressure relief between very-high pressure steam (produced by boiler) to MPS and LPS is estimated using the cogeneration estimation table for fulling the MPS demand at all TSLs and LPS demand at TSL 2, which 3,648 kWh of electricity generation potential is found for this case study. It is then calculated with the renewable electricity generation and power demands by the industrial sites, local buildings and household residential units to be the net electricity generation ($DC_{power,i}$).

Table 1: Total Site Hydrogen Cascade (TS-H₂SC)

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16
i	Time (h)	TSL	DC_{therm} (kWh)	$DC_{power,i}$ (kWh)	$DC_{net,i}$ (kWh)	$H2_{gen,i}$ (kg/h)	Initial $H2Casc_i$ (kg/h)	Final $H2Casc_i$ (kg/h)	Start-Up $BH2Casc_i$ (kg/h)	$H2_{loss,i}$ (kg/h)	$BH2_{def,i}$ (kg/h)	$Elec_{req,i}$ (kWh)	Continuous $BH2Casc_i$ (kg/h)	$H2_{loss,i}$ (kg/h)	$BH2_{def,i}$ (kg/h)	$Elec_{req,i}$ (kWh)
0	19:00						0	341	0				430			
1	20:00	4	314	101	416	161	161	501	156	-5	0	0	586	-5	0	0
2	21:00	1	587	74	661	256	416	757	404	-8	0	0	834	-8	0	0
3	22:00		587	-116	471	182	598	939	580	-5	0	0	1,010	-5	0	0
4	23:00		587	-18	568	220	818	1,159	794	-7	0	0	1,224	-7	0	0
5	0:00		587	-43	543	210	1,028	1,369	997	-6	0	0	1,427	-6	0	0
6	1:00		587	16	603	233	1,261	1,602	1,224	-7	0	0	1,653	-7	0	0
7	2:00		587	-92	495	191	1,453	1,793	1,409	-6	0	0	1,839	-6	0	0
8	3:00		587	-140	447	173	1,626	1,966	1,577	-5	0	0	2,007	-5	0	0
9	4:00		587	-113	473	183	1,809	2,149	1,754	-5	0	0	2,184	-5	0	0
10	5:00		587	-113	473	183	1,992	2,332	1,932	-5	0	0	2,362	-5	0	0
11	6:00		587	80	667	258	2,249	2,590	2,182	-8	0	0	2,612	-8	0	0
12	7:00	2	-310	-125	-434	-332	1,918	2,259	1,847	-3	0	0	2,277	-3	0	0
13	8:00		-310	-179	-489	-1,067	851	1,191	769	-11	0	0	1,199	-11	0	0
14	9:00		-310	-189	-498	-1,088	-237	103	0	-8	326	149	100	-11	0	0
15	10:00		-310	262	-47	-36	-341	**0 PINCH**	0	0	103	47	0	3	0	0
16	11:00		-310	337	28	11	-330	11	0	0	-11	-28	0	0	-11	-28
17	12:00		-310	347	37	14	-316	25	0	0	-14	-37	0	0	-14	-37
18	13:00		-310	447	137	53	-263	78	0	0	-53	-137	0	0	-53	-137
19	14:00		-310	538	229	88	-174	167	0	0	-88	-229	0	0	-88	-229
20	15:00		-310	383	74	29	-146	195	0	0	-29	-74	0	0	-29	-74
21	16:00		-310	336	26	10	-135	205	0	0	-10	-26	0	0	-10	-26
22	17:00		-310	311	1.16	0.45	-135	206	0	0	-0.45	-1.16	0	0	-0.45	-1.16
23	18:00	3	479	318	798	309	174	514	236	-7	-65	-169	236	-7	-65	-169
24	19:00	4	314	202	517	200	373	714	430	-6	0	0	430	-6	0	0
TOTAL				2,624	6,195	441			16,291	-102	159	-504	21,980	-103	-271	-701

Table 2: Summary of utility requirement after TSHI targeting and the cogeneration estimation table

TSL	Duration (h)	Q_{MPS} (kW)	Q_{LPS} (kW)	Q_{HW} (kW)	Q_{CW} (kW)	Turbine Inlet Utility		Power Generation (kW)	Total Power Generated (kWh)
						Back Pressure	Condensing		
1	10	3,783	-832	-11,186	-6,969	MPS	-	237.4	2,374.4
2	11	3,423	376	-904	-1,080	MPS	-	58.1	638.9
3	1	3,273	-3,326	-3,103	-1,080	MPS	-	205.4	205.4
4	2	3,423	-1,976	-2,503	-1,080	MPS	-	214.8	429.7

The energy recovery through the hydrogen storage system is then targeted using the TS-H_2SC, as shown in Table 1. The LPS and HW excess shown in Table 2 is used to calculate the electricity production potential through the ORC system is determined as the $DC_{thermal,i}$ in Column 3, Table 1. The ORC thermal efficiencies are assumed at 10.77 % ($\eta_{ORC,LPS}$) and 4.72 % ($\eta_{ORC,HW}$) (Kazemiani-Najafabadi and Amiri Rad, 2022), while the inverter conversion rate is considered at 0.95 (Al Zahrani and Dincer, 2018). When the LPS and HW excess is in a negative sign, the utility is in deficit, which electric heater would be used to generate the utility from the hydrogen (η_{heater} = 0.98). The $DC_{thermal,i}$ is added with the $DC_{power,i}$ to get $DC_{net,i}$ (Column 5). The hydrogen generation potential $H2_{gen,i}$ (Column 8) is calculated based on the electrolysis yield (0.021 kg H_2/kWh), fuel cell efficiency (0.5), Fraction of hydrogen used as fuel for the hydrogenation process (0.0359), Fraction of hydrogen used as fuel for the dehydrogenation process (0.4343) and maximum hydrogen loading capacity in LOHC (0.062 kg H2/kg loaded LOHC) (Mah et al., 2021). Based on the conventional cascade analysis, the Pinch point is found at time 10:00, in which the minimum LOHC requirement and excess are 341 kg LOHC and 714 kg LOHC. The start-up and continuous operations hydrogen storage cascade ($BH2Casc_i$ – Column 9 and 13) is constructed based on the $H2_{gen,i}$ (Column 8), $H2_{loss,i}$ (Column 10 and 14) and $BH2_{def,i}$ (Column 11 and 15). The losses are determined based on the LOHC charging and discharging efficiencies at 0.97 and 0.99 (Mah et al., 2021). The energy demand only happens from 6:00 to 10:00. The insufficient LOHC stored in the system before the Pinch point in the start-up cascade is satisfied directly by outsourced electricity supply (197 kWh). After the Pinch at the start-up operation until the Pinch point at the continuous cycle, there is an excess hydrogen supply, which may cause accumulation in the LOHC storage system. Therefore, charged LOHC excess is identified and back-calculated into the equivalent electricity excess (total of 701 kWh) in Columns 12 and 16 from 10:00 to 18:00 to ensure zero flow at the continuous operation cascade. The continuous operation cascade is ensured to have the same initial and final value in the cascade. The LOHC storage system's capacity is 2,612 kg, in which the storing process happens from 17:00 to 6:00 to satisfy the requirement from 6:00 to 10:00.

The result from the TS-H_2SC (Scenario 1) is compared to the situation where the UIS run without energy storage (Scenario 2) and with thermal energy storage (Scenario 3), as shown in Table 3. The excess LPS in Scenario 1 is assumed to be recovered by ORC and stored in LOHC. However, the low efficiency of ORC in the case study has reduced the energy recovery opportunities. Scenario 4 studied the use of condensing turbine to generate power from the excess LPS and charge it into the LOHC system. The result found that the use of an energy storage system can reduce the thermal energy consumption of the UIES. The LOHC system managed to recover energy from the HW, which avoided the energy load on the power system. In fact, Scenario 4 demonstrated the best situation with a lower boiler load while maintaining the higher amount of excess electricity sold to the electricity grid. The energy harvested from the turbine system met all the energy requirements at all the time intervals, which caused no energy to be loaded into the LOHC storage in Scenario 4. This is obviously due to the high HW excess available in the case study, and the condensing steam turbine has higher efficiency than the ORC system, which enhanced the energy saving of the LOHC storage system integration in the UIES.

Table 3: Summary of final energy consumption for hydrogen storage system integration compared to several energy recovery configurations

	Scenario 1 (with LOHC storage – excess LPS to be recovered through ORC)	**Scenario 2** (without energy storage)	**Scenario 3** (with thermal energy storage)	**Scenario 4** (with LOHC storage – excess LPS to be recovered through condensing turbine)
Boiler Load (kWh/d)	79,988	83,967	79,988	83,967
Hot Water Excess (kWh/d)	0	129,913	129,913	0
Outsourced Electricity (kWh/d)	0	0	70	0
Excess Electricity for Sales (kWh/d)	701	7,727	5,800	13,553

4. Conclusion

The TS-H_2SC is proposed in this paper to target the power and thermal energy recovery through a hydrogen energy storage system to balance the energy supply and demand in an integrated urban-industrial energy system. The methodology is demonstrated with a storage system of liquid organic hydrogen carriers, which the methodology can be adopted into other types of hydrogen storage mediums. In the illustrative case study, the total electricity to be sold to the grid is found at 701 kWh, while the capacity of the LOHC system is targeted at 2,616 kg of loaded LOHC. The research found that the LOHC system with condensing steam turbine rather than ORC has the most significant potential for energy saving in the UIES. For future works, a comprehensive study for comparing the integration of the hydrogen storage system with the conventional battery and thermal energy storage systems in the UIES.

Acknowledgements

The authors would like to thank you for the financial support from Universiti Teknologi Malaysia through the UTM Encouragement Research Grant (Q.K130000.3843.31J02). The research has also been supported by the Sustainable Process Integration Laboratory SPIL project, funded as project No. CZ.02.1.01/0.0/0.0/15_003/0000456, the Operational Programme Research, Development and Education of the Czech Ministry of Education, Youth and Sports by EU European Structural and Investment Funds, Operational Programme Research, Development and Education under a collaboration agreement with UTM, Malaysia.

References

Abe J.O., Popoola A.P.I., Ajenifuja E., Popoola O.M., 2019, Hydrogen energy, economy and storage: Review and recommendation, International Journal of Hydrogen Energy, 44(29), 15072-15086.

Al Zahrani A.A., Dincer I., 2018, Modeling and performance optimisation of a solid oxide electrolysis system for hydrogen production, Applied Energy, 225, 471-485.

Butturi M.A., Lolli F., Sellitto M.A., Balugani E., Gamberini R., Rimini B., 2019, Renewable energy in eco-industrial parks and urban-industrial symbiosis: A literature review and a conceptual synthesis, Applied Energy, 255, 113825.

Colbertaldo P., Agustin S.B., Campanari S., Brouwer J., 2019, Impact of hydrogen energy storage on California electric power system: Towards 100% renewable electricity, International Journal of Hydrogen Energy, 44(19), 9558-9576.

Eypasch M., Schimpe M., Kanwar A., Hartmann T., Herzog S., Frank T., Hamacher T., 2017, Model-based techno-economic evaluation of an electricity storage system based on Liquid Organic Hydrogen Carriers, Applied Energy, 185, 320-330.

Kazemiani-Najafabadi P., Amiri Rad E., 2022, Optimisation of the boiler pressure and working fluid in a binary organic Rankine cycle for different heat sources, Energy, 238, 121671.

Lee P.Y., Liew P.Y., Walmsley T.G., Wan Alwi S.R., Klemeš J.J., 2020, Total Site Heat and Power Integration for Locally Integrated Energy Sectors, Energy, 204, 117959.

Liew P.Y., Wan Alwi S.R., Ho W.S., Abdul Manan Z., Varbanov P.S., Klemeš J.J., 2018, Multi-period energy targeting for Total Site and Locally Integrated Energy Sectors with cascade Pinch Analysis, Energy, 155, 370-380.

Lin X., Zamora R., 2022, Controls of hybrid energy storage systems in microgrids: Critical review, case study and future trends, Journal of Energy Storage, 47, 103884.

Mah A.X.Y., Ho W.S., Hassim M.H., Hashim H., Liew P.Y., Muis Z.A., 2021, Targeting and scheduling of standalone renewable energy system with liquid organic hydrogen carrier as energy storage, Energy, 218, 119475.

Mahon H., O'Connor D., Friedrich D., Hughes B., 2022, A review of thermal energy storage technologies for seasonal loops, Energy, 239, 122207.

Mohammad Rozali N.E., Ho W.S., Wan Alwi S.R., Manan Z.A., Klemeš J.J., Mohd Yunus M.N.S., Syed Mohd Zaki S.A.A., 2018, Peak-off-peak load shifting for optimal storage sizing in hybrid power systems using Power Pinch Analysis considering energy losses, Energy, 156, 299-310.

Yong W.N., Liew P.Y., Woon K.S., Wan Alwi S.R., Klemeš J.J., 2021, A pinch-based multi-energy targeting framework for combined chilling heating power microgrid of urban-industrial symbiosis, Renewable and Sustainable Energy Reviews, 150, 111482.