Applied Energy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Optimal network design of hydrogen production by integrated utility and biogas supply networks

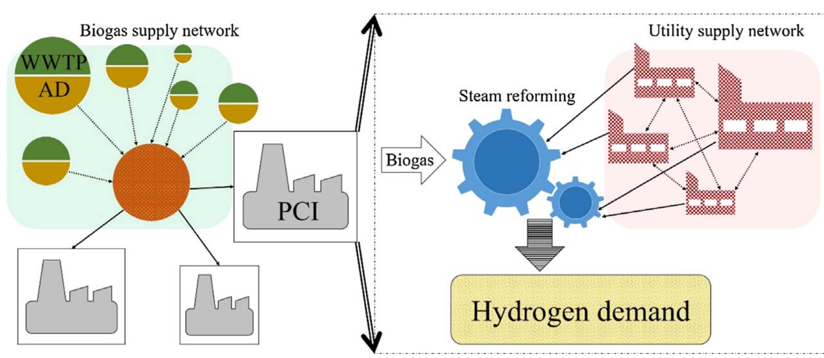
Soonho Hwangbo, Seungchul Lee, Changkyoo Yoo*

Department of Environmental Science and Engineering, Center for Environmental Studies, Kyung Hee University, Yongin-Si 446-701, South Korea

HIGHLIGHTS

- Utility and biogas supply networks are integrated and optimized by gas pipelines.
- A steam reforming process is employed as a linkage process.
- Mixed-integer linear programming is used to design an integrated network model.
- A case study based on the industrial hydrogen demand in Korea is presented.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Utility supply network
Biogas supply network
Hydrogen
Mixed-integer linear programming
Optimization

ABSTRACT

This research aims to develop a mathematical model to construct a network model for producing hydrogen by integrated utility and biogas supply networks (IUBSNs). In this model, a utility supply network exists in a huge petrochemical industry while a biogas supply network consists of a wastewater treatment plant and anaerobic digestion. Pipelines connect the utility and biogas supply networks. The steam reforming process, which is the most well-known process able to generate large amounts of hydrogen, is employed to harness hydrogen as well as to integrate the two networks. In IUBSNs, the needed steam is obtained by optimizing a utility supply network while methane-rich biogas is generated by placing anaerobic digestion tanks into a number of wastewater treatment plants allocated by region. This study uses an algorithm for solving the mixed-integer linear programming problems to minimize the total annual costs of IUBSNs and simultaneously satisfy hydrogen demand. IUBSNs can be a great alternative to a hydrogen supply network that imports and consumes fossil fuels to produce hydrogen, furthermore, it is able to positively influence environmental issues through the reduction of the amount of fossil fuel used in petrochemical industries. A case study of the Republic of Korea illustrates the feasibility of the proposed model. Three cases (base case, only optimized utility supply networks, and IUBSNs) are conducted, and an increase in hydrogen demand is applied to each case. The results demonstrate that IUBSNs construction decreases the total costs by about 13% compared to the existing situation, and as hydrogen demand increases, the gas pipeline structure in IUBSNs employs a hub city to transport biogas flexibly.

* Corresponding author.
E-mail address: ckyoo@khu.ac.kr (C. Yoo).

http://dx.doi.org/10.1016/j.apenergy.2017.10.051
Received 14 July 2017; Received in revised form 7 October 2017; Accepted 11 October 2017
0306-2619/

Nomenclature

Sets

f fuel
w water
e electricity
s steam
SOx sulfur oxides
GHG greenhouse gas
ft fuel tank
b boiler
h header
t turbine
v valve
wn water unit
en electricity unit
c company
u utility supply network
$wwtp$ wastewater treatment plant
as AD size

Parameters

OD operating days (day/year)

(Utility)

$Inventory_{f,ft,c,u}$ initial fuel inventory in fuel tank (ton)
Cal_f calorific value
eff_b efficiency of boiler
$PSOx_f$ sulfur oxides emission parameters of fuels
$PGHG_f$ greenhouse gas emission parameters of fuels
α_b^{ele} fixed electricity consumption constant
β_b^{ele} variable electricity consumption constant
$SD_{s,c,u}$ steam demand (ton/day)
$ED_{c,u}$ electricity demand (kW h/day)
$WD_{c,u}$ water demand (ton/day)
$SCP_{s,s'}$ steam type conversion parameter
CG condensate generation parameter
TP_s turbine parameter for steam
TP_w turbine parameter for water
$Price_f$ price of fuels (US \$/ton)
$Price_{SOx}$ sulfur oxides clean-up cost (US \$/ton)
$Price_{GHG}$ greenhouse gas clean-up cost (US \$/ton)
$Price_w$ price of water (US \$/ton)
$Price^{ele}$ price of electricity (US \$/kW h)
$SP^{\max}$ maximum steam production (ton/day)
$SP^{\min}$ minimum steam production (ton/day)
BN big number
$Dist_{c',c,u}^{utility}$ distance between utility companies (km)
FI fixed investment cost parameter (US \$/year/km)
VI variable investment cost parameter (US \$/ton/km)
FO fixed operating cost parameter (US \$/year/km)
VO variable operating cost parameter (US \$/ton/km)
DP depreciation parameter

(Steam reforming)

HD_{PCI} hydrogen demand in PCI (ton/day)
$SSH2R$ steam-hydrogen ratio (ton of steam/ton of hydrogen)
$SEH2R$ electricity-hydrogen ratio (kW h/ton of hydrogen)
$SMH2R$ methane-hydrogen ratio (ton of methane/ton of hydrogen)
$NGprice$ NG price (US \$/MMBtu)
$SCOM$ratio of steam reforming capital and operating & management cost to hydrogen production

(WWTP-AD)

FC_{wwtp} facility capacity of WWTP (m^3/day)
UR wastewater usage ratio (m^3 of sludge/m^3 of wastewater)
MF mole fraction of biogas
MD methane density (ton/m^3)
SR WWTP conversion ratio of sludge to wastewater input amounts
BR AD conversion ratio of sludge to biogas (m^3 of biogas/m^3 of sludge)
ADI_{as} AD investment cost parameter depending on AD size (US \$/year)
ADC_{as} AD capacity depending on AD size (ton/day)
ADO_{as} AD operating cost parameter depending AD size (US \$/ton)
x_{wwtp} wastewater input amounts of WWTP (m^3/day)
x_{wwtp}^{biogas} biogas amounts from WWTP (m^3/day)
$x_{wwtp}^{methane}$ methane amounts from WWTP (ton/day)
x_{wwtp}^{sludge} sludge amounts of AD (m^3/day)
$TC_{investement}^{AD}$ AD investment cost (US \$/year)
$TC_{operating}^{AD}$ AD operating cost (US \$/year)

(Pipeline)

CEP compression energy parameter (kW h/ton)
PC pipeline capital cost parameter (US \$/ km)
$MainDist^{ADPCI}$ main pipeline distance between AD and petrochemical industrial complex (km)
$BranchDist^{ADMP}$ branch pipeline distance between AD and main pipeline (km)
$TC_{capital}^{pipeline}$ pipeline capital cost (US \$/year)
$TC_{operating}^{pipeline}$ pipeline operating cost (US \$/year)
$TC_{energy}^{pipeline}$ compression energy cost (US \$/year)

Variables

TC total cost (US \$/year)

(Utility)

$TC_{raw}^{utility}$ total raw material cost of utility network (US \$/year)
$TC_{investment}^{utility}$ total investment cost of utility network (US \$/year)
$TC_{operating}^{utility}$ total operating cost of utility network (US \$/year)
$x_{f,ft,c,u}$ fuel amounts at fuel tank (ton/day)
$x_{SOx,b,c,u}$ sulfide oxides amounts from boiler (ton/day)
$x_{GHG,b,c,u}$ greenhouse gas amounts from boiler (ton/day)
$x_{f,ft,b,c,u}$ fuel amounts from fuel tank to boiler (ton/day)
$x_{s,b,h,c,u}$ steam amounts from boiler to steam header (ton/day)
$ex_{w,wn,c,u}$ external water amounts at water unit (ton/day)
$x_{w,wn,b,c,u}$ water amounts from water unit to boiler (ton/day)
$ex_{en,c,u}^{ele}$ external electricity amounts at electricity unit (kW h/day)
$x_{t,en,c,u}^{ele}$ electricity amounts from turbine to electricity unit (kW h/day)
$x_{en,b,c,u}^{ele}$ electricity amounts from electricity unit to boiler (kW h/day)
$x_{en,c,u}^{ele}$ electricity amounts from electricity unit (kW h/day)
$x_{s,h,c,u}$ steam transfer amounts from steam header (ton/day)
$x_{s,v,h,c,u}$ steam amounts from valve to steam header (ton/day)
$x_{s,h,v,c,u}$ steam amounts from steam header to valve (ton/day)
$x_{s,h,t,c,u}$ steam amounts from steam header to turbine (ton/day)
$x_{s,t,h,c,u}$ steam amounts from turbine to steam header (ton/day)
$x_{w,t,wn,c,u}$ water amounts from turbine to water unit (ton/day)
$x_{w,wn,c,u}$ water amounts from water unit (ton/day)