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# Energy Supply Systems Functional Capabilities of Elite Female Skiers of Various Sport Specialization

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***Abstrac*—The study points out main energy supply systems functional capabilities of elite cross-country female skiers of various sports specialization (Distance, Universal, Sprint) and at its specific manifestations of formation at different stages of the preparatory period under the influence of strictly regulated training loads construction. The main specific features of achieving the model level of functioning of various sport specialization elite cross-country female skiers main energy supply systems are determined. The results of the study show that the feature functional state formation of skiers at the beginning of the preparatory period in all training groups (Distance, Universal and Sprint) is the low implementation readiness due to the the lactic acid system low level of activity, which was the highest in the group Distance, and combined with a higher level of the oxidative system functioning and the state of intersystem regulation. A feature of skiers-racers functional state formation at the end of the preparatory period is the leveling of differences in the level of physical performance, and in the groups of Universals and Sprint in relation to the group Distance, mainly due to the increase in the power capabilities of the lactic acid energy system. The results can be used to control the training process on the basis of sports training used tools and methods selective training impact to achieve and maintain the model performance capabilities of power supply systems of elite cross-country female skiers at various stages of the Olympic cycle.**

***Keywords—cross-country skiing; women; the preparatory period of the annual cycle of training; the functionality of the oxidative and lactic acid systems; anaerobic threshold.***

## I. INTRODUCTION

In sports practice, it is known that the growth of athletic results in the course of longstanding training is determined by the ongoing increase in the requirements of competitive activity for the athletes' physical condition, the main component of which is the functionality of energy supply systems [1, 2, 3]. To fulfill these requirements athletes have to use different methodological approaches: to increase the amount of cyclic and acyclic loads, to increase the intensity of the training task, to change the set of components for dosing muscle loads that cause the corresponding current shifts and further general changes in the functional systems of the body [1, 4, 5].

Considering the responsibility that coaches, specialists and athletes face in the process of preparing for the XXIV Winter Olympic Games in Beijing (China) in 2022, mistakes made in preparing for the 2018 Olympic Games in Pyeongchang (Republic of Korea) must be avoided. It is necessary to use the results of the studies and to plan on that basis the development of functional capabilities in compliance with the stage of the annual training cycle taking into account specific features of muscle activity at various competitive distances of female racers specializing in various types of competitive activity.

Modern methodological approaches to assessing the functional capabilities of the main energy supply systems presented in the studies [3-17] show great attention to this section of the work in the training system of highly qualified athletes while the amount of research on female racers in modern scientific and methodological literature is extremely rare and low. Moreover, those few studies dedicated to female skiers [4-5, 10-12, 16-17] do not have a common research methodology, use a different set of test procedures, a different nomenclature of indicators and therefore do not provide a systematic assessment of the main energy systems functional capabilities that affect the performance of competitive exercises and, as a result, cannot be fully used by national experts working in cross-country skiing.

## II. RESEARCH METHODOLOGY

### *A. Subjects*

The athletes of the national team and the closest reserve took part in the study. They were divided into groups based on the performance efficiency at different distances: 8 people of long-distance orientation (hereinafter referred to as Distance),

 

6 people of universal orientation (hereinafter referred to as Universal) and 5 sprinters (hereinafter referred to as Sprint). A total of 19 athletes aged 20 to 29 years with qualifications ranging from a Candidate Master of Sports to a Master of Sports of International Class were monitored. Their background characteristics are shown in Table I.

TABLE I. CHARACTERISTICS OF 19 ELITE FEMALE CROSS-COUNTRY SKIERS INVOLVED IN THIS STUDY

| Parameter | Mean ± SD | | |
|---|---|---|---|
| | ***Distance (n=8)*** | ***Universal (n=6)*** | ***Sprint (n=5)*** |
| Beginning of the training period (Start) | | | |
| Age (years) | 23.3 ± 2.1 | 23.7 ± 4.3 | 22.2 ± 1.1 |
| Body height (cm) | 164.1 ± 3.9 | 165.4 ± 2.7 | 165.4 ± 4.1 |
| Body mass (kg) | 57.3 ± 5.2 | 61.7 ± 4.7 | 63.5±4.7 |
| Body mass index (g/cm) | 348.6 ± 29.6 | 373.0 ± 28.6 | 383.8 ± 28.6 |
| Muscle mass (%) | 49.8 ± 2.1 | 51.8 ± 2.7 | 50.4 ± 1.7 |
| Body fat (%) | 13.5 ± 3.6 | 14.5 ± 5.4 | 15.9 ± 2.7 |
| End of training period (End) | | | |
| Age (years) | 23.3 ± 2.1 | 23.7 ± 4.3 | 22.2 ± 1.1 |
| Body height (cm) | 164.1 ± 3.9 | 165.4 ± 2.7 | 165.4 ± 4.1 |
| Body mass (kg) | 57.7 ± 4.6 | 59.7 ± 3.8 | 63.3 ± 3.3 |
| Body mass index (g/cm) | 351.7 ± 27.4 | 361.1 ± 23.9 | 382.8 ± 17.1 |
| Muscle mass (%) | 50.8 ± 2.5 | 52.2 ± 2.3 | 51.6 ± 1.1 |
| Body fat (%) | 12.3 ± 2.3 | 12.6 ± 4.4 | 14.1 ± 1.4 |

### *B. Overall design of the study*

Functional surveys were conducted in the laboratory of physical education and sport cyclic Olympic sports of the Federal scientific center (Moscow). The test program included two protocols: (1) stepwise increasing load "to muscular failure" on a running treadmill and (2) ultimate 60 seconds all-out muscular work on a bicycle ergometer. The methodological feature of the study was the offer to athletes of all groups of a unified training program with increasing the base level by the volume of the cyclic load with the task of bringing the athletes to the level of 9300-9500 km (the second year of the Olympic preparation season 2015-2016, an intervening year without a World Cup).

### *C. Test protocols*

A study of female skiers functional capabilities was carried out as a part of the methodological framework during the sequential comprehensive examination at the beginning and the end of the preparation period. The examination program consisted of two test procedures:

- stepwise increasing load "to muscular failure" (test 1);
- ultimate 60 seconds muscular work performed according to “all-out” type (test 2, MAP-60, assessment of glycolytic power).

The application of the selected test procedures, tools and control methods for the studied indicators of the body’s energy supply systems was carried out on the basis of methodological recommendations for the study of highly qualified athletes functional state during physical exercises in the laboratory [2, 6-7].

The first test (stepwise increasing load until the muscular failure) provides information on the dynamics of the studied parameters in the range from low (moderate zone) to high (submaximum) intensity, which makes it possible to assess the power and capacity of energy supply systems. This test allows us to establish not only the limiting level of researched systems functioning but also the level of the anaerobic threshold characterizing active starting of the anaerobic glycolysis process and, as a result of this, to establish the level of intersystem interactions formation.

The second test (60-second sprint) provides information on the dynamics of the lactic acid energy system power capabilities’ formation and, as a result, the degree of its readiness for implementation (glycolytic power).

As an ergometric tool which allows standardizing the method of setting muscle load in test 1 we used the Quinton running treadbahn (USA) providing a loading task in a different power range (from minimum to maximum) of the studied systems functioning.

Test 2 was carried out on a Monark mechanical bicycle ergometer (Sweden) adapted to fulfill maximum muscle loads, which allow quantifying (by the value of achieving mechanical power) the implementation readiness of the lactic acid energy system.

The load on a treadmill and bicycle ergometer during all stages of work (at the beginning and the end of the preparatory period) was set according to the following protocol:

- stepwise increasing load on a running treadbahn:

  1) running speed at the initial stage - 2.5 m/s (9.0 km/h);

  2) surplus running speed - 0.5 m/s (1.8 km/h);

  3) loading stage duration is 3 minutes;

- 60-second “all-out” load performed on a bicycle ergometer:

  1) the resistance value was selected according to the weight of the athletes and amounted to a range of 3.0-3.5 kps;

  2) the cadence rate was recorded throughout the entire performance time every 5 seconds.

Resting time between tests 1 and 2 did not exceed 5 minutes.

The functional capabilities of the studied energy systems (oxidative and lacticidal) were assessed by measuring physiological and biochemical indices by expiratory air indices on a “MetaLyzer – II” automatic gas analysis indicator (Cortex, Germany) and lactic acid concentration in capillary blood using the photocolorimetric method.

The choice of the research period was based on the idea that the beginning of the preparation period reflects the basic (initial) level of physical condition and the end of the preparation period reflects the influence of the methodological orientation of the training process construction.

## III. RESULTS

The results of the study, presented in table II and in figures 1, allow us to characterize the features of energy supply systems functionality formation depending on the chosen methodological orientation of the training process construction in female skiers-racers' groups specializing in different types of competitive activity.

TABLE II. DYNAMICS OF PHYSICAL PERFORMANCE AND FUNCTIONAL CAPABILITIES INDICATORS OF ENERGY SUPPLY SYSTEMS FOR FEMALE SKIERS AT THE BEGINNING (START) AND THE END OF THE PREPARATORY PERIOD (END)

| Parameter | Period | Mean ± SD | | |
|---|---|---|---|---|
| | | *Distance (n=8)* | *Universal (n=6)* | *Sprint (n=5)* |
| Performance time in test 1, min | Start | 16.14 ± 1.19 | 14.05 ± 1.52 | 13.43 ± 1.32 |
| | End | 16.57 ± 1.14 | 16.33 ± 1.18 | 15.37 ± 1.28 |
| Running speed in test 1, m/s | Start | 4.71 ± 0.22 | 4.35 ± 0.31 | 4.29 ± 0.26 |
| | End | 4.83 ± 0.21 | 4.76 ± 0.22 | 4.60 ± 0.24 |
| VO2max, l/min | Start | 3.478 ± 0.204 | 3.588 ± 0.250 | 3.561 ± 0.440 |
| | End | 3.614 ± 0.169 | 3.708 ± 0.260 | 3.760 ± 0.273 |
| VO2max/kg, ml/min/kg | Start | 60.95 ± 2.95 | 58.30 ± 3.94 | 56.03 ± 4.50 |
| | End | 62.78 ± 3.13 | 62.15 ± 3.11 | 59.33 ± 1.93 |
| MBC, l/min | Start | 122.8 ± 10.8 | 115.9 ± 15.8 | 118.8 ± 14.9 |
| | End | 129.4 ± 11.5 | 126.9 ± 16.0 | 122.6 ± 12.6 |
| RQ, % | Start | 3.63 ± 0.28 | 3.86 ± 0.40 | 3.75 ± 0.30 |
| | End | 3.72 ± 0.26 | 3.78 ± 0.36 | 3.96 ± 0.38 |
| Heart Rate max, bpm | Start | 193.8 ± 6.9 | 188.8 ± 7.0 | 191.4 ± 3.6 |
| | End | 193.1 ± 6.4 | 195.3 ± 5.6 | 193.4 ± 6.5 |
| Oxygen pulse, ml/bpm | Start | 17.96 ± 1.08 | 19.01 ± 1.37 | 18.58 ± 2.02 |
| | End | 18.73 ± 0.99 | 18.99 ± 1.37 | 19.43 ± 0.98 |
| Lactate at the finish in test 1, mmol/l | Start | 10.3 ± 1.2 | 8.1 ± 1.5 | 8.8 ± 2.4 |
| | End | 10.4 ± 1.2 | 10.2 ± 1.3 | 10.2 ± 2.5 |
| Speed at the AT level, m/s | Start | 3.95 ± 0.20 | 3.82 ± 0.13 | 3.72 ± 0.12 |
| | End | 4.15 ± 0.16 | 4.05 ± 0.23 | 4.00 ± 0.16 |
| Oxygen consumption at AT, ml/min/kg | Start | 51.6 ± 2.7 | 51.2 ± 3.2 | 49.2 ± 3.4 |
| | End | 55.1 ± 3.5 | 54.5 ± 3.4 | 52.8 ± 2.6 |
| Heart rate at the AT level, bpm | Start | 168.1 ± 7.5 | 169.3 ± 3.8 | 171.6 ± 4.8 |
| | End | 169.3±5.1 | 171.3 ± 2.8 | 170.8 ± 4.3 |
| Power in test 2 (MAP-60), kgf-m/min | Start | 1931.5 ± 162.7 | 1989.1 ± 96.6 | 2134.8 ± 177.2 |
| | End | 1982.3 ± 156.7 | 2050.1 ± 114.6 | 2203.9 ± 117.3 |
| Power in test 2 (MAP-60), kgf-m/min/kg | Start | 33.77 ± 1.32 | 32.37 ± 2.27 | 33.71 ± 2.89 |
| | End | 34.36 ± 1.56 | 34.39 ± 1.74 | 34.87 ± 2.47 |
| Load in test 2 (MAP-60), kps | Start | 3.50 | 3.50 | 3.50 |
| | End | 3.50 | 3.50 | 3.50 |
| Cadence in test 2 (MAP-60), 1/min | Start | 95.0 ± 8.0 | 97.8 ± 4.8 | 105.0 ± 8.7 |
| | End | 97.5 ± 7.7 | 100.8 ± 5.6 | 108.4 ± 5.8 |
| Lactate in test 2 (MAP-60), mmol/l | Start | 13.6 ± 2.0 | 11.6 ± 0.9 | 12.7 ± 1.6 |
| | End | 13.3 ± 1.4 | 13.8 ± 1.8 | 13.9 ± 1.9 |
| Heart rate in test 2 (MAP-60), bpm | Start | 180.8 ± 10.4 | 180.3 ± 7.0 | 182.4 ± 3.8 |
| | End | 181.3 ± 7.5 | 182.3 ± 5.5 | 183.6 ± 5.0 |

Within the framework of studies, it was found that the Distance group have a higher level of physical performance at the beginning of the preparatory period (Fig. 1), coupled with a longer time in test 1 (in a stepwise increasing load to muscular failure) - 16.14 ± 1, 19 min and, as a result, higher running speed at muscle failure - 4.71 ± 0.22 m/s in relation to the Universal and Sprint groups (4.35 ± 0.31 m/s, 9.0% and 4.29 ± 0.26 m/s 9.8%). This difference was due to:

- different power capabilities state of energy supply systems appeared in a higher activity of the functioning oxidative and lactic acid energy systems with an inhomogeneous degree of statistic differences when comparing the Distance and Sprint groups according to the VO2rel indicator - 60.95 ± 2.95 and 56.03 ± 4.50 ml/min/kg, respectively (differences 8.8% at the level of $p < 0.1$), for the groups Distance and Universal - 60.95 ± 2.95 and 58.30 ± 3.94 ml/min/kg, respectively (differences 4.5%) and more marked in the functioning of the lactic acid energy system - intergroup differences are statistically significant when comparing the Distance and Universal groups in terms of the maximum lactate concentration - 10.3 ± 1.2 and 8.1 ± 1.5 mmol/l , respectively (differences 27.0% with significance level $p < 0.05$), for the Distance and Sprint groups - 10.3 ± 1.2 and 8.8 ± 2.4 mmol/l, respectively (differences 16.4%).

A higher power of the oxidizing system's functioning in Distance group is formed on the background of the external respiration processes primary dominance - the prevalence of external respiration power indices (MBC -122.8 ± 10.8 l/min, circulation of a greater inspiratory volume through the lungs) over oxygen consumption (the lowest value RQ - 3.63 ± 0.28%) in the process involved organs and muscles; with a similar trend for the Universal and Sprint groups;

- saving capabilities of energy supply systems which is more marked in the Distance group in comparison with other groups: a difference in the indices of the anaerobic threshold (sprint speed and oxygen consumption at the level of the anaerobic threshold) with varying degrees of statistically significant values when comparing the Distance and Universal groups (by running speeds at the level of the anaerobic threshold (VAT) - 3.95 ± 0.20 and 3.82 ± 0.13 m/s, respectively, differences 3.5% at the level of $p < 0.2$, reflects a differences trend), for the Distance and Sprint groups (3.95 ± 0.20 and 3.72 ± 0.12 m/s, s respectively, differences 6.1% at the level of $p < 0.05$) the type of differences in oxygen consumption at the level of the anaerobic threshold indicates a tendency for a greater volume of excessive inactive body mass in the Universal and Sprint groups (comparing to the Distance group) reducing the effective muscle activity.

A specific characteristic of the functional state formation at the beginning of the preparatory period in all groups (Distance, Universal, Sprint) is a low implementation readiness which can be seen in the results of test 2 (MAP-60, aptitude for work of glycolytic power), which turned out to be the highest in the distance training group (Nmax/kg - 33.77 ± 1.32 kgf-m/min/kg). Moreover, the higher relative power index in this test was also based on the higher ability of the lactic acid energy system to produce lactate. It reflects the degree of the functional system formation. At this stage of training the highest activity of the lactic acid system was seen in the distance training group (lactate concentration was 13.6 ± 2.0 mmol/l), then sprinting (12.7 ± 1.6 mmol/l) and the least (ready for implementation activity) was in the group of universal orientation (11.6 ± 0.9 mmol/l) where the maximum concentration of lactate significantly differentiated by 16.8%

at the level of p <0.05 in comparison with the distance training group.

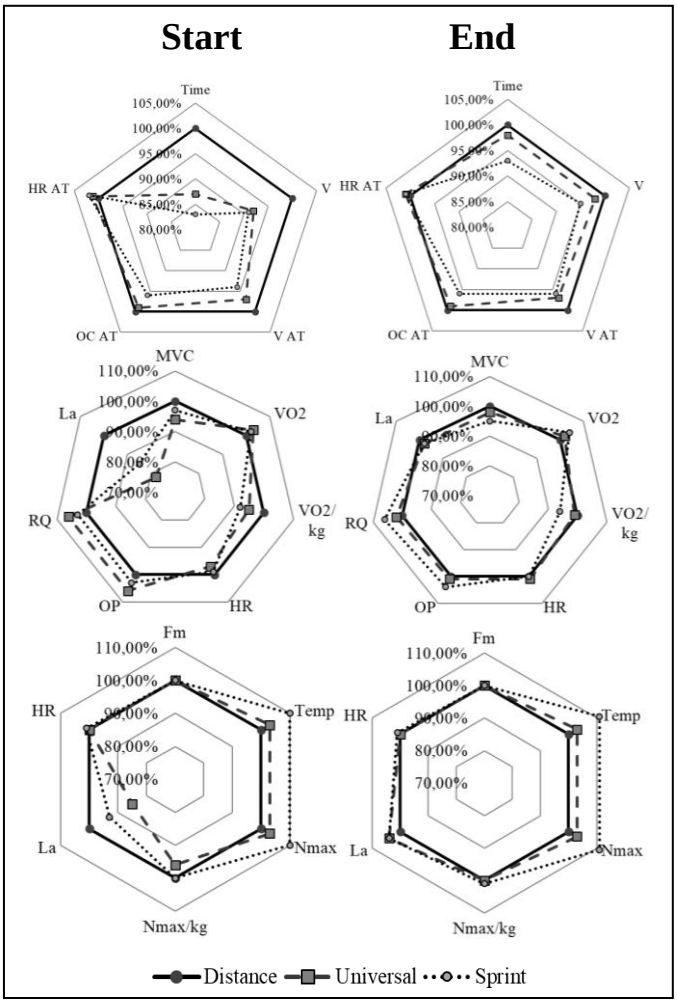


Fig. 1. Dynamics of the energy supply systems' functionality possibilities for female skiers-racers of various groups at the beginning and the end of the preparatory period (according to the results of tests 1, 2, differences are expressed in % in relation to the Distance group)

The results of the study conducted at the end of the preparatory period allowed to establish that under the influence of the proposed construction of the training process (increase total volume of the cyclic load) the level of physical performance and functional state (assessed in test 1) are equalized in the Distance and Universal groups (Table II, Figure 1) while retaining significant differences in comparison with the Sprint group. The dominance of the Sprint group can be seen in implementation readiness conjugated with the performance in test 2 (MAP-60, glycolytic capacity).

- differences in the power level of the oxidizing system are less marked: in absolute indicator (VO2abs) with the domination of development in the Universal and Sprint groups (3.708 ± 0.260 and 3.760 ± 0.273 l/min, respectively) comparing to the Distance group (3.614 ± 0.169 l/min, differences -2.5% and -3.9%, respectively) and in relative indicator (VO2rel), while the domination of the Distance and Universal groups (62.78 ± 3.13 and 62.15 ± 3,11 ml/min/kg, respectively, differences +1.0 and + 5.8% at the level of p <0.05) in comparison with the Sprint group (59.33 ± 1.93 ml/min/kg);

- the peculiarity of VO2 level formation in the Distance and Universal groups was a balanced ratio between the processes of air circulation in the lungs MBC - 129.4 ± 11.5 and 126.9 ± 16.0 l/min, respectively (MBC differences + 1.9%) and oxygen utilization in muscles RQ - 3.72 ± 0.26 and 3.78 ± 0.36%, respectively (differences - 1.5%), the dominance of oxygen assimilation in the Sprint group (122.6 ± 12.6 l/min, 3.96 ± 0.38) in relation to the Distance group (MBC - 5.5%; RQ of -6.1%);

- balancing out the differences between the groups (Distance in relation to the Universal and Sprint groups) in the activity of the lactic acid energy system in tests 1 and 2 when assessing aerobic performance (lactate concentration of 10.2-10.4 mmol/l). Universal and Sprint groups slightly exceeded in anaerobic performance indices (13.3-13.9 mmol/l);

- balancing out the differences between the Distance and Universal groups in the demonstration of the energy supply systems capabilities saving, which can be seen in the magnitude of the differences in the indices of the anaerobic threshold: running speed - 4.15 ± 0.16 and 4.05 ± 0.23 m/s (differences +2,6%) and oxygen consumption at AT - 55.1 ± 3.5 and 54.5 ± 3.4 ml/min/kg, respectively (differences + 1.1%), and a high level of running speed differences between the Distance and Sprint groups - 4.15 ± 0.16 and 4.00 ± 0.16 m/s (differences + 3.8% at p <0.2) and oxygen consumption at AT - 55.1 ± 3.5 and 52.8 ± 2.6 ml/min/kg, respectively (differences 4.4%);

- appearance of increasing differences clear trend in the level of implementation readiness in absolute power indicators in test 2 (MAP-60, aptitude for work of glycolytic power) between the Distance group in comparison with the Universal Nmax - 1982.3 ± 156.7 and 2050.1 ± 114.6 kgf-m/min respectively (differences -3.3%) and Sprint groups Nmax - 1982.3 ± 156.7 and 2203.9 ± 117.3 kgf-m/min, respectively (differences -10.1% at p <0.05) and balancing out the differences in relative power indicators between the group Distance Nmax/kg - 34.36 ± 1.56 kgf-m/min/ kg in relation to the Universal and Sprint Nmax groups/kg - 34.39 ± 1.74 and 34.87 ± 2.47 kgf-m/min/kg, respectively (differences -0.1% and -1.4%), indicating the beginning of the dominance in the development of female skiers' functional systems in the types of competitive activities with high demands on the development of the lactic acid energy system which affects the formation of power capabilities including the oxidative energy system.

It should be noted that the significantly reduced (comparing to the beginning of the preparatory period) level of differences in performance time and running speed in test 1 (assessing physical performance) between the Distance group and Universal and Sprint groups at the end of the preparatory period is determined not only by the increase in power and saving capabilities of the oxidative energy system (VO2max, OC at AT) but also by balancing out the activity of the lactic

acid system functioning which dominates precisely in the Universal and Sprint groups.

## IV. CONCLUSION

The athletes' results at the main international competitions of the World Cup, World Championships and Olympic Games in 2017-2019 seasons indicate the dominance of skiers-racers of the Universal group over athletes of the Distance and Sprint groups who also successfully perform at different distances. At the same time, the revealed intergroup differences which can primarily be seen in the state of the main energy supply systems functional capabilities should be taken into account to choose a methodological focus of the training process construction in order to optimize it and achieve the highest results during the main starts.

The presented results of intergroup differences in the functionality formation of the highly qualified female skiers-racers energy supply systems not only allow us to establish the dynamic features of the physical condition components formation but also give an idea of the ways how training process can be organized to the full, selectively aimed at eliminating the limiting factors established at the beginning of the preparatory period.

The results of intergroup differences study in the energy supply systems functional capabilities of different groups female skiers-racers made it possible to establish that at the beginning of the preparatory period the representatives of the Distance group were characterized by a higher level of both aerobic performance development in terms of power and saving the oxidative energy supply system's capabilities relative to the Universal and Sprint groups and the anaerobic performance on the general background of low implementation aptitude for work of glycolytic power, which generally indicates a more cohesive formation of the Distance group functional systems. The obtained data provided the basis for the significance rethinking of the lactic acid energy system development as a system that stimulates the formation of the oxidizing system power capabilities and intersystem interactions between oxidative and lactic acid energy systems.

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