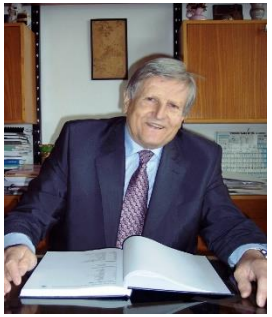
The Potential of Oxygen-Pressure Swing Adsorption Unit Connected with Electricity Storage System



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Motivation

The pressure swing adsorption (PSA) units are widely used as oxygen sources where oxygen is produced in a gaseous form with purity up to 95 %.

The start-up time of minutes is an undeniable advantage of PSA technology compared to cryogenic air separation having start-up time taking hours or days.

PSA:

small-capacities (< 500 $Nm^3/h \propto 17$ t/d), higher specific energy consumption comparing to ASU ($\propto$ 805 kWh/t_{O2})

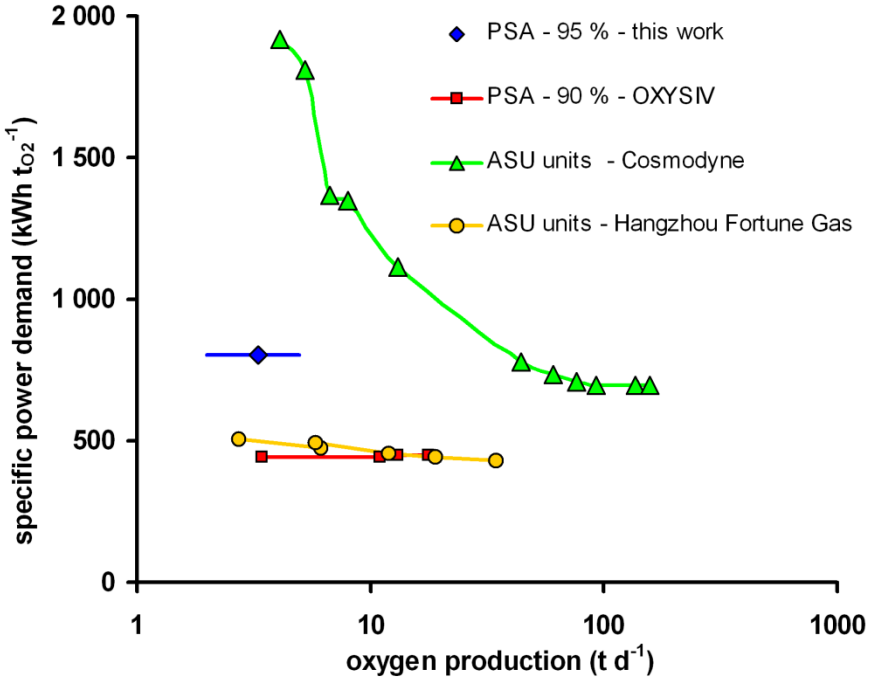
ASU:

EIGA (2019): 99.5 % LOX 638 kWh/t_{O2},

GOX (40 bar) 400 kWh/t_{O2}

$\Rightarrow$to decrease energy consumption

$\Rightarrow$to improve economy

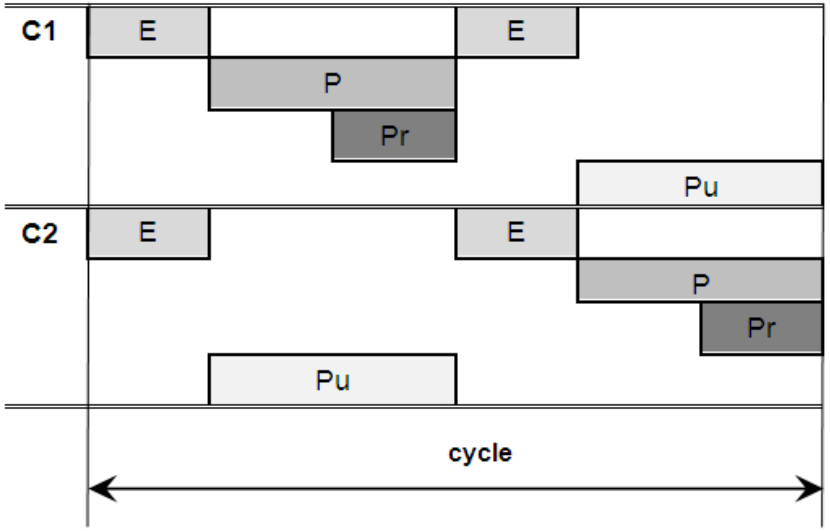


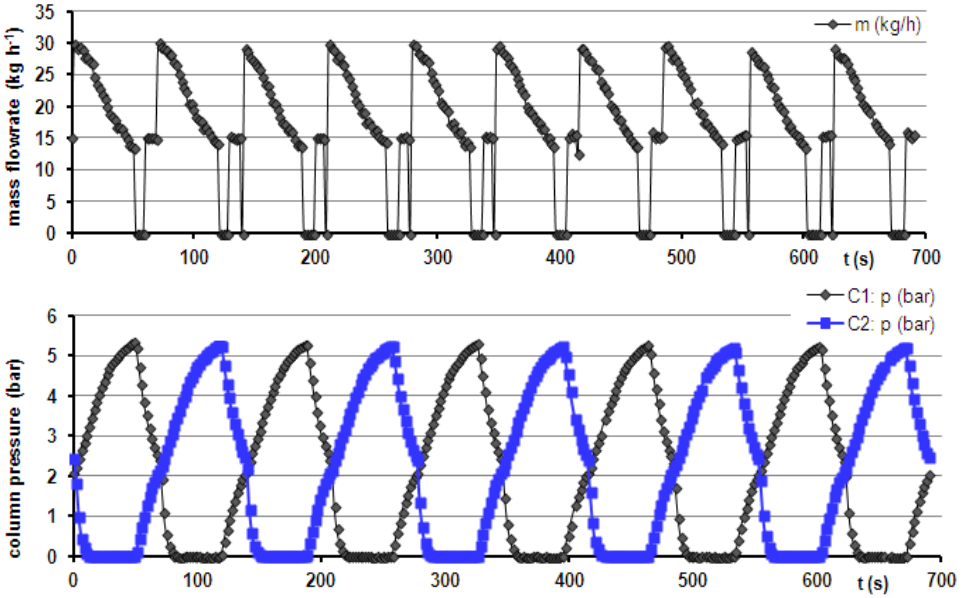
1. Oxygen by PSA technology

Adsorption air separation units

Skarstrom (1960) first PSA technology for O_2 separation
Guerin and Domine (1964) – VPSA

The scheme of adsorption cycle used for columns C1 and C2: E-equalization (19 s), P-pressurization (48 s), Pr-production (24 s), Pu-purging





2. The potential of energy savings

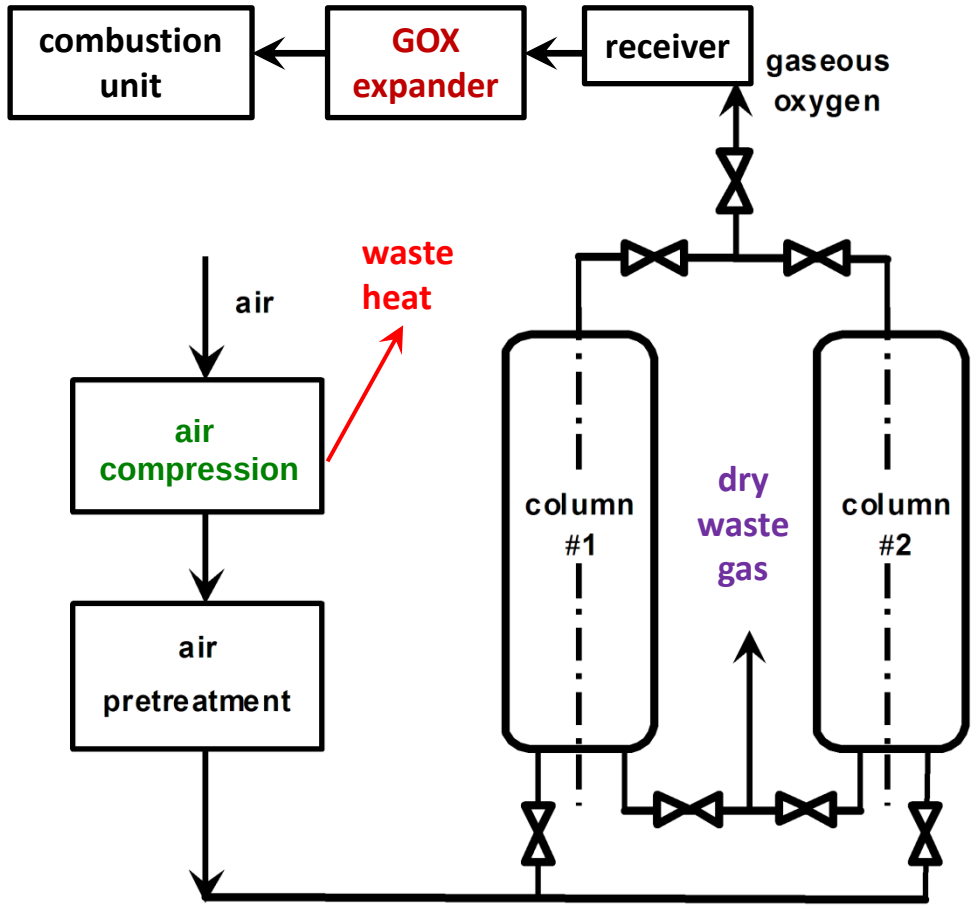
The following four options were analyzed:

i) **single or dual compression**,

ii) **utilization of waste compression heat** for coal or biomass dewatering,

iii) **utilization of dry waste gas from the PSA unit** for coal or biomass dewatering, and

iv) energy recovery by an **expansion of pressurized oxygen** (GOX) before combustion.



Case study: small oxy-combustion unit with a 500 kW thermal power load

95 % oxygen purity ; INMATEC POC8900 PSA unit ; pure oxygen flowrate = 96 Nm^3/h = 3.3 t/d

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A) Single or dual compression

- **Single compression = 805 kWh/t_{O2}, dual compression = 0.728 kWh kg_{O2}^{-1}**
- **Using dual compression, 10 % of electrical energy may be saved.**
  It represents a saving of 85.68 MWh y^{-1} for the annual operating time of 8,160 hours.

B) The GOX expansion is capable to recuperate 2.7 % of electrical energy.

C) Utilization of low-grade waste compression heat for fuel drying

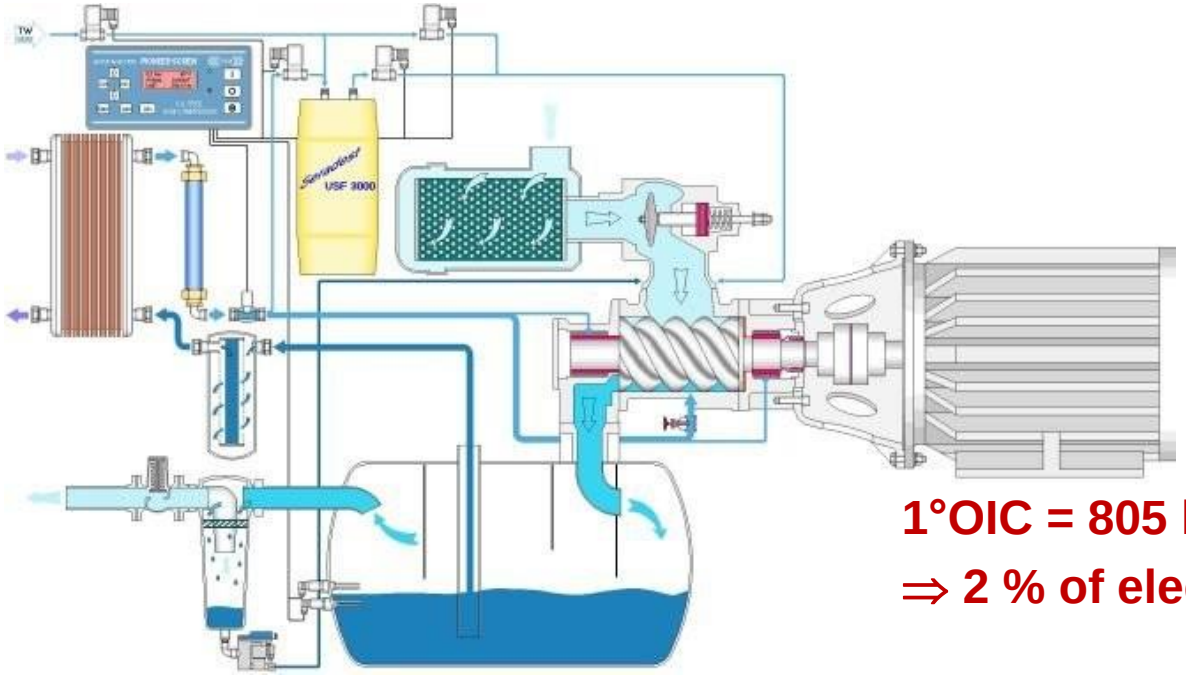
A. Lignite coal: drying of raw lignite coal from **40 wt. %** moisture to **10 wt. %** moisture.
B. Wood: drying of raw wood from **50 wt. %** moisture to **20 wt. %** moisture.

The waste compression heat is capable:

1) to dry a consumed fuel, and

2) to save 5.3 % of lignite or 10.4 % of wood.

3. The potential of water-injected compressor technology for energy saving



Water injected compressors:

- **MultiAir Italia, (2022): 20 % energy saving could be potentially obtained by reaching the isothermal compression.**
- **Venu Madhav and Kovačević (2015): the 5 % energy saving could be achievable.**

1°OIC = 805 kWh/t_{O2} ⇒ 1°WIC = 788 kWh/t_{O2}

⇒ 2 % of electrical energy can be saved

η_{POLY}: 0.77 → 0.9

⇒ energy-saving grows up to 15 %

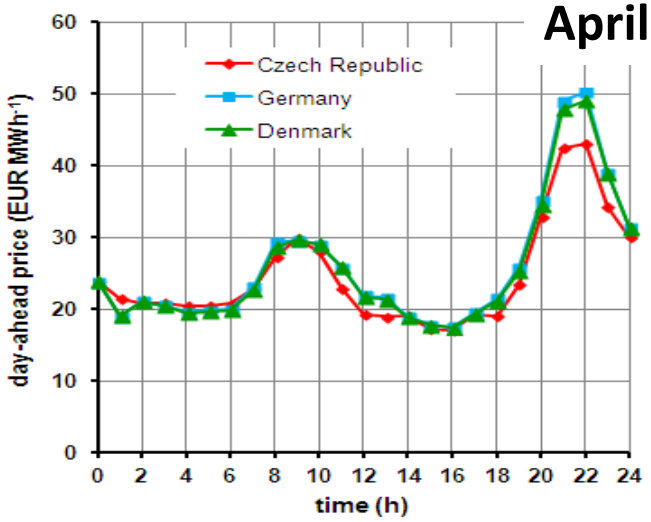
waste compression heat is capable to dry raw wood

Case 1: base case
compressed air outlet temp = 100°C, water injected outlet temp = 90°C (estimated); *polytropic efficiency fitted to the compressor power input* (Compair D-serie compressor datasheet).
Case 2: influence of polytropic efficiency (0.77 → 0.9)
Case 3: influence of outlet temperature (air → 85°C , water → 80°C)

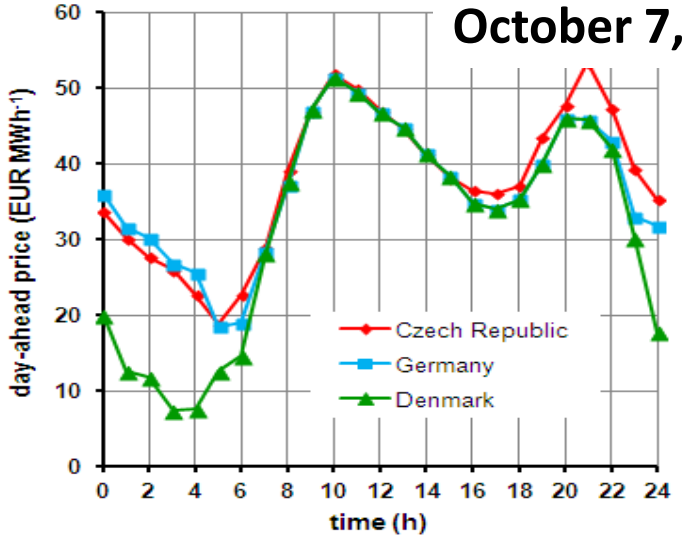
4. The potential of PSA unit connected with electricity storage system

- **The increasing share of renewable electricity causes intraday electricity price fluctuations.**
- **These fluctuations can be an opportunity to improve the economy of a plant accumulating electricity using battery energy storage system.**

April 8, 2020



October 7, 2020



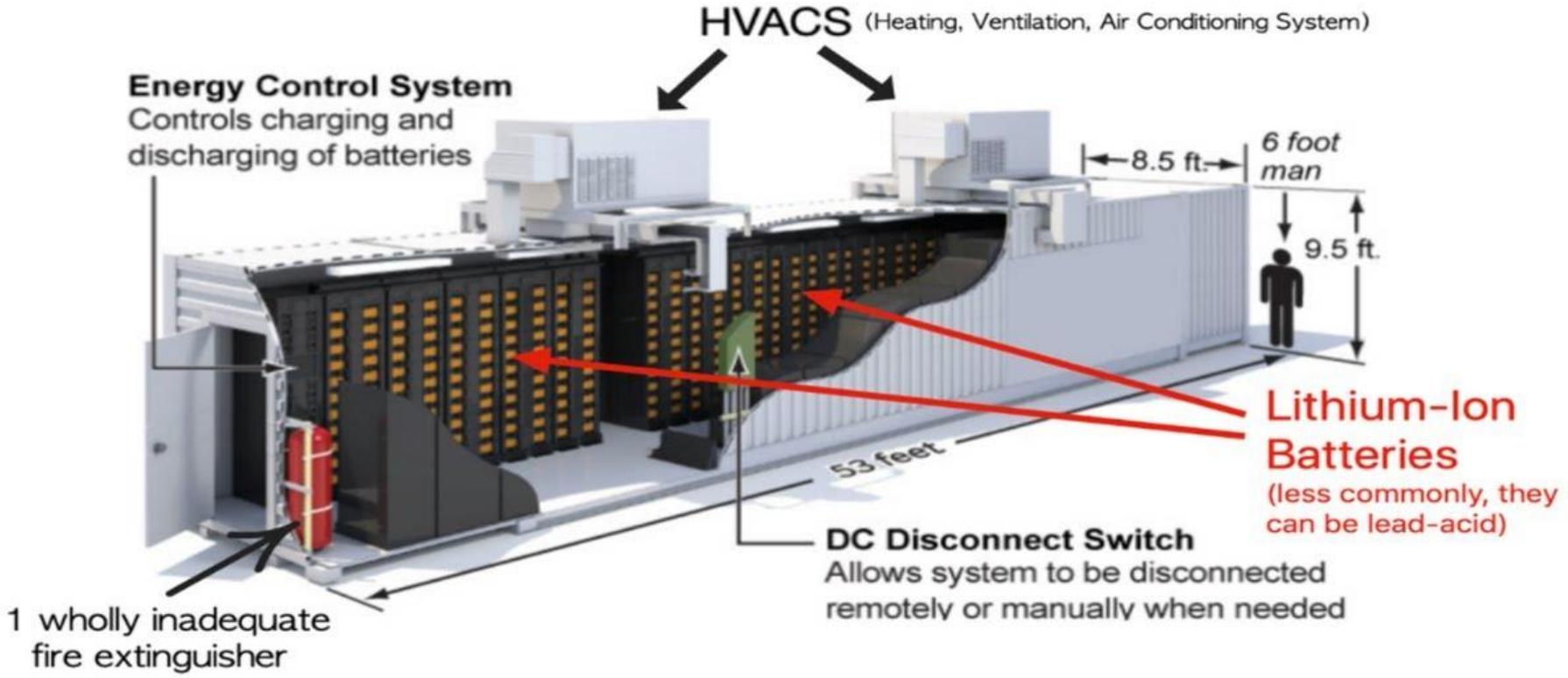
The analysis was carried out for the Czech Republic, Germany, and Denmark.

These countries **differ** significantly in the **energy mix**.

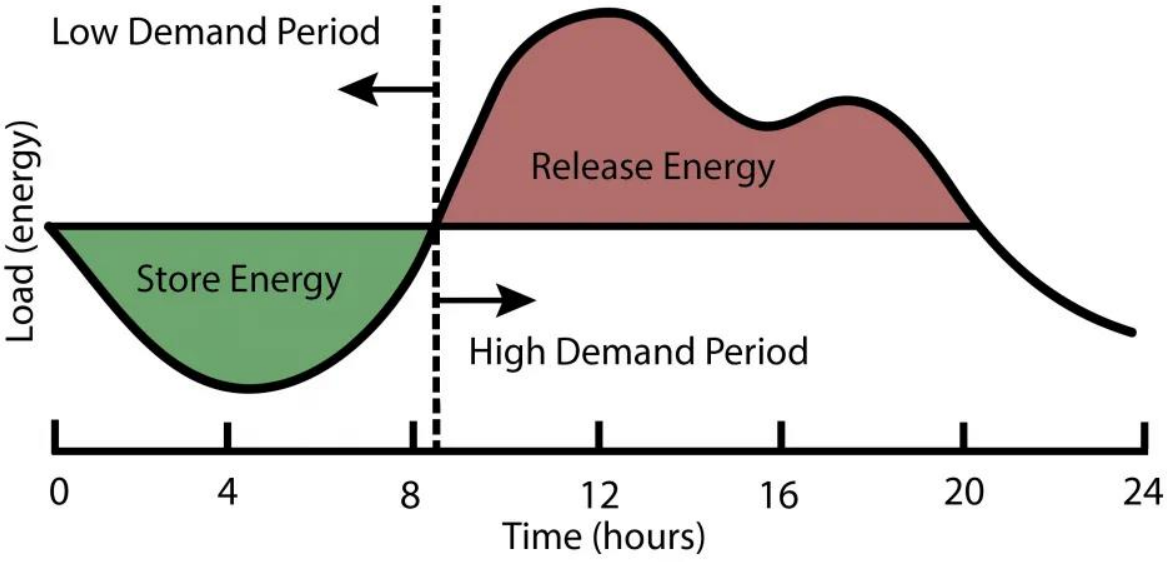
The price data for the randomly selected 2nd Wednesday in January, April, July, and October of the year 2020 respecting the winter, spring, summer, and autumn seasons, respectively, were overtaken.

Energy Storage Systems & Types

Battery Energy Storage System



The **electric energy time-shift** is one of the grid applications of battery energy storage systems. Electric energy time-shift involves **purchasing inexpensive electric energy**, available during periods when prices or system marginal costs are low, to charge the storage system so that the **stored energy** can be **used or sold** at a later time when the **price or costs are high**. **This application has also a potential for CO_2 emission reduction.**



The electricity needed for the PSA unit is supplied **by the grid during an off-peak period in which the electricity price is low**. When the electricity price is lowest, **the electricity from the grid is stored** in a battery energy storage system during the **charging period**. During the **electricity price peak**, the **electricity needed** for the PSA unit is **supplied by the charged BESS**.

Table 1: On-site PSA unit with Battery Energy Storage System (BESS) – Czech Republic

Description	Unit	January 8	April 8	July 8	October 7
Input data					
Daily average day-ahead price *1	**EUR MWh^{-1}**	**44.84**	**24.54**	**42.59**	**38.00**
Average electricity price for charging period *1	**EUR MWh^{-1}**	**35.05**	**21.11**	**33.93**	**25.62**
Off-peak average electricity price *1	**EUR MWh^{-1}**	**43.79**	**22.25**	**40.84**	**35.41**
***Single compression* *3,4**					
PSA unit: cost for daily average el. price	EUR d^{-1}	866	474	823	734
PSA unit: cost for off-peak production	EUR d^{-1}	670	340	625	542
PSA unit: cost for peak production with BESS	EUR d^{-1}	141	85	137	103
Oxygen cost using BESS	EUR d^{-1}	811	425	761	645
Gain (+)/loss (-)*5	**%**	**6.4**	**10.3**	**7.5**	**12.2**
***Dual compression* *3,4**					
PSA unit: cost for daily average el. price	EUR d^{-1}	784	429	744	664
PSA unit: cost for off-peak production	EUR d^{-1}	606	308	565	490
PSA unit: cost for peak production with BESS	EUR d^{-1}	128	77	124	93
Oxygen cost using BESS	EUR d^{-1}	733	385	688	583
Gain (+)/loss (-)*5	%	**6.4**	**10.3**	**7.5**	**12.2**

Note:*1 Operation time = 24 h d^{-1}, charging period from 0 a.m. to 6 a.m., peak period: from 8 a.m. to 10 a.m. and from 7 p.m. to 10 p.m.

Note:*3 PSA unit: specific electricity demand: single compression 0.805 MWh t_{O2}^{-1}, dual compression 0.728 MWh t_{O2}^{-1}.

Note: *4: Calculation was performed for the specific oxygen production capacity of 1 t h^{-1}.

Note: *5 Gain/loss: related to the cost of PSA production for daily average electricity price.

charging period: 0-6 a.m.;
peak period: 8-10 a.m. + 7-10 p.m.

On-site PSA unit with Battery Energy Storage System (BESS)

Gain (+)/loss (-)	Unit	**January 8**	**April 8**	**July 8**	**October 7**
Czech Republic	%	6.4	10.3	7.5	12.2
Germany	%	22.1	12.7	7.6	10.3
Denmark	%	19.9	12.4	13.9	21.4

The **theoretical potential of BESS** installation and use in electricity price peak was found to be around **9-16 % of cost-saving** on average **compared** with **the daily operation of PSA unit** when the **off-peak** average electricity price was from **95 to 91 %** of the **daily average electricity price** respectively.
Widening the price gap due to increasing RES share, the **potential is growing**.

The analysis was executed for the static charging period from 0 a.m. to 6 a.m regardless of the actual electricity price. **The system operated with a dynamically changed charging period based on the forecast prediction model for electricity price may further maximize the cost-saving.**

On-site PSA unit with LOX supply at electricity price peak as 2nd option

LOX supply at electricity price peak (during the electricity price peak, the oxygen needed for the process is produced from liquefied oxygen (LOX) supplied from large ASU facilities continuously operated through a day.

Gain (+)/loss (-)	Unit	January 8	April 8	July 8	October 7
Czech Republic	%	6.2*1 / 4.4 *2	11.7 / 9.9	7.6 / 5.8	9.7 / 8.0
Germany	%	10.8 / 9.0	12.6 / 10.8	8.0 / 6.3	8.9 / 7.2
Denmark	%	10.3 / 8.5	12.3 / 10.6	9.8 / 8.1	12.3 / 10.6

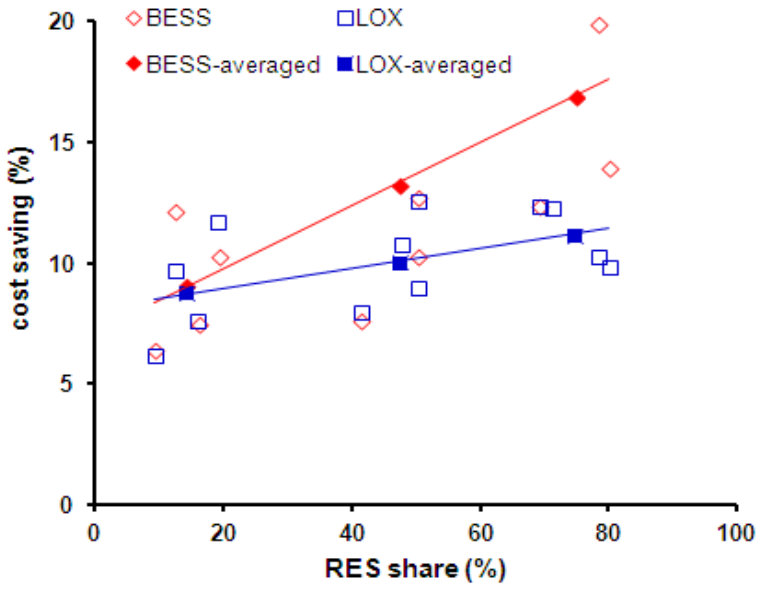
Note: *1 Single compression, *2 dual compression

The **theoretical potential of LOX supply 8-11 % of cost-saving** on average.

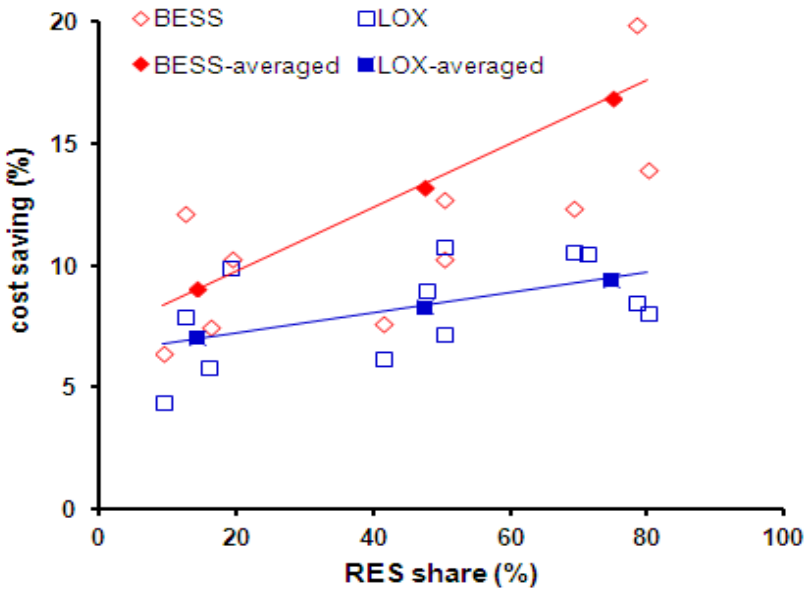
The **theoretical potential of BESS 9-16 % of cost-saving** on average.

Effect of the ratio of renewable energy sources (RES share) on cost-saving percentage:

The values of cost-saving percentages for each country were plotted on the share of renewable energy sources (RES) in the energy mix for each country.



a) single compression



b) dual compression

Conclusions

- The pressure swing adsorption (PSA) units are widely used as oxygen sources where oxygen is produced in a gaseous form. The storage of pressurized gaseous oxygen is limited by the capacity of a pressure vessel.
- The increasing share of renewable electricity sources (RES) causes intraday electricity price fluctuations. These fluctuations can be an opportunity to improve the economy of a plant.

- The theoretical potential of BESS installation and use in electricity price peak was found to be around 9-16 % of cost-saving on average compared with the daily operation of PSA unit.
- Widening the price gap due to increasing RES share, the potential is growing.

- For comparison, the LOX supply in the electricity peak was also analyzed as 2nd option. The theoretical potential of LOX supply for the same conditions was found around 8 - 11 % of cost-saving on average compared with the daily operation of the PSA unit.

Thank you very much for your attention.

Acknowledgements

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