
# *TARGET COMPLEX PROGRAMME FOR RESEARCH OF NATIONAL ACADEMY OF SCIENCES OF UKRAINE*

## *Development of scientific bases for hydrogen production, storage and use in autonomous energy supply systems*

## **Development of autonomous cogeneration hydrogen power plants with solid organic waste conversion**

**Project #3**

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**Thermal Energy Technology Institute of NAS of Ukraine**

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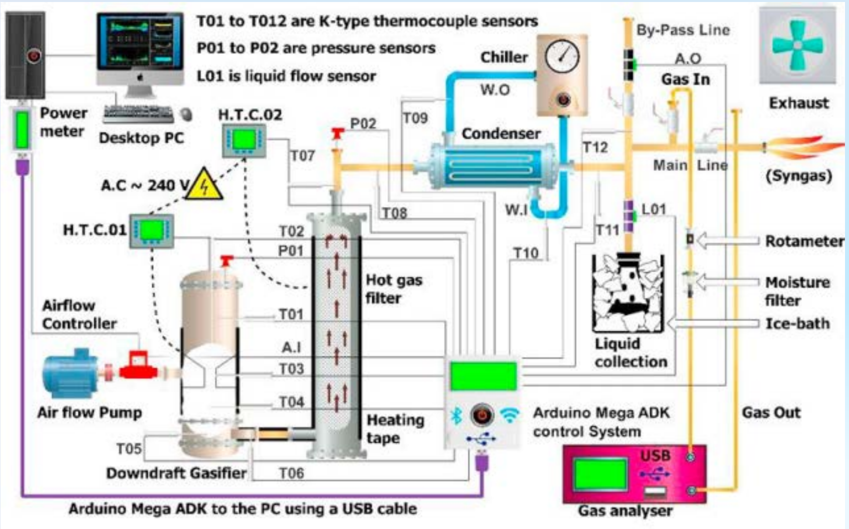
**The purpose of the work :**

- Development of ecologically friendly and scientifically substantiated methods of thermochemical processing of solid organic waste for renewable hydrogen energy and creation of new circuits of autonomous cogeneration hydrogen power plants on solid organic waste;
- Experimental determination of solid organic waste conversion characteristics with conversion of macromolecular compounds in gasifier zones: pyrolysis (without use and using plasma torches), partial oxidation (in a modified conversion chamber), reduction (with and without catalysts) and in a catalytic reactor;
- Development of new technologies for autonomous cogeneration hydrogen power plants using a gasifier-transformer, an electric generator with an internal combustion engine, an electrochemical generator with solid oxide and polymer (with proton exchange membrane) fuel cells.

**Tasks of the work**:

1. Analysis of experimental data obtained in the Thermal Energy Technology Institute of NASU at experimental installations of carbonization and gasification of solid biological, industrial and household waste Analysis of foreign latest solutions for the conversion of solid organic waste.
2. Determination of equipment's performance operating on hydrogen-enriched synthesis gas and hydrogen for heating and hot water supply.
3. Creation of parts of the cogeneration hydrogen power plant with a gasifier-transformer, an electric generator with an internal combustion engine and a recovery boiler (with gas coolers after the gasifier and combustion products) .
4. Based on the designs of a gasifier-transformer for gasification of solid organic waste and a high-temperature catalytic reactor for the conversion of macromolecular compounds, the development of a new installation for the operation of an SOFC electrochemical generator.
5. Creation of a plant parts for producing combustible gas without carbon with the use of a gasifier-transformer, a catalytic reactor for CO conversion and a carbon dioxide absorption reactor for the operation of PEM fuel cell electrochemical generator.

# ANALYTICAL REVIEW OF EXPERIMENTAL RESULTS



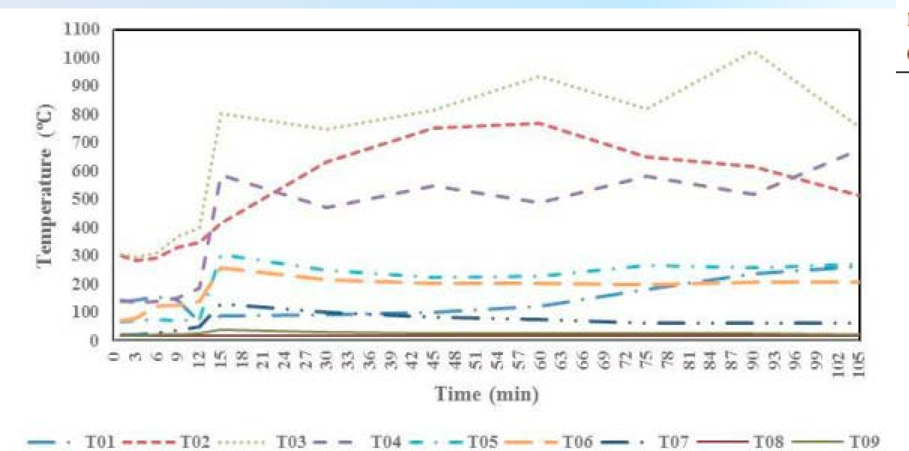

**Plant of University of Glasgow (UK): internal diameter of installation - 70 mm; height - 720 mm, the diameter of the oxidation chamber is 31 mm. Thermal power - 3.4 kW. During ignition, the gasifier is heated by electric heaters up to 350 ºC. Fuel - Miscanthus. ER = 0.3. Installations are installed in the UK, China, Pakistan and Colombia.**

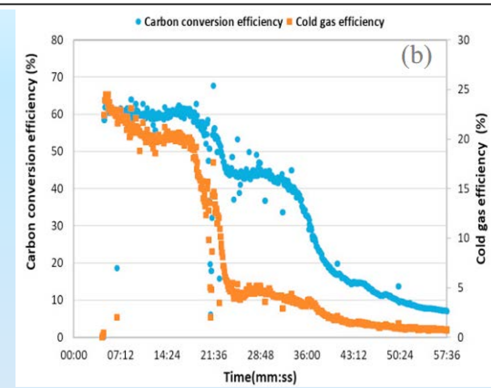
Elemental compositions of different genotypes of *Miscanthus*

| *Miscanthus* | Ultimate analysis wt. (%) | | | | Proximate analysis wt. (%) | | | | | LHV (MJ/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Moisture | Volatile | Fixed C | Ash | C | H | N | S | O[a] | |
| OPM12 | 9.1 | 73.9 | 14.6 | 2.4 | 44.6 | 5.6 | 0.5 | 0.1 | 49.2 | 17.44 |
| MxG | 3.7 | 78.4 | 15.9 | 2.0 | 46.0 | 5.6 | 0.2 | 0.0 | 48.2 | 18.65 |
| OPM53 | 6.2 | 76.3 | 15.0 | 2.6 | 45.0 | 5.7 | 0.6 | 0.1 | 48.7 | 18.03 |

Table 3. Producer gas composition profiles

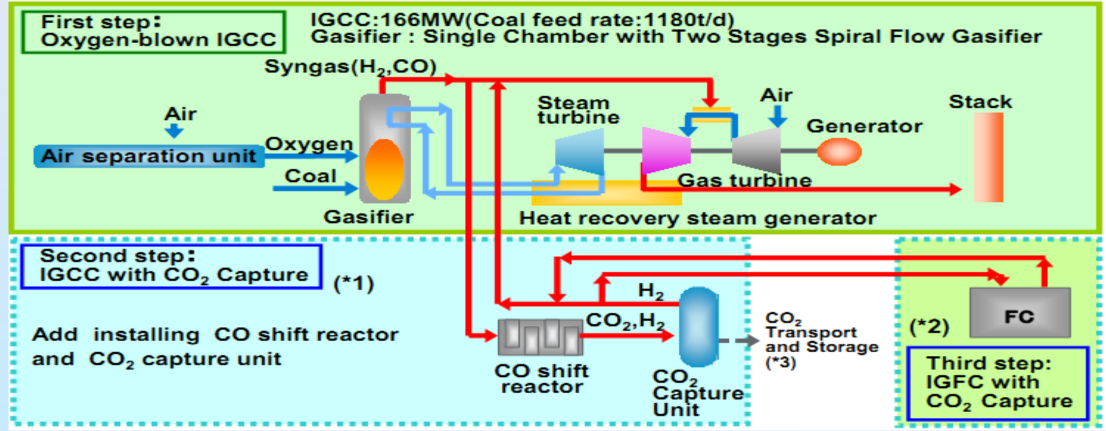
| *Miscanthus* | $CH_4$ Vol (%) | CO Vol (%) | $CO_2$ Vol (%) | $O_2$ Vol (%) | $H_2$ Vol (%) | $N_2$ Vol (%) |
|---|---|---|---|---|---|---|
| OPM12 | 0.22 | 19.30 | 8.66 | 1.07 | 3.25 | 67.50 |
| MxG | 21.70 | 13.40 | 17.97 | 0.27 | 3.14 | 43.52 |
| OPM53 | 16.58 | 15.36 | 16.65 | 0.74 | 6.50 | 44.17 |



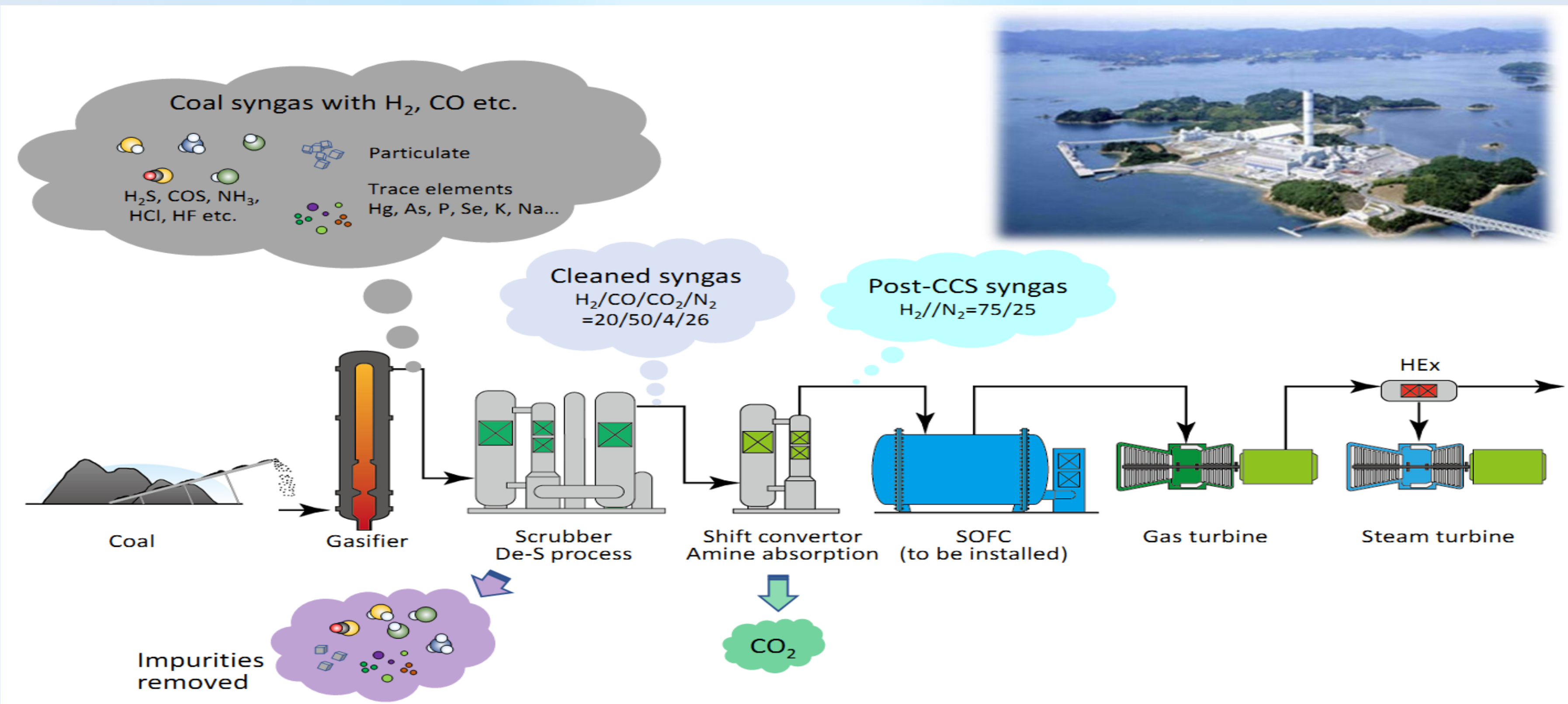




# Osaki Cool Gen Project

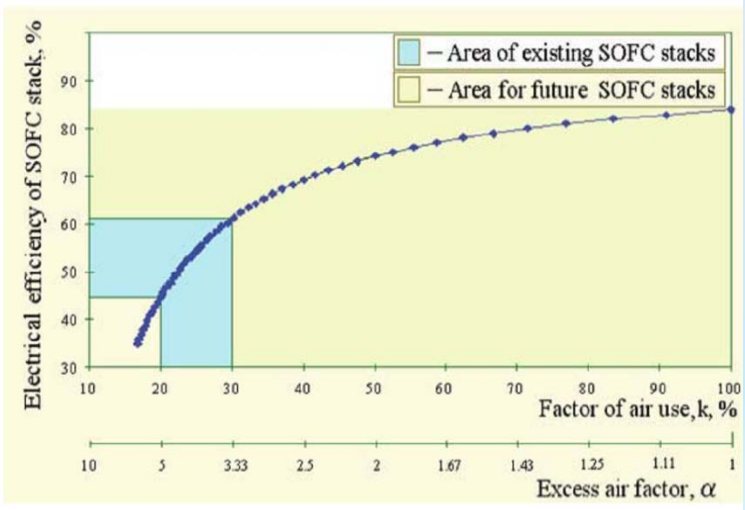
| Major Specification | |
|---|---|
| Output | 166 MW (gross) |
| Gasifier | Oxygen-blown Single-chamber Two-stage Entrained-flow |
| Gas Clean-Up | MDEA (Methyldiethanol Amine) |
| Gas Turbine | H-100 GT (1 on 1) |
| Plant Efficiency | 40.5% (HHV, net) (42.7%(LHV, net)) |
| **Project Schedule** | |
| Construction Started | March 2013 |
| Demo. Operation Started | March 2017 (First step) |



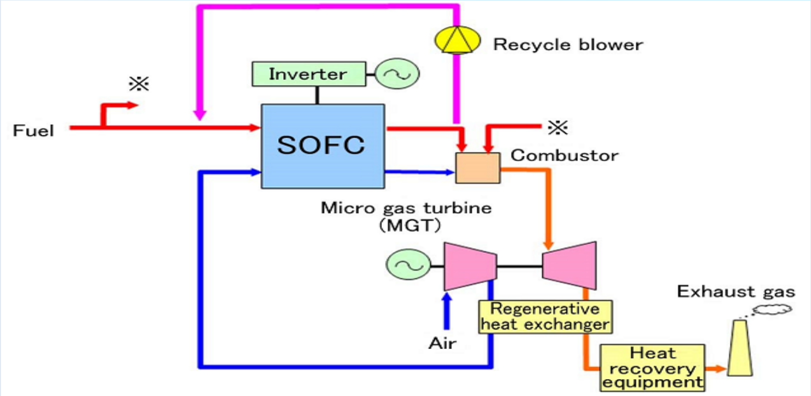

It is planned to show the possibility of achieving electric efficiency at the level of 47.0% with 90% capture of carbon dioxide for power units with an electric capacity of 500 MW



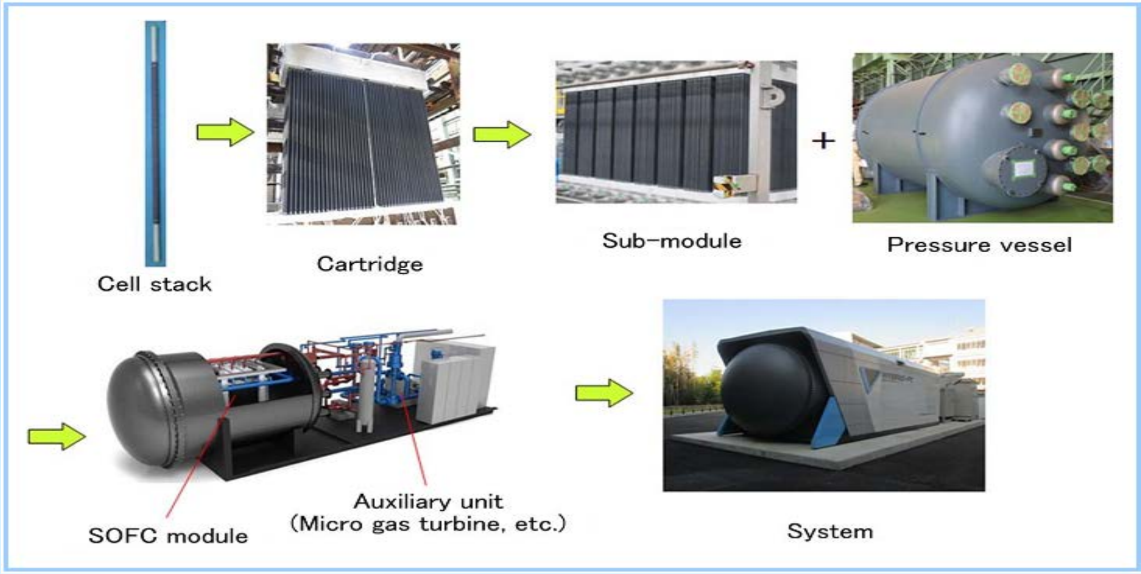
# Electric efficiency of SOFC plants




| Type | HYBRID-FC power generation system |
|---|---|
| Rated output (kW) | 250 |
| Net efficiency (%-LHV) | 55 |
| Dimension of the unit (m) | 3.4 (W) × 11.5 (L) × 3.5 (H) |
| Fuel | City gas: 13A |

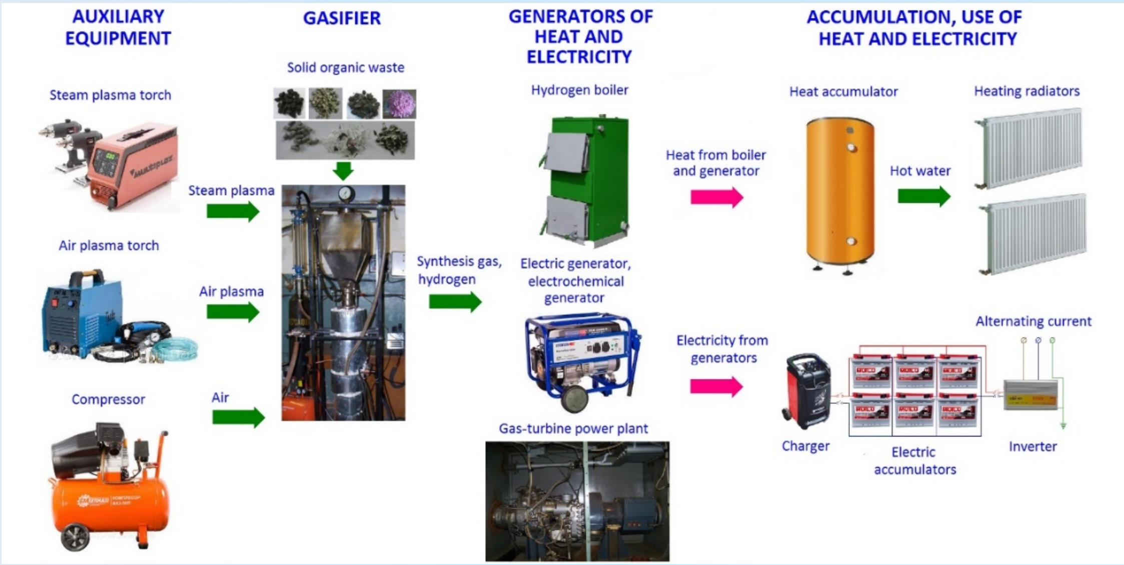



# New hybrid power plants on solid oxide fuel cells (SOFC) in Japan




# The principle of autonomous operation of cogeneration plants with solid organic waste conversion using equipment of Thermal Energy Technology Institute of the National Academy of Sciences of Ukraine

Hydrogen-rich synthesis gas and, if it is necessary, pure hydrogen are produced in the TETI gasifier, which can be transformed for the various solid organic waste conversion in the **different modifications of moving and fluidized beds**. The gasifier start is carried out using **plasma** torches (steam or air). The gasifier can operate both with and without plasma torches depending on the solid organic waste properties.




**A parallel-series circuit of heat and electricity generation units** was used for the construction of cogeneration power plants. Depending on the needs in the cold season, only heat can be produced in the boiler using hydrogen-rich synthesis gas or pure hydrogen. In order to achieve autonomy, energy efficiency improvement, and the plant operation in the mode of **heat load change**, the hot water obtained in the boiler is fed into the heat accumulator that provides the possibility of boiler periodic operation with continuous independent heat supply from heat accumulator for heating. In the case of heat and electricity generation, the heat from an electric generator with an Internal Combustion Engine (ICE), Fuel Cell Electrochemical Generator (FC ECG) or a Gas Turbine Unit (GTU) is fed into the heat recovery unit. In the cogeneration power plant circuits, FC ECG can be involved, for example, with Bloom Energy or Rolls Royce planar solid oxide fuel cells; Mitsubishi Hitachi Heavy Industries, Bosch Thermotechnology/Aisin Seiki tubular solid oxide fuel cells or others

In order to **achieve autonomy, energy efficiency** improvement, and the plant operation in the mode of electrical load change, electricity generated by power generators is fed through the charger to **the electric accumulators**, from which electricity is fed through the inverter to the consumer. Thus, cogeneration plants are hybrids for generating both electricity and heat using accumulators. In these plants, both periodically operating power units and batteries are used to achieve autonomy. This is done to reduce the load on the main equipment (gasifier, plasma torches, boiler, electric generators, and fuel cells) and to increase the life time of power plants, which operate intermittently with continuous supply of electricity and heat from batteries to the consumer.

For further energy efficiency improvement, cogeneration plants may contain metal hydride hydrogen accumulators (to store hydrogen in the warm season and to use it in the cold season in a hydrogen boiler), solar cell panels without the use of electrolyzers and with the use of electric accumulators for power supply and for the operation of electric heaters built into the heat accumulator, and with electrolyzers (with the production of hydrogen for the FC ECG operation and oxygen for the gasifier operation), as well as heat pumps. **Solar and wind power plants with reversible electrolyzers can be added to the existing hydrogen utilization circuit** for increasing efficiency of plants in reverse mode using cogeneration, trigeneration, and polygeneration units.

# Optimization of gasifier-transformer. Researches under maximal loading and design change

The gasifier was tested on different types of Solid Organic Waste (SOW) under maximal loading.

**Results of approximate analysis of SOW**

| Solid Organic Waste | Moisture ($W^a$) | Volatile matter ($V^a$) | Ash ($A^a$) | Fixed carbon ($C_{fix}^a$) |
|---|---|---|---|---|
| | wt. % | | | |
| Paper waste | 3.82 | 67.44 | 24.31 | 4.43 |
| Sunflower husk | 12.10 | 81.01 | 1.67 | 5.22 |
| Wood waste pellets | 9.21 | 85.23 | 0.32 | 5.25 |
| Plastic (PET) | 0.70 | 92.90 | 0.08 | 6.32 |
| Wood waste | 9.79 | 73.31 | 0.65 | 16.25 |

**Research results**

| Solid Organic Waste | SOW feed rate, kg/h | Dry gas output, $nm^3/h$ | Plant thermal capacity, kW | Cold gas efficiency, % |
|---|---|---|---|---|
| Paper waste | 2.8 | 4.6 | 9.0 | 74.8 |
| Sunflower husk | 3.7 | 7.4 | 14.5 | 66.9 |
| Mixture of wood waste and PET (26/74 wt. %/wt. %) | 2.7 | 6.3 | 8.2 | 74.6 |
| Wood waste pellets | 2.6 | 8.2 | 14.1 | 65.9 |

The optimal choice of the design of the partial oxidation zone and two stage conversion allowed to achieve increased cold gas efficiency.

The temperature of the gases at the outlet of the carbonization zone of the gasifier should be 300 to 500º C, at the outlet of the gasifier - above 600 ºC.

**Results of approximate analysis of feed stock**

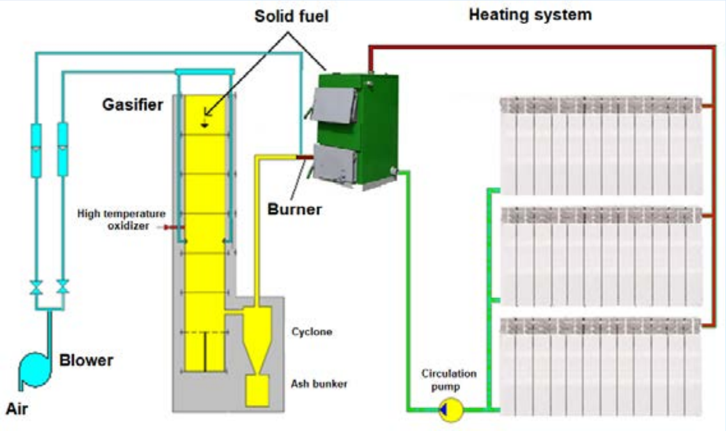
| Feed stock | Moisture ($W^a$) | Volatile matter ($V^a$) | Ash ($A^a$) | Fixed carbon ($C_{fix}^a$) |
|---|---|---|---|---|
| | wt. % | | | |
| Wood char coal | 8.2 | 16.0 | 1.1 | 74.7 |
| Savage sludge | 42.3 | 24.2 | 27.9 | 5.6 |

**Influence of steam adding on hydrogen yield**

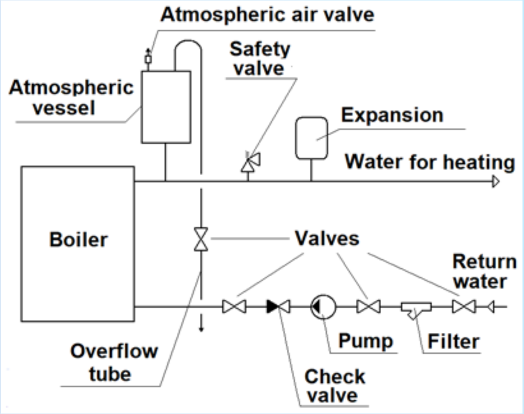
| Feed stock | Wood char coal | | Wood waste | | Savage sludge | |
|---|---|---|---|---|---|---|
| Steam/oxygen in blasting, mol/mol | - | 1.08 | - | 1.24 | - | 1.01 |
| $H_2/CO$ in obtained gas, mol/mol | 0.26 | 0.85 | 0.51 | 0.84 | 0.85 | 2.17 |
| Hydrogen yield, nm3/kg of dry ash free (DAF) feed stock | 0.24 | 0.74 | 0.24 | 0.45 | 0.48 | 0.76 |

The use of a steam plasma torch increased the hydrogen yield by 1.5-3.0 times.

# Gasifier-boiler system




## Circuit of boiler connection with heating system



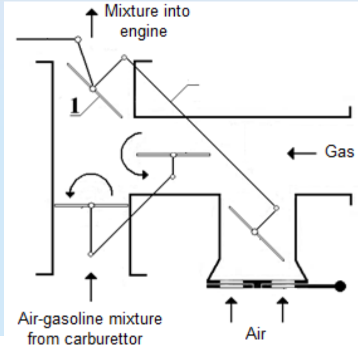

## Performance of the system

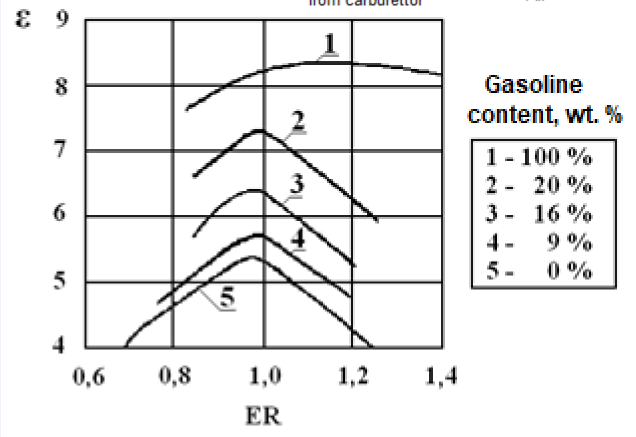
| Fuel | | Anthracite | Bituminous coal | Wood | Hydrogen | Carbon | Synthesis gas |
|---|---|---|---|---|---|---|---|
| Parameter | Dimension | Value | | | | | |
| Fuel feed rate | kg/hr | 2.7 | 3.7 | 5.9 | 0.6 | 2.0 | 17.7 |
| Fuel thermal capacity | kW | 21.0 | 21.5 | 22.4 | 19.1 | 19.2 | 19.7 |
| Heating system thermal capacity | kW | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 |
| Water pressure in boiler | MPa | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| Water feed rate through boiler (80/60 ºC) | kg/s | 0.215 | 0.215 | 0.215 | 0.215 | 0.215 | 0.215 |
| Boiler efficiency | % | 85.6 | 83.7 | 80.3 | 94.0 | 93.7 | 91.3 |
| Excess air ratio | - | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2/1.13* |
| Oxygen feed rate | nm³/hr | 5.0 | 5.2 | 5.3 | 3.8 | 4.6 | 3.6 |
| Air feed rate | nm³/hr | 24.0 | 24.5 | 25.4 | 18.2 | 21.8 | 17.2 |
| Flue gas composition | | | | | | | |
| $CO_2$ | vol. % | 16.1 | 14.1 | 14.1 | 0.0 | 17.5 | 14.9 |
| $H_2O$ | | 3.0 | 7.4 | 16.0 | 29.8 | 0.0 | 16.9 |
| $SO_2$ | | 0.2 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| $N_2$ | | 77.3 | 74.9 | 67.0 | 67.2 | 79.0 | 66.3 |
| $O_2$ | | 3.4 | 3.3 | 3.0 | 3.0 | 3.5 | 1.9 |
| Total | | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Yield of flue gas | nm³/hr | 24.6 | 25.9 | 30.0 | 21.4 | 21.8 | 31.0 |
| Temperature of flue gas | ºC | 140 | 140 | 140 | 140 | 140 | 140 |
| Heat loses with exhaust gases | % | 6.3 | 6.5 | 7.3 | 6.0 | 6.1 | 8.6 |
| Yield of water under condensation | кг/год | 0.7 | 2.3 | 3.9 | 5.1 | 0.0 | 4.2 |
| Flue gas composition (140 ºC) | м/с | 1.62 | 1.71 | 1.98 | 1.41 | 1.44 | 2.05 |

The main equipment for the operation of the cogeneration plant, a boiler and electric generators, was identified, selected, and purchased. The boiler is Kolvi Euroterm KTK standard solid fuel-fired boiler with thermal capacity up to 18 kW with anthracite, coal, briquettes, and wood combustion for autonomous heating of rooms up to 200 m$^2$.

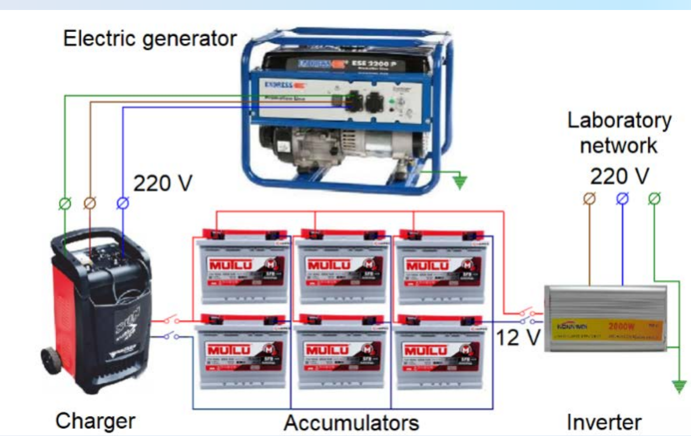
**The boiler was transformed for combustion of synthesis gas and hydrogen obtained in the gasifier (the way from carbonization to decarbonization).**

# Gasifier-electric generator system



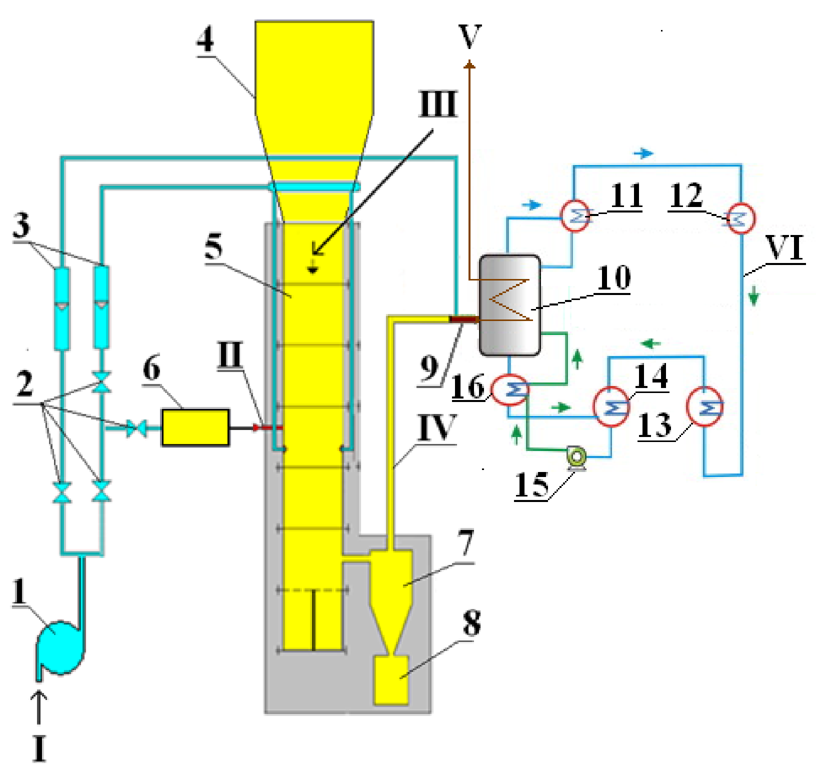

| Fuel | Gasoline | Synthesis gas |
|---|---|---|
| Composition, wt. % | | |
| C | 84,21 | 14,01 |
| H | 15,79 | 2,64 |
| N | 0,00 | 49,19 |
| O | 0,00 | 34,17 |
| Heat value, MJ/kg | 44,82 | 4,01 |
| Composition of combustion products | | |
| $CO_2$ | 12,5 | 16,45 |
| $H_2O$ | 14,1 | 18,58 |
| $N_2$ | 73,4 | 64,97 |
| Fuel feed rate, kg/h | 1,14 | 12,14 |
| Air feed rate, nm3/h | 13,29 | 9,83 |
| Thermal capacity, kW | 14,14 | 13,51 |
| Electric capacity, kW | 2,5 | 1,72 |
| Electric capacity, % | 17,68 | 12,73 |




The electric generator with ICE Endress ESE 3200P with nominal electric power of 2.35 kW, which was modified to operate on hydrogen-rich synthesis gas, was used in the power supply circuit. The electric generator with different carburetors can also operate autonomously on gasoline, propane-butane, and natural gas.

**Hybrid electricity obtaining for energy saving of fuel in maneuvering mode operation**

# Trigeneration. Principal circuit of cold production using solid organic waste

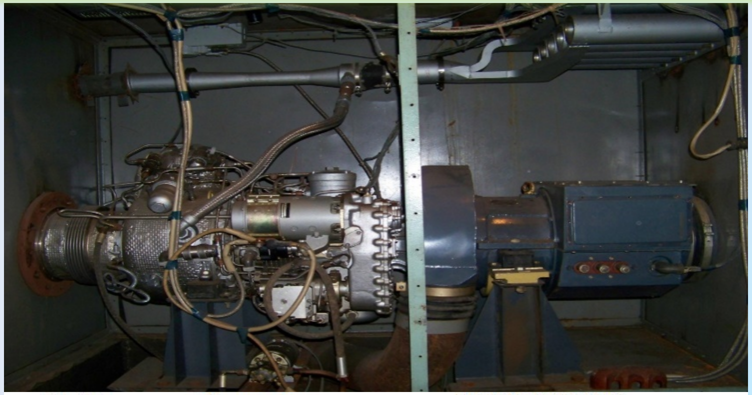


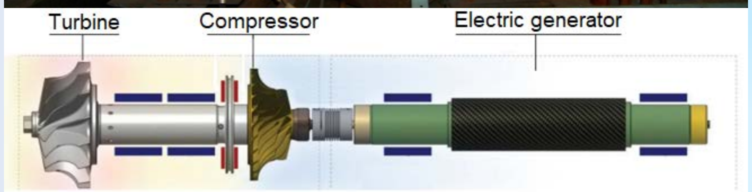

I - air, II - air plasma, III - solid organic waste, IV - purified gas, V - chilled combustion products, VI - liquid ammonia; 1 - the compressor, 2 - gas valve, 3 - rotameter, 4 - bunker with organic waste, 5 - gasifier, 6 - air plasmatron, 7 - cyclone, 8 - the ash bunker, 9 - torch, 10 - generator-boiler, 11 - reflux condenser, 12 - condenser, 13 - evaporator, 14 - absorber, 15 - pump, 16 - heat exchanger

The heat capacity of the solid organic waste gasifier system - air conditioner for the room with an area of 40 $m^2$, height 4.1 m, volume 164 $m^3$, wall thickness 75 cm at an ambient temperature (outside) 35$^o$ C will be 4.4 kW. Residual heat is used for hot water supply using a heat accumulator.

It is determined that the use of autonomous trigeneration power plants for the production of electricity, heat, and cold is necessary for full autonomous climate control in rooms. In this case, the maximum energy efficiency of the SOW energy use is achieved when changing both the daily load and the load at different times of the year. The use of the trigeneration principle provides the highest fuel efficiency at different times of the year. The principle circuit of the installation for obtaining cold using of solid organic waste has been developed.

# The principle circuit of a hybrid power plant with gasifier and solid oxide fuel cell electrochemical generator (SOFC EG)



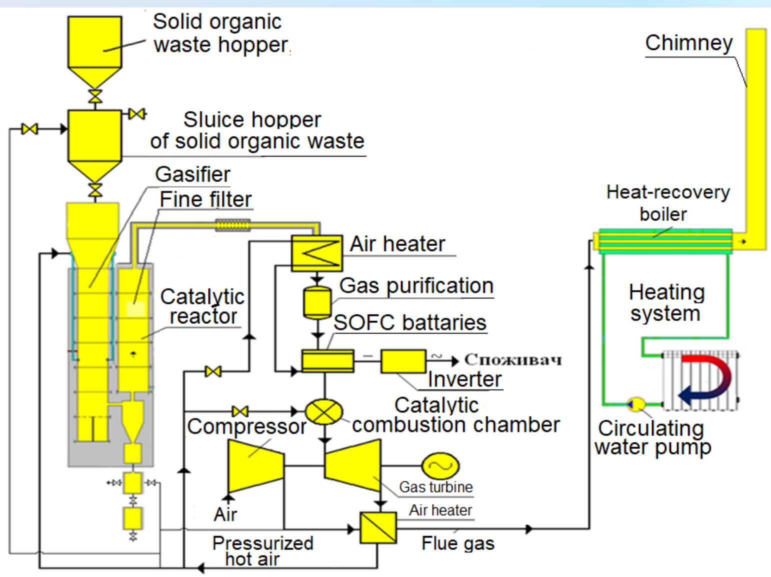



Gasifier-transformer under pressure and gas turbine unit (GTU) 9I120 is proposed to use as part of a hybrid power plant (HPP) with an electrochemical generator on solid oxide fuel cells (ECG on TOPE) operating enriched hydrogen synthesis gas.

GTU 9I120: Compressor - centrifugal, single-stage.Turbine - axial, single-stage. The speed of the gas turbine is 38,000 rpm. The speed of the generator (after the gearbox) - 8,000 rpm. Weight of GTU - 150 kg. Weight of the electric generator - 178 kg. Fuel gas pressure in front of the gas turbine 5.5 bar.
The temperature of the combustion products is 915 °C. Electric efficiency in the case of kerosene use -11%.

| | |
|---|---|
| Wood waste feed rate | 150 kg/h |
| Wood LHV | 13.9 MJ/kg |
| Thermal capacity on wood feed rate | 579 kW |
| Air feed rate in gasifier | 208 nm³/h |
| Gas pressure at the outlet of the gasifier | 5.6 bar |
| Fuel gas composition : | |
| $H_2$ | 16.5 vol. % |
| CO | 19.3 vol. % |
| $CO_2$ | 8.3 vol. % |
| $H_2O$ | 14.5 vol. % |
| $N_2$ | 41.4 vol. % |
| Fuel gas LHV | 4.2 MJ/nm³ |

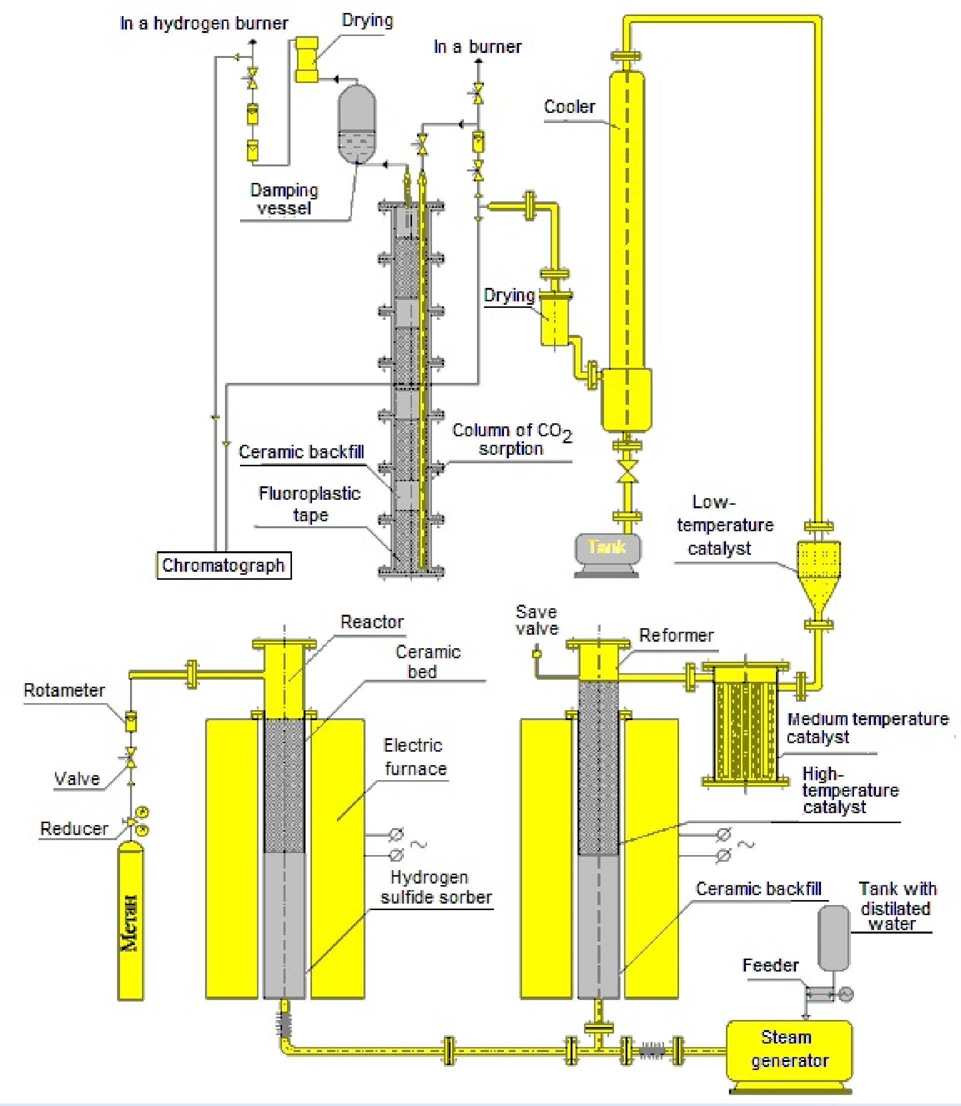
| | |
|---|---|
| Fuel gas productivity | 396 nm³/h |
| Thermal capacity on fuel gas | 462 kW |
| Cold gas efficiency | 79.8 % |
| Electric capacity of SOFC ECG | 210 kW |
| Electric capacity of GTU | 40 kW |
| Electric capacity of hybrid power plant | 250 kW |
| Electric efficiency of SOFC EG | 36.3 % |
| Electric efficiency of GTU | 6.9 % |
| Efficiency of hybrid power plant | 43.2 % |
| Overall thermal efficiency (with heat-recovery boiler) | 84.1 % |




The principle circuit of a hybrid power plant with an electric power of 250 kW with pressurized gasifier, 9I120 gas turbine unit, and electrochemical generator on solid oxide fuel cells has been developed.

# System for obtaining hydrogen from methane using reactors of desulphurization, high temperature catalytic steam reforming, mild temperature catalytic CO conversion and low temperature $CO_2$ sorption

| Parameter | Value | Dimension |
|---|---|---|
| Methane feed rate | 50.0 | L/hr |
| Pressure in reformer | 135 | кPa |
| Temperature of the steam-gas mixture in the reformer | 783 | °C |
| Steam feed rate | 0.73 | kg/hr |
| Steam temperature | 530 | °C |
| Temperature of low-temperature catalyst | 235 | °C |
| Yield of dry synthesis gas before $CO_2$ sorption | 240 | L/hr |
| Synthesis gas composition before $CO_2$ sorption: | | |
| $H_2$ | 79.19 | vol. % |
| $CO_2$ | 19.01 | |
| $CH_4$ | 0.75 | |
| CO | 1.05 | |
| Degree of methane conversion | 96.2 | % |
| LHV of dry synthesis before $CO_2$ sorption | 8.95 | $MJ/nm^3$ |
| The volume of a water solution of monoethanolamine in a $CO_2$ absorption reactor | 3.4 | L |
| Yield of dry synthesis gas after $CO_2$ sorption | 198 | L/hr |
| Synthesis gas composition after $CO_2$ sorption: | | |
| $H_2$ | 96.24 | vol. % |
| $CO_2$ | 1.57 | |
| $CH_4$ | 0.91 | |
| CO | 1.28 | |
| The degree of $CO_2$ sorption | 93.2 | % |
| LHV of dry synthesis after $CO_2$ sorption | 10.88 | $MJ/nm^3$ |
| Hydrogen output power | 598 | W |
| Electrical efficiency of polymeric fuel cell power unit | 33.4 | % |
| Electrical capacity of polymeric fuel cell power unit | 200 | W |



## The possibility of obtaining carbon-free gas from gas at the outlet of the gasifier-transformer using of a high-temperature reactor for conversion of macromolecular compounds, a water shift catalytic reactor, and a low-temperature carbon dioxide sorption reactor

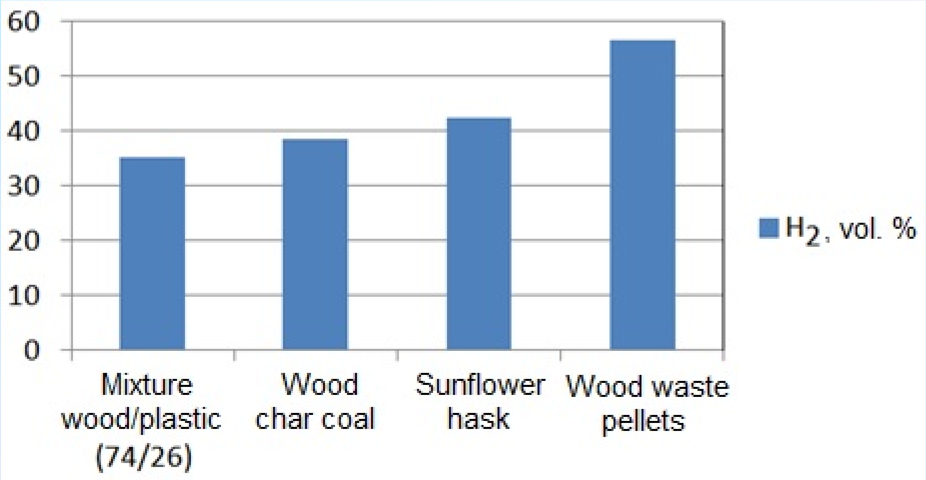
The maximal possible theoretical yield of hydrogen in the process of air steam gasification of dry biomass with the following catalytic conversion of CO by steam by the reaction of water shift ($CO + H_2O = CO_2 + H_2$) can be obtained by the overall reaction:

$$C_{1.0}H_{1.4}O_{0.6} + 0.2\ O_2 + 0.75\ N_2 + 1.0\ H_2O = 1.0\ CO_2 + 1.7\ H_2 + 0.75\ N_2$$

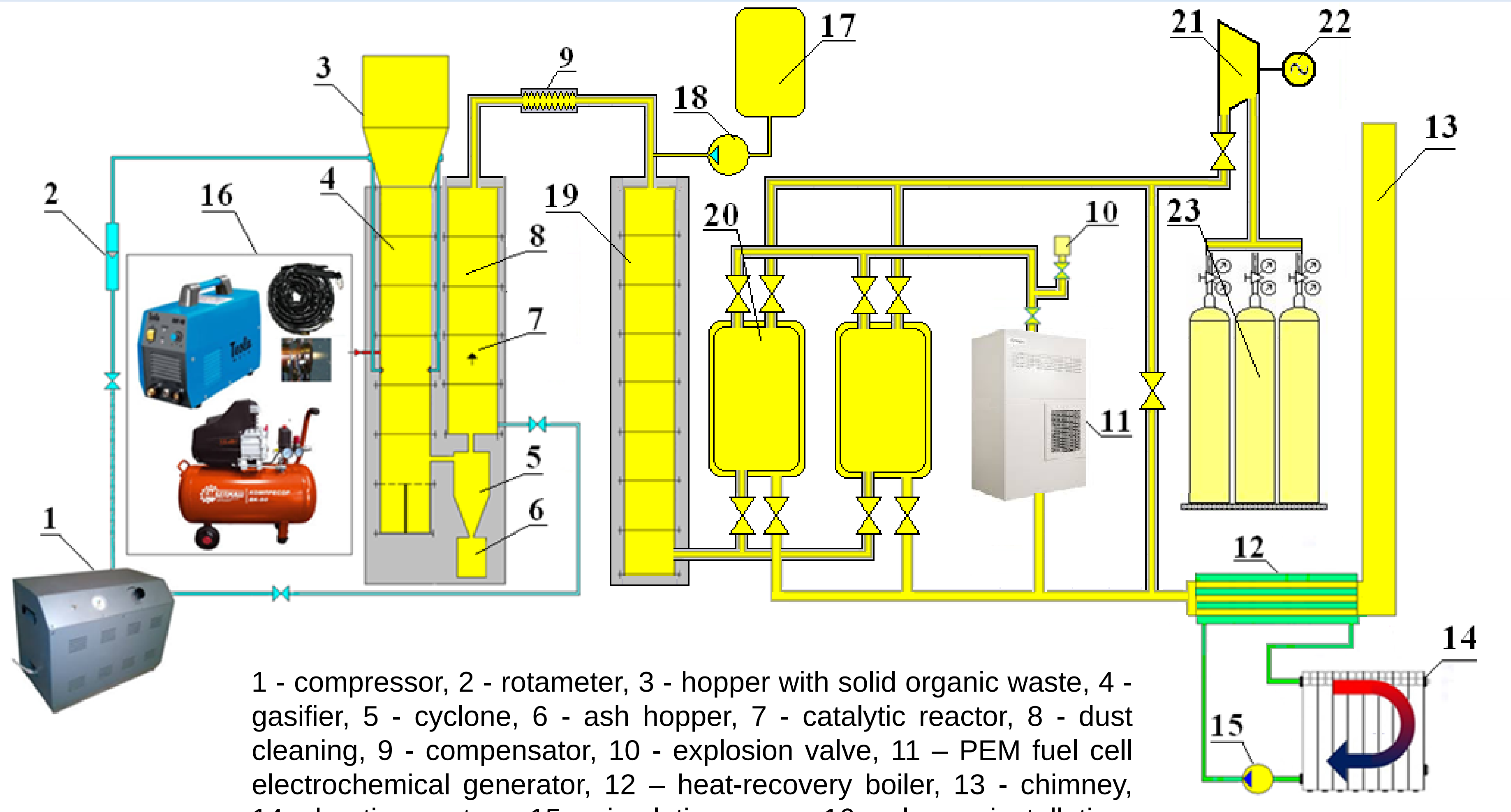
| Parameter | Value | Dimension |
|---|---|---|
| **Composition of dry ash free (DAF) biomass:** | | |
| **C** | 52.2 | wt. % |
| **H** | 6.1 | |
| **O** | 41.7 | |
| **Air feed rate in recalculation on DAF biomass feed rate** | 1.2 | kg/kg |
| **Steam feed rate in recalculation on DAF biomass feed rate** | 0.8 | kg/kg |
| **Composition of dry synthesis gas before sorption of $CO_2$ :** | | |
| **$H_2$** | 49.2 | vol. % |
| **$CO_2$** | 29.0 | |
| **$N_2$** | 21.8 | |
| **LHV of dry synthesis gas before $CO_2$ sorption** | 5.3 | $MJ/nm^3$ |
| **Composition of dry synthesis gas after $CO_2$ sorption:** | | |
| **$H_2$** | 69.3 | vol. % |
| **$N_2$** | 30.7 | |
| **LHV of dry synthesis gas after $CO_2$ sorption** | 7.5 | $MJ/nm^3$ |
| **Yield of hydrogen in recalculation on weight of DAF biomass** | 0.148 | kg/kg |

Estimation of volumetric hydrogen content taking into account experimental data obtained during gasification of a mixture of wood and plastic (74/26 wt.%), wood charcoal, sunflower husk and wood waste pellets.

The possibility of obtaining carbon-free gas from gas at the outlet of the gasifier-transformer using of a high-temperature reactor for conversion of macromolecular compounds, a water shift catalytic reactor, and a low-temperature carbon dioxide sorption reactor was tested.



# The principle circuit of power plant with gasifier and PEM fuel cell electrochemical generator




1 - compressor, 2 - rotameter, 3 - hopper with solid organic waste, 4 - gasifier, 5 - cyclone, 6 - ash hopper, 7 - catalytic reactor, 8 - dust cleaning, 9 - compensator, 10 - explosion valve, 11 – PEM fuel cell electrochemical generator, 12 – heat-recovery boiler, 13 - chimney, 14 - heating system, 15 - circulating pump, 16 - plasma installation, 17 - tank with distilled water, 18 - pump, 19 - CO catalytic conversion reactor, 20 – reactor of sorption and desorption of $CO_2$, 21 - compressor, 22 - electric motor, 23 - $CO_2$ cylinders

The principle circuit of a power plant (up to 5 $kW_e$) with gasifier and electrochemical generator on polymeric fuel cells has been developed.

# Analysis of the possibility of using a by-product of conversion ($CO_2$) for the operation of polygenerational hydrogen power plants

### $CO_2$ OBTAINING

- After standard boilers
- After boilers operating on a mixture of oxygen and CO2
- From gas after gasification, pyrolysis, reforming, fermentation

### THE INDUSTRIAL USE OF $CO_2$

- For increasing the productivity of oil and gas wells
- Working fluid in the modern power plants
- Production of value-added products

### $CO_2$ SEPARATION AND PURIFICATION

- Adsorption with pressure change (PSI)
- Cleaning in water scrubbers
- Physical absorption in organic solvents
- Chemical absorption in organic solvents
- Membrane separation
- Low temperature separation

### $CO_2$ CONVERSION TECHNOLOGIES FOR PRODUCTION OF ADDED VALUE PRODUCTS

- Electrochemical
- Photo-catalytic
- Photo-thermal catalytic
- Catalytic
- Biological
- Copolymerization
- Mineral-carbonization

In the world, most technologies for the production, purification and utilization of carbon dioxide have already been tested in various industries on a commercial scale. Further introduction of these technologies in the latest energy-chemical combined complexes for energy production and chemical products, taking into account the properties of the source organic fuels will significantly reduce the impact of carbon dioxide on the environment and climate change on Earth. An overview of technologies and proposals for the production, separation, purification and use of carbon dioxide is given in the joint work of the Thermal Energy Technology Institute and L.V. Pisarzhevsky Institute of Physical Chemistry of NAS of Ukraine. https://doi.org/10.48126/conf2020#page=47

The analysis was carried out and proposals were prepared on the possibility of using the by-product of SOW conversion – carbon dioxide for the operation of polygeneration cogeneration hydrogen power plants for the production of electricity, fertilizers, plastics, third generation biofuels, construction materials, nanocarbon, etc.

# Activiti

The results of the work were reported:

➢at International scientific and practical conferences:

- "Coal heat power generation: Ways of reconstruction and development" (2019-2021 - 5 reports),
- "Renewable energy and energy efficiency in the XXI century" (2021 - 1 report), and

➢scientific reporting sessions of the Target Complex Programme for Research of the National Academy of Sciences of Ukraine "Development of scientific bases for hydrogen production, storage and use in autonomous energy supply systems“ (2019-2020 - 2 reports).

The results of the research were reported:

➢under the support of the German-Ukrainian Chamber of Commerce and Industry at on-line seminars with participants in the implementation of the National Strategy of the Federal Government of Germany on green hydrogen by the Fraunhofer Institute of Ecology, Security and Energy Technology (Sulzbach-Rosenberg branch) and the Institute for Energy and Climate Research (Forschungszentrum Jülich GmbH) (2021 - 2 reports), and

➢at the seminar "Hydrogen Economics and Energy" in the State University of Food Technology of the Ministry of Education and Science of Ukraine (2021 - 1 report).

According to the results of work in 2019-2021, 12 works were published:

articles - 4, reports - 6, abstracts - 2.

A Chapter in the monograph was prepared for publication.

# CONCLUSIONS

1. Analysis of experimental data obtained in the Thermal Energy Technology Institute of NASU at experimental installations of carbonization and gasification of solid biological, industrial and household waste is carried out. Analysis of foreign latest solutions for the conversion of solid organic waste is made.
2. Gasifier performance optimized. The optimal choice of the design of the partial oxidation zone and two stage conversion allowed to achieve increased cold gas efficiency up to 75 %. The temperature of the gases at the outlet of the carbonization zone of the gasifier should be 300 to 500 $^{o}$C, at the outlet of the gasifier - above 600 $^{o}$C. The use of a steam plasma torch increased the hydrogen yield by 1.5-3.0 times.
3. Equipment's performance operating on hydrogen-enriched synthesis gas and hydrogen for heating and hot water supply is determined.
4. The main equipment for the operation of the cogeneration plant, a boiler and electric generators, was identified, selected, and purchased. The boiler was transformed for combustion of synthesis gas and hydrogen obtained in the gasifier (the way from carbonization to decarbonization).
5. Parts of the cogeneration hydrogen power plant with a gasifier-transformer, an electric generator with an internal combustion engine and a recovery boiler are made.

## CONCLUSIONS

6. Based on the designs of a gasifier-transformer for gasification of solid organic waste and a high-temperature catalytic reactor for the conversion of macromolecular compounds, a new principal circuit of operation of an SOFC electrochemical generator is prepared.

7. Plant parts for producing combustible gas without carbon with the use of a gasifier-transformer, a catalytic reactor for CO conversion and a carbon dioxide absorption reactor for the operation of PEM fuel cell electrochemical generator.

# PUBLICATIONS ON THE PROJECT

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2. O. Dudnyk. Hydrogen economics and energy. Proceedings of the 17th International Scientific and Practical Conference *"Coal heat power generation: Ways of reconstruction and development"*. Kyiv: Gnozis, October 19-20, 2021, pp. 66-74. https://doi.org/10.48126/conf2021

3. O.M. Dudnyk, I.S. Sokolovska, V.G. Borisevich. Optimization of circuits of cogeneration and trigeneration power plants operation with solid organic waste gasification. Proceedings of the 16th International Scientific and Practical Conference *"Coal heat power generation: Ways of reconstruction and development"*. Kyiv: Gnozis, November 13, 2020, pp. 110-115. https://doi.org/10.48126/conf2020#page=111

4. O.M. Dudnyk, N.I. Dunaevska, I.S. Sokolovska, A.I. Tripol’skii, P.E. Stryzhak. $CO_2$ production, purification and utilization in the processes of power generation and chemical production. Proceedings of the 16th International Scientific and Practical Conference *"Coal heat power generation: Ways of reconstruction and development"*, Kyiv: Gnozis, November 13, 2020, pp. 46-55. https://doi.org/10.48126/conf2020#page=47

5. O.M. Dudnyk, N.I. Dunaevska, I.S. Sokolovska. Development of the world market of fuel-cell power plants. Creation of normative base for hydrogen power. *The Problems of General Energy*, 2020, 1(60), pp. 66-73. https://doi.org/10.15407/pge2020.01.066

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# PUBLICATIONS ON THE PROJECT

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8. Dudnyk O.M., Dunaevska N.I., Sokolovska I.S. Application of the technologies of combined-cycle power plants with the integrated gasification of solid and liquid fuel in the global energy industry and prospects for their introduction in Ukraine. *The Problems of General Energy*, 2019, 3(58), pp. 32-39. https://doi.org/10.15407/pge2019.03.037

9. O.M. Dudnyk, I.S. Sokolovska. Autonomous cogeneration power plant using energy of solid organic fuels and hydrogen. Proceedings of the 15th International Scientific and Practical Conference *"Coal heat power generation: Ways of reconstruction and development"*, Kyiv: Gnozis, October 1-2, 2019, pp. 46-49. http://www.materials.kiev.ua/Hydrogen_2019-2021/3a_pr.pdf

10. O.M. Dudnyk. New Fuel Cell Combined Cycle and Hybrid Power Plants. Proceedings of the 15th International Scientific and Practical Conference *"Coal heat power generation: Ways of reconstruction and development"*, Kyiv: Gnozis. October 1-2, 2019, pp. 40-43. http://www.materials.kiev.ua/Hydrogen_2019-2021/3b_pr.pdf

11. O.M. Dudnyk. Development of biogas power technologies in PRC and Ukraine. *Energy news*, 2019, #1, pp. 23-26.

12. O.M. Dudnyk, I.S. Sokolovska. Analytical review of experimental results on the conversion of solid organic waste. Creation of the autonomous hydrogen cogeneration unit using gasifier-transformer, electric generator on an internal combustion engine and heat recovery boiler. Abstracts of reports of the Scientific Reporting Session *"Development of scientific bases for hydrogen production, storage and use in autonomous energy supply systems"*, December 11, 2019, Kyiv: Frantsevich Institute for Problems of Materials Science of NAS of Ukraine, 2019, p. 12.

13. O.M. Dudnyk, I.S. Sokolovska. Development of autonomous cogeneration hydrogen power plants with solid organic waste conversion. Monograph *“Development of scientific bases for hydrogen production, storage and use in autonomous energy supply systems”*, 2021 – In press.

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# *Thank you for your attention!*